On-line Conference

Dark and Quiet Skies II for Science and Society

WORKING GROUP REPORTS

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Walker also acknowledges the input and effort by satellite engineers who participated in the Dark & Quiet Skies II conference and in the WGs. We look forward to working further with these and other satellite operators.

Part 1. Dark & Quiet Skies II Introduction

Figure 1.1: Starlink trails from objects deployed during Flight 6 are seen in this panoramic view of the night sky. Photo by Mike Lewinski, licensed under CC BY 2.0.

"Interference of our view of the sky caused by ground-based artificial lights, optical and infrared trails of satellite constellations, and radio transmission on the ground and in space is an existential threat to astronomical observations. Viewing the night sky has been culturally important throughout humanity's history, and dark skies are important for wildlife as well. This D&QS II Conference helps address the mitigation efforts we can take to minimize the unintended negative impacts of our technological advances."

— Debra Elmegreen, International Astronomical Union President

Foreword

This Report presents the main results of the Conference "Dark and Quiet Skies for Science and Society II" which took place on-line on 3–7 October 2021. This conference was the logical follow-up of the first one, organized as an on-line workshop with the same title on 5–9 October 2020. Both conferences were co-organized by UNOOSA, IAU and the Government of Spain and were well attended. The focus of the second conference was about the feasibility of implementing the recommendations presented by the first one in its extensive report. The main qualifying difference between the first and the second conferences was a more explicit involvement of the industrial stakeholders and of space policy experts, whose contributions were instrumental in presenting a credible review of the proposed mitigating measures as well as of possible regulatory guidelines.

As better explained in the report, the main findings of the conference are also being presented to the 59th Session of the Scientific and Technical Sub Committee (STSC) of COPUOS in the form of a Working Paper.

1. The origins of the Dark and Quiet Skies for Science and Society conferences

The International Astronomical Union (IAU), representing more than 12,000 professional astronomers from about 90 countries, has as its mission the promotion and safeguard of the science of astronomy in all its aspects. In 2017 the IAU approached the UN Committee for the Peaceful Use of Outer Space (COPUOS), proposing to include the protection of the astronomical sky within its mandate. COPUOS asked the UN Office for Outer Space Affairs to co-organize a Conference with the title Dark and Quiet Skies for Science and Society, its aim being to assess the impact of any artificial interferences affecting the visibility of the sky and the detection of cosmic radio signals.

At the time, the potential for interference by the large satellite constellations was not yet known, but by the time the first conference was organized in October 2020 it had become the most serious problem and more aligned to the primary mission of COPUOS. The advantages to society that the communication constellations are offering cannot be disputed, but their impact on the pristine appearance of the night sky and on astronomy must be considered with great attention because they affect both the cultural heritage of humanity and the progress of science.

The Conference could not be held in-person, because of the Covid-19 pandemic. Instead, an online Workshop took place in October 2020, resulting in specific recommendations for mitigating the impact of artificial interferences. They were presented to the Scientific and Technical Sub Committee of COPUOS (STSC) in April 2021 and received the attention of several Delegations. The UN/Spain/IAU Conference took place in October 2021, focusing on the feasibility of implementing adequate mitigating measures. These will be presented at the STSC meeting in February 2022.

2. The three categories of artificial interferences negatively impacting astronomical observations

The Dark and Quiet Skies II conference in October 2021 and its report focused on the three categories of artificial interferences that negatively impact astronomical observations:

- The urban illumination or artificial light at night;
- The optical/infrared trails of satellites in low Earth orbits;
- The radio transmission by ground and space emitters that affects radio astronomy.

2.1 The urban illumination or artificial light at night

The interference by artificial light at night (ALAN), that affects both amateur and professional astronomers, has become an acute problem with the advent of the light-emitting diode (LED), particularly those with a high level of blue light. The IAU has established a recommended maximum tolerable threshold of light pollution for astronomical sites of 10% above natural background levels. Light pollution is growing globally at an estimated rate of 2% to 6% per year and is reducing darkness everywhere, including at observatory sites where world-class sites risk hitting the 10% threshold in the next decade. In addition to the impact on astronomy, ALAN may have significant biological effects, to flora and fauna, both vertebrates and invertebrates, which requires further study by appropriate experts.

2.2 The optical/infrared trails of satellites in low Earth orbits

The new satellite constellations, made of thousands of satellites in low Earth orbit (LEO) being launched by private companies and governments, play a role in telecommunications on Earth. However, these new constellations have a serious impact on the appearance of the night sky and on astronomical observations. The problem is primarily related to the large number of satellites; by the end of the decade it may be as high as 100,000. The visibility and brightness of a satellite during the night depends on the altitude of its orbit (currently ranging from ~350 to ~1200 km) and on its surface reflectivity and attitude with respect to the observer. A fraction of the satellites will be visible by the naked eye (those with magnitude < 7), but all of them are potentially detectable by highly sensitive telescopes' detectors. Therefore, they leave traces of their transit on astronomical images, significantly decreasing the scientific usability of the collected data. Post-processing of the affected images only partially remedies the problem: the brighter trails may saturate the detectors, making portions of images unusable, while the removal of the fainter trails leaves residual effects that seriously affect important scientific programs, as, e.g., statistical, automated surveys of faint galaxies.

The impact of the large satellite constellations on optical/infrared astronomy is also affecting telescopes with large fields of view as well as the automated searches for fast-moving objects, like the International Asteroid Warning Network (IAWN), a programme initiated and supported by the UN Office of Outer Space Affairs and aimed at detecting potentially dangerous near-Earth objects (NEOs).

2.3 The radio transmission by ground and space emitters that affects radio astronomy

The protection of radio astronomical observations, known as spectrum management, is the responsibility of the Radio Communication Sector of the International Telecommunication Union (ITU-R). The Radio Regulations provide allocations for various services, including radio astronomy under the radio astronomy service (RAS). Indeed, radio astronomy has a long history of negotiation activity aimed at protecting frequency bands of astronomical interest from harmful interference generated by artificial radio emissions within the wavelength range of astronomical interest.

However, the situation created by the new large constellations of telecommunication satellites poses new threats to radio astronomy which deserve further study. In particular, the Dark and Quiet Skies II report recommends that satellite designs should have the capacity to avoid direct illumination of radio telescopes and radio-quiet zones and the cumulative background electromagnetic noise created by the constellations should be kept below the limit agreed by the ITU.

3. The role of intergovernmental bodies and private enterprises now and in the future

The STSC, in its 2021 report of the 58th Session, encouraged the UNOOSA to engage with all relevant stakeholders, including the IAU, on the matter of dark and quiet skies as it relates to the mandate of the STSC and its subcommittees. It also highlighted that the second conference on Dark and Quiet Skies could provide inputs to a focused discussion on opportunities for international cooperation. Indeed, the private companies that are currently launching or planning to launch the constellations were invited to participate in the conference and contributed effectively to the discussion about the mitigating measures that could be implemented. Some of them had already tried to modify the design of their satellites in order to lower their apparent luminosity in orbit.

More work has to be done, but it is clear that, in parallel with the definition of internationally agreed guidelines, a close collaboration between industry and the astronomical community will be instrumental in mitigating the negative effects. This action is particularly important for the future foreseeable satellite constellations. The Industry Subgroup of the conferences concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or impact on the schedule.

To provide a pathway forward toward solutions the IAU has recently announced the constitution of a coordination centre that will continue to foster dialogue between all the stakeholders and the astronomers.

Figure 1.1: City of Athens by night, Athens metropolitan area, Greece. Credit: Costis Bouroussis, Greece.

Part 2. Artificial Light at Night Working Group

"Since the introduction of urban illumination more than a century ago, the visibility of the pristine starry night sky has been gradually fading. In recent times, the level of the artificial light at night (ALAN) has been rocketing, especially through the advent of the new illumination devices (LEDs, or light-emitting diodes) which, because of their low energy consumption and high content of blue light, contribute to an exponential increase of the light pollution in vast regions of the globe. It is estimated that entire generations living in inhabited areas not only never experienced the vision of the Milky Way, but rarely saw even the brighter constellations: visions that inspired humanity for millennia!

ALAN is not only cancelling a precious cultural heritage, it is also affecting the progress of science: light pollution propagates through the atmosphere with no boundaries and it is now threatening the remote sites where major astronomical facilities are operating. In addition, there is convincing evidence that ALAN is also *negatively affecting the environment, biological systems and human health. Actions to reverse all these negative aspects are urgently needed.*

The reports of the Conferences Dark and Quiet Skies for Science and Society I and II present a detailed analysis of the impacts of ALAN, and the current report in particular indicates clear and simple guidelines to prevent further damage and eventually reduce it. While the recently constituted IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference will concentrate on mitigating the negative interference caused by the large satellite constellations (an action that has to be taken at international level), the IAU will continue to encourage all members of society to act on their local, regional and national authorities, making them aware of the negative effects of ALAN and promoting the introduction of mitigating regulations."

> — Piero Benvenuti, Professor Emeritus, University of Padova; Director, IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference

Chapter 1. Policy Summary

Taking action to protect the peaceful use of outer space for all

This document presents a summary of the findings and recommendations of the Artificial Light at Night Working Group (ALAN WG) of the United Nations / Spain / International Astronomical Union Dark and Quiet Skies II (D&QS2) conference, held virtually in October 2021. It is intended as a high-level overview for policy-makers on artificial light at night (ALAN), light pollution, the importance for the COPUOS mission of controlling them, and recommended approaches to controlling them. Accompanying this Policy Summary are two additional supporting documents: (1) a Technical Guidance report, and (2) a more detailed Policy Framework and Applications Guidance report.

The charge of the D&QS2 ALAN WG was to build on the work of the first Dark and Quiet Skies for Science and Society conference (D&QS1), held in 2020, and its report[2], published in 2021, which contains consensus conclusions about ALAN from the perspectives and recommendations for a protective framework against the negative impacts of light pollution from three separate working groups: (1) protecting astronomical observatory sites, (2) dark sky oases, and (3) the bio-environment. The current ALAN WG aimed to merge and develop those recommendations into actionable goals to propose to UN COPUOS and its member states.

Below we first summarize our findings and recommendations, and then expand on them briefly.

[2] https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf

1. The top-level findings

The top-level findings are:

- The mission of COPUOS is to govern the exploration and use of space for the benefit of all humanity: for peace, security, and development.
- The easiest and most distributed, economical, democratic and powerful way to explore the cosmos scientifically is with the use of astronomical telescopes based on the ground.
- Ground-based telescopic observations are critical to multiple aspects of the COPUOS mission.
    - There are 40 telescopes in the world with apertures in the range of 3 to 11 meters, supplemented by a global network of thousands of small- to moderate-aperture telescopes. These projects represent a huge technological achievement and confirm the validity of international cooperation.
    - Much of the critical data for planetary defense against near-Earth objects; the census of orbiting objects; and astronomical and planetary science research come from this network of ground-based telescopes that is not and cannot be duplicated in orbit.
- The rapid increase in ALAN threatens this international investment and the COPUOS mission.
    - The International Astronomical Union (IAU) has established a maximum tolerable threshold for the increase of sky brightness at astronomical sites of 10% above natural background levels.
    - Light pollution is growing globally at an estimated rate of 2 to 6% per year and is reducing darkness everywhere, including at observatory sites where world-class sites risk hitting the 10% threshold in the foreseeable future, and many smaller sites are already impaired.
- For the vast majority of people on the planet, the peaceful use of outer space starts with being able to look up and see the stars. It is estimated that 83% of people on the Earth live under light-polluted skies, many unable to see the Milky Way.
- Many Indigenous and traditional communities rely on the stars for cultural connections, for navigation purposes, and to ensure that their traditions are passed to future generations.
- Artificial light at night negatively affects most biological groups, both flora and fauna, vertebrates and invertebrates, and negatively affects the functioning of ecosystems and the free services that they provide to human societies, including pollination of food crops. Light pollution interacts with climate change, air pollution and biodiversity degradation, and presents an additional stressor on the environment.
- Existing outdoor lighting is being rapidly replaced worldwide with light-emitting diode (LED) technology that has the potential to significantly reduce light pollution by controlling directionality, spectral response, dimming, and timing. Unfortunately, the high efficiency and low cost of LEDs combined with misinformation and misguided political decisions are instead leading to an increase in the total quantity of light and a significant increase in the proportion

of blue in the light spectrum, which is especially detrimental to the natural darkness of the night sky and astronomical observations, to human health, and to flora and fauna.

- Adequate and well designed outdoor lighting can enhance community well-being by promoting social activities, but too much light at night, especially in the blue part of the spectrum, can have detrimental health effects. Scientific studies show that higher levels of intrusive light are associated with increased rates of cancer, diabetes, obesity, and mood disorders.
- As natural darkness has become scarce, it has become a valuable resource to support sustainable economic development through astro-tourism and nature-based tourism.
- Light pollution does not recognize national boundaries; therefore, solutions need to be regional and international in scale.

2. Recommendations

Here are the three recommended main actions for COPUOS to consider:

2.1 Endorse the overarching goal of reducing ALAN: We call on COPUOS to endorse the goals (i) to reduce, stop, and then reverse, on the timescale of a decade, the growth of ALAN, including the contribution by artificial satellites and space debris, that impacts critical areas such as astronomical observatories and sensitive environmental areas; (ii) to keep the total contribution to skyglow from ALAN substantially below the 10% dark site limit defined by the IAU; and ultimately, (iii) to control and reduce light pollution where it is mainly produced: in human population centers including cities and towns, and in industrial and agricultural production centers.

2.2 Endorse a policy framework for controlling ALAN: More specifically, authorities should recognize the value of naturally dark locations as essential resources that support the COPUOS mission, astronomy, the health of ecosystems, and human health and well-being:

- Each member state of COPUOS should develop its own set of rules and regulations concerning ALAN and the protection of the night sky.
- Authorities should identify, preserve and restore sensitive dark sites, including astronomical observatories and natural environments. These sensitive dark sites should not be illuminated unless safety is at stake.
- Authorities should develop and implement regional plans to ensure the long-term protection of the nighttime environment, including the establishment of total acceptable illumination budgets for each region.
- Authorities should adopt the following principles for outdoor lighting:
    - Light should have a clear and useful purpose, and should be designed and installed so as to minimize negative effects on the night sky, human health, and the environment.

Before installing or replacing a light, determine if light is needed, and how important the need is. Consider how the use of light will impact the area, including wildlife and the environment. Consider using reflective paints or self-luminous markers for signs, curbs, and steps to reduce the need for permanently installed outdoor lighting.

- Light should be directed only where needed. Use shielding and careful aiming to target the direction of the light beam so that it points downward and does not spill beyond where it is needed.
- Light should be no brighter than the minimum level required for the intended application. Be mindful of surface conditions as some brighter surfaces may reflect more light into the night sky than intended.
- Light should be used only when it is useful. Use controls such as timers or motion detectors to ensure that light is available when it is needed, dimmed when possible, and turned off when not needed.
- Light should be of a warmer color where possible. Limit the amount of shorter wavelength (blue-violet) light to the least amount needed.

2.3 Coordinate with related UN-level agencies: We call on COPUOS to recommend that the UN Office of Outer Space Affairs (UNOOSA) coordinate with other United Nations agencies and parties responsible for international agreements, including the International Union for Conservation of Nature; the UN Environmental Programme; the Convention on the Conservation of Migratory Species; the World Health Organization; and the UN Declaration on the Rights of Indigenous People to raise awareness of the harmful impacts of light pollution and coordinate efforts to reduce it globally.

3. Control of ALAN is critical to the mission of COPUOS

Ground-based telescopic observations are critical to multiple aspects of the COPUOS mission. They provide the essential data for planetary defense, the earliest possible detection of potentially hazardous asteroids. The census of orbiting objects, from major scientific facilities such as the Hubble Space Telescope to clouds of debris, is kept updated by a network of small- to moderate-aperture telescopes around the world. Ground-based observations are necessary in most cases to provide targets and full astrophysical interpretation of observations made by telescopes in orbit. And they fulfill a primary aspect of the COPUOS mission (as included in the wording that defines the purpose of COPUOS, set out in UN Resolution 1472 (XIV)) by enabling "*continued research and the dissemination of information on outer space matters*". To the extent that glare, skyglow, and over-illumination from ALAN obscure faint objects and inhibit their detection, these aspects of the COPUOS mission are compromised.

Much of the critical data for astronomical and planetary science research come from a suite of major ground-based telescopes that is not and cannot be duplicated in orbit. That is because ground-based optical/infrared telescopes can be built at a substantially larger scale and much lower cost per unit collecting area than those launched into orbit. There are 40 telescopes in the world with apertures in the range 3–11 meters, sited in the US, Chile, Spain, South Africa, Russia, China, Australia and India, constituting a world-wide investment (e.g., https://en.wikipedia.org/wiki/List_of_largest_optical_reflecting_telescopes; also see Figure 1.2). With the launch of the James Webb Space Telescope, there will be only one such telescope in orbit, following a multi-decade effort at a total cost close to US $10B.

Figure 1.2: World astronomical observatories. There are over 600 institutionally supported optical/infrared research telescopes worldwide. An interactive map is at https://www.google.com/maps/d/u/0/viewer?ie=UTF8&hl=en&msa=0&ll=-3.81666561775622e-14%2C13.870833000000005&spn=172.105191%2C360&t=h&z=1&mid=1KmPNeOPltDHEisXIi1UwuvNa4b4. Credit Nausicaa Delmotte.

Major ground-based observatories are typically funded and operated by international consortia. The three largest telescopes planned for construction this decade in the 20–40-meter aperture range are good examples: The European Southern Observatory is an international treaty organization with 17 member nations; the Thirty-Meter Telescope project has university and governmental partners from five countries; and the Giant Magellan Telescope project has institutional partners from five countries. These telescopes will be situated in locations where control of ALAN is subject to local or national regulations. Space agencies fund the operations of some smaller ground-based telescopes directly to obtain specific mission-critical data. The needed reduction in the growth of ALAN goes counter to two trends, population growth and economic development, so it requires political will. COPUOS endorsement of the protection of ground-based observing sites and other critical areas will provide strong impetus for national and local governments to provide such protection.

Astronomical observations are not done exclusively by professional observatories, but also by amateur astronomers. For over 100 years, devoted amateur astronomers have discovered comets, searched galaxies for supernovae, and crowd-sourced monitoring campaigns of variable stars. More recently, a world-wide network of amateurs has contributed many thousands of person-nights of observing time to confirming exoplanet candidates in support of missions such as NASA's Transiting Exoplanet Survey Satellite (TESS). Given the significant contributions to astronomical science by amateurs, it is alarming that 83% of the world's population lives under light-polluted skies[3]. It is therefore critical not to limit the effort to reduce light pollution to only those regions directly related to professional astronomy, but to protect the natural darkness of the night sky in general, including over areas of dense human population such as cities.

4. Broader benefits of controlling ALAN

As discussed in the first D&QS report, ALAN is generally seen as a net positive, with many benefits to society, such as extending the opportunity for leisure and commercial activities into the hours of darkness. As such, ALAN represents great technological progress and is a ubiquitous feature of modern society.

However, light pollution has been recognised as a threat not only to ground-based astronomy, but also to the natural world and human health on local and global scales, and it is growing exponentially in terms of its geographic presence and reach. The identification of light pollution's effects and the development of methods to reduce them has become an area of transdisciplinary research and knowledge exchange. Research results increasingly identify human over-consumption of ALAN as the fundamental driver of light pollution[4], and identify the main challenge as how best to maximize the benefits of outdoor light at night while simultaneously limiting its costs in both environmental and financial terms[5].

Of the world population, more than 80% of all people and more than 99% of the US and European populations live in places where the night sky is fouled by light pollution[6]. Between 1992 and 2017, the

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[3] Falchi et al. 2016. The New World Atlas of Artificial Night Sky Brightness. Sciences Advances 2:e1600377

[4] Leng, W., He, G., & Jiang, W. (2019). Investigating the Spatiotemporal Variability and Driving Factors of Artificial Lighting in the Beijing-Tianjin-Hebei Region Using Remote Sensing Imagery and Socioeconomic Data. *International Journal of Environmental Research and Public Health*, 16(11). doi:10.3390/ijerph16111950.

[5] Gaston K, *et al*. (2013). Benefits and costs of artificial nighttime lighting of the environment. *Environmental Reviews*, 23(1), 14–23. doi:10.1139/er-2014-0041.

[6] Falchi, F., *et al*. (2016). The new world atlas of artificial night sky brightness. *Science Advances*, 2(6). doi:10.1126/sciadv.1600377.

amount of artificial light directed upward into space on a per-country basis increased by an average of 270%, with some countries' light emissions increasing by as much as 400%[7]. This artificial brightening of the night sky obscures the stars and the Milky Way, forcing a separation of most humans from millennia of inspiration, science, solace, and cultural heritage. Today, many Indigenous and religious groups around the world continue to turn to the starry sky for connection to their ancestors and their cultural practices; for many of them, light pollution erases those cultural connections, and thus has been likened to a form of "cultural genocide"[8].

ALAN, especially in the short-wavelength blue part of the visible spectrum, has been shown to have adverse and detrimental effects on human biology. There is a wide variation in sensitivity to **ALAN exposure in humans,** and safe dosage thresholds are not clearly established. Despite this uncertainty there are clear indications that ALAN has effects on humans[9]. People who live in regions with a high level of outdoor ALAN with subsequent light leakage through windows into bedrooms experience suppression of melatonin production during sleep hours. Suppression of melatonin disrupts the circadian rhythm[10,11] that governs everything from the timing of hormone secretion to the sleep-wake cycle. This melatonin suppression can occur at surprisingly low levels of light leakage. ALAN has been associated with metabolic disorders and related morbidities, including obesity[12], diabetes[13], and certain types of hormonally linked cancer[14] such as breast and prostate among others. Finally, glare from poorly shielded street lighting is a driving hazard that increases in severity with advancing age, and is a road hazard for all drivers.

ALAN exposure is known to harm a **vast array of species** on Earth from the level of the individual up to entire populations and ecosystems[15]. Wasted outdoor light at night is also **wasted energy**. The United Nations Environment Program estimates that a transition to energy-efficient lighting would reduce

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[7] Sánchez de Miguel, Alejandro, Jonathan Bennie, Emma Rosenfeld, Simon Dzurjak, and Kevin J. Gaston 2021. "First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution" *Remote Sensing* 13, no. 16: 3311. https://doi.org/10.3390/rs13163311

[8] Hamacher D.W., de Napoli, K., and Mott, B. 2020. " Whitening the Sky: light pollution as a form of cultural genocide. *Journal of Dark Sky Studies*, Vol. 1. https://arxiv.org/abs/2001.11527

[9] Zielinska-Dabkowska, K. M. Make lighting healthier. *Nature* **2018**, *553*, 274–276, doi:10.1038/d41586-018-00568-7

[10] Walmsley, L., *et al*. (2015). Colour As a Signal for Entraining the Mammalian Circadian Clock. *PLoS Biology*, 13(4), e1002127. doi:10.1371/journal.pbio.1002127.

[11] Kumar, P., *et al*. (2019). Artificial Light Pollution at Night: A Risk for Normal Circadian Rhythm and Physiological Functions in Humans. *Current Environmental Engineering*, 6(2), 111–125. doi:10.2174/2212717806666190619120211.

[12] Rybnikova, N., Haim, A., & Portnov, B. A. (2016). Does artificial light-at-night exposure contribute to the worldwide obesity pandemic? *International Journal of Obesity*, 40(5), 815–823. doi:10.1038/ijo.2015.255.

[13] Opperhuizen, A.- L., *et al*. (2017). Light at night acutely impairs glucose tolerance in a time-, intensity- and wavelength-dependent manner in rats. *Diabetologia*, 60(7), 1333–1343. doi:10.1007/s00125-017-4262-y.

[14] Anbalagan, M., *et al*. (2019). SAT-337 Disruption Of The Circadian Melatonin Signal By Dim Light At Night Promotes Bone-lytic Breast Cancer Metastases. *Journal of the Endocrine Society*, 3(Supplement_1). doi:10.1210/js.2019-SAT-337.

[15] Falcón, J., Torriglia, A., Attia, D., Viénot, F., Gronfier, C., Behar-Cohen, F., Martinsons, C., & Hicks, D. (2020). Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems. *Frontiers in Neuroscience*, 14. https://doi.org/10.3389/fnins.2020.602796.

global electricity demand for lighting by 30-40% in 2030[16]. However, the exceptionally rapid global transition to solid state lighting (SSL) in the name of energy efficiency has inadvertently worsened the problem of light pollution by making outdoor light at night cheaper to produce, fueling higher consumption. As ALAN has become cheaper to produce, its consumption has increased substantially; humans now consume thousands of times more lumens than they did in the past[17] — an example of the Jevons Paradox[18].
There is also increasing evidence that ALAN interacts with other stressors in the bio-environment like climate change and air pollution. ALAN therefore cannot be evaluated or mitigated as an isolated problem, but is part of the current global threat to our survival.

Among the causes of light pollution is the popular belief that the use of outdoor light at night necessarily improves **road and traffic safety** and discourages or prevents the perpetration of both **violent and property crimes**. While under certain circumstances the careful application of outdoor lighting may improve nighttime safety, this belief is not grounded in peer-reviewed scientific evidence. As concerns the impact of outdoor lighting on both crime and road safety, a survey of the literature reveals conflicting results. In a 2018 paper, Fotios and Gibbons write, "*recommendations for the amount of light* [for drivers and pedestrians] *do not appear to be well-founded in robust empirical evidence, or at least do not tend to reveal the nature of any evidence*."[19]

Given the wide range of negative effects of ALAN on the bio-environment, human health, and cultural and religious practice, regulations adopted for the protection of astronomical observation sites would also lead to much broader benefits. Maximizing the benefits of ALAN while minimizing its environmental and financial costs will help state budgets, protect and restore natural habitats, promote human health and well-being, promote socio-economic development especially in rural areas, and minimize harmful greenhouse gas emissions.

The task of stopping the growth of and reducing light pollution should therefore be coordinated among organizations concerned with the different aspects of light pollution, including environmental conservation, protection of human health, and protection of cultural heritage. Though COPUOS will most likely focus on areas related to astronomical observatories, COPUOS should work towards protecting dark skies and abating light pollution worldwide in cooperation with other United Nations agencies and parties responsible for international agreements, including the International Union for

[16] *Accelerating the Global Adoption of Energy Efficient Lighting*, UNEP United for Efficiency Policy Guide Series, 2017
[17] Fouquet, R., & Pearson, P. J. (2006). Seven centuries of energy services: The price and use of light in the United Kingdom (1300-2000). *Energy Journal*, 27, 139–177. No doi. https://www.jstor.org/stable/23296980.
[18] Arrobbio O. (2019) Maladaptation to Resource Scarcity: The Jevons Paradox. In: Leal Filho W., Azul A., Brandli L., Özuyar P., Wall T. (eds) Climate Action. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. https://doi.org/10.1007/978-3-319-71063-1_115-1, https://link.springer.com/referenceworkentry/10.1007%2F978-3-319-71063-1_115-1#howtocite
[19] Fotios, S., & Gibbons, R. (2018). Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations. *Lighting Research & Technology*, 50(1), 154–186. doi:10.1177/1477153517739055.

Conservation of Nature; the UN Environmental Programme; the Convention on the Conservation of Migratory Species; UNESCO; the World Health Organization; and the UN Declaration on the Rights of Indigenous People.

Chapter 2. Regulations, Laws, Rules, Policies, Models and Application Guidance

This report builds upon the conclusions from the Dark & Quiet Skies for Science and Society conference related to ALAN.[20] While that document included many recommended practices, the top-level goal was simple:

> *"The goal of the model regulatory framework proposed in this document is to slow, stop, and reverse the rate of increasing artificial skyglow at major professional observatories in no more than a decade and on shorter timescales wherever possible."*

The specific goal is to keep the total contribution of ALAN at major astronomical observatories and sensitive environmental sites substantially below the 10% dark site limit defined by the IAU. This must include consideration of ground-based ALAN, in addition to increases in sky brightness due to satellites and space debris.

This document provides principles and a legal framework to balance the problems that ALAN can cause against the benefits that light at night can offer. Without immediate concerted action, the rampant growth of light pollution will continue, and we will lose the world's remaining dark skies. This will certainly be an irreplaceable loss to professional astronomers, but the impact will also be felt by every person and every living thing on the planet.

To achieve this goal, we recommend adopting two complementary strategies in order to reduce ALAN to sustainable levels:

- Establish regional lighting master plans through zonal lumen caps that support the protection of Dark Sky Oases.
- Implement control at the level of light installations to minimize wasted light to the greatest extent practicable.

These should be implemented at the regional, country, and local level, through a combination of laws, policies, and incentives. We believe that a simple, practical, balanced approach with a consistent regulatory framework will support the protection and restoration of natural darkness and allow everyone to enjoy the benefits of sustainable outdoor lighting. As identified in the D&QS1 report,

[20] ALAN is light that, due to humans, is introduced into the natural or built environment during night time. Light pollution is defined as the alteration of natural lighting levels as a consequence of ALAN.

where current regulations or regionally referenced professional lighting authorities place tighter limits, those should take precedence in all cases.

This document includes: (1) A summary of policy approaches and a comparison of ALAN to other common pollutants; (2) an overview of recommended principles and legal framework; and (3) a summary of existing laws, policies, and regulations on ALAN and light pollution.

1. Introduction

1.1 Overview of lighting policies

The development of rules against light pollution started in the 1950's. The first activists against highly illuminated skies were astronomers. As a result of their actions, the first dark-sky protection law was adopted in the City of Flagstaff, Arizona in 1958[21]. The main purpose of the ordinance was the protection of Lowell Observatory from searchlights. Since then, light pollution laws and policies have emerged in many jurisdictions around the globe.

Currently, light pollution laws and policies are adopted at different levels from international to local. Most of them are focused on only some aspects of ALAN and light pollution, mostly energy efficiency and dark sky protection. Other aspects have not received due attention, thereby reducing the effectiveness of legal measures taken to address light pollution consequences. There are very few examples of a comprehensive approach at a significant scale, with a handful of proposals in process (e.g., Spain, Italy, Chile). Another problem of the existing light pollution regulations is enforcement, especially for privately owned luminaires. In addition, many types of public lighting may be excluded from coverage in the name of public safety. Lack of an effective controlling system on the implementation of light pollution measures reduces the implementation level.

1.2 Comparison of ALAN with other pollutants

It is informative to compare the growth in light pollution over recent years with other common pollutants. A recent study[22] calculated that over a 25-year period between 1992 and 2017, light pollution has grown at least 49%, as shown in Figure 2.1. Owing to the difficulty in measuring short-wavelength emissions, the true increase averages 270%, with some emissions increasing by as much as 400% in specific regions.

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[21] https://www.flagstaff.az.gov/4042/International-Dark-Sky

[22] Sánchez de Miguel A, Bennie J, Rosenfeld E, Dzurjak S, Gaston K.J. First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution. *Remote Sensing*. 2021; 13(16):3311. https://doi.org/10.3390/rs13163311

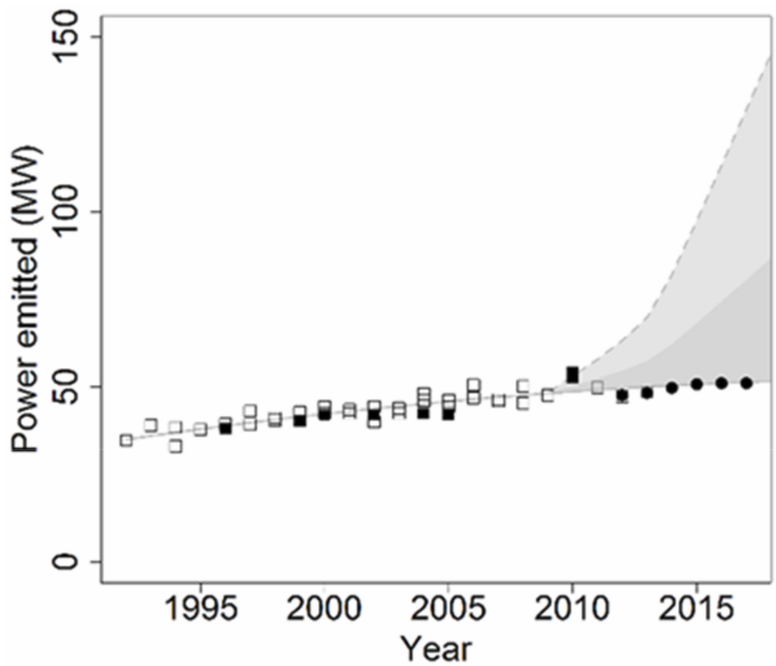

Figure 2.1. Model of global power emitted in a blue-bandpass filter based on satellite data taken at longer wavelengths. The upper envelope growing from ~2010 represents a model assuming all LEDs were chosen to have correlated color temperature of 4000 K. The intermediate curve represents 3000 K, while the lower curve through the data points assumes 2000 K. From Sanchez de Miguel et al. 2021. https://doi.org/10.3390/rs13163311

This is in stark contrast to air quality trends in both Europe and the US. As shown in Figure 2.2 from the European Environment Agency, all other major indicators of air quality have improved since 2000 even while gross domestic product (GDP) has increased[23].

[23] Air Quality in Europe — 2020 report, EEA Report No 09/2020. https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

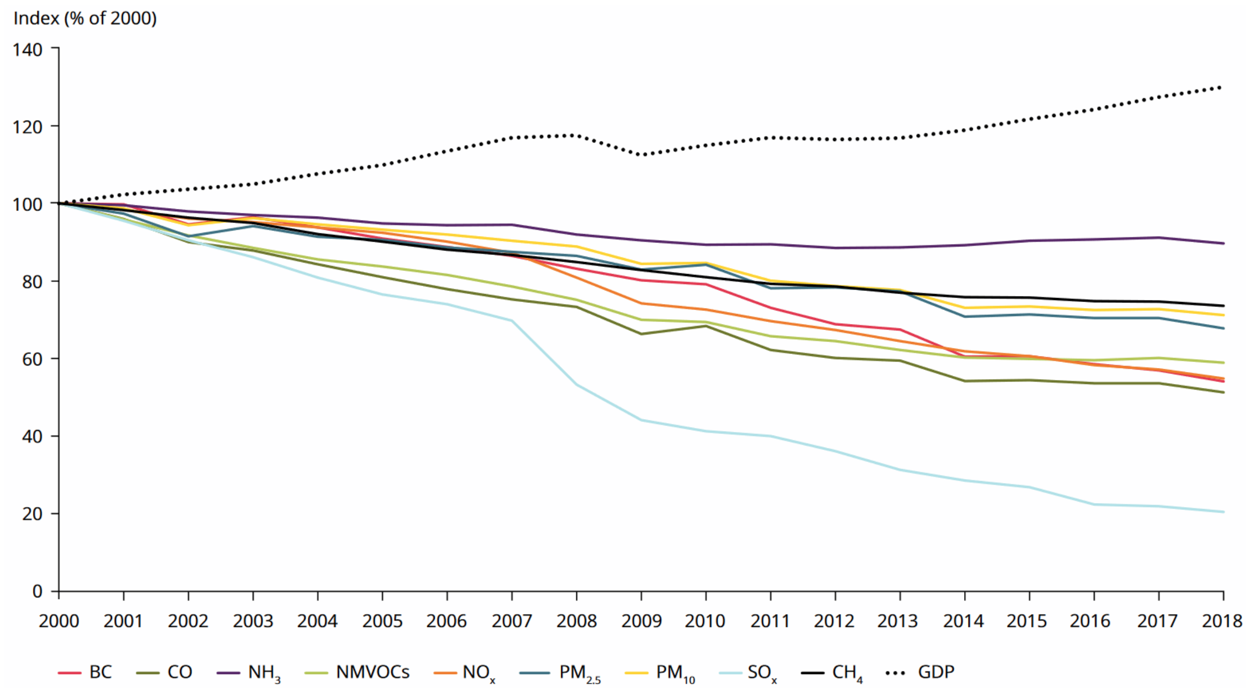

Figure 2.2: Major indicators of air quality (solid lines) have improved (decreased) in Europe since 2000 while GDP has increased. [*https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report*](https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report)

Similarly, in the US, as reported by the EPA, air quality improved across the board over the period 2000–2020, as shown in Table 1. Over the same period, the US GDP doubled from approximately $10 trillion to $20 trillion.

Percent Change in Air Quality

	1980 vs 2020	1990 vs 2020	2000 vs 2020	2010 vs 2020
Carbon Monoxide	-81	-73	-57	-12
Lead	-98	-98	-93	-86
Nitrogen Dioxide (annual)	-67	-61	-53	-29
Nitrogen Dioxide (1-hour)	-64	-54	-39	-21
Ozone (8-hour)	-33	-25	-20	-10
PM_{10} (24-hour)	---	-26	-27	+9
$PM_{2.5}$ (annual)	---	---	-41	-18
$PM_{2.5}$ (24-hour)	---	---	-30	+3
Sulfur Dioxide (1-hour)	-94	-91	-85	-74

Table 1: Change in air quality indicators in the United States from 1980 to 2020. Air quality improved even while GDP doubled. Source: https://www.epa.gov/air-trends/air-quality-national-summary

This shows that when concerted efforts to control certain pollutants are applied, they can be successful on decade timescales and national and regional levels, in contrast to light pollution, which has only worsened over the last 25 years.

1.3 Impacts of light pollution

Light pollution is a concern on many fronts, including astronomy, ecology, human health, energy, climate change, safety, state budgets, human rights and beyond. Below are some examples of light pollution impacts:

- **ALAN has a significant carbon footprint**. Combined, it is estimated that electrical light sources are responsible for around 1/6 to 1/5 of worldwide electricity production[24]. It is estimated that about 275 TWh is due to road lighting. By adding all other outdoor lights for advertising, residential, industrial, tertiary and sport facilities, at least 400 TWh can be estimated to be consumed, implying some 200 billion ($2x10^{11}$) kg of CO_2 produced yearly to sustain outdoor lighting. This is more than 0.5% of the $3.5x10^{13}$ global CO_2 emissions (https://ourworldindata.org/co2-emissions). This figure does not consider the CO_2 for

[24] Zissis G. (2017) Energy Consumption and Environmental and Economic Impact of Lighting: The Current Situation. In: Karlicek R., Sun CC., Zissis G., Ma R. (eds) Handbook of Advanced Lighting Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-00176-0_40

producing, installing, maintaining and disposing or recycling all the infrastructure connected with every luminaire.

- **Astronomical research.** In the State of Arizona, it is estimated that astronomy represents a capital investment of $1.3 billion, supports 3300 jobs and generates an annual economic return of $250 million to the state[25]. Investment in the astrophysics sector in the Canary Islands in 2016 amounted to over 124 million euros and over 1500 full-time jobs. This is to say nothing of the very significant social return on investment for basic research[26].
- **Dark Sky Tourism.** A 2019 study[27] estimated that economic impact from dark sky tourism on the Colorado Plateau in the United States was worth $5.8 billion over 10 years. Some 200,000 people per year visit Teide National Park in the Canary Islands to see the stars, over 50,000 people per year visit Mont Mégantic Observatory's AstroLab in Québec, Canada, and over 35,000 per year visit Montsec Astronomy Park, Catalonia, Spain, with a local tourism annual economic impact of ca. 3 million euros.
- **Efficient Use of Light.** The city of Tucson, Arizona saved $2.16 million per year in energy savings by transitioning to a new streetlight system that also reduced skyglow[28].
- **Environment.** While there are no specific studies on economic loss from light pollution on wildlife, in 2008 scientists estimated that the worldwide economic value of pollinating insects at €153 billion in 2005 for the main crops that feed the world[29]. A similar US study placed the value at $29 billion to US farmers[30]. Light pollution has been identified as one of the primary factors leading to the current decline in insects, and hence pollinators, globally[31].
- **Health.** The research has found a significant connection between increased amounts of indoor and intrusive outdoor lighting and health problems, both mental and physical. The deterioration of the natural day and night cycle contributes to various diseases and illnesses,

[25] https://azastronomy.org/economic-impact/

[26] E.g. Jones, B. & Summers, L. 2020. "A Calculation of the Social Returns to Innovation" https://www.nber.org/system/files/working_papers/w27863/w27863.pdf

[27] Mitchell, David, and Terrel Gallaway. "Dark Sky Tourism: Economic Impacts on the Colorado Plateau Economy, USA", Tourism Review (2019). https://bearworks.missouristate.edu/cgi/viewcontent.cgi?article=1007&context=articles-chpa

[28] https://www.darksky.org/nights-over-tucson/

[29] Helmholtz Association of German Research Centres. "Economic Value Of Insect Pollination Worldwide Estimated At U.S. $217 Billion." ScienceDaily. ScienceDaily, 15 September 2008. www.sciencedaily.com/releases/2008/09/080915122725.htm

[30] https://news.cornell.edu/stories/2012/05/insect-pollinators-contribute-29b-us-farm-income

[31] Avalon C.S. Owens, Précillia Cochard, Joanna Durrant, Bridgette Farnworth, Elizabeth K. Perkin, Brett Seymoure, Light pollution is a driver of insect declines, Biological Conservation, Volume 241, 2020 https://doi.org/10.1016/j.biocon.2019.108259

such as: sleeping problems, hormone-dependent cancers, risks of obesity and diabetes, heart disease, cognitive and affective impairment, premature aging, depression, etc[32, 33].

- **Culture**. Light pollution's impact on the ideas, customs, and social behavior of a particular people or society, and the way we live our lives and interact with nature is difficult to quantify but may be one of the most important and long-lasting negative consequences of light pollution. For centuries astronomy was playing a role as a cultural experience[34]. For example New Zealand is home to the indigenous Polynesian people (Māori) whose cultural heritage has a strong association to, and extensive astronomical knowledge of, the night sky, including the moon, planets and the stars (Māori astronomical knowledge is known as tātai arorangi). This understanding is skillfully integrated into several aspects of their traditional lives and cultural practices[35].

2. Recommended principles and legal framework

Globally recognized international environmental law principles aim to provide environmental sustainability[36] and develop measures to reduce different types of environmental pollution. Therefore, these principles could have a significant value for the global efforts to control and diminish light pollution levels.

2.1 Accepted principles of environmental law

The following generally accepted principles of international environmental law are of particular importance for controlling light pollution:

- **The Prevention Principle.**

[32] See for e.g., Ron Chepesiuk (2009) Missing the Dark: Health Effects of Light Pollution, Environ Health Perspect. 2009 Jan; 117(1): A20–A27, doi: 10.1289/ehp.117-a20; available on-line: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2627884/; A. Haim & B.A. Portnov (2013), Light pollution as a new risk factor for human breast and prostate cancers (p. 168); Diana Paksarian & Kara E. Rudolph, et al. (2020), Association of Outdoor Artificial Light at Night With Mental Disorders and Sleep Patterns Among US Adolescents, JAMA Psychiatry. doi:10.1001/jamapsychiatry.2020.1935; Published on-line July 8, 2020; M. Helbich, et al., (2020), Outdoor light at night, air pollution and depressive symptoms: Across-sectional study in the Netherlands, Science of the total Environment 744 (2020), 140914.

[33] Z.A. Khan, T. Yumnamcha, et al. (2020) Artificial Light at Night (ALAN): A Potential Anthropogenic Component for the COVID-19 and HCoVs Outbreak. Front. Endocrinol. 11:622. doi: https://doi.org/10.3389/fendo.2020.00622

[34] Austin, M. (2009). From Ancient to Modern: The role of astronomy as a cultural experience. Proceedings of the International Astronomical Union, 5(S260), 225-228. doi: https://doi.org/10.1017/S174392131100233X https://www.cambridge.org/core/journals/proceedings-of-the-international-astronomical-union/article/from-ancient-to-modern-the-role-of-astronomy-as-a-cultural-experience/31DE1826415DCB8DB5DB916E321202BA

[35] Harris, P. et. al. A review of Māori astronomy in Aotearoa-New Zealand. Journal of Astronomical History and Heritage 2013, 16(3), pp. 325-336; http://www.narit.or.th/files/JAHH/2013JAHHvol16/2013JAHH...16..325H.pdf

[36] UN Doc. A/CONF.151/26 (vol. I), 31 ILM 874 (1992), 14/06/1992, Rio Declaration on Environment and Development, https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf

This principle obliges the state to take action to protect the environment at an early stage. The main goal is to prevent the damages that may occur, instead of restoring the disturbed or damaged environmental condition. The discharge of emissions like ALAN in quantities or concentrations that exceed the capacity of the environment must be halted in order to avoid significant damage to the ecosystems. Actions should be taken at very early stages to reduce this type of pollution. The *environmental impact assessment* is a widely used decision-making instrument that follows this principle[37].

- **The Precautionary Principle.**
  The precautionary principle is the 15th principle proclaimed by the Rio Declaration on Environment and Development 1992[38]. It states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". It is impossible to identify the total damage that ALAN may produce or is already producing on most ecosystems, given their complexity and interrelations. Therefore, the precautionary principle requires that, if there is a risk that ALAN is affecting the ecosystem, it is better to limit it than to wait for incontrovertible scientific evidence for all the species of this ecosystem.
- **The Polluter Pays Principle.**
  Environmental harm is mostly caused by producers who "externalize" the costs of their activities. Effective environmental laws and regulations should include the obligation to force polluters to bear the real costs of their pollution. Even though the costs in terms of light pollution impacts on the environment are difficult to estimate precisely, the role of this principle should not be underestimated as a sufficient measure to decrease the levels of ALAN.

2.2 Specific principles for ALAN

International environmental law principles provide a general framework. The mitigation of ground-based light pollution should be based on additional specific principles that emphasize the particular nature of light pollution and allow the development of the most effective measures to combat its negative consequences.

[37] General Principles of International Environmental Law, Max Valverde Soto.
[38] https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf

Specific Principles	*Scope and notes*
Integral approach	**Light pollution is a transversal problem**, encompassing environment, visual ergonomics, energy management, public health, public expenditure, safety, cultural, and social issues. Legislators should consider this fact and include all these aspects in top-level norms. Specific provisions can be developed for one or several of these fields by lower-level regulations.
Inter-territoriality	**Photons know no borders[39].** Light pollution effects reach tens to hundreds of kilometers away from the sources of light. Regions that either do or do not emit light nevertheless become jeopardized by emissions from neighboring areas. This cross-border effect is at its highest in the case of pollution generated by satellites, where a single nation, or even a single private company, can ruin the night environment all over the world.
Global effects indicators: a goal-oriented approach	**Top-level legislation must explicitly establish definite goals to effectively abate light pollution[40]** in all relevant fields (e.g., achieving target values of the night sky brightness in cities and rural areas, ensuring specific darkness at ground level in protected areas, ensuring acceptable ranges of circadian exposure, limiting the brightness of each launched satellite and the total cumulative brightness of all satellites, etc.).
Targeting energy efficiency and climate change goals	**Promoting energy-efficient lighting systems to help save energy and money cannot be the only target**, as otherwise light pollution may actually increase because of greater use of outdoor lighting encouraged by higher efficiency. This rebound effect (the Jevons Paradox[41]) is now at work with LEDs, the same rebound that has been experienced in every change of lighting technology, from oil lamps to gas lamps, to incandescent, to mercury vapor to high-pressure sodium.

[39] Salvador Bará & Raul C. Lima (2018), Photons without borders: quantifying light pollution transfer between territories, International Journal of Sustainable Lighting: Vol. 20 No. 2, https://doi.org/10.26607/ijsl.v20i2.87

[40] Salvador Bará, Fabio Falchi, Raul C. Lima, Martin Pawleye (2021) Keeping light pollution at bay: A red-lines, target values, top-down approach, Environmental Challenges, Volume 5, December 2021, 100212; https://doi.org/10.1016/j.envc.2021.100212

[41] Arrobbio O. (2019) Maladaptation to Resource Scarcity: The Jevons Paradox. In: Leal Filho W., Azul A., Brandli L., Özuyar P., Wall T. (eds) Climate Action. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. https://doi.org/10.1007/978-3-319-71063-1_115-1, https://link.springer.com/referenceworkentry/10.1007%2F978-3-319-71063-1_115-1#howtocite

Targeting environmental protection strategies	**Similar to many sources of pollution, ALAN can have negative effects on the environment**, and direct radiance from light sources is able to produce direct harm. Every ambitious environmental protection effort will be hampered by any lack of ALAN regulation. This is because: (a) light emissions increasingly brighten protected areas and fragment valuable habitat for biodiversity protection; (b) light pollution directly affects pollinators and their resources; (c) migrating birds can get distracted from their global routes even by local light pollution and are drawn away of beneficial habitat into urban settings due to light pollution; (d) light pollution directly affects plants and many or most animals' physiology and behavior; (e) owing to a lack of awareness, lighting systems are today not managed in a sustainable manner, both ecologically and economically.
Minimum use of the resource	**Recognizing ALAN as a source of pollution implies adopting by default a "principle of lesser emissions",** that can be implemented by means of common pollution abatement strategies, e.g., setting up direct emission limits (including overall caps), education of public and administrative bodies, and perhaps complementary tax and licensing policies. Unlike the present situation in some countries (where any dimming of the lighting systems has to be comprehensively justified), the default policy should instead be to not illuminate, while any lighting installations must be specifically justified.
Plurality of sources	**Legislation must encompass by default all light emissions** with effects on the outdoor environment, not only from public streetlight systems but also from any other sources of light, installed in public or private grounds, whose emissions reach the outdoor space (including commercial, industrial, backyard lights and home windows). Emissions from self-luminous signs, billboards, façade advertisements and art objects including official and traffic signaling ones, must be counted in the overall emission budget, even if their installation and functioning is regulated by additional specific norms.
Long-term planning	**Keeping light pollution at bay requires establishing maximum emission caps**. The allocation of maximum allowable amounts of light emissions to local communities shall be made taking into account environmental sustainability and social solidarity criteria, and explicitly addressing the different needs of different local communities and sectors. This is not a technical, but a social and political issue.

Institutional liability	The institutional bodies responsible for enforcing the attainment of the light pollution abatement goals from the highest union of countries or country levels down to local county/municipality levels **must be clearly identified**. Practicable enforcement mechanisms shall be contemplated at all actor levels.
Obligation of active remediation	Legislation must contemplate that if any environmental light pollution parameter exceeds the target values, clear and definite transition plans shall be elaborated and put into practice to **ensure satisfactory remediation** in a pre-established time period.
Continuous monitoring	The same way as for noise and air pollution levels, light pollution variables (e.g., night-sky brightness or ground-level irradiances) shall be considered relevant environmental variables, **routinely recorded by public agencies in charge of gathering environmental data**. Examples of relevant variables are the artificial night sky brightness, light trespass and glare, the spectral irradiance in urban and rural areas, the emissions in lumen, and the actual energy consumption at all relevant territorial levels.
Transparency	Light pollution **data should be openly accessible** to the public and interested stakeholders (as, e.g., current meteorological and air quality information). **Representative councils should be created** at all relevant decision levels, with stakeholders from different disciplines, including at least the disciplines of chronobiology, public health, ecology, lighting technology and astronomy[42].

2.3 Incentive-based approaches to reducing ALAN

The most common approach to controlling ALAN from urban and suburban sources remains command-and-control regulation. These regulations may quantitatively regulate the amount of light emissions permitted by different types of land uses, for example commercial businesses versus residential buildings, or establish rules for permitted or restricted types of outdoor light fixtures, shielding of light fixtures, and times of night when lighting may be used. These regulatory approaches are often supported with the threat of civil fines as a means of enforcement, but in practice are difficult to enforce beyond the point of initial construction. Enforcement requires active monitoring by individuals specifically trained to recognize violations in lighting regulations.

[42] Pérez Vega, C.; Zielinska-Dabkowska, K.M.; Hölker, F. Urban Lighting Research Transdisciplinary Framework — A Collaborative Process with Lighting Professionals. Int. J. Environ. Res. Public Health 2021, 18, 624. https://doi.org/10.3390/ijerph18020624

An alternative to command-and-control regulation are economic or incentive-based approaches to regulation. Economic incentives seek to leverage economic self-interest and carrots rather than sticks to encourage compliance with regulations. While there are many approaches to economic incentives, one of the best known is the collection of approaches that fall under the general term "cap-and-trade". Cap-and-trade has been used in other circumstances with similarities to the challenge of ALAN and may hold promise for reducing ALAN using the power of economic self-interest and markets. It is also a flexible approach that can be scaled from local to regional.

2.3.1 Basic principles of cap-and-trade

Cap-and-trade programs always have two basic features and usually a third. The first is the cap. The cap is a total amount of a target pollutant that may be emitted by all regulated parties subject to the cap-and-trade regulation, for example tons of carbon dioxide equivalent or pounds of chlorofluorocarbons. The cap is typically set at a level below the current level of total emissions of the target pollutant by regulated parties. If the cap is set too high, the cap-and-trade program is unlikely to reduce pollution or initiate a market for the pollutant.

Second is the establishment of pollution allocations for regulated parties. Pollution allocations, or "credits", are the amount of the target pollutant that may be emitted by each regulated party. Allocations to regulated parties are fixed but credits may be exchanged with other regulated parties — the "trade" portion of the cap-and-trade program. The total amount of all pollution allocations to all regulated parties must be less than or equal to the cap. In order to sell credits, a regulated party must be emitting less than their pollution allocation, providing excess credits to market to regulated parties over the cap. The ability to sell excess credits is an economic incentive to reduce pollution and may drive innovation in management or development of new technologies where regulated parties believe they can make more money from selling credits than it costs to adopt new practices or technology.

The optional third element of cap-and-trade is a decreasing cap. Decreasing caps are used to drive down emissions of the target pollutant over time by reducing the amount of allowable emissions of the pollutant. A decreasing cap is typically paired with decreasing allocations to regulated parties, forcing either purchase of emissions from other regulated parties, investment in pollution control, or technological innovation to reduce emissions. The need for a decreasing cap is a function of the specific goals of the cap-and-trade program. Most proposals for cap-and-trade programs for pollutants such as carbon dioxide equivalents include a reducing cap as a means of eventually eliminating greenhouse gas emissions.

In the case of ALAN, elimination of all nighttime light is not a feasible goal. Therefore, the use of a decreasing cap is necessarily limited. Instead, an overall cap on light emissions for a given geographic area set to an achievable level that balances the needs of people, wildlife, and astronomy may be the best approach. This cap may be fixed or reduced over time to a certain level. This approach would require all new development to either limit ALAN or purchase light emission credits from existing development, thus allowing for new development without new increases in ALAN, while also potentially driving down ALAN emissions from existing development.

Cap-and-trade programs are not without challenges. To initiate economic activity that serves as the incentive to follow regulations, individual allocations to regulated parties should be less than current typical emissions, but not so low that parties cannot meet emissions targets through a variety of reasonable actions such as technological innovations, changes in practices, or purchase of pollution credits from others. This level may be difficult to determine. Establishing a new regulation on existing emitters can be difficult and require significant political capital to achieve. Monitoring and enforcement is a challenge for cap-and-trade just as it is for command-and-control regulation. It is common for cap-and-trade programs to build resources for enforcement and monitoring into the market mechanisms for exchange of credits, using a portion of the value of the credits to carry out these activities.

ALAN presents a particular challenge for cap-and-trade. Most examples of cap-and-trade programs are focused on specific classes of polluters that are relatively easy to identify, e.g., major industrial operations such as electrical power generating stations that are emitters of carbon dioxide or wastewater treatment plants that are emitters of nutrient-rich, warm water. ALAN polluters are more diverse. A key consideration in the development of a cap-and-trade approach to mitigating the impacts of ALAN is deciding who should be regulated, from large businesses with signage and parking lot lighting, to small businesses with more limited signage, to individual homeowners, to local governments responsible for street lighting. A program encompassing a greater breadth of polluters has greater potential to limit new ALAN over time but also brings significant monitoring and enforcement challenges. A more limited program may not limit the growth of ALAN due to new emissions from non-regulated sectors but monitoring and enforcement are simpler and therefore regulatory certainty is greater.

2.4 Recommended approach

Based on the information gathered and the analyses considered, we recommend the following approach for the proper control of ALAN.

2.4.1 Control at the territory level with quotas of ALAN to respect limits of light pollution indicators

Adopting global indicator limits on light pollution is formally equivalent to setting maximum light emission caps for the surrounding territories. This is a direct consequence of the fact that the detrimental effects of light pollution increase monotonically (albeit not always linearly) with the absolute amount of emitted lumens, for any given spatial distribution and angular and spectral emission patterns of the light sources installed across the surrounding territory.

A wide class of photometric indicators (e.g. night sky brightness) depend linearly on the source emissions. Consequently, if a global indicator (e.g., the artificial night sky brightness at a first-class astrophysical observatory under standard atmospheric conditions) is below the maximum admissible limit as agreed in the regional lighting plan, there would be hypothetically some margin for proportionally increasing the light emissions at the regional level without compromising the limit compliance, but the default strategy should be to meet the goal of stopping the growth of regional artificial skyglow and then reducing the measured indicator over the long term.. Conversely, if the indicator is above threshold, a proportional reduction of the total actual emissions would be required in order to achieve the target values.

Additionally, there are straightforward conceptual and numerical tools that enable one to determine, under very general assumptions, the individual percent contribution of each district of the surrounding territory to the final value of a global indicator. Taking into account the present levels of the global indicators and their desired target values, this allows one to set up a light emissions quota allocation scheme, whereby each district is granted a definite lumen emissions budget. Depending on whether the present emissions are below or above these limits, new installations could be deployed or emissions reduction measures should be adopted at the district level. This emission quota allocation would be a basic tool for enabling long-term urban development planning while at the same time ensuring consistency with the overall light pollution abatement goals.

The distribution of light emission or reduction quotas among districts and municipalities is a far-reaching political issue that shall be handled with social solidarity criteria, since it transversally affects many aspects of human life. Determining the appropriate emission limits requires a previous consensus about the reasonable amount of socially required light, and a clear understanding of how this amount of light correlates with the overall structure of the inhabited territory. The allocation could eventually be flexible: a cap-and-trade scheme for redistribution of quotas between municipalities can be implemented to accommodate new local lighting needs, keeping continuous attention on not surpassing the threshold values.

Cap-and-trade schemes, if successfully applied[43], can be instrumental for keeping light pollution within acceptable limits. Their implementation does not exclude the use of complementary tools like appropriate taxation of lumen emissions. Note, however, that taxation policies cannot guarantee by

[43] This cannot be taken for granted, as the experience of frauds in the European Union in the case of CO_2 emission cap-and-trade shows (see: https://www.enea.it/it/seguici/news/ridurre-le-emissioni-meglio-la-tassa-sulle-emissioni-o-meglio-il-commercio-delle-emissioni)

themselves that light emissions will be kept within admissible limits. Also note that, artificial lighting being a basic service, plain taxation in districts with more lighting needs per inhabitant (e.g., rural municipalities with sparse population) may increase social inequalities.

In the present situation, where light pollution levels are close to or above critical thresholds in many regions of the world, social allocation of light emission caps seems to be a useful instrument, in combination with others, for achieving remediation in heavily light-polluted places and for avoiding exceeding thresholds in other areas that are currently relatively free of light pollution.

2.4.2 Control at the level of single light source or single light installations

This was and still is the traditional way to try to control the spread of light pollution, in the hope that the combined effect of many single less impacting installations will automatically result in a permanent control of the problem. This approach, where implemented, surely lowered the expected increase of light pollution resulting from the increase of ALAN. We now have 50+ years of experience at some county levels (e.g., Tucson and Pima county, Arizona, USA) and 20+ years at regional/national levels (e.g., Lombardia, Emilia-Romagna, Veneto and most other Italian regions; Canary Islands, Spain, Slovenia, Chile). In Lombardia, where all the territory and its almost 10 million inhabitants are under a law that imposes full shielding of all lighting fixtures against glare and uplighting, the sky is as bright now as it was in the year 2000, when the law was first enforced, while in most other parts of the world, sky brightness has increased significantly. The continuous increase of the number of lights, while less polluting on a one-to-one basis, prevented a reduction of light pollution. However, as ALAN flux has generally doubled in the past 20 years, we can surmise that without the law, the light pollution would also have doubled by now. This means that the following prescriptions are necessary but not sufficient (unless combined with caps or other limits). Unfortunately, there does not exist a no-light-pollution or anti-light-pollution lighting fixture, so the main way to prevent light pollution is to have no light at all, as the first choice.

There is broad agreement[44] on best practices for using light at night in a manner that minimizes its impact. The core principles are as follows:

- **Useful:** Light only when there is a clear purpose for the light.
- **Targeted:** Light should be directed only where it is needed. It should be fully shielded (i.e., no light can escape directly above horizontal) with no spilling (i.e. no light should go outside the area that needs to be lit, to prevent light trespass), and should avoid glare.

[44] See for instance, Global Lighting Association Position Statement, Light at night: the importance of quality lighting and night preservation, October 2020 (https://globallightingassociation.org/library), and the IDA-IES Light to Protect the Night, Five Principles for Responsible Outdoor Lighting (https://www.darksky.org/our-work/lighting/lighting-principles/).

- **Low Light Levels**: Light should be no brighter than necessary. Use the lowest possible lighting levels[45].
- **Controlled:** Light should be used only when there is someone present who needs it. Use adaptive controls, such as timers or motion detectors, to ensure that light is available when needed, dimmed when possible, and turned off when not needed.
- **Spectrum:** Use the least harmful light spectra possible. Limiting the emitted spectrum to narrow wavelength bands can reduce its adverse impacts. Although the adverse effects of the spectrum are highly species dependent, blue light has the highest potential to affect the widest number of organisms and to be scattered in the atmosphere, which causes skyglow relatively near to light sources — a serious problem for astronomy. Thus it is important to limit the blue part of the spectrum for outdoor lighting.

There may be resistance to accepting the total caps per inhabitant or per area or caps derived by the threshold rules we propose here. But it should be noted that the measures proposed here do not impose significant restrictions on the selling of luminaries by manufacturers., e.g., single LED or LED installations with lower content in blue in their spectra and/or full shielding and/or lower flux.

See Appendix A. for a list of existing models of laws, rules, regulations and policies regarding ALAN and light pollution.

[45] It should be noted that many of the norms as established by professional bodies should be revisited in light of new technology and new evidence concerning visibility. Many current norms are not based upon empirical data.

Chapter 3. Technical Guidance

1. Introduction and summary

The report of the 2020 UN/IAU/IAC-sponsored Workshop on Dark and Quiet Skies for Science and Society[46] (D&QS1) contained the reports of three topic-based working groups: Dark Sky Oases, Optical Astronomy and Bio-environment. The findings and recommendations of each group represented consensus conclusions from subject matter experts, lighting professionals and representatives of the lighting industry, and dark sky advocates. Although independently developed, the three groups' specific recommendations for protection of critical areas, extending to preservation of worldwide darker sky conditions, had many common elements (Figure 3.1). This section of the current ALAN WG report consolidates those recommendations. It states the major principles by which the goal of stopping the growth and starting the reduction of ALAN can be accomplished, with specific supporting technical examples.

The overarching goal is to stop and reverse, on a 10-year timescale, the growth of ALAN and its negative effects. Because the current most aggressive approaches to controlling ALAN have only slowed its growth rather than stopping it, this proposal contains important new elements. Protection of critical sites requires regional planning, with initial measurement and continued monitoring to assess progress towards achieving goals. The basis of that planning should be the assumption of no artificial light in protected areas, plus a requirement for strong justification for adding light into the critical zones near protected sites. Should lighting be allowed, its use must depend on the specific needs (e.g., road lighting, depending on volume of either vehicular or pedestrian traffic), with active controls setting the lighting levels appropriate for instantaneous or time-averaged use.

As elaborated in this section, the elements of technical control of ALAN are the following:

- Regional lighting masterplan, starting with the assumption of no light near critical areas of protection.
- Adaptive control facilitating dynamically defined lighting zones.
- Spectral control of light sources, e.g. to minimize blue light or other color bands.
- Lighting levels held near the minimum of the recommended ranges for the given application.
- Adoption of geographic lighting overlay zones.
- Adoption of sky brightness limits based on maximum agreed increase over current values.

[46] https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf

- Minimal levels of illumination of architectural buildings and structures and signs, media façades, billboards etc., with strong directional control, turned off after curfew and not allowed in critical zones. Strong control of glare and elimination of light trespass.
- Use a standardized metrology system for light pollution based on traceable methods and instrumentation, with measurements readily available through reference databases.
- Avoid commercial and military air traffic routes over critical areas.

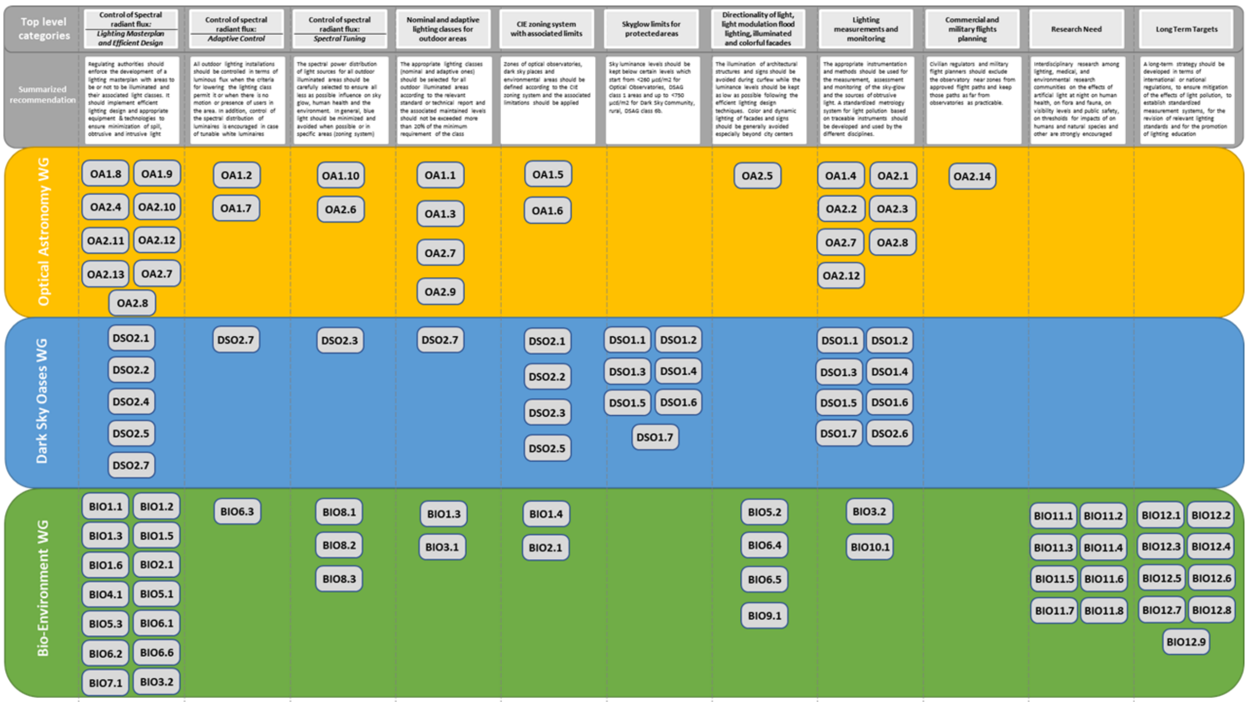

Figure 3.1. Categorization of the recommendations from the three Working Groups of D&QS1.

Growing awareness of the need for protection of sensitive areas from the negative impact of ALAN can lead to opportunities both for sustainability and for the deployment of lighting consistent with the needs for spectral management and active control. Placing the emphasis on visual perception rather than absolute lighting levels can point the way toward a new generation of standards at the lower levels of illumination required to meet the goal of reducing ALAN.

2. Principles and examples to meet the goal of stopping the growth and starting the reduction of ALAN

2.1 Lighting masterplan and efficient design

Principle(s): Regulating authorities should enforce the development of a lighting master plan that defines areas with and without illumination and their associated lighting classes. To achieve the aim of stopping the growth of anthropogenic skyglow, the masterplan must set regional targets and limits on total illumination for those areas in which it is allowed. The masterplanning should implement efficient lighting design and the appropriate equipment and technologies to ensure minimization of obtrusive and intrusive light.

A basic requirement is measurement of the current baseline artificial skyglow, with sufficient angular resolution to note changes in individual major sources. In addition, establishment of a monitoring program is necessary to assess the rate of change. Based on that information and predictive modeling, stakeholders set regional targets. That agreement is essential, because regional and zonal lumens caps and restrictions on development near critical areas of protection are very likely to be required.

The region in this case in which regulating authorities cooperate to produce the plan is the geographical region surrounding a critical area of protection in which there are sources that contribute to the artificial skyglow measured for the area. That region may lie totally within one jurisdiction, or cross international boundaries. The approach to implementation of this concept is discussed extensively in the policy chapter of this report.

Example: An optical observatory has produced a measured baseline of artificial skyglow with an upward trend. Regional authorities agree to protect the site, and agree on an upper limit to the artificial sky brightness with a plan to reduce, stop and reverse the growth of artificial skyglow at the site, keeping it below the agreed limit. Detailed radiative transfer modeling of light sources must be used to predict the impact of lighting growth as a function of area. On that basis, requirements are developed for lighting zones with total upward lighting limits. Mechanisms for engaging such requirements are discussed in Section 3. This case study is elaborated in Falchi and Bará (2020).

2.2 Adaptive control

All outdoor lighting installations should be controlled in terms of luminous flux when the criteria for lowering the lighting class permit it or when there is no motion or presence of users in the area. This approach applies to roadways, pedestrian areas and outdoor nighttime work places. In other words, **lighting class should be determined dynamically based on actual usage**, by active monitoring or averaged over intervals during the night or using statistical data. The illumination level should be set to the minimum of the recommended level required for task related safety. In addition, control of the spectral power distribution of luminaires is encouraged in case of tunable white light sources.

Example: International Commission on Illumination (CIE) Technical Report 115:2010 introduces a classification system according to the type and operational profile of roads for motorized traffic, pedestrians and low-speed traffic areas, conflict areas, and also for some specific situations. Lighting classes for motorized traffic, based on road surface luminance, range from M1 (the highest class) to M6 (the lowest class). Actual traffic volume can be used as a criterion to provide a reduction of a major artery to a lighting level lower than M6 (0.3 cd m^{-2}) after rush hour. In remote areas the lighting can be switched off or decreased to a minimum maintained level when no users are present. See the D&QS1 report for details.

2.3 Spectral tuning

The spectral power distribution of light sources for all outdoor illuminated areas should be carefully selected to ensure minimal influence on skyglow, human health and the environment. In general, blue-rich white light should be minimized and avoided when possible or in specific areas (zoning system). The motivation is to minimize melanopsin-activating blue content within the radiant/luminous flux. This approach is useful for humans and mammals where the circadian timing system has a similar spectral sensitivity as humans.

However, there is a large variability in photoreceptors, photobiological processes and light-related behavioral responses across bio-environment. Although reducing blue content is expected to be useful in many cases, individual species/ecosystems may require different, dedicated spectral approaches.

Whenever possible, near-monochromatic sources should be deployed near observatories and critical dark areas. **For near zones of protection, the approach is to start from the assumption that no color rendition is required, allowing exceptions for strongly made cases for safety.**

Examples: The recommendation from the D&QS1 observatories protection working group for the critical near zones is that the blue light content (percentage of light emitted below 500 nm over the total light emitted) should be null. The lighting devices should be quasi-monochromatic sources with maximum radiant flux (in watts per nm) lying within the 585–605 nm spectral range and having full width half maximum (FWHM) smaller than 18 nm. If modest color rendition is approved as a necessity, spectra with broader FWHM of ~100 nm can be used in those exceptional cases.

The need for restriction of blue light content is explicitly stated in the D&QS1 Dark Sky Oases and Bio-environment reports as well.

2.4 Nominal and adaptive lighting classes for outdoor areas

The appropriate lighting classes (nominal and adaptive ones) should be selected for all outdoor illuminated areas according to the relevant research-based lighting standard or the relevant national or international technical reports or standards, and the associated maintained levels should not exceed 20% of the minimum requirement of the class.

2.5 Lighting zone system with associated limits

Geographic definition of the near zones of optical observatories, dark sky places and sensitive environmental areas is critical for their protection. The CIE zoning system is one current example with relevant qualitative and quantitative descriptions. It should be continually updated to reflect evidence-based understanding of the actual needs for the protection of astronomical observatories, the environment, human health, and astro-tourism. In Zones E0 and E1 closest to the critical area, the approach should be to assume that there will be no outdoor lighting, even on roadways or pedestrian areas. Developers or operators should be required to demonstrate the need for any illumination, and if so, the safety-based need for any color rendition. In the context of a lighting master plan, some areas may not be allowed to reach the limits (e.g. lumen caps) in a lighting zone overlay, in order to stay within the regional goals for limiting the artificial skyglow in the critical area. Other lighting zones than E0 and E1 generally correspond to relatively high population densities. To the extent that such areas impact the ALAN skyglow of the protected areas even from hundreds of kilometers away, lighting master plans should include the ongoing control and reduction of ALAN in those higher density zones as well. Because of the negative effects of ALAN on human health and human engagement with the dark night sky, ultimately all areas of human habitation should benefit from plans to reduce artificial skyglow.

2.6 Skyglow limits for protected areas

Sky luminance levels in protected areas should be kept below certain levels. Protection must be based on currently measured site quality and the locally agreed maximum ALAN contribution to additional sky brightness; i.e., for optical observatories and critical Dark Sky places, these upper limits may be much brighter than current levels, in which case reasonable effort should be made to maintain current levels.

Example: The IUCN Dark Skies Advisory Group (DSAG) published quantitative sky brightness limits for categories of dark sky designations (see the recommendations of the Dark Sky Places Working Group in D&QS1). The recommendation for astronomical observatories and DSAG class 1 areas is a total sky brightness limit of 264 µcd m^{-2} at zenith, or $V > 21.7$ mag $arcsec^{-2}$ and should not exceed 750 µcd m^{-2} for Dark Sky Community, rural, and DSAG class 6b areas.

Example: The IAU Commission on Site Protection defined a limit of artificial skyglow beyond which observations requiring darkest sky conditions are increasingly compromised. That limit was defined as an increase in sky brightness at 45° elevation due to artificial light not more than 10 % of the lowest natural level in any part of the spectrum between wavelengths 300 and 1000 nm for optical observatories[47]. The recommendation did not specify a bandwidth, but context suggests that the Commission was considering relatively broad-band filter imaging.

2.7 Façade lighting and colorful illumination and control of glare

All outdoor lighting should be fully shielded against glare, uplighting, and obtrusive light onto neighboring properties or protected sites. To afford full protection, no façade lighting or illuminated advertising should be permitted in Zones E0 and E1. The illumination of architectural structures and signs should be avoided during curfew while the luminance levels should be kept as low as possible following the efficient lighting design techniques. Color and dynamic lighting of façades and signs should be generally avoided especially beyond city centers. Discretionary lighting, such as advertising and façade illumination, should be held to more stringent limits based on minimum requirements for visibility, such as those of the IES/IDA. Directionality is a key element in control of artificial skyglow; if light in city centers is ever directed above horizontal, its spatial distribution must be highly shaped and controlled to avoid spill.

2.8 Lighting measurements and monitoring

The appropriate instrumentation and methods should be used for the measurement, assessment and monitoring of skyglow, direct light exposure, and the sources of obtrusive light. A standardized metrology system for light pollution based on traceable instruments should be developed and used by the different disciplines. Measurements should be readily available through national and international reference databases for sites.
Depending on the application, different measurements are needed. Sky brightness and data from satellites give overall information on a larger scale but they do not give sufficient information on light exposure of individuals or the directionality of light apart from upwards.

Examples: From a decomposition of the night sky spectrum, Kolláth et al. (2020a) determined that the ‘continuous’ component of the natural sky (zodiacal light, scattered starlight and airglow pseudo-continuum) is nearly constant at all visible wavelengths and has a spectral radiance of ~2 nW m^{-2} sr^{-1} nm^{-1}, or 2 dsu (dark sky units). Because of the relatively limited range of broad-band color variations of natural skyglow under clear, moonless conditions, digital camera-based, three-color (RGB) radiance measurements in dsu give a usable sky brightness measurement (Kolláth et al. 2020b). Both broad-band and spectrophotometric measurements are calibrated on the basis of stellar standards, with fluxes measured with respect to laboratory standards.

There are already several operational skyglow measurement networks implemented by different governments as part of their environmental data-gathering and public release of information policies.

[47] Transactions of the International Astronomical Union , Volume 17, Issue 1: Reports on Astronomy, 1979 , pp. 215–223; DOI: https://doi.org/10.1017/S0251107X00010798

They are mostly based on sky quality meters (SQM) integrated in automated weather stations, providing data in real time though their websites.

The readings of zenith brightness are a proxy for the density of artificial photons in the vicinity of the detector, and provide useful information about the light pollution at different places of the territory and their long-term evolution.

Example: The network of the Environment Ministry of the Galician Government (autonomous community of the kingdom of Spain), whose data are released in the 'Air quality' section of the Galician Meteorological Public Agency website, together with the index of air quality, levels of noise pollution in major cities, etc.[48] Similar networks exist in environment/meteo public agencies of other governments, e.g. the Swiss territory of Ticino[49] and in Northern Italy[50].

2.9 Commercial and military flight planning

Civilian regulators and military flight planners should exclude the observatory near zones from approved flight paths and keep those paths as far from observatories as practicable.

2.10 Need for research

Interdisciplinary research among lighting, medical, and environmental research communities on the effects of artificial light at night on human health, on flora and fauna, on visibility levels and public safety, on thresholds for impacts on humans and natural organisms and other related topics should be strongly encouraged. The research must use correct metrics and lighting research methods to ensure the results can be communicated between disciplines and implemented.

2.11 Long-term targets

A long-term strategy should be developed in terms of international, national or regional regulations, to ensure mitigation of unwanted effects of light pollution, to establish standardized measurement systems, for revision of relevant lighting standards and for the promotion of lighting education. The plans will evolve based on the experience of early adopters of the masterplan approach for wider application.

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[48] https://www.meteogalicia.gal/Caire/brillodoceo.action
[49] https://www.oasi.ti.ch/web/dati/inquinamento-luminoso.html
[50] https://www.arpa.veneto.it/bollettini/meteo/brillanza/Mappa_BRILLAIST.htm

3. Areas where the tasks require special application beyond the merged framework and those aspects of the framework that must allow flexibility by region

Locations with special needs in terms of light pollution include environmentally vulnerable areas like nature reserves. Applications of ALAN should fully consider the local biodiversity and the need of resident species. For example, while the majority of studied species are negatively affected by short-wavelength light, some glow-worm species are harmed by long-wavelength light. From a health and well-being point of view, special care has to be taken to avoid intrusive light in hospitals and nursing homes, since elderly people and children are especially sensitive to light.

4. Research areas with progress in the last year and those with high priority need for support to strengthen the basis for the recommendations

Light pollution has increasingly been the subject of research in several disciplines. The following points need further investigation.

A growing number of studies have provided data and a growing consensus on the negative impact of light pollution on almost all organismic groups. More research is needed on the impact of different light levels experienced by organisms in the field and on **thresholds for relevant impacts** (e.g., melatonin suppression, phototaxis glare), including as a function of the light's spectral distribution. It is also necessary to assess the impact of light pollution not as an isolated stressor, but as one of several interacting environmental stressors, e.g., climate change, air pollution, and water pollution, since these stressors amplify each other.

Epidemiological studies have shown a negative impact of the intrusive part of outdoor lighting on human health and well-being, which can be explained by laboratory studies on indoor light on human physiology. More robust data are needed on the amount and spectral characteristics of light needed to suppress melatonin and to disturb sleep independent from melatonin, e.g. due to psychological stress. We also need stronger data on correlations or causations for diseases possibly related to ALAN, combined with **more detailed and personalized light measurements for these studies**.

To determine realistic values for recommendations on outdoor light with reduced negative impact, we need robust data from well-designed trials on the **amount and characteristics of light needed for human eyes** (e.g., car drivers, pedestrians, advertisement boards).

Current labeling of commercial lighting products lacks the information needed to assess a light source's environmental impact. We need to establish measuring units and labels to describe blue content. Based on knowledge about human vision and the impact of light pollution we need to **develop light sources with less harmful effects on nature**.

Knowledge about light needs to be transferred between disciplines, i.e., astronomy, physics, lighting technology, biology, health, urban planning, cultural science. **A lingua franca and transdisciplinary projects are vital for better use of artificial light**.

Recommendations will be successful only if their necessity is understood. Light generally has a positive connotation, while its negative effects are less well known, so we need to **raise awareness of the value of dark nights**. We need to **educate communities** on the aspects of human health, ecology, culture, etc., and encourage positive emotions for darkness in people's minds. Light pollution is an excellent topic for schools, covering basically all disciplines of education. **Lighting professionals** need to understand priorities and "myths" in the use of light (i.e., more light does not automatically mean better vision independent of the characteristics of this light). **Medical professionals** also need information on the health aspects of light in general.

Appendix A. Existing Models of Laws, Rules, Regulations and Policies

In this Appendix we present lists of treaties, acts, policies, laws, and regulations connected to light pollution. These lists are intended only to show that the interest in protecting the night environment is strong at different levels, from the local level up to the international. The lists are necessarily incomplete.

It should be emphasized that none of the existing legal instruments related to light pollution can be considered as perfect. To a certain degree all have positive and negative aspects. Moreover, currently none of the existing regulations implements the proposed Regional Lighting Masterplan, which we strongly suggest adopting in order to finally achieve a reduction of light pollution. In fact, while some policies have been successful at preventing light pollution from increasing, *none* of the current regulations has been able to reduce levels of light pollution in a balanced way. We believe the reason for this is that they have relied primarily on control at the installation level.

A.1 International level

This table provides examples of current international policies and regulations related to light pollution. This table aims to highlight the process of recognition of light pollution as a global issue and to show the response of the international community on this fast-growing problem.

Organization / body	Treaty, Act, Policy	Year	Main aim of the legal act	light pollution recognition
UN General Assembly	Resolution A/RES/68/221 on International Year of Light and Light-based Technologies, 2015	2014	Proclaim 2015 the International Year of Light and Light-based Technologies.	Considered that technology and design can play an important role in the achievement of greater energy efficiency, in particular by limiting energy waste, and in the reduction of light pollution, which is key to the preservation of dark skies.
UNEP	The Convention on Biological Diversity (CBD)	1992	The first global agreement to cover all aspects of biological diversity.	COP15 discussing the need to include reduction of light pollution as a target into the Post-2020 Biodiversity Framework. See: Report of the Open-ended Working Group on the Post-2020 Global Biodiversity Framework on its third meeting (Part I) (CBD/WG2020/3/5)
UNEP	The Convention on Conservation of Migratory Species of Wild Animals (CMS)	1979	The CMS acts as a framework Convention	COP13 the Resolution 13.5 Light Pollution Guidelines for Wildlife and its Annex confirmed the hazardous environmental impact of light pollution and encouraged Parties to develop measures to decrease the amount of ALAN.
UNEP	The Agreement on the Conservation of Populations of European Bats (EUROBATS)	1991	The Bat Agreement aims to protect various bat species through legislation, education, conservation measures and international cooperation. The Agreement provides a framework of co-operation	Resolution 8.6: Bats and Light Pollution 2018 (Doc.EUROBATS.StC14-AC23.18 .Rev.1) adopted during 14th Meeting of the Standing Committee and 23rd Meeting of the Advisory Committee noted the rapid growth and extent of

			for the conservation of bats throughout Europe, Northern Africa and the Middle East.	artificial light at night and its detrimental impact (light pollution). Moreover, it urged Parties among others to ensure that the impacts of artificial light on bats are included in environmental impact assessment procedures. Guidelines for consideration of bats in lighting projects (2018)
UNEP	The Convention for the Protection of the Marine Environment and Coastal Region of the Mediterranean (Barcelona Convention) and its Protocols	1976	The Barcelona Convention and its Protocols constitute a unique and advanced multilateral legal framework for the protection of the marine and coastal environment and sustainable use of their resources in the Mediterranean.	COP21 (2019) Decision IG.24/7 Strategies and Action Plans. This Decision encouraged the Parties to cover issues such as use of artificial lights while developing measures and management rules aimed at protecting critical habitats.
UNEP	Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA)	1995	The Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) is an intergovernmental treaty dedicated to the conservation of migratory waterbirds and their habitats across Africa, Europe, the Middle East, Central Asia, Greenland and the Canadian Archipelago.	Section 2.1.2 (b) of the Agreement placed an obligation on the Parties to regulate the modes of taking, and in particular prohibit the use of all indiscriminate means of taking and the use of all means capable of causing mass destructions, as well as local disappearance of, or serious disturbance to, populations of a species, including artificial light sources.
Intergovernmental Science-Policy Platform on Biodiversity	Work programme of the Platform: thematic assessment on pollinators,	2016	Thematic assessment on pollinators, pollination and food production. The assessment report is composed of a summary	Section 2.3.4.3 Light pollution highlights that ALAN has or may have a negative impact on biodiversity.

and Ecosystem Services (IPBES)	pollination and food production IPBES/4/INF/1		for policymakers, and individual chapters and their executive summaries.	
UNESCO, UNWTO, IAU	Starlight Declaration	2007	Recognised the significant value of the dark sky for environment, astronomy, socio-cultural development, etc.	Encouraged the Parties to decrease light pollution levels.
UNWTO Scientific Tourism Working Group and UNWTO's Affiliate Members	The Starlight Tourist Certification System	2010	Astrotourism Group, led by Starlight Foundation (from 2019), supports the protection of the dark sky in order to perform astronomical activities and organize scientific tours in dark sky sites.	Starlight Tourist Destinations are visitable sites with excellent conditions for observing the stars, which are protected from light pollution and are suitable for tourist activities based on the stars as an integral part of nature.
UNESCO	Urban Futures Heritage of Astronomy	2003	UNESCO plays a major role in protection of dark-sky, namely for astronomical activities.	Several astronomical sites were included into the World Heritage List: Struve Geodetic Arc, the Jantar Mantar, Jodrell Bank Observatory and Risco Caido, Chankillo Astronomical Complex.
UNEA	Thematic Report of the Second session of the United Nations Environment Assembly of the United Nations Environment Programme Nairobi, 23–27 May 2016	2016	Thematic Report "Healthy environment, healthy people"	The Report recognized that two-thirds of the world live under light-polluted skies. Moreover, it highlighted the potential negative effects of ALAN for human health and environment.
The UN Department of Economic and Social Affairs	The United Nations Declaration on the Rights of Indigenous Peoples	2007	Cultural ideas and cultural property rights, legal protection and mechanisms protecting the	For the indigenous peoples the role of dark-sky is of significant importance, e.g. for performing rituals, etc. The conservation of

Indigenous Peoples (UN DESA) and UNDRIP Declaration on Rights of Indigenous Peoples	(UNDRIP)		rights of groups as well as individual property owners	the natural dark sky environment will lead to protection of the unique way of life of indigenous peoples. See, for. e.g. Australian Indigenous Astronomy.
UNOOSA United Nations Office for Outer Space Affairs and COPUOS Committee on the Peaceful Uses of Outer Space	Conclusions and proposals of the International Astronomical Union/Committee on Space Research/United Nations Special Environmental Symposium "Preserving the Astronomical Sky" Annual Report of the UN Office for Outer Space Affairs	1999 2020	Stated conclusions and proposals of the International Astronomical Union/Committee on Space Research/United Nations Special Environmental Symposium "Preserving the Astronomical Sky". Report from the activities of the organization for 2020.	The Third UN Conference on the Exploration and Peaceful uses of Outer Space (21 July 1999): recognised that human-made light pollution has already made large areas of the world unsuitable for astronomical observations and is beginning to influence wildlife and encouraged Member States to control pollution of the sky by light. Has organized on-line workshops on the topic of "Dark and Quiet Skies for Science and Society" (October 2021) to address light pollution.
IUCN	Resolution 084. Taking action to reduce light pollution	2021	The IUCN World Conservation Congress's main goal is to set priorities and drive conservation and sustainable development action.	Recognized various negative impacts of ALAN and encouraged the Parties to take measures against light pollution.
The Parliamentary Assembly of the Council of Europe	Resolution 1776 (2010) "Noise and light pollution"	2011	The resolution highlights the negative effects arising from light and noise pollution. Moreover, it emphasizes the need to protect the natural dark	The Assembly emphasizes the need to preserve an "unpolluted" night sky. Furthermore, the Resolution states that light pollution affecting flora and fauna poses

			sky.	one of the worst threats to urban biodiversity, but above all has harmful effects on human metabolism. Moreover, it highlights the impacts on energy consumption. It also encourages the Parties to develop the needed measures to address light pollution.
The Council of Europe	The European Landscape Convention of the Council of Europe (the Florence Convention)	2000	The first international treaty to be exclusively devoted to all aspects of European landscape. It applies to the entire territory of the Parties and covers natural, rural, urban and peri-urban areas.	Memento contributing to the implementation of the European Landscape Convention of the Council of Europe — Towards integrated approaches for landscape monitoring. Adopted by the 10th Council of Europe Conference on the European Landscape Convention, in Strasbourg on 7 May 2019. Considered that lighting emissions should be included in landscape monitoring.
Trilateral agreement (NL, D, DK)	Leeuwarden Declaration (2018) Protection of the Wadden Sea	2018	The Declaration aims at the protection and maintenance of the Wadden Sea World Heritage.	Requested the Wadden Sea Board to stimulate various initiatives aiming to reduce light emissions, such as measures to avoid unnecessary lighting, the exchange of best practices, technological innovations or monitoring, for the benefit of the whole Wadden Sea Area, whilst ensuring safety standards prescribed by pertinent legislation.

Light pollution is of a transboundary character and requires joint actions against this relatively new problem[51]. Current legal instruments at the international level have shown a tendency to gradually recognize light pollution as a hazardous threat for astronomy, the environment, biodiversity, etc. The negative impacts of ALAN have been recognized especially within the field of biodiversity conservation. Various United Nations Environment Programme (UNEP) conventions have drawn attention to light pollution and adopted guidelines on how to minimize its adverse effects. However, it should be noted that those guidelines are of an advisory nature, hence the parties are not obliged to develop their own measures to reduce light pollution. On the other hand, the existing international legal framework provides for the protection of dark skies to a certain limited degree. For instance, the special conservation regime of astronomical sites, which are included in the World Heritage List, requires the preservation of the natural dark skies above these areas. In addition, light pollution is considered for inclusion as one of the targets for the Post-2020 Biodiversity Strategy[52]. This could be an important milestone for the adoption and development of policies and regulations against increased ALAN as an environmental problem.

A.2 EU level

This table provides examples of current policies and regulations related to light pollution developed by the European Union. This table aims to show that the problem of light pollution has been gradually acknowledged within the EU framework.

[51] Hölker, F., T. Moss, B. Griefahn, W. Kloas, C. C. Voigt, D. Henckel, A. Hänel, P. M. Kappeler, S. Völker, A. Schwope, S. Franke, D. Uhrlandt, J. Fischer, R. Klenke, C. Wolter, and K. Tockner. 2010. The dark side of light: a transdisciplinary research agenda for light pollution policy. Ecology and Society 15(4): 13. [on-line] URL: http://www.ecologyandsociety.org/vol15/iss4/art13/

[52] Open-ended WG on the Post-2020 Global Biodiversity Framework Zero Draft of the Post-2020 Global Biodiversity Framework CBD/WG2020/2/3/Add.1 of 6 January 2020, Target 4 Reduce by 2030, pollution from excess nutrients, biocides, plastic waste and other sources by at least [50%]: Change in amount of other pollutants (including light and noise). page 7, Available on-line: https://www.cbd.int/doc/c/2f5f/ea7d/3c7ff4e05fb89094a2222144/wg2020-02-03-add1-en.pdf; See also: Open-ended WG on the Post-2020 Global Biodiversity Framework First Draft of the Post-2020 Global Biodiversity Framework CBD/WG2020/3/3 of 5 July 2021: Target 7. Reduce pollution from all sources to levels that are not harmful to biodiversity and ecosystem functions and human health. Available on-line: https://www.cbd.int/doc/c/abb5/591f/2e46096d3f0330b08ce87a45/wg2020-03-03-en.pdf

Organization / body	**Treaty, Act, Policy**	**Year**	**Main aim of the legal act**	**Light pollution recognition**
European Parliament and Council of the European Union	Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products	2009	Established a framework for the setting of ecodesign requirements for energy-related products.	Defines the regional provisions for setting eco-design requirements on light products as energy-related products and establishing requirements of the production, distribution, use and end-of-life practice of light products.
European Parliament and Council of the European Union	Directive 2000/55/EC of the European Parliament and of the Council of 18 September 2000 on energy efficiency requirements for ballasts for fluorescent lighting	2000	This Directive aims at reducing energy consumption for ballasts for fluorescent lighting by moving gradually away from the less efficient ballasts, and towards the more efficient ballasts which may also offer extensive energy-saving features.	Provides standardization measures for the use of more energy efficient lighting.
European Parliament and Council of the European Union	Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment	2011	This Directive shall apply to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment.	Annex IV.1 (c) A description of the project shall include, in particular: an estimate, by type and quantity, of expected residues and emissions (water, air and soil pollution, noise, vibration, light, heat, radiation, etc.) resulting from the operation of the proposed project.
European Commission	Commission Regulation (EU) 2019/2020 of 1	2019	This Regulation creates ecodesign requirements for light	The Commission shall review this Regulation in the light of technological progress and shall

	October 2019 laying down ecodesign requirements for light sources and separate control gears		sources.	present the results of this review, including, if appropriate, a draft revision proposal, to the Consultation Forum no later than 25 December 2024. This review shall in particular assess the appropriateness of: (a) setting more stringent energy efficiency requirements for all light source types, in particular for non-LED light source types, and for separate control gears; (c) setting more stringent requirements on flicker and stroboscopic effects, while extending them to separate control gears; (d) setting requirements on dimming, including the interaction with flicker; (g) setting lifetime requirements; etc. These amendments may be consistent and effective for light pollution mitigation.
European Parliament	European Parliament resolution of 9 June 2021 on the EU Biodiversity Strategy for 2030: Bringing nature back into our live	2021	The new EU Biodiversity Strategy for 2030.	The EU Parliament recognizes that: (AT) light pollution alters the natural night light levels for humans, animals and plants, thus negatively affecting biodiversity by, for example, unbalancing the migratory, nocturnal and reproductive activity of animals, leading also to the loss of insects and pollinators who are fatally drawn to artificial light'; -(127)'Calls on the Commission to set an ambitious reduction target for 2030 on the use of outdoor artificial light and to

				propose guidelines on how artificial light at night can be reduced by the Member States'; -(128)'...in the upcoming zero pollution action plan, which should also address light and noise pollution'.

At the European Union level, lighting issues are considered mostly from the perspective of energy efficiency. However, back in 2010, the European Union drew attention to other aspects of negative consequences associated with ALAN and highlighted the need to protect the dark sky. Currently, there is a tendency to recognize light pollution as an environmental problem, as evidenced by the EU Biodiversity Strategy for 2030. This recently adopted Strategy will stimulate the member states to develop and adopt policies and regulations to protect the environment and population from the adverse effects of light pollution.

A.3 National level

This table provides examples of current national policies and regulations related to light pollution. This table aims to show how different national frameworks have responded to the newly recognized problem of light pollution. The table provides a small overview and gives comments on how light pollution is considered within a national framework. This collection of rules and regulations shows the widespread concern about ALAN and light pollution, but its large range of policy approaches and effectiveness also underscores the need for coordination and leadership at the international level.

Country	**Legal Instrument**	**Year**	**Legal aspects related to light pollution**
Slovenia	Law on limit values for light pollution of the environment	2007	Provides for the protection of nature against the harmful effects of light pollution, the protection of living quarters from disturbing lighting due to the lighting of uncovered surfaces, the protection of people against glare, the protection of astronomical observations against skyglow and the reduction of electricity consumption.
UK	The National Planning Policy Framework	2012	185. Planning policies and decisions should also ensure that new development is appropriate for its location taking into account the likely effects (including cumulative effects) of pollution on health, living conditions and the natural environment, as well as the potential sensitivity of the site or the wider area to impacts that could arise from the

			development. In doing so they should: c) limit the impact of light pollution from artificial light on local amenity, intrinsically dark landscapes and nature conservation.
	Environmental Protection Act	1990	Prohibits lighting nuisances: (fb) 79 artificial light emitted from premises so as to be prejudicial to health or a nuisance.
	Clean Neighbourhoods and Environment Act	2005	Sec.102: Statutory nuisance: lighting. Limitation — public places are excluded from obligation to emit less lighting.
France	Decree of 27 December 2018 relating to the prevention, reduction and limitation of light pollution	2018	Detailed rules for reducing light pollution, including requirements on proper installations and time limitations for lighting usage.
	Decree No. 2011-831 on the prevention and limiting of light pollution	2011	Provide several approaches to light pollution mitigation according to various types of lighting installations.
	Decree No. 2012-118 on the outdoor advertising, signs and signposting	2012	Amended the Environmental Code of France in relation to outdoor lighting installations, namely signs and outdoor advertising.
	Order on the night-time lighting of non-residential buildings in order to limit light pollution and energy consumption	2013	This decree applies to the lighting installations of non-residential buildings, covering both the interior lighting emitted to the exterior of these buildings and the illumination of the facades of buildings, excluding lighting installations. intended to ensure the protection of goods when they are slaved to motion or intrusion detection devices.
Germany	Law on the protection against harmful environmental effects from air pollution, noise, vibrations and similar processes (Federal Immission Control Act — BImSchG)	1974	Art 3(2) Emissions within the meaning of this Act are air pollution, noise, vibrations, light, heat, radiation and similar environmental effects affecting people, animals and plants, the soil, water, the atmosphere as well as cultural and other material assets.

	The Federal Nature Conservation Act	2009	New amendments (2021) related to the insect diversity protection program were adopted. Several provisions provide protection of animals and plants from adverse effects of artificial light.
Spain	Law on air quality and protection of the atmosphere	2007	Art.3(f): "Light pollution": The luminous nocturnal glow or brightness produced by the diffusion and reflection of light in gasses, aerosols and suspended particles in the atmosphere, which alters the natural conditions of the night hours and makes astronomical observations of celestial objects, the natural brightness, attributable to radiation from sources or celestial objects and the luminescence of the upper layers of the atmosphere, having to be distinguished from the luminous radiance due to light sources installed in outdoor lighting.
	Law on Protection of the Astronomical Quality of the Observatories of the Institute of Astrophysics of the Canary Islands	1988	Outdoor lighting, the installation and operation of stations and the establishment of industries, activities or services that produce atmospheric pollution, as well as other factors that prove degrading to the atmospheric quality of the observatories on the island of La Palma will be subject to the limitations established in this Law.
	Law on Environmental Management of Lighting for the Protection of the Night Environment	2001	The object of this Law is the regulation of the installations and the exterior and interior lighting devices, with regard to the light pollution that they may produce.
	Royal Decree, which approves the Regulation of energy efficiency in outdoor lighting installations and its complementary technical instructions EA-01 to EA-07	2008	The purpose of this regulation is to establish the technical conditions for design, execution, and maintenance that outdoor lighting installations must meet, in order to: improving energy efficiency and savings, as well as reducing greenhouse gas emissions; limit nighttime light glare or light pollution and reduce intrusive or disturbing light.
Chile	The Emission Standard for the regulation of light pollution (under consideration — 2021)	N/A	The Standard proposes several restrictions in order to minimize light pollution. The regulations will apply at different levels, as well as for public and private lighting installations.

Croatia	Light Pollution Protection Act	2019	This Act regulates protection against light pollution, which includes taxpayers for protection against light pollution, measures for protection against light pollution, the manner of determining the maximum allowable values of lighting, restrictions and prohibitions of lighting, conditions for planning, construction, maintenance and reconstruction of outdoor lighting, measurement and monitoring environmental lighting and other issues in order to reduce light pollution and the consequences of light pollution.
Czech Republic	Air Protection Act	2002	This law defines light pollution as visible radiation from artificial light sources, which can annoy people or animals and cause them harm or disrupt some of their activities. How light sources are located is crucial for the intensity of light pollution. The Act allows a municipality (Section 50 (3) (c)) to issue a generally binding decree adopting measures against light pollution. These measures should be aimed at regulating the projection of neon signs and effects on the sky.
Italy	Provisions for the sustainable management of public lighting and for the contrast of light pollution (under consideration — 2019)	N/A	Light pollution is considered as the alteration of the natural quantity of light present in the nocturnal environment caused by the introduction of artificial light outside the areas to which it is functionally directed or with irradiation directed above the horizon line, or rather to an extent higher than the minimum lighting levels provided for by this law and by safety regulations or which may induce negative effects, even temporary ones on humans or alterations of the environment, such as mortality or removal of sensitive species, loss of biodiversity, alteration of the composition of habitats and ecological balances, increased environmental fragmentation, effects on the physiology and behavior of animal species and on the photoperiod of plants, loss of natural resources, worsening of air quality and less usability of the vision of the starry night sky. The Draft of Law proposes requirements needed to decrease light pollution and mitigate its consequences.
Netherlands	Decree on Environmental Management Activities	2007	Article 2.1 (2h) Preventing or limiting the occurrence of adverse effects on the environment as referred to in the first paragraph is understood to mean, in particular: preventing or, insofar as this is not possible, limiting light nuisance to

	Environmental and Planning Act (under consideration)	Comes into force in 2022	an acceptable level. Darkness can be included as one of the environmental values; therefore, the protection of the dark sky will be considered as a necessity for environmental protection.
New Zealand	Resource Management Act (RMA)	1991	The RMA promotes the sustainable management of natural and physical resources such as land, air and water. The specific sections of the RMA which are most relevant to the protection of starlight as a natural resource of cultural significance are Part II: Purpose and Principles, sections 5, 6, 7 and 8.
Korea	Light Pollution Prevention Act	2012	This regulation introduced limits on the average luminance and maximal vertical plane illuminance of flashing screen videos based on four environmental zones and the time of application.
Mexico	General Law of Ecological Balance and Environmental Protection	1988	Light was recognised as a polluter. The Law has definitions of light pollution and intrusive light. Provided the need to organize measures against environmental pollution caused by intrusive light.
Poland	Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location	2002 (2019)	The Regulation describes maximum nuisance values caused by light trespass (from luminaires and advertisements) to users such as pedestrians and drivers which shouldn't be exceeded, and it explains how to measure these values. Other aspects of light pollution such as skyglow, glare and overlighting are not considered.

Legal regulations related to light pollution have gradually been developed under national legislation frameworks. A number of countries consider artificial light as a pollutant in general environmental laws (the UK, France, Germany, etc.) and develop legal norms aiming at reduction of ALAN levels for only conservation purposes. Some countries have adopted separate legal regulations against light pollution (Slovenia, Croatia, Spain, Korea, etc.). These legal instruments are specifically focused on the mitigation of negative impacts of light pollution and provide a wider range of measures against it, in contrast to general environmental law frameworks.

Currently, there is no uniform approach on how to eliminate excessive lighting, and therefore countries set measures within various legislative frameworks, mainly environmental law. Moreover, the adopted measures against light pollution are consistent with the objectives of the chosen legislative frameworks, so this does not always contribute to a decrease of light pollution levels. In addition, the existing legal instruments are focused on certain aspects of the negative light pollution consequences, e.g. astronomical activities or biodiversity protection, and this, in turn, also does not help to address light pollution as a complex problem.

A.4 Subnational level

This table provides examples of current subnational policies and regulations related to light pollution in order to highlight that ALAN-mitigating regulations are being gradually adopted within different levels of one national jurisdiction.

Country	Legal Instrument	Year	Legal aspects related to light pollution
City of Cottonwood, USA	City of Cottonwood Zoning Ordinance	1999	Section 408. Outdoor Lighting Code MISSION STATEMENT: To afford every citizen of Cottonwood the flexibility to engage in the pursuit of safe, inexpensive lighting practices for the purpose of commerce and private use without being impeded upon or impeding upon other citizens desiring a more pristine night time environment free from light pollution, waste, trespass, or clutter while providing nighttime safety, security and productivity.
Taos County, USA	Night Sky Protection Act	2006	The Ordinance promotes energy efficiency and reduction or prevention of light pollution. The Ordinance protects the night skies for the future generations.
Coconino County, USA	Coconino County Zoning Ordinance	2019	**Ch. 4 Performance Standards; 4.3. Lighting:** The intent of this Ordinance is to encourage lighting practices and systems that will minimize Light Pollution, light trespass, impacts to nocturnal wildlife, and conserve energy while maintaining nighttime safety, utility, security, and productivity. Because not all areas in the County are near established observatories, four Lighting Zones are established, allowing increased flexibility in the uses of outdoor lighting farther from the observatories.
Flagstaff, USA	Flagstaff Zoning Code	2011	**Division 10-50.70: Outdoor Lighting Standards:** the purpose of this division is to help assure that dark skies remain a resource to be enjoyed by the Flagstaff community and its visitors, and to provide safe and efficient outdoor lighting regulations that protect Flagstaff's dark skies from careless and wasteful lighting practices. Dark starry nights, like natural landscapes, forests, clean water, wildlife, and clear unpolluted air, are valued in many ways by the residents of this community, and they provide the natural resource upon which our world-renowned astronomical industry depends.

San Jose, USA	Public Streetlights Policy	1980	Goals: reduce per capita energy use by 50 percent; obtain 100 percent of the City's electrical power from clean, renewable resources; divert 100 percent of the waste from our landfill; replace 100 percent of streetlights with smart, zero emission lighting [powered exclusively with renewable energy].
San Angelo, USA	Ordinance of San Angelo, Texas Amending Chapter 8, Offenses & Nuisances To Add New Article 8.1200	2014	These ordinances specifically create standards for outdoor lighting to help minimize light pollution, glare and light trespass caused by inappropriate or misaligned light fixtures, while improving nighttime public safety, utility, and security.
City of Presidio, USA	Outdoor Lighting Ordinance	2021	This Ordinance aims at mitigating light pollution by setting specific measures against intrusive lighting, e.g. spotlights should be pointed straight down.
Italian regional laws: Abruzzo LR12/05 Alto Adige LP4/11 Basilicata LR41/00 Campania LR12/02 Emilia Romagna LR19/03 Friuli V.G. LR15/07 Lazio LR23/00 Liguria LR22/07 Lombardia LR 31/15 (exLR17/00) Marche LR10/02	Law of the Regione (Italy is divided in 19 regions and two autonomous provinces); only two regions don't have a law on light pollution.	1997 (Veneto, first law) to 2018 (Piemonte, updated the 2000 law)	The best Italian regional (NUTS2 administrative units) laws have these pros: • Act in all territory of each region, not only in particular 'protected' areas (including large cities like Rome, Turin and Milan). • Act for public and private lights. • Prescribe fully-shielded lights (only exceptions: monumental and historic building lights, with additional constraints, like curfew). • Assign a maximum allowed luminance or illuminance for roads. • Have rules for advertising signs (curfew, maximum luminance, maximum total flux). • Stop the increase of zenith artificial sky brightness. Cons: • Fail to reverse the increase of light pollution due to the lack of a red-lines approach. • Lack of a total cap in the ALAN produced. • Lack of a roadmap to reduce ALAN. • Enforcement not successful for private lights (lack of controls). • Enforcement not successful for some historic

Molise LR2/2010 Piemonte LR31/00 Puglia LR15/05 Sardegna D.G.R. 48/31 Toscana LR37/00 Trentino LP16/07 Umbria LR20/05 Valle d'Aosta LR17/98 Veneto LR17/09			buildings.
Australia, National Capital Authority	Outdoor Lighting Policy	2012	This policy has been prepared to guide the range of considerations necessary when installing or renewing outdoor lighting in the nationally significant areas of the Australian Capital Territory. It seeks to ensure that the planning, design and operation of lighting balances the needs of people and the environment.
Spain Castilla and León Navarra	 Law on the prevention of light pollution and the promotion of energy saving and efficiency derived from lighting installations Law on the regulation of lighting for the protection of the night environment in Navarra	 2010 2005	 The purpose of this Law is to regulate the operation of the facilities, lighting devices and auxiliary lighting / outdoor lighting equipment of public or private ownership, with the purpose of preventing and, where appropriate, correcting light pollution in the territory of the Community of Castilla y León, as well as promoting energy saving and efficiency in lighting systems. It is the object of this Regional Law to regulate the installations and elements of exterior and interior lighting, with regard to the light pollution that they can produce and their energy efficiency. The aim is to establish the conditions that new outdoor lighting installations, both public and private, located in the

			Autonomous Community of Navarra must meet, as well as the corrective measures to be applied to existing inadequate installations, in order to improve the protection of the environment through an efficient and rational use of the energy they consume and the reduction of nighttime light glare, without compromising the safety that the lighting must provide to pedestrians, vehicles and properties.
Cantabria	Light pollution prevention law	2006	The purpose of this Law is to regulate lighting installations and devices to prevent and, where appropriate, correct light pollution in the territory of the Autonomous Community of Cantabria, as well as promote the efficiency and energy saving of lighting systems, and all this without detriment to the safety that the lighting must provide to pedestrians, vehicles and properties.
Andalusía	Law on Integrated Management of Environmental Quality	2007	Title IV, Chapter II Quality of the atmospheric environment: the prescriptions contained in this chapter shall apply to ambient air and to the pollution introduced into it by substances, by light of artificial origin and by noise and vibrations.
Extremadura	Law on prevention and environmental quality of the Autonomous Community of Extremadura	2010	E.g., Section 4. Light Pollution Article 89. Public Administrations, within the scope of their powers, will promote the prevention and reduction of light pollution.
Belgium			
Flanders	Order of the Flemish Government of 1 June 1995 concerning General and Sectoral provisions relating to Environmental Safety (VLAREM II)	1995	Provisions on lighting nuisance (Chapter 4.6 and Chapter 6.3): requires to limit the amount of light and lighting intensity to prevent the lighting nuisance. The use and the intensity is limited to the necessities regarding operation and safety.

	Decree General Provisions Environmental Policy	1995	Light is considered as a polluter factor. One of the objectives of the Decree is protection of people and the environment from, in particular, nuisance and risks resulting from the direct or indirect introduction of light into the air, water or soil that can affect human health or the quality of the environment.

Subnational legal instruments, as well as national, are diverse and use different approaches and measures against light pollution. Three different approaches to creating a legal framework can be identified: (1) Some of the local acts set the requirements for decreasing ALAN levels in Zoning or Lighting Ordinances (Coconino County, Cottonwood, Flagstaff (USA); Australian Capital Region (Australia), etc.); (2) Another approach is based on limiting ALAN levels for conservation of nature (Andalusia (Spain); Flanders (Belgium), etc.); in addition, (3) the adoption of specific legal instruments against light pollution at subnational level is also well developed (various Italian regions; Cantabria, Navarra (Spain); Taos County (USA), etc.). The last of these seems to be the most effective because, in most cases, such regulations include more varied and detailed measures and obligations needed to address a wide range of negative light pollution effects.

A.5 Light pollution control to protect major observatories

This table provides some examples of lighting management to protect major observatories. The table highlights specific measures aiming at dark sky protection above the observatories.

Observatory	**Regulation**	**Year**	**Main idea(s)**
Kitt Peak, Mt. Hopkins, Mt. Graham	City of Tucson/Pima County Outdoor Lighting Code	2012	All cut-off of the light depends on zone and type. Lighting zones: Urban, rural & observatory protection. Limits: 12,000 lumens/acre residential. Curfew: 23.00–sunrise. Illumination limits on advertising signs & roadways.
Palomar and Mount Laguna	San Diego	2012	Full cut-off of all but decorative or low intensity lighting installations. Lighting zoning: special districts & observatory protection. Limits: <4050 lumens/fixture. Curfews: 23:00–6:00. Urban lighting CCT<4000K. Advertising signs exempt from full cut-off.
Lick Observatory	San Jose	2000	Full cut-off of all but decorative or low intensity lighting installations. Lighting zoning: special districts & observatory protection. Curfews: diming after 00.00.

Paranal/ Armazones, CTIO, Las Campanas	Chile Norma Luminica	2016	All cut-off; exceptions are holiday and emergency. Lighting zones are not determined. Lasers & searchlights above 110 degrees from zenith are prohibited. Luminance limits on signs. Intensity pattern constraints on luminaires.
McDonald	Jeff Davis County	2007	All cut-off; exceptions are decorative or low intensity. Lighting zones are not determined. Curfews closing hours or 00.00. Hg-vapor and searchlights are prohibited. Spotlights within 20 degrees vertically down.
Observatorio del Roque de Los Muchachos	La Palma	1988	All cut-off; exceptions are decorative or low intensity. Lighting zones are not determined. Curfews 00.00. Public lighting dimmed at 0:00; outdoor fixtures on certified list.
South Africa Large Telescope	Sutherland Astronomy Advantage Area	2018	Lighting zones: radial zone for observatory protection.Light emission shall be limited to above 500 nanometres.
Xinglong, China	Ministry of Environmental Protection and Ministry of Urban Development	vario us	Lighting zones: two radial zones for observatory protection. Local governments are still to be engaged. See e.g., Urban Lighting Management Regulations 2010; Shenzhen Special Urban Lighting Plan (2021-2035)
San Pedro Martir , Mexico	Ensenada, Mexicali (State of BC)	2006	All cut-off; exceptions are decorative or low intensity. Lighting zones are not determined. Curfews 23.00. Uplit signs, lasers & searchlights above horizontal are prohibited. Sport & commercial lighting turned off at closure. Specs set by the technical committee of stakeholders.
Siding Spring Obs., Australia	Warrumbungle Shire	2004	All cut-off; exceptions are decorative or low intensity. Lighting zones: three radial zones for observatory protection. Curfews 23.00. Lasers & searchlights and uplit signs are prohibited. Motion detectors required for brighter fixtures. Dark Sky Planning Guidelines for implementation.
Apache Point Observatory	Alamagordo, NM	2021	All cut-off; exceptions are old LPS & HPS. Zone E1: internal 1-km radius, & periphery. Curfews 23:00–sunrise. Searchlights are prohibited. Sports lighting exempt from shielding requirements. Required conversion of

			non-conforming by deadline.
Calar Alto, Spain	Andalucia	2010	All cut-off; exceptions are holiday, emergency, and historic areas. Lighting zones are not determined. Curfews 0:00 or 1:00–6:00. Lasers & searchlights above horizontal, illuminated signs are prohibited. Sports lighting exempt from shielding requirements. Required conversion of non-conforming by deadline.
The University of Canterbury Mount John Observatory (UCMJO), previously known as Mt John University Observatory (MJUO), New Zealand	The Mackenzie District Lighting Ordinance, part of Mackenzie District Plan and the Resource Management Act	1981	Controls outdoor lighting (types of light, full cut-off, limits emission below 440 nm, restricts times when outdoor recreational illumination is permitted.

A.6 Non-binding — lighting standards and model lighting codes

In addition to binding laws, there is a growing body of standards, models and recommended practices. These non-binding recommendations may be used for the development of more detailed and effective measures for reduction of light pollution.

Authority	**Name**	**Year**	**Main idea(s)**
Flagstaff, USA	Pattern Outdoor Lighting Code	2010	The Code defines practical and effective measures by which the obtrusive aspects of outdoor light usage can be reduced, while preserving safety, security, and the nighttime use and enjoyment of property.
International Commission on Illumination (CIE)	CIE 126-1997. Guidelines for minimizing sky glow CIE 150:2017. Guide on the limitation of the effects of obtrusive light	1997 2017	Gives general guidance for lighting professionals and policy makers on the reduction of the skyglow. The purpose of this Guide is to help formulate guidelines for assessing the environmental impacts of outdoor lighting and to give recommended limits for relevant

	from outdoor lighting installations, 2d edition		lighting parameters to contain the obtrusive effects of outdoor lighting within tolerable levels.
Illuminating Engineering Society of North American (IES)	ANSI/IES LP-11-20 Environmental Considerations for Outdoor Lighting ANSI/IES TM37-21 Description, Measurement, and Estimate of Sky Glow	2020 2021	Outlines the environmental consideration of exterior lighting and impacts on flora and fauna, including specific recommendations for lighting outdoor areas. Provides guidance on means of reducing human contributions to light in the night sky and information on estimating the relative effectiveness of the different options available.
The All-Party Parliamentary Group for Dark Skies (APPG), UK	Ten Dark Sky Policies for the government	2021	This policy plan provides a basis for the focus of the APPG's campaigns in Parliament and calls on the government to implement a set of ten actions which would reverse the exponential growth of environmental pollution caused by artificial light.
Institution of Lighting Professionals (ILP)	GN01-21. Guidance Note 1 for the reduction of obtrusive light 2021	2021	Specifies limitations and recommendations for lighting to prevent obtrusive light. It also considers industry comment regarding the assessment and definition of obtrusive lighting. It establishes upward light, intensity and illuminance criteria for lighting zones.
Australia	National Light Pollution Guidelines for Wildlife, including Marine Turtles, Seabirds, and Migratory Shorebirds	2020	The guidelines raise awareness of the impacts of artificial light on wildlife. They can help safeguard Australia's threatened wildlife. The guidelines provide: 1) a framework for how to assess and manage the light pollution impacts on protected wildlife 2) detailed guidance for how to manage artificial light 3) specific advice on how to protect marine turtles, seabirds and migratory shorebirds. *These Guidelines were adopted by CMS COP13 the Resolution 13.5 Light Pollution Guidelines for Wildlife and its Annex
International Dark-Sky	IDA-IES Model Lighting Ordinance	2011	The IDA and IES collaborated on developing a model lighting ordinance to control light pollution in North America. The model is currently under review.

Association	Five Principles for Responsible Lighting	2020	Adopted by both IDA and IES this document establishes top-level principles for outdoor lighting. It has been translated into Spanish, French, Mandarin, Arabic, Portuguese, Polish, Swahili, Japanese, Slovenian, Italian, German, Malay, and Tamil.
	Value-Centered Outdoor Lighting Policy	2021	Provides more detailed guidance on how to implement the Five Principles.
Portugal	Resolution 193/2019 of the Portuguese Parliament	2019	Advisory. Recommends that the Government regulate, legislate, and adopt measures to combat the impact of light pollution on the environment supported by scientific research, including the formation of a multidisciplinary, technical and scientific commission to evaluate and present proposals to mitigate light pollution, control ALAN, raise awareness on light pollution and include light pollution in school curricula. Also recommends excluding immediately the use of high CCT outdoor lighting.
Interprovincial Consultation (Netherlands)	Guidelines: Lighting policy and implementation tools for provinces	2010	The Guidelines provide recommendations on lighting policies for provinces in the Netherlands.

Part 3. Satellite Constellation Working Group

Figure 1.1: Starlink in front of the Pleiades. This image by Torsten Hansen, Germany won third place in the 2021 IAU OAE Astrophotography Contest, category Light pollution. Credit: Torsten Hansen/IAU OAE/Creative Commons Attribution.

"Astronomy is entering into a golden age of discovery driven by surveys of the deep sky powered by cutting edge technology in optics, electronics and computing. Technical advances are also propeling explosive growth in global communication satellites. We can balance these to ensure that dark and quiet skies are protected for all humanity. Great progress has been made in recent months, but there is much more to be done to ensure that future generations can experience the wonders of the night sky".

— Pat McCarthy, Director of NSF's NOIRLab

Chapter 1. Introduction, Overview and Key Recommendations

1.Executive summary

International Telecommunication Union (ITU) and national regulatory filings indicate that nearly 100,000 satellites could be launched into low Earth orbit (LEO) in the coming decades. Several companies have already begun construction and launch of satellite constellations. Without action from the international community, policymakers and industry, abundant LEO satellites will increasingly tarnish the pristine view of the natural night sky from our planet, and will increasingly negatively impact astronomical science. This report summarizes the recommendations and findings from an expert Satellite Constellation Working Group covering: 1) international law and governance of Outer Space, 2) national policy and regulation, 3) industry engagement and collaboration with the astronomy community, and 4) astronomy and observatory requirements.

1.1 International governance of outer space

Analysis of international space law and relevant discussions in international fora (e.g. COPUOS) indicates that astronomy constitutes a legitimate form of accessing, exploring, and using outer space. Balance and coordination must therefore be found between both astronomical observations and satellite activities.

There are regulatory tools that, with correct application, allow such international coordination in the exploration and sustainable use of outer space. In addition to international space law instruments, policy makers should acknowledge the broader system of international law, which also pertains to outer space and can be applied according to Article III of the Outer Space Treaty, which requires that States conduct their space activities in accordance with international law. Examples detailed in this report include principles of international environmental law, such as the precautionary principle, the "polluter pays" principle, the prevention of transboundary harm, and the principle of sustainable use. Given current awareness of the risks associated with uncontrolled satellite constellation activities, these principles should be applied to activities in outer space, and particularly to those taking place in LEO.

States are responsible for authorizing and continually supervising national activities for their complete duration, including on-orbit operational phases of satellite operations and the potential impact they may have on the environment and society, such as humanity at large who are global stakeholders in the shared natural environment of the night sky. States are obliged to guide private actors to ensure responsible and sustainable use of space, and are responsible for their compliance to international law and principles through the imposition of relevant requirements for the authorisation and supervision of space activities.

1.2 National policy and regulation

While many governments are developing or have already in place national space policies and space activity licensing processes, neither astronomy nor the impact on dark and quiet skies are considered. This report recommends a number of measures to ensure that these impacts are considered in the policy and regulatory systems governing space activities. In particular, government authorities responsible for licensing the launch and operation of satellites should require an impact assessment covering, but not limited to:

- An analysis of the impact on the space environment;
- An analysis of brightness, taking into account the quantitative limits defined in the report of the 202 Dark and Quiet Skies for Science and Society (D&QS1) report and in SATCON1;
- An analysis of the cumulative radio emissions from antenna sidelobes and unintentional electronic noise, including strategies to avoid ground-based radio-quiet zones;
- The requirements for operational data sharing to mitigate impacts on astronomy;
- Consideration of the balance between mission objectives, orbital sustainability, and interference on other space activities.

Furthermore, governments and industry should:

- Endorse a temporary agenda item at the Committee on the Peaceful Uses of Outer Space or its sub-committees, as appropriate, which can be removed one the situation has reached a satisfactory equilibrium;
- Ensure that necessary funding and staff resources are available from public sources or from industry, to support the analysis and execution of mitigations for astronomical observatories;
- Sponsor innovation and applied research on, for example, novel technologies to reduce satellite brightness;
- Develop spacecraft systems and operational standards that take into account the impacts on astronomical science. Areas include: reflectivity of surface materials, brightness of space objects, telemetry data, spurious and out of band emissions, and unintentional electromagnetic radiation (i.e., electronic noise.)

1.3 Industry engagement

Satellite operators are more likely to adopt voluntary practices or mitigation tools if companies engage with astronomers early in their project cycles, before spacecraft designs are finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact. To that end, a series of "best practices" are identified, which could be adopted by existing and new satellite manufacturers and operators, in addition to providing guidance for regulatory authorities. These guidelines are at an early stage of development and future cooperation and collaboration with industry are recommended to advance their development.

1.4 Observatories and astronomy community

A number of technical developments, education and training, and extensive observational data are required to develop and widely deploy the necessary software and accurate positional predictions to mitigate incurred impacts. More extensive modeling and simulations will also be required to assess the impact on key scientific and mission-specific programs as well as estimating the aggregate threat of increasing the diffuse skyglow. To date, efforts expended toward these mitigations have been made on a volunteer basis or on a limited contractual basis by individual observers at industry request. The substantial scope of remaining effort must be adequately resourced to prevent substantial data quality loss with the rapid rate of launch of satellite constellations. That provision of resources must include the efforts on international coordination and provision of data and software based in the institutions to be supporting the IAU Centre. States that produce, launch, or license for operation large constellations of satellites in low Earth orbit must provide resources adequate to develop, produce and maintain the means to mitigate the damage to astronomical observational data quality and analysis and astrophotography produced by those constellations worldwide.

2. Introduction

2.1 Background

The impact of the tens of thousands of communication satellites that are being placed in LEO has only recently come to the attention of the astronomical community and of the general public. Their real impact has now been carefully established on the basis of sound simulations and initial observational data. Following a proposal[53] made by the International Astronomical Union (IAU) to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the Committee tasked the United Nations Office for Outer Space Affairs (UNOOSA) to hold a conference together with the IAU on Dark and Quiet Skies for Science and Society and Spain volunteered to host the event.

D&QS1 should have taken place in October 2020, but because of the COVID-19 pandemic it was postponed and rescheduled to be held in Santa Cruz de La Palma, Canary Islands, Spain, from 3 to 7 October 2021. However, because of the urgency of protecting the right of humankind to access an uncontaminated night sky, both for its intrinsic cultural value and for the progress of science, the

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[53] https://www.unoosa.org/res/oosadoc/data/documents/2017/aac_1052017crp/aac_1052017crp_24_0_html/AC105_2017CRP24E.pdf

organizers decided to hold an on-line workshop in October 2020, on the same theme as the originally planned conference. Following this on-line workshop the IAU released a report[54] containing a number of recommendations to mitigate the impact of human activities on the visibility of the starry sky and the progress of the science of astronomy.

The follow-up conference in 2021 (which was also held virtually because of the volcanic eruption in La Palma) focused on the implementation of the report's recommendations, in particular identifying both the technical and political actions needed for their effective realization, as well as which stakeholders and partners would need to collaborate to implement a satisfactory solution for the preservation of a dark and quiet skies.

Three working groups on the main sources of interference (Artificial Light At Night, Satellite Constellations and Radio Transmission) prepared critical analyses of the various implementation processes that were presented at the conference and finalized into reports afterwards. The working groups were composed of a limited number of invited experts, national practitioners and policymakers, space law specialists, governmental and funding agencies representatives, and scientists. This document describes the findings and conclusions of the Satellite Constellation Working Group.

2.2 Objectives of the Satellite Constellation Working Group

The Dark and Quiet Skies Satellite Constellation Working Group (DQS SATCON WG) aimed to identify policy and regulatory instruments at the national and international levels, and actions for the industry and the astronomy community, in order to implement the recommendations outlined in the D&QS1 report. The results of the WG inform a report submitted to the 59th Session of the Scientific and Technical Subcommittee of COPUOS.

The DQS SATCON WG divided into four sub-working groups on the following topics:

- International law
- National policies and regulation
- Industry action
- Effort by observatories and the astronomy community to safeguard astronomical science.

2.3 Problem statement: the satellite constellation challenge for astronomy

ITU and national regulatory filings indicate that nearly 100,000 satellites could be launched into low Earth orbit in the coming decade. Several companies have already begun construction and launch of satellite constellations. Without action from the international community, policymakers and industry,

[54] Connie Walker & et al., (2020). *Dark and Quiet Skies for Science and Society. Report and recommendations.* International Astronomical Union. https://www.iau.org/news/announcements/detail/ann21002/

abundant LEO satellites will increasingly tarnish the pristine view of the natural night sky from our planet, and will increasingly negatively impact astronomical science.

As the number of satellites continues to grow, astronomy is facing a tipping point situation of increasing interference with observations and loss of science. More than 5000 satellites will be above the local horizon at any given time at a typical dark sky observatory location (30 degrees latitude north or south), assuming that several of the largest constellation projects come to fruition. A few hundred to several thousand of these satellites will be illuminated by the Sun (however, owing to the geometry of the constellation shells, the numbers illuminated can be worse at higher latitudes). These satellites will be detectable by even the smallest optical or infrared telescopes, depending on the hour of night and season. Moreover, up to several hundred satellites may be visible even to the unaided eye, particularly low on the horizon and in twilight hours.

Initial studies of the effects of unmitigated satellites show a variety of impacts on astronomy from minor to severe, depending on the nature of the telescope and satellite system[55]. Observations with telescopes that view large portions of the sky will be severely impacted without substantial mitigations. While narrow-field of view telescopes are less impacted due to a lower probability of satellites crossing the field of view, observations with long exposure times and particularly in the hours close to twilight and low on the horizon are still significantly affected. Wide field astrophotography will be affected, too. The impacts are not only limited to ground-based observatories: space-based telescopes in low Earth orbit will also be affected and in those cases, mitigations are more challenging to implement.

Observations conducted by radio observatories will also be harmed by satellite constellations. With the growing abundance of space-based transmitting objects above the horizon, radio astronomy faces a substantial loss unless preventative action is taken. Radio-quiet zones (RQZs) are impacted and radio interference crossing frequency band boundaries poses a threat to the limited set of frequency bands allocated to radio astronomy.

There are several key policy problems which motivate the need for the Dark and Quiet Skies project in the area of satellite constellations.

[55] E.g. see: Walker,C. E., & et al., (2020). *Dark and Quiet Skies for Science and Society. Report and recommendations.* International Astronomical Union; Hainaut, O. R., & Williams, A. P. (2020). Impact of satellite constellations on astronomical observations with ESO telescopes in the visible and infrared domains. *Astronomy and Astrophysics*. https://doi.org/10.1051/0004-6361/202037501 ; McDowell, J. C. (2020). The Low Earth Orbit Satellite Population and Impacts of the SpaceX Starlink Constellation. *The Astrophysical Journal*. https://doi.org/10.3847/2041-8213/ab8016 ; Tyson, J. A., et al. (2020). Mitigation of LEO Satellite Brightness and Trail Effects on the Rubin Observatory LSST. http://arxiv.org/abs/2006.12417

Optical spectrum / light pollution. With the exception of a US law preventing space-based advertising[56], there are no laws regulating the visual appearance of the night sky. Furthermore, the commercial and government use of optical spectrum is not managed or regulated in any fashion. There are no regulations compelling satellite manufacturers, operators, and license holders to reduce or control unintended reflected sunlight or intentional optical transmissions from satellites.

Radio spectrum management. Radio frequency spectrum is heavily regulated at national and international levels. Radio astronomy has many bands allocated on a primary basis between 13 MHz and 275 GHz and can therefore claim protection from other radio services within these bands. Not all frequency ranges that are allocated to radio astronomy are allocated on a primary basis, however — in some bands, other radio services have priority. For some bands shared on a co-primary basis between radio astronomy and other services, radio astronomers cooperate to share the same spectrum resource. As scientific discoveries can be made outside the approximately 2% of spectrum allocated to radio astronomy, observatories have set up RQZs in cooperation with national or regional governments to secure access to a larger part of the spectrum in a certain limited geographical region, usually in a remote area. The prospect of thousands of satellites continually transmitting overhead now means that the protection offered by RQZs is threatened. Even if satellite transmissions can be controlled and directed away from the observatory sites, the cumulative background noise from antenna sidelobe emissions and also the electronic noise of the satellite system itself now adds to the noise experienced by a sensitive radio astronomy receiver.

Space governance. The impacts on astronomy from satellite constellations are one concern amongst many in this "NewSpace" era[57]. The forthcoming large numbers of satellites planned for LEO raises concerns of growing amounts of space debris, increasing the difficulty to safely operate satellites in LEO, and generally to introduce a global approach to space traffic management. These issues then raise a number of secondary questions of governance and regulation in terms of liability for harmful interference and damage, and more broadly key questions about how to treat LEO as a regulated environment and deal with transboundary impacts. The implication for astronomy and dark and quiet skies is that at the current time, there is little recourse to address harms and prevent them in the future, other than direct interaction with willing space operators and appealing to government funding agencies and regulators.

[56] https://www.law.cornell.edu/uscode/text/51/50911
[57] Boley, A.C., Byers, M. (2021). Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth. Sci Rep 11, 10642. https://doi.org/10.1038/s41598-021-89909-7

2.4 Working Group charges

The working groups will be the basis for the sessions of the satellite constellation of the DQS conference, which will have the following themes and objectives — the recommendation numbers refer to those in the D&QS1 report[58]:

- *Identification of the relevant international legal framework*: review the applicability of the international legal framework for the protection of dark and quiet skies and identify other international instruments that have similar objectives to those of the astronomy community, with particular regard to the impact of space activities and satellite constellations on astronomical observations. Recommendations Sat_Con18–19.
- *National policy and regulation working group*: identify how national policymakers and regulators can implement the recommendations and identify any key challenges. What existing regulatory instruments can be adapted to take account of astronomy, or which new instruments are needed? Recommendations Sat_Con12–17.
- *Industry Engagements*: understand how the international astronomy community can coordinate efficiently and effectively with industry stakeholders to mitigate impacts, raise awareness and promote mutual interests while learning lessons from similar initiatives. Understand how to strengthen industry support on the recommendations and monitor industrial standpoints. Recommendations Sat_Con3–7.
- *Observatories and Astronomy Community*: review efforts to ensure that observatories can maximize their operations in the presence of satellite constellations, avoid negative impacts on science, and coordinate the community. Recommendations Sat_Con1, 2, 7–12.

The subject of astronomy impacts is a relatively new concern in the NewSpace era. Space stakeholders are only now becoming aware of the issue and the possible mitigations. The Dark and Quiet Skies project, in general, provides an opportunity to:

- Build on previous work (e.g. the NOIRLab/AAS-sponsored workshops SATCON1[59] and SATCON2[60]) and coordinate with national and international initiatives with similar objectives (e.g. other groups set up by the Royal Astronomical Society, the American Astronomical Society, the European Astronomical Society, and others);
- Engage with relevant stakeholders and national delegations at COPUOS to raise awareness and get the subject on the agenda;
- Strengthen the link to UN COPUOS and its subcommittees, but in a venue that allows freer exploration of ideas;

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[58] Walker, C. E., & et al., (2020). *Dark and Quiet Skies for Science and Society. Report and recommendations.* International Astronomical Union. https://www.iau.org/news/announcements/detail/ann21002/

[59] Walker, C., Hall, J., Allen, L., Green, R., Seitzer, P., Tyson, T., et al. (2020). Impact of satellite constellations on optical astronomy and recommendations toward mitigations. Bulletin of the American Astronomical Society, 52(2).

[60] https://doi.org/10.5281/zenodo.5608820

- Explore the relationship between the spectrum management process under the ITU system and space matters under COPUOS;
- Broaden discussion and perspectives from the current US-dominated players.

2.5 Scope of the report

In addition to the impacts on astronomy and dark and quiet skies, the LEO constellation plans are leading to a number of technical challenges in orbital sustainability and space traffic management, and political challenges in terms of how to regulate, allocate and govern orbital resources, avoid harmful interferences on space activities and ensure environmental sustainability. This report focuses primarily on the challenges to astronomy and more generally to dark and quiet skies, but touches where necessary on the broader aspects of governance of the space sector and Earth's orbital environment.

In general, recommendations pertain to constellations in LEO as a priority issue, however, their applicability can be extended to all satellites and space activities.

The views expressed in this document are those of the experts assembled for the working groups and do not constitute an official position of the IAU, UN OOSA or any other organization.

2.6 Statement of requirements

The overall aim of the D&QS2 project was to study the implementation of the recommendations made by the D&QS1 report. While the 40 recommendations listed in the main report were organized by main implementing stakeholders: observatories, industry, astronomy community, science funding agencies, national and international policymakers, technical and policy requirements were not clearly defined. In order to further the implementation of these recommendations, the D&QS SATCON WG created a list of "astronomy requirements" to guide and structure the work.

The first group of requirements covers the provision of publicly available and timely industry data during the design and manufacture process and after deployment, including:

- Operational data given satellite location, timings, maneuvers, and rotations and attitude adjustments.
- Spacecraft system data in terms of dimensions, profile, albedo, and reflectance.
- Radio emission data including antenna specifications, equivalent power flux density calculations for sidelobes and main beams, and electronic system noise emissions.

The second group of requirements focuses on engineering and operational constraints on individual satellite units and an overall mission design:

- Minimisation and control of satellite reflectance to below visual magnitude.

- Minimisation of illumination of RQZs and observatories.
- Minimisation and control of intentional optical transmissions.
- Minimisation of satellite unit numbers at any stage of operations.
- Minimisation of satellite operational altitudes.
- Sufficient orbital control of satellites to reduce reflected sunlight and radio emissions on astronomy facilities.

The third set of requirements focuses on broader policy and regulatory measures which should include astronomy concerns in national and international space regulation and policy.

- Development of industry standards.
- Development and implementation of coordination mechanisms to avoid harmful interference.
- Support for mitigation measures in national science policies and funding instruments.
- Incentives for corporate social responsibility.
- Assessments of cumulative effects.
- Coordination with other space policy issues, *inter alia* space traffic management, environmental issues, space debris, and spectrum management.

3. Recommendations for the international governance of outer space

From the analysis of international space law documents, in particular the Outer Space Treaty, and the relevant discussions in international fora involving astronomical activities (e.g. COPUOS), it is reasonable to affirm that astronomy constitutes a legitimate form of accessing, exploring, and using outer space. Accordingly, as legitimate forms of exploration and use of outer space, balance and coordination must be found between both astronomical observations and satellite activities.

It has been noted that general freedom exists to access space and that its exploration and use constitute provinces of all humankind. However, these freedoms are not absolute, and must find a limit in the freedoms exercised by other actors.

To this end, as described by this report, there is a list of regulatory tools that with correct application allow correct international coordination in the exploration and sustainable use of outer space. These are not limited to international space law instruments. As noted, international space law constitutes a minor branch of a broader system of international law, which also pertains to outer space and can be applied according to Article III of the Outer Space Treaty. Examples detailed in this report include principles of international environmental law, such as the precautionary principle, the "polluter pays" principle, the prevention of transboundary harm, and the principle of sustainable use. Given current awareness of the risks associated with uncontrolled satellite constellation activities, these principles should be applied to activities in outer space, and particularly to those taking place in LEO.

It is a duty of States, with an international responsibility to authorize and continually supervise national activities, to apply these principles for the complete duration of satellite activities. States must also have regard to the on-orbit operational phases of satellite operations and the potential impact they may have on the environment and society. Indeed, the potential impact of satellite constellations is limited not only to the astronomical community, but affects to a wider extent humanity at large who are global stakeholders in the shared natural environment of the night sky.

To conclude, States are responsible for guiding private actors to ensure responsible and sustainable use of space. Still, also and foremost, they are responsible for their compliance with international law and principles through the imposition of relevant requirements for the authorization and supervision of space activities.

4. National policy and regulatory recommendations

The national policy and regulation working group formed from the D&QS SATCON WG was tasked to identify how national policymakers and regulators can implement the D&QS1 recommendations and to consider regulatory solutions. The WG decided to organize this work around a framework highlighting the ultimate intent behind any regulatory solution: Avoid, Reduce, Cooperate (ARC).

- Avoid: Policies and instruments to avoid effects on astronomy either before launch or once satellite systems are launched.
- Reduce: Policies and instruments to reduce the impacts of effects that occur.
- Cooperate: Policies and instruments to prevent the occurrence of astronomy impacts before they can happen, establish the conditions for dialogue and exchange of information; achieve government policy coherence.

For each particular astronomy requirement defined in Section 2.6 above, regulatory and policy measures were suggested, taking into account the recommendations from D&QS1.

Requirements	Avoid: Policies and instruments to avoid effects on astronomy either before launch or once satellite systems are launched	Reduce: Policies and instruments to reduce the impacts of effects that occur	Cooperate: Policies and instruments to prevent the occurrence of astronomy impacts before they can happen, establish the conditions for dialogue and exchange of information; achieve government policy coherence
Provision of industry data during design process and after deployment			
Operational data (location, timings, maneuvers, rotations) Spacecraft data (dimensions, profile, albedo, reflectance) Radio emission data (antenna specifications, EPFD, electronic noise in system)	Governments should request detailed satellite design and mission parameters at an early stage before licensing, e.g. concurrent with spectrum licensing process. This data should be made public to the maximum extent possible. Any substantial updates should also be communicated on a regular basis.	Industry should provide real-time data (8-hourly updates or after maneuvers) to the astronomy community, either via government or third party portal or central clearing house such as the IAU Centre. Industry should provide measured spectral masks of the radio transmitters on board satellites to allow radio observatories to anticipate potentially contaminated channels.	Governments and industry should develop mechanisms to improve the ability of space operators to share proprietary and commercially or security sensitive data with third parties, including the development of common or interoperable standards for space situational awareness data. Industry should establish joint testing schemes in collaboration with astronomers to model reflectance and radio emission profiles. Governments and industry should support the development of space domain decision intelligence collecting data of proposed satellite constellations and existing orbiting space objects, modeling satellites, their operations in the space environment, and estimate uncertainties to assess the impact of satellite constellations on ground-based astronomical observations.

	Avoid: Policies and instruments to avoid effects on astronomy either before launch or once satellite systems are launched	Reduce: Policies and instruments to reduce the impacts of effects that occur	Cooperate: Policies and instruments to prevent the occurrence of astronomy impacts before they can happen, establish the conditions for dialogue and exchange of information; achieve government policy coherence
Required engineering and operational constraints on individual satellite units and overall mission design, which should ideally be regulated by a licensing process			
Minimisation and control of satellite reflectance	National licensing procedures should incorporate assessments of reflectance. Industry should conduct reflectance analyses as part of the design process.	Industry should provide real-time data on satellite attitude and spatial orientation (8-hourly updates of after maneuvers) to the astronomy community, either via government or third party portal or central clearing house such as the IAU Centre.	Governments should fund research to develop new types of materials and spacecraft coatings to minimize reflection while maintaining thermal control. Governments should fund research to support the development of reflectance analyses and simulations. Governments and industry should collaborate to determine a pathway to meeting the reflectance requirements.

Minimisation of illumination of radio-quiet zones	Industry should be encouraged to utilize technology that allows satellites to avoid direct illumination of radio telescopes and radio-quiet zones, especially high-power applications; As part of the satellite licensing process, governments should incorporate assessments of unintentional electromagnetic radiation from satellites that could generate harmful interference into radio astronomy receivers. Governments should develop radio licensing procedures to ensure that satellites avoid direct illumination of radio telescopes and radio-quiet zones, especially the radar and other high-power satellite applications that are capable of burning out radio astronomy receivers; Industry should be encouraged to minimize antenna sidelobe levels so that their indirect illuminations of radio telescopes and radio-quiet zones do not generate harmful interference, individually or on aggregate.		In collaboration with the radio astronomy community and industry, governments should develop an internationally agreed mechanism to protect radio-quiet zones and observatories from unnecessary and unintentional electromagnetic radiation. Governments should encourage flexible technology that can better share spectral resources while ensuring protection of sensitive radio astronomy operations.

Minimization and control of intentional optical transmissions	Governments should develop licensing procedures to ensure that intentional optical transmissions to the ground (e.g. beacons or comms) are highly directive to target ground stations only, or are minimized to only critical uses	Industry should provide real-time data on intentional optical transmissions from satellites (8-hourly updates) to the astronomy community.	Governments should work to create an international regime governing intentional optical transmissions to prevent harmful interference and to preserve the visual appearance of the night sky.
Minimization of satellite unit numbers at any stage of operations			Governments should establish multidimensional criteria for authorisation of constellation systems that feature balance between mission objectives, orbital sustainability, and interference on other space activities
Minimization of satellite operational altitudes	Industry should: a) minimize operational altitudes — satellites in constellations with higher orbital shells are illuminated by the Sun for longer during the night and appear more 'in focus' to telescopes; in general, the impact on astronomy increases with constellation altitude. Scientific analysis shows that orbits on the order of 600 kilometers or below offer a compromise between brightness and the length of time satellites are illuminated during the night; b) minimize the number of satellite units as second priority to altitude while maintaining safe operational practices.		Governments should establish multidimensional criteria for authorisation of satellite systems that feature balance between mission objectives, orbital sustainability, and interference on other space activities

Orbital control of space objects	Industry should ensure that satellites are minimally reflective during the operational raising phase. Industry should minimize the time spent in orbit when not in service.		

	Cooperate: **Policies and instruments to prevent the occurrence of astronomy impacts before they can happen, establish the conditions for dialogue and exchange of information; achieve government policy coherence**
Broader, cross-cutting policy measures	
Development of industry standards	Governments and industry should develop spacecraft systems and operational standards that take into account the impacts on astronomical science. Areas include: reflectivity of surface materials, brightness of space objects, telemetry data, spurious and out-of-band emissions, and unintentional electromagnetic radiation (i.e., electronic noise.)
Development and implementation of coordination mechanisms to avoid harmful interference	Governments should include astronomy and/or scientific community representatives in decision-making and advisory governance structures for national space policy and economy. Governments should support the inclusion of the topic of Dark and Quiet skies as an agenda item at the UN COPUOS.
Support for mitigation measures in national science policies and funding instruments	Governments are encouraged to provide funding for support to the international centre governed by the IAU. Governments should create staff positions in national funding agencies and Ministries overseeing science to support optical inference and spectrum management for national scientific organizations. Governments should provide industrial innovation and research funding support for the development of advanced low reflectivity materials for spacecraft, development of bidirectional reflectance distribution function testing at satellite facilities, refinement of space situational awareness data and astronomy mitigations.

Incentives for corporate social responsibility	Governments, industry and the astronomy community should create mechanisms for industry and government to take responsibility for damage to scientific space activities, in the event that regulatory, licensing and voluntary measures are insufficient. Industry and the astronomy community should collaborate to create rating schemes for satellite operators to demonstrate the ability to share information with the astronomy community, enact recommended mitigations and support policies to protect the dark and quiet skies.
Assessments of Cumulative effects	Governments should develop approaches to understand the cumulative effects of growing satellite numbers on the global levels of light pollution, the impact on science, and the ability to perform critical functions such as asteroid detection and characterisation.
Coordination with other space policy issues (e.g. space traffic management, environmental issues, space debris, spectrum management)	At both international and national levels, efforts can build upon frameworks in radio astronomy and space debris, informed by this report and by capacity-building and outreach efforts that bring stakeholders together for purposes of discussion and moving policy development forward, such as this international workshop.

5. Recommendations for industry

The Industry WG formed from the D&Q SATCON WG had as its objective to understand how the international astronomy community can coordinate efficiently and effectively with industry stakeholders to mitigate impacts, raise awareness and promote mutual interests while learning lessons from similar initiatives.

The Industry WG concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact. To that end, a series of “best practices” were identified, which could be adopted by existing and new satellite manufacturers and operators, in addition to providing guidance for regulatory authorities. These guidelines are at an early stage of development and future cooperation and collaboration with industry is recommended to advance their development.

6. Recommendations for astronomy

A key recommendation from the SATCON2 report is for the coordination of effort and dissemination of data and information to be performed through a central virtual clearinghouse and repository, designated there as SatHub. The major needs identified for the community include the following:

- Coordinated observations of individual satellites from multiple sites to map the reflection of sunlight in multiple colors as a function of orbital phase angle and other parameters. This activity is critical for the prediction of apparent brightness.
- Development of algorithms with robust implementation for wide distribution for identifying and masking streaks (TrailMask), predicting satellite passages through specific planned observational pointings (PassPredict), and for current probabilistic predictions in all-sky mode for general observational planning.
- One or more image data repositories for the testing of algorithms for sunlight streak identification and masking.
- Research on the impacts of satellite trails on scientific analysis, in cases such as filtered measures of weak gravitational lensing, determination of orbital parameters for near-Earth objects, or analyzing continuous diffuse objects such as emission nebulae.
- Research on the aggregate impact of the increasing number of objects in near-Earth space on diffuse sky brightness, with particular emphasis on increased atmospheric aerosols and the small particle distribution in LEO.
- Research on the impacts of satellite trails on other astrophysical subfields not mentioned above, including spectroscopic and radio studies, with a particular focus on how this impact is changing as a function of time and frequency/color/bandpass. (Image data repositories will be crucial for these studies.)
- Development of strong education and outreach materials (e.g., the SatHub Training Curriculum outlined in SATCON2 OBS WG report) for the general public, amateur, and professional astronomers.

Much of this functionality is expected to be coordinated and made accessible to the community by the planned IAU Centre for the Protection of Dark and Quiet Skies from Satellite Constellation Interference.

To date, efforts expended toward these mitigations have been done on a volunteer basis or on a limited contractual basis by individual observers at industry request. The substantial scope of remaining effort must be adequately resourced to prevent substantial data quality loss with the rapid rate of launch of satellite constellations. That provision of resources must include the efforts on international coordination and provision of data and software based in the institutions to be supporting the IAU Centre.

Request for COPUOS Endorsement:
States that produce, launch, or license for operation large constellations of satellites in low Earth orbit must provide resources adequate to develop, produce and maintain the means to mitigate the damage to astronomical observational data quality and analysis and astrophotography produced by those constellations worldwide.

Chapter 2. International Report

1. Introduction

The working group had the goal of reviewing the applicability of the international legal framework for protecting dark and quiet skies and identifying other international instruments that have similar objectives to those of the astronomy community, particularly regarding the impact of space activities and satellite constellations on astronomical observations. This section of the report looks at Recommendation no. 40 of the 2020 Dark and Quiet Skies for Science and Society (D&QS1) report, addressing international policymakers, and the following "Explanatory Note on Existing International Law.", which states as follows:

- **R40 — International policymakers**
  Policymakers are encouraged to contemporaneously develop international agreements, on the one hand, and national laws within their respective legal frameworks, on the other hand, relating to reflected or emitted electromagnetic radiation from satellites, its impacts on science (particularly, but not exclusively, astronomical science), and efforts to mitigate (if not eliminate) the deleterious aspects of such impacts.

  At both international and national levels, efforts can build upon frameworks in radio astronomy and space debris, informed by this report and by capacity-building and outreach efforts that bring stakeholders together for purposes of discussion and moving policy development forward, such as this international workshop.

- **Explanatory note on existing international law**
  International law applicable to astronomy is scarce, with international law addressing light pollution and the visual appearance of and access to the night sky nearly nonexistent. Of the five United Nations space treaties (only four of which have been adopted by most countries), only the Outer Space Treaty (OST) and the Liability Convention can arguably apply to the impacts of reflected sunlight from satellites. As to the OST, the language relating to freedom of scientific exploration, non-interference, cooperation, and the environment can arguably be interpreted to implicitly include astronomy and dark skies (Articles I and IX). As to the Liability Convention, it only sets a framework for addressing disputes.

  However, the foregoing arguments remain theoretical because of their implicit aspects and the absence of any judicial cases where such arguments have been applied to astronomy. That being said, there do exist international regulations and guidelines (e.g., ITU) and national laws protective of radio astronomy in the context of avoiding harmful interference in applicable radio frequencies (https://www.itu.int, ITU Reports on radio astronomy, ITU Handbook on radio astronomy). Additionally, there do exist laws regulating space advertising through, in particular, the use of satellites. (U.S. (51 U.S.C. § 50911)), and international guidelines on and national laws for mitigating space debris, which is a related topic. And yet, there exist no known domestic or national laws addressing the impacts of reflected sunlight or reflected or emitted thermal radiation from satellites.

2. Astronomy, space exploration, and the Outer Space Treaty

The report primarily sought to identify whether astronomy is a form of space 'exploration' or 'use', through a Treaty interpretation as for the 1969 Vienna Convention on the Law of Treaties, which states:

Article 31 General rule of interpretation

1. *A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.*
2. *The context for the purpose of the interpretation of a treaty shall comprise, in addition to the text, including its preamble and annexes:*
    a. *any agreement relating to the treaty which was made between all the parties in connection with the conclusion of the treaty;*
    b. *any instrument which was made by one or more parties in connection with the conclusion of the treaty and accepted by the other parties as an instrument related to the treaty.*
3. *There shall be taken into account, together with the context:*
    a. *(a) any subsequent agreement between the parties regarding the interpretation of the treaty or the application of its provisions;*
    b. *(b) any subsequent practice in the application of the treaty which establishes the agreement of the parties regarding its interpretation;*
    c. *(c) any relevant rules of international law applicable in the relations between the parties.*
4. *A special meaning shall be given to a term if it is established that the parties so intended.*

Article 32 Supplementary means of interpretation
Recourse may be had to supplementary means of interpretation, including the preparatory work of the treaty and the circumstances of its conclusion, in order to confirm the meaning resulting from the application of article 31, or to determine the meaning when the interpretation according to article 31:

(a) leaves the meaning ambiguous or obscure; or

(b) leads to a result which is manifestly absurd or unreasonable.

We seek to understand whether astronomy is a form of space 'exploration' or 'use' such that, upon applying the ordinary meaning of those terms in the appropriate context, astronomy is clearly recognized as an activity that is protected by the provisions of the OST and is thus subject to non-interference, freedom of use, and due regard.

To proceed, we apply the codified approach to treaty interpretation as laid out in Articles 31 and, if required, Article 32 of the 1969 Vienna Convention on the Law of Treaties.[61] While the OST and indeed the core treaties that form the base of space law were concluded before the Law of Treaties entered into effect, the application of the Law of Treaties to earlier treaties is nonetheless relevant, as the Law of the Treaties is the formalization of customary international law that already existed when the OST and subsequent treaties were established.[62]

Article 31 states that "*A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose"* (para. 1).

We begin thus with the terms 'use' and 'exploration'. What is 'use'? The noun form has many definitions, but fortunately the first of the normal usage is the most relevant:

1 a: the act or practice of employing something
1 b: the fact or state of being used
1 c: method or manner of employing or applying something[63]

Several entries for the transitive verb form are also of relevance:

1: to put into action or service : avail oneself of : employ
2: to expend or consume by putting to use —often used with *up*
(...)
5: to carry out a purpose or action by means of *(ibid)*

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[61] 1969 Vienna Convention on the Law of Treaties, 23 May 1969. 1155 UNTS 331.
[62] The International Court of Justice has often stated that the Vienna Convention codifies customary international law. See, e.g.: Legal Consequences of the Construction of a Wall in the Occupied Palestinian Territory (Advisory Opinion) [2004] ICJ 136, 174, para. 94; Armed Activities on the Territory of the Congo (Democratic Republic of the Congo v Rwanda) (Judgement), [2006] ICJ 6, 51–52, para. 125; Case Concerning Kasikili/Sedudu Island (Botswana/Namibia) (Judgement), [1999] ICJ 1045, 1059, para. 18. For the preexisting rules of customary international law, see: McNair, Lord. 1961 (republished 1986). *The Law of Treaties*. Oxford. Oxford University Press.
[63] "Use." *Merriam-Webster.com Dictionary*, Merriam-Webster, https://www.merriam-webster.com/dictionary/use. Accessed 14 Sep. 2021.

We might further be interested in the legal definition of 'use'. However the noun form is defined in connection with property, which is problematic for its application to areas beyond national jurisdiction. The verb form is more straightforward: "to put into service : have enjoyment of" *(ibid)*.

Astronomy has long had the practice of putting space "into service" for understanding natural phenomena, discovering and testing physical laws, and enjoying the cosmos. Indeed, it is recognised as being one of the oldest sciences[64] and one of the first ways humanity explored space. Not only did Tycho Brahe's observations of the planets and Kepler's meticulous data analysis enable Newton to develop Newtonian gravity, but astronomy today provides the most stringent tests of Einstein's generalization of gravity, the general theory of relativity. In many ways, there is a direct link between astronomical observations and the placement of satellites into orbit.

What about 'exploration'? The verb is more helpful, as exploration is just the act of exploring. Turning again to the dictionary definition:[65]

> Transitive
>
> > 1 a: to investigate, study, or analyze : look into
> > 1 b: to become familiar with by testing or experimenting
> > 2: to travel over (new territory) for adventure or discovery
> > 3: to examine especially for diagnostic purposes
>
> Intransitive
>
> > 1: to make or conduct a systematic search *(ibid)*

Before analyzing 'to explore' further, we should consider the definition of astronomy. Merriam-Webster defines astronomy as: "*the study of objects and matter outside the Earth's atmosphere and of their physical and chemical properties*".[66]

In practice, an astronomer would likely describe astronomy as an observational science that seeks to understand and *explore*[67] the solar system, galaxy, and universe as well as to understand how Earth is situated in the universe. It is also used to test physical laws.

For the purposes here, we do not include the related planetary science, that inter alia, places spacecraft on and into orbit about other celestial bodies, which requires the exploration of space by all definitions.

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64 UN General Assembly, A/RES/62/200, International Year of Astronomy
65 "Explore." *Merriam-Webster.com Dictionary*, Merriam-Webster, https://www.merriam-webster.com/dictionary/explore. Accessed 6 Sep. 2021.
66 "Astronomy." *Merriam-Webster.com Dictionary*, Merriam-Webster, https://www.merriam-webster.com/dictionary/astronomy. Accessed 5 Sep. 2021.
67 We will return to this usage momentarily

Astronomy, itself, fulfills the first and third definitions of exploration for the transitive case, as well as the definition of the intransitive case. In ordinary usage, astronomy is a form of exploring space and the oldest way that this has been done.

However, we cannot yet be satisfied, as we need to ask whether it is possible that the OST was meant to *only* focus on the second definition, which would require an act of traveling through space. To answer this question, we need to turn to the provisions of the treaty, including its preamble.

We begin with the ultimate paragraph of the OST's Article I:

> *There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation (*OST Article I*).*

There is no restriction on how that scientific investigation is to be done. Certainly, Art. I uses the wording "in" outer space, but it refers to scientific investigation in outer space in a broader sense. And indeed, by including the subclause "including the moon and other celestial bodies," we see that the phrasing is intended to mean the study of outer space and objects in it, broadly.

OST Article IV states that nuclear weapons and weapons of mass destruction shall not be placed in orbit or on celestial bodies. It further states that military bases and installations cannot be placed on celestial bodies. However, "*The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration of the moon and other celestial bodies shall also not be prohibited*" (OST Article IV)

In this case, scientific research is again general, but also discussed within the context of activities in orbit or on a celestial body, including the Moon. This makes a clearer connection with the second definition of 'explore', but it also does not exclude the broader meanings.

OST Article IX has several relevant sections. First, "*States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose*" (OST Article IX).

Here, the treaty language separates "study" and "explore". There is some ambiguity in whether "explore" best refers to the second definition or the third definition. However, the reason one conducts exploration, according to the treaty language, is in part "t*o avoid their harmful contamination*". In this sense, the third definition of “explore”, “to examine especially for diagnostic purposes”, is reasonable. One might then argue that the only way to conduct exploration in a way that avoids harmful contamination is to first examine and analyze. With this in mind, that same sentence continues with “*and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter*”. There is no other way to view this part of the article as referring to the second definition of explore. Altogether, it can be inferred that all meanings are used and in fact intended. But Article IX continues:

> *If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment* (OST Article IX).

This section of the article starts by discussing activities or experiments conducted by one Party “in space”. But this is specific to an activity in space interfering broadly with the “*peaceful exploration and use of outer space, including the moon and other celestial bodies*''. So again, while there is some qualification for activities being “in space”, this is only in relation to an on-orbit activity interfering with the otherwise *unqualified* exploration and use of space.

The language and context of the treaty suggest a broad application of exploration, including scientific investigation and study, regardless whether that investigation is in space or from Earth, supporting the proposition that astronomy is protected by the OST.

This can be explored further by returning to the first two paragraphs of Article I:

> *The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.*
>
> *Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies* (OST Article I).

There are several complexities about interpreting these paragraphs, particularly with the phrase "*shall be the province of all* [humankind]". However, as Hertzfield et al. explain:

> *Analyzing the Outer Space Treaty's phrase 'province of all mankind', especially in light of the rights and obligations enshrined in that article and across the Treaty, elucidates that the* ***activity*** *of exploring and using outer space is a right held by all, and that no State can lawfully deny another State's freedom to access space* (emphasis in original).[68]

Everyone has the right to explore space "*without discrimination of any kind*" (OST Article I). Moreover, the "*degree of economic or scientific development*" (ibid) is irrelevant when considering the right to use space or how those who are using and exploring space must conduct their activities. These points are further emphasized in the treaty's preamble:

> *BELIEVING that the exploration and use of outer space should be carried on for the benefit of all peoples* ***irrespective of the degree of their economic or scientific development*** (OST preamble) (emphasis added).

Taken altogether, the OST does not judge what is or is not a space activity, but has laid the groundwork to be as inclusive as practicable. Given the deep connections between astronomy and other forms of space exploration, it seems reasonable to assert that astronomy is a space activity.

Nonetheless, we can take the treaty language alone as being insufficient as well and move on to "*subsequent treaties, practice, and international rules of law"* (Law of Treaties Article 31). In this sense, we might first look at the subsequent space treaties derived from the OST: Liability Convention, Rescue Agreement, Moon Agreement, and Registration Convention. This is a quick exercise. There is no indication that there is an attempt to give a special meaning to the terms 'use' or 'exploration'; nor is astronomy explicitly included.

What about subsequent practice? Interestingly, astronomy has not been so clearly discussed in COPUOS as an explicit space exploration activity, but astronomy has been implicitly discussed in that context.

During the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna from 19 to 30 July 1999,[69] actions were proposed to protect the global and space environment and guarantee equal access to space science and its benefits. In the

[68] https://swfound.org/media/205390/how-simple-terms-mislead-us-hertzfeld-johnson-weeden-iac-2015.pdf
[69] UN Doc. A/CONF.184/6, Report of the Third United Nations Conference on the Exploration and the Peaceful Uses of Outer Space (19 October 1999)

recommendations presented in the final report[70], it is stated that the strategy to be adopted to address global challenges must include "*advancing scientific knowledge of space and protecting the space environment.*"

In this regard, some actions to be taken were also identified:

> *1.c.(i) To improve the scientific knowledge of near and outer space by promoting cooperative activities in such areas as astronomy, space biology and medicine, space physics, the study of near-Earth objects and planetary exploration;*
>
> *(ii) To improve the protection of the near-Earth space and outer space environment through further research in and implementation of mitigation measures for space debris*
>
> *(v) To ensure that all users of space consider the possible consequences of their activities, whether ongoing or planned, before further irreversible actions are taken affecting future utilization of near-Earth space or outer space, especially in areas such as astronomy, Earth observation and remote sensing, as well as global positioning and navigation systems, where unwanted emissions have become an issue of concern as they interfere with bands in the electromagnetic spectrum already used for those applications* (ibid).

Point (v) is particularly germane: It makes a strong connection between astronomy and space activities.

In 2001, a study on environmental impact on astronomy was presented by the International Astronomical Union (IAU), with a background paper submitted to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS). The study was considering the detrimental effect of obtrusive space advertising on astronomical observations.[71] On that occasion, it was underlined how, with increasing activities in space, commercial and non-commercial, an imposing qualitative change in the environmental conditions for astronomy took place, causing a gradual loss of the possibility of observing a pristine sky. With this awareness, the IAU encouraged COPUOS member states to adopt legislation prohibiting issuing licenses to any form of obtrusive advertising. An example of such legislation is the one adopted by the United States and Federal Communications Commission.[72]

However, what might be the most explicit acknowledgment of astronomy as a space activity is the establishment of the International Asteroid Warning Network (IAWN) along with the Space Mission

[70] Space Millennium Declaration: Vienna Declaration on Space and Human Development (SPACE/V/9).
[71] International Astronomical Union 2001
[72] US Government 2010

Advisory Group (SMPAG) in 2013 by the UN Office of Outer Space Affairs, then endorsed by COPUOS at its fifty-sixth session, and formally supported by UN General Assembly resolution 68/75. As UNOOSA explains:

> *The International Asteroid Warning Network (IAWN) is a virtual network linking together the institutions performing functions such as discovering, monitoring and physically characterizing the potentially hazardous near-Earth object population and maintaining an internationally recognized clearing house for the receipt, acknowledgment and processing of all near-Earth object observations. It was established as a network that would also recommend criteria and thresholds for notification of an emerging impact threat and recommend strategies using well-defined communication plans and procedures to assist Governments in their response to predicted impact consequences.*[73]

Of note is that the members of this virtual network are predominantly ground-based observatories, with participation ranging from major international facilities to engaged “amateur” astronomers.

Looking forward, the *Consolidated draft “Space2030” agenda and implementation plan*[74] gives several references to the importance of astronomy providing broad access to space. The introduction reminds us that COPUOS promotes international cooperation in the conduct of space activities:

> *The United Nations has been at the centre of international cooperation in space activities since the beginning of the space age. The Committee on the Peaceful Uses of Outer Space came into being as a result of the recognition by the General Assembly, in its resolution 1348 (XIII) of 13 December 1958, of the importance of using outer space for peaceful purposes and of the need to promote international cooperation in the conduct of space activities; in its resolution 1472 A (XIV) of 1959, the Assembly permanently established the Committee* (Paragraph 1, ibid).

As the document further explains:

> *The ‘Space2030’ Agenda and implementation plan is submitted by the Committee to the General Assembly as a forward-looking strategy for reaffirming and strengthening the contribution of space activities and space tools to the achievement of global agendas, 2 addressing long-term sustainable development concerns of humankind. It also contributes to charting the future contribution of the Committee to the framework for the global governance of outer space activities, consistent with international law* (paragraph 7).

[73] https://www.unoosa.org/oosa/en/ourwork/topics/neos/iawn.html
[74] UN COPUOS 2021, A/AC.105/L.321

To do this, the document identifies “*four overarching objectives are structured around the four pillars of space economy, space society, space accessibility and space diplomacy. Those four pillars are complementary and mutually reinforcing*.” Of relevance is

> *Overarching objective 3: Improve access to space for all and ensure that all countries can benefit socioeconomically from space science and technology applications and space-based data, information and products, thereby supporting the achievement of the Sustainable Development Goals*
>
> > *“3.5. Increase knowledge of outer space, including through enhanced access to astronomical and space science data, for the benefit of humankind.*

In its implementation plan the Space2030 agenda lists tools needed to meet the four overarching objectives. We see again planetary defense being explicitly noted:

> *24 In implementing the “Space2030” Agenda, Member States could contribute to and benefit from a number of international and regional mechanisms, programmes, projects and platforms that are already in place or are being developed, such as the following:*
>
> > *(...)*
> > *(i) The International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG), 9 which are designed to strengthen preparedness for the threat of potential impacts of near-Earth objects through international cooperation and information-sharing.*

Astronomy is also referenced as a form of capacity-building, in terms of space exploration and use, for all states:

> *25. In addition, several tools and initiatives have been and are being developed by the Office for Outer Space Affairs, as part of the capacity-building for the twenty-first century, and in cooperation with its partners, including:*
>
> > *(...)*
> > *(b) The Open Universe initiative, in order to enhance access to astronomical and space science data*.

The Open Universe initiative itself builds on the UNISPACE III action items noted above. The third pillar of the Open Universe, supported by COPUOS, is

> *BROADEN THE USER-BASE of astronomy and space science data: to include as well the rapidly growing community of citizen scientists, by providing the necessary tools to use astronomy and*

space science data for a range of target groups, including educators and students, planetariums, amateur scientists or other potential end-users; and by promoting STEM education, particularly among women and youth in developing countries.[75]

Finally, we note the report on the 62nd session of COPUOS, in which it states

9. General exchange of views on the legal aspects of space traffic management:

(...)

The view was expressed that a comprehensive international space traffic management system could enhance the safe and sustainable conduct of space activities and could include the following: improved multilateral sharing of information on space situational awareness; enhanced international registration procedures; international mechanisms for the notification and coordination of launches, in-orbit maneuvers and re-entry of space objects; and safety and environmental provisions. ***The delegation expressing this view was also of the view that such a system was all the more relevant in the context of very large satellite constellations, which could pose a heightened risk for the safety and sustainability of space activities, in particular with regard to the mitigation of space debris, and could present challenges for astronomical observation*** [emphasis added] (para. 241).[76]

As discussed earlier, Article IX OST generally provides protections for the exploration and use of space from the harmful interference of an activity in space: "*A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment*." Despite that this paragraph only constitutes the view of one or more delegations, it is relevant considering that the report on the 62nd session of COPUOS is explicitly expressing the concern that astronomy will be impacted by satellite constellations and by doing so acknowledges astronomy as space exploration.

In light of the analysis above, involvement of COPUOS, and international level of engagement in astronomical activities related to space exploration, the matter is settled. Astronomy is or at least can be a form of space use and exploration and the obligations of due regard, non-interference, and freedom of use, as laid out by the OST, protect astronomy.

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[75] Barres 2019, World Space Forum. At: https://www.unoosa.org/documents/pdf/WSF/Presentations/Session/Access/3._OpenUniverse_WSF2019_UlissesBarres_final.pdf

[76] UNGA, Report of the Committee on the Peaceful Uses of Outer Space, COPUOS 62nd Sess, Supp No 62, UN Doc A/74/20 (2019).

3. Public international law and space law

While acknowledging the laudable aim of satellite constellations in providing internet access to rural and remote areas, and their role in furthering a digitalized society and achieving the goal of sustainable development, it is also necessary to recognize that appropriate measures are necessary to mitigate the negative impact on the space environment, the skies and their natural and cultural heritage.

Pursuant to Articles I and III OST, space activities shall be carried out in accordance with international law. The text of Article III reads in full: "*States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding*". This provision confirms that space law is part of the broader system of international law, and that it is not a complete autonomous subsystem: Manfred Lachs credited the OST with ensuring "*international law would acquire a new dimension. That was the result of the extension of States' activities into the new domain of outer space, since there could be no legal vacuum in any field of activity*."[77] Customary law on treaty interpretation embodied in the Vienna Convention on the Law of the Treaties is the legal foundation for the systemic interpretation (Article 31(3)(c)),[78] according to which "*treaties are a creation of the international legal system*".[79]

As a starting point, it should be underscored that Article III OST is neither the first nor the only reference to international law in space law. In effect, in a series of resolutions, the General Assembly consolidated this premise of space law. As early as 1961, General Assembly Resolution 1721 (XVI) acknowledged the application of international law to outer space and the celestial bodies as a guiding principle.[80] One year later, a reference to respect international law in carrying out space activities was inserted in the preamble to General Assembly Resolution 1802 (XVII); this time with a recommendatory formulation.[81] Another milestone in this chronology is General Assembly Resolution 1962 (XVIII), which turned the recommendatory language into a mandatory wording, and placed in the operative part of the resolution the provision that activities in the use and exploration of outer space shall be carried

[77] United Nations General Assembly (1st Committee), Summary Record of the 1491st Meeting', 16 Dec 1966, UN Doc A/C.1/SR.1491. See Simma, B. and Pulkowski, D., *Of Planets and the Universe: Self-contained Regimes in International Law,* in 'European Journal of International Law, Vol. 17, No. 3, 2006, p. 492; JOHNSON C.D., 'The Law of Outer Space: A Self-Contained Regime?' in Philipe Achilleas and Stephan Hobe (eds), *Fifty Years of Space Law — Space Law in Fifty Years* (The Hague Academy of International Law 2020).
[78] Dörr, O. and Schmalenbach, K. (eds), *Vienna Convention on the Law of the Treaties. A Commentary*, Berlin-Heidelberg, 2012, pp. 560-561 (para. 89).
[79] Report of the International Law Commission on its 58th Session, UN Doc. A/61/10, p. 413 (para. 17).
[80] United Nations General Assembly, Resolution 1721A (XVI), 20 December 1961, A/RES/1721B (XVI), op. 1 (a).
[81] United Nations General Assembly, Resolution 1802 (XVII), 14 December 1962, A/RES/1802 (XVII).

out in accordance with international law.[82] Finally, the OST consolidated this normative trend and transformed it into a treaty binding obligation under Article III. Nowadays, Article III OST is considered to embody customary law.[83]

However, a remarkable point is that none of the legal sources mentioned before refers to *relevant* international law, which would have been a more precise formulation since international law *in toto* is not applicable.[84] In effect, as some authors have underscored, Article III is not a blanket extension of the entire realm of international law to outer space and the celestial bodies.[85] In this vein, it is an interpretative task that member states might wish to undertake to elucidate which areas of international law may be imported into space law to give content and clarity to some of its provisions, such as the obligation to avoid harmful contamination. The Cologne Commentary has considered that principles of other fields of international law — like the precautionary principle of environmental law — are imported into space law,[86] and there might be other important principles of environmental law that may be applicable, such as the good neighborliness principle.[87] Likewise, customary international law on State responsibility may fill the gaps of the built-in international responsibility regime enshrined in Article VI of the Outer Space Treaty.

Moreover, the harmonization of conflicting freedoms and interests in the use and exploration of outer space may call for a broader understanding of the treaty text where 'accordance with international law' might also include other areas of international law that guarantee, *inter alia*, the right to starlight, indigenous rights, and the right to development (the latter including the right to internet access, which has been labeled as a global public good by the UN SG "Our Common Agenda"[88]. However, the enjoyment of one right should not lead to the exclusion of another, and it should not be necessary to make a choice between global internet and the preservation of the night sky).

4. Satellite constellations and international space law

4.1 Fundamental freedoms and their limitations

Article I of the OST states the following:

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[82] United Nations General Assembly, Resolution 1962 (XVIII), A/RES/1962 (XVIII), 13 December 1963, see op. 4.
[83] Lyall, F. and Larsen P., *Space Law. A Treatise*, Farnham-Furlington, 2009, p. 510.
[84] Ribbelink, O., *Article III* (Outer Space Treaty), in Hobe S., Schmidt-Tedd, B. and Schrogl, K-U. (eds), *Cologne Commentary on Space Law* (Vol. I), Cologne, 2009, p. 67 (para. 12).
[85] Maogoto, J. and Freeland, S., *Space Weaponization and the United Nations Charter Regime on Force: A Thick Legal Fog or a Receding Mist?*, in 'The International Lawyer', Vol. 41, No. 4, 2007, p. 1098.
[86] Ribbelink, O., *Article III* (Outer Space Treaty), cit. note 8, p. 67 (para. 14).
[87] See the Declaration of the United Nations Conference on the Human Environment, Stockholm, 16 June 1972, and the Rio Declaration on Environment and Development, Rio de Janeiro, 14 June 1992.
[88] UN SG our common agenda

> *The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.*
> *Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.*
> *There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation*.

In accordance with this Article, States are free to access and explore outer space without requesting permission from another State or an external authority. Private entities, duly authorised to conduct space activities, are also free to carry out space programmes without discrimination in accordance with international law.

However, the rapidly growing number of satellites in near-Earth orbit is increasing the risk of congestion and collisions, as the proposed launch of multiple satellite constellations leads to the orbital area becoming less predictable. The increasing prevalence of satellite constellations and these associated risks threaten adverse consequences to the free access and use of outer space.

One may consider that one State's freedoms are limited by the freedoms of other States. The mass occupation of an orbit by a single actor with tens of thousands of satellites, for example, may present a limit to the freedom of other States and operators to deploy space assets within that orbit. This paper will argue that such a scenario can be seen as a violation of Article II of the OST, as further discussed in section 4.2.

Satellite constellations can also have an adverse impact on the freedoms of night sky observers on the Earth. Bright "light trails" from satellite constellations risk affecting astronomical observations from Earth, corrupting the data astronomers collect for astronomical images, and if visible by the human eye may further influence how humanity in general experiences the observations of the night sky. The increased number of orbital objects in outer space requires the adoption of adequate measures to protect the natural state of the night sky and the opportunity for global citizens to observe the stars and the Milky Way. These matters will be discussed further in section 8.

To conclude, the increasing prevalence of satellite constellations will lead to Earth's orbits becoming more crowded in the coming years. Consequently, the use of satellite constellations requires better space traffic management, space debris and remediation measures in the coming years, particularly given the increased risks and consequences of on-orbit fragmentations associated with such dense occupation of specific orbits. In this context, international cooperation is essential, and a regulatory framework is needed to ensure that outer space remains accessible and safe for space operations.

4.2 Non-appropriation

Article II of the OST is clear on the point that the appropriation of outer space, including the appropriation of either void space or of celestial bodies or subsections thereof, is an impermissible and prohibited action under international law. No means or methods of possession or occupation of outer space will legitimize the appropriation or ownership of outer space, or of subsections thereof.

Suppose satellite constellations would exclude others from the same orbits, would be done without international coordination, would be long-term, done without due regard for others, threaten harmful contamination, and are the responsibility of their authorizing governments. In that case, their activity might cross over the threshold from mere lawful access and utilization of outer space into impermissible contamination and appropriation of the sections of space that they inhabit.

4.2.1 Excludes others

While access to outer space is nonrivalrous — in the sense that anyone with the technological capacity to launch space objects can therefore explore space — orbits closer to Earth are unique, valuable, and therefore limited natural resources. When any actor utilizes an orbit to the extent current and proposed constellations do, it means that other actors simply cannot go there. To allow any one user to so overwhelmingly occupy a number of altitudes with so many of their spacecraft essentially means that this user will henceforth be the sole user of that orbit (at least if and until their satellites are removed).[89] The dense occupation of such a particular orbit limits the freedom of other operators to safely share that orbit without significant risk of collision. While space traffic management is possible within a private entity's space operations, this delicate dance of spacecraft at orbital speeds without any currently existing norms for “right of way” in space means that users of the same orbits are taking risks with each other.[90] Consequently, the sole occupant will therefore be the one and only possible user. If “possession is nine-tenths of the law”, then that one user appears to be the sole owner of that orbit.

4.2.2 Lack of international coordination

Satellite constellation operators conduct space activities without engaging in meaningful international conversation about numbers or orbital occupation, which is especially egregious and transgressive of the norms of outer space. Compared to the regime for geosynchronous orbit (GSO), administered by

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[89] *Island of Palmas* Case (Netherlands/USA) (1928), 2 RIAA 829, 838-839 (“Sovereignty in the relations between States signifies independence... the right to exercise therein, to the exclusion of any other State, the functions of a State. territorial sovereignty belongs always to one, or in exceptional circumstances to several States, to the exclusion of all others.”
[90] Jeff Foust, ‘SpaceX and OneWeb Spar over Satellite Close Approach’ *SpaceNews* (22 April 2021) *available at* https://spacenews.com/spacex-and-oneweb-spar-over-satellite-close-approach/.

the ITU and national frequency administrators, activity in low Earth orbit (LEO) is essentially uncoordinated. Operators' mega-satellite-constellation plans are in practice an attempt to take advantage of this lack of authority and claim entire portions of LEO for their own operations, and to do so before any international agreement, consensus, or discussion has been conducted. This "first come, first served" basis of LEO administration is at odds with the sustainable use of space and with longstanding norms of international cooperation and consultation.

4.2.3 Long-term occupation constitutes appropriation

The proposed altitudes for satellite constellations in LEO are of particular significance in the conversation around orbital occupation. In lower LEO, which includes orbits lower than approximately 500 km, non-functional spacecraft will take only a few months or years to re-enter the Earth's atmosphere. This means that matters of satellite occupation in lower LEO are generally a fundamentally impermanent affair. The orbits desirable to satellite constellations, however, are broadly higher than 500 km and consequently have a much longer associated 'natural' deorbiting time. Spacecraft at the altitudes selected for satellite constellations will thus remain in those orbits for decades, or even centuries, except in the case of deliberate de-orbiting or other intervention.

A comparable case for these long-term orbits is the management of GSO, where satellites likewise have a long natural longevity in their selected orbit. The granting of rights for orbital slots in GSO is allocated in 15-year increments. By not allocating orbits in a similar and timescale-proportionate manner for satellite constellations, any launched satellite constellations in the coming years will remain in place for a far longer unaccountable time than currently takes place in GSO. The satellite constellation occupation for such long spans of time at these altitudes further bolsters the contention that the occupation of these orbits by operators rises to the level of appropriation of these orbits.

4.2.4 No due regard for others

That these satellite constellations violate the prohibition on appropriation in Article II could be additionally supported by Article IX OST. Article IX requires that in the exploration and use of outer space, States "*shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space... with due regard to the corresponding interests of other States....*" The deployment of satellite constellations, in the proposed numbers[91] and if uncoordinated, may show a lack of due regard to the corresponding interests of others, as further discussed in Chapter 4.5. This lack of regard could further support the notion of their unilateral transgressive violations of the intentions and purposes of space law, namely the exhortations of international cooperation.

[91] Add ref to numbers to date

4.2.5 Harmful contamination

The impacts of the spacecraft on the pressing issue of space debris need not be elaborated further here. Suffice to say, *megaconstellations* threaten *megadebris*. The failure rate of these comparatively cheap satellites should give pause, because if 5% of a constellation of 100 satellites fails, this means five guaranteed additional new anthropogenic space objects of certain debris intentionally introduced to the fragile space domain. And in an orbital environment of 100,000 new satellites, a failure rate of 5% is comparable to all satellites (active and defunct) in orbit in 2019.

Article IX OST warns of harmful contamination of the space environment and requires States to take appropriate measures to prevent this harmful contamination. A government exercising due diligence over all activities for which it is internationally responsible would not permit the intentional release of such amounts of space debris, especially in the already fraught orbits that many constellations are headed towards. While the threat of space debris is not directly relevant to the accusation of appropriation of outer space, it goes towards the argument that these actors are conducting unilateral activities in a manner lacking in regard and coordination with others, and amounts to excluding others from using the space domain. By effectively excluding others, this has the effect of taking orbits for themselves, which would be occupation.

4.2.6 Governments are responsible for authorizing and supervising satellite constellations activities

Under international space law, what a nongovernmental entity does, a State is responsible for. Article VI OST requires that at least one State authorize and supervise its nongovernmental entities, and assure their continuing compliance with international law. As such, the prohibition on non-appropriation imposed upon States via Article II OST applies equally to nongovernmental private entities. More broadly, a State cannot circumvent a prohibition placed upon it by contracting its violative activity to a nongovernmental actor. Nevertheless, through the launching and bringing into use of the various satellite constellations, the operator of each constellation will be the sole occupant, and thereby, possessor (both in fact and in law) of each altitude (e.g. 550 km, 1100 km, 1130 km, 1275 km, and 1325 km, or whatever orbits they eventually occupy above our planet, will be their possession). The same is true for other operators of satellite constellations which will solely occupy entire orbits. This appears to be an effective but transparent method for the governments that authorize and supervise them to appropriate particular orbits for themselves. Henceforth, these orbits would be under the control of the authorizing governments whose private entities occupy them.

4.2.7 If this isn't appropriation, then what is?

Arguing in the alternative, if these satellite constellations, within their dominant occupation of entire orbits in orbital planes constituting shells around the Earth, could be considered (merely for the sake of argument) to not be appropriation, we must therefore ask: what would be appropriation? What use of void space, including orbits of the Earth, would constitute actual appropriation? What further additional fact of these uses of space, if added to the scenario, would cause that satellite constellations to cross over the line into clearly prohibited appropriation of space? Perhaps the exact same scenario, but supplemented with a formal claim of sovereignty, issued by a government, is the only element which could be added to satellite constellations which would then cross the threshold into appropriation. However, a formal claim of sovereignty would be merely an act occurring on Earth and would not change any actual facts in the space domain. Additionally, under Article II, a claim of sovereignty has no legal effect. It is also very unlikely that any government would issue such a claim of sovereignty. Consequently, the lack of a formal claim of sovereignty should not be the deciding criteria in arriving at the conclusion that satellite constellations constitute appropriation of orbits.

4.2.8 Preliminary conclusions on appropriation

In conclusion, satellite constellations effectively occupy entire orbital regions with their vast fleet of spacecraft, and in so doing effectively preclude other actors from sharing those domains. They have done so, or are attempting to do so, without any international consensus or discussion, which is most egregious for a domain outside of State sovereignty and which no State can own. Governments will ultimately be responsible for this appropriation, and are prohibited from appropriating space. In distinction to GSO, launch authorisation of satellite constellations leads to occupation of orbital regions for incredibly long periods — which again shows their appropriation. Satellite constellations significantly prevent others from using those regions, which therefore interferes with others' right to explore and use space. And ultimately, this reckless ambition could be interpreted as paying no due regard (as per Article IX OST) for the corresponding rights of others. As such, these satellite constellations could be considered an impermissible appropriation of particular regions of outer space, regardless of any formal, official claim of such by a responsible, authorizing government.

4.3. Satellite constellations and 'continuing supervision'

Serious issues of concern regarding operation and impact of numerous satellites have constantly been raised by space debris mitigation proponents, which, in due course of time, led to the adoption of voluntary international guidelines regarding mitigation of space debris or space junk. In turn, national legislations have used these guidelines to systemize and solidify their respective binding legal requirements in their national legislations.[92] In all likelihood, this can be seen as act(s) by respective (or, appropriate) State governments (or, State Parties to the OST) to fulfill their obligations under Article VI OST.

[92] United Nations Office for Outer Space Affairs, Compendium of space debris mitigation standards adopted by States and international organizations, accessible at: https://www.unoosa.org/oosa/en/ourwork/topics/space-debris/compendium.html (Last accessed Sep 24, 2021).

In its part and barring the last sentence pertaining to responsibility of international organizations, Article VI OST[93] provides for (i) State responsibility for national activities carried out by governmental agencies or by non-governmental entities; and that (ii) national activities shall require authorisation and continuing supervision. Respective State governments should therefore fulfill the requirements of authorisation, under their respective State legislations, policies, directives, action plan(s), etc. by providing for launch and re-entry licenses, payload registrations, end of life or de-orbit requirements.

However, it has been identified[94] that a missing link or gap exists in that no consideration or protection whatsoever is currently being accorded to the on-orbit operational phases of satellite constellations. There is a need to regulate this additional aspect given the impact of increasing numbers of satellites. As the numbers of satellites in LEO have started increasing rapidly over the course of the last couple of years or so, another group of stakeholders (or, affected national entities[95]) of concerned astronomers, observers, scientists, have taken the lead in confirming and establishing issues of 'light pollution' emanating from LEO and seriously affecting their respective line of work in multiple ways. In many instances, the workings and functioning of large-scale, government-established, -run and -funded astronomical observatories have experienced errors in their astronomical observations. There are also emerging and upcoming issues of spectrum pollution.

4.3.1 How can this missing link or gap be addressed: points for further consideration or discussions in the international community

The requirement of "continuing supervision", as stipulated in the second sentence of Article VI OST, would imply that State governments maintain "continuing supervision" over the space activities of its private actors, and that the scope of such supervision be extended to the on-orbit operational phase of satellites while they are in Earth orbits. The need to regulate all aspects of a space activity i.e. (i) launch and placement of satellites, (ii) <u>operation of such satellites in Earth orbits, including their impacts</u>; and (iii) de-orbit and end of mission life, was identified by United General Assembly Resolution 68/74 on *Recommendations on national legislation relevant to the peaceful exploration and use of outer space*[96], which in its relevant portion, states:

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[93] *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, 27 January 1967, 610 UNTS 205, (entered into force 10 October 1967) [*Outer Space Treaty*], Art VI.
[94] REF to SATCON2 report
[95] The term 'affected national entities' finds expression in the UN Committee on the Peaceful Uses of Outer Space, *Guidelines for the Long-term Sustainability of Outer Space Activities*, 27 June 2018, UN Doc. A/AC.105/2018/CRP.20, Guideline A.2. In our concerted view, astronomical societies, observatories or associations around the globe would then be deemed to be a 'nationally affected entity' due to the manner in which their line of work is being affected by space activities. Guideline A.2 recommends States to amend their national laws, regulations, policies, etc., and asks that in doing so, the views and concerns of nationally affected entities be taken into account.
[96] United Nations General Assembly, *Recommendations on national legislation relevant to the peaceful exploration and use of outer space*, UNGA Res. 68/74 (adopted by the General Assembly on 11 December 2013), UN Doc. A/RES/68/74 (16 December 2013).

Recommends the following elements for consideration, as appropriate, by States when enacting regulatory frameworks for national space activities, in accordance with their national law, taking into account their specific needs and requirements:

1. The scope of space activities targeted by national regulatory frameworks may include, as appropriate, the launch of objects into and their return from outer space, the operation of a launch or reentry site and the operation and control of space objects in orbit; …

And therefore the authors of this report wish to draw the attention of the international community to the following points for further consideration:

§ The form and manner of "continuing supervision" may vary[97], and thus, States may consider a conduct of due diligence to ascertain the impact of on-orbit operation of satellites prior to launch of such satellites in Earth orbits; and

§ May prescribe a continuing manner in which this may be achieved on an annual basis.

4.3.2 Are there any additional requirements which States may look into?

In addition to the requirement that the on-orbit operational phases of satellite constellations, and more importantly their impact, need to be looked into, certain elaborative attempts of the international community find expression in the the *Guidelines for the Long-term Sustainability of Outer Space Activities*, *2019* as adopted in June 2019.[98] Guideline A.2, which assumes prime importance in the context of this report, specifies that States consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities. States are required to: (i) consider recommendations of GA Resolution 68/74; (ii) address risks to people, property, public health and the environment associated with the launch, in-orbit operation and re-entry of space objects; (iii) promote regulations and policies that support the idea of minimizing the impacts of human activities on Earth as well as on the outer space environment; and (iv) encourage

[97] *Ibid*, at "5. Appropriate procedures should ensure continuing supervision and monitoring of authorized space activities by applying, for example, a system of on-site inspections or a more general reporting requirement; enforcement mechanisms could include administrative measures, such as the suspension or revocation of the authorization, and/or penalties, as appropriate."

[98] UN Committee on the Peaceful Uses of Outer Space, *Guidelines for the Long-term Sustainability of Outer Space Activities*, 27 June 2018, UN Doc. A/AC.105/2018/CRP.20, as adopted in June, 2019. These guidelines are constantly increasing in their importance and value to the international community. For example, see the declaration of United States in their National Space Policy 2020 (09 December 2020), p. 14:
"Preserving the Space Environment to Enhance the Long-term Sustainability of Space Activities Preserve the Space Environment.
To preserve the space environment for responsible, peaceful, and safe use, and with a focus on minimizing space debris the United States shall:
• Continue leading the development and adoption of international and industry standards and policies, such as the Guidelines for the Long-term Sustainability of Outer Space Activities and the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space; …"

advisory input from affected national entities during the process of developing regulatory frameworks governing space activities to avoid unintended consequences of regulation that might be more restrictive than necessary or that conflict with other legal obligations.

Briefly elaborating on the specific context of input from affected national entities, it becomes very important to address the question of whether the responsibility under Article VI OST entails a responsibility of States to strike a balance between conflicting national interests.

In this case, astronomical societies and associations around the world are presenting (have presented) good evidence of the manner in which space activities being conducted by private entities are presenting hindrances and are in conflict with the workings and functioning of government based, run, and operated observatories. These observatories are national assets of their respective governments, with huge-scale funding involved in their establishment and organization.

And thus, an important question again is: should governments rush to enhance their space operations without any considerations whatsoever to the interests of affected national entities?

Guideline A.3 further requires, amongst other stipulations, that in fulfilling the requirements under Article VI OST, including the responsibility of continuing supervision, States should encourage each entity conducting space activities to: (i) develop specific requirements and procedures to address the safety and reliability of outer space activities under the entity's control, <u>during all phases of a mission life cycle</u>; (ii) assess all risks to the long-term sustainability of outer space activities associated with the space activities conducted by the entity, <u>in all phases of the mission life cycle</u>, and take steps to mitigate such risks to the extent feasible.

The authors note that previous sections of this report, as well as other international endeavors such as SATCON1 and SATCON2, have identified and laid down issues, concerns and risks associated with the large-scale deployment of satellite constellations, including emerging issues of light pollution emanating from Earth orbits.

4.3.3 Impact of human activities on Earth as well as the outer space environment

An important concern in this regard is the identification of the domain to be regulated. For instance, one important step adopted by the Long-term Sustainability of Outer Space Activities (LTS) guidelines in 2018 was the provision to support minimizing the impacts of human activities on Earth as well as in the outer space environment, thus dealing with the dichotomy between the Earth and space environments in one single and whole manner.

In this context, a useful suggestion by the authors of this report may be to bring about a shift in focus of concerned governments, legislators and policymakers to regulate the impact of human space activities *wherever* felt and needed. For example, the impacts and risks of satellite constellation operations may be felt in both Earth and space environments, depending on and at all phases of the mission life cycle.

Thus, a shift in focus regarding the impact of human space activities, wherever they may be felt, may be a good alternative to the persistent dilemma of the separation of domains. States may consider devising this shift in focus akin to an environmental impact assessment or as due diligence, prescribed and conducted within the aegis of environmental law.

4.4. Art IX, due regard, harmful interference, and coordination

Article IX of the OST is one of the provisions of international space law that most readily applies to the problem that we are discussing here. Article IX[99] states the following:

> *In the exploration and use of outer space... States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space... with due regard to the corresponding interests of all other States Parties to the Treaty. (...) If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space... would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space... it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space... would cause potentially harmful interference with activities in the peaceful exploration and use of outer space... may request consultation concerning the activity or experiment.*

Article IX has been described by many legal scholars as vague, as it seems to raise more questions than it answers clearly, owing to its programmatic formulation. However, it has also been noted by commentators that the entire OST contains general principles rather than detailed rules.[100]

From this provision, it seems that States Parties to the OST must 1) conduct all of their activities in outer space with due regard to the corresponding interests of all other States Parties to the Treaty; 2) conduct all their activities in outer space avoiding harmful interference with the activities of others; and 3) engage in international consultations whenever necessary.

[99] Art. IX OST.
[100] Sergio Marchisio, "Article IX", in Hobe, Stephan/Schmidt-Tedd, Bernhard/Schrogl, Kai-Uwe (eds.), Cologne Commentary on Space Law (CoCoSL), Volume I, Carl Heymanns, Cologne 2009.

In this sense, Article IX amounts to a limitation of the freedom of exploration and use of outer space that is established in Article I.2 OST.

In addition, it is worth recalling that for all purposes of the OST, “activities in outer space” means all national space activities, whether carried out by governmental agencies or non-governmental entities (i.e. private companies and private organizations).[101]

4.4.1 The notions of due regard, harmful interference, and appropriate consultations

Key terms used in Article IX that are relevant for our discussion are ‘due regard’, ‘harmful interference’, and ‘appropriate consultations.’ While the notion of ‘due regard’ has been identified as coming from international air law, the term ‘harmful interference’ seems more akin to international telecommunications law.

The notion of ‘due regard‘ is taken from the 1944 Chicago Convention,[102] which embodies principles and procedures for the safety of civil air navigation. Article 3 of the Convention exempts State aircrafts from the Convention, but it requires these aircrafts to fly with “*due regard for the safety of civil aviation*”. This sentence is understood as giving rise to a duty of due diligence upon operators of State and military aircrafts to ensure the safety of the navigation of civil aircrafts.[103]

Under this principle of ‘due regard’ as contained in Article IX, space activities carried out by a given State should be conducted in accordance not only with its own interests, but also with the interests and rights of the remaining States Parties to the Outer Space Treaty.[104]
According to the ITU Radio Regulations, harmful interference is defined as any “interference which endangers the functioning of a radionavigation service ... or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these *[Radio] Regulations*.”[105] Additionally, “harmful interference occurs when the interference is deep and/or long enough to deteriorate the services of the affected systems.”[106]

Activities that “would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space” are subject to international consultations.[107] State Parties assume the obligation to at least engage in a consultation prior to causing harmful interference with the activities of another.

[101] Art. VI OST.
[102] Convention on International Civil Aviation (done 07 December 1944, entered into force 04 April 1947).
[103] S. Marchisio, “Article IX”, in CoCoSL Vol. I.
[104] S. Marchisio, “Article IX”, in CoCoSL Vol. I
[105] https://www.its.bldrdoc.gov/fs-1037/dir-017/_2541.htm. Cfr. also the definitions of ‘interference’ and ‘harmful interference’ used by the Committee on Radio Astronomy Frequencies (CRAF): https://www.craf.eu/some-definitions/harmful-interference/.
[106] https://www.sciencedirect.com/topics/engineering/harmful-interference.
[107] Art. IX OST.

These international ‘appropriate consultations’ could be compared to the coordination procedures that are conducted by States under the auspices of the ITU. States engage in such procedures whenever the use of a particular frequency or band of frequencies is desired by two States, but its use by both would cause harmful radioelectric interferences between them, hence the need for coordination.

4.4.2 Space activities and astronomy

An important question here is whether ground-based astronomical observations could be considered a space activity and thus be protected by these obligations of due regard, prevention of harmful interference, and engaging in international consultations. The lack of judicial decisions based on Article IX makes it difficult to provide a definitive assessment. However, it is possible to argue on behalf of an affirmative response based on historical interpretation of the OST.

Ground-based astronomy is obviously not conducted in outer space, but rather is conducted on Earth, and so in principle would not qualify as a space activity proper. Under this restrictive view, the due regard and the rest of Article IX obligations would not apply to our case.

On the other hand, there are arguments in favor of admitting ground-based astronomy as a space activity in a wider sense. First, it is an activity that is clearly oriented towards outer space and has the nature of a space exploration, so it could be covered under the expression “peaceful exploration of outer space” that is prevalent throughout the OST.

Secondly, there is one important historical precedent that supports the idea of including ground-based astronomical observations under the activities to be taken into account when carrying out activities in outer space: the case of the West Ford Experiment (1961 to 1963). This was an experiment in space communications carried out by the United States military and NASA, involving the launch and release of millions of copper needles into low Earth orbit for the purpose of creating an artificial belt around the Earth to reflect long-range radio waves from ground stations. The USSR and other countries complained that this project had been conducted without prior consultation with the global scientific community. Radio astronomers worldwide further complained that the experiment had the potential to interfere with scientific radio observations of the sky.[108]

Following this criticism, an agreement was reached in 1963 on a recommendation that directed the attention of COPUOS “*to the urgency and the importance of the problem of preventing potentially harmful interference with peaceful uses of outer space*.”[109]

[108] The Harvard Crimson, “Project West Ford”, May 24, 1963: https://www.thecrimson.com/article/1963/5/24/project-west-ford-pfour-hundred-million/.
[109] S. Marchisio, “Article IX”, in CoCoSL Vol. I.

On the basis of COPUOS's work, the UN General Assembly adopted shortly afterwards the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space[110], where Principle 6 established that:

> *In the exploration and use of outer space, States shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space with due regard for the corresponding interests of other States. If a State has reason to believe that an outer space activity or experiment planned by it or its nationals would cause potentially harmful interference with activities of other States in the peaceful exploration and use of outer space, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State which has reason to believe that an outer space activity or experiment planned by another State would cause potentially harmful interference with activities in the peaceful exploration and use of outer space may request consultation concerning the activity or experiment*.

On 20 May 1964, the Executive Council of COSPAR adopted a Resolution on 'No harmful interference from Westford Experiment'. On this basis, the STSC of COPUOS adopted a new recommendation urging all Member States proposing to carry out experiments in space to give full consideration to the problem of possible interference with other peaceful uses of outer space.[111]

Thus, on 15 December 1966, when the draft text of the OST was submitted to the First Committee of the UN General Assembly, the provision which was to become Article IX was present with all its final elements; as summarized by the report: "*The observance of corresponding interests of other States in outer space, the conduct of exploration of outer space, including the moon and celestial bodies, so as to avoid the harmful contamination and adverse changes in the environment of the Earth; the conduct of international consultations if an activity or experiment planned by a State or its nationals in outer space would cause potentially harmful interference with activities of other States*."[112]

According to the previous reasoning, a significant part of Article IX derives from the effects of the West Ford Experiment. The main negative consequences of this experiment were felt on the ground, and not in other activities conducted in outer space proper. Still, the impact caused by the experiment *inter alia* on astronomical observations was reason enough to discontinue the experiment and add several new provisions to the 1963 Declaration, and subsequently to the OST.

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110 Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, UNGA Res 1962 (XVIII) (13 December 1963).
111 S. Marchisio, "Article IX", in CoCoSL Vol. I.
112 Yearbook of the United Nations 1966, pp. 36 f. Cited by S. Marchisio, "Article IX", in CoCoSL Vol. I.

4.4.3 Application of OST Article IX to satellite constellations

When applied to the case at hand, the 'due regard' principle mandates that States Parties to the OST implement activities in space with due regard to (i.e., duly taking into account) the corresponding interests of other States that will be affected by the optical and radio pollution created by satellite constellations.

When it comes to non-governmental activities in outer space, the way to comply with this international obligation is for the different States involved in the authorisation of satellite constellations to adopt licensing conditions that take into account the impact of those satellite constellations on ground-based astronomy, with an aim to reduce that impact as much as practicable.

In this context it is worth remembering that the US Federal Communications Commission has been tasked with the reduction of the creation of new space debris and the pollution of Earth's orbit by these satellite constellations, and it is accordingly updating its orbital debris mitigation rules[113]. In addition, the United Kingdom's Outer Space Act of 1986 states that a license for space activities may contain particular conditions imposed on private operators, such as the requirement to conduct their operations in such a way as to prevent the contamination of outer space or adverse changes in the environment of the Earth[114].

Additionally, States Parties are to consult other States whose activities may be subject to 'potentially harmful interference' by an activity or experiment that the first State intends to pursue. As already noted, this consultation is engaged in either voluntarily by the States carrying out the activity causing interference or at the request of the State that fears such interference with its activities[115].

Following the previous reasoning that traces the origin of some of the provisions of Article IX to the West Ford Experiment, then we should conclude that activities conducted in outer space that cause a harmful interference to other space activities, including the exploration of outer space conducted from the ground, are subject to this obligation to engage in international consultations, either by the State causing the interferences or by the State that is suffering them. When applied to our case, States Parties to the OST have an obligation to enter into consultations with other States as a result of the potential light pollution created by satellite constellations.

As a final remark, Article IX has been described as related to other branches of international law, such as international environmental law. In particular, Principle 21 of the 1972 Stockholm Declaration on Human Environment and Principle 2 of the 1992 Rio Declaration on Environment and Development,

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[113] FCC, "FCC Updates Orbital Debris Mitigation Rules for the New Space Age", April 24, 2020: https://www.fcc.gov/document/fcc-updates-orbital-debris-mitigation-rules-new-space-age-0.
[114] Section 5 (2) (e) (i), Outer Space Act 1986.
[115] Francis Lyall and Paul B. Larsen, Space Law — A Treatise, Ashgate, 2009, p. 69.

both of which are recognised as customary rules of international law, establish that States have the duty to avoid the contamination of areas beyond their national jurisdiction. In this latter case, it is clear beyond any doubt that those areas out of the jurisdiction of all States, the contamination of which must be avoided, include outer space, and certainly the orbits around the Earth.

5. Astronomy and planetary defense

Astronomy plays an integral role in planetary defense, which involves the detection and characterisation of Near-Earth Objects (NEOs) and, if needed, the mitigation or management of Earth impacts. NEO impacts pose a significant and complex risk to both human life and critical infrastructure, and have the potential to cause substantial and possibly even unparalleled economic and environmental harm. While a NEO making impact is functionally in line with a traditional natural disaster, it is rhetorically linked to an act of war[116]. Thus, planetary defense is considered a national security interest for many States. Firstly, planetary defense may be understood as a global security interest, purely on the basis that an asteroid plummeting toward Earth is nearly guaranteed to cause incredible and likely irreparable damage. Secondly, maintaining systems that identify exoatmospheric planetary threats such as asteroids or other NEOs is an interest aligned with global security goals.

Satellite constellations may impact the effectiveness of planetary defense, which relies on astronomy as one of its principal tools. This type of interference has broad implications for public policy and disaster management. Any light pollution which impairs the functionality of a telescope tasked with any aspect of planetary defense could impact global security. This concern is particularly broad given the multi-functional nature of most telescopes.

Telescopes play an integral role in planetary defense. The NASA Center for Near Earth Object Studies (CNEOS) computes the orbit paths of NEOs based on position data provided by the International Astronomical Union's Minor Planet Center, the official repository of NEO observational data. The Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) uses the Wide-Field Infrared Survey Explorer telescope to survey NEOs. Wide-field telescopes are used to identify objects moving in the sky.

The Asteroid Terrestrial-Impact Last Alert System (ATLAS) is an early-warning system, funded by NASA and developed at the University of Hawai'i, comprising two telescopes on Mauna Loa and Haleakala. It is intended to provide one day's warning for a 30-kiloton (equivalent TNT) "town killer," one week's warning for a 5-megaton "city killer," and three week's warning for a 100-megaton "county killer."[117]

[116] Andrea Harrington, *National and International Security in Space: International Law Implications of Space Force and Planetary Defense,* 48 Ga. J. Int'l. Comp. L. 767, 770 (2020).
[117] *Asteroid Terrestrial-impact Last Alert System,* Atlas, https://atlas.fallingstar.com/home.php (last accessed Aug. 17, 2021).

Once NEOs are identified, follow-up telescopes are used to determine size, shape, orbit, etc of the objects. These telescopes include the following:

- Spacewatch
- Astronomical Research Institute
- Las Cumbres Observatory
- Magdalena Ridge Observatory
- Mission Accessible Near-Earth Objects Survey (MANOS)
- Infrared Telescope Facility (IRTF)
- NOIRLab large-aperture telescopes: Gemini, WIYN, Blanco, SOAR

International coordination for planetary defense takes place through the United Nations Office of Outer Space Affairs (UNOOSA). Upon the recommendation of COPUOS, two collaborative bodies were established to strengthen international cooperation on NEO studies: the Space Mission Planning Advisory Group (SMPAG) and the International Asteroid Warning Network (IAWN).

SMPAG is an advisory group of space agencies from Member States. As UNOOSA explains:

> [SMPAG's] *responsibilities include laying out the framework, timeline and options for initiating and executing response activities, informing the civil-defense community about the nature of impact disasters and incorporating that community into the overall mitigation planning process through an impact disaster planning advisory group*[118].

Two things should be kept in mind: (1) SMPAG is advisory only and does not have any decision-making authority. (2) SMPAG does not have direct industry involvement, and the role of industry and NewSpace on planetary defense efforts are not internationally coordinated.

The second forum for international cooperation on planetary defense is IAWN, which is:

> *A virtual network linking together the institutions performing functions such as discovering, monitoring and physically characterizing the potentially hazardous near-Earth object population and maintaining an internationally recognized clearing house for the receipt, acknowledgment and processing of all near-Earth object observations*[119].

Participation in the IAWN network is open to applicants, and requires a signed commitment to IAWN's charter and Statement of Intent. The IAWN Steering Committee decides whether to admit the

[118] *SMPAG,* UNOOSA, https://www.unoosa.org/oosa/en/ourwork/topics/neos/smpag.html (last accessed Aug. 21, 2021)
[119] *IAWN*, UNOOSA, https://www.unoosa.org/oosa/en/ourwork/topics/neos/iawn.html (last accessed Aug. 21, 2021).

applicant as a member. As a result of this process, the IAWN network participation ranges from amateur astronomers, to major observatories, to national space agencies[120]. IAWN's role is one of information sharing and cooperation, but again does not have decision making authority.

Fostering international cooperation and maintaining efficient ways to promote information sharing is of general importance to the international community, as demonstrated by UN General Assembly Resolution 73/91:

> [The General Assembly] reiterates *the importance of information-sharing in discovering, monitoring and physically characterizing potentially hazardous near-Earth objects to ensure that all countries, in particular developing countries with limited capacity for predicting and mitigating a near-Earth object impact, are aware of potential threats, emphasizes the need for capacity-building for effective emergency response and disaster management in the event of a near-Earth object impact, and notes with satisfaction the work carried out by the International Asteroid Warning Network and the Space Mission Planning Advisory Group to strengthen international cooperation to mitigate the potential threat posed by near-Earth objects, with the support of the Office, serving as the permanent secretariat of the Advisory Group* (paragraph 10)[121].

Nonetheless, despite a general view of the importance of planetary defense, the field suffers from a lack of international policy. Decision making is ultimately a national matter. Notably, mistaking a satellite as a NEO is not the concern. Rather, the concern is the loss of detection efficiency as a direct result of data loss — which corresponds, in practice, to a loss of time in which to respond. As the United States National NEO Preparedness Strategy and Action Plan explains:

> *Early detection and characterization of hazardous NEOs increases the time available to make decisions and take effective mitigating action, and it is the first priority for planetary defense*[122].

Indeed, a persistent theme that arises from the planetary defense tabletop exercises, held every two years, is the need for observational follow up after the discovery of a potential impactor. Through the participation of multiple IAWN members, some inefficiencies in data collection can be tolerated. However, the initial discovery of a *hazardous* impactor could be delayed.

[120] *Id.*

[121] G.A. Res. 73/91, International Co-operation in the Peaceful Uses of Outer Space (Dec. 18, 2018); *see also* Comm. on the Peaceful Uses of Outer Space, Report of the Scientific and Technical Subcommittee on its fifty-fourth session (Jan. 10-Feb. 10, 2017).

[122] https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf

There could also be issues with "precoveries," i.e., an often-used technique that involves searching through archival data for objects which may have previously missed detection. Such missed detections will be common for faint objects, and precoveries rely on having information about where the object should be within a certain uncertainty. The object might not even be noticeable in a single image, relying instead on combining multiple images to obtain sufficient signal relative to the noise. If large fractions of archival data cannot be searched for faint objects, then this important component of planetary defense could be partially compromised.

Altogether, we do not expect satellite constellations to prevent planetary defense from operating. Rather, satellite constellations risk causing delays in the identification of objects, under certain conditions, which may have widespread ramifications if that object is on an Earth-impact trajectory. This will further affect responses by numerous US government agencies and could delay an internationally coordinated response.

6. Environmental law in space

6.1 The applicability and scope of environmental law in near-Earth orbit

While international law has not settled the definition of 'environment', its protection has been generally evaluated and understood in relation to human quality of life. The International Court of Justice (ICJ) has indicated that "t*he environment is not an abstraction but represents the living space, the quality of life and the very health of human beings, including generations unborn*."[123] With an acceleration of human activities in the near-Earth orbits, there is an increasing recognition that they are also an "environment" impacted by humans[124], and that near-Earth orbits constitute critical infrastructure of importance to the quality of life for humankind.[125]

International environmental law has often, although not always, considered outer space within its scope of application, including in the Brundtland Report,[126] the International Law Commission (ILC) Draft Articles on the Prevention of Transboundary Harm,[127] and the recent International Law

[123] *Legality of the Threat or Use of Nuclear Weapons* (Advisory Opinion) 1996 ICJ Rep 226, para 29. See also the proposal of what became the Stockholm Conference, defining "the human environment" as the "natural surroundings of man", Letter from Sweden to the Secretary General of the UN (20 May 1968) UN Doc E/4466/Add.1, para 2.
[124] Elena Cirkovic, "International Law beyond the Earth System: Orbital debris and interplanetary pollution" (December 2021) 13 *Journal of Human Rights and the Environment* 2.
[125] Eg Space Infrastructure Act, HR 3713, 117th Cong (2021) (US); Endless Frontier Act, S.1260, 117th Cong., §623(a) (2021) (US); Security Legislation Amendment (Critical Infrastructure) Bill 2020 (Cth) sch 1 items 18, 21 (Australia).
[126] World Commission on Environment and Development, *Brundtland Report* (WCED, 1987), ch 10 para 80 (calling debris regulation "clearly overdue").
[127] ILC, 'Draft articles on Prevention of Transboundary Harm from Hazardous Activities, with Commentaries' (2001) UNYBILC 2(2), p. 151 para 10.

Association (ILA) resolution on sustainable development.[128] Space is also considered within the environment in the Partial Test Ban Treaty,[129] and the Environmental Modification Convention.[130]

Analysis of state practice before the OST shows that many states considered the free use of space to be contingent upon its environmental protection.[131] India, the first state to raise space law to the international agenda,[132] considered its function to be preventing "[t]*he possibility that the future of mankind might be jeopardized by a single act of negligence*" by one state.[133] After Project West Ford, the IAU passed a 1961 resolution noting "*the grave danger that some future space projects might seriously interfere with astronomical observations*," emphasizing "*that no group has the right to change the Earth's environment in any significant way without full international study and agreement*".[134] Similarly, in 1963 the *Institut de Droit International* passed a resolution stating that:

> [Space activities] *which may involve a risk of modifying the natural environment of the Earth, of any of the celestial bodies or in space in a manner liable to be prejudicial to the future of scientific investigation and experiment, the well-being of human life, or the interests of another State, necessarily affect directly the interests of the whole international community. The provisions of this resolution should be supplemented by appropriate international arrangements to forestall such risk*.[135]

Industry and popular media from the time similarly rejected a "*United States right unilaterally to make changes in the space environment of this planet*."[136] South African press discussed space traffic management and orbit contamination from 1951,[137] and Indian national newspapers framed

[128] ILA Res 4/2020, 'The Role of International Law in Sustainable Natural Resources Management for Development' (Kyoto, 29 November-13 December 2020), Annex I, para 1.1.
[129] Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, art I, 5 August 1963 480 UNTS 43 (entered into force 10 October 1963).
[130] Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) (signed 10 Dec 1976, entered into force 5 Oct 1978) 1108 UNTS 151, art 2.
[131] UNGA (1st Comm), (6 December 1962) A/C.1/PV.1293, 21-22 (Netherlands) (arguing free use was meaningless if one state could impair the rest's "actual or potential use"); UNGA (1st Comm), (17 December 1966) A/C.1/PV.1492, 47 (Austria).
[132] ICAO (LC) (1956) ICAO Doc A10-WP/30, LE.1, para 157, proposed by Secretary Roy (India).
[133] UNGA (1st Comm), (7 December 1962) A/C.1/PV.1294, 58 (India); UNCOPUOS (LSC), (12 July 1966) A/AC.105/C.2/SR.57, 19 (India).
[134] International Astronomical Union, 'Resolution No. 1' (1961) 6 Proc IAU 4.
[135] Institut de Droit International, ''The Legal Regime of Outer Space' (1963), para 12; see also similar resolutions by the International Union of Radio Science, the International Council of Scientific Unions, and national scientific and astronomical societies in France, Belgium, America, and Britain: Lisa Ruth Rand, 'Orbital Decay: Space Junk and the Environmental History of Earth's Planetary Borderlands' (PhD Dissertation, University of Pennsylvania 2016) 105.
[136] The New York Times, 'More Needles in Space' *The New York Times* (New York, NY, 8 May 1963) 1; Francis Boyd, 'Threat to Space Research: Danger of Contamination' *The Guardian* (London, 17 May 1963) 22; 'Rubbish Round the Earth' *The Guardian* (London, 17 May 1963) 10; 'US Space Needles Criticized by British' *Chicago Tribune* (Chicago, Ill, United States, 17 May 1963) 6; Bernard Lovell, 'The Pollution of Space' (1968) 24 Bulletin of the Atomic Scientists 42.
[137] Editorial, 'More Lunacy' *Rand Daily Mail* (Johannesburg, 5 September 1951) 8.

spaceflight as an environmental issue from 1964.[138] Reflecting on the norms at play in negotiating space law, Eilene Galloway recounted in 1981 that "[i]*deas and concepts for the governance of outer space as a fourth environment — added to land, air and sea — had already been generated long before spacecraft were launched into Earth orbit. Space law was not only for outer space as a separate and distinct spatial area but also for operations performed there for functional uses on the Earth*."[139] This environmental focus continued into the 1990s in the practice of states and scholars alike.[140]

6.2 Applicability of international environmental law principles

Considering that international law compatible with *corpus juris spatialis* is applicable to space activities,[141] it is necessary to address other domains of international law that may be applicable in the context of this issue, namely environmental law.

The principle of preventing transboundary harm put down in the ILC's Draft Articles on the Prevention of Transboundary Harm from Hazardous Activities (ILC PTH) may apply to satellite constellation-related activities, as they are not prohibited by international law (Article 1) and carried out under jurisdiction or control of the State (Article 2). The latter requirement is also consistent with OST norms, since the State of registration of satellites in the constellation will have jurisdiction and control over them.[142] As a result, the government should take all necessary steps to prevent or mitigate damage.[143] This ILC PTH Articles clause is compatible with the principle of due regard in space law,[144] enhancing the potential of its applicability.[145]

Furthermore, when it comes to satellite constellations, experts focus on **the precautionary principle**, which is inscribed in Principle 15 of the 1992 UN Rio Declaration on Environment and Development. The concept implies that even if the severity of a threat is unknown, it is still vital to take action to eradicate it.[146] Recognising the vulnerability of the space environment,[147] as well as the uncertainties associated with transition to a new type of satellite operation in the form of satellite constellations, the

[138] 'Misuse of Outer Space: India Cautions Russia and US' *The Times of India* (Mumbai, 30 March 1964) 6 (on the ozone and atmospheric harms of spaceflight).
[139] Eilene Galloway, 'Perspectives of Space Law' (1981) 9 Journal of Space Law 21, 21.
[140] UNCOPUOS, (1989) A/AC.105/PV.323, 67-68 (Brazil) (on urgent "threats posed to… the preservation of space's environment itself"); Ernst Fasan, 'Technical and Policy Issues Related to the Use of the Space Environment' (1995) 23 J Space Law 89, 91.
[141] Article III OST; CoCoSL I, p. 279.
[142] Article VIII OST.
[143] Article 3 ILC PTH.
[144] Article IX OST.
[145] Munters, Ward. "Small Satellites, Large Constellations and Space Debris: In Dubio Pro LEO?" Commercial Uses of Space and Space Tourism — Legal and Policy Aspects 1, (January 2017): 64-111, p.99.
[146] Sandin, Per. "Dimensions of the Precautionary Principle." Human and Ecological Risk Assessment: An International Journal, V.5 (1999): 889-907, p.898.
[147] See *A/RES/70/82*.

precautionary principle should be applied to inspire appropriate action for safeguarding the space environment.[148]

The next environmental law principle that applies in the present case is **the "polluter pays" principle**, which stipulates that the 'polluter' must pay compensation for the produced damage.[149] Unlike the Convention on International Liability for Damage Caused by Space Objects (the "Liability Convention"), this approach specifically addresses environmental harm caused by activities, making its use to satellites more viable.[150]

The principle of sustainable use supports the use of any resource in such a way as to prevent rapid depletion leading to extinction. The logic behind this principle is that nature's bounty should be used in a controlled way, since it should serve everyone. This principle also supports the idea of intergenerational equity, making resources available to all. The application of the principle of sustainable use to outer space is of great importance in various ways, including with respect to the use of low Earth orbit.[151] In order to minimize the generation of debris, operators may also be asked to limit the launch of components of each space mission to only those that are absolutely necessary,[152] which is also reflected in the Inter-Agency Space Debris Coordination Committee (IADC) approach.

The principles of environmental law discussed here can be extended to both the preservation of the space environment from debris and its light pollution.

6.3 The obligation to conduct an EIA in international law

States have customary obligations to conduct "*due diligence in respect of all activities which take place under the jurisdiction and control*" that risk "*significant transboundary environmental harm*."[153] To determine if an activity risks significant transboundary harm, states must conduct an environmental impact assessment (EIA) *before* the activity.[154] The EIA forms a critical part of due diligence in transboundary environmental contexts.[155] While due diligence is an obligation of conduct and not one

[148] Munters, p.109; see also Preserving the Outer Space Environment: The "Precautionary Principle" Approach to Space Debris Olavo de O. Bittencourt Neto
[149] Stubbe, Peter. State Accountability for Space Debris : A Legal Study of Responsibility for Polluting the Space Environment and Liability for Damage Caused by Space Debris. Brill | Nijhoff, 2018, p.124.
[150] Byers, Michael, Boley, Aaron. "How Elon Musk can help save astronomy." Los Angeles Times, Last modified December 13, 2019, available from https://www.latimes.com/opinion/story/2019-12-13/spacex-elon-musk-starlink-satellites, 2019.
[151] Elena Cirkovic, "The Next Generation of International Law: Space, Ice, and the Cosmolegal Proposal" (March 2021) 21 German law journal Volume 2.
[152] B. Sandeepa Bhat. (2014). Application of Environmental Law Principles for the Protection of the Outer Space Environment: Feasibility Study. Annals of Air and Space Law, 39, 323-354
[153] *Case Concerning Pulp Mills on the River Uruguay (Argentina v Uruguay)* (Judgment) [2010] ICJ Rep 14, para 197.
[154] *Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua)* (Judgment) 2015 ICJ Rep 665 ('San Juan River'), para 104.
[155] *Pulp Mills*, para 204; IACtHR, *Indigenous Community Members of the Lhaka Honhat (Our Land) Association vs. Argentina* (6 February 2020), para 208.

of result, states must enact their due diligence obligations in "*not only the adoption of appropriate rules and measures, but also a certain level of vigilance in their enforcement and the exercise of administrative control applicable to public and private operators*."[156]

According to the ICJ, "*the general obligation of States to ensure that activities within their jurisdiction and control respect the environment of other States or of areas beyond national control is now part of the corpus of international law relating to the environment*."[157] While the ICJ was originally referring to "industrial activities" as engaging this obligation, they have since broadened it to encompass any activity which may have a significant risk of transboundary environmental harm.[158] The harm involved must be "*caused to persons, property or the environment*,"[159] and is assessed by "*a factual determination*" of measurable, 'real' detrimental effects to "*for example, human health, industry, property, environment or agriculture in other States*."[160]

Despite its name, transboundary harm "*includes, in addition to a typical scenario of an activity within a State with injurious effects on another State, activities conducted under the jurisdiction or control of a State, for example, on the high seas, with effects on the territory of another State or in places under its jurisdiction or control*."[161] International courts approach harm beyond national jurisdiction and in transboundary contexts in the same way.[162] This obligation requires states to conduct due diligence to prevent transboundary harm, and thus to conduct an EIA, for activities within their jurisdiction and control.[163] In the ILC's words, "*the intention is to be able to draw a line and clearly distinguish a State under whose jurisdiction and control an activity covered by these articles is conducted from a State which has suffered the injurious impact*."[164] States explicitly "retain" jurisdiction and control over their space objects, and therefore activities after registration.[165]

The obligation to conduct an EIA particularly applies where the activity risks harm to a "shared *resource*".[166] The WTO has qualified the word "resource" in international law as "not 'static' in its

[156] *Pulp Mills*, para 197.
[157] *Legality of the Threat or Use of Nuclear Weapons* (Advisory Opinion) 1996 ICJ Rep 226, para 29.
[158] *San Juan River*, para 104, citing *Pulp Mills*, para 204.
[159] ILC, 'Prevention of Transboundary Harm from Hazardous Activities' (2001) UN Doc A/56/10 ('ILC Draft Articles'), art 2(b).
[160] ILC, 'Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, with Commentaries' (2001) UNYBILC 2(2) ('ILC Commentary'), p. 150 para 6, p. 152 para 4.
[161] ILC Commentary, p. 153 para 9.
[162] *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area* (Advisory Opinion of 1 February 2011) ITLOS Reports 2011, 10, para 148.
[163] Ibid.
[164] ILC, 'Draft articles on Prevention of Transboundary Harm from Hazardous Activities, with Commentaries' (2001) UNYBILC 2(2), p. 153 para 9.
[165] OST, art VIII.
[166] *Pulp Mills*, para 204.

content or reference but is rather 'by definition, evolutionary'."[167] Orbits associated with radio frequencies, and perhaps low Earth orbits, are limited natural resources.[168]

6.3.1 Specific contents of an EIA

States may determine the specific contents and procedure of EIA on a case-specific basis,[169] but ICJ practice and soft law guidelines inform the bare elements an EIA should include. The ICJ includes:[170]

- "*the nature and magnitude of the proposed development*".
- "*its likely adverse impact on the environment*".
- "*the need to exercise due diligence in conducting such an assessment*."

Meanwhile, per the United Nations Environment Programme (UNEP) Guidelines overwhelmingly approved by the United Nations General Assembly, EIAs "*should include, at a minimum*:

> *(a) A description of the proposed activity;*
> *(b) A description of the potentially affected environment, including specific information necessary for identifying and assessing the environmental effects of the proposed activity;*
> *(c) A description of practical alternatives, as appropriate;*
> *(d) An assessment of the likely or potential environmental impacts of the proposed activity and alternatives, including the direct, indirect, cumulative, short-term and long-term effects;*
> *(e) An identification and description of measures available to mitigate adverse environmental impacts of the proposed activity and alternatives, and an assessment of those measures;*
> *(f) An indication of gaps in knowledge and uncertainties which may be encountered in compiling the required information;*
> *(g) An indication of whether the environment of any other State or areas beyond national jurisdiction is likely to be affected by the proposed activity or alternatives;*
> *(h) A brief, non-technical summary of the information provided under the above headings*.[171]

The standard of review required by EIAs is proportional to the harm's risk and severity, and varies with new scientific, technological, or factual understandings.[172] In many jurisdictions, EIAs must include public announcement, consultation, and/or participation to satisfy procedural environmental rights to environmental information, public participation in decision-making, and access to justice. Regional standards from Europea, Latin America, and the Caribbean define this group as "*the public affected or*

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[167] WTO, *United States-Shrimp, India and ors v United States — Report of the Appellate Body* (12 October 1998) WT/DS58/AB/R, para 130.
[168] Constitution of the ITU as amended by the 1998 Plenipotentiary Conference (signed 22 December 1992, entered into force 1 July 1994), art 44(2).
[169] *San Juan River*, para 104.
[170] *Pulp Mills*, para 205.
[171] Decision 14/25 of the Governing Council of UNEP, 'Goals and Principles of Environmental Impact Assessment' (17 June 1987) UN Doc UNEP/GC/DEC/14/25, approved by UN General Assembly Resolution 42/184 (11 December 1987) (1987), approved with 149 votes in favor, 1 against.
[172] *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area* (Advisory Opinion of 1 February 2011) ITLOS Reports 2011, 10, para 117.

likely to be affected by, or having an interest in, the environmental decision-making; for the purposes of this definition, non-governmental organizations promoting environmental protection and meeting any requirements under national law shall be deemed to have an interest."[173] Some formulations stress that these rights must be provided "*without discrimination as to citizenship, nationality or domicile and, in the case of a legal person, without discrimination as to where it has its registered seat or an effective centre of its activities*."[174]

6.4. Unresolved issues for environmental law in space

States are obliged to prevent transboundary harm, ensure due diligence, and conduct EIAs — but even on the international level it is unclear to whom these obligations are owed, and who could claim their breach.

Generally, "*damage to the environment, and the consequent impairment or loss of the ability of the environment to provide goods and services, is compensable under international law*."[175] But in the space context, this becomes ambiguous.

Valuation is not prescriptive, but case specific.[176] Once "*a direct and certain causal link*" between the environmental damage and the state's activities is established,[177] it evaluates two key criteria:

- The price of restoration,[178] which "*accounts for the fact that natural recovery may not always suffice to return an environment to the state in which it was before the damage occurred. In such instances, active restoration measures may be required in order to return the environment to its prior condition, in so far as that is possible*."[179]
- The value of "*the impairment or loss of environmental goods and services prior to recovery*."[180]

Applying these principles to orbit results in two unresolved issues. First, if calculated according to ICJ practice, compensation for damage to an orbital resource might be valued exorbitantly because of the difficulty of repair, or not at all because of the difficulty of establishing direct causation. Moreover, "[w]*here damage is irreparable for physical, technical or economic reasons*," as is currently the case for space debris, "*additional criteria should be made available for the assessment of damage*. Impairment of use, aesthetic and other non-use values, *domestic or international guidelines*, intergenerational

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[173] Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (signed 25 June 1998, entered into force 30 October 2001) 2161 UNTS 447, art 2(5); Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (signed 4 March 2018, entered into force 22 April 2021).
[174] Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (signed 25 June 1998, entered into force 30 October 2001) 2161 UNTS 447 ('Aarhus Convention'), art 3(9).
[175] *San Juan River* (Judgment on Compensation) 2018 ICJ Rep 15, paras 41-42.
[176] Ibid., para 52.
[177] Ibid., para 72.
[178] Ibid., para 53.
[179] Ibid., para 43.
[180] Ibid., para 53.

equity, *and* generally equitable assessment *should be considered as alternative criteria for establishing a measure of compensation*."[181] This would support the relevance of aesthetic and intergenerational impacts of satellite constellations to the night sky as part of the assessment of compensation for transboundary environmental harm.

7. Private actors and non-governmental entities

Private actors and non-governmental entities can constitute non- and para-governmental organizations, multinational enterprises, individuals, and groups of individuals, in particular indigenous peoples and minorities.

This section will focus on the role of industry in the outer space sector and look at the interplay among private enterprise as "private actors"/"non governmental entities" in relation to other non-governmental entities in international law, corporate social responsibility (CSR), environmental protection in outer space, and current developments such as the space sustainability rating (SSR) mechanism.

This report's primary concern is the international legal regime applicable to outer space. In the sphere of corporate governance, national space legislation provides direct instruments for implementation of international legal obligations arising from space treaties and general international law at the domestic level vis-a-vis private entities. This concerns the OST, the 1972 Liability Convention and the 1975 Registration Convention. For this reason, part of this section will also elaborate on the interplay between corporate governance and supranational regulatory regimes.

Considering, that private entities are carrying out activities in outer space, and; recognising that international space law has not dealt with the specifics of private actors in outer space, which includes the commercialization and privatization of space; this section addresses the extent to which international legal obligations of States arising from space treaties and general international law can apply to public and private corporations.

Recognising that private enterprise is not directly bound by public international law, States have obligations in international law and liability for space activities and actors in outer space.

The corporation as a legal entity is the main form of organization for large, capital-intensive businesses. It is a dominant form for organizing businesses ranging from small entrepreneurial activities where one person is the sole shareholder, the board and the only employee, to large, multinational entities. As a separate legal entity, the corporation allows for capital from many different

[181] Institut de Droit International, 'Responsibility and Liability under International Law for Environmental Damage' (Strasbourg, 4 September 1997), art 25 (emphasis added).

investors to be channeled to risky business ventures that otherwise might not receive financing. This makes it possible for investors to limit their liability to the creditors of the business while having a legitimate expectation of returns, typically through dividends or sale of the shares to other investors. The raising of capital and selling of shares is coordinated, both domestically and across borders, through modern stock exchanges.

In discussing the role of a corporation, "shareholder primacy"[182] should be distinguished from the legal norm denoted shareholder value. Shareholder value is a legal term, shareholder primacy is not. Stakeholders are defined as "*any group or individual who can affect or is affected by the achievement of the firm's objectives"*[183]

Company law rules cover issues such as the formation, capital and disclosure requirements, and operations (mergers, divisions) of companies.[184] Corporate governance is the broader, balancing of interests with stakeholders (for e.g.).[185] The definition and interpretation of "governance" applicable to this discussion includes any form of collective action taken to manage the common affairs of society and occurs as intentional and self-organized interactions among governments, private groups, and formal and informal institutions. This includes the "voluntary codes of conduct", which are non-legislated commitments, voluntarily made by companies. In relation to outer space sustainability, self-regulation and voluntary codes of conduct can consider the CSR principle. The concept of CSR derives from existing corporate legal and governance structures as well as legal regimes on environmental protection and climate governance. The corporation is not inherently geared towards unsustainability or sustainability.[186] As the number of private actors in outer space, transnational regulation becomes relevant as it includes all law which regulates actions or events that transcend national frontiers. Both public and private international law are included, as are other rules which do

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[182] See, for instance, the Berle-Dodd debate in corporate law: A. A. Berle, 'Corporate Powers as Powers in Trust' 44 Harvard Law Review, 1049-74; E. M. Dodd, 'For Whom Are Corporate Managers Trustees?' 45 ibid 1145-63; A. A. Berle, 'For Whom Are Managers Trustees: A Note' ibid 1365-72. See also, Gary Herrigel, Guest Editor's Introduction: A New Wave in the History of Corporate Governance, 8(3) Enterprise and Soc. 475 (2007); and Corporate Governance, in The Oxford Handbook of Business History 470 (Geoffrey Jones & Jonathan Zeitlin eds., 2009)l Nicholas Foster, Company Law Theory in Comparative Perspective: England and France, 48 Amer. J. of Com. L. 573 (2000); Norbert Reich, Die Entwicklung des Deutschen Aktienrechts im Neunzehnten Jahrhundert (The development of the German Stock Corporation Law in the Nineteenth Century), IUS Commune II (1969), available at: http://data.rg.mpg.de/iuscommune/ic02_reich.pdf; Udo Braendle, Shareholder Protection in the USA and Germany — On the Fallacy of LLSV (German Working Papers in Law and Economics Paper No. 18, 2006), available at: http://www.bepress.com/gwp/default/vol2006/iss1/art18/; Mathias Siems, Legal Origins: Reconciling Law & Finance and Comparative Law, 52 McGill L. J. 55 (2007)

[183] R.E. Freeman, Strategic Management: A Stakeholder Approach (Boston: Pitman, 1984), at 46.

[184] Pistor, Katerina, Yoram Keinan, Jan Kleinheisterkamp & Mark West, The Evolution of Corporate Law: A Cross-Country Comparison, 23 U. Pa. J. Int'l. Econ. L. 791 (2002).

[185] See, generally on this understanding, M. Gelter, 'Taming or Protecting the Corporation? Shareholder-Stakeholder Debates in a Comparative Light' 7 NYU Journal of Law & Business, 641-730, p. 686ff.; M. Höpner, Wer beherrscht die Unternehmen? Shareholder Value, Managerherrschaft und Mitbestimmung in Deutschland (Campus Verlag, Frankfurt am Main 2003).

[186] A. Beckers, Enforcing Corporate Social Responsibility Codes: On Global Self-Regulation and National Private Law (Hart Publishing, Oxford 2015); See for instance, WBCSD Corporate Social Responsibility: Making Good Business Sense, World Business Council for Sustainable Development, Geneva, 2000.

not wholly fit into such standard categories.[187] This means also a consideration of activities by transnational corporations, which are any corporations that are registered and operate in more than one country at a time; also called a multinational corporation. A transnational, or multinational, corporation has its headquarters in one country and operates wholly or partially owned subsidiaries in one or more other countries. The subsidiaries report to the central headquarters.[188]

For the purpose of this report, this section refers to the definition of sustainability as a state where the needs of the present generation are met "*while safeguarding Earth's life-support system, on which the welfare of current and future generations depends*".[189] The adoption of the United Nations Sustainable Development Goals (SDGs) has given new impetus to the debate on how to achieve sustainability, including in business and finance.

7.1 Corporate governance and outer space law

States have duties under Article VI OST with respect to private space activities. These duties include:

- The international accountability of the relevant State for private space actors' activities;
- A requirement on State Parties to implement and enforce the provisions of the Treaty vis-á-vis private enterprise and private involvement in space activities;
- A fundamental duty to provide for authorisation and continuing supervision of private space activities.

Article VII OST holds the launching State internationally liable for damage caused by its satellite (or the one belonging to its private company) to another State Party to the Treaty. The matter of payment to the injured State of compensation for the damage is left to the domestic law of the launching State. Domestic laws of some States provide for liability arrangements between the State and private entities concerned in cases where a State might be held liable to pay compensation for damage caused by a satellite of a private space company. Often, there are regulatory mechanisms for reimbursement to the State by the concerned private company as per the State national (domestic) space law, mainly through a regulatory process related to licensing of private space companies.

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[187] Philip Jessup, Transnational Law (New Haven: Yale University Press, 1956), pages 1-8. On the history of Lex Mercatoria see Claire Cutler, Private Power and Global Authority, Transnational Merchant Law in the Global Political Economy (Cambridge University Press), and on the global corporate culture and practice the seminal, John Braithwaite and Peter Drahos, Global Business Regulation (Cambridge University Press 2000); Wai, Robert. "Transnational Liftoff and Juridical Touchdown: The Regulatory Function of Private International Law in an Era of Globalization." Columbia Journal of Transnational Law 40.2 (2002): 209-274; Sjajfel, B. Sustainable Value Creation Within Planetary Boundaries — Reforming Corporate Purpose and Duties of the Corporate Board Sustainability 2020, 12(15), 6245; https://doi.org/10.3390/su12156245; "Corporate Social Responsibility in Outer Space" (2021) Space Watch Global https://spacewatch.global/2021/03/spacewatchgl-opinion-corporate-social-responsibility-in-outer-space/

[188] See, e.g., the Draft United Nations Code of Conduct on Transnational Corporations, UN Doc. E/C.10/1982/6, 5 June 1982 (revised UN Doc. E/1983/17/Rev.1); UN Guiding Principles on Business and Human Rights 2011 (A/HRC/17/31) endorsed by the UN Human Rights Council on 6 July 2011 (A/HRC/RES/17/4).

[189] Elena Cirkovic, "International Law beyond the Earth System: Orbital debris and interplanetary pollution" (December 2021) 13 Journal of Human Rights and the Environment 2.

The incentives to States to provide for authorisation and continuing supervision of private space activities fall under international law as follows:

Article VIII provides for the best way for a State to establish a national registry for relevant space objects and thus further ensuring jurisdiction and control over such space objects and the operators thereof on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body.

Article VIII OST and the Registration Convention provide incentives for laws governing corporate activities in outer space (not only promoting commercialisation), but also to ensure ongoing State jurisdiction and control over operators and space objects thereof.

From the liability requirements an indirect incentive arises for an inclusion of licensing systems to be established by national space laws and requirements for insurance to be taken by relevant licensees.

The Liability Convention imposes absolute liability on the launching state(s) for terrestrial damage from space objects. In addition, the launching state(s) of space objects, including debris, that collide with other space objects and cause damage can be found liable following a showing of negligence. See Convention on International Liability for Damage Caused by Space Objects (1972), art IV, 24 UST 2389, 2393 (1973).

7.2. Addressing the public-private distinction

There is no clear public-versus-private distinction between the state and business. In some instances, states and other public bodies are directly involved in business, notably as controlling shareholders and as institutional investors. Conversely, there are prominent cases of strong corporate influence and outright corporate capture of legislation and of regulatory enforcement.[190]

Recognising that there is no company law in any jurisdiction that promotes companies as a business form based on the assumption that this will maximize returns to shareholders to the detriment of society, [191] corporate entities can also have a duty to contribute to sustainability. This suggests the need for further discussion of the systemically entrenched barrier posed by shareholder primacy to

[190] M. J. Horwitz, 'The History of the Public/Private Distinction' 130 University of Pennsylvania Law Review, p. 1426: “Paralleling arguments then current in political economy, they [legal realists, AB] ridiculed the invisible-hand premise behind any assumption that private law could be neutral and apolitical. (…)”.

[191] This section refers to the information presented by Elena Cirkovic, Minoo Rathnasabapathy, Danielle Wood, Kristi Acuff,and Simon Potter “Sustainable orbit and the Earth System: mitigation and regulation” (2021) Conference Proceedings, European Space Agency ESA/ESOC : 8th European Conference on Space Debris (2021).

corporate sustainability and to the contribution of business to sustainability by informing the externalization of societal impacts across global value chains.

While especially strong in listed companies, shareholder primacy affects also non-listed companies, and has knock-on effects on other business forms. Over two-thirds of trade now takes place through global value chains.

7.3 Corporate social responsibility[192]

The LTS Guideline C.4 aims to "*Raise awareness of space activities*" which includes both the "*awareness of the important societal benefits of space activities*" and "*of the consequent importance of enhancing the long-term sustainability of outer space activities*". To this end, the States should raise awareness about national and international policies, legislation, regulations and best practices applicable to space activities among non-governmental entities as well. The LTS Guidelines do not identify or define the nature of non-governmental activities, but rather emphasize the need for best practices. Other existing supranational Guidelines include OECD Guidelines for Multinational Enterprises, together with the United Nations Guiding Principles for Business and Human Rights. In addition, the ISO 26000 is intended to "*assist organizations in contributing to sustainable development*." It encourages "*compliance with law*" as a fundamental duty of any organization and an essential part of their "*social responsibility*". As cases such as *Eutelsat S.A. v. United Mexican States* (ICSID Case No. ARB(AF)/17/2) demonstrate, there is an ongoing need for better clarification of corporate conduct in outer space.

Despite the image of private actors' operations beyond or outside of State regulation (or jurisdiction), States act as important facilitators of movement of transnational, global, and now seemingly extra-terrestrial corporate interests.

There is a need for better identification of the needs and objectives of various space agencies and their possible participation in a discussion on sustainable corporate governance. This includes topics such as: due regard for stakeholder interests; inclusion of issues such as human rights; and environmental pollution (including the Earth system, the orbit, and interplanetary contexts). Further to this, there is a need for mitigation of corporate and financial risks of current and potential unsustainability, e.g., for an increase in orbital debris.

An international regulatory framework for sustainable uses of outer space would apply also to all undertakings in outer space. Sustainable value creation is an emerging concept in corporate law and

[192] Porter, M. E. and M. R. Kramer "Strategy and Society: The link between competitive advantage and corporate social responsibility" (2006) Harvard Business Review (December): 78-92.

corporate governance.[193] An estimation of impacts on stakeholders and the environment needs a clarified duty of care and the due diligence duty. These would be expected to have positive impacts on stakeholders and the environment, including in the supply chain.[194] CSR is likely to contribute to the long-term success of an enterprise. A CSR approach to outer space activities can bring benefits in terms of risk management, cost savings, access to capital, customer relationships, human resource management, and innovation capacity. It encourages more social and environmental responsibility from the corporate sector.

As specified in this section, “Voluntary Codes of Conduct”[195] range from broader declarations of business principles applicable to international operations, to more substantive efforts at self-regulation. They tend to focus on the social conditions and the environment. A variety of stakeholders, including international trade union organizations, development and environmental NGOs, and the corporate sector itself have all played a role in the elaboration of codes of conduct for international business.

For instance, the World Economic Forum has chosen a team led by the Space Enabled research group at the MIT Media Lab together with a team from the European Space Agency (ESA) to launch the Space Sustainability Rating (SSR), a concept developed by the Forum’s Global Future Council on Space Technologies.[196] As stated in the World Economic Forum press release:

> *The new Space Sustainability Rating (SSR) has been developed to reduce space debris and help ensure that rapidly increasing space missions are managed safely and sustainably.*

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[193] European Commission, IP/11/469 Brussels, 13 April 2011 Twelve projects for the 2012 Single Market: together for new growth https://ec.europa.eu/commission/presscorner/detail/en/IP_11_469

[194] Sjåfjell, B. Sustainable Value Creation Within Planetary Boundaries—Reforming Corporate Purpose and Duties of the Corporate Board. Sustainability 2020, 12, 6245. https://doi.org/10.3390/su12156245; The European Parliament. Access to Legal Remedies for Victims of Corporate Human Rights Abuses in Third Countries. 2019. Available on-line: www.europarl.europa.eu/RegData/etudes/STUD/2019/603475/EXPO_ STU(2019)603475_EN.pdf.

[195] The ILO Tripartite Declaration of Principles Concerning Multinational Enterprises and Social PolicyóTen Years After, ILO, Geneva, 1989; Overview of Global Developments and Office Activities Concerning Codes of Conduct, Social Labelling and other Private Sector Initiatives Addressing Labour Issues, Working Party on the Social Dimensions of the Liberalization of International Trade, GB.273/WP/SDL/1(rev1) ILO, Geneva, 1998; OECD Codes of ConductóAn Expanded Review of their Contents, OECD Working Party of the Trade Committee, TD/TC/WP(99)56/FINAL, Paris, 2000. See, G. Teubner, 'Self-constitutionalizing Transnational Corporations? On the Linkage of “Private” and “Public” Corporate Codes of Conduct' 18 Indiana Journal of Global Legal Studies, 17-38; M. Herberg, 'Global Legal Pluralism and Interlegality: Environmental Self-Regulation in Multinational Enterprises as Global Law-Making' in O. Dilling, M. Herberg and G. Winter (eds.), Responsible Business Self-Governance and Law in Transnational Economic Transactions (Hart Publishing, Oxford 2008), 17-40;

[196] Rathnasabapathy, Minoo, Danielle Wood, Francesca Letizia, Stijn Lemmens, Moriba Jah, Aschley Schiller, Carissa Christensen, Simon Potter, Nikolai Khlystov, Maksim Soshkin, Kristi Acuff, Miles Lifson, Riley Steindl. Space Sustainability Rating: Designing a Composite Indicator to Incentivise Satellite Operators to Pursue Long-Term Sustainability of Space” 71st International Astronautical Congress (IAC) — The CyberSpace Edition, 12-14 October 2020.

SSR will score space missions based on markers such as evidenced-based debris mitigation and alignment with international guidelines.
EPFL Space Center (eSpace) has been chosen to lead and operationalize the SSR. It will begin issuing sustainability certifications to mission operators in early 2022

The SSR aims to promote mission designs and operational concepts that avoid an unhampered growth in space debris. It promotes a future where environmental review would be taken into consideration during the early stages of design and development. The SSR concept intends to create a voluntary system of regulation that still operates based on “encouragement”. Arguably, an additional framework for CSR in space would facilitate such initiatives and induce compliance.

Given the exponential increase in objects in space over recent years, coupled with both an expected growth in large constellations of satellites and an increase in the number of commercial and government space actors, a significant challenge is posed to current and future operations in the space environment.[197]

The SSR aims to provide a standardized and flexible tool for measuring the degree of sustainability of a mission, consequently incentivising mission design compatible with sustainable and responsible operations, and motivating in-orbit operations that reduce potential harm to the orbital environment and impact on other operators.[198]

The design methodology used for the SSR and in consultation with multiple stakeholders resulted in the first iteration of the SSR incorporating six modules. These six modules were based on key related decisions faced by space operators in all phases of the mission and include design, in-orbit operation, and end-of-life phases.

As part of the SSR, mission operators are evaluated on mandatory or voluntary adoption of internationally recognised design and operations standards towards safe and sustainable operations in the space environment. The Design and Operations Standards module of the SSR consists of a questionnaire whereby applicants are awarded for mandatory adoption (points gained that impact the SSR baseline tier) and voluntary adoption (bonus points that impact the bonus SSR). The scoring methodology used in the module aims to find a balance between discouraging the selection of looser regulatory regimes and recognising behaviors that go beyond minimal requirements.

[197] Minoo Rathnasabapathy et al, “Space Sustainability Rating: Towards An Assessment Tool To AssuringThe Long-Term Sustainability Of The Space Environment”. IAC 2019
[198] The rest of the section refers to, Elena Cirkovic, Danielle Wood, Minoo Rathnasabapathy, Kristi Acuff, and Simon Potter “Sustainable orbit and the Earth System: mitigation and regulation” (2021) Conference Proceedings, European Space Agency ESA/ESOC : 8th European Conference on Space Debris (2021).

The SSR Design and Operations Standards modules consider the adoption and/or tailoring of the following:

- Space debris mitigation guidelines (e.g. IADC).
- UN COPUOS Long-Term Sustainability guidelines.
- Space debris mitigation standards or verifiable laws (e.g. ISO, FSOA).
- Standardized operational products (e.g. CCSDS).
- In case of close proximity or rendezvous operations: relevant safety standards (e.g. CONFERS).

Additional questions in the module also request information from the SSR applicant regarding:

- The release of debris in orbit from the satellite or launcher;
- The probability of explosion;
- The ability of the satellite to be passivated after its operational lifetime;
- The use of disposal orbit after end of operations for spacecraft and launch vehicle upper stage;
- A commitment to registering payload and associated objects with COPUOS's Register of Objects Launched into Outer Space.

8. Societal impacts

8.1 Satellite constellations and dark skies

Astronomy is recognised as being one of the oldest of all the natural sciences[199], and inhabitants of the Earth have consulted the night skies in search of knowledge and inspiration since antiquity. Following such a shared common heritage has come not only scientific discovery, with the development of the field of astronomy, but also innumerate cultural and societal factors centered around a shared experience of the stars and humankind's place in the universe.

Satellite constellations in their number and magnitude present an indiscriminate threat to this experience of the night sky in all parts of the world. The very nature of the problem is of a planetary scale. The scale is such that the impacts will be seen not only over urban areas, already affected by local light pollution, but impacts all latitudes and night sky environments on Earth. In scale and breadth this is an unprecedented change to the status of global night skies; while urban artificial light at night may make a greater difference to night skies within a local radius, satellite constellations will be seen by those in dark sky oases, by those in remote communities, and by those who may have little investment in space technology but maintain a long-standing cultural relationship with the stars.

[199] UN General Assembly, A/RES/62/200, International Year of Astronomy

8.2 Dark skies and multiple stakeholders

Recognising the findings of the Community Working Group SatCon2 Report[200] , it is critical to refer to the plurality of interests among global and local stakeholders, in addition to States. This includes, *inter alia*, a recognition of different sources of knowledge on and the significance of uninterrupted night skies, a shared global heritage of astronomy, navigation, and other practices including religious and cultural considerations.

8.2.1 Dark skies and access to science: heritage and cultural rights, and other stakeholders

Night skies for astronomy are a resource to all humanity, and the net of stakeholders in astronomical skies is far wider than only that of professional astronomy. The permanent loss of practicable scientific astronomy to global communities can therefore also affect heritage and cultural rights, which are protected under international law.

Some societal stakeholders outside of the professional astronomical community include amateur astronomers and astrophotographers. Amateur astronomers are numerous in countries worldwide and include amongst their number both hobbyists and students of astronomy. The field of art and astrophotography invites many with limited or very specific resources to enjoy the night skies, and astrophotography in particular is almost as sensitive to light trail corruption as wider-recognised astronomical data are in practice. In local and national context with limited economic resources, casual observation and astrophotography are of potential cultural as well as scientific significance.

While scientific investigation will be impacted by a range of satellite brightness levels, casual observations and astrophotography are primarily affected by naked-eye constellation scenarios. As noted in SATCON-1, while there are presently no known plans to build a large-scale naked-eye constellation, there is also currently no technical or legal barrier to building one in the future. Meanwhile, existing plans for satellite constellations do include naked-eye satellite scenarios about launch and twilight; short 'flares' from satellites will also impact astro-photographers working with long exposure times.

The impacts of satellite constellations may also be felt inequitably across the global professional astronomical community. In practice, stakeholder conversations about available capacity to process corrupted data may be biased towards organizations with more resources, which is not necessarily reflective of the capabilities of the worldwide net of astronomical stakeholders.

Under such satellite constellation scenarios, these global societal stakeholders in the night sky face an unmitigable obstruction of the continued practice of their astronomical ventures. Recent debates around the impacts of satellite constellations consider end-based correction as part of a working

[200] https://noirlab.edu/public/products/techdocs/techdoc033/ — https://doi.org/10.5281/zenodo.5608820

solution for light trail mitigation. SATCON-1, for example, recommends that observatories support software application development for satellite tracking and avoidance, and recommends that they take efforts to reduce the impact through image post-processing and precise shutter closure timing. Wider societal stakeholders might not have sufficient facilities or funding to practise such measures. In this way, it is therefore important to consider satellite constellation impacts in the context of unequal and underrepresented consequences for a diverse global range of societal stakeholders in the night sky.

8.2.2 Indigenous peoples' rights in international law

We recognize the applicability of indigenous rights protection in general international law, including relevant international declarations and treaties. For instance, Article 8 parentheses 2(a) and (b) of the United Nations Declaration of the Rights of Indigenous Peoples (2007) requires states to provide "*effective mechanisms*" to prevent any action which aims or has the effect of "*depriving them of their cultural integrity as distinct peoples*" or "*dispossessing them of their lands, territory or resources*".

Article 32 (2) of the Declaration states that states should consult with the people in order to obtain their free, prior, and informed consent before undertaking projects "*affecting their lands, territory and other resources, particularly in connection with development, utilization, or exploitation of minerals, water, or other resources*''. And further, Article 4 (1) of the United Nations International Labour Organization Convention (No. 169) (1989) requires states to adopt measures to safeguard indigenous and tribal peoples' property, cultures, and environment. Article 6, 1(a) requires states consult with indigenous and tribal peoples and their representatives "*whenever consideration is being given to legislative or administrative measures which may affect them directly*" and states in Article 6, 2 (pp. 117–118) that such consultation must have "*the objective of obtaining indigenous and tribal peoples' agreement or consent to the proposed measures*".

The UN Special Rapporteur on Indigenous Peoples' Rights has found that "*free, prior and informed consent is essential for the protection of human rights of indigenous peoples*" (see the Report of the Special Rapporteur on the Situation of Human Rights and Fundamental Freedoms of Indigenous Peoples, UN Doc. E/CN/4/2003/90, 21 January 2003, p. 2). The opinion of the Special Rapporteur finds support in a resolution passed by the United Nations General Assembly of the World Conference on the Rights of Indigenous Peoples (22 September 2014). Paragraph 3 of the aforesaid resolution states:

> *We reaffirm our support for the United Nations Declaration on the Rights of Indigenous Peoples, adopted by the General Assembly on 13 September 2007, 2 and our commitments made in this respect to consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free, prior and informed consent before adopting and implementing legislative or administrative measures that may affect them, in accordance with the applicable principles of the Declaration*. (UN Doc. A/RES/69/2)

Indigenous Peoples, who possess deep and diverse cultural, religious, and historical relationships with the night sky, number among the global range of societal stakeholders invested in uncorrupted dark skies and should therefore be taken into consideration in accordance with these rights under international law.

9. Conclusions

From the analysis of international space law documents, in particular the OST, and the relevant discussions in international fora involving astronomical activities (e.g. COPUOS), it is reasonable to affirm that astronomy constitutes a legitimate form of accessing, exploring, and using outer space. Accordingly, as legitimate forms of exploration and use of outer space, balance and coordination must be found between both astronomical observations and satellite activities.

It has been noted that general freedom exists to access space and that its exploration and use constitute provinces of all humankind. However, these freedoms are not absolute, and must find a limit in the freedoms exercised by other actors.

To this end, as described by this report, there is a list of regulatory tools that with correct application allow correct international coordination in the exploration and sustainable use of outer space. These are not limited to international space law instruments. As noted, international space law constitutes a minor branch of a broader system of international law, which also pertains to outer space and can be applied according to Article III OST. Examples detailed in this report include principles of international environmental law, such as the precautionary principle, the "polluter pays" principle, the prevention of transboundary harm, and the principle of sustainable use. Given current awareness of the risks associated with uncontrolled satellite constellation activities, these principles should be applied to activities in outer space, and particularly to those taking place in LEO.

It is a duty of States, with an international responsibility to authorize and continually supervise national activities, to apply these principles for the complete duration of satellite activities. States must also have regard to the on-orbit operational phases of satellite operations and the potential impact they may have on the environment and society. Indeed, the potential impact of satellite constellations is limited not only to the astronomical community, but affects to a wider extent humanity at large who are global stakeholders in the shared natural environment of the night sky.

To conclude, States are responsible for guiding private actors to ensure responsible and sustainable use of space. Still, also and foremost, they are responsible for their compliance to international law and principles through the imposition of relevant requirements for the authorisation and supervision of space activities, as will be further addressed in the following chapter.

Appendix A. Definitions

- **Corporation:** The corporation as a legal entity is the main form of organization for large, capital- intensive businesses. It can be private owned, state owned, or a hybrid. Corporate law culture varies historically.[201]
- **Corporate Social Responsibility:** Corporate social responsibility concerns actions by companies over and above their legal obligations towards society and the environment. Certain regulatory measures create an environment more conducive to enterprises voluntarily meeting their social responsibility.[202]
- **Conjunction:** a close approach between two orbital bodies, such as two satellites or a satellite and piece of debris.
- **Collision:** when two or more orbital bodies make damaging physical contact.
- **Interference:** in the context of telecommunications, a term applied to the undesirable superposition of two or more radiofrequency signals in a receiver.[203] [204]
- **Environmental impact assessment (EIA):** “a national procedure for evaluating the likely impact of a proposed activity on the environment.”[205] The contents of an EIA are not defined under binding international law, but soft law provides that it “*should include, at a minimum:*

  (a) A description of the proposed activity;

  (b) A description of the potentially affected environment, including specific information necessary for identifying and assessing the environmental effects of the proposed activity;

  (c) A description of practical alternatives, as appropriate;

[201] Pistor, Katerina, Yoram Keinan, Jan Kleinheisterkramp & Mark West, The Evolution of Corporate Law: A Cross-Country Comparison, 23 U. Pa. J. Int'l. Econ. L. 791 (2002).

[202] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A renewed EU strategy 2011-14 for Corporate Social Responsibility/* COM/2011/0681 final */ https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0681

[203] Cambridge Dictionary of Space Technology, pg 182.

[204] See Dean Rusk, *Progress in outer space negotiations exceptional,* US Declassified Documents on-line, July 23, 1966, at 3, *available at* Gale USDDO CK2349173357, accessed 10/18/2021: “Contamination is to be understood as a type of harmful interference with experiment or other activities. Thus consultation procedures would apply to both.” See also UNGA 'Report of the COPUOS' (13 Nov 1964) UN Doc A/5785: "There are a variety of ways in which man can alter the conditions in the upper atmosphere, and the degree of such alteration can obviously vary over a wide range. Some such effects are merely detectable, and are probably not ‘potentially harmful’, while there are other changes that cause interference with future experiments that can be considered as harmful in other ways. In order to discuss the vastly different effects that could be caused by injections of chemicals into the upper atmosphere, it has been convenient to distinguish between four classes of effects, which are:
(a) A harmless, short-term and localized alteration of the upper atmosphere that can be readily observed at the ground;
(b) A long-term and world-wide alteration of the observable characteristics of the upper atmosphere, but one which causes no identifiable interference or harmful effect;
(c) An extensive alteration of the upper atmosphere that interferes with scientific experiments or other human activities;
(d) An atmospheric alteration that affects man's environment.

[205] Espoo Convention (n 141), art 1(vi).

(d) An assessment of the likely or potential environmental impacts of the proposed activity and alternatives, including the direct, indirect, cumulative, short-term and long-term effects;
(e) An identification and description of measures available to mitigate adverse environmental impacts of the proposed activity and alternatives, and an assessment of those measures;
(f) An indication of gaps in knowledge and uncertainties which may be encountered in compiling the required information;
(g) An indication of whether the environment of any other State or areas beyond national jurisdiction is likely to be affected by the proposed activity or alternatives;
(h) A brief, non-technical summary of the information provided under the above headings.[206]

- **Harm (Environmental h.)**: "*harm caused to persons, property or the environment*",[207] with "*a real detrimental effect on matters such as, for example, human health, industry, property, environment or agriculture in other States*" and able to be "*measured by factual and objective standards*."[208]
- **Harm (Transboundary environmental h.)**: harm "*caused in the territory of or in other places under the jurisdiction or control of a State other than the State of origin, whether or not the States concerned share a common border*,"[209] including "*activities taking place in outer space or on the high seas*."[210]
- **Harmful interference:** An interference that is deep and/or long enough to deteriorate the services of the affected systems.[211];[212]
- **Long-Term Sustainability of Outer Space Activities**: ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations.[213]

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[206] Decision 14/25 of the Governing Council of UNEP, 'Goals and Principles of Environmental Impact Assessment' (17 June 1987) UN Doc UNEP/GC/DEC/14/25.
[207] ILC, 'Draft Articles on Prevention of Transboundary Harm from Hazardous Activities' (2001) UN Doc A/56/10, art 2(b); See also Convention on Environmental Impact Assessment in a Transboundary Context (25 Feb 1991, entered into force 10 Sept 1997) 1989 UNTS 309 ('Espoo Convention'), art 1(viii).
[208] ILC Draft Articles, with Commentary (2001) UNYBILC 2(2), p. 152, para 4.
[209] Ibid., art 2(c).
[210] Commentary (2001) UNYBILC 2(2), p. 151, para 10.
[211] https://www.sciencedirect.com/topics/engineering/harmful-interference.
[212] Also, in ITU RR 1.169: "Harmful interference — interference which endangers the functioning of radionavigation service or of other safety services or seriously degrades,obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations". https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.43.48.en.101.pdf
[213] Guidelines for the Long-term Sustainability of Outer Space Activities (27 June 2018) A/AC.105/2018/CRP.20, para 5: https://www.unoosa.org/res/oosadoc/data/documents/2018/aac_1052018crp/aac_1052018crp_20_0_html/AC105_2018_CRP20E.pdf

- **Orbital Shell:** collection of orbital planes with different longitudes of ascending node at a defined altitude above the surface of Earth.
- **Orbital Plane:** geometric plane described by a satellite around a celestial object (in this case Earth), defined by its inclination angle (with respect to the equator) and the longitude of the ascending node.
- **Satellite constellations:** very large constellations of satellites. A specific number is not used to define "satellite constellations". Rather, the term is used to emphasize the large change in orbital infrastructure associated with large satellite constellations, as well as to avoid the term "mega-constellations", which is often used in a negative context.
- **Space Traffic Management**: a set of technical and regulatory provisions to promote safe access to and return from outer space, and to maintain operations in space, secure and free from physical or radio interference.[214]

[214] IAA Definition, also included in https://www.unoosa.org/res/oosadoc/data/documents/2019/aac_105c_2l/aac_105c_2l_309add_1_0_html/AC105_C2_L.309Add01E.pdf LSC Draft Report 2019

Chapter 3. National Space Policy and Regulation Country Case Studies

1. Introduction

The National Policy and Regulation Working Group of the Dark and Quiet Skies Satellite Constellation Working Group (D&QS SATCON WG) studied the implementation of the recommendations made on satellite constellations for the first Dark and Quiet Skies for Science and Society conference in 2020. One of the high-level objectives of the Dark and Quiet Skies effort, led by the International Astronomical Union (IAU), is to increase the number of States and industry companies that take account of astronomy in the design and operation of satellite constellations. With this in mind, the National Policy and Regulation WG undertook to conduct a review of space policy and regulation from a variety of countries, in order to support the development of more detailed recommendations to protect astronomy. Understanding the landscape of national space policy and how space activity licensing functions, provides useful context for understanding how astronomy can be included in these processes and policies.

This section of the report first describes the method used for the review, then conducts a series of case study reviews of national space policy systems, organized around a common framework. While the findings supported the development of the recommendations made in the main body of this report, the detailed descriptions of national policy and regulation systems can serve as a reference source for future efforts, in particular the IAU Centre for the Protection of Dark and Quiet Skies from Satellite Constellation Interference, which is set to be established in 2022.

2. Methodology

A number of countries were selected for case studies, the ambition being to ensure a diverse sample at different stages in the development of their space activities, space economy and policy systems (see Figure 3.1). The countries retained for this study all have a number of existing instruments, whether there is a complex, well-established, and multi-dimensional regime in place, or a nascent one. The countries were selected as a convenience sample, based on the expertise of the working group and the ease of access of publicly available information. No significance should be attributed to the choice of country.

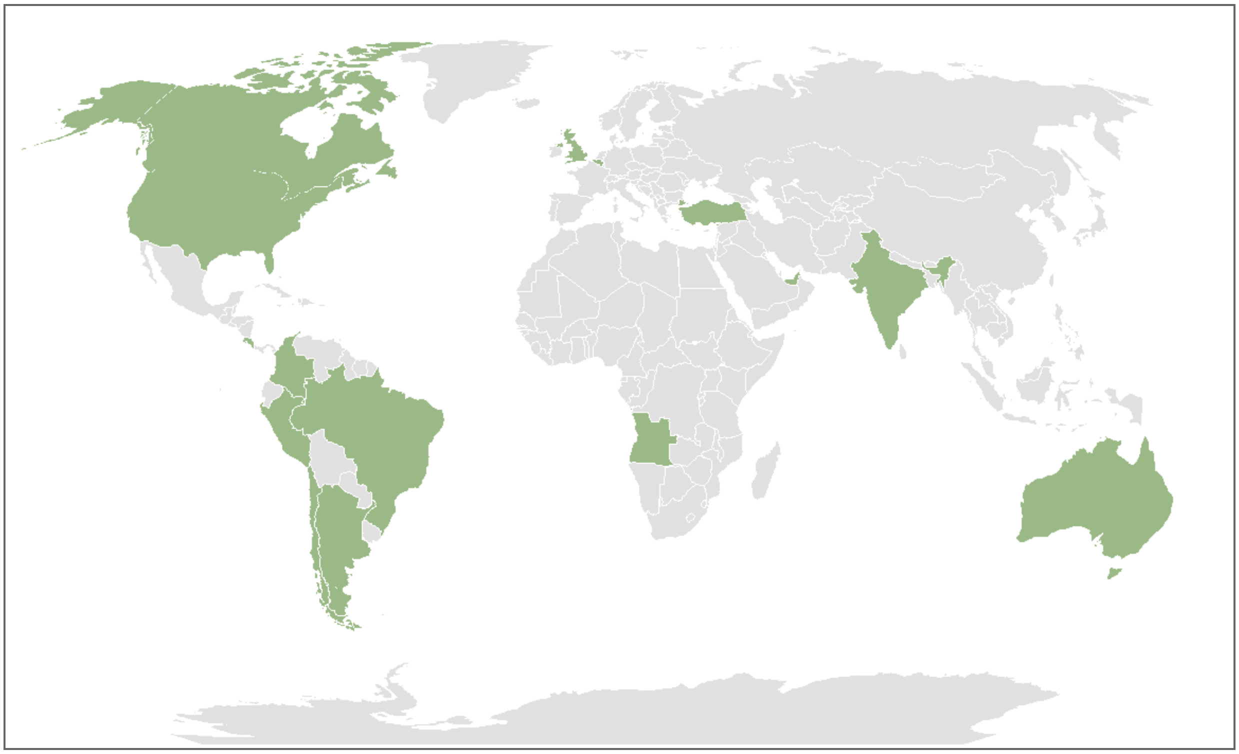

Figure 3.1: Map of selected countries. Credit: Bing Maps.

In order to remain consistent, each national review follows the same structure. First, relevant provisions found in the domestic law are identified. Second, the same is done for national policies. Third, ground astronomy activities conducted in the country are listed. Fourth, relationships and attitudes vis-à-vis different international instruments are established. On the one hand, this means membership to the main UN space treaties, on the other, participation or support in the development of international initiatives such as the Long-Term Sustainability of Outer Space Activities (LTS) Guidelines, or linked to any other similar issue (*e.g.* space debris, sustainability, etc.). Lastly, an overview of constellation plans is provided.

Throughout the text, different elements are highlighted:

Who grants licenses for space activities? What rules do they follow, and what relevant requirements exist?

Is there anything in the laws or policies that mentions astronomy, the protection of the outer space environment, or something similar? To what extent does national policy reflect the balances and compromises between rapid commercial development and orbital and environmental sustainability?

- Is there a space council or a board with representation from the scientific community (or the astronomical community in particular)?

Is astronomy one of the core activities of the national space agency or similar entity? (Is there a department dedicated to space science including astronomy, is there a main project of the entity having to do with astronomy?).

Do national instruments reflect international standards and best practices in general (which could mean that they would consider the LTS guidelines, the D&QS recommendations, etc.)?

Do national instruments show a commitment to cooperate (which could mean that they would compel their industry to be transparent and share timely and open data about their satellites, especially with the astronomical community)?

Do national instruments show a commitment to update engineering and manufacturing techniques to be up to the best and most recent standards (which would mean they would commit to build their satellites in a way that takes recommendations about brightness, altitude, etc., into account)?

Are there constellations registered in the country; are there companies or institutions in the country launching or planning to launch constellations?

These questions provide understanding of the extent to which a country could respond to the impacts of satellite constellations on astronomy and the potential level of awareness of the issue. The review indicates that in most countries there are already entities, mechanisms or frameworks in place that could be adapted; meaning the work towards addressing the impact of satellite constellations on astronomy at national level need not start from scratch.

The diverse selection of case study countries ensures that the recommendations are broadly applicable, rather than being limited to, for example, an advanced space economy. Every country has a different relation to nature, to the observation of the sky, and to the development of a national space sector, the findings and recommendations must be informed by perspectives from different cultural, social, and economic backgrounds. As the impact on astronomy is a relatively new issue, another goal is to find pieces of answers wherever they exist, albeit in a tentative manner. Not only it is the case that every country has a different relation to nature, to the observation of the sky, and to the development of their space sector, but it should also be stressed that the result of our recommendations can only be efficient and in tune with reality if informed by perspectives from different cultural, social, and economic backgrounds.

3. Case studies

3.1 Angola

3.1.1 National law

The Angolan legal system includes several relevant Decrees: Presidential Decree No. 101/13, Presidential Decree No. 154/13, Executive Decree No. 183/14, and Presidential Decree No. 152/21. The main institutions created through these laws are the Inter-ministerial Commission for the General Coordination of the National Space Program and the National Space Program Management Office (GGPEN).[215]

First, **Presidential Decree no. 101/13** of 9 October creates the Inter-ministerial Commission for the General Coordination of the National Space Program.[216] It is coordinated by the Minister of Telecommunications and IT and is composed of, amongst others, the Minister of Science and Technology, the Minister of Industry, and the Secretary of State for Telecommunications.[217] Its attributions include ensuring "*the acquisition and transfer of technology and knowledge inherent to the good performance of the project objectives*", and the studying "*the need and feasibility of setting up an Angolan Space Agency*". In its activities the Commission is supported by a Technical Group coordinated by the Secretary of State for Telecommunications and composed of members representing Telecommunications, Science and Technology, the Industry, Intelligence and Security and other fields. This composition is not a closed one, since the Decree gives the possibility to invite other entities into the Technical Group.

The Decree also informs on the existence of INFRASAT and the Inter-ministerial Commission for the General Coordination of the Telecommunications Via Satellite Project (CISAT), created under Presidential Dispatch no. 21/06 of 21 June. Not much information can be found on the latter other than the fact that it focuses on "*activities inherent to the production, launch and operation of the Angolan satellite ANGOSAT and on the creation of bases for the structuring of the National Space Program*".[218] INFRASAT, for its part, operates ANGOSAT-1 and provides services derived from it.[219]

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[215] Gabinete de Gestão do Programa Espacial Nacional (GGPEN)
[216] Comissão Interministerial para a Coordenação Geral do Programa Espacial Nacional. Despacho Presidencial No. 101/13 de 9 de Outubro, Diário da República, I Série, No. 194, 2675-76 (2013). https://www.cmc.gv.ao/sites/main/pt/Lists/CMC%20%20PublicaesFicheiros/Attachments/116/2013%20DRI%20194%20(28)%20OK.pdf
[217] Despacho Presidencial No. 101/13 de 9 de Outubro, Diário da República, I Série, No. 194, 2675-76 (2013). https://www.cmc.gv.ao/sites/main/pt/Lists/CMC%20%20PublicaesFicheiros/Attachments/116/2013%20DRI%20194%20(28)%20OK.pdf
[218] Despacho Presidencial No. 101/13 de 9 de Outubro, Diário da República, I Série, No. 194, 2675-76 (2013). https://www.cmc.gv.ao/sites/main/pt/Lists/CMC%20%20PublicaesFicheiros/Attachments/116/2013%20DRI%20194%20(28)%20OK.pdf
[219] Infrasat (n.d.). *Angosat*. http://www.infrasat.co.ao/angosat?lang=en

Second, **Presidential Decree on the Creation of GGPEN** no. 154/13 of 9 October, created the body with the "*objective to manage and accompany the development of the National Space Program, or PEN*".[220] Among other things, the responsibilities of the GGPEN include establishing cooperation protocols with technical and scientific institutions in the space domain, producing technical reports with respect to the PEN.[221] In the words of the Spatial Strategy (see infra), GGPEN "*promotes the peaceful use of space, as well as the conduct of strategic studies that aim to established agreements of cooperation with technical and scientific institutions in the space field, ensuring the creation of national technological and human competences, technology transfer and know-how in the framework of the PEN*".[222]

Third, **Executive Decree no. 183/14** sets the organic statute of GGPEN, which was tasked with: planning and implementing programs and projects related to science, technology and space industry; promoting and encourage the transfer, dissemination and development of space science and technology; implementing national policy on commercial exploitation of the potential of the national space industry; establishing cooperation protocols with technical and scientific institutions in the space domain; and developing rules, regulations and operating instructions for the office and submit it to the Inter-ministerial Commission for the General Coordination of the National Space Program for approval.

This Executive Decree has recently been revoked and replaced by a newer version, **Presidential Decree no. 152/21**,[223] While not yet public at the time of writing, a few words were published on the restructuring of GGPEN under the Presidential Decree no. 152/21. It is learned that the objective is to strengthen GGPEN's functions and ability to meet the goals of the PEN.[224] An addition has been made to the composition of GGPEN, with the constitution of a board of directors offering "*consultative support and monitoring matters related to the activities of the GGPEN*", as well as a Department of Support to the Director General, tasked with "*legal advice and cooperation" and "ensuring the flow of information throughout the institution*".[225] It has also been affirmed that the restructuration is already

[220] Decreto Presidencial n.o 154/13 de 9 de Outubro, Diário da República, I Série, No. 194, art. 1 (2013). https://www.cmc.gv.ao/sites/main/pt/Lists/CMC%20%20PublicaesFicheiros/Attachments/116/2013%20DRI%20194%20(28)%20OK.pdf
[221] Decreto Presidencial n.o 154/13 de 9 de Outubro, Diário da República, I Série, No. 194, art. 3 (2013). https://www.cmc.gv.ao/sites/main/pt/Lists/CMC%20%20PublicaesFicheiros/Attachments/116/2013%20DRI%20194%20(28)%20OK.pdf
[222] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 8. https://ggpen.gov.ao/recursos/
[223] Decreto Presidencial n.º 152/21. https://www.lexlink.eu/conteudo/geral/ia-serie/3964947/decreto-presidencial-no-15221/14793/por-tema
[224] Iderawumi, M. (2021, July 20). Angolan Government Strengthens its National Space Program. AfricaNews. https://africanews.space/angolan-government-strengthens-its-national-space-program/
[225] Iderawumi, M. (2021, July 20). Angolan Government Strengthens its National Space Program. AfricaNews. https://africanews.space/angolan-government-strengthens-its-national-space-program/

improving the communication as a new institutional portal and updated information on the activities of GGPEN are increasing transparency.

3.1.2 National policy

The main policy paper is the **Space Strategy of the Republic of Angola 2016–2025**, approved through Presidential Decree No. 85/17. The main drivers for conducting space activities are the prospected socio-economic development and soft power (or the "*positioning of Angola*" as stated in the text) that come with successfully carrying space activities.[226] To fulfill these ambitions the Strategy is built on five pillars, (1) space infrastructure development, (2) capacity building and promotion of the space sector, (3) industrial growth and space technologies, (4) international affirmation of the Angolan State in space, and (5) internal set up of organizational structures.[227] The point of industrial growth has to do with supporting private initiatives, diversifying space investments and contributing to the development of the space sector. The one of international affirmation is linked with "*ensuring that the country contributes to the definition of the main international guidelines in this field and participates in initiatives and relevant projects*".[228]
The Strategy also affirms that the national space activities will continue to be carried out in a "*sustainable and effective manner*" under the space strategies and programs even beyond 2025.[229]

Based on the previous **ICT White Paper** (approved by Presidential Order No. 71/11 of 12 September), the Strategy establishes certain goals, such as the development of the national industry, of national technological skills, and of international cooperation in the peaceful use of space resources.[230] The Strategy also indicates that the PEN seeks to benefit four areas:

1. strategic (technological support for different services).
2. social (technological support for availability, connectivity, etc. of services to citizens).
3. scientific (support to programs within universities, research centers, and industry).
4. industrial (create a national industry that supports the implementation of the PEN, incentivize economic growth with productive demand and national incorporation policies).

The Strategy identifies several benefits of using space and how they can help achieve national strategic goals. Amongst those, one can find:

- Economic Development and the Private Sector, depicting the space sector as an "engine for economic growth" and a way to diversify economic activities;
- Source of Revenue, since it is seen that other countries investing in space reap important revenues through renting or selling services and leasing orbital positions;

[226] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 14. https://ggpen.gov.ao/recursos/
[227] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 14. https://ggpen.gov.ao/recursos/
[228] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 4. https://ggpen.gov.ao/recursos/
[229] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 4-5. https://ggpen.gov.ao/recursos/
[230] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 8-9. https://ggpen.gov.ao/recursos/

- Science and Research, with the recognition that space exploration has enabled to better understand the Universe but has also contributed to important scientific and technological advances, citing medicine, energy, transportation, navigation, environmental management, and others as example;
- International Prestige as "investment in space plays an important role in the international affirmation of States and in strengthening their sovereignty, prestige and influence".[231]

Those benefits are supposed to be in line with the Long-Term Goals from the Angolan National Strategy 2025. Promoting sustainable, competitive, and equitable development, promoting science, technology and innovation, as well as supporting the private sector are all part of these long-term goals.[232] The strategy presents the linkages between the benefits in the Spatial Strategy and the long-term goals from the National Strategy.[233] Surprisingly, Research and Science from the Spatial Strategy, and the long-term goal to promote sustainable development are not linked.

There are seven goals in the Space Strategy of the Republic of Angola, four of them are (a) ensuring Angola's independence in the space sector, (b) ensuring the sustainability of space investment in Angola, (c) ensuring the transparency and predictability of Angolan space activities, and (d) ensuring recognition by the population of the importance of investing in the use of space.

The Strategy also mentions the need to restructure national entities where the Inter-ministerial Commission would essentially retain its competences and the GGPEN would merge into a space agency. This space agency would act under the Inter-ministerial Commission, as does GGPEN today, and would be responsible for licensing and monitoring private space activities and keeping the registry of space objects.[234]

Another section of the Space Strategy is dedicated to strategies and actions surrounding orbital positions and spectrum management. It refers to the (at least older version of the) ICT White Paper, implementing certain of its dispositions and assertions, for example:

- on the limits of the spectrum and orbital positions as resources;
- on the fact that "the Executive will ensure through legislation that these resources remain part of the public domain and subject to strict, transparent, and auditable management criteria", and rational and parsimonious use;
- on the mandate given to the Executive to follow a policy of responsible use of satellite orbits.[235]

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[231] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 11. https://ggpen.gov.ao/recursos/
[232] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 12. https://ggpen.gov.ao/recursos/
[233] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 12. https://ggpen.gov.ao/recursos/
[234] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 44. https://ggpen.gov.ao/recursos/
[235] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 29-39. https://ggpen.gov.ao/recursos/

It also refers to the Electronic Communications and Information Society Services Law No. 23/11, of 20 June, and builds on it to instigate a clear frame to manage and use the orbital positions.[236] In this way, recommendations are made on the one hand on the necessity to study procedures applicable to attribution of orbital positions and licensing to private entities (as it relates to pre-assigned orbital positions). On the other hand, it is recommended to look into the obtention of favorable orbital positions for the placement of satellites and into the evaluation of "*approval of procedures that allow a private entity to require the allocation of orbital positions not pre-allocated to the ITU through the Republic of Angola*".[237] Overall, active participation in the ITU processes and in the field of orbital positions in general is seen as an "*indispensable condition for the sustainability of Angolan space activities*."[238]

Astronomy is mentioned briefly in the strategic axis on training and education. According to it, "*the Angolan Center for Space Studies should have an increased responsibility by carrying out research and studies related to space sciences, by developing independent Angolan space application (namely in the areas of (…) astronomy (…), and for ensuring an effective technology transfer process with the space industry*".[239] The text furthers that bridges between academia and industry have to be built and transfers between research centers and the industry should be made.

According to an article from Africanews.space, the Angolan Ministry of Telecommunications and IT approved a **2019-2022 Strategic Plan of the GGPEN** in May 2019, but the text was not published. The article does mention that the Plan is supposed to be aligned with the content of the Spatial Strategy 2016-2025 and other national documents such as the ICT White Paper 2019–2022. Another point is that the Plan supposedly lists fourteen growth and sustainability guidelines to reach its objectives. It is not known how those guidelines are framed.

3.1.3 National astronomy programs

There are no astronomical observatories in the country. The Angolan Center for Space Studies should at some point carry out astronomical activities as planned in the Strategy, but the status of this development is unclear.

3.1.4 International involvement

As of October 2021, Angola has neither ratified, nor signed, any of the UN space treaties. GGPEN did affirm in 2020 that was a priority for the government to ratify the Outer Space Treaty (OST) and the

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[236] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 30. https://ggpen.gov.ao/recursos/
[237] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 31. https://ggpen.gov.ao/recursos/
[238] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 31. https://ggpen.gov.ao/recursos/
[239] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 35. https://ggpen.gov.ao/recursos/

Registration Convention.[240] It should enable the country to reach its strategic objective, i.e., soft power within the international community and a seat at the table, notably at the UN Committee on the Peaceful Uses of Outer Space (COPUOS).[241] A will to participate in the UN-SPIDER program and in COPUOS regional centers for space science and technology education has also been demonstrated.[242] The country is a Party to the Agreement Relating to the International Telecommunications Satellite Organization (ITSO), and a Member of the International Telecommunication Union (ITU).

In general, and as said in the Spatial Strategy, "i*t is necessary to (…) follow international trends in this field, positioning the country definitively at the central stage of the space sector*".

3.1.5 Constellation developments

To date, there are no known plans to build a constellation in Angola. It was reported in 2020 that the Director General of the GGPEN, also holding a position in the Angolan Institute of Communications (INACOM), would tackle a framework with regulations necessary for the launch of a possible Angolan constellation while considering all the requirement (e.g. from the ITU) that must be fulfilled for such an enterprise.[243]

3.2 Argentina

3.2.1 National law

According to **Decree 242/2016** on the Operation of the Comisión Nacional de Actividades Espaciales (CONAE) under the Ministry of Science, Technology, and Productive Innovation, CONAE is the only organism with the competence to control, manage, and administer space projects, ventures, and activities.[244]

Then, according to Article 5 of the **National Decree 125/95** on the Creation of a national register for objects launched in outer space, the National Register, created under the dependency of CONAE, must indicate several elements, including:

[240] Teodoro, E. (2020, August 24). The Space Economy Initiative: International Cooperation to grow responsible and sustainable space activities, Insights Reports, 7-9. UNOOSA. https://www.unoosa.org/documents/pdf/Space%20Economy/Space_Economy_Insight_Report_International_Cooperation.pdf

[241] Teodoro, E. (2020, August 24). The Space Economy Initiative: International Cooperation to grow responsible and sustainable space activities, Insights Reports, 7-9. UNOOSA. https://www.unoosa.org/documents/pdf/Space%20Economy/Space_Economy_Insight_Report_International_Cooperation.pdf

[242] GGPEN (December 2016). *Estrategia Nacional del Espacio 2016-2025*, 41. https://ggpen.gov.ao/recursos/

[243] Space in Africa (2020, November 11). Zolana João, GGPEN Director General Re-Appointed to the Board of Angolan Institute of Communications. AfricaNews. https://africanews.space/zolana-joao-ggpen-directors-term-extended-at-inacom-board/

[244] CONAE. Decreto 242/2016 Dispónese funcionamiento bajo la órbita del Ministerio de Ciencia, Tecnología e Innovación Productiva (2016). InfoLEG. http://servicios.infoleg.gob.ar/infolegInternet/anexos/255000-259999/258124/norma.htm

- Precautions taken in relation to the non-contamination of outer space, including celestial bodies, especially if there are mechanisms for moving to a transfer orbit once the useful lifetime of a space object has ended (art. 5(15)).
- Planned date of disintegration, recuperation, or loss of contact with the space objects (art. 5(16)).
- Identification mark located on non-disintegrable parts (art. 5(17)).[245]

In 2019, CONAE was reorganized through **Provision 548/2019**.[246] According to its **Annex IIIb,** there is a department in charge of "environmental management". **Annex II**[247] and **Annex IV**[248] on the primary responsibilities and actions to be taken by the different departments give more details on what falls in the remit of each department and sub-department. Several of those departments have been selected below because of their tasks and the margin for action that exists for them to tackle the issue of satellite constellations, including with respect to astronomy.

The **Coordination Management** promotes programs and actions for social responsibility and care for the environment.[249] Within the Coordination Management, the **Social Responsibility Sub-Management** deals with compliance with environmental and industrial safety norms in all HQ's/locations of the Organization.[250] Acting under this Sub-Management are the **Institutional Strengthening Unit** and the **Environmental Management and Industrial Safety Unit** are respectively responsible for (a) the coordination of the actions aimed at achieving the organization's social responsibility and the proposition of a code of ethics as well as its update, so as to responds to the requirements of CONAE,[251] and (b) compliance with applicable environmental norms, in accordance with CONAE's policy on the matter, and participate in different events tending to the update of norms related to the thematics under its competence.[252]

The **Technological Liaison Management** promotes (a) the participation of the national and international scientific system in the projects and activities of the National Space Plan, and (b)

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[245] Decreto Nacional 125/95, Creación del Registro Nacional de Objetos Lanzados al Espacio Ultraterrestre (1995). https://www.argentina.gob.ar/sites/default/files/3.pdf
[246] CONAE. Disposición 548/2019 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/norma.htm
[247] CONAE. Disposición 548/2019, Anexo II (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[248] CONAE. Disposición 548/2019, Anexo IV (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[249] CONAE. Disposición 548/2019, Anexo II, 3 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[250] CONAE. Disposición 548/2019, Anexo IV, 6 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[251] CONAE. Disposición 548/2019, Anexo IV, 7 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[252] CONAE. Disposición 548/2019, Anexo IV, 7 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pd

cooperation and synergy among members of the space industry in order to increase collective achievements.[253] This department is also charged with integrity and ethics matters.[254] To this end, it promotes and facilitates the application of current regulations and their sanctions, as provided by the "Enforcement Authority" (La Autoridad de Aplicación). The Space Sector Promotion Sub-Management supports the growth of the space industry in the country, and seeks to create exchanges between scientific and academic institutions such as to enable the transfer of space technologies from the scientific sphere to the market.[255] In addition, the National Cooperation Unit within the Institutional Cooperation Sub-Management deals with agreements for the development of projects that incorporate space technologies in all the different sectors mentioned in the National Space Plan, whether it be academic, scientific, environmental, production, or social.[256]

The **Legal Affairs Management** takes part in the elaboration of legal texts as asked by CONAE.[257] It also plays a role in the elaboration, execution, and application of agreements and conventions with entities of the National Government, as well as Space Agencies and International Organizations, when they are related to fulfilling the objectives of CONAE and the National Space Plan.[258]

The **Earth Observation (EO) Management** (and the EO Missions Sub-Management) is involved in the requirements that are asked of new missions.[259] It also carries scientific and technical studies for the development of future instruments and satellite missions, as well as assessing to what extent new missions satisfy social, economic, and productive needs. In the same line, the **Satellite Projects Management** (and the Architecture Sub-management) are in charge of advanced technological concepts and of developing/providing a prospective vision of satellite technology in international activity.[260]

[253] CONAE. Disposición 548/2019, Anexo II, 8 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[254] CONAE. Disposición 548/2019, Anexo II, 8 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[255] CONAE. Disposición 548/2019, Anexo IV, 21 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[256] CONAE. Disposición 548/2019, Anexo IV, 22 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[257] CONAE. Disposición 548/2019, Anexo II, 10 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[258] CONAE. Disposición 548/2019, Anexo II, 10 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-2.pdf
[259] CONAE. Disposición 548/2019, Anexo IV, 8 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[260] CONAE. Disposición 548/2019, Anexo IV, 11 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf

The **Access to Space Management** (and the Ground Segment and Launch Services) are tasked with the supervision of the flight safety system for contracted launch services, in order to ensure the well-being of the population, property, and the environment.[261]

The **Technology "Control" Management** (and the Satellite Operations Unit within the Ground Stations and Operations Sub-Management) provides maintenance support of the integrated logistics for all operations of the National Space Plan space missions, according to international standards relative to this area (it does so through life-cycle cost analysis, repair level analysis, and optimization of spare parts).[262] The Laboratories, Integration, and Testing Sub-Management promotes endogenous developments of technology for components, parts and subsystems so they can be used in CONAE's projects or for commercialization internationally.[263] The Research, Development, and Innovation Sub-Management amongst other things, contributes to research and technological development of new technologies, identifies emerging technologies applicable in the space field, and proposes design and processes improvements.[264]

Beyond what applies nationwide, some regional instruments are worth mentioning. That is the case of the **Municipal Ordinance No. 1298/2005** from the Municipality of Malargüe in the Province of Mendoza. The text recognizes that "*the sensation of calm and wellbeing that comes from looking at the starry sky is something necessary, especially considering the speed at which modern life is developing and the stress that it produces*".[265] Although the Ordinance pertains to light pollution around the Pierre Auger Observatory, this recognition emphasizes that the skies are not just a strategic and commercial domain, but a heritage that has guided humanity in its evolution, and still have a huge cultural and social value. Another example can be found in Buenos Aires where different instruments reveal an interesting conception of "visual quality". The **Constitution of the Autonomous City of Buenos Aires**, in its fourth chapter "Environment", deems the environment to be a common heritage, and mandates the City to develop a policy on urban environment planning and management and to this end to preserve and restore visual quality of the citizens.[266]

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[261] CONAE. Disposición 548/2019, Anexo IV, 12 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[262] CONAE. Disposición 548/2019, Anexo IV, 16 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[263] CONAE. Disposición 548/2019, Anexo IV, 17 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[264] CONAE. Disposición 548/2019, Anexo IV, 18 (2019). http://servicios.infoleg.gob.ar/infolegInternet/anexos/320000-324999/324997/disp548-4.pdf
[265] Lazzeroni, C.F. Impacto de la contaminación lumínica en la calidad del cielo nocturno en las ciudades. Estudio de caso: El barrio de Belgrano de la Ciudad Autónoma de Buenos Aires, Argentina, 34. UNICEN (2019). https://www.ridaa.unicen.edu.ar/xmlui/bitstream/handle/123456789/2266/Lazzeroni%20Claudia.pdf?sequence=1&isAllowed=y
[266] Constitución de la Ciudad Autónoma de Buenos Aires, arts. 26-27. InfoLEG. http://www.infoleg.gob.ar/?page_id=166

3.2.2 National policy

Argentina was until 2021 operating according to the ambitions of the National Space Plan 2016–2027 (PEN). The text was never approved by the Executive power, thus remaining an abstract instrument, at least to the public eye. Eight pillars, or "courses of action", formed part of the PEN, with brief and superficial descriptions of what they each entail. Still, it may be worth mentioning the pillar on "Satellite Systems", and the objective to operate joint constellations by integrating endogenous satellites with those of other Space Agencies, as well as the pillar "Exploration and Peaceful Use of Outer Space", which includes collaboration for Deep Space Networks installed on the territory.[267] With the advent of on-line events due to the Covid 19 crisis, the country increased transparency on the main objectives of the PEN, but the emphasis was on satellite and rocket programs rather than astronomy or concerns stemming from space activities regarding the space environment.

In June 2021, CONAE initiated the revision of the PEN, seeking to come up with the National Space Plan 2021–2030.[268] It has been said that in the 2030 Global Agenda, sustainable development will be taken into account and that the text will aspire to dynamize the productive sector and improve the impact on social and environmental sectors.[269] However, it is not known whether the actors of this initiative will explore the environmental impacts of satellite constellations (e.g. on astronomy, space debris, etc.). The meetings that took place did allegedly include stakeholders from different scientific and technological bodies, users, companies, and academics. In addition, the notice of this new PEN from CONAE does say that the meetings and consultations will result in a document that is participative, representative, and federal that will cater to all the sectors involved in the national space sector.[270]

3.2.3 National astronomy programs

ICATE (Institute of Astronomical, Earth, and Space Sciences)[271] is the research branch in Astronomical and Earth Science created by CONICET(National Scientific and Technical Research Council).[272] ICATE participates in the "Master Global Robotic Net" project, a mobile astronomical system of telescope robots.[273] Its objectives include investigating space weather and the astronomical effects on the

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[267] CONAE (n.d.). *Cursos de acción*. https://argentina.gob.ar. https://www.argentina.gob.ar/ciencia/conae/plan-espacial/cursos-de-accion

[268] CONAE (2021, June 18). *La CONAE inició la revisión estratégica del Plan Espacial Nacional 2021-2030*. argentina.gob.ar. https://www.argentina.gob.ar/noticias/la-conae-inicio-la-revision-estrategica-del-plan-espacial-nacional-2021-2030

[269] CONAE (2021, June 18). *La CONAE inició la revisión estratégica del Plan Espacial Nacional 2021-2030*. https://argentina.gob.ar. https://www.argentina.gob.ar/noticias/la-conae-inicio-la-revision-estrategica-del-plan-espacial-nacional-2021-2030

[270] CONAE (2021, June 18). *La CONAE inició la revisión estratégica del Plan Espacial Nacional 2021-2030*. https://argentina.gob.ar. https://www.argentina.gob.ar/noticias/la-conae-inicio-la-revision-estrategica-del-plan-espacial-nacional-2021-2030

[271] Instituto de Ciencias Astronómicas, de la Tierra y del Espacio

[272] Consejo Nacional de Investigaciones Científicas y Técnicas

[273] ICATE (n.d.). Proyectos internacionales en los que participa el ICATE. ICATE-CONICET. https://icate.conicet.gov.ar/proyectos-internacionales/

evolution of life on Earth, and cooperating with other entities.[274] Its mission is to conduct multidisciplinary research in both space and Earth sciences and projects in the fields of astrophysics, aeronomy, astronomy, solar physics, stellar physics, space climatology, etc.[275]

Overall, there are six observatories in Argentina:

- the Argentinian Institute of Radio Astronomy (IAR) in Buenos Aires.
- the Felix Aguilar Astronomical Observatory (OAFA) in San Juan.
- the Astronomical Observatory of La Plata in La Plata.
- the Leoncito Astronomical Complex (CASLEO) in San Juan.
- the Astronomical Observatory of Córdoba (OAC) in Córdoba.
- the Pierre Auger Observatory in Malargüe.

In August 2021, CASLEO organized two webinars on light pollution and the protection of dark skies: "Contaminación lumínica: La Ciencia y el Turismo protagonistas importantes en la protección de los cielos nocturnos".[276] CASLEO is an astronomical observatory dependent on CONICET and different National Universities.[277] The biggest telescope of the Complex is the Telescope Jorge Sahade, and one of its objectives and functions is to monitor compliance with norms that protect the environment and the quality of the skies.

Through CONAE and its cooperation schemes with China and ESA, Argentina is hosting deep space stations in Malargüe (ESA) and Neuquén (CNSA).[278]

3.2.4 International involvement

Argentina has ratified the UN space treaties, with the exclusion of the Moon Agreement. It has also ratified the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water (NTB), the Agreement Relating to the International Telecommunications Satellite Organization (ITSO), Convention on the International Mobile Satellite Organization (IMSO), and International Telecommunication Union (ITU) Constitution and Convention. Argentina has signed the Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite (BRS).

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[274] ICATE (n.d.). *NUESTROS OBJETIVOS*. https://icate.conicet.gov.ar/objetivos/

[275] ICATE (n.d.). *NUESTRA MISIÓN.* https://icate.conicet.gov.ar/mision/; ICATE (n.d.). INVESTIGACIÓN. https://icate.conicet.gov.ar/investigacion/

[276] CONICET (2021, August 2). Contaminación lumínica: La Ciencia y el Turismo protagonistas importantes en la protección de los cielos nocturnos. https://casleo.conicet.gov.ar/contaminacion-luminica-la-ciencia-y-el-turismo-protagonistas-importantes-en-la-proteccion-de-los-cielos-nocturnos/; Conferencias de Astronomía FCEFN — UNSJ (2021, August 9). *8va charla:"Contaminación lumínica:La ciencia y el turismo protagonistas en la protección del cielo".* https://www.youtube.com/watch?v=WxFhNtNbPc4

[277] CONICET (n.d.). *Acerca del CASLEO*. https://casleo.conicet.gov.ar/historia-sitio/

[278] CONAE (n.d.). *Centros y Estaciones*. Argentina.gob.ar. https://www.argentina.gob.ar/ciencia/conae/centros-y-estaciones

Argentina has been a member of COPUOS since 1958, making it one of the first 18 countries to be so. The Argentinian Association of Astronomy is a member of the IAU.

3.2.5 Constellation developments

Argentina has two partial satellite constellations in orbit. The first, SAOCOM, is a public endeavor from CONAE and manufactured by INVAP. For the moment, it is composed of two EO satellites orbiting in geosynchronous Earth orbit (GEO), with a substantial negative brightness impact.[279] Two more satellites are planned. The second, Aleph, is also an EO constellation. Manufactured and operated by the company Satellogic, the constellation will count approximately 300 systems, of which 17 have already been launched to this day.[280] Some of the latter already show a certain negative brightness impact. Lastly, the communication constellation “Libertadores de America” from Innova Space, still in its earlier stage, should count around 100 pico-satellites (pocketQubes) and use Machine to Machine communication and an IoT system. No brightness issue should come from those. The first three satellites are expected to be launched in 2021 and 2022.

3.3. Australia

3.3.1 National law

Australian space activities are regulated by the *Space (Launches and Returns) Act 2018* (Cth) and three pieces of delegated legislation under this Act that detail license requirements and other criteria: *Space (Launches and Returns) (General) Rules 2019*, *Space (Launches and Returns) (High Power Rocket) Rules 2019*, and *Space (Launches and Returns) (Insurance) Rules 2019*.[281] Under the *Space (Launches and Returns) Act*, the Minister for Industry, Science and Technology is responsible for granting licenses, permits and authorisations for Australian space activities.[282] This 2018 Act amended and updated previous Australian space legislation (the *Space Activities Act 1998* (Cth)) to ensure that Australian Commonwealth law considered new technological advances in the space sector and would foster innovation.[283]

The outer space and terrestrial environment are to a large extent considered under the *Space (Launches and Returns) Act*. Environmental safeguards for outer space first appear in section 34 of the Act, which requires that a licensee have a debris mitigation strategy. Part 3, section 54 of the *Space (Launches and Returns) (General) Rules 2019* clarifies that a “debris mitigation strategy” be submitted when applying for both an Australian launch permit and for an overseas payload permit — which

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[279] SAOCOM 1A and 1B have a respective Practical Brightness Limit of –6.6 and –6.7 and orbit at around 600 km altitude.
[280] Satellogic (n.d.). *Technology : Constellation*. https://satellogic.com/technology/constellation/
[281] Australian Government, Department of Resources, Science, Energy and Resources (n.d.). *Regulating Australian Space Activities.* https://www.industry.gov.au/regulations-and-standards/regulating-australian-space-activities
[282] *Space (Launches and Returns) Act 2018 (Cth)*. Retrieved from the Federal Register of Legislation https://www.legislation.gov.au/Details/C2019C00246.
[283] Australian Government, Department of Resources, Science, Energy and Resources (n.d.). *Regulating Australian Space Activities.* https://www.industry.gov.au/regulations-and-standards/regulating-australian-space-activities

applies to Australian space objects launched from a fixed or mobile facility outside of Australia.[284] Debris mitigation strategies for both types of permits are to be "*based on an internationally recognised guideline or standard for debris mitigation*," and to "*identify the guideline or standard being used*."[285] Applicants are also required to describe the specifics of their debris mitigation measures. Some examples include providing information about how debris generation will be limited during missions, potential break-ups and efforts to minimize their impacts, and how operators will limit the "*long-term presence of payloads and launch vehicle orbital stages in the low-Earth orbit region or in geosynchronous Earth orbit" post-mission*.[286]

Debris mitigation strategies required for an Australian launch permit are to also "*include an orbital debris assessment based on an internationally recognised model*."[287] An overseas payload permit differs in that it only requires that a strategy "*include an orbital debris assessment*,"[288] with no mention that it be based on an "internationally recognised" model.

Regarding protections for the terrestrial environment, safeguards first appear under the *Space (Launches and Returns) (General) Rules 2019* part 3, section 55 which requires that applicants include (if relevant to the applicable launch) "*an assessment of the likely impact of the launch and any connected return*[289] *on the environment, and information on how any adverse effects on the environment are to be monitored and mitigated*."[290]

Safeguards for the terrestrial environment also arise when one or more space object(s) are being returned — both to places or areas within or outside of Australia. A 'return' under the Act is defined as "*return the space object from an area beyond the distance of 100 km above mean sea level to Earth, or attempt to do so*." Space objects are defined in the Act as:

(a) an object the whole or a part of which is to go into or come back from an area beyond the distance of 100 km above mean sea level; or

[284] *Space (Launches and Returns) Act 2018 (General) Rules 2019,* Part 3, Section 54. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[285] *Space (Launches and Returns) Act 2018 (General) Rules 2019*, Part 3, Division 2, Section 54. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[286] *Space (Launches and Returns) Act 2018 (General Rules) 2019,* Part 3, Division 2, Section 54. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[287] *Space (Launches and Returns) Act 2018 (General Rules) 2019*, Part 3, Division 2, Section 54. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[288] *Space (Launches and Returns) Act 2018 (General Rules) 2019*, Part 4, Division 2, Section 79. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/C2019C00246.
[289] A 'return' in this case likely refers to the return of a rocket stage/other components of a launch vehicle.
[290] *Space (Launches and Returns) Act 2018 (General Rules) 2019,* Part 3, Division 2, Section 55. Retrieved from the Federal Register of Legislation https://www.legislation.gov.au/Details/F2019L01118

(b) any part of such an object, even if the part is to go only some of the way towards or back from an area beyond the distance of 100 km above mean sea level.[291]

Part 5, section 91 of the General Rules notes that applicants planning to return a space object, or a series of space objects, to an area or place within Australia must have "*appropriate environmental approvals, or an adequate environment plan if no environmental approvals are required* ..."[292] Additionally, part 5, section 101 stipulates that information is to be provided about environmental plans of the Australian state or territory the return will occur in.[293] If an environmental approval is not required for a return to the state or territory in question, applicants must submit an adequate "environmental plan" that assess the "likely impact" on the environment; a plan for "monitoring and mitigating adverse effects on the environment;" as well as provide "*mechanisms for reporting on the implementation of those arrangements and for reviewing the plan*."[294]

If an applicant is returning an object to a place outside of Australia, then they must submit an environmental plan; if the country in which the return is planned to occur requires its own environmental plan, then the applicant must complete that plan.[295]

Although a common practice, a requirement in the Act that may contribute to the mitigation of light pollution from satellites — in terms of coordination with astronomers — is that the basic orbital parameters must be submitted by the applicant to the Minister, then to be entered in a space object registry kept by the Minister. Parameters include the "*nodal period; its inclination; and its apogee and perigee*" and the "*space objects general functions*."[296]

3.3.2 National policy

Over the past several years, the Australian Commonwealth Government has substantially increased investment in their national space sector. Many government agencies and departments have responded by allocating more resources to space activities. A significant step in this space sector shift was the creation of the Australian Space Agency in 2018, which has the aim of growing the country's

[291] *Space (Launches and Returns) Act 2018 (General Rules) 2019*, Division 2—Definitions, Part 8. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[292] *Space (Launches and Returns) Act 2018 (General Rules) 2019*, Part 5, Section 91. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[293]https://www.legislation.gov.au/Details/F2019L01118 (Part 5, Section 101) In this case, "State" refers to Australia's six federated states and "Territory" refers to its two federated territories.
[294] Space (Launches and Returns) Act 2018 (General Rules) 2019, Part 5, Division 2, Section 101. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[295] Space (Launches and Returns) Act 2018 (General Rules) 2019, Part 5, Division 2, Section 101. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118
[296]*Space (Launches and Returns) Act 2018 (Cth)*, Part 5, Section 76. Retrieved from the Federal Register of Legislation: https://www.legislation.gov.au/Details/F2019L01118

space sector to a value of $12 billion and creating 20,000 new jobs by 2030.[297] The Agency defines the Australian "*space sector*" as "*a set of space-related activities along the space value chain [which] is part of the broader space economy [and where] all actors (private, public and academic) participating in production, operation, supply and enablement activities that form the space value chain are part of the space sector*". It continues by stating:

> *Space value chain segments broadly include: Manufacturing and core inputs (Ground and Space segment manufacturing and services); space operations; space applications; and enablers (such as regulation and essential service delivery, infrastructure and capabilities, research, development and engineering, and specialized support services). While the space sector captures the provision of space related goods, services and applications to broader industries, it does not include subsequent non-space (value adding) activities that are enabled by space activities (such as food grown using precision agriculture techniques). These flow-on activities are captured by the broader space economy*."[298]

The Agency coordinates space sector activities with stakeholders and government agencies through several fora. The Australian Space Coordination Committee (ASC), which is chaired by the Australian Space Agency, serves as a forum where government agencies can share information on civilian space activities by enabling them to "*coordinate and discuss whole-of-government policy settings on civil space activities" as the sector grows*.[299] One of the products to come out of the ASC is Australia's State of Space Report, an annual document that reviews the development of Australia's space activities, and which has been produced in collaboration with the Australian Space Agency ever since the Agency 's creation in 2018 — to date the 2018–2019[300] and 2019–2020[301] reports. There is also the Space Industry Leaders Forum, a biannual meeting that keeps the Agency informed on "*industry relevant issues and provides a coordination point for the civil space sector*."[302]Lastly, the State and Territory Space Coordination Committee (STSC), a quarterly meeting between state and territory counterparts, exists to promote cohesive national space policies and strategies. The meetings help to "*regularly connect*"

[297] Australian Government Space Coordination Committee (2020). *State of Space Report*. Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2020-12/state-of-space-report-2019-20.pdf
[298] Australian Government (n.d.) *Defining the Australian Space Sector*. https://www.industry.gov.au/data-and-publications/definition-of-the-australian-space-sector/defining-the-australian-space-sector
[299] Australian Government Space Coordination Committee (2020). *State of Space Report* (Pg. 14). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2020-12/state-of-space-report-2019-20.pdf
[300] Australian Government Space Coordination Committee (2019). *State of Space Report*. Retrieved from the Australian Government Website: https://www.spaceindustry.com.au/wp-content/uploads/2020/05/state-of-space-report-2018-19.pdf
[301] Australian Government Space Coordination Committee (2020). *State of Space Report*. Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2020-12/state-of-space-report-2019-20.pdf
[302] Australian Government (n.d.) Space Industry Leader Forum. https://www.industry.gov.au/about-us/space-industry-leaders-forum

the Agency with "*state and territory counterparts*" in order to receive updates on their relevant space activities and to "*coordinate international outreach*."[303]

The Australian Space Agency commissioned a 2018 report entitled "The Economic Contribution of Australia's Space Sector in 2018-19."[304] The purpose of this report was "*to describe the economic contribution of the local civil space sector in Australia and the role of industry, government, researchers, and educators in fostering the local space ecosystem*."[305] One curious aspect of the report is the inclusion of Australia's astronomy activities. In its survey of economic contributors of the Australian space sector, it mentions Australia's radio astronomy projects as part of the small yet growing space sector.[306] The "education, training and astronomy research" facilitated by Australian universities and other civil firms is also considered an aspect of the Australian space sector in that it supports space activities, such as the operation of space objects.[307]

In 2019, The Australian Space Agency produced "Australia's Advancing Civil Space Strategy 2019–2028,"[308] a policy document which marked the Agency's transition from an establishment phase to an operational one.[309] The Strategy commits to growing the domestic space sector in order to remain globally competitive and cooperate with international partners on space projects via industry and government partnerships. Additionally, the Strategy pledges to uphold a domestic regulatory framework that adheres to its international obligations under space treaties, facilitates domestic space

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[303] Australian Government Space Coordination Committee (2020). *State of Space Report* (Pg. 15). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2020-12/state-of-space-report-2019-20.pdf

[304] Alpha Beta (2019). *The Economic Contribution of Australia's Space Sector 2018-19.* Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2021-02/the-economic-contribution-of-australias-space-sector-in-2018-19.pdf

[305] Alpha Beta (2019). *The Economic Contribution of Australia's Space Sector 2018-19* (Pg. 7). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2021-02/the-economic-contribution-of-australias-space-sector-in-2018-19.pdf

[306] Alpha Beta (2019). *The Economic Contribution of Australia's Space Sector 2018-19* (Pg. 9). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2021-02/the-economic-contribution-of-australias-space-sector-in-2018-19.pdf

[307] Alpha Beta (2019). *The Economic Contribution of Australia's Space Sector 2018-19* (Pg. 11). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/2021-02/the-economic-contribution-of-australias-space-sector-in-2018-19.pdf

[308] Australian Space Agency (2019). *Australia's Advancing Civil Space Strategy 2019–2028.* Retrieved from Australian Government Website: https://publications.industry.gov.au/publications/advancing-space-australian-civil-space-strategy-2019-2028.pdf

[309] Australian Space Agency (2019). *Australia's Advancing Civil Space Strategy 2019–2028.* Retrieved from Australian Government Website: https://publications.industry.gov.au/publications/advancing-space-australian-civil-space-strategy-2019-2028.pdf

industry growth, and maintains "*safe and secure operation in space and on Earth*."[310] Australia's contributions to astronomy are briefly mentioned in the Strategy's executive summary as being an important aspect of their unique, growing and globally competitive space sector. Light pollution from satellite activity and its effects on astronomy are not mentioned specifically.

Earlier policy documents also emphasize the protection of the outer space environment. For instance, the summary of Australia's Satellite Utilisation Policy (ASUP) 2013[311] begins by pointing to increasing orbital congestion and the associated risks to space capabilities, then stating that Australia has a strong interest in "*contributing to international efforts to limit debris creation and develop international norms on conduct in space*,"[312] and that "(s)uch "*rules of the road protect the space environment and ensure our continued ability to share the benefits of space*."[313] Principle 4 of the 2013 Policy, entitled "Contribute to a Stable Space Environment," highlights an ongoing commitment to "*support rules-based international access to the space environment,*" by, amongst other initiatives, continuing the work of COPUOS, adhering to existing international guidelines, and making "f*urther statements of policy on space security and the space environment at appropriate future times*."[314] Australia's 2011 Principles for a National Space Industry Policy,[315] which the 2013 ASUP compliments on but does not supersede, exemplifies a similar, yet less developed, commitment to participate both nationally and internationally in promoting sustainable space activities.

Although not a space policy document, Australia's National Light Pollution Guidelines for Wildlife: Including marine turtles, seabirds and migratory shorebirds*,* produced by the Department of

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[310] Australian Space Agency (2019). *Australia's Advancing Civil Space Strategy 2019–2028* (Executive Summary). Retrieved from Australian Government Website: https://publications.industry.gov.au/publications/advancing-space-australian-civil-space-strategy-2019-2028.pdf

[311] Australian Government (2013) *Australia's Satellite Utilisation Policy 2013.* Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/May%202018/document/pdf/australias_satellite_utilisation_policy.pdf?acsf_files_redirect

[312] Australian Government (2013) *Australia's Satellite Utilisation Policy 2013* (Pg. 5). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/May%202018/document/pdf/australias_satellite_utilisation_policy.pdf?acsf_files_redirect

[313] Australian Government (2013) *Australia's Satellite Utilisation Policy 2013* (Pg. 5). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/May%202018/document/pdf/australias_satellite_utilisation_policy.pdf?acsf_files_redirect

[314] Australian Government (2013) *Australia's Satellite Utilisation Policy 2013* (Pg. 14). Retrieved from the Australian Government Website: https://www.industry.gov.au/sites/default/files/May%202018/document/pdf/australias_satellite_utilisation_policy.pdf?acsf_files_redirect

[315] Australian Government (2011) *Australia 's 2011 Principles for a National Space Industry Policy.* Retrieved from the Australian Government Website: https://www.spaceindustry.com.au/wp-content/uploads/2019/04/Principles-for-a-National-Space-Industry-Policy.pdf

Environment and Energy in 2020 is worth mentioning.[316] The guidelines do not specifically cover light pollution from satellites, but they do aim to encompass any instance "*where there is the potential for artificial lighting to affect wildlife*," including "*new projects, lighting upgrades (retrofitting) and where there is evidence of wildlife being affected by existing artificial light*."[317] To protect species delicate to light pollution, the guidelines encourage new projects to undertake an environmental impact assessment considerate of the "*potential effects of artificial light on wildlife*," and to adopt best practice lighting design.

3.3.3 National astronomy programs

The Australian Government has long supported the many ground-based optical and radio astronomy projects located there.[318] The Commonwealth Scientific and Industrial Research Organisation (CSIRO) operates several radio observatories within Australia and internationally, collectively known as the Australian Telescope National Facility (ATNF).[319] Investment in Australian radio astronomy continues, with the government investing $387 million into the Square Kilometre Array (SKA) — construction of which will begin in 2022.[320] The Siding Spring Observatory, operated by the Australian National University (ANU), is home to several optical telescopes including the Anglo-Australian Telescope — Australia's largest. ANU also operates additional optical telescopes at different locations (e.g., SkyMapper).

Funding is also provided by the Government for projects advancing astronomy such as Astralis Instrumentation Consortium (Astralis), a partnership between Macquarie University, the Australian National University (ANU), the University of Sydney (USYD) and Astronomy Australia Ltd facilitating the creation of world-leading astronomical instrumentation.[321] The funding comes from the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) Program via Astronomy Australia Limited.

In 2017 the Australian Commonwealth Government entered a 10-year strategic partnership with the European Southern Observatory (ESO)[322] to provide Australian astronomers the opportunity to stay at

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[316] Australian Government, Department of Environment and Energy (2020). Australia's National Light Pollution Guidelines for Wildlife: *Including marine turtles, seabirds and migratory shorebirds.* Retrieved from the Australian Government Website: https://www.awe.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

[317] Australian Government, Department of Environment and Energy (2020). Australia's National Light Pollution Guidelines for Wildlife: *Including marine turtles, seabirds and migratory shorebirds.* Retrieved from the Australian Government Website: https://www.awe.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

[318] Australian Government, Department of Resources, Science, Energy and Resources (n.d.). *Optical Astronomy in Australia.* https://www.industry.gov.au/policies-and-initiatives/optical-astronomy-in-australia

[319] Australian Telescope National Facility (November 1, 2021). About ATNF. https://www.atnf.csiro.au/the_atnf/index.html

[320] Australian Government, Department of Resources, Science, Energy and Resources (n.d.). *Co-hosting the SKA Telescope.* https://www.industry.gov.au/policies-and-initiatives/co-hosting-the-ska-telescope

[321] Astralis (n.d.). About Us. https://astralis.org.au/about-us/

[322] European Southern Observatory (July 1, 2017). *Australia Enters Strategic Partnership with ESO*. https://www.eso.org/public/australia/news/eso1721/

the forefront of astronomical discovery via access to the most advanced telescopes and instruments. The partnership also intends to create opportunities for Australian industries developing space science hardware.

There are several Australian astronomical organizations, some of which receive funding from the Australian Government. The Astronomical Society of Australia,[323] created in 1966, serves as the country's primary organization of professional astronomers. They currently run a sustainability working group (SWG), although it only concerns refitting ground astronomy facilities so that they are more sustainable in terms of energy use and other working practices. Astronomy Australia Limited (AAL) operates as a non-profit, with members including "*Australian research universities*," as well as "*research organisations with a significant astronomical research capability*."[324] AAL receives funding from and works with the Australian Government to reach the scientific goals proposed in the Decadal plan for Australian astronomy 2016-2025.[325] An example of a project that the AAL facilitates funding for is the previously mentioned Astralis Instrumentation Consortium.

There is also the Australian Dark Sky Alliance (ASDA)[326] with the objectives to: "*educate the public and policymakers about night sky conservation; Promote environmentally responsible outdoor lighting; Create business opportunities that support night sky preservation; Empower everyone with the tools and resources to help bring back the night; Support communities to create IDA Designated DarkSky Places in the Southern Hemisphere*."[327]

3.3.4 International involvement

Australia has ratified all four core international space treaties and is one of the 18 States Parties to the Moon Agreement. Interestingly, Australia has also signed the Artemis Accords which arguably stands at odds with the general philosophy of the Moon Agreement. Additional treaties relevant to pollution that could be caused by space activities have been ratified by the Australian Government, including the 1985 Vienna Convention on the Protection of the Ozone Layer and its 1987 Montreal Protocol on Substances that Deplete the Ozone Layer,

Australia is a member of the International Astronautical Federation, the Asia-Pacific Regional Space Agency Forum, and COPUOS.[328] The Australian Government has voiced support for the preamble and 21 long-term sustainability guidelines of outer space activities, and the creation of a working group

[323] https://asa.astronomy.org.au/about-2/the-society-and-council/
[324] https://astronomyaustralia.org.au/who-we-are-astronomy-australia-ltd.html
[325] https://www.science.org.au/files/userfiles/support/reports-and-plans/2015/astronomy-decadal-plan-2016-2025.pdf
[326] https://www.australasiandarkskyalliance.org/astronomical
[327] https://www.australasiandarkskyalliance.org/astronomical
[328] https://www.industry.gov.au/sites/default/files/2020-12/state-of-space-report-2019-20.pdf

"*on the implementation of the agreed guidelines and related aspects of the long-term sustainability of outer space activities*."[329]

In April 2021 Australia joined other states in submitting a proposal for the establishment of a new Working Group (WG) on the long-term sustainability of outer space activities of the Scientific and Technical Subcommittee (LTS 2.0). The WG seeks to implement LTS guidelines by further developing responsible practices, identifying new challenges, exchanging information and promoting capacity building with emerging space nations.[330]

Established, nationally based centers within Australia also aim to improve the international space environment generally. For instance, there is the Space Environment Research Centre (SERC), a partnership that brings together expertise from Australian and international space agencies, universities and commercial research providers to monitor and mitigate space debris and develop new technologies to preserve the space environment.[331] Some of their current developments include the GEO Tracker Telescope, which assists in global space object tracking, and SERC's Space Object Catalogue, a data log that is used in conjunction analysis and collision warnings.[332] An initiative through the Australian National University's Institute for Space called the Centre for Space Situational Awareness Research (CeSSAR) has the goal of incentivising "*responsible behaviour in space by tracking compliance with national and international norms regarding space debris mitigation, freedom from interference, and sustainability of outer space activities*."[333] CeSSAR seeks to achieve this by mobilizing a transdisciplinary group of space experts from science, law and policy backgrounds to both enhance SSA data collection and technologies, as well as "*endorse and promote compliance*" with existing international norms.[334]

The national law and policy mentioned in the preceding sections also exemplifies a commitment to adhere to existing international space sustainability guidelines, and to continue involvement in international fora with the goals of promoting new space sustainability measures.

3.3.5 Constellation developments

A few Australian registered companies are launching constellations soon. LatConnect 60 will launch an initial 3 satellites in 2021. The satellites are being manufactured by York Space Systems in Denver, Colorado. Fleet Space has a planned constellation of approximately 140 satellites.[335]

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[329] http://www.unoosa.org/documents/pdf/copuos/stsc/2020/statements/2020-02-04-PM-Item13-03-AustraliaE.pdf
[330] A/AC.105/C.1/2021/CRP.19/Rev.1
[331] SERC "About page"
[332] https://www.serc.org.au "Achievements page"
[333] https://inspace.anu.edu.au/cessar/vision
[334] https://inspace.anu.edu.au/cessar/vision
[335] https://fleetspace.com/#:~:text=Australia's%20Leading%20Space%20Company,satellites%20in%20Low%20Earth%20Orbit
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3.4 Belgium

3.4.1 National law

There are two principal instruments organizing space activities in Belgium, the Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects and its Implementing Royal Decree of 19 March 2008.

The **Law of 17 September 2005** on the Activities of Launching, Flight Operation or Guidance of Space Objects (as revised by the Law of 1 December 2013) regulates several important aspects of space activities.[336] The application for authorization is submitted by the operator to the Minister "*in charge of space research and its applications in the framework of international cooperation*", at times also referred to as the Minister in charge of science policy (art. 7, §1).[337] The application must contain an environmental impact assessment for all activities covered, which is done at different stages of the activities (art. 8, §1). For this, one or more experts are designated by the Minister. Three types of studies exist:

- An initial study, before the authorization can be granted. The aim is to assess the potential impacts of launching or operating the space object on the environment[338] on Earth or in outer space (art. 8, §2).
- An intermediate study, after the launch or during the operation of the space object in order to assess the real consequences of the activities on the environment on Earth or in outer space (art. 8, §4).
- A final study, when the space object returns to Earth's atmosphere (art 8, §5).

An example of a request for authorization from AEROSPACELAB[339] shows that certain standard elements are requested such as the apogee and perigee of the system once in orbit. The environment impact assessment in annex[340] is a thorough and long document. Astronomy is not mentioned, but cumulative impacts have to be assessed. In this precise case, they only concern the potential impacts on the air quality in the region and on biological resources.

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[336] Loi du 17 septembre 2005 relative aux activités de lancement, d'opération de vol ou de guidage d'objets spatiaux (2005). http://www.belspo.be/belspo/space/doc/beLaw/Loi_fr.pdf

[337] Example of authorization in French: http://www.belspo.be/belspo/space/documents/2020-01_AUTH_fr.pdf

[338] "Environment" is translated in the original French version not by "environement" but by "milieu", both when it refers to Earth or outer space: "*Cette étude est destinée à évaluer les incidences potentielles sur le milieu terrestre ou dans l'espace extra-atmosphérique du lancement ou de l'opération de l'objet spatial*".

[339] Loi du 17 septembre 2005 relative aux activités de lancement, d'opération de vol ou de guidage d'objets spatiaux — Arrêté royal d'exécution — Annexe 3, Formulaire de Demande d'Autorisation. http://www.belspo.be/belspo/space/documents/2020-01_REQU.pdf

[340] Aerospacelab (2020). *RRF ENVIRONMENTAL IMPACT ASSESSMENT -- RRF MISSION & ARTHUR-1 –.* http://www.belspo.be/belspo/space/documents/2020-01_ANN1.pdf

The Royal Decree of 19 March 2008 Implements certain provisions of the Law of 17 September 2005 on the activities of launching, flight operations and guidance of space objects.[341] More details are given on what the study shall address. Article 7 and 8 are dedicated to the "*protection of the environment*" and ask to provide information on the impact of the activities on the terrestrial environment,[342] including the atmosphere, and in particular on the natural and human environment of the place of launching (art. 7, § 1, 2°), and the impact of the activities on outer space (art. 7, § 1, 3°), and formulate recommendations on steps to be taken in order to reduce or limit any environmental impact (art. 7, §1, 4°).

The activities must be assessed on what their general impact as well as their impact on the environment will be in the short, medium, and long term. During the assessment, a specific emphasis shall be put on the risks during a potential re-entry and on compliance with applicable international standards intended to limit space debris (art. 7, §2). In addition, the Minister can collect any other technical data useful to assess the impact on the environment (art. 7, §5). The impact study also has to include, if applicable, steps that the operators have taken and progress made when it comes to the use of limited natural resources, in particular, GEO. The use of "in particular" indicates that it is not limited to GEO.

3.4.2 National policy

Belgium has a dedicated Space Strategy. Although the full text was not found, Belspo, the federal scientific policy body in Belgium, shares the main lines on its website. Some of the objectives have to do with supporting Belgian industry to retain their central position in their niches and conquer new markets.[343] For that, the environment must provide the tools to the industry to be competitive on the European and international markets. The Strategy also recognizes that adaptations have to be made in order to account for major developments in the space sector (mentioning NewSpace developments and the will to compete with current projects such as the launchers from Space X, and EO activities from Planet Labs). No mention is made of sustainability. Similarly, no link is made between industrial growth and the development of commercial activities, and the need for sustainability and environmental concerns.

Some context of the Belgian Space Policy is given by the Ministry of Foreign Affairs.[344] It says:

> *Aerospace is above all an international matter. Consequently, the FPS Foreign Affairs closely monitors this sector and more specifically its international context. Since the 1960s, Belgium has*

[341] Arrêté royal portant exécution de certaines dispositions de la Loi du 17 septembre 2005 relative aux activités de lancement, d'opération de vol ou de guidage d'objets spatiaux (2005) http://www.belspo.be/belspo/space/doc/beLaw/AR_spatial_fr.pdf
[342] Environment is here again translated from "milieu", see footnote 124.
[343] Belspo (n.d.). *Belgian Space Strategy*. http://www.belspo.be/belspo/space/bePolicy_en.stm
[344] In French, the term "Ministry" or "Ministère" became "FPS", i.e. "Federal Public Service".

been involved in space policy. The concept and the implementation of the relevant policy were entrusted to the national administration for scientific research, currently BELSPO, on the basis of the following principles: scientific exploration, free access to outer space and sustainable application of aerospace technology in the interest of society and humanity.[345]

The principles set out in this paragraph would all support the right of those observing the skies to retain their undisturbed visual access to the skies. It also calls for aerospace technology to be applied sustainably. It is not entirely clear what is aerospace technology and whether in this case that includes satellites and the way in which they are manufactured. It is also not clear whether "*a sustainable application*" would involve operators having to apply recommendations seeking to mitigate the impact of their activities on astronomy or space debris.

Belspo has the **2020 Environmental Declaration**. The website says that they "*had to take into consideration (their) environmental impact, especially since it is directly linked to (their) missions*". They also refer to the EMAS Regulation. It is not clear whether that extends to the activities managed and supported by Belspo in the space field (e.g. in pushing for commercial activities, the industry, etc.).

3.4.3 National astronomy programs

Belspo is composed of eleven DG's, amongst which DG Royal Observatory of Belgium and the Planetarium and DG Royal Belgian Institute for Space Aeronomy.[346] **The Royal Observatory of Belgium** is a federal scientific research institute acting under the authority of the "SPP Politique Scientifique", i.e. Belspo.[347] Researchers study the planet Earth and other, near and distant objects in space. Scientists at the observatory are involved in the following fields: astronomy, astrophysics, geophysics, seismology, space geodesy and solar physics.[348] Permanent monitoring of solar activity and the dissemination of information on a variety of astronomical phenomena are amongst the services offered by the observatory.[349] **The Planetarium** is a federal scientific facility aiming to raise awareness among the greater public about the sciences and astronomy.[350] **Science Connection**, the federal science policy magazine (Belspo), addresses astronomy among other scientific topics.[351]

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[345] Foreign Affairs, Foreign Trade and Cooperation (n.d.). *Aerospace*. Diplomatie Belgium. https://diplomatie.belgium.be/en/policy/policy_areas/peace_and_security/aerospace

[346] Belspo (n.d.) Qui sommes-nous : Structure et organigramme. http://www.belspo.be/belspo/organisation/about_organigram_fr.stm

[347] Observatoire royal de Belgique (n.d.). *A propos de l'Observatoire.* https://www.astro.oma.be/fr/informations/propos-de-lobservatoire/; Astronomy & Astrophysics (n.d.) *Astronomy & Astrophysics*. https://aa.oma.be.

[348] Belspo (n.d.). Musées et Établissements Scientifiques Fédéraux, Observatoire royal de Belgique (ORB) et le Planétarium. http://www.belspo.be/belspo/fsi/orbksb_fr.stm

[349] Belspo (n.d.). Musées et Établissements Scientifiques Fédéraux, Observatoire royal de Belgique (ORB) et le Planétarium. http://www.belspo.be/belspo/fsi/orbksb_fr.stm

[350] Belspo (n.d.). *Recherche et Applications spatiales, Education & Grand Public*. http://www.belspo.be/belspo/space/index_edu_fr.stm

[351] Belspo (n.d.). *Recherche et Applications spatiales, Publications.* http://www.belspo.be/belspo/space/edu_all_publ_fr.stm

There is also the **Royal Belgian Institute for Space Aeronomy** which carries out research on Earth's atmosphere, planets, comets, and interplanetary space. (According to the Institute, "*simply listing the problems associated with the ozone layer, the greenhouse effect, the propagation of radio waves in the ionosphere or the magnetic storms that disrupt telecommunications, is enough to demonstrate the importance of knowing and understanding all the phenomena observed in the upper atmosphere and the terrestrial environment".*[352]*) It "plays a central role in the study of global climate change, attempts to provide the answers to our society's questions on the condition of our atmosphere"*.[353]

The Astronomical Society of Liège often informs the public via social media on astronomical phenomena that can be observed on certain days and organizes activities also for the general public. It also holds monthly conferences, publishes a monthly review called "Le Ciel", and has its own planetarium.[354] It organizes night sky observation, accessible to the public but also dedicated to scientific research. It also gives ephemerides for easily visible artificial satellites that pass over the city, with for example the name of the satellite, its magnitude and altitude, as well as the observation of which natural constellation will be disturbed.[355]

3.4.4 International involvement

Belgium has ratified all five UN space treaties. It is one of the few countries to have ratified the Moon Agreement. In addition, it has ratified the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water (NTB), the Agreement Relating to the International Telecommunications Satellite Organization (ITSO), and the Convention on the International Mobile Satellite Organization (IMSO). It has signed the Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite (BRS). It is a member of ESA, EUTELSAT, EUMETSAT, and the ITU. Belgium is also one of the first members of COPUOS and the The Royal Academies for Science and the Arts of Belgium is a member of the IAU.

During the 2021 Scientific and Technical subcommittee of the COPUOS, Belgium focused its intervention on the long-term sustainability of outer space, a presented the document A/AC.105/C.1/2021/CRP.12, called "Implementation of the Guidelines for the Long-term Sustainability

[352] Belspo (n.d.). Museums and Federal Scientific Institutes, Royal Belgian Institute for Space Aeronomy (BIRA-IASB). http://www.belspo.be/belspo/fsi/iasbbira_en.stm

[353] Belspo (n.d.). Museums and Federal Scientific Institutes, Royal Belgian Institute for Space Aeronomy (BIRA-IASB). http://www.belspo.be/belspo/fsi/iasbbira_en.stm

[354] Société Astronomique de Liège (n.d.). *Qui sommes-nous?, L'ASBL*. http://www.societeastronomique.uliege.be/accueil/qui-sommes-nous/presentation/

[355] Société Astronomique de Liège (n.d.). Éphémérides de passages de satellites artificiels facilement visibles établies pour Liège. http://societeastronomique.uliege.be/astronomie-pratique/evenements-astronomique/satellites-artificiels

of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space".[356] Belgium also called on COPUOS to address the preservation of the astronomical sky:

> *The multiplication of objects in orbit begs the question, not only of sharing orbital resources and of utilizing outer space in a way that is in line with international law principles, but also of the interferences caused by other types of activities, including those of space observation from the terrestrial ground. Studies carried by certain international organizations, governmental and non-governmental, must stimulate reflections within COPUOS on this issue.*[357]

3.4.5 Constellation developments

Although Belgium does not yet have constellations in orbit, two projects are in development: the constellation VHR from Aerospace Lab and an unnamed ten-satellite constellation by ScanWorld, a spinoff company from SpaceBel. Neither of them should present a significant issue to astronomy in terms of brightness or reflectivity.

3.5. Brazil

3.5.1 National law

The legal regime in the country, although not new, is still rather rudimentary. The principal text, **Law No. 8.854 of 10 February 1994**, creates the Brazilian space agency, or Agência Espacial Brasileira (AEB) and establishes a list of its competences.[358]

To mention a few of those competences, it is incumbent on the AEB to:

- Execute and enforce the National Policy for the Development of Space Activities (PNDAE) and propose guidelines and updates;
- Manage the National Space Activities Programs (PNAE);
- Support the participation of universities and other research institutions involved in the space field;
- Support the participation of private space initiatives;

[356] D'hoop, G. (2021, April 22). UNCOPUOS STSC 058, Intervention par la Belgique sous le point 12. UNOOSA. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-22-AM-Item12-03-BelgiumF.pdf; D'hoop, G. (April 2021). *Intervention de M. Ghislain D'hoop, Ambassadeur et Représentant permanent de la Belgique auprès de l'Organisation des Nations Unies à Vienne, à l'occasion de la 58ème session du Sous-Comité scientifique et technique du Comité des Nations Unies pour les Utilisations pacifiques de l'Espace extra-atmosphérique*. UNOOSA. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-20-AM-Item03-03-BelgiumF.pdf

[357] Excerpt translated from French from D'hoop, G. (April 2021). Intervention de M. Ghislain D'hoop, Ambassadeur et Représentant permanent de la Belgique auprès de l'Organisation des Nations Unies à Vienne, à l'occasion de la 58ème session du Sous-Comité scientifique et technique du Comité des Nations Unies pour les Utilisations pacifiques de l'Espace extra-atmosphérique. UNOOSA. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-20-AM-Item03-03-BelgiumF.pdf

[358] Lei No. 8.854, de 10 de Fevereiro de 1994, Cria, com natureza civil, a Agência Espacial Brasileira (AEB) e dá outras providências (1994). http://www.planalto.gov.br/ccivil_03/leis/L8854.htm

- Organize the joint use of technical space installations, aiming at the integration of available means and the rationalization of resources;
- Establish norms and grant licenses and authorization for space activities;
- Apply quality and productivity standards regarding space activities.[359]

As seen, the AEB is responsible to grant licenses for space activities, but said activities are not framed. The Law does not address or define space activities, or even attempt to regulate the space sector. It thus remains unclear what sort of activities need a license.

In addition, there is a Superior Council sitting within the AEB. This deliberative body includes different representatives, including one from the scientific community and one from the industrial sector, both involved in the space field.[360]

The internal structure of the AEB is further expanded on in **Decree No. 10.469 of 19 August 2020**.[361] More information is given in it on the composition of the Superior Council, i.e. the Ministry of Economy and the Ministry of Science, Technology and Innovation (MCTI) are both present, as well as the National Council for Scientific and Technological Development.[362]

Another regulatory text is **Decree No. 1.953, of 10 July 1996**, Creating the National System for the Development of Space Activities (SINDAE).[363] Through it, one can learn that SINDAE is tasked with organizing the execution of space activities of national interest.[364] While the AEB is responsible for the general coordination of the System, specific “sectoral” and “participating bodies” deal with the coordination and execution of more specific actions as listed in the National Space Activities Program (PNAE).[365] Those are the Department of Research and Development of the Ministry of Aeronautics

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[359] Lei No. 8.854, de 10 de Fevereiro de 1994, Cria, com natureza civil, a Agência Espacial Brasileira (AEB) e dá outras providências, art 3 (1994). http://www.planalto.gov.br/ccivil_03/leis/L8854.htm
[360] Lei No. 8.854, de 10 de Fevereiro de 1994, Cria, com natureza civil, a Agência Espacial Brasileira (AEB) e dá outras providências, art 6 (III) (1994). http://www.planalto.gov.br/ccivil_03/leis/L8854.htm
[361] Decreto No. 10.469, de 19 de Agosto de 2020, Aprova a Estrutura Regimental e o Quadro Demonstrativo dos Cargos em Comissão e das Funções de Confiança da Agência Espacial Brasileira e remaneja e transforma cargos em comissão e funções de confiança (2020) http://www.planalto.gov.br/ccivil_03/_Ato2019-2022/2020/Decreto/D10469.htm#art7
[362] Decreto No. 10.469, de 19 de Agosto de 2020, Aprova a Estrutura Regimental e o Quadro Demonstrativo dos Cargos em Comissão e das Funções de Confiança da Agência Espacial Brasileira e remaneja e transforma cargos em comissão e funções de confiança, Annex 1, art 16 (II) (2020) http://www.planalto.gov.br/ccivil_03/_Ato2019-2022/2020/Decreto/D10469.htm#art7
[363] Decreto No. 1.953, de 10 de Julho de 1996, Institui o Sistema Nacional de Desenvolvimento das Atividades Espaciais — SINDAE e dá outras providências (1996). http://www.planalto.gov.br/ccivil_03/decreto/1996/d1953.htm
[364] Decreto No. 1.953, de 10 de Julho de 1996, Institui o Sistema Nacional de Desenvolvimento das Atividades Espaciais — SINDAE e dá outras providências, art 1 (1996). http://www.planalto.gov.br/ccivil_03/decreto/1996/d1953.htm
[365] Decreto No. 1.953, de 10 de Julho de 1996, Institui o Sistema Nacional de Desenvolvimento das Atividades Espaciais — SINDAE e dá outras providências, arts 2-3 (1996). http://www.planalto.gov.br/ccivil_03/decreto/1996/d1953.htm

(DEPED), the National Institute for Space Research of the Ministry of Science and Technology (INPE), and participating are the Ministries, Secretariats, Municipalities and other entities when relevant.[366] The private sector is also invited to participate provided a prior approval from the Superior Council of the AEB.[367]

There seems to be no clear licensing mechanism in place. There are several indications for launch activities from the territory,[368] but not for carrying out other space activities or having a satellite launched and operated. In 2021, there was a major update, but once more, it is constrained to the regulation of rocket launches and their licensing.[369]

Some hints of what information can be requested regarding satellites can be found in **Ordinance No. 96, of 30 November 2011** on the implementation and functioning of the Register of space objects launched in outer space, under the responsibility of the Brazilian Government. The text gives the AEB the duty to implement and operate the national registry of space objects and details about the frequencies for radiocommunications, orbital positions and change thereof, and date of reentry for instance must be given.[370] In addition, Article 9 considers the preservation of the environment, in airspace or in outer space, and the serious threat to the safety of orbital flights considering the growing presence of space debris. In this regard, service-life forecast, the type of material used, the energy source, and the fuel used, must all be specified. Then, Article 13 charges the AEB to monitor the evolution of issues related to registration within COPUOS and other relevant fora and to accept additional guidelines that may be adopted by the international community and that aim to a better fluidity, coexistence, and cooperation between countries.

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[366] Decreto No. 1.953, de 10 de Julho de 1996, Institui o Sistema Nacional de Desenvolvimento das Atividades Espaciais — SINDAE e dá outras providências, art 3 (II)-(III) (1996). http://www.planalto.gov.br/ccivil_03/decreto/1996/d1953.htm

[367] Decreto No. 1.953, de 10 de Julho de 1996, Institui o Sistema Nacional de Desenvolvimento das Atividades Espaciais — SINDAE e dá outras providências, art 3 (III) (1996).

[368] See Portaria No. 5, de 21 de Fevereiro de 2002 at https://sbda.org.br/wp-content/uploads/2018/10/Portaria_5_AEB_-2002.pdf or Portaria No. 27, de 20 de Junho de 2001 at https://sbda.org.br/wp-content/uploads/2018/10/Portaria-27_AEB_2001.pdf

[369] See AEB (2021, September 1). Nova portaria atualiza regulamento de lançamentos de foguetes no território brasileiro. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/nova-portaria-atualiza-regulamento-de-lancamentos-de-foguetes-no-territorio-brasileiro or AEB (2021, September 1). *Portaria Nº 698, de 31 de Agosto de 2021*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/servicos/licenciamento/portaria-no-698-de-31-de-agosto-de-2021

[370] Portaria Nº 96, de 30 de novembro de 2011, arts 1, 8, 10 (2011). https://www.gov.br/aeb/pt-br/assuntos/programa-espacial-brasileiro/objetos-espaciais-brasileiros/dou-registro-de-objetos-espaciais-portaria-96-111130-1.pdf. Registered objects can be found at https://www.gov.br/aeb/pt-br/programa-espacial-brasileiro/objetos-espaciais-brasileiros.

Since 2013, there seem to have been some internal initiatives seeking to develop the domestic legal regime, although they appear not to have been fruitful yet.[371] The Center for Space Law Studies (NEDE) within the Brazilian Association of Aeronautical and Space Law (SBDA) created a working group called "General Law of Space Activities in Brazil".[372] A "Brazilian Code of Space" was published by NEDE in February 2019. While merely preliminary, the proposition contains elements greatly lacking in the current regime, e.g., as mentioned the lack of definitions. Among these definitions, space activities would be all actions that aim at the exploration or use of outer space, especially those contained in the Brazilian Space Program.[373] It also contains notions such as the responsible and sustainable use of the space environment and would provide for the adoption of environmental protection measures during all phases of space activities and mitigation of space debris.[374]

3.5.2 National policy

There are two relevant documents regarding the Brazilian national policy on space, the National Policy for the Development of Space Activities (PNDAE) and the National Program of Space Activities, the latter being a ten-year instrumentation of the former.

First, the PNDAE found in the Annex of Decree No. 1.332 of 8 December 1994, says that its main objective is to promote the country's ability to use space resources and techniques to solve national problems and to bring benefits to the Brazilian people.[375] Two elements of interest can be noted. Firstly, space activities are defined as "*a systematic effort to develop and operate space systems, as well as the necessary and corresponding infrastructure, aiming to allow the man to expand his knowledge of the universe, in particular of planet Earth and its atmosphere, as well as exploring (…) the availability of these new devices*".[376] It's not clear whether astronomy could fit such a definition, although astronomy is the quintessential example in enabling humankind to expand its knowledge of the Universe. Secondly, the section "Valorization of Scientific Activities" states that "*scientific investigation or basic research space activities should be valued not only for their contribution to universal knowledge, but mainly for their contribution to national development*".[377]

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[371] Revista Direito.UnB. Setembro–Dezembro, 2020, V. 04, N. 03. ISSN 2357-8009. pp. 106-138, p122

[372] Monserrat Filho, J. (2013, April 6). *Rumo à Lei Geral das Atividades Espaciais no Brasil*. Defesanet. https://www.defesanet.com.br/space/noticia/10369/Rumo-a-Lei-Geral-das-Atividades-Espaciais-no-Brasil/

[373] SBDA (February 2019). *Codigo Brasileiro do Espaço*, art 3. https://sbda.org.br/wp-content/uploads/2019/05/Proposta-CBE.pdf

[374] SBDA (February 2019). *Codigo Brasileiro do Espaço*, arts 7 (XI), 16. https://sbda.org.br/wp-content/uploads/2019/05/Proposta-CBE.pdf

[375] Decreto no 1.332, de 8 de dezembro de 1994, que estabelece a Política Nacional de Desenvolvimento das Atividades Espaciais (PNDAE) (1994). http://www.planalto.gov.br/ccivil_03/decreto/1990-1994/d1332.htm

[376] Decreto no 1.332, de 8 de dezembro de 1994, que estabelece a Política Nacional de Desenvolvimento das Atividades Espaciais (PNDAE), Anexo I, II, 3 (1994). http://www.planalto.gov.br/ccivil_03/decreto/1990-1994/d1332.htm

[377] Decreto no 1.332, de 8 de dezembro de 1994, que estabelece a Política Nacional de Desenvolvimento das Atividades Espaciais (PNDAE), Anexo I, V, 10 (1994). http://www.planalto.gov.br/ccivil_03/decreto/1990-1994/d1332.htm

Second is the PNAE 2012–2021, current and fourth version of the Program. One of the strategic lines of the Program is to create a National Council of Space Policy. However, it does not seem that such a Council ever saw the light of day.[378] According to a timeline from the Observatory of the Brazilian Space Sector, an initiative was started in 2020 with the creation of the National Space Policy Working Group (or GT-PNE).[379] The Group is supposed to organize the space activities of the country, consolidate the revision of the PNDAE, propose the National Space Policy (PNE), propose a National Space Strategy (ENE), the latter supposed to translate the PNE into strategic orientation for the national space sector.[380]

The paper makes several mentions of using space for sustainability and the environment on Earth but does not really consider the opposite, the sustainability of space activities. On the other hand, it does consider economic gains from space activities and a thriving space industry and from having a legal framework enabling such gains, how to grow participation of the satellite manufacturing and launching industry, and how to grow the market.

As mentioned in the national law section, existing legislation does not address space activities as such and there is no clear framework in place. The PNAE did push for the "*creation of a general law on space activities with rules that meet international standards in terms of space security, quality of products and services*", etc.[381] As of the PNAE 2012–2021, this has still not been achieved.

The PNAE contains a projected budget that was supposed to be invested between 2012 and 2021. Out of R$ 9,1 billion covering satellite missions, launchers, infrastructures to operate satellites and develop launching activities, and others, around R$ 350 million only are attributed to S&T missions and Research in Space Science and Climate; less than 4%.[382]

The PNAE for the next period, 2022–2031, is currently in development. It was expected to be finalized by the end of 2021.[383] For the moment, it has been announced that national disaster prevention, environmental monitoring, water security, and a greater participation of the industry and academia

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[378] AEB. Programa Nacional de Atividades Espaciais 2012–2021, 8 (2012). Ministro da Ciência, Tecnologia e Inovação.
[379] Observatório do Setor Espacial Brasileiro (n.d.). *Linha do tempo das atividades espaciais no Brasil*. AEB. https://observatorio.aeb.gov.br/politica-espacial/cronologia-do-programa-espacial-brasileiro
[380] Observatório do Setor Espacial Brasileiro (n.d.). *Linha do tempo das atividades espaciais no Brasil*. AEB. https://observatorio.aeb.gov.br/politica-espacial/cronologia-do-programa-espacial-brasileiro
[381] AEB. Programa Nacional de Atividades Espaciais 2012–2021, 15 (2012). Ministro da Ciência, Tecnologia e Inovação.
[382] AEB. Programa Nacional de Atividades Espaciais 2012–2021, 16 (2012). Ministro da Ciência, Tecnologia e Inovação.
[383] AEB (2021, April 7). *PNAE tem 5º Workshop de Revisão com decisões importantes*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/pnae-tem-5o-workshop-de-revisao-com-decisoes-importantes

will be such things considered in tailoring the new Program.[384] While the budget of the former PNAE equated to R$ 300 million, the new budget should be three times that.

3.5.3 National astronomy programs

Astronomy is not really part of the core activities of the Brazilian Space Program, which is focused on launchers, launching facilities, and satellites and their applications.[385] Still, references to the field can be found in different contexts and there exists a National Observatory (ON) tied to the MCTI.[386]

Aside from ON, there are five other observatories in the country: Longa Vista Observatory (Itatiba), Malakoff Tower (Recife), Pico dos Dias Observatory (Minas Gerais), and Valongo Observatory (Rio de Janeiro). Other astronomical instruments include the Brazilian Decimetric Array and the Galactic Emission Mapping Telescope (GEM) both in Cachoeira Paulista, the Pierre Kauffman Radio Observatory, also called Itapetinga Radio Observatory in Atibaia, and the Northeastern Space Radio Radio Observatory (ROEN) in Eusébio.

As part of the PNAE, there is a reference to a "Lattes" satellite to support research on phenomena happening in outer space and astronomical research. Specifically, it should monitor and collect images of a region of the sky rich in sources emitting X-rays.[387] However, if the satellite was meant to be launched in 2017, it appears that the project never made it into orbit.

The Master Plan 2016–2919 of INPE states that Brazil is pioneering in certain areas of Space and Atmospheric Sciences, e.g. space astronomy, radio interferometry, gravitational wave detectors. instrumentation in infrared astronomy.[388]

Amongst the different programs of INPE, one can find:

- "Research and Development of Technologies for the Space Sector" which involves research in Aeronomy, Astrophysics and Space Geophysics;
- "Development, Launch and Operation of Satellites with the Associated Infrastructure" involving the development of scientific satellites intended for basic and applied sciences, e.g. stellar astrophysics and planetary science;
- "Management of Participation in National and International Bodies and Entities" which involves contributing to the scientific collaboration of the Laser Interferometer

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[384] AEB (2011, July 14). *PRESIDENTE DA AEB FALA SOBRE NOVO PNAE NA SBPC*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/presidente-da-aeb-fala-sobre-novo-pnae-na-sbpc

[385] MCTI (2021, October 1). PALESTRA: O Programa Espacial Brasileiro — AEB. Youtube. https://www.youtube.com/watch?v=qPxoTNJ0HLY

[386] Observatório Nacional (2017, July 7). *Apresentação*. Ministro da Ciência, Tecnologia e Inovação. https://www.gov.br/observatorio/pt-br/acesso-a-informacao/institucional/apresentacao

[387] AEB. Programa Nacional de Atividades Espaciais 2012–2021, 23 (2012). Ministro da Ciência, Tecnologia e Inovação.

[388] INPE. Plano Diretor do INPE 2016-2019, 66 (2016). http://antigo.inpe.br/gestao/planejamento/plano-diretor/arquivos/Plano_Diretor_2016-2019.pdf

Gravitational-wave Observatory (LIGO) which enables research in astronomy and astrophysics.[389]

While the space program does not particularly showcase astronomy, it still is a valued field in the country, especially in academia and education. For example, the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG-USP) is a noteworthy actor in the country. Also, AEB regularly organizes webinars in astronomy through a series called "Ciclo de Palestras sobre Ciências Espaciais do AEB Escola", or "Cycle of Lectures on Space Sciences of the AEB School". Themes can range from historical aspects of astronomy to gravitational-wave astronomy, or yet X-ray astronomy. The fact that the series is called space sciences and that one of the activities of the national space agency is to raise awareness on astronomy leads to the conclusion that Brazil considers astronomy to be a space activity. Another example is the Brazilian Olympiad of Astronomy and Astronautics (OBA) carried through over twenty schools and attended by the President of the country and the Minister of Science, Technology and Innovation (MCTI).[390] In June 2021, Brazil also organized its first "International Seminar of Astronomy and Astronautics of the MCTI" during which the importance of including and inspiring young people was a priority.[391] That being said, it seems the seminar focused on space in general, citing for instance the role of the two Brazilian launch centers and other national programs.

3.5.4 International involvement

Brazil has ratified all four main UN space treaties. Interestingly, even though it did not sign or ratify the Moon Agreement, it was at the time one of the few countries that came up with Article 11 and the notion that the natural resources on the Moon formed a common heritage of "mankind". It also ratified the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water (NTB), the Agreement Relating to the International Telecommunications Satellite Organization (ITSO), Convention on the International Mobile Satellite Organization (IMSO). It signed the Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite (BRS).

Brazil was also one of the first members of COPUOS and is a member of the ITU and the IAF; it is one of the priorities of INPE to financially contribute to the IAF. Brazil is a member of the IAU through its Brazilian Astronomical Society, Sociedade Astronômica Brasileira.

[389] INPE (2021, July 29). *Ações e Programas*. Ministro da Ciência, Tecnologia e Inovação. https://www.gov.br/inpe/pt-br/acesso-a-informacao/acoes-e-programas
[390] AEB (2021, June 28). *Entregues medalhas da Olimpíada Brasileira de Astronomia e Astronáutica*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/entregues-medalhas-da-24a-olimpiada-brasileira-de-astronomia-e-astronautica
[391] AEB (2021, June 09). *AEB participa do Seminário Internacional de Astronomia e Astronáutica*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/aeb-participa-do-seminario-internacional-de-astronomia-e-astronautica

During the 2021 COPUOS Scientific and Technical Subcommittee, Brazil has been vocal about the importance of discussing and implementing discussions on the long-term sustainability of outer space, and said it was the "*single most important item in their agenda*".[392] Amongst others, it points to the opportunities but also challenges stemming from increased New Space activities and their impact on the outer space environment.[393] It also took a stance on space debris and related threats.[394]

3.5.5 Constellation developments

Two constellations are planned in Brazil, both in their early stages. One is private, the other public. Firstly, Alya is working on an Earth observation constellation of nanosatellites. The company, founded in 2019, is committed to sustainable development and resolute in "*incorporating Agenda 2030 in its goals*" and supports at least 15 UN SDGs.[395]

Secondly, the AEB announced the Catarina constellation in 2020, and has effectively been concretizing the project since May 2021.[396] The network will initially involve a set of thirteen satellites destined for Earth observation. Its applications will mainly be used for civil defense and agribusiness.[397] At around 1 kg each, they should be manufactured and launched by indigenous capabilities.

3.6. Canada

3.6.1 National law

Canada's relevant legal framework consists of the Canadian Remote Sensing Space Systems Act (RSSSA), the Canadian Client Procedures Circular for Licensing of Space Stations, and the Canadian Space Agency Act.[398] These instruments contain requirements that Canadian space systems operators must adhere to in order to obtain licenses from the respective Ministries. Information on all authorized and approved Canadian satellites is included in an open registry.[399]

[392] Brazil (2021, April 19). Agenda Item 12. Scientific and Technical Sub Committee, COPUOS. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-19-PM-Item12-07-BrazilE.pdf
[393] Brazil (2021, April 19). Agenda Item 12. Scientific and Technical Sub Committee, COPUOS. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-19-PM-Item12-07-BrazilE.pdf
[394] Brazil (2021, April 21). Agenda Item 7, Space Debris. Scientific and Technical Sub Committee, COPUOS. https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-21-AM-Item07-08-BrazilE.pdf
[395] Alya (n.d.). https://alyananosatellites.com
[396] AEB (2020, October 29). *Agência Espacial Brasileira fecha parceria para produção de constelação de satélites*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/agencia-espacial-brasileira-fecha-parceria-para-producao-de-constelacao-de-satelites; AEB (2021, May 13). *Constelação Catarina começa a sair do papel*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/constelacao-catarina-comeca-a-sair-do-papel
[397] AEB (2021, May 13). *Constelação Catarina começa a sair do papel*. Ministério da Ciência, Tecnologia e Inovações. https://www.gov.br/aeb/pt-br/assuntos/noticias/constelacao-catarina-comeca-a-sair-do-papel
[398]Remote Sensing Space Systems Act (S.C. 2005, c. 45). Retrieved from the Justice Laws website:https://laws-lois.justice.gc.ca/eng/acts/R-5.4/; Government of Canada (n.d.) *Canadian Procedures Circulars—Space Stations.* https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06136.html; Canadian Space Agency Act (S.C. 1990, c. 13). Retrieved from the Justice Laws website https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html
[399] Government of Canada (August 19, 2021). *Authorized and Approved Canadian Satellites*. https://bit.ly/3Elw5L7

Remote Sensing Space Systems Act (RSSSA)

The RSSSA lists requirements for remote sensing systems, which are granted licenses by the Minister of Foreign Affairs.[400] Some environmental considerations concerning the disposal of satellite systems are contained in Section 9, "System disposal plan and arrangements." For example, applicants must submit a disposal plan that "*provides for the protection of the environment, public health and the safety of persons and property*," and satisfactory arrangements guaranteeing that "*the performance of the licensee's obligations under the system disposal plan*."[401] Under section 9(3) the Minister is given the power, under certain circumstances, to amend a system disposal plan either on application or on the Minister's own initiative.[402]

The RSSSA is accompanied by an Operating Licence Application which considers both Canada's obligations under the Liability Convention and the Space Debris Mitigation guidelines. Section 6.2[403] elaborates on the disposal plan requirements, first by expressing Canada's responsibilities under the Liability Convention, then stating that "t*he disposal plan is a means for the Government to ensure that a Licensee meets these obligations*."[404]Section 6.2 also stipulates that the "*disposal plans are required to meet the Space Debris Mitigation guidelines of the UN Committee on Peace Uses of Outer Space*." Additionally, operators are required to provide a description of the disposal process, including the components and data. If a ground station is to be terminated, operators must also "*describe the procedures to restore the physical site to a state required by environmental laws*."[405]

No specific mention of the 'space environment' appears within the RSSSA, but rather a mention of the environment in a more general sense. Indeed, the disposal plan requirements[406] somewhat embody the protection of the space environment through requiring debris mitigation plans that abide by the IADC guidelines. Impacts on astronomy are not directly mentioned in the RSSSA.

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[400] Remote Sensing Space Systems Act (S.C. 2005, c. 45). Retrieved from the Justice Laws website:https://laws-lois.justice.gc.ca/eng/acts/R-5.4/

[401] Remote Sensing Space Systems Act (S.C. 2005, c. 45). Retrieved from the Justice Laws website:https://laws-lois.justice.gc.ca/eng/acts/R-5.4/

[402] Remote Sensing Space Systems Act (S.C. 2005, c. 45). Retrieved from the Justice Laws website: https://laws-lois.justice.gc.ca/eng/acts/R-5.4/

[403] Government of Canada (March 8, 2021). *Remote Sensing Space Systems Act — Operating licence application guide.*https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/RSSSA-guide-LSTS.aspx?lang=eng#6.2

[404] Government of Canada (March 8, 2021). *Remote Sensing Space Systems Act — Operating licence application guide*. https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/RSSSA-guide-LSTS.aspx?lang=eng#6.2

[405] Government of Canada (March 8, 2021). *Remote Sensing Space Systems Act — Operating licence application guide.*https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/RSSSA-guide-LSTS.aspx?lang=eng#6.2

[406] Government of Canada (March 8, 2021). *Remote Sensing Space Systems Act — Operating licence application guide*. https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/RSSSA-guide-LSTS.aspx?lang=eng#6.2

Canadian Client Procedures Circular for Licensing of Space Stations

There are four Canadian Client Procedures Circulars applicable to space stations: CPC-2-6-01 — Procedure for the Submission of Applications to License Fixed Earth Stations and to Approve the Use of Foreign Satellites in Canada; CPC-2-6-02 — Licensing of Space Stations; CPC-2-6-06 — Guidelines for the Submission of Applications to Provide Mobile Satellite Services in Canada; and CPC-2-6-07 — Roaming of Foreign Satellite News Gathering (SNG) Transportable Earth Stations in Canada.[407] They each detail requirements and specifications that applicants must meet when operating Canadian satellites or when broadcasting from foreign satellites to Canadian territory.

Of the procedures for space stations, CPC-2-6-02 — which covers the requirements for both geostationary (GSO) and non-geostationary (NGSO) systems[408] — is the most relevant in terms of environmental mitigation relating to satellite operations. CPC-2-6-02 stipulates that under the Radiocommunication Act "*radio licences, spectrum licences, or other types of authorizations*" are to be granted by the Minister of Innovation, Science and Economic Development Canada (ISED).[409] To obtain a license, an operator must apply for either "*a spectrum licence for fixed-satellite services (FSS)*", "*broadcasting-satellite services (BSS) satellites and mobile satellite services (MSS) satellite*," or "*a radio licence for all other satellite services (including Earth exploration, space research, etc), as well as for the FSS spectrum used solely for telemetry, telecommand and control (TT&C) and feeder links for MSS satellites*." The CPC uses a first-come, first-served (FCFS) system for granting the use of satellite spectrum.

Section 3.3.3 considers the outer space environment in that it requires a disposal plan adhering to both IADC debris mitigation guidelines and ITU recommendations:

> *For all satellites (GSO and NGSO), a plan must be submitted that describes, in operational detail, how the satellite(s) will be deorbited, and what other measures will be implemented to mitigate the possibility of orbital debris. For GSO satellites, the plan must be in accordance with Recommendation ITU–R S.1003-2, Environmental Protection of the Geostationary Satellite Orbit.*[410] *For NGSO satellites, the plan must be consistent with the guidelines issued by the Inter-Agency Space Debris Coordination Committee, including the requirement for the satellite(s) to de-orbit within 25 years of end of operational life*.[411]

[407] Government of Canada (n.d.) *Client Procedure Circulars — Space Stations.* *https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06136.html*

[408] Government of Canada (n.d.) *CPC-2-6-02 — Licensing of Space Stations.* https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html

[409] Government of Canada (n.d.) *CPC-2-6-02 — Licensing of Space Stations.* https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html

[410] Found at https://www.itu.int/rec/R-REC-S.1003/en

[411] Government of Canada (n.d.) *CPC-2-6-02 — Licensing of Space Stations.* https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html

These requirements are derived from the broader United Nations (UN) space debris mitigation guidelines,[412] which cover many elements, including:

- limiting debris released during normal operations
- minimizing the potential for break-ups during operational phases
- limiting the probability of accidental collision in orbit
- avoiding intentional destruction and other harmful activities
- minimizing potential for post-mission break-ups resulting from stored energy
- limiting the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit region after the end of their mission and
- limiting the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit region after the end of their mission

The recommendations referred to in this section directly mention the outer space environment in their full texts. For example, the "Background" of the IADC guidelines states in part: "…*The prompt implementation of appropriate debris mitigation measures is therefore considered a prudent and necessary step towards preserving the outer space environment for future generations*." Similarly, in ITU-R S.1003-2, the protection of the outer space environment — particularly the geostationary environment — is mentioned in the title and throughout the document guidelines.[413]

Section 3.2.4 requires that applicants include a technical plan with basic information about their system design including "*schematic of the network location of the ground facilities*," and "*gateways and coverage maps*." Operators must also present information about their system's orbital parameters.

Environmental impact assessments and public consultation in accordance with the Canadian Environmental Assessment Act are required under CPC-2-6-01, but only for ground stations that facilitate satellite operations.[414] This is mostly to ensure human exposure to radio frequency fields is not surpassing a safe limit.

[412] http://www.unoosa.org/documents/pdf/spacelaw/sd/COPUOS_space_debris_mitigation_guidelines.pdf

[413] https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1003-2-201012-I!!PDF-E.pdf

[414] Government of Canada (September 21, 2021) CPC-2-6-01 — Procedure for the Submission of Applications to License Fixed Earth Stations and to Approve the Use of Foreign Satellites in Canada. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01940.html; Canadian Environmental Assessment Act, 2012 (S.C. 2012, c. 19, s. 52). Retrieved from the Justice Laws website: https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html https://laws-lois.justice.gc.ca/eng/acts/C-15.21/page-1.html

An important consideration about the Client Procedures Circulars is that a 2017 public consultation led to changes in the licensing requirements for FSS and BSS NGSO satellites[415] to "*reflect the increasing commercial deployment*"[416] of satellite mega-constellations. Companies including OneWeb, SpaceX, Telesat, and others were involved in the process.[417] Among the changes are clarified implementation milestones for large commercial constellations, including that "large constellations" be defined as systems that consist of 30 or more satellites; omission of the requirement that the Department of Innovation, Science and Economic Development Canada assess "*coexistence with authorized and approved Canadian NGSO systems*"; and that there be no limit imposed on "*the number of licences issued per frequency band for any NGSO systems*."[418]

Prior to the 2017 consultation, Canadian satellite licensing policy was updated in 2014 with revisions to the FCFS policy, implementation of FCFS licensing for FSS and BSS systems, and the introduction of spectrum requirements for FSS and BSS system. An additional spectrum licensing fee was added in 2016.[419] The aforementioned 2017 consultation allowed the Canadian government to gauge the appropriateness of the 2014 changes in the context of large commercial satellite constellations. Another consultation, regarding specifics about licensing fees, is taking place at the time of the writing of this report.[420]

The Canadian Space Agency Act

The Canadian Space Agency Act acknowledges the importance of space science and the peaceful use of outer space. For instance, the objects of the Agency are to "*promote the peaceful use and development of space, to advance the knowledge of space through science and to ensure that space science and technology provide social and economic benefits for Canadians*".[421] There is no specific mention of 'astronomy' in the Act, although 'space science' does encompass astronomy. No mention

[415] Government of Canada (March 2017). Consultation on the Licensing Framework for Non-Geostationary Satellite Orbit (NGSO) Systems and Clarification of Application Procedures for All Satellite Licence Applications. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11263.html

[416] Government of Canada (March 2017). Consultation on the Licensing Framework for Non-Geostationary Satellite Orbit (NGSO) Systems and Clarification of Application Procedures for All Satellite Licence Applications. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11263.html

[417] Government of Canada (June 2017). Decisions on the Licensing Framework for Non-Geostationary Satellite Orbit (NGSO) Systems and Clarification of Application Procedures for All Satellite Licence Applications. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11302.html.

[418] Government of Canada (June 2017). Decisions on the Licensing Framework for Non-Geostationary Satellite Orbit (NGSO) Systems and Clarification of Application Procedures for All Satellite Licence Applications. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11302.html.

[419] Government of Canada (March 2017). Consultation on the Licensing Framework for Non-Geostationary Satellite Orbit (NGSO) Systems and Clarification of Application Procedures for All Satellite Licence Applications. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11263.html

[420] Government of Canada (August 2021) Consultation on Updates to the Licensing and Fee Framework for Earth Stations and Space Stations in Canada. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11723.html#s1.

[421] Canadian Space Agency Act (S.C. 1990, c. 13). Retrieved from the Justice Laws website https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html Objects (4) of the Act.

of the space environment is present. The emphasis, again, is mainly on the development of the commercial space sector, as it is stated that "*commercial exploitation of space capabilities, technology, facilities and systems*" is encouraged.[422] This encouragement takes the form of "*grants and contributions in support of programs or projects relating to scientific or industrial space research and development and the application of space technology*".[423] The rationale behind this sort of incentive is to "*determine the commercial potential of that science and technology, but not including any programs or projects relating solely to the commercial exploitation of space science or technology*".[424]

3.6.2 National policy

Canada has produced a general space strategy that outlines a national "vision for space" in the context of new developments — from commercial sector growth and national security, to advances in space science and the Lunar Gateway project. [425]

The document commits Canada to sustain investment in space activities, with an emphasis on international partnerships and commercial sector partnerships. One of the strategy's goals is to create "*simpler, clearer and more modern regulatory systems*," by reviewing "*Canada's regulatory framework for space-related activities to ensure they provide timely responses for industry, maintain strategic oversight for national security and enable commercial growth*."[426]

Protection of the space environment is not explicitly mentioned. However, a brief consideration of promoting a sustainable space sector is included in the document's "Vision Statement", in which Canada "*recognizes the space sector (as) a strategic national asset and seeks to ensure Canada remains a spacefaring nation*".[427] Further, as part of this new vision, Canada puts the sustainability of the space sector at the forefront and emphasizes that a whole-of-government approach is needed.[428] It indicates that Canadian space exploration will create more partnerships with industry in order to create new jobs, and will seek to inspire youth, to solve everyday challenges faced by citizens and to "*unlock the secrets of our universe*".[429]

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[422] Canadian Space Agency Act (S.C. 1990, c. 13). Retrieved from the Justice Laws website https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html "Functions" 2(d) of the Act
[423] Canadian Space Agency Act (S.C. 1990, c. 13). Retrieved from the Justice Laws website https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html "Functions" 3(c) of the Act
[424] Canadian Space Agency Act (S.C. 1990, c. 13). Retrieved from the Justice Laws website https://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html "Functions" 3(c) of the Act
[425] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.
[426] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.
[427] https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf (Page
[428] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.
[429] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.

The sustainable use of space is also mentioned under the "Space Policy" section on the Canadian government's website [430] which reads in part: "(…) *Canada works in close partnership with the US and other space-faring nations to ensure the safe, secure and sustainable use of space. As such, Canada supports international initiatives suggesting a step-by-step approach to address space security*." The page then cites the four core space treaties as being the "*most important global treaties to ensure the safe, sustainable use of outer space*."[431]

Going back to the space strategy document, there is mention of the importance of astronomy, and Canada's commitment to it and other space science projects. See some of the following examples:

- "*Canada has made significant contributions to major astronomy and planetary exploration missions in the form of payloads and technologies*." [432]
- "*Canada's space scientists are world-renowned and experts in many disciplines, including astronomy, atmospheric, Earth systems, planetary, solar-terrestrial, and space life sciences. In fact, Canadian scientists are helping further humanity's understanding of the causes of climate change, the effects of pollution on our environment, and the origins of the universe.*"[433]
- "*Enable scientific opportunities and global partnerships: Building on the Government's historic investment of nearly $4 billion in research and the next generation of scientists, Canada's participation in the Gateway will open new opportunities for space science in Canada, including global partnership opportunities for Canada's astronomers and planetary scientists to continue their efforts to probe the origins of the universe and explore new worlds (…)*"[434]

No protection for astronomical science, issues of light pollution, or other issues related to astronomy are mentioned in the document.

Also of interest is Canada's support of dark skies through "Parks Canada". In fact, the Parks Canada website states that it "*protects more dark skies than any other agency or jurisdiction in the world*".[435] The program is a collaboration between Parks Canada and the Royal Astronomical Society of Canada

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[430] Government of Canada (January 13, 2021) *Space policy and the Remote Sensing Space Systems Act (RSSSA).* https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/space-espace.aspx?lang=eng

[431] Government of Canada (January 13, 2021) *Space policy and the Remote Sensing Space Systems Act (RSSSA).* https://www.international.gc.ca/world-monde/issues_development-enjeux_developpement/peace_security-paix_securite/space-espace.aspx?lang=eng

[432] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.

[433] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.

[434] Canadian Space Agency (2019). A New Space Strategy For Canada. Retrieved from the Government of Canada website: https://www.asc-csa.gc.ca/pdf/eng/publications/space-strategy-for-canada.pdf.

[435] Parks Canada (September 22, 2021) *Dark-Sky Preserves.* https://www.pc.gc.ca/en/voyage-travel/experiences/ciel-sky. See full list of dark-sky protected areas here: https://rasc.ca/lpa/dark-sky-sites

(RASC)[436], which designates areas as Dark-Sky Preserves, Urban Star Parks, and Nocturnal Preserves. In order to obtain a designation as one of the three types of parks, a minimum light abatement management plan is required to be in place. Parks Canada oversees thirteen Dark-Sky Preserves, one of which is an International Dark Sky Preserve, crossing the border into the United States.[437]

Another important development in the country is Canada's Space Advisory Board,[438] which has been engaging with Canadians to develop new national space strategies.[439] Those strategies, following the lines of the Vision will serve to grow the economy, innovate, and inspire the next generation of space scientists.[440]

In a document called *Consultation Paper for the Space Advisory Board: Driving Canada's Future in Space*, there is a brief mention of astronomy as being connected to space exploration and being part of space sciences.[441] Indeed, Canada plans to keep engaging "*across the space science disciplines, including life sciences, planetary science, astronomy, Earth system science, atmospheric science and solar terrestrial science*".[442] Additionally, emerging issues related to the space environment are raised. It is recognized that although efforts are being made at international and national level to keep space activities safe, sustainable, and responsible, space is not regulated well enough, despite space assets' being highly vulnerable and the continuous lowering of the technological threshold to access space.[443] Threats to be wary of and resulting from both manmade and natural occurrences are listed, such as potential adversaries, space weather, and space debris.[444]

3.6.3 National astronomy programs

The CSA does support space astronomy but is not directly involved with ground-based astronomy. CSA's involvement has historically been opportunistic and being an important but less than 10% partner — in terms of investment and other contributions — on projects. The LEAP program[445] is one of

[436] RASC is a large and active citizen astronomer organization in Canada.
[437] Parks Canada (September 26, 2019). *Waterton-Glacier International Peace Park.* *https://www.pc.gc.ca/en/culture/spm-whs/sites-canada/sec02l*
[438] Government of Canada (February 26, 2021) *Canadian Space Industry.* https://www.ic.gc.ca/eic/site/082.nsf/eng/h_03983.html
[439] Government of Canada (February 26, 2021) *Canadian Space Industry.* https://www.ic.gc.ca/eic/site/082.nsf/eng/h_03983.html
[440] Government of Canada (February 26, 2021) *Canadian Space Industry.* https://www.ic.gc.ca/eic/site/082.nsf/eng/h_03983.html
[441] Government of Canada (August 20, 2018). *Consultation Paper for the Space Advisory Board: Driving Canada's Future in Space.* https://www.ic.gc.ca/eic/site/082.nsf/eng/03984.html
[442] Government of Canada (August 20, 2018). *Consultation Paper for the Space Advisory Board: Driving Canada's Future in Space.* https://www.ic.gc.ca/eic/site/082.nsf/eng/03984.html
[443] Government of Canada (August 20, 2018). *Consultation Paper for the Space Advisory Board: Driving Canada's Future in Space.* https://www.ic.gc.ca/eic/site/082.nsf/eng/03984.html
[444] Government of Canada (August 20, 2018). *Consultation Paper for the Space Advisory Board: Driving Canada's Future in Space.* https://www.ic.gc.ca/eic/site/082.nsf/eng/03984.html
[445] Government of Canada (May 21, 2020). *About the Lunar Exploration Accelerator Program.* https://www.asc-csa.gc.ca/eng/funding-programs/programs/leap/about.asp

the largest efforts at this time but is not focused on astronomy.[446] Canada has also been providing instruments for the James Webb Space Telescope (JWST).

There is the Canadian Astronomical Society (CASCA),[447] the Canadian professional society of astronomers. CASCA is responsible for developing Canada's Long-Range Plan for Astronomy,[448] an exercise that was conducted in 2019/2020, with ongoing ramifications. At CASCA, the Joint Committee on Space Astronomy (JCSA) meets regularly with the CSA. As the committee's name implies, the JCSA is focused on astronomical operations in space.[449]

The Association for Canadian Universities for Research in Astronomy (ACURA) is a consortium of universities that organize large observing programs in Canada. As per their website, "*ACURA is a liaison between Canadian member universities and international partners designed to help coordinate large-scale national initiatives of its member institutions, and advocate for the priorities in the Canadian Astronomical Society's Long-Range Plan*."[450] Two of ACURA's major ongoing projects include the VLOT/TMT and SKA.

3.6.4 International involvement

Canada has ratified the four core space treaties — the OST, Rescue Agreement, Liability Convention, and the Registration Convention. It also played an active role in the drafting of the Long-term Sustainability of Outer Space Activities Guidelines (LTS). A statement commits that Canada will continue working with all member states toward the "*national implementation of the preamble and 21 guidelines*."[451] The LTS guidelines have further been recognized by Canada as a crucial element in the promotion of ongoing international discussion regarding the rules for emerging space activities.[452] The Canadian Space Agency (CSA) is also a member of the IADC and played a role in the creation of the Space Debris Mitigation Guidelines. The CSA has committed to applying the guidelines to all projects undertaken by the Agency.[453]

In addition to space related instruments, Canada has ratified international treaties that could be relevant to other environmental effects associated with re-entering satellites (e.g. alumina

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[446] Although it could support astronomy.
[447] Canadian Astronomical Society (n.d.). https://casca.ca/
[448] Canadian Astronomical Society (n.d.). *Long Range Plan 2020-2030.* https://casca.ca/?page_id=11499
[449] Canadian Astronomical Society (n.d.). *Ground-Based Astronomy Committee.* https://casca.ca/?page_id=281.
[450] ACURA (n.d.) *About Acura*. https://www.astro-acura.ca/en/about
[451] United Nations Committee on Peaceful Uses of Outer Space (2020 February 3-14) 57th UNCOPUOS STSC 2020: Canadian Statement on Agenda Item — 13 Long-term sustainability of outer space activities, *UNOOSA.* https://www.unoosa.org/documents/pdf/copuos/stsc/2020/statements/2020-02-04-AM-Item13-02-CanadaEF.pdf
[452] Government of Canada (October 26, 2021). *A framework for future space explorations activities — background information.* https://www.asc-csa.gc.ca/eng/astronomy/moon-exploration/framework-future-space-exploration-activities-background-info.asp
[453] https://www.unoosa.org/documents/pdf/spacelaw/sd/Canada.pdf

deposition), including the Convention on Long-range Transboundary Air Pollution (CLRTAP)[454] and the Vienna Convention on the Protection of the Ozone Layer (VCPOL).[455]

3.6.5 Constellation developments

There are no recorded issues of brightness from Canadian-based satellite constellations. Manufacturer information is available for a few Canadian-based constellations: The Government of Canada's RADARSAT is being manufactured by MDA, while Kepler Communications satellites are internally produced. We were unable to find manufacturer information on the remaining constellations: Telesat, NorthStar Earth, Space Inc., UrtheCast, CB2.0 Communications, GHGSat, Helios Wire, Wyvern, Aireon, exactEarth and Stealth.

3.7 Chile

In general, most of the legislative and policy documentation relates to aspects of security and defense, environment, and telecommunications. In different texts, space activities are understood as referring to EO mainly, but not in relation to the observation of outer space. In this context, the construction of satellites and access to information from them are paramount, as they have a civilian use — observation of the national territory, the ocean, agricultural activity, the behavior of atmospheric variables, the thickness of arctic ice, and the evolution of forests, among other things. To date, Chile does not have a National Space Agency — from 2001 to 2011 the Chile Space Agency (ACE) existed. In its place, the following institutions took some of its responsibilities: the Ministry of National Defence; the Ministry of Transportation and Telecommunications; the Ministry of Science, Technology, Knowledge and Innovation; and the Council of Ministers for Space Development (CMSD, created in 2014) — all of them are governmental. Nevertheless, the National Space Centre (CEN) is planned to be inaugurated in 2022. Chile does not have a clear institutional framework for space matters (national space policy). The military sector, especially the air force, contributes to the development of the national space sector.

3.7.1 National law[456]

Chile counts within its national law several relevant decrees and laws.

Decree 818 "Enacting the Convention on International Liability for Damage Caused by Space Objects of 29 March 1972" [Ministry of Foreign Affairs] enacted in 1977, affirms the responsibility of "Launching

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[454] Government of Canada (June 11, 2020). *Long-range transboundary air pollution: protocol on heavy metals*.https://www.canada.ca/en/environment-climate-change/corporate/international-affairs/partnerships-organizations/transboundary-air-pollution-heavy-metals.html

[455] Government of Canada (April 27, 2020). Ozone layer protection: Vienna Convention https://www.canada.ca/en/environment-climate-change/corporate/international-affairs/partnerships-organizations/ozone-layer-protection-vienna-convention.html

[456] https://www.bcn.cl/leychile/

States" for causing damage (described in Art. I) to persons, state property and/or objects launched into space (may be the two previously named). It is governed by international law.

Decree 814 “Enacting the Agreement on The Registration of Objects Launched into Outer Space” [Ministry of Foreign Affairs] enacted in 1981, affirms the responsibility of the "Launching States" for the registration of objects launched into Earth orbit and outer space (e.g. date and place of launch, basic orbital parameters, etc.), information to be provided by the launching states to the UN Secretary General. This decree is relevant as it presents an opportunity to know, for example, how many satellites have been launched by each country (possible regulatory use and also in terms of space debris).

Decree 77 “Enacting the Convention on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies” [Ministry of Foreign Affairs], enacted in 1982, defines the principles governing states regarding the exploration and use of outer space. Thus, Art. I defines: "*The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic and scientific development, and shall be the province of all mankind (...) shall be open for exploration and use by all States without discrimination on the basis of equality and in accordance with international law, and there shall be freedom of access to all regions of celestial bodies (...) shall be open to scientific research, and States shall facilitate and encourage international cooperation in such research*”.

Decree 516 “Enacting the Complementary Protocol Signed With Brazil, Which Establishes the Bilateral Cooperation Programme in the Space Area” [Ministry of Foreign Affairs] In the context of the signature between the Government of the Republic of Chile and the Government of the Federative Republic of Brazil of the Complementary Protocol to the Basic Agreement on Scientific, Technical and Technological Cooperation signed on 1990, which establishes the Bilateral Cooperation Programme in the Space Area; this decree enacted in 1994 defines the cooperation between the two parties. The content mainly relates to: 1) cooperation and policy coordination in international organizations (art. I); 2) academic cooperation and space law (art. II); and 3) scientific cooperation and bilateral programmes (art. III). In the latter, the main focus of the programmes and collaborations is on Earth observation and the use of satellite data, but no mention is made of outer space observation or the development of astronomy as a science.

Decree 1629 “Enacting the Agreement with the People's Republic of China on Cooperation in the Area of Space” [Ministry of Foreign Affairs], was adopted in the framework of the Basic Agreement on Scientific and Technical Cooperation (1981). This bilateral agreement decree enacted in 1997 aims to “*establish a scheme of cooperation in the field of space science and technology between the Parties on the basis of equality, mutual benefit and reciprocity*” (Art. I), which defines as areas of development and implementation: 1) satellite remote sensing technology and applications; 2) technology for satellite manufacturing and experimentation; 3) space science; 4) commercial launch services; 5) spin-offs of space technology; and 6) other areas as may be agreed between the parties (art. III). Similarly to the previous decree (decree 516), the main focus is on Earth observation and satellite developments, but no mention is made of outer space observation or the development of astronomy as a science.

Decree 1160 "Enacting the Agreement with the United Kingdom of Great Britain and Northern Ireland on Liability for Damages Arising from the Launch of The Fasat-Bravo Satellite" [Ministry of Foreign Affairs], enacted in 1998, and as defined by its name, rectifies the responsibilities of the parties with regard to the launch of the satellite and the possible damage associated with it.

Decree 11 "Establishing the Registration of Space Objects Launched into Earth Orbit or Beyond" [Ministry of Foreign Affairs] acts as a continuation and ratification of what is stated in Decree 814. Enacted in 2015, it ratifies the benefit of defining a mandatory system of registration of objects launched into outer space for the implementation and development of international law governing the exploration and use of outer space.

Decree 4 "Approving Chile's National Defence Policy 2020 Edition" [Ministry of National Defence; Undersecretariat for Defence], enacted in 2021, corresponds to the authorisation of the National Defence Policy of the Chilean Ministry of Defence (its content is discussed in the national policy section).

Decree 19 "Creating Ministerial Scientific Advisory Committee on Climate Change", [Ministry of Science, Technology, Knowledge, and Innovation] in the context of the creation of the Ministry of Science, Technology, Knowledge and Innovation (CTCI), and its commitment to collaborate permanently in the articulation of the national scientific community to provide evidence and recommendations to guide the design and implementation of national policies and plans in these matters (fostered by the holding of COP25), the creation of a scientific committee is required to provide the necessary tools to enable the Ministry of CTCI to collaborate effectively and dynamically with the Ministry of Environment and all other public institutions on climate change. In that sense, this decree enacted in 2020 creates the Ministerial Scientific Advisory Committee on Climate Change to advise and support the Minister on climate change matters (article one) framed by both the national and international context (article five). The Committee will be chaired by the Minister of CTCI or his or her designate (article four). The Committee will carry out its functions until December 2022 (article twelve).

Decree 52: Creates a permanent presidential advisory commission on climate change [Ministry of Environment]. Enacted in 2018, this decree creates the Permanent Presidential Advisory Commission on Climate Change, whose function is to advise the President in all matters related to the identification and formulation of policies, plans, programmes, measures and other activities related to climate change, as well as the fulfillment of Chile's international commitments, in particular the Paris Climate Agreement, and in the elaboration and proposal of a national public climate policy (article 1).

Law 20417 “Creating the Ministry, the Environmental Assessment Service and the Superintendence of the Environment” [Ministry General Secretariat of the Presidency] enacted in 2010 (last version modified in 2021), as its name indicates, creates the Ministry of the Environment, the Environmental Assessment Service and the Superintendence of the Environment. Broadly speaking, one of the main objectives is to centralize the supervision of environmental matters for improvement at the national level (purpose associated with civil benefits). In addition, it establishes consultation with local authorities on environmental impact and the possibility of carrying out citizen participation processes in environmental impact statements that refer to projects that generate environmental burdens for nearby communities. There is no explicit mention of issues related to Earth orbit and outer space (matters associated with telecommunications and national defence), or astronomy.

Law 19300 “Approving Law on General Bases of the Environment” [Ministry General Secretariat of the Presidency], enacted in 1994 (last version modified in 2021), gives concrete and legal content to the right guaranteed by the constitution (1980) to live in a pollution-free environment. It is a rather general and gradual framework that defines basic guidelines and responsibilities (it also incorporates the notion of monetary sanctions). No mention is made — either explicitly or implicitly — of astronomy or the use of outer space.

Law 20096 “Establishing Control Mechanisms Applicable to Ozone Depleting Substances” [Ministry General Secretariat of the Presidency] enacted in 2006, presents the general provisions (guidelines, control mechanisms, and penalties) governing the use of ozone-depleting substances, which is based on the Montreal Protocol.

3.7.2 National policy

Several policies and initiatives are relevant to the present issue. The first is the **National Space Policy** (2014–2020)[457], which is not currently active. The second is the **Chile National Defence Policy 2020**[458] [Ministry of Defence of Chile]. It mostly refers to the operation of different space assets, such as satellites and international space stations, in outer space. The policy focuses on the use of outer space for EO purposes (defence and security). Third, from Chile's Ministry of Science, Technology, Knowledge and Innovation, are the **National Science, Technology, Knowledge and Innovation Policy**[459] (2020-2022) and the **Action Plan — National Science, Technology, Knowledge and Innovation**

[457] http://www.mtt.gob.cl/wp-content/uploads/2014/02/politica_espacial_31_01_14.pdf
[458] http://163.247.42.118/transparencia/POLDEF/POLDEF2020/POLDEF2020.pdf
[459] https://www.minciencia.gob.cl/politicactci/documentos/Politica-Nacional-CTCi_Chile-2020.pdf

Policy[460] (2020-2022). In both documents, mention is made of astronomical development, but in terms of monitoring aspects associated with climate change, meteorology, and other aspects of EO ("Future" section).

3.7.3 National astronomy programs

Very broadly speaking, astronomical activity as a **science** falls mainly on the academic and scientific world, i.e., national universities and collaborative projects with foreign organizations/institutions. Within these we can find the study programmes in higher education (undergraduate and postgraduate), the implementation of programmes in schools to promote the choice of scientific careers, and the possibility of funding for research projects by the Chilean National Agency for Research and Development (ANID), among others. Some ministries have units/departments that include astronomy in their areas/lines of work, mostly concentrating on EO. Most of the astronomical activity is in terms of observatories — macro projects such as ALMA — together with initiatives such as scientific dissemination and training programmes run by the academic world (some of these receive public funding). Finally, there are also astronomical societies that contribute to the scientific development of the country through different actions.
The following is a list of some of the activities previously mentioned:

- National Astronomical Observatory of Chile [OAN] — part of the Department of Astronomy of the University of Chile
- Atacama Large Millimeter/submillimeter Array (ALMA)
- SOAR Observatory — administered by the Ministry of Science, Technology and Innovation (Brazil); National Optical Astronomical Observatory (NOAO); Michigan State University and University of North Carolina at Chapel Hill (USA)
- Gemini Observatory, Gemini South Telescope (administered by Gemini and AURA Consortium)
- Vera C. Rubin Observatory (administered by LSST corporation)
- La Silla Astronomical Observatory (administered by ESO)
- Paranal Observatory (administered by ESO)
- Cerro Pochoco Observatory (administered by the Chilean Association of Astronomy and Astronautics ACHAYA)
- ELT (administered by ESO) — under construction
- Chilean Astronomy Society SOCHIAS
- Chilean Astronomy Foundation
- Chilean Skies Foundation
- Directorate for Energy, Science and Technology and Innovation [DECYTI] — hosted by the Ministry of Foreign Affairs, one of the areas of work is astronomy, with the protection of clean

[460] https://www.minciencia.gob.cl/politicactci/documentos/Politica-Nacional-CTCI_Plan_Accion_Chile_2020.pdf

and dark skies being one of the key issues. Bulletins are created with relevant information on this subject.[461]

- The National Coordination System for Territorial Information [SNIT] — hosted by the Ministry of National Assets, it leads the Chilean GeospatialData Infrastructure (IDE Chile).

3.7.4 International Involvement

Chile has been a member of COPUOS since 1973. It has ratified all five UN Space Treaties. It has also ratified other international treaties,[462] such as the:

- Minamata Convention (member since 2018);
- Paris Agreement (member since 2017);
- UNCCD (member since 1997);
- Convención Marco de las Naciones Unidas sobre el Cambio Climático (CMNUCC; member since 1994)
- Montreal Protocol (member since 1990);
- Vienna Convention (member since 1990).

3.7.5 Constellation developments

The new National Satellite System (SNSat) was launched in 2021. This 15-year programme has different phases of operation, the first of which is the replacement of the FASat-Charlie satellite with the FASat-Delta model, which will be put into orbit during the first quarter of 2022. SNSat will comprise ten satellites, including eight satellites that will be manufactured in the CEN (Chile) by Air Force technicians and engineers along with professionals from several Chilean universities. The other two, FASat Delta and FASat Echo 1, will be assembled in Israel.

In addition to the 10 satellites, there will be 3 mini-satellites of less than 100 kilos each (FASat Delta, FASat Echo 1 and FASat Echo 2) and 7 microsatellites of up to 20 kilos (not yet named). The 3 mini-satellites will be launched by SpaceX between 2021 and 2024, and the 7 micro-satellites in the following order: one in 2023, three in 2024 and three in 2025.

In conjunction with SNSat, the National Space Centre (CEN) will be inaugurated in 2022, which will have four areas: a laboratory for manufacturing satellites and payloads; a space mission control center; a geospatial information analysis and processing center; and a Centre for Space Entrepreneurship and Innovation.

[461] The latest bulletin can be found at the following link [in Spanish] https://minrel.gob.cl/politica-exterior/secretaria-general-de-politica-exterior/decyti

[462] https://observatoriop10.cepal.org/es

3.8 Colombia

Colombia has two significant bodies in relation to space development. One is the Colombian Space Commission (CCE), Colombia's government body for the promotion and use of space, created in 2006. The other is the Colombian Space Agency (AEC), which has been operating since 2017 as a private non-profit corporation and has contributed significantly to the development of the national space sector. The AEC was created with the aim of developing the country's aerospace technologies and services industry, allowing it to evolve in the application and development of satellite technologies.[1]

Similarly to Chile and Peru (but mostly the former), most of the documentation on space development relates to satellites and EO for civil and environmental purposes. The predominant discourse is one of security, defense, and development at the national level, in which the construction of satellites and access to information from them is paramount.

3.8.1 National law

Agreement N° 7 ECC "High-level endorsement of the implementation of the National Plan for Earth Observation" (2008): As noted above, the focus on space issues is on EO for civil and environmental purposes. In this sense, this agreement supports the implementation of the National Plan for Earth Observation considering the importance of "*achieving an integral understanding of the Earth System, composed of the climate, oceans, territory, geology, natural resources, ecosystems and the natural and human factors that affect it, [and] in order to improve human health, security and well-being, providing appropriate solutions for the protection of the environment and the achievement of sustainable development objectives*". In addition, Article 4 states that this plan "*involves participatory actions in international initiatives*" such as GEO, GEOSS, COPUOS, among others.

Agreement N° 5 ECC "High-level support to boost the development of satellite projects in Colombia" (2007): Considering that the ECC sees as "*strategic the use of satellite technologies to continue promoting the development of telecommunications, satellite positioning and observation of the national territory*", it is agreed (sole article) to support the steps "*aimed at carrying out the corresponding technical, pre-feasibility and financial studies, which will allow the formulation and implementation of national and international strategies to develop the country's capacities in relation to the acquisition, construction, launch, operation and administration of Colombian satellites*".

Agreement N° 3 ECC "National Space Policy Guidelines" (2007): To establish the policy framework that should guide the functions assigned to the ECC, guidelines and objectives are agreed upon according to seven main fields of action (working teams functioning within the Technical Committee): 1) Telecommunications; 2) Satellite Navigation; 3) Earth Observation; 4) Astronautics, Astronomy and Aerospace Medicine; 5) Knowledge Management and Research; 6) Policy and Legal Affairs; and 7) Colombian Spatial Data Infrastructure (ICDE). In general, the document gives general notions about the responsibilities and/or lines of action of each field. Although astronomy is mentioned in one of these, no further detail is given in relation to the specific development themes.

Agreement N°1 CCE "Rules of Procedure of the Colombian Space Commission" (2006): In general, this document presents the guidelines for the functioning of the commission at the organizational level, as well as the responsibilities and commitments that the commission assumes with its creation.

Decree 2442 of 18 July 2006. By which the Colombian Space Commission is created: As its name indicates, this decree creates the ECC, defining it as the "*inter-sectoral body for consultation, coordination, guidance and planning*" with the objective of "*guiding the execution of the national policy for the development and application of space technologies, and coordinating the elaboration of plans, programmes and projects in this field*" (Article 2). This document presents the general definitions of the ECC, which entities/persons form part of the CCE (e.g. ministries and individuals), its responsibilities and scope, and the general guidelines for its functioning and organization.

Other relevant Decrees include **Decree 2258** of 6 December 2018, whereby rules and procedures are established for the Registration of Objects Launched into Outer Space (Title 9 of Part 2 of Book 2 of Decree 1070 of 2015 is added)**, Decree 328** of 24 February 2016, enacting the "Convention on International Liability for Damage Caused by Space Objects" (1972), and **Decree 1065** of 10 June 2014, enacting the "Convention on Registration of Objects Launched into Outer Space" (1974).

3.8.2 National policy

CONPES 3934 of 2018. GREEN GROWTH POLICY[3]

(National Planning Department; Ministry of Agriculture and Rural Development; Ministry of Labour; Ministry of Mines and Energy; Ministry of Commerce, Industry and Tourism; Ministry of Education; Ministry of Environment and Sustainable Development; Ministry of Housing, City and Territory; Ministry of Transport; Administrative Department of Science, Technology and Innovation; National Administrative Department of Statistics; Hydrology, Meteorology and Environmental Studies Institute; Mining and Energy Planning Unit; Colombian Agricultural Research Corporation)

This 13-year time horizon policy (2018–2030) is aligned with international commitments such as the 2030 Agenda and its Sustainable Development Goals, and it is also articulated with national sectoral and environmental policies and plans.

This document establishes the importance of seeking new sources for sustainable growth, and it is composed by five strategic areas to develop: 1) new economic opportunities based on the sustainable use of natural capital; 2) the use of natural resources in the economic sectors; 3) the generation and strengthening of human capital; 4) to establish strategic actions in science, technology and innovation;

and 5) to define the actions to ensure the inter-institutional coordination and articulation required for the implementation of this policy.

Throughout the document, there is no mention of astronomy or astronomical development.

CONPES 3983 of 2020. SPACE DEVELOPMENT POLICY: ENABLING CONDITIONS FOR BOOSTING NATIONAL COMPETITIVENESS[463]
(National Planning Department; Administrative Department of the Presidency of the Republic; Ministry of National Defence; Ministry of Commerce, Industry and Tourism; Ministry of Information Technology and Communications; Ministry of Science, Technology and Innovation)

This document is the most recent in relation to space policy. It recognises Colombia's debt in establishing long-term guidelines and implementing actions that allow the country to have a significant presence in space issues, despite its geostrategic capacity. It notes that "t*hree CONPES documents have been approved for the purchase of satellites, two for communications and one for Earth observation. All these policy documents were aimed at satisfying specific needs in terms of communications and satellite imagery, without establishing a clear strategy to widely exploit the benefits of these technologies and boost the country's productive development and competitiveness*". With this in mind, this policy aims to "*generate the enabling conditions and the institutional environment so that with a long-term vision the space sector can contribute to the productivity, diversification and sophistication of the country's productive apparatus*".

An action plan is presented, covering mainly 2020 to 2021, which includes various lines of action such as characterisation of the Colombian space market, diagnosis of scientific and technological capacities (both actions are the responsibility of the Ministry of Science, Technology and Innovation, in coordination with the Ministry of Labour), education programmes that seek to "*raise awareness of space issues among citizens in general, with a particular emphasis on the education sector*" (to be carried out by the Ministry of Science, Technology and Innovation, in coordination with the Ministry of Information and Communication Technologies and with the support of the Ministry of National Education and the private sector), among others.

Throughout the document, there is no mention of astronomy or astronomical development.

3.8.3 National astronomy programs

Broadly, it can be said that national astronomy programmes are mostly the responsibility of the academic and private sectors. Governmental actions on space issues focus on satellites and technology for EO, but do not engage with astronomy as a science. Most of the astronomical activity is

[463] http://cce.gov.co/normativa

based on observatories and planetariums, which are hosted and/or associated with universities that offer activities to the general public, although its use is mostly for academic purposes and limited to affiliated students and staff (in addition to external researchers). Preliminarily, it can be said that no national astronomy programmes organized, managed and/or developed by governmental bodies/entities are in place at the moment, although there are proposals for bilateral agreements that can be a potential national astronomy programme in the future. There are also astronomy associations that can be considered as private and are not necessarily related to governmental bodies, some examples being:

- Agustín Codazzi Geographic Institute [IGAC] — Colombian Government entity in charge of producing official maps and basic cartography of the national territory and managing the national cadastral infrastructure and the national land survey. This coordinates the National Image Bank [BNI] in its capacity as national coordinator of the Colombian Spatial Data Infrastructure [ICDE];
- Institute of Hydrology, Meteorology and Environmental Studies [IDEAM];
- National Astronomical Observatory (part of the National University of Colombia);
- Sergio Arboleda University's Astronomical Observatory;
- El Bosque University’s Astronomical Observatory;
- District University’s Astronomical Observatory;
- Planetarium and Observatory — Technological University of Pereira [UTP];
- Planetarium of Bogotá;
- Planetarium of Barranquilla;
- Astronomy Association of Colombia [ASASAC];
- Space Society “National Space Society Colombia”;
- Joint project of the Ecuadorian Space Agency [EXA] and the Colombian Space Agency [AEC] signed in 2018 to implement the Colombian-Ecuadorian Lunar Programme.

3.8.4 International involvement

Colombia has been a member of COPUOS since 1977. It has ratified the OST, the Liability Convention, and the Registration, and signed the Rescue Agreement. Other ratified international treaties include the Minamata Convention (member since 2019), the Paris Agreement (member since 2018), the UNCCD (member since 1999), the CMNUCC (member since 1995), the Montreal Protocol (member since 1993), the Vienna Convention (member since 1990), and the Escazú Agreement (signed in 2019).[464]

3.8.5 Constellation developments

There are no known constellations under development in the country at this time.

[464] https://observatoriop10.cepal.org/es

3.9 India

3.9.1 National law

Space activities in India are governed by the Department of Space[465] (DoS) and have been primarily conducted through the country's space agency, the Indian Space Research Organization.[466] The DoS functions under Government of India (Allocation of Business) Rules 1961 and directly reports to the Prime Minister's Office. Considering the need for space-specific legislation, in 2017, the DoS released a Draft Space Activities Bill, which awaits enactment from the parliament.[467] The Bill has potential environmental safeguards. It contains sections requiring the operator to secure a license from the Central Government for Commercial Space Activity[468] and the licensee to conduct operations in such a way as to (a) prevent the contamination of outer space or adverse damage or pollution to the environment of Earth, (b) avoid interference with the activities of others in peaceful exploration and use of outer space, (c) avoid any breach of India's international obligations and (d) preserve the public health, sovereignty and integrity of India, the security of the State, the defence of India, friendly relations with foreign states, public order, decency, and morality.[469]

According to the Bill, within 15 days after the license has been granted, the licensee shall provide to the Central Government information relating to date, territory and location of launch, basic orbital parameters such as nodal period, inclination, apogee, perigee and other information the government may deem necessary.[470]

The Bill also seeks to punish those who cause damage or pollution to the environment of Earth, airspace or outer space including celestial bodies.[471] In this way, the Draft Bill has the potential to help mitigate the impact of satellite constellations on astronomy, not merely through its licensing and regulation measures, but particularly through the insurance that breaking the rules will have consequences and be followed by punitive actions. That is if the policy of India implements measures vis-a-vis satellite constellations and their impact on optical and radio astronomy.

After this Draft Bill, a major shift took place in the Indian space sphere in 2020, when the country opened up the full range of space activities to the private space industry. To perform licensing and

[465] Department of Space *hereinafter* DoS
[466]Indian Space Research Organization *hereinafter* ISRO
[467] PRS Legislative Research (2021, September, 21) Draft Space Activities Bill, 2017, *PRS INDIA*
https://prsindia.org/files/bills_acts/bills_parliament/1970/Draft%20Space%20Activities%20Bill%202017.pdf
[468] Draft Space Activities Bill, § 7 (2017)
https://prsindia.org/files/bills_acts/bills_parliament/1970/Draft%20Space%20Activities%20Bill%202017.pdf
[469] Draft Space Activities Bill, § 8 (2017)
https://prsindia.org/files/bills_acts/bills_parliament/1970/Draft%20Space%20Activities%20Bill%202017.pdf
[470] ibid
[471] Draft Space Activities Bill, § 16 (2017)
https://prsindia.org/files/bills_acts/bills_parliament/1970/Draft%20Space%20Activities%20Bill%202017.pdf

supervision of private space activities as per Article VI of the OST, the government established a single-window Nodal Agency called Indian National Space Promotion and Authorization Centre (IN-SPACe). The role and responsibilities of IN-SPACe are to authorize and monitor private space activities and actors (known as NGPEs — Non Governmental Private Entities).[472] For the purposes of authorization, IN-SPACe will perform a multi-disciplinary review through its assessment mechanism consisting of a Legal Directorate, Technical Directorate, Security Directorate and a continuous Supervision by IN-SPACe Monitoring Directorate in consideration with the safety norms, Security Norms, Statutory Guidelines and Clearances.[473] The IN-SPACe Monitoring Directorate shall report back to IN-SPACe for any corrective actions and resolutions. Applicants requiring permissions/authorizations for space activities will be able to monitor the progress of their applications through the IN-SPACe on-line portal.[474]

In future, IN-SPACe could be able to monitor the designs and operations of the space objects operated by private entities vis-a-vis their brightness and reflectivity to ensure that their impact on astronomy and the dark and quiet skies is mitigated or possibly prevented.

India being a signatory of the Registration Convention, it duly registers its space objects at its national registry maintained by the DoS[475] and has continuously given to the UN Secretary General information about its space objects as per Article IV of the Registration Convention.[476] So far, India has made 53 such submissions from 1982 to 2021.[477] The registration mechanism of India's space objects should therefore be robust enough to cater to the registration of potential Indian satellite constellations in future.

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[472] Department of Space, Indian Space Research Organization (2021, September 21) Indian National Space Promotion and Authorization Centre, Roles and Responsibilities, *Indian Space Research Organization* https://www.isro.gov.in/indian-national-space-promotion-and-authorization-center-space/roles-and-responsibilities

[473] Department of Space, Indian Space Research Organization, (2021, September 21) Indian National Space Promotion and Authorization Centre, Process for IN-SPACe permission, *Indian Space Research Organization* https://www.isro.gov.in/indian-national-space-promotion-and-authorization-center-space/process-space-permission
Department of Space, Indian Space Research Organization (2021, September 21) Indian National Space Promotion and Authorization Centre, Roles and Responsibilities, *Indian Space Research Organization* https://www.isro.gov.in/indian-national-space-promotion-and-authorization-center-space/roles-and-responsibilities

[474] Department of Space, Indian Space Research Organization (2021, September 21) Indian National Space Promote and Authorization Centre, Monitoring and Promotion Directorate of IN-SPACe, I*ndian Space Research Organization* https://www.isro.gov.in/indian-national-space-promotion-and-authorization-center-space/monitoring-and-promotion-directorate

[475] United Nations Office for Outer Space Information Furnished by the Permanent Mission of India to United Nations in a letter dated 11 February 1987, (1987, March 4) *Information Furnished under the Convention on Registration of Objects launched into Outer Space* UN Doc ST/SG/SER.E/INF/8 https://www.unoosa.org/pdf/reports/regdocs/SER_INF_008E.pdf

[476] United Nations Office for Outer Space (2021, September 21) Registration Submissions under Article IV of The Convention on the Registration of Objects Launched into Outer Space, *UNOOSA* *https://www.unoosa.org/oosa/en/spaceobjectregister/submissions/india.html*

[477] United Nations Office for Outer Space (2021, September, 21) Notification from States &Organizations: India United Nations Office for Outer Space Affairs *UNOOSA* https://www.unoosa.org/oosa/en/spaceobjectregister/submissions/india.html

Currently, India's policy, supervision and regulatory frameworks are evolving to accommodate the growing private sector and the subsequent increase in operational satellites with the aim of ensuring the safety and security of space operations and space assets. The establishment of IN-SPACe is the right initiative to solidify India's commitment to the COPUOS LST guidelines and this can further be backed by promulgating the Space Activities Bill in the near future with necessary accommodations in consideration of these recent institutional changes in India's space sector. Although there is no express reference in the regime to the impact of satellite constellations on astronomy, the regime is well equipped to accommodate the policy requirements of mitigating such impacts in the future when the government decides to implement them.

3.9.2 National policy

Currently India has drafted new space policies such as the Draft Space Based Communication Policy 2020, the Draft Norms, Guidelines and Procedures for implementation Spacecom Policy 2020,[478] the Draft Space Based Remote Sensing Policy 2020, the Draft Humans in Space Policy for India, 2021 and the Draft National Space Transportation Policy 2020[479].

India is a member of the ITU and a party to the ITU Convention. Thereby, considering India's international commitment to the ITU regime, the Draft Norms, Guidelines and Procedures for implementation Spacecom Policy 2020 mandates the DoS to protect and enhance orbital resources,[480] and IN-SPACe to grant necessary authorizations and permissions for all activities related to satellite communications, to or from Indian territory, as per the applicable acts, regulatory provisions and exemptions and statutory guidelines.[481] The DoS is empowered to bring in necessary policies and guidelines to govern this authorization process according to need. Further, the Draft Spacecom Policy mandates the space communication system operator to provide important technical information, *inter-alia* orbital parameters, perform interference analysis during the orbit and frequency application to ensure an interference-free operation[482] and also offer an undertaking of non-interference.[483] This will be an important policy to ensure that orbits and frequencies are used in an efficient, equitable manner and to avoid interference with the peaceful exploration and use of outer space which can

[478] Draft Spacecom Policy (2020); Draft Spacecom NGP (2020) https://www.isro.gov.in/sites/default/files/draft_spacecom_policy_2020.pdf
[479] Draft National Space Transportation Policy (2020) https://www.isro.gov.in/sites/default/files/draft_national_space_transportation_policy.pdf
[480] Draft Norms, Guidelines and Procedures for Implementation of Space Based Communication Policy of India § 7 (2020) https://www.isro.gov.in/sites/default/files/draft_spacecom_policy_2020.pdf
[481] Draft Norms, Guidelines and Procedures for Implementation of Space Based Communication Policy of India § 8 (2020) https://www.isro.gov.in/sites/default/files/draft_spacecom_policy_2020.pdf
[482] Department of Space, Indian Space Research Organization (2020) Application for establishment of space-based system for communications over India (using Indian orbit resources) Form A *Indian Space Research Organization* https://www.isro.gov.in/sites/default/files/draft_spacecom_policy_2020.pdf
[483] ibid

include radio astronomy. Thus the Draft Satcom Policy 2020 has provisions that can be used to ensure that Indian satellites orbiting Earth do not interfere with radio astronomy.

3.9.3 National astronomy programs

Being the land of the great astronomer Aryabhata and the historical marvel of Jantar Mantar, an archaeoastronomical and a UNESCO world heritage site,[484] India has a rich astronomical heritage and culture. India has its own multiwavelength space observatory, ASTROSAT, launched in 2015[485] and has also proposed promising space-based astronomy programs for the future. At the ground level, it has several ground-based telescopes, notably the Indian Astronomical Observatory in Hanle, Ladakh, the 9th-highest optical telescope site in the world[486], which hosts GROWTH, India's first robotic telescope, and has been emerging as a preferred location for infrared and optical astronomy studies according to studies by Royal Astronomical Society,[487] the Solar Observatory in Kodaikanal with its H-alpha telescope,[488] the Giant Metrewave Radio Telescope in Maharashtra[489] and the Devasthal Observatory run by the Aryabhatta Research Institute of Observational Sciences (ARIES).[490] The country is also establishing the 3rd LIGO detector in Maharashtra in collaboration with the USA.[491]

These are just a few of the several observatories and telescopes across the country. These initiatives indicate India's prominence in both space-based and ground-based astronomy.

Finally, in the area of astronomy-based tourism, the Indian Institute of Astrophysics along with the government is drawing up plans for establishing community-based astro-tourism at Hanle in Ladakh, aimed at promoting sustainable development and popularizing the study of astronomy and astrophysics among the public.[492]

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[484]World Heritage Committee, United Nations Educational Scientific and Cultural Organization, Nomination of the Jantar Mantar, Jaipur for inclusion on World Heritage List, *UNESCO* https://whc.unesco.org/uploads/nominations/1338.pdf

[485] Department of Space, Indian Space Research Organization (2015, September, 28) Astrosat, *Indian Space Research Organization* https://www.isro.gov.in/Spacecraft/astrosat

[486] Indian Institute of Astrophysics (2021, September 21) Indian Astronomical Observatory, Hanle, *Indian Institute of Astrophysics*, https://www.iiap.res.in/?q=centres_iao.htm

[487] India Today (2021,September 30) Indian observatories becoming hot-spot for deep space observations: Study, *INDIA TODAY* https://www.indiatoday.in/science/story/indian-astronomical-observatory-astrophysics-hot-spot-hanle-leh-1859166-2021-09-30

[488] Indian Institute of Astrophysics (2021, September 21) Kodaikanal Solar Observatory (KSO), *Indian Institute of Astrophysics* https://www.iiap.res.in/?q=kodai.htm

[489] National Centre for Radio Astrophysics — Tata Institute of Fundamental Research (2021, September 21) Giant Meter Radio Telescope, *NCRA-TIFR* https://www.gmrt.ncra.tifr.res.in/

[490] Aryabhatta Research Institute of Observational Sciences (2021, September 21) Devasthal Campus, *ARIES* https://www.aries.res.in/about-us/devasthal-campus

[491] (2021, September 21) Laser Interferometer Gravitational-wave Observatory, LIGO India, https://www.ligo-india.in/

[492] (2021, September 21) IIA, govt draw up plans for community-led Astro-tourism in Ladakh, *Times of India* https://timesofindia.indiatimes.com/india/iia-govt-draw-up-plans-for-community-led-astro-tourism-in-ladakh/articleshow/86045533.cms

3.9.4 International involvement

India is a party to the OST, the Return and Rescue and Agreement, the Liability Convention, and the Registration Convention. India is also a signatory to the Moon Agreement.

India was a founding member of COPUOS in 1958 and along with its member states has actively contributed to the Committee's role in the development of treaties, agreements, principles and guidelines. India has been an active proponent of the recently developed LTS guidelines and has remained committed to the national implementation of the guidelines to ensure safe and sustainable space exploration and use through a variety of measures.[493] For example, the Netra airborne early warning system, the UNIspace Nanosatellite Assembly and Training Initiative capacity building program, the Collision Avoidance (COLA) and Space Object Proximity (SOPA) assessments and an ongoing process to develop a green propellant for launch vehicles are some of the active measures initiated by India towards the LTS guidelines.

The current chair of the Working Group on the Long-term Sustainability of Space Activities is R. Umamaheswaran from India.[494] India has also been a member of UNESCO since its inception in 1946. India's role and participation in COPUOS and the LTS 2.0 will be crucial especially if there are any proposals for inclusion of new guidelines related to the impact of satellite constellations on astronomy.

In the area of international cooperation, India is part of the Brazil, Russia, India, China, South Africa (BRICS) Astronomy Working Group (BAWG) that has recommended the networking of existing telescopes in BRICS countries and creating a regional data network. The BAWG is working on building an intelligent telescope and data network, studying transient astronomical phenomena in the Universe, big data, artificial intelligence and machine-learning applications to process the voluminous data generated by enhanced multi-wavelength telescope observatories.[495]

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[493] United Nations Committee on Peaceful Uses of Outer Space (2021 April 19-30) 58th UNCOPUOS STSC 2021: India Statement on Agenda Item — 12 Long-term sustainability of outer space activities, *UNOOSA* https://www.unoosa.org/documents/pdf/copuos/stsc/2021/statements/2021-04-19-PM-Item12-01-IndiaE.pdf

[494] United Nations Committee on Peaceful Uses of Outer Space (2021, August, 26) Proposal by the Chair of the Working Group on the Long-term Sustainability of Outer Space Activities, Terms of reference, methods of work and work plan of the Working Group on the Long-Term Sustainability of Outer Space Activities of the Scientific and Technical Subcommittee, UN Doc A/AC.105/2021/CRP.18, *UNOOSA* https://www.unoosa.org/res/oosadoc/data/documents/2021/aac_1052021crp/aac_1052021crp_18_0_html/AC105_2021_CRP18E.pdf

[495] Press Information Bureau, Government of India (2021, May 21) BRICS countries underline importance of enhancing collaboration among astronomers; *Press Information Bureau* https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1720614; (2021, August, 19) BRICS signs deal on cooperation in remote sensing satellite data sharing, *The Hindu,* https://www.thehindu.com/news/national/brics-signs-deal-on-cooperation-in-remote-sensing-satellite-data-sharing/article35992097.ece

India is also participating in the construction of the pioneering Thirty Meter Telescope in Hawai‘i, USA that has the potential to revolutionize astronomical observations[496] and in the construction of one of the largest radio telescopes in the world, the Square Kilometre Array in Australia and South Africa[497].

3.9.5 Constellation developments

ISRO has the Indian Regional Navigation Satellite System (IRNSS) also known as Navigation Satellite Constellation NavIC, comprising seven satellites for navigational support.

OneWeb by Bharati Airtel and the UK Government are eyeing to offer their services to India by 2022.[498] A range of private startups have also shown interest in launching satellite constellations.[499] Entities such as PIXXEL (EO — planned 36 satellite constellations), Vestaspace Technology (communication satellites — planned 35-plus satellite constellations) and SatSure–Bellatrix Aerospace (satellite imaging) have plans to launch satellite constellations from India.

3.10 Peru

The National Commission for Aerospace Research and Development (CONIDA) is the governing body for space activities in Peru and the headquarters of the Peruvian Space Agency, an institution attached to the Ministry of Defence. At the macro-structural level, CONIDA is composed of six directorates, including:[500]

- **Directorate of Astrophysics (DIAST)** — part of the Technical Directorate of Space Sciences and Applications (DICAE). It is dedicated to the research and development of scientific projects in three main areas: Observational Astronomy, Space Weather and Space Surveillance. Currently DIAST has deployed its instrumentation in three observation centers.

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[496] Press Information Bureau, Ministry of Science and Technology, Government of India (2020, November, 10) Indian astronomers collaborated with Nobel laureate on Thirty Meter Telescope Project *Press Information Bureau* https://pib.gov.in/PressReleasePage.aspx?PRID=1671685

[497] Press Information Bureau, Ministry of Science, Government of India (2021Ministry of Science & Technology has played a key role in developing global S&T partnership in critical areas : Union Minister Dr. Jitendra Singh

[498] (2020, December 20) OneWeb announces launch of 36 satellites; to offer hi-speed internet in India by mid-2022, *The Hindu*, https://www.thehindu.com/sci-tech/science/oneweb-announces-launch-of-36-satellites-to-offer-hi-speed-internet-in-india-by-mid-2022/article33377289.ece

[499] (2020, May 26) Indian startup to launch 35+ satellite constellation for 5G, *Times of India* https://timesofindia.indiatimes.com/india/indian-startup-to-launch-35-satellite-constellation-for-5g/articleshow/76005571.cms; (2021, July 26) After six-month delay, start-up targets satellite launch in October, *Hindustan Times* https://www.hindustantimes.com/india-news/after-six-month-delay-start-up-targets-satellite-launch-in-october-101627237587576.html

[500] These names/units/directorates are slightly different from the line bodies described in CONIDA's rules of structure and functions (official document described below). It would be necessary to corroborate the differences/similarities between these directorates/units (information not available on the website, at least not for the review conducted). General information on the directorates described in this section can be found at the following link https://www.gob.pe/8546-comision-nacional-de-investigacion-y-desarrollo-aeroespacial-organizacion-de-comision-nacional-de-investigacion-y-desarrollo-aeroespacial

- **National Centre for Satellite Image Operations (CNOIS) —** monitors and operates the PerúSAT-1 satellite, as well as requesting and downloading images from different sensors to be made available to all institutions using the Peruvian Satellite System.
- **Technical Directorate of Spatial Studies (DITEE) —** responsible for the dissemination of knowledge in space science and technology.

In general, most of the documentation on astronomy and space development relates to satellites and EO with civil purposes (with exceptions such as the DIAST and Directorate for Astronomy and Space Sciences). Similarly to Chile, the predominant discourse is one of security, defense, and development at the national level, in which the construction of satellites and access to information from them is paramount for EO.

3.10.1 National law

Four instruments exist in the Peruvian regime that can inform our research.

First, there is **Decree Law Nº 20643** on the Creation of the National Commission for Aerospace Research and Development in the Aeronautics Sector, enacted in 1974.[501] CONIDA is created as a public institution of the aeronautical sector, with administrative autonomy, and as part of the National Plan for Scientific and Technical Research (article 1). Its duration is indefinite (article 4), and its purpose and functions are mainly related to the promotion of work and research in space matters, as well as to the establishment of agreements (public-private; national-international) for the development of the country and of human capital in space matters (article 5).

Second is the **Head Resolution [Resolución Jefatural] N° 081-2020-JEINS-CONIDA**, Establishing the National Space Policy Commission, and enacted in 2020.[502] This is the resolution designating and approving the establishment of the National Space Policy Commission in charge of drafting the National Space Policy.

The third is **Head Resolution [Resolución Jefatural] N° 060-2020/JEINS/CONIDA** on the Rules of Organisation and Functions of the Space Agency of Peru — CONIDA, enacted in 2020.[503] Broadly, this document presents the general provisions of CONIDA, specifying its organizational structure and the functions of its various bodies, units, and directorates. Article 34 of this resolution names the Line Bodies, which correspond to five directorates directly related to the astronomical field, and whose functions include the development or updating of the National Space Policy, National Space Plan, or directives that promote or generate space development, which are as follows:

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[501] https://www.peru.gob.pe/docs/PLANES/85/PLAN_85_2015_1.2.1.0._NORMA_DE_CREACION_DE_LA_ENTIIDAD_D.L._20643_11_JUN1974.PDF
[502] https://cdn.www.gob.pe/uploads/document/file/1395019/RJ%20081-2020%20CONFORMA%20COMISI%C3%93N%20POLITICA%20NACIONAL%20ESPACIAL%20%281%29%5BR%5D%5BR%5D-signed.pdf.pdf
[503] https://cdn.www.gob.pe/uploads/document/file/1319076/ROF%20CONIDA%20APROBADO%20DEL%2023-09-2020.pdf

- Directorate of Spatial Applications and Geomatics — mainly associated with the management of geospatial data and the use of images from the Peruvian satellite system. Among other functions, it seeks to contribute to the socio-economic development and management of the national territory through the implementation of geospatial applications in environmental issues, mining, agriculture, energy, transport, housing, health, disaster risk management, among others that require geospatial information (article 37, point d).
- Directorate of Space Technology (Article 39) In charge of researching and developing national rocketry and satellite technology, providing the means to carry out in-situ studies of the middle and upper atmosphere, achieving access to outer space by national means, sharing with scientific research centers of universities, public and private institutions, the knowledge and other space resources obtained, with the aim of contributing to the development of space activity in the country, as well as implementing projects and studies in these fields.
- National Satellite Imagery Operations Centre (CNOIS) — In charge of providing images to Peruvian State institutions through the operation of satellite systems under its responsibility, so that they can generate spatial information that supports development, security and national defense. The CNOIS can provide satellite images to other authorized entities [article 41]. One of its organizational units is the Satellite Operations Unit, which is responsible for operating and maintaining in optimal conditions the satellite EO systems assigned to the CNOIS, as well as interacting with operators of other foreign satellite EO systems, within the framework of current agreements, in order to ensure the continuous supply of satellite images to different users (article 57).
- Directorate of Space Studies (Article 43) Responsible for strengthening, promoting, developing and disseminating knowledge in space science and technology in the country through academic events and programmes, as well as supporting the work of CONIDA, through the management of knowledge in the space field of its researchers and specialists, proposing contracts and/or agreements with institutions, companies, professionals and specialists, public and/or private, from all sectors of national and international activity, as appropriate, in relation to the implementation of training and specialization programmes.

The fourth instrument is **Supreme Decree No. 005-2021-DE,** Approving the "National Multisectoral Policy on National Security and Defence to 2030" (enacted in 2021).[504]

3.10.2 National policy

The country does not yet have a dedicated space policy or strategy.

[504] https://cdn.www.gob.pe/uploads/document/file/2063277/DS%20005-21-DE.pdf.pdf

3.10.3 National astronomy programs

In general, most astronomical activity is observatory- and planetarium-based. The state/government presence in astronomical development exists in, for instance, the use of instrumentation of certain units/directorates of CONIDA in observatories or research centers. Examples include:

- Moquegua Astronomical Observatory [OAM] — it operates the Ritchey-Chrétien Optical Telescope, which aims to develop observational astronomy in Peru (it works with DIAST instrumentation);
- Radio Observatory of Jicamarca — the observatory is a facility of the Geophysical Institute of Peru, which is operated with the support of the US National Science Foundation through a cooperative agreement with Cornell University;
- Morro Solar Planetarium, also called Digital Planetarium of Lima José Castro Mendivil (administered by the Peruvian Association of Astronomy);
- Geophysical Institute of Peru (administered by the Ministry of Environment) — its work and studies focus on environmental issues;
- Punta Lobos Scientific Base [BCPL] in Pucusana, where it operates a network of VLF (Very Low Frequency 3–30 kHz) antennas for monitoring mainly solar activity and its effects on the upper atmosphere (it works with DIAST instrumentation);
- Centre for Space Observations [COE] in Huancayo (it works with DIAST instrumentation).

3.10.4 International involvement

Peru has been a member of COPUOS since 1994. It has ratified all five UN Space Treaties. It has also ratified other international treaties,[505] such as the:

- Minamata Convention (member since 2016);
- Paris Agreement (member since 2016);
- UNCCD (member since 1995);
- CMNUCC (member since 1993);
- Montreal Protocol (member since 1993);
- Vienna Convention (member since 1989);
- Escazú Agreement (signed in 2018);
- Asia-Pacific Space Cooperation Organization (APSCO) — beneficiary of several APSCO cooperative networks;
- Framework Agreement on Cooperation in the Peaceful Uses of Outer Space between Brazil and Peru, signed in 2006.

3.10.5 Constellation developments

Peru has no constellation plans at this time.

[505] https://observatoriop10.cepal.org/es

3.11 United Arab Emirates

3.11.1 National law

There are two laws in the UEA relevant to our topic, Federal Law No. 12 of 2019, and Federal Law No. 17 of 2015.

First, **Federal Law No. 12 of 2019** on the Regulation of the Space Sector is the main national space law. Article 1 contains several definitions that can help draw the stance of the UAE on certain topics. For instance, it defines space activities as those that "*target* [any area above eighty kilometers], *including its discovery, making an impact thereon, using, or utilizing it (…)*". The word 'target' is interesting in that it does not impose a physical presence in the area in order to be considered a space activity, but merely to target it. Similarly, the space sector is defined as "*the sector that includes all activities, projects and programs related to Outer Space*", the latter being "*the area above the Earth's atmosphere*". From those dispositions alone, it can be understood that not only is astronomy included in the concept of space activities but also in the concept of the space sector. Such conceptions are expressly confirmed in other parts of the text. On the one hand, it can be read, in Article 4 "Regulated Activities", that "*this Law regulates space activities, which include (…) scientifically exploring space, conducting space-related scientific experiments, and participating in astronomy activities*."[506] On the other hand, having astronomy as a space activity regulated under a Law designed to regulate the space sector, makes it unequivocally part of the space sector.

The objectives of the Law are three, all directed towards the creation of a regulatory environment that can support and enable the national space policy. In the words of the Law, they cover:

1. the stimulation of investment and encouragement of private and academic sector participation in the Space Sector and related activities.
2. the support of implementation of the necessary safety, security and environmental measures to enhance the long-term stability and sustainability of Space Activities and related activities.
3. The support of the principle of transparency and the commitment of the State to implement the provisions of international conventions and treaties related to Outer Space and to which the State is a party.[507]

The Law also sets out the competences of the Emirates Space Agency, e.g. declaring it responsible for granting permits authorizing space activities.[508] On this point, Article 14 states that the general conditions regarding the permit and other types of modalities are determined by decision of the Council of Ministers or whomever it delegates, and the UAE Space Agency has to ensure that the application for the permit meets the requirements. It is not clear what those requirements are and

[506] Federal Law No. 12 of 2019 on the Regulation of the Space Sector is the main national space law, arts 1 (l), 4 (2019).
[507] Federal Law No. 12 of 2019 on the Regulation of the Space Sector is the main national space law, art 2 (2019).
[508] Federal Law No. 12 of 2019 on the Regulation of the Space Sector is the main national space law, art 1 (2019).

whether they include environmental and sustainability clauses. The only open information that can be found is on the website of the UAE Agency and reads "*The Agency is currently in the process of developing the Authorization and auditing framework for space activities*".[509]

There exists an exception to Article 14, for permits specific to providing satellite communication services. As stated in Article 15 "*any Person wishing to provide fixed or mobile space communication services or space broadcasting services shall obtain a prior no-objection from the Agency, provided that the final Permit is issued by the Telecommunications Regulatory Authority*" which forms a necessary condition for a final permit. The section about permits also bears a provision dedicated to space debris mitigation.[510]

Besides the authorization of space activities, Article 7 goes into more detail on other attributions of the Agency, indicating that the latter <u>may</u>:

- propose policies, strategies, and legislation related to the space sector;
- support research and studies in theoretical and applied fields of space;
- finance or facilitate the financing of any space activities, as well as establish investment projects in the space sector;
- provide technical and advisory support to the entities concerned with the space sector, provide advice and guidance to the national space programs and work to solve the challenges facing them;
- support national and international initiatives that seek to make the outer space environment more sustainable and stable;
- support the development of facilities and infrastructure needed for space sector technologies.

Article 31 adds that the Agency <u>shall</u> establish a national register of space objects.[511]

The achievement of these objectives and implementation of the space policy ultimately rest in the hands of the Board of Directors of the Agency.[512] The board was recently reorganized so that it can better support the country in realizing its strategic objectives.[513]

The Federal Law No.12 is complemented by a series of National Space Sector Regulations. The "Insurance Guidelines", the "Space Debris Mitigation Guidelines", the "Regulation on Registration of

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509 UAE Space Agency (n.d.). AUTHORIZATIONS FOR SPACE ACTIVITIES. https://www.space.gov.ae/Page/20122/20219/Authorizations-for-Space-Activities
510 Federal Law No. 12 of 2019 on the Regulation of the Space Sector is the main national space law, art 19 (2019).
511 More info at https://www.space.gov.ae/Page/20122/20217/Registrations-of-Space-Objects
512 Federal Law No. 12 of 2019 on the Regulation of the Space Sector is the main national space law, art 9 (2019).
513 Gulf Today (2020, October 12). Cabinet approves new Board of Directors of UAE Space Agency. https://www.gulftoday.ae/news/2020/10/12/cabinet-approves-new-board-of-directors-of-uae-space-agency

the Space Object", and the "Regulation on Authorization of the Space Object" could enlighten the present discussion. However those texts are either not openly accessible or still in development.[514]

The second relevant Law in the Emirati legal framework is **Federal Law No. 17 of 2015**, Establishing the Mohammed Bin Rashid Space Centre (MBRSC). According to the Law, the MBRSC is "*the Government entity responsible for the space sector and advanced space science and technology in the Emirate of Dubai*".[515] The Centre is more of a programmatic entity (e.g. developing satellites and other space systems) in comparison with the UAE Space Agency, the latter being a sort of "management entity" that organizes and regulates the national space sector. In line with this, the objectives of the MBRSC are rather science-oriented. For instance, the Centre seeks to be competitive in the field of advanced sciences and in making scientific discoveries, to encourage innovation and creativity within the space and related sciences while promoting a sustainable development through knowledge-economy, and to support scientific and technological research and studies.[516] It shall also adopt *"the best international practices and applications pertaining to satellites and space technology and other sciences and technologies relevant to the scope of work of the MBRSC"*.[517]

In order to achieve those objectives, the Centre is granted several functions, such as:
- develop and supervise the implementation of the policy of Dubai for the space sector;[518]
- establish companies and support companies through investments, etc.;
- conduct and fund studies and research for the development of the space sector;
- invest in projects relating to satellite science and applications;
- establish a suitable infrastructure for designing and manufacturing satellites in the UAE;
- propose legislation pertaining to the space sector.[519]

The tools given to the MBRSC are significant. Since the Centre develops satellites for national programs, but is also a scientific entity at core, allowing it to have a say in legislation and local policy can ensure that decisions impacting the space sector are informed by scientific and space experts. Even within the MBRSC, the Board of Directors, approving the policy and strategy of the Centre, has the possibility to invite consultants and specialists to attend its meetings.[520] So if the MBRSC was to

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[514] UAE Space Agency (n.d.). NATIONAL SPACE SECTOR REGULATIONS. https://www.space.gov.ae/Page/20122/20218/National-Space-Sector-Regulations
[515] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, art 6 (2015). https://bit.ly/3efFpVO
[516] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, art 5 (3) (5) (6) (2015). https://bit.ly/3efFpVO
[517] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, art 5 (9) (2015). https://bit.ly/3efFpVO
[518] Dubai is one of the Emirates forming part of the UAE.
[519] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, art 6 (1) (3) (5) (6) (8) (2015). https://bit.ly/3efFpVO
[520] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, arts 9 (e), 10 (1) (3) (2015). https://bit.ly/3efFpVO

build a satellite constellation or create/support a company that does, it can invite astronomers to consult on how to mitigate the impact of the constellation on astronomy in order to inform the strategy taken to achieve the project. The MBRSC also has the ability to form specialized sub-committees.[521] Such a committee could address our topic.

3.11.2 National policy

The 2016 **National Space Policy (NSP)** builds on previous broader strategic documents, i.e. the UAE Vision 2021 launched in 2010, the Higher Policy for Science, Technology and Development, and the National Innovation Strategy.[522] From the introductory paragraphs astronomy is mentioned. The "*historical affinity*" of the country with outer space is linked with its ancestral knowledge of astronomy and navigation.[523] The rationale behind the NSP was partly to "*regulate the space sector and ensure its sustainability*", and partly to "*stress the importance of international cooperation in the domain of outer space*".[524] The latter point is further emphasized in the Principles of the NSP, the fifth one being the respect of international laws and treaties. This point "*recognizes the right of all nations to explore and use space for peaceful purposes and for the benefit of humanity. A safe, sustainable and stable space environment, free from impediments to access and utilization, is a vital national interest*".[525] Beyond merely vowing to act in line with the international laws, the UAE vouch for the development of standards and regulations "*enhancing the security and stability of the space environment including debris mitigation*".[526]

The NSP also outlines specific goals that the UAE wants to achieve in the context of its space program. They include:

- developing a sustainable, competitive, and innovative commercial space industry (diversification of the economy, support of active and diversified commercial space industry, ambition of leadership in the field, economic incentives, regulatory environment attractive to global companies, investment in the space sector, etc.);
- conducting scientific space missions (lists astronomy and the Hope Mars mission and affirms that the UAE ambitions to train world class professionals in the fields of astronomy, space S&T, and engineering, and to develop education projects related to astronomy);

[521] Law No. (17) of 2015 Establishing the Mohammed bin Rashid Space Centre, art 10 (9) (2015). https://bit.ly/3efFpVO
[522] UAE Space Agency (September 2016). *National Space Policy*, 16 https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[523] UAE Space Agency (September 2016). *National Space Policy*, 14 https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[524] UAE Space Agency (September 2016). *National Space Policy*, 15-16 https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[525] UAE Space Agency (September 2016). *National Space Policy*, 21 https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[526] UAE Space Agency (September 2016). *National Space Policy*, 33 https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf

- promoting a safe and stable space environment that supports sustainable space activities (noting the increased risk of space collision, space debris, and the sustainability of space activities and calling for national and international efforts, efficient use of the radiofrequency spectrum and orbital slots, transparency, information sharing, SSA, access to space, etc.);
- establishing and expanding the country's leadership in space, regionally and internationally (especially when it comes to the peaceful uses of outer space, disaster management, telecommunications, navigation, land observation, S&T and space exploration programs, and when it has to do with investing in lucrative commercial space projects).[527]

Another interesting fact is that commercial enterprises are not the only ones which shall benefit from investment and financial support, but the UAE Space Agency and other institutions are also developing financing mechanisms to fund national governmental and scientific space projects.[528]

On the topic of commercial enterprises, one element appears to have been overlooked in the NSP. Within the section on Commercial Sector Guidelines, there does not seem to be anything about mitigating the environmental impact of space activities. The "*creation of a sustainable commercial space industry*" is mentioned, but upon closer inspection the content of this guideline is oriented towards economic recommendations, not environmental ones.

Following the NSP is the **UAE National Space Strategy 2030 (NSS)**, or the translation of the NSP into concrete actions. It reiterates that the trajectory chosen by the UAE will align with international laws and policies, citing for instance the OST, SDG2030 and the LTS Guidelines.[529] The NSS also considers the result of the Second International Forum for Space Exploration (ISEF2), which addressed sustainability in the context of space activities.[530]

One of the strategic goals in the NSP is explicitly the development of sciences related to space and astronomy.[531] But there is a detail even more telling of how the country sees astronomy and where it places it within the realm of space activities. If Federal Law No.12 recognized astronomy as a space activity, an integral part of the space sector, the NSP incorporates astronomy in the notion of a "*space*

[527] UAE Space Agency (September 2016). *National Space Policy*, 23-26
https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[528] UAE Space Agency (September 2016). *National Space Policy*, 33
https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf
[529] UAE Space Agency (n.d.). National Space Strategy (summary), 25-26.
https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[530] See https://www.mext.go.jp/isef2/pdf/forum_summary.pdf
[531] UAE Space Agency (n.d.). National Space Strategy (summary), 46.
https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf

sector value chain".[532] Indeed, one of the "*global directions in the space sector value chain*" is science and the increase of "*interest in space sciences and astronomy*".[533]

The Space Law and Policy Development Team is composed of state public entities such as the UAE Space Agency, the Telecommunications Regulatory Authority (today called Telecommunications and Digital Government Regulatory Authority), and the MBRSC.[534] However, it also includes another type of actor, the industry — the main telecommunications companies of the country, Thuraya, Yahsat, and du, as well as Masdar, a renewable energy company.[535] Despite the numerous allusions to astronomy in legal and policy papers, and its inspiring and important role, no astronomical bodies made it into this decision-making nucleus. That being said, the NSP says that the UAE Space Agency will need to engage with different stakeholder groups in order to implement the "National Space Policy Framework", which includes both industry and astronomical stakeholders.[536]

In addition to the NSP and the NSS, the MBRSC published its own Strategy in 2021, the **Mohammed Bin Rashid Space Centre Strategy 2021–2031**. It defines six projects, one of which is the UAE Space Sector Sustainability Program.[537]

3.11.3 National astronomy programs

The UAE seems to have created an environment that, if used to its full potential, can enable the growth of the satellite industry and the continuation of astronomical activities to coexist. This potential synergy or bridge that can exist between business and science influences national astronomy. That is the case **of the Abu Dhabi International Astronomical Center**, cofounded by a businessman fond of astronomy and by a healthcare practitioner describing themselves as "*astronomer at heart*".[538] The latter created an astronomy group where people could share their passion for astronomy and the enterprise later became the starting point for the creation of the **Al Sadeem Observatory**, a private

[532] UAE Space Agency (n.d.). National Space Strategy (summary), 32. https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[533] UAE Space Agency (n.d.). National Space Strategy (summary), 32. https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[534] UAE Space Agency (n.d.). National Space Strategy (summary), 28. https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[535] UAE Space Agency (n.d.). National Space Strategy (summary), 28. https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[536] UAE Space Agency (n.d.). National Space Strategy (summary), 53. https://space.gov.ae/Documents/PublicationPDFFiles/2030-National-Strategy-Summary-EN.pdf
[537] Government of Dubai (2020, September 26). Vice President reviews Mohammed bin Rashid Space Centre strategy 2021-2031. Media Office. https://mediaoffice.ae/en/news/2020/September/26-09/Mohammed%20bin%20Rashid
[538] Abu Dhabi Talking (n.d.). Alejandro Palado Helps Promote Astronomy & Space In The Community. https://www.abudhabitalking.com/alejandro-palado-promotes-space-and-astronomy-in-the-community/

observatory.[539] The observatory is involved in black hole monitoring amongst other things and fulfills the wish of the country to be a prominent actor in scientific observation.[540]

The quasi-sacred relationship between astronomy and the Emiratis is demonstrated in the case of the International Astronomical Center since it looks at the night sky every month to observe the Moon in order to determine the timing of Islamic holidays such as Ramadan or Eid.[541] This initiative was instigated by the then IAC Chairperson Mohammed Odeh and the creation of the Islamic Crescents Observation Project which included a number of astronomers.[542]

Another national astronomy program is the Dubai Astronomy Group, "*founded to encourage and promote the study of Astronomy and its related fields*".[543] The Group also provides consulting services to the public and private sector and will reportedly explore stargazing tourism possibilities.[544] One of the activities of the Group is an initiative called "Preserve the Night Sky".[545] Its description mentions the "*night sky heritage*" and the damage to it by artificial lighting.

3.11.4 International involvement

The UAE is Party to all UN space treaties, except for the Moon Agreement. It has also ratified the Agreement Relating to the International Telecommunications Satellite Organization (ITSO) and the Convention on the International Mobile Satellite Organization (IMSO). It is a member of the ITU, ARABSAT, and COPUOS.

In 2020, during the Scientific and Technical Subcommittee of COPUOS, the UAE submitted a proposal to establish a working group under the agenda item on the long-term sustainability of outer space activities.[546] The same year, UNOOSA and the UAE reinforced and made official their collaboration through an agreement on the long-term sustainability of space activities and the promotion of using

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539 Abu Dhabi Talking (n.d.). Alejandro Palado Helps Promote Astronomy & Space In The Community. https://www.abudhabitalking.com/alejandro-palado-promotes-space-and-astronomy-in-the-community/
540 Abu Dhabi Talking (n.d.). Alejandro Palado Helps Promote Astronomy & Space In The Community. https://www.abudhabitalking.com/alejandro-palado-promotes-space-and-astronomy-in-the-community/
541 Pennington, R. (2017, September 21). *Inside the UAE's astronomical centre which helps determines Islamic public holidays*. The National News. https://www.thenationalnews.com/uae/inside-the-uae-s-astronomical-centre-which-helps-determines-islamic-public-holidays-1.630340
542 Pennington, R. (2017, September 21). *Inside the UAE's astronomical centre which helps determine Islamic public holidays*. The National News. https://www.thenationalnews.com/uae/inside-the-uae-s-astronomical-centre-which-helps-determines-islamic-public-holidays-1.630340
543 Dubai Astronomy Group (n.d.). https://dubaiastronomy.com
544 Dubai Astronomy Group (n.d.). https://dubaiastronomy.com
545 Dubai Astronomy Group (n.d.). *Preserve the Night Sky.* https://dubaiastronomy.com/preserve-the-night-sky/
546 UAE (2020, February 3). Proposal by the United Arab Emirates (A/AC.105/C.1/2020/CRP.10). Scientific and Technical Subcommittee, COPUOS. https://www.unoosa.org/res/oosadoc/data/documents/2020/aac_105c_12020crp/aac_105c_12020crp_10_0_html/AC105_C1_2020_CRP10E.pdf

space for sustainable development.[547] One of the actions taken is the creation of an office in the UAE that will "*act as a new global hub to foster international progress on space sustainability and space for development issues*".[548]

3.11.5 Constellation developments

There are no known plans to build and launch a satellite constellation in the UAE. Although the industry and commercial actors are growing, purely indigenous satellite manufacturing capabilities are still nascent. The first satellite entirely manufactured in the country, DubaiSat-3, was launched in 2018. That is 18 years after the first UAE satellite, Thuraya 1, was acquired from Hughes in 2000, and nine years after Dubaisat 1, launched in 2009 and on which Emirati engineers contributed.

3.12 United Kingdom

3.12.1 National law

UK legislation on outer space is encompassed in the [Outer Space Act 1986 (OSA)](), which currently underpins the licensing of UK entities who procure an overseas launch and/or operate a satellite in orbit from overseas. In addition, the [Space Industry Act 2018 (SIA)]() received Royal Assent on 15 March 2018. The Act's provisions also ensure that spaceflight activity taking place from the UK is carried out in compliance with the UN space treaties and other international obligations. The requirement for these to be met is one of the primary duties of the regulator, as set out in the SIA, section 2(2)(g). On 29 July 2021, the [Space Industry Regulations 2021](), which were made under the SIA, came into force. These Regulations enable the licensing and regulation of spaceflight activities, spaceports and range control services in the UK.

While the OSA regulates activities carried out by UK entities overseas (i.e. launch and procurement of launch of a space object overseas, and operation of a satellite in orbit by a UK entity based overseas), the SIA regulates activities carried out from the UK, as detailed in the Space Industry Regulations 2021. Those activities cover launch and return (space or sub-orbital), procurement of a UK launch (space or sub-orbital), operation of a satellite in orbit, operation of a spaceport, and provision of range control services.

The current UK licensing process explicitly assesses the potential risks to people, property, public health and the environment for in-orbit operation and space object re-entry, and this also includes an assessment of launch activities. UK licensing also adheres to a variety of international technical standards and guidelines, such as those published by the International Organization for

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[547] UNOOSA (2020 June 10). *UNOOSA and UAE Space Agency announce agreement to advance space sustainability.* https://www.unoosa.org/oosa/en/informationfor/media/2020-unis-os-532.html
[548] UNOOSA (2020 June 10). *UNOOSA and UAE Space Agency announce agreement to advance space sustainability.* https://www.unoosa.org/oosa/en/informationfor/media/2020-unis-os-532.html

Standardization (ISO) and the Inter-Agency Space Debris Coordination Committee (IADC). Where relevant, these have been incorporated into the Space Industry Regulations 2021.

The drafting of the SIA and the regulations that implement it was a co-ordinated workstream across government, including input from other regulatory bodies.

As part of the UK licensing procedures, supervision of space objects authorized by the UK forms an integral part of national policy. All UK-licensed activities require operators to complete regular compliance reports to verify adherence to license conditions. This provides a mechanism for the UK Government to meet its obligation to monitor and supervise the activities of its nationals under Article VI of the OST.

The UK currently ensures equitable, rational and efficient use of the radio-frequency spectrum and the various orbital regions used by satellites through use of the Office for Communications (Ofcom), the national regulatory body responsible for managing civilian use of the radio spectrum. This ensures UK compliance under the Constitution and the Radio Regulations of the International Telecommunication Union (ITU) and recognises the limited natural resource that the radio-frequency spectrum represents.

The SIA requires the Secretary of State to maintain a national register of launches both from UK spaceports and launches taking place from outside the UK (but where the space object is operated by a UK entity).[549] The OSA requires the Secretary of State to maintain a national register of space objects for which it is responsible. Objects on this national register must be reported to the UN. A single national register may be kept for both space objects and launches, but there is no obligation to report launches to the UN. Internal procedures ensure that registrations are reported to the UN in the appropriate way. This ensures that the UK acts in accordance with its obligations under the UN Convention on Registration of Objects Launched into Outer Space to ensure the UN is notified of UK-licensed space objects. Notifications are also issued in accordance with the Hague Code of Conduct and the Missile Technology Control Regime.

The UK recently established a National Space Council chaired by the Prime Minister. This includes high-level representatives from a range of government departments with an interest in space (e.g. the Secretary of State for Defence, Secretary of State for Transport, Secretary of State for Business, Energy, and Industrial Strategy, Secretary of State for Digital, Culture, Media, and Sport, etc.). The aim of this body is to "*consider issues concerning prosperity, diplomacy and national security in, through and from Space, as part of coordinating overall Government policy*".[550] Astronomy is not explicitly represented,

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[549] Duties and Supplemental Powers of the Regulator in https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/777686/190208_Understanding_the_SIA_-_Final_For_Publication_-_Legal_Cleared_-_Initial_Publication.pdf

[550] https://questions-statements.parliament.uk/written-questions/detail/2021-07-22/HL2293

though science, research and innovation sit within the remit of the Department for Business, Energy, and Industrial Strategy.

It is an offense for a person to whom the Act applies to carry out such an activity without a license. If the satellite or payload is operated from abroad by UK entities it is currently licensed and regulated under the OSA. The Civil Aviation Authority in the UK regulates activities under both Acts. Consent for the grant of an orbital license is issued through the Secretary of State for Business, Energy and Industrial Strategy (BEIS) or deputies appointed to act on behalf of the Secretary of State. Where there are specific requirements for a licensee to meet requirements not specified in either Act, the regulator can make use of license conditions when granting a license. When granting a license, there are various factors the regulator must consider, including taking into account the environmental objectives set by the government, and 'users of land.'

As part of an application for an orbital license a prospective licensee must complete an assessment questionnaire which specifically relates to safety, security, sustainability. Unlike for other license types such as launch, there are no specific regulations that prescribe what the regulator must consider in assessing applications for orbital licenses. This is because a flexible, outcomes-based approach is appropriate for orbital operations given the wide diversity in mission profiles and technologies that can be used.

General principles around how the Regulator will assess orbital applications is in the 'Assessment Principles' section of the guidance for orbital operators. On sustainability this guidance states:

> *The focus of this principle is to ensure that activities licensed in orbit are sustainable. A sustainable activity (or mission) is one that meets the requirements of the present without compromising the ability of subsequent generations to embark on activities (or missions) to meet their own requirements in the future. Sustainability is inherently linked to safety and security: whereas safety and security look to mitigate impacts of spacecraft activities on the operations of existing spacecraft, sustainability attempts to mitigate the impacts of spacecraft activities on the future environment.*

Applicants must demonstrate how they will adhere to the same orbital sustainability objectives as currently licensed operators by demonstrating how they will:
- prevent on-orbit break-ups, either from collisions with other objects in orbit or fragmentation;
- limit the number of objects released during normal operations;
- remove spacecraft and orbital stages that have reached the end of their operations from the most used, useful and densely populated orbital regions.

Spectrum is regulated nationally by Ofcom under the Communications Act 2003. They efficiently distribute this finite resource and license UK spectrum users. Ofcom set out their key areas of work through an annual plan. They represent the UK internationally, at meetings such as the International Telecommunication Union (ITU), through an Memorandum of Understanding with the Department for Culture, Media and Sport (DCMS), who are the lead government department for spectrum. Satellites are allocated priority spectrum access rights in globally harmonized spectrum through a satellite filings process managed by the ITU. The Radio Regulations and rules of procedure which govern the ITU and spectrum use are revised at World Radio Conferences (WRC) held approximately every 4 years. The 2023 conference will significantly affect space, enabling new space services, refining the satellite regulatory process, and identifying new sharing opportunities to meet the insatiable demand for mobile broadband capacity.

In order to ensure departments value their spectrum use, and to incentivize release or sharing, public sector spectrum is taxed. For BEIS this is £10M/year. These charges are currently under review, with an extension of the range of frequencies in scope and cost per MHz, which is based on what that spectrum might be worth if it were commercially available.

Ofcom is the national regulator. Ofcom are in the process of updating their UK spectrum policy. It should be noted that spectrum access is a shared resource which is sequentially prioritized. This means that those lower down in the prioritization order need to coordinate and ensure that they don't cause interference with those higher up in the priority list.

3.12.2 National policy

The UK's recently published National Space Strategy reflects the government's commitment to promoting a sustainable space environment. The UK is a strong supporter of space sustainability and is the first country to have funded a project directly with the United Nations Office for Outer Space Affairs on the implementation of the LTS guidelines.

The UK government recognises the importance of preserving dark and quiet reserves for the purposes of ground-based optical and radio astronomy. The UK government has been engaging with both orbital operators and the astronomical community, including the Royal Astronomical Society and the European Astronomical Society, on this matter.

3.12.3 National astronomy programs

The UK subscribes to the mandatory Science Programme in ESA. Astronomy is a key area for the UK Space Agency's National Space Science Programme, which funds the development of science instruments for ESA astronomy missions. The UK Research and Innovation – Science and Technology Facilities Council (UKRI-STFC) funds the exploitation of data returned from these missions, and also supports the ground-based astronomy research community, including investing in large-scale international astronomy facilities on the ground. The UK Space Agency and UKRI-STFC work together to ensure that investments in science instrumentation for space missions are aligned with the science priorities of the UK research community. Space-based and ground-based infrastructures are used synergistically; data from ground-based observatories are used to inform space science missions, e.g. by selecting the best targets for observation in space. The UK Space Agency has been collaborating closely with the Royal Astronomical Society to consider the potential interference issues posed by mega-constellations to both radio and optical astronomy, and the ways these may be mitigated for the benefit of the community as a whole.

Although not yet relevant to dark skies with regard to satellite constellations, it is worth mentioning that in the UK, in January 2020, an All-Party Parliamentary Group (AAPG) for Dark Skies was established by Lord (Martin) Rees of Ludlow and Andrew Griffith, MP for Arundel and South Downs. Through consultation with over 170 academics, legal professionals, national park associations, professional and amateur astronomers, members of local and national government, lighting professionals, engineers and businesses, the AAPG proposed 10 policies for the UK government to consider. Their plan sets out the major causes of growing light pollution in the UK which threaten dark sky preservation and advocates policy solutions to mitigate or remedy such issues. Their policy approach focuses across three broad themes: challenging the existing legal framework for the parts of the planning process which regulate light pollution; overhauling the rules applicable to outdoor lighting installations; and introducing new initiatives at every level of government which educate and incentivize the reduction of light pollution and obtrusive light. The APPG campaigns in Parliament and is calling on the UK government to implement a set of ten actions which would reverse the exponential growth of environmental pollution caused by artificial light.

3.12.4 International involvement

The UK is a Party to the OST, the Rescue Agreement, the Liability Convention and the Registration Convention. The country also follows different non-binding instruments:

- Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space;
- The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting;
- The Principles Relating to Remote Sensing of the Earth from Outer Space;
- The Principles Relevant to the Use of Nuclear Power Sources in Outer Space;
- The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries;
- Hague Code of Conduct;
- Missile Technology Control Regime;
- the Artemis Accords.

In addition, the UK is a contributor, member or signatory to several space debris mitigation measures:

- Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space;
- Guidelines for the Long-term Sustainability of Outer Space Activities;
- European Code of Conduct For Space Debris Mitigation;
- IADC Space Debris Mitigation Guidelines;
- Space Debris Mitigation Requirements BS ISO 24113-2019;
- Disposal of orbital launch stages BS ISO 16699:2015;
- Requirements Space Debris Mitigation ESA Projects.

At the 58th session of the COPUOS Scientific and Technical subcommittee, the UK recognised the importance of this issue in its national statement. The UK government will continue to engage with the astronomical and orbital communities and across government to develop an approach to the issue of preserving the dark and quiet skies, utilizing international fora such as COPUOS to ensure alignment with international best practice in this area.

3.12.5 Constellation developments

The UK government is a part owner of the company OneWeb, a low Earth orbit (LEO) satellite telecommunications company. As of 14 October 2021, the company has so far launched 358 satellites into orbit and when complete will have a constellation of 648 satellites in its first-generation fleet to provide high-speed, low-latency global connectivity.[551] OneWeb plans to eventually supplement its first-generation constellation with a second-generation constellation. Plans were initially submitted to the US Federal Communications Commission (FCC) for a constellation numbering 47,884 satellites, but this was later revised down to 6372 satellites.[552] This would bring the total number of orbital systems to 7020 satellites if both generations are operating at full capacity simultaneously.

OneWeb has produced several documents dedicated to publicizing their approach to space utilization and corresponding environmental issues ranging from journal articles and white papers to more accessible brochures. While a single such publication states "*The orbital environment must support healthy competition and cannot be allowed to become polluted, dangerous, or disruptive to scientific ... endeavours*", there is no mention of the impact on astronomy and the emphasis throughout is squarely on orbital debris issues. In contrast, technical FCC submissions by OneWeb (registered as the former company WorldVu Satellites Limited) indicate potential interference between both satellite downlink transmissions and user terminal stations across various bands and US-based radio astronomy. The company there states that it "*has started the process of coordinating with the [Radio Astronomy Service (RAS)] community regarding its LEO component*", that it "*will also coordinate with the National Science*

[551] https://oneweb.net/media-center/oneweb-confirms-successful-launch-of-36-satellites-from-vostochny
[552] https://oneweb.net/media-center/oneweb-streamlines-constellation

Foundation regarding transmissions from its user terminal Earth stations", and is "is committed to protecting … RAS allocations".[553]

Inmarsat is a UK-based telecommunications company and satellite operator. Inmarsat currently operates a fleet of 14 satellites in geostationary orbit and has several single-satellite launches planned over the next few years at a rate of approximately one per year. These satellites operate across the *L* band, *Ka* band, and the *S* band.[554] In July 2021 Inmarsat announced their intent to establish the Orchestra constellation, comprising 150–175 LEO satellites providing terrestrial 5G services, with operations beginning in approximately 2026.[555]

While UK-based constellation operators are not particularly numerous, it may be of interest to note that the UK is significantly more prolific as a prime contractor for the manufacture of orbital platforms for existing or planned satellite constellation projects (e.g. Surrey Satellite Technologies Ltd., AAC Clyde Space.)

3.13 United States

Within the United States, there certainly exist space specific laws, beginning with adherence to certain treaties and followed by federal statutes and regulations. Despite these laws, policy often dictates the direction in which winds will blow from one administration to the next. This overview begins by providing a synopsis of United States space-related laws and policy. It then focuses on specific issues of astronomy and satellite constellations.

3.13.1 National law

Space law within the United States comes from myriad directions and sources. To begin with, the United States legal system places international treaties above all other laws. From here, the United States Constitution governs all other laws on both a federal and state level. Not surprisingly, where a federal law exists on a particular matter, federal law shall be supreme over any state or more localized law. For this reason, states and local governments within the United States generally do not enjoy jurisdiction over broader space policy (though there could be state and local laws focused on environmental or land use for space facilities). Within the federal system, following the Constitution, statutes and regulations form the majority of space-focused law (with statutes having supremacy over regulations). In sum, absent an issue on the constitutionality of statutes or regulations, the United States system of space law focuses on international treaties, statutes, and regulations.

Statutes

[553] OneWeb FCC Attachment — Technical Narrative
[554] https://www.inmarsat.com/en/about/technology/satellites.html
[555] https://www.inmarsat.com/en/news/latest-news/corporate/2021/inmarsat-announces-orchestra.html

Rather than provide an historical review of all space related statutes enacted by the United States (which arguably date back to the 1950s), this overview will focus on some of the more recent and/or prominent statutes. Most recently, the United States enacted the National Defense Authorization Act of Fiscal Year 2020[556] which, among other provisions, established the United States Space Force.[557] Though now a separate branch under the United States Air Force, the United States Space Force authority includes some operations that had already been implemented within the Air Force. Given that, the creation of the Space Force should *not* be perceived as an intent by the United States to militarize space.

A few years earlier, in 2015, the United States signed into law the Commercial Space Launch Competitiveness Act.[558] Rather than simply abstaining from ratifying or signing the Moon Agreement, the United States enacted language within this Act inconsistent with the Moon Agreement. Specifically, the statute provides that material mined from celestial bodies can be privately owned:

> *A United States citizen engaged in commercial recovery of an asteroid resource or a space resource under this chapter shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States*.[559]

This policy has since been followed by a few other countries, such as Luxembourg (2017), the United Arab Emirates (2019) and Japan (2021), that have adopted or seek to adopt similar laws.
Certainly, there exist additional acts and statutes directly focused on space within the United States (e.g. the National Aeronautics and Space Administration Transition Authorization Act of 2017,[560] Weather Research and Forecasting Innovation Act of 2017,[561] National and Commercial Space Programs Act of 2010,[562] Commercial Space Launch Amendments Act of 2004,[563] Commercial Space Launch Act of 1984,[564] the Land Remote-Sensing Policy Act of 1992,[565] Commercial Space Act of 1988,[566]

[556] National Defense Authorization Act for Fiscal Year 2020, Pub. L. No. 116-92, §§ 951-961, 133 Stat. 1198 (2019).
[557] The Space Force, 10 U.S.C. §§ 9081-9085 (2021).
[558] U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90, 129 Stat. 704.
[559] 51 U.S.C. § 51303.
[560] National Aeronautics and Space Administration Transition Authorization Act of 2017, Pub. L. No. 115-10, 131 Stat. 18.
[561] Weather Research and Forecasting Innovation Act of 2017, Pub. L. No. 115-25, 131 Stat. 91 (2017).
[562] National and Commercial Space Programs Act of 2010, Pub. L. No. 111-314, 124 Stat. 3328 (codified as amended at 51 U.S.C.).
[563] Commercial Space Launch Amendments Act of 2004, Pub. L. No. 108-492, 118 Stat. 3974.
[564] Commercial Space Launch Act of 1984, Pub. L. No. 98-575, 98 Stat. 3055 (codified as amended at 51 U.S.C. §§ 50901-50923 (2015)).
[565] Land Remote Sensing Policy Act of 1992, Pub. L. No. 102-555, 106 Stat. 4163 (codified as amended at 51 U.S.C. ch. 601).
[566] Commercial Space Launch Act Amendments of 1988, Pub. L. No. 100-657, 102 Stat. 3900.

Land Remote-Sensing Commercialization Act of 1984,[567] National Aeronautics & Space Act of 1958,[568] and the Communications Act of 1934[569]). Moreover, Congress continues to consistently introduce new legislation related to space activities. In fact, during the current Congress, more than 60 separate pieces of legislation have been introduced between the United States House of Representatives and United States Senate focused on space in one form or another. However, most of the space law applicable on a day-to-day basis now arises through US regulatory agencies.

Regulations

The National Aeronautics and Space Administration (NASA) represents the best-known and most prominent space agency within the United States. Rather than a regulatory agency governing third party activities in space, NASA operates the United States' space program. Throughout its history, NASA contracted with private commercial partners. However, for the most part, the United States' space program represented a governmental operation. With the growth of the private commercial space sector, this has begun to change — not only in terms of space activities, but also the manner in which NASA programs develop. Over the last few years, the public-private collaboration between NASA and commercial entities has expanded significantly. This will likely expand across other aspects of the United States government, particularly with military-commercial collaboration.

As to governance of commercial space activities, the Federal Aviation Administration (FAA) and the Federal Communications Commission (FCC) represent two of the better-known federal agencies regulating space activities within the United States. Within the FAA there exists the Office of Commercial Space Transportation. The governing FAA regulations arise from the international space treaties ratified by the United States and the Commercial Space Launch Act of 1984.[570] With respect to commercial space, the FAA governs launch vehicles and launch sites (or spaceports) within the United States.[571] It regulates launch and re-entry of vehicles, safety review, payload review and determination, fiscal responsibility, and more.[572] As of 2021, there have been 416 licensed launches.[573] There also exist twelve spaceport operator licenses issued and spaceports in Alaska, California, Colorado, Florida, New Mexico, Oklahoma, Texas, and Virginia.[574] Once launched into orbit, the FCC governs satellites and satellite communications.

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[567] Land Remote-Sensing Commercialization Act of 1984, Pub. L. No. 98-365, 98 Stat. 451.
[568] National Aeronautics and Space Act of 1958, Pub. L. No. 85-586, 72 Stat. 426.
[569] Communications Act of 1934, Pub. L. No. 73-416, 48 Stat. 1064.
[570] Commercial Space Transportation, Federal Aviation Administration, Department of Transportation, 14 C.F.R. §§ 400-460 (2021).
[571] Commercial Space Launch Activities, 51 U.S.C. §§ 50901-50923 (2021).
[572] (Commercial Space Launch Activities, 2021).
[573] Federal Aviation Administration. (2021). *Commercial Space Data*. FAA.org. Retrieved November 16, 2021 from at https://www.faa.gov/data_research/commercial_space_data/.
[574](Federal Aviation Administration, 2021).

The FCC licenses the operations of satellites.[575] Consequently, any person seeking to operate a satellite that communicates with a ground station in the United States must obtain a license through the United States. This process begins with Form 312.[576] Among other requirements, the FCC now requires applicants to address mitigation of space or orbital debris.[577] In terms of potential regulations relating to adverse effects of satellites on astronomy, the FCC would be the primary and logical source from which they would emanate.

Beyond these two agencies, the Commercial Remote Sensing Regulatory Affairs office of the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce (DOC) regulates satellites that focus on EO (remote-sensing).[578] The DOC also oversees the implementation of the Export Administration Regulations (EAR) governing the sharing of sensitive information with non-US citizens.[579] As a corollary, the Department of State oversees the International Traffic in Arms Regulations (ITAR)[580] and its United States Munitions List (USML)[581] which imposes stricter controls on the export of information and technology from the United States than EAR. In both cases, the terms “arms” and “munitions” could to some suggest inapplicability of EAR and ITAR to commercial satellite operators. The scope of the export regulations extends much further than military applications and remains a critical component of regulatory compliance for actors in the technology sectors.

The applicability of United States regulatory agencies and their regulations should not be considered limited to United States entities or geography. For, should a foreign entity seek to communicate within the United States or use a United States ground station, it generally would be subject to certain United States regulations and require applicable licensure. Similarly, a United States entity would be remiss in thinking that it can avoid United States regulatory authority by launching outside the United States or communicating solely with foreign ground stations. Indeed, a United States company engaged in remote sensing requires a license from NOAA even where it limits observations to non-United States geography.

As a general rule, any license application submitted to any of the foregoing licensing or regulatory agencies will be open for public comment. Consequently, this provides opportunity for interested parties from all sectors to voice concerns for the applicable agency to consider. This same process applies to new or updated regulations proposed by the regulatory agencies.

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[575] 47 C.F.R. §§ 25.101-25.702 (2021).
[576] Federal Communications Commission. *Federal Communications Commission Application for Satellite Space and Earth Station Authorizations*. Retrieved on November 16, 2021 from https://transition.fcc.gov/Forms/Form312/312Fill.pdf.
[577] 47 CFR § 25.114(d)(14) (2021).
[578] National and Commercial Space Programs Act, 51 U.S.C. §§ 60101-60162 (2021).
[579] Export Administrative Regulations, 15 C.F.R. §§ 730-774.
[580] International Traffic in Arms Regulations, 120 C.F.R. §§ 120-130.17 [hereinafter ITAR].
[581] 22 C.F.R. § 121.

Regulatory Updates
Over the last couple years, NOAA,[582] the FAA,[583] and the FCC[584] engaged in an extensive overhaul of space-related regulations. Most recently, the FCC implemented new regulations addressing space debris[585] and streamlining the regulatory process for small satellite companies.[586] In the near future, the FCC will likely promulgate additional regulations related to orbital debris. Moreover, there may be continued updates relating to commercial space operations across agencies. In June 2021, while recognizing the improvements in the 2020 FAA regulations, the United States Government Accountability Office noted that further regulatory updates should occur within the agency.[587]

Beyond the agencies and their regulatory updates, a particular issue with respect to satellites and the regulatory process made its way to the judicial arena when Viasat filed a lawsuit appealing an FCC order authorizing SpaceX' modification of its operation of Starlink, an NGSO satellite constellation.[588] Among its arguments, Viasat — notably a SpaceX competitor — argued that the FCC did not properly require SpaceX to account for an environmental impact of its satellite constellation under the National Environmental Policy Act (NEPA) and the implementing Council on Environmental Quality (CEQ) regulations (NEPA constitutes a significant environmental law imposing upon the United States' agencies the requirement to consider environmental impact of their operations; the CEQ regulations implement NEPA). In short, this can be synthesized into the question of whether NEPA and the CEQ implementing regulations define 'environment' to include (or exclude) Earth's orbital space. If included, the question then becomes whether the inclusion can be construed as compulsory or permissive. Given neither NEPA nor the CEQ regulations explicitly include Earth's orbital space, it will be interesting to see how the courts will interpret the ambiguity. The anticipated interpretation will then dictate the analysis with respect to the FCC's current limitation of its environmental scope to terrestrial concerns. Notably, the court denied Viasat's request to suspend SpaceX launches pending a decision on the broader issues.[589] Oral arguments were scheduled for 3 December 2021,

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[582] NOAA, 15 C.F.R. § 860, et seq.
[583] FAA, 14 C.F.R. § 400, et seq.
[584] FCC, 47 C.F.R. §§ 5, 25, 97.
[585] FCC, Mitigation of Orbital Debris in the New Space Age, 85 FR 52445 (https://www.govinfo.gov/content/pkg/FR-2020-08-25/pdf/2020-13184.pdf); see also Mitigation of Orbital Debris in the New Space Age, 86 FR 52191 (https://www.govinfo.gov/content/pkg/FR-2021-09-20/pdf/2021-20193.pdf) (focused on 47 CFR 5.64(b) and 97.207(g)(1)).
[586] In re Further Streamlining Part 25 Rules Governing Satellite Services, 86 FR 11880, FCC 20-159 (Jun 1, 2021); see also In re Further Streamlining Part 25 Rules Governing Satellite Services, 86 FR 52102, FCC 20-159 (September 20, 2021) (related specifically to 47 CFR 25.136(h)).
[587] See generally Government Accountability Office, "Commercial Space Transportation: FAA Continues to Update Regulations and Faces Challenges to Overseeing an Evolving Industry," June 16, 2021 (https://www.gao.gov/assets/gao-21-105268.pdf).
[588] Viasat v. Federal Communications Comm'n, 21-1123, United States Court of Appeals for the District of Columbia Circuit (May 26, 2021).
[589] Order, July 20, 2021.

3.13.2 National policy

For more than sixty years, space has occupied a place within the United States consciousness and domestic policy. That being said, the strength and focus of this policy did not remain consistent. For example, the budget for NASA reached its high mark (in terms of percentage) in 1966 when it comprised over 4% of the national budget. This occurred within the years 1961–1974 when United States space policy focused on the space race with the Soviet Union. Since 1975, except for a few anomalies, the NASA budget has fallen below 1% of the national budget with the last decade at or below 0.5%. Despite being less than 1% of the United States budget, at more than $20 billion the United States government spends more on space activities than any other country. This does not include amounts allocated to space that may fall within the United States military or other budget line items.

In 2021 the United States maintains a strong space policy and wants to maintain its presence as a global leader in space. At the same time, it seeks international cooperation in its endeavors. In particular, with the vision of returning to the Moon, establishing the lunar Gateway, and eventual transport of humans to Mars, the United States implemented the Artemis Accords[590] and invited countries to join in its vision. As of October 2021, NASA states that thirteen countries have embraced the Artemis Accords.[591] After more than five decades, the Artemis Accords build upon and expand on the OST. However, it should be understood that the Artemis Accords do not constitute a multilateral treaty. Rather, they serve the United States in facilitating bilateral cooperation.

Beyond international cooperation, the United States also seeks to facilitate the increasing involvement of commercial partners with the government through public-private partnerships. This can already be observed through SpaceX and its transportation of people and cargo to the International Space Station. For the United States this represents a significant development. For, following the retirement of the Space Shuttle program in 2011, the United States became dependent on Russia for transport to the ISS through 2020. Beyond ISS transportation, the United States has encouraged commercial partnership in military and other space developments. For this and other reasons, the United States has implemented regulatory changes to facilitate participation in the commercial space growth.

Contemporaneously, as stated above, the FCC implemented stricter regulatory requirements relating to the mitigation of orbital or space debris.[592] In this context, one could argue that there exists a

[590] https://www.nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf.
[591] https://www.nasa.gov/specials/artemis-accords/index.html
[592] FCC, Mitigation of Orbital Debris in the New Space Age, 85 FR 52445 (https://www.govinfo.gov/content/pkg/FR-2020-08-25/pdf/2020-13184.pdf); see also Mitigation of Orbital Debris in the New Space Age, 86 FR 52191 (https://www.govinfo.gov/content/pkg/FR-2021-09-20/pdf/2021-20193.pdf) (focused on 47 CFR 5.64(b) and 97.207(g)(1)).

growing recognition of stewardship of Earth's orbital space. That being said, the current iteration of United States space debris regulations follows nearly three decades of development.

As elsewhere, national policy in the United States evolves over time as new issues emerge and capture attention of policymakers. To secure this attention, affected parties must engage in discussions and deliberations on a continual and repeated basis. Eventually, and ideally, these issues reach policymakers and regulators through informal and formal channels. Albeit only a passing mention, a recent FAA Draft Programmatic Environmental Assessment for SpaceX operations in Florida recognized that "*[i]n unique circumstances, the nighttime sky may be considered a visual resource*."[593] With respect to the adverse effects of satellite mega-constellations on astronomy, a similar mention recently occurred before the United States Senate Committee on Commerce, Science, and Transportation. On 21 October 2021, the prepared testimony of former NASA Administrator Jim Bridenstine called on the FCC to "*analyze and report on the effects [satellite] constellations will have on launch, the International Space Station, the environment, astronomers, and future space exploration*."[594] Albeit brief, this mention before a United States Senate committee carries significance and provides the potential for further Congressional action. However, this potential can only be activated in conjunction with continued, vocal discussions among interested parties serving as a catalyst.

3.13.3 National astronomy programs

Whether through public or private funding, the United States actively engages in ground-based astronomy. There exist more than 300 active professional observatories in the United States. The National Science Foundation (NSF), through its Division of Astronomical Studies within the Division for Mathematical, Physical, and Engineering Sciences, represents a primary support vehicle for ground-based astronomy occurring in the United States. This support includes "*forefront research in ground-based astronomy to help ensure the scientific excellence of the US astronomical community*;" "*access to world-class research facilities*;" "*development of new instrumentation and next-generation facilities*;" and, encouragement of broad understanding of the "*astronomical sciences by a diverse population of scientists, policy makers, educators, and the public at large*." Further, the Division supports:

> *research in all areas of astronomy and astrophysics as well as related multidisciplinary studies. Because of the scale of modern astronomical research, the Division engages in numerous interagency and international collaborations. Areas of emphasis and the priorities of specific*

[593] Federal Aviation Administration. (2021, September). Draft Programmatic Environmental Assessment for the SpaceX Starship/Super Heavy Launch Vehicle Program at the SpaceX Boca Chica Launch Site in Cameron County, Texas. FAA.gov. Retrieved November 16, 2021, from https://www.faa.gov/space/stakeholder_engagement/spacex_starship/media/Draft_PEA_for_SpaceX_Starship_Super_Heavy_at_Boca_Chica.pdf.

[594] https://www.commerce.senate.gov/services/files/4CE62711-708C-493C-A325-E0B845B34372

programs are guided by community recommendations, which have been developed and transmitted by National Research Council decadal surveys and by federal advisory committees[595].

NSF operates the National Optical–Infrared Astronomy Research Laboratory (NOIRLab), which manages national facilities for optical and infrared ground-based astronomy, and the National Radio Astronomy Observatory (NRAO), which manages radio astronomy facilities. NOIRLab is responsible for five programs — Cerro Tololo Inter-American Observatory (CTIO), the Community Science and Data Center (CSDC), Gemini Observatory, Kitt Peak National Observatory (KPNO) and Vera C. Rubin Observatory. The Association of Universities for Research in Astronomy, Inc. (AURA) operates these facilities and NSF's NOIRLab under a cooperative agreement with NSF. NRAO is responsible for the Very Large Array (VLA), the Atacama Large Millimeter/submillimeter Array (ALMA), and the Very Long Baseline Array (VLBA). The NRAO is funded by NSF under the terms of a cooperative agreement between NSF and Associated Universities, Inc. (AUI), a science management corporation. AUI also partners with NSF on Green Bank Observatory (GBO). Though currently non-operational, NSF additionally operates the radio astronomy facility Arecibo Observatory under a cooperative agreement with the University of Central Florida.

NSF additionally carries out spectrum management activities concerning several scientific areas across the Division of Mathematical, Physical, and Engineering Sciences. Many of these activities are especially vital for radio astronomy. From NSF's Future Spectrum Requirements report[596]:

> *NSF has two key spectrum needs now and in the future: protection of existing uses of the spectrum and a framework for facilitating future innovation. NSF needs continued protection of existing frequencies identified for the radio astronomy service (RAS), the Earth exploration satellite service (EESS), and for both active and passive frequencies utilized for weather, hydrologic, and climate monitoring and prediction research. NSF also needs advances in modern communications technology to facilitate the effectiveness of remote environmental data sensor networks and exploratory field science, such as in the polar regions and the high seas. With the rapid development of commercial applications, without the forethought to set aside electromagnetic "preserves", scientific progress in the future will be hindered. Especially for radio astronomy, NSF needs expanded protections in specific geographic areas. In addition, NSF needs a framework for flexible testing and development for its wireless research community. A key NSF goal is the development of technologies and techniques to better enable enhanced spectrum efficiency and the co-existence of scientific investigation and other uses of the radio spectrum. NSF has invested substantial funding for innovative technologies and research in spectrum use,*

[595] https://www.nsf.gov/mps/ast/about.jsp

[596] National Science Foundation. (2019). *National Science Foundation's Future Spectrum Requirements.* National Science Foundation. https://www.nsf.gov/mps/ast/NSF_Future_Spectrum_Requirements_Report_2019-08-27.pdf

efficiency, and compatibility, and plans to undertake new initiatives to continue basic R&D in electromagnetic spectrum use in the coming 10–15 years.

High-energy astrophysics is carried out under the Department of Energy (DOE) Office of Science, High-Energy Physics (HEP) Division. HEP programs include ground-based astronomy projects for dark matter, dark energy, and the cosmic microwave background (CMB). Of those projects affected by satellite constellations, DOE HEP currently manages the Dark Energy Spectroscopic Experiment (DESI) at KPNO and the developing CMB-S4 telescope in the Atacama Desert. DOE HEP is also a partner in Vera C. Rubin Observatory.

Additionally, the United States Congress mandated that NSF, NASA, and the DOE establish an Astronomy and Astrophysics Advisory Committee (42 U.S.C. § 1862n-9). Congress tasked the Advisory Committee with: (1) assessing and making recommendations regarding the coordination of astronomy and astrophysics programs of the NSF, NASA, and DOE; (2) assessing and making recommendations regarding their activities as they relate to reports from the National Research Council; and, (3) submit an annual report on the Advisory Committee's findings and recommendations under (1) and (2).

The United States additionally supports one of the world's largest astronomy professional societies — the American Astronomical Society (AAS). The AAS has roughly 8000 members, including physicists, mathematicians, geologists, engineers, and others whose research and educational interests lie within the broad spectrum of subjects now comprising the astronomical sciences[597]. The AAS has a standing policy committee composed of members and a dedicated policy team in Washington, DC, advocating on behalf of the astronomical sciences — both ground- and space-based.

3.13.4 International involvement

As described above, the United States engages internationally in matters involving astronomy. To begin with, the United States ratified four of the five United Nations space treaties: The OST,[598] the Rescue Agreement,[599] the Liability Convention,[600] and the Registration Convention.[601] Any laws in the United States must be consistent with these treaties. As with many other countries, the United States has neither ratified nor signed the Moon Agreement.

[597] https://aas.org/about-aas
[598] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].
[599] Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, Apr. 22, 1968, 19 U.S.T. 7570, 672 U.N.T.S. 119 (entered into force Dec. 3, 1968) [hereinafter Rescue Agreement].
[600] Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 13810 [hereinafter Liability Convention].
[601] Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15, (entered into force Sept. 15, 1976) [hereinafter the Registration Convention].

The United States actively participates in international policy-making that could affect space and the sciences. Further, the United States, through a variety of partnerships, engages in international scientific cooperation. With respect to satellite licensing and operations, it submits filings to the ITU on behalf of actors seeking licensing through the FCC.

3.13.5 Constellation developments

Currently, there exist no regulations specifically imposing stricter requirements on satellite constellations (as opposed to a single satellite). That being said, the FCC recently sought comment on whether certain orbital debris metrics should differ for constellations. Specifically, the issue focuses on whether metrics should be per satellite or across constellations. Not surprisingly, some satellite companies expressed concern about applying criteria across the entire constellation (which would constitute a much stricter threshold to meet). Given these issues relate to the orbital debris regulations already implemented, the FCC could promulgate new regulations making a determination on this and other issues at any time. Moreover, the GAO recently noted the growing concern that satellite constellations pose with respect to orbital debris and identified the FCC, NOAA, and the FAA as all being involved in regulating the mitigation of orbital debris.[602] This follows concerns raised by NASA about the potential conjunctions and collisions that may result from a proposed constellation in the 400 km A-Train range.[603] Certainly, the concerns with satellite constellations will only continue to grow as the numbers of constellations and satellites increase.

In terms of specific numbers, definitive answers remain somewhat amorphous. For, one needs to differentiate between (a) the number of satellites for which a license has been submitted; (b) the number of satellites authorized; (c) the number of satellites actually planned (in any specific period); (d) the number of satellites launched: and, (e) of those in (d), the number remaining in orbit. By way of example, SpaceX sought license approval for tens of thousands of Starlink satellites. Yet most sources reflect the 4425 planned in the current iteration.[604] Of these, nearly 2000 have been launched. Beyond the single Starlink constellation of a single company (SpaceX), one source identifies 11 constellations involving joint ventures between United States and foreign interests[605] and nearly an additional 100 with interests solely within the United States.[606] Of these 100 constellations, about 30 have launched at least one satellite so far (e.g., SpaceX, OneWeb, Spire, Swarm, AST SpaceMobile, Stara, Aireon, Iridium,

[602] GAO, "COMMERCIAL SPACE TRANSPORTATION FAA Continues to Update Regulations and Faces Challenges to Overseeing an Evolving Industry," June 16, 2021 (https://www.gao.gov/assets/gao-21-105268.pdf).
[603] NASA, Letter, October 29, 2020 (http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-441408&f_number=SATPDR2020041300034) (submitted in response to the FCC's Public Notice of October 2, 2020 Application for Fixed Satellite Service Mobile Satellite Service by AST & Science).
[604] https://airtable.com/shrbfAxhYJ8AbCo0O/tbl9y3pPy04L6QZjV; https://www.nanosats.eu/database; see also, https://www.newspace.im/.
[605] https://airtable.com/shrbfAxhYJ8AbCo0O/tbl9y3pPy04L6QZjV
[606] Ibid.

SEOPS, Analytical Space, Capella, Astro Digital, Umbra, HawkEye 360, Globalstar, etc.).[607] Since the beginning of November 2021, the FCC authorized Boeing to construct, deploy, and operate 132 NGSO satellites,[608] while Astra Space Operations, Inc. filed an application to deploy a constellation of 13,600 satellites.[609]

3.14. Other countries

As mentioned in the Methodology, the list of case studies is not exhaustive. Some countries do not yet have enough mechanisms, regulations, or policies in place in order to be the subject of as thorough a review as the previous ones. Still, certain elements found in other countries are worthy to note.

One is the case of Turkey. Turkey already has some basic legislation in place, such as Law 278 on the Establishment of the Scientific and Technological Research Council of Turkey (TUBITAK), Law 406 on the establishment of TURKSAT, Statutory Decree 655/703 on the Organization and Duties of the Ministry of Transport and Infrastructure, and Presidential Decree 23 on the establishment of the Turkish Space Agency. Several developments are under way in the country, for instance the potential merging of TUBITAK and the Turkish Space Agency and a new Law for the latter.

Besides these two actors, the Turkish Ministry of Industry and Technology, together with the Ministry of Transportation and Infrastructure, are the main governing bodies related to space activities. Then, in cases of launches and flights or where explosives are involved, military and enforcement institutions are responsible (e.g. to grant authorization).

On the policy side, the National Space Policy is expected to be published in the near future and will be coordinated and overseen by the Turkish Space Agency.

Turkey is also involved in astronomical activities, including in the Chinese eXTP x-ray astronomy satellite project and in a potential future program featuring nanosatellites astronomical purposes. In addition, the country has an observatory operated under TUBITAK and another one under construction, set to become the largest observatory in the country.

There seems to be some level of astronomical representation and visibility within the Turkish Space Agency, since the Director of the national observatory TUG sits at the EC of the Agency and the Acting President of the Turkish Astronomical Society also holds the position of Head of the Space Science Branch within the Agency.

[607] Ibid.
[608] In the Matter of The Boeing Company, Application for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Fixed-Satellite Service, FCC 21-115 (November 2, 2021) https://www.fcc.gov/document/fcc-authorizes-boeing-broadband-satellite-constellation
[609] https://licensing.fcc.gov/myibfs/download.do?attachment_key=13337304

The next country is Costa Rica. Since 2021 the country has had a governmental space agency, the Costa Rican Space Agency (AECR). Together with the Space Centre (itself part of the AECR), it will carry out research on meteorological activity, environmental monitoring, telecommunications management, geographic location, among others. Although the AECR will operate with donations, there is still a lot of resistance from the public and some actors in the political sector owing to the anticipated monetary expense involved.

The main relevant legislation is **Law Nº 9960 Creates the Costa Rican Space Agency (AEC).**[610] It establishes the regulatory framework of the AEC "*with the aim of creating the strategic architecture and the operational model necessary to design, develop, execute and implement the national space strategy*" (Article 1). According to Article 3, the AEC is a "*non-state public entity, with legal personality and its own assets, with technical, administrative and managerial autonomy for the fulfillment of its attributions, objectives and purposes*", although its operation "*will be subject to the guidelines issued by the Ministry of Science, Innovation, Technology and Telecommunications [MICITT] as the governing body in the area of science and technology*". Its functions are defined in Article 4, and some of them are: "*to develop research, technological innovation, collaboration and articulation projects focused on the solution of humanity's problems in terms of the generation of space scientific knowledge, space exploration and management of resources inside and outside planet Earth, within the framework of the sustainable development objectives of the United Nations (UN); to contribute to the generation of lines of research and national space policy; to conduct projects in accordance with the National Science, Technology and Innovation Plan and the Costa Rican Space Policy; and to authorize and supervise national activities in outer space carried out by governmental agencies or national non-governmental entities, which may generate responsibility for the country, in accordance with international law*". This law also mentions the creation of the Guanacaste Space Centre, which is created as a dependency of the AEC and responsible for the implementation of space research, development and innovation projects, the promotion of space science and the management of complementary services related to the space area (Article 11).

There are some legal developments: a **File n° 21.330, Law for the Creation of the Costa Rican Space Agency (AEC)**[611] is currently under review. The Government will present a proposal to reform the law in order to ensure that it has a reasonable cost and that it is adapted to the country's time and budget possibilities. In general, the articles make no mention of the promotion of astronomical or satellite development, but rather indicate the functions of the agency and the space center dependent on it; it has an eminently technical criterion.

[610] Sistema Costarricense de Información Jurídica (pgrweb.go.cr)
[611] http://proyectos.conare.ac.cr/asamblea/21330.pdf

Lastly, Costa Rica is rather active in the astronomy field, with different activities and programs such as the National Centre of Science and Technology (CIENTEC), Space Systems Laboratory (SETECLab), Space Radar Costa Rica, and the Planetary and Astronomical Observatory of San José (University of Costa Rica).

4. Takeaways

From the case studies analyzed, a number of themes emerge and some general observations can be made. While not applicable to every case study, these takeaways represent a general picture of the situation across the cases.

4.1 Balancing economic growth and environmental concerns

In many cases, it was observed that national space policies and strategies catered to the growth of the space economy and the support of the space industry and commercial activities. Relatively few cases identify that policies and regulation to foster commercial and government space activities should also specifically account for impacts on the natural environment. Several countries refer to the importance of sustainability, but without detailed implementation steps. One exception is space debris mitigation measures, which have found their way into domestic instruments, and some licensing procedures.

4.1.1 Extending environmental impact assessment

Several countries require those filing for a launch or operator license to complete an environmental impact assessment as part of the application. While these impact assessments cover a range of environment topics and in some examples consider the cumulative impacts of the activity, none of the cases reviewed covers astronomy or impacts on the dark and quiet sky. The overall assessment, and especially the review of cumulative impacts within, could be extended to ensure the impact on astronomy, astrotourism, or on the dark and quiet skies in general is taken into account.

4.2 Updating conceptualizations of space activities and outer space

4.2.1 Finding the place of astronomy in the field of space

Most countries have a direct interest in the preservation of dark and quiet skies since they run astronomical programs in which considerable human and financial resources are invested. Those activities are also the result of bilateral and international cooperation (for example, the Square Kilometre Array Observatory, and the European Southern Observatory) and as such represent a means to build crucial bridges between nations in order to unite efforts to observe our universe and exchange scientific knowledge. In spite of this, the occasions on which astronomy is directly and meaningfully represented in space policies are still rare. There is currently limited recognition of the threats faced by astronomy and the policy means to mitigate them.

Several countries explicitly or implicitly consider astronomy to be a space activity. Examples found amongst the countries studied include astronomy being classified as a space activity in a piece of legislation, the space agency funding and running astronomical projects, or yet another national space research institute carrying astronomical activities or managing observatories. Some even go further and consider astronomy part of their space sector or space economy. On the one hand, having astronomy under the umbrella of the space sector can ensure that all policies and strategies aimed at developing space activities and the space sector automatically include astronomy. One of the benefits is that if the astronomy community is an official and recognized stakeholder, it will be included in decision-making processes or consultations. Another concrete benefit is that when the national law mandates the space agency for instance to finance or facilitate the financing of space activities, it already includes astronomical activities. Lastly, it can also facilitate internal considerations of harmful interference between space activities. On the other hand, including astronomy in the concept of space economy would help valorize the discipline and its contributions not only to science, but to society as well.

4.2.2 Outer space as an environment

Several countries requiring environmental impact assessments indicated that this encompasses both Earth and outer space, implying that outer space is part of the environment, or at least an environment of its own. In order to realize the intent to protect the environment from damage from space activities, countries should comprehensively identify all the threats to the outer space environment, including its visual appearance from Earth.

4.2.3 Understanding low Earth orbit

Developing a comprehensive understanding and model of our closest outer space neighborhood — LEO — is essential. That includes answering what LEO represents for countries and the international community today, whether it is a (limited natural) resource, a strategic playground, an operational domain for defense, or all of these and more. Countries should also methodically evaluate what benefits or advantages LEO brings, and the challenges they face now or in the future to reap those benefits fully and sustainably. Few cases identify the strategic balances required in LEO in terms of the impact of increasing numbers of space objects and the concomitant impacts on the LEO environment, capacity, scientific value or ability of others to equitably access the resource.

4.3 Looking outward

4.3.1 Echoing international behaviors

The case studies demonstrate that emerging space nations are attentive to the practices and policies of established space nations and the benefits they reap from their space sector. Some have recognised that development of a national space sector would provide a pathway to be able to compete with “developed countries”, and eventually become one. Yet, this vision rests on development in terms of economic and technological capacity, rather than steps to care for the environment and ensure long term sustainability of outer space. That should be an incentive for established space nations to lead by example.

4.3.2 Creating leverages

Aiming to reinforce international prestige, soft power, or secure a strategic place in the region are often factors driving countries, especially emerging space nations, to develop their space sector. Many countries recognize various international standards such as space debris mitigation and long term sustainability and recent initiatives are encouraging compliance with these standards as a way to demonstrate advanced space capability and signal prestige. Going further than compliance, active involvement in shaping such standards can be leveraged in international fora or in bilateral cooperation as a way to secure a seat at the table and take the opportunity to influence decisions. That willingness can also be used as a leverage to include the issue of the impact of space activities and satellite constellations on astronomy.

From a technical perspective, several countries would like to see their industry flourish and have nationally-developed innovations reach international markets. Just as there is a new sector of the market for debris removal technologies (not usually seen as a cost-effective activity), a country could push some of its engineers to develop manufacturing techniques and materials that help satellites be less reflective while maintaining their performance and so become a niche of the "sustainable space market". That could be implemented through dedicated funding for projects that seek to improve the sustainability of outer space, but also in giving visibility to national companies working on this to ease partnerships with international actors. Another way is for national or subnational institutions that provide funding to satellite manufacturers and operators to identify the issue and privilege "good students' when deciding who to fund. Space agencies could also choose to work with manufacturers that are "environmentally-friendly" on outer space.

4.4 Guiding and making private actors responsible and accountable

While the value of growing a national space sector through private sector investment and involvement is attractive, some countries lack clear and detailed frameworks and mechanisms to guide such private endeavors in terms of operating with sustainability and environmental concerns in mind. In general, industry is typically receptive to level playing field international guidance on sustainable practices. In any case, states are bound by international law and they have a responsibility to ensure their private companies act accordingly. It is up to sovereign states to act at their level and transpose international laws and guidelines into their domestic legislation. That should not replace international operations (e.g. COPUOS discussing the dark and quiet sky) but that should certainly be done in addition to it. Where international measures can take a long time to mature, countries have the power to act within their own borders and change the situation for the better in a considerably shorter span.

A sound legal regime that tackles questions of registration, liability, protection of the environment, sustainability of space activities, and so on, can be the foundation of a space sector and a space industry with all the tools to mitigate the impact of satellite constellations, including on astronomy.

4.4.1 Involving startups and SMEs

Countries increasingly consult with their industry. However, the industry is a large and diverse mix of startups, small and medium sized enterprises (SMEs), and established companies. It's important to consult with each and recognize the differences in the input they can provide and the experience they can have both in the space sector and in applying general recommendations. First, numerous are the new space companies seeking to monitor and fight climate change, improve life on Earth, prevent and respond to natural disasters, solve problems for their local communities, etc. Sustainable development and environmental concerns are usually part of their core values, then ingrained in their business model. Their perceptions and insights complement those of established space companies. Second, startups and SMEs may not have the financial or human capacity needed to apply broad international recommendations. They may also not have the infrastructure to do so. National guidelines for the industry should recognize that. A solution could be for the government to facilitate partnerships and knowledge transfer between all industrial actors.

4.5 Creating strong synergies

Dialogues and synergies are needed between the national astronomical community, industry, and government. Several countries have boards within their space agency or body with a similar function. Those boards are commonly composed of representatives from different ministries or authorities, the ministry of science or of industry, for example. Oftentimes, external actors can also be invited to provide inputs where relevant. This indicates that mechanisms already exist to make way for dialogue. But, for it to be effective, astronomy needs to be directly represented as such and included in, or inform, decisions. One person to represent the scientific community as a whole is probably not enough to enable decision makers or the industry to understand the needs and challenges of all different scientific disciplines. As demonstrated throughout this report, astronomy has specific needs and is affected in a singular way by satellite constellations.

Several countries are reorganizing agencies in charge of space, updating their laws, and re-evaluating their strategies. Scientific and academic actors seem to be increasingly consulted in those instances. The prerequisite is that astronomers have to be identified as relevant scientific actors in order to be consulted. But, beyond that, there is an opportunity in these new developments. If astronomy and industrial actors are included, they can both put their concerns and interests forward from the start, so that the new policy or regulation reflects that.

4.6 Optimizing mechanisms

All countries reviewed are building or diversifying their space programs, requiring a level of organization coordinated through laws and policies by governmental bodies. However, some countries are fragmenting efforts, with a compound of new bodies and documents, to a point where it is difficult to understand the role of each actor, who are the leaders of the projects, and how strategies relate to each other. Without a policy coherence in the space sector, coordinating and centralizing discussions with the relevant actors becomes challenging. Generally speaking, cross-disciplinary or cross-sectoral national space boards seem more efficient than accumulating separate bodies.

Also, some countries already have various astronomical committees and space centers, which would make ideal fora in which to address the challenges faced by astronomy with respect to satellites constellations and light pollution. That is because of the mandate they already have or because of previously established connections and ties with space agencies and decision-making bodies. It then becomes a matter of adjusting and attributing the tasks to those who will be the most suitable. That prevents creating yet new entities and ensures the mechanisms already in place are used optimally. Overall, there is a compelling need to formalize engagement on the impact of satellite constellations. It requires a standing forum at national level to bring together the satellite licensing agencies, space agencies, funders, satellite operating companies and representatives from the astronomical community.

Another way to optimize actions taken by countries would be to create clear and independent national space policies, separated from the policies existing within other ministries (e.g. ministries of defense, and of science, technology, knowledge and innovation). However, this does not mean that space policies and guidelines should not be embedded in national ministerial policies or plans.

4.7 Involving citizens

A population that is interested in science and understands its benefits is a population that supports government investment in scientific projects. Many countries already recognize that by mentioning the importance of raising citizens' awareness of national space programs. At times the idea remains on paper and, with people seeing space as the distant playground of billionaires rather than a medium to help improve life on Earth in very practical ways, there can be a lot of misunderstanding and discontent about public budgets being invested in space. Similarly, there should be bridges between the scientific community and the population, facilitated by government institutions, so that people learn about what astronomy can do for them, are inspired about the field of astronomy in general, and ultimately care about the future of the field. In this case, a concerned population is one that can be vocal to the government about a cause they support and make things move in government-industry relations.

4.7.1 Investing private funds in astronomy

More than offering support, a population involved in the scientific development of the country that takes pride in national discoveries can also generate individuals that invest in said development. That is the case in a particular country where the sciences are highly valued and inspiring the youngest through space programs and astronomy is also part of its history. The consequence is that there is a smaller barrier for private investors to fund astronomical infrastructure because they already understand the value of it.

As an overall point, being active in space does not merely come with rights and benefits, it also comes with duties and responsibilities. Those don't only come from international norms but also have to come from self-imposed guidelines and rules. Space is not only a tool to increase the prestige, innovation, or the size of the economy, it is also an environment that needs and is entitled to protection. This should be acknowledged explicitly and countries should act accordingly and in concert.

Chapter 4. Industry Working Group

1. Introduction

1.1 Industry Working Group charge

The Industry Working Group was tasked with understanding how the international astronomy community can coordinate efficiently and effectively with industry stakeholders to mitigate impacts, raise awareness and promote mutual interests while learning lessons from similar initiatives. The group looked to understand how to strengthen industry support on the recommendations and monitor industrial standpoints.

The work was focused on the 2020 Dark and Quiet Skies for Science and Society recommendations Sat_Con3–7.

Dark and Quiet Skies 2020 Recommendations
Sat_Con 3. Raise awareness of the impacts on astronomy amongst designers, investors, regulators, manufacturers and operators, and include impact mitigations as a core component of corporate social responsibility and sustainability strategies.
Sat_Con 4. Design missions to minimize negative impacts on astronomical observations by: a) minimizing operational altitudes — satellites in constellations with higher orbital shells are illuminated by the sun for longer during the night and appear more 'in focus' to telescopes; in general, the impact on astronomy increases with constellation altitude. Scientific analysis shows that orbits on the order of 600km or below offer a compromise between brightness and the length of time satellites are illuminated during the night; b) minimizing the number of satellite units as second priority to altitude while maintaining safe operational practices; c) minimizing the time spent in orbit when not in service.
Sat_Con 5. Design satellites to minimize negative impacts on astronomical observations by: a) guaranteeing that all satellites appear fainter than *7.0 Vmag +2.5 × log(SatAltitude / 550 km)* with a minimum value — corresponding to maximum brightness — of visual magnitude (Vmag) 7 during all flight phases, which makes them undetectable to the unaided eye; b) minimizing antenna sidelobe emissions such that their indirect illumination of radio observatories and radio-quiet zones do not interfere, individually or in the aggregate; c) preventing direct illumination of radio observatories and radio-quiet zones with a satellite's main antenna beam.

Sat_Con 6. Provide timely, transparent and reliable data to the astronomy community and observatories to allow sufficient planning to avoid impacts and post-hoc analysis of incurred impacts. Data required include: spacecraft design, brightness data, mission designs and orbital profiles, attitude control, and predicted and real-time orbital elements.
Sat_Con 7. Raise awareness of the impacts of satellite constellations and possible mitigation strategies and their costs and requirements amongst key astronomy stakeholders. Develop mechanisms to coordinate approaches across communities and countries and share information on industry interactions, mitigation solutions and observational data.

2. Best practices guidelines for low Earth orbit[612] satellite constellations to mitigate impacts on the astronomical sciences[613]

I. Priority No. 1: Address the visible brightness of the satellites as seen from the ground.
    A. Objective: Reduce brightness to minimize impact on astronomy and night sky observers
    B. Guidelines:
        1. Endeavor to reach the fainter of these in all phases of a constellation:
            a) Unaided eye visibility[614]: V > 7.0 mag where V is the photopic vision sensitivity curve. Or
            b) $V > 7.0 + 2.5 \log_{10}(r_{orbit}/550\ \text{km})$, equivalent to 44 x $(550/r_{orbit})$ watts/steradian, where r_{orbit} is the mean altitude of the satellite orbit in km and *V* in this case is the Johnson *V* bandpass at 550 nm.
        2. Encourage that reflectance simulation analysis be performed by operators/manufacturers as part of the satellite design and development phase.
            a) Pair with laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements.

[612] Mitigation of other orbits may be necessary, but they may have other technical requirements, and are beyond the scope of these guidelines for low Earth orbit satellite constellations.
[613] The constellations are of concern to astronomy because they represent multiple orders of magnitude increase in the number of bright satellites. While the most obvious mitigation solution might be to launch fewer satellites, that option is not included on this list as a large number of satellites are needed for global coverage at low orbital altitudes. For more details, see the SatCon1 Report: https://noirlab.edu/public/media/archives/techdocs/pdf/techdoc003.pdf
[614] Some relevant information on the color dependence is contained in the analysis of satellite impacts on the Rubin Observatory by Tyson et al. (2020, Astronomical Journal, 160, 226). These limits depend on the sensitivity of the Rubin Observatory system, including the filters and detector. Brightness limits in other bands within the LSST bandpass system, which still permit cross-talk calibration, are $u \approx 5.5$ mag; $r \approx 7$ mag; $i \approx 6.5$ mag; $z \approx 6.8$ mag; and $y \approx 6.5$ mag. Remaining fainter than these limits is comparable to adhering to $V \geq 7$ mag at 550 km. Note that these are not equivalent to a wavelength-independent reflection of the solar spectrum. Visual reference for LSST filter bandpasses are found at https://www.lsst.org/scientists/keynumbers.

3. Noting that reflected sunlight is slowly varying with the orbital phase, and that flares are rare events, endeavor to reduce and/or control the effect of specular reflection (flares) in the direction of the ground, as follows:
    a) Design/manufacture satellites with a reduced number of facets on the reflective surface, where practicable.
    b) Minimize non-rigid specular materials on the nadir face of the satellites, where practicable.
    c) Minimize, where practicable, the fine texture on the reflecting surface of the satellite, such as multi-layer insulation, which creates rapidly varying reflectivity known as glints.
    d) If operationally viable, adjust attitude to avoid flares projecting onto major ground-based observatory sites.

II. Priority No. 2: Address the visibility impact on astronomical sciences of large constellations of LEO satellites with altitudes above 600 km.
    A. Objective: Navigate the balance between constellation size and altitude to allow achievement of satellite service objectives while minimizing impact on astronomy
    B. Guidelines
        1. Endeavor to have satellite constellations operate in orbits with altitudes below about 600 km, if practicable, when consistent with operational and safety objectives and constraints, in order to minimize the rate of sunlight streaks in the dark hours between evening and morning twilight for the largest-aperture telescopes.
        2. If the constellation cannot be planned for altitudes below ~600 km, the impact on astronomical observations would still be reduced on balance if the constellation designers were to choose a lower rather than higher operational altitude.

    Note: The altitude of the LEO satellite constellation does not have a uniform impact on observations around the world. Lower orbit altitudes impact programs disproportionately at latitudes outside of +35 and –35, and increasing the number of satellites on orbit impacts programs that depend on observations in twilight, such as those for planetary defense. Further, if the satellites are not dimmer than naked-eye brightness natural and cultural heritage may be affected.

III. Priority No. 3: Provide access to high-accuracy public data on predicted locations of individual satellites (or ephemerides).
    A. Objective: Enable the real-time use of high-accuracy public data on satellite locations to enable some adjustments to observational strategies and reduction of disruptions.

B. Guidelines:
   1. Endeavor to provide publicly-available, live-updated positional information or processed telemetry on LEO satellites that is accurate enough to enable telescope pointing avoidance and mid-exposure shuttering during satellite passage.
      a) Any information provided should be provided through a database that enables astronomers to determine that the transit of any unit across the field during the exposure interval can be predicted within 12 hours in advance of the observation, to an accuracy of 2 seconds in time. Where practicable, enable astronomers using the database to know the position of the track to within 6 arcminutes in the cross-track direction and 6 arcminutes in position angle.
   2. The satellite and observation communities should [use][develop jointly] a new standard format for publicly available ephemerides beyond two-line-elements (TLEs) in order to include covariances and other useful information.

IV. Priority No. 4: Orbit raising and deorbit considerations
   A. Objective: Minimize disruptions to observations from satellites immediately post launch and during de-orbit/reentry phases of operation.
   B. Guidelines:
      1. Immediate post-launch satellite configuration in multiple-satellite launches should be grouped as tightly as practicable, consistent with safety-of-flight and other relevant considerations, thereby affording rapid passage of the train through a given telescope's pointing area.
      2. Endeavor, where practical to control post-launch and re-entry attitudes to minimize reflected light on the satellites' ground track.
      3. Deorbit as soon and as quickly as practicable, taking due account of relevant protocols for such operations, while also taking into account brightness mitigations, where practicable.

V. Priority No. 5: Continued collaboration between the observation and satellite communities.
   A. Objective: Enabling astronomers and industry to collaborate to ascertain and confirm the efficacy of mitigation techniques through follow-up observations and apply/publicize positive lessons learned
   B. Guidelines:
      1. Support a comprehensive satellite constellation observing network with uniform observing and data reduction protocols for feedback to operators and astronomical programs. Mature constellations will have the added complexity of deorbiting of the units and on-orbit aging, requiring ongoing monitoring.

2. These standards reflect recommendations that are based on the current state of knowledge of constellation designs and the coupling between orbits and illumination. It is understood that this knowledge may evolve due to operational experience or changes in constellation designs. Periodic reassessment of these recommendations will be necessary in collaboration between operators and the astronomical community.
3. Establish a practical means for coordination between the satellite and observing communities regarding collection of data through the IAU Centre for the Protection of Dark and Quiet Skies from Satellite Constellation Interference.

3. Possible draft action plan on dark and quiet skies non-GSO matters

Problem-focused interaction between organizations can happen in several distinct modes (e.g., often called coordination, cooperation, collaboration) where each mode represents a higher level of joint problem solving, information sharing, shared goals, leadership commitment and trust. Interaction structures should aim to enhance these dimensions. Industry–astronomy-community interaction structures should facilitate the following roughly sequential steps, moving from deconfliction to cooperation to collaboration.

The points below build upon initiatives and ideas presented in the 2020 Dark and Quiet Skies for Science and Society Recommendations.

I. In furtherance of Sat_Con 3, identify core constituency from among astronomers, satellite system designers/manufacturers/operators, and regulators to discuss:
    A. Next steps to address non-GSO satellite issue impacts on astronomy
        1. Gain awareness of astronomy impacts
        2. Understand qualitative impact category
            a) High priority: NGSO constellation systems (need to work on rough criteria...e.g. totalling X units (meaning Y are overhead at any one time) in LEO or MEO. Include satellite mass (or albedo), presence of nadir facing reflective surfaces and certain spectrum usage;
            b) Second priority: all other types of satellite and space systems.
    B. How to consider/address impact of future changes in astronomy or the non-GSO satellite industry early in the respective project cycles
    C. Work under the IAU Centre umbrella to continue to host the means to mitigate the issues.
        1. Invite core constituency members and Centre personnel to participate in bilateral discussions, host a regular event (e.g. annual or semi-annual forum

meeting on-line or in person) to review current updates, share information, and review proposals for joint research and development.
2. Establish sub-groups that meet regularly to address specific areas that need addressing (software issues for avoidance, observations for brightness determination, better TLE determinations that are accessible by observatories, hardware testing to minimize brightness, etc) and meet with other astronomy-based working groups with overlapping topics.
3. Engage in awareness-raising activities at industry and academic conferences, and via media publications.

II. In furtherance of Sat_Con 4, 5, 6 and 7, agree on set of best practices guidelines for industry and astronomy

A. Identify methods for provision of/exchange of timely, transparent, and reliable data between Industry and the astronomy community to assess effectiveness of and make any necessary adjustments to best practices.
   1. Data should include, as appropriate, relevant information on spacecraft design, brightness, mission designs/orbital profiles, attitude control, and predicted and real-time orbital elements.
   2. Information from astronomers on observation practices and plans, as appropriate and relevant, should be provided to Industry by the astronomy community on a regular basis in a common format.
B. Provide guidance on how to optimize (for both groups) operational altitude issues, performance objectives, numbers of satellites, and post-service considerations.
C. Identify steps available to Industry to:
   1. Practicably minimize maximum brightness of spacecraft;
   2. Practicably reduce main-beam illumination of radio observatories and radio-quiet zones;
   3. Practicably reduce individual and aggregate indirect illumination of radio observatories and radio-quiet zones;
D. To implement methods identified, the following points should be considered, as applicable:
   1. Mechanism for organizational commitment to take action.
   2. Develop internal review of how company would impact along elements provided by the astronomy community.
   3. Commitment/deployment of resources to work and test potential mitigation techniques.
   4. Regularly monitor best practices for future research needs and potential government actions.

E. Formulate research funding requirements. Governments are supporting the development of satellite testing facilities services, and also could fund innovation / technology research on advanced non-reflective materials

III. Proposed Timeline for Actions

A. Establishment within the core constituency (IAU Centre)
B. Adopt Best Practices Guidelines — Q1 2022
C. Address potential sensitive information issues and establish meaningful data sharing mechanism — Q3 2022

Chapter 5. Observatories

1. Introduction and summary

This report represents the effort that must be undertaken by the astronomical community to characterize and mitigate the strongly negative impact of reflected sunlight from constellations of communications satellites in low Earth orbit (LEO). It builds on the series of workshops that began with the US NSF-sponsored SATCON1, followed by the first UN/IAU/IAC-sponsored Dark & Quiet Skies Workshop, then SATCON2, and the current Dark & Quiet Skies II. This report follows closely on the recommendations of the Observations and Algorithms Working Groups of the SATCON2 Workshop. It focuses on next steps and implementation strategies. We note that reflected sunlight is only one of the deleterious effects on astronomy, with radio interference and sustainable scientific use of increasingly crowded LEO space among the other concerns.

A key recommendation from the SATCON2 report is for the coordination of effort and dissemination of data and information to be performed through a central virtual clearing house and repository, designated as SatHub. The various functional needs are represented graphically in Figure 5.1 below, from the SATCON2 report.

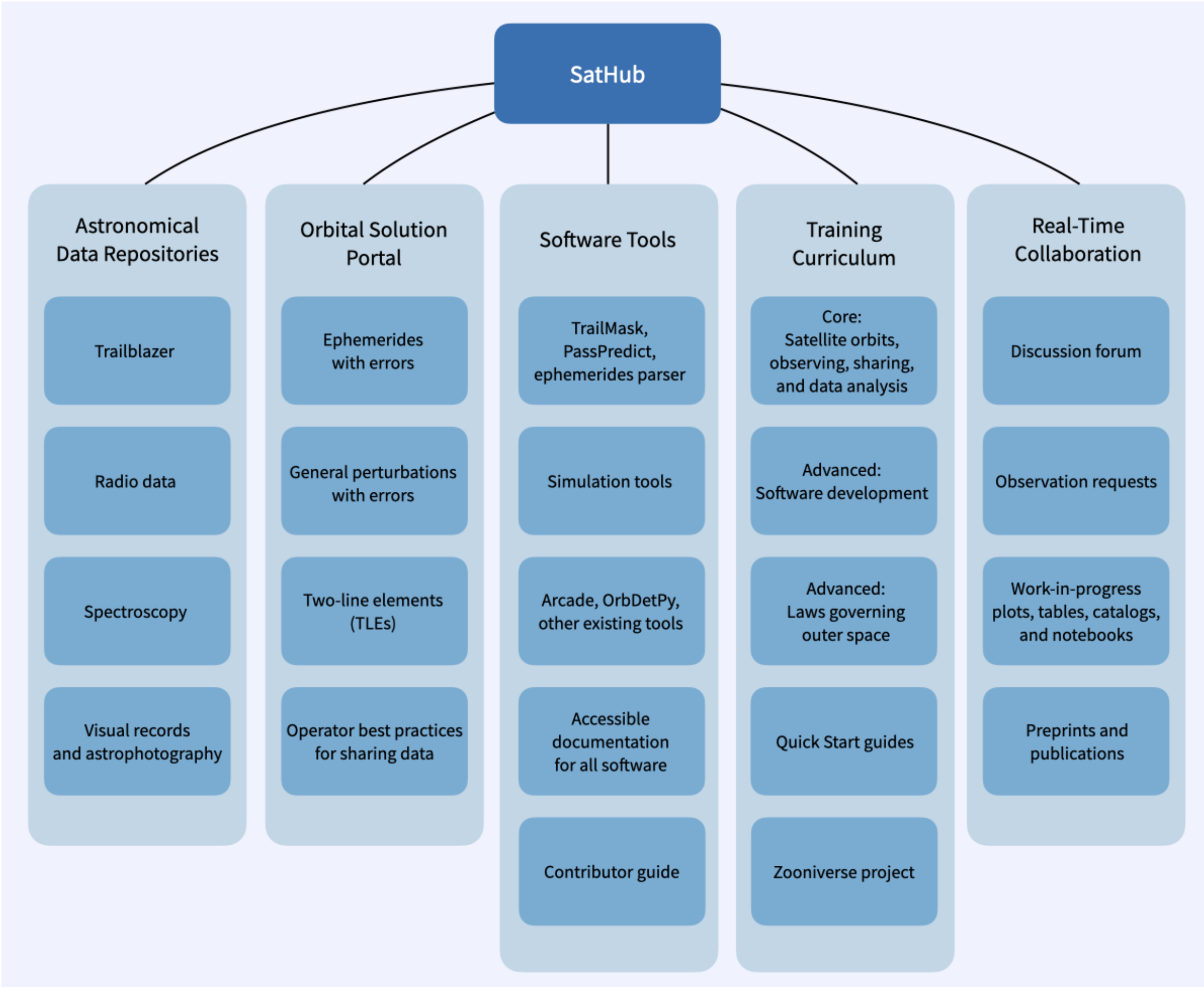

Figure 5.1: SatHub concept overview from the SATCON2 Observations WG report. This diagram shows key elements needed urgently to have an effective, organized, and sustained satellite constellation observation campaign.

The major needs identified for the community include the following:

- Coordinated observations of individual satellites from multiple sites to map the reflection of sunlight in multiple colors as a function of orbital phase angle and other parameters. This activity is critical for the prediction of apparent brightness.
- Development of algorithms with robust implementation for wide distribution for identifying and masking streaks (TrailMask); predicting satellite passages through specific planned observational pointings (PassPredict); simulating streaks in images and addition of solar spectra to spectral data to test detection, masking and removal approaches; and for current probabilistic predictions and visualization in all-sky mode for general observational planning.

- One or more image data repositories for the testing of algorithms for sunlight streak identification and masking.
- Research on the impacts of satellite trails on scientific analysis, in cases such as filtered measures of weak gravitational lensing, determination of orbital parameters for near-Earth objects, or analyzing continuous diffuse objects such as emission nebulae.
- Research on the aggregate impact of the increasing number of objects in near-Earth space on diffuse sky brightness, with particular emphasis on increased atmospheric aerosols and the small particle distribution in LEO.
- Research on the impacts of satellite trails on other astrophysical subfields not mentioned above, including spectroscopic and radio studies, with a particular focus on how this impact is changing as a function of time and frequency/color/bandpass. (Image data repositories will be crucial for these studies.)
- Development of strong education and outreach materials (e.g., the SatHub Training Curriculum outlined in the SATCON2 OBS WG report) for the general public, and amateur and professional astronomers.

Much of this functionality is expected to be coordinated and made accessible to the community by the planned IAU Centre for the Protection of Dark and Quiet Skies from Satellite Constellation Interference.

To date, efforts expended toward these mitigations have been done on a volunteer basis or on a limited contractual basis by individual observers at industry request. The substantial remaining effort must be adequately resourced to prevent substantial data quality loss with the rapid rate of launch of satellite constellations.

Request for COPUOS Endorsement:
States that produce, launch, or license for operation large constellations of satellites in low Earth orbit must provide resources adequate to develop, produce and maintain the means to mitigate the damage to astronomical observational data quality and analysis and astrophotography produced by those constellations worldwide.

2. Coordinated observations

A key aspect of the required engagement by the astronomical community is obtaining sufficient observational data to characterize the multi-color reflectivity of various satellite types as a function of viewing and illumination angle. The following discussion explores implementation of community-wide plans for professional and amateur observers.

2.1 Dynamics and photometry

Computation of ephemerides (including position, velocity and apparent brightness), for forecast and for backcast (identification of trails on past observations), requires models and data of two different kinds: dynamical and photometric.

The dynamical information leads to the computation of satellite position and velocity. The current information available to the astronomy community has uncertainties in the cross-track direction on the order of arcminutes, which are much too large for detailed predictions of the impact on specific target fields. The current reporting format of Two-Line Elements does not contain the uncertainty information needed for predictions. Better input data are already known to the owners of the constellations, with the highest available precision. No doubt this precision level is well suited to the needs of the companies that operate the spacecraft for their own purposes, and they are already getting the input data required to keep track of the satellites. Making this information available in a usable way to the astronomical community is more a matter of negotiation and logistics than of observation. If the astronomical community needed even better ephemerides, the additional data should be obtained and the required resources would be connected with the IAU Centre. Also, orbital models of higher fidelity may be needed to improve the results. Whether all this is really necessary and/or feasible is being discussed, but for now it seems clear that observation campaigns are not specifically focused on the dynamic side of the problem.

The most accurate and precise ephemerides will come from the satellite owners themselves, since only they will have access to the telemetry data from the satellites. Their ephemerides will most likely be based on data from GPS receivers onboard the satellites. There may be cases when these data are not available and will need to be supplemented by data from other sources, such as LEOLABS which will shortly have 24 ground based radars dedicated to tracking LEO objects, and COMSPOC (Commercial Space Operations Center). Should the IAU Centre coordinating this aspect of SatHub require a commercial subscription from such other sources, it will be necessary to make the agreement so that the entire astronomical community has transparent access.

It is photometry that requires much more attention. The prediction of the apparent brightness of satellites is still affected by considerable uncertainty. There are many complex factors involved: sunlight intensity (penumbra cone included), classical phase angle, distance, and the combination of satellite geometry, attitude and observatory position with their reflectivity pattern (normally described by a complex function). The situation gets even more complex if we take into account two additional factors: defocusing of the satellite image and possible spatial resolution of satellite structure, both affecting the object profile and the resulting flux density on the detectors. Current models are far too simple and, although an extreme degree of accuracy is most probably not needed, the current situation is not yet satisfactory.

2.2 Requirements for photometry campaigns

Therefore the main interest of observations has to be centered on improving the performance of the photometric predictions. The complex interaction of the many factors involved requires that many observations should be gathered. The need to cover the variation range of all parameters implies that observations should cover many different phase angles, satellite attitudes and sunlight incidence conditions. One of the implications is that data should be obtained from many different observatories, located at different latitudes on Earth. This leads directly to the need to normalize and unify the photometric system, the observation protocol and the data reduction process. This is relevant both for professional and for amateur observatories that may contribute to this effort.

Considering color, the current assumption is that each satellite model will display a similar and common reflection spectrum. It is true that some chromatic reflectivity differences have to be present, but the initial work may assume that these effects would be below the accuracy requirements, although this is something that should be checked. Under this assumption, the color dependence may be described as one function or set of parameters per satellite model, and this multi-band information may be deduced from less massive sets of data, that may be provided by just a small set of professional observatories. In this framework, the massive international effort should focus on single-filter photometry. But unifying the passband, observational method and reduction procedures is a must. Should there be effects like a color dependence on viewing angle, such complexities will need to be taken into account in the modeling.

In principle, the Johnson *V* band may seem like a straightforward choice. However, the need to have enough reference stars in the field of view for differential photometry may lead to changing this selection to some photometric band with a denser and more accurate representation all over the sky. To this end, some of the Sloan or Gaia bands may be considered. The first multiwavelength observations of Starlink satellites have been conducted for two cases, one standard V1.0 (Starlink-1113) satellite and Starlink-1130 (dubbed Darksat) in Sloan *g*, *r* and *i*, as well as *J* and *Ks* spectral bands using the Chakana telescope and the VIRCAM instrument at the Visible and Infrared Survey Telescope for Astronomy (VISTA) (Tregloan-Reed et al. 2020; Tregloan-Reed et al. 2021).

2.3 Ideas for observation and data reduction strategy

In general, the observatories available (professional or amateur) will not have the capability to track on the satellites. So, the observations would be performed in the stare and wait mode. Relying on the ephemerides of the satellites, considering the observatory location and taking into account the need to have a good set of photometric reference stars, some centralised server would select a pointing position and a specific time to stare and track (sidereally) on that point. Then, a pre-specified integration starts (integration time may be set by the same server according to the characteristics of the equipment) that would include the satellite passage at approximately the centre of this time interval. Stars would appear as point-like sources, allowing an automated world coordinate system (WCS) astrometric solution, leading also to a photometric evaluation from the reference stars identified in the image. A trail detection algorithm would find and characterize the satellite trail and, relying on information about the apparent angular speed of the satellite (that should be obtained from the satellite orbital ephemeris that allowed the observation), the trail intensity would lead to a photometric result. It is crucial for observers to share the details of how they performed satellite photometry, e.g., via a GitHub repository containing data tables, images, and/or analysis scripts, to enable accurate comparisons between various studies and observing campaigns.

The trail position on the image may provide some astrometric information in the direction perpendicular to the trajectory. These data may be useful to improve orbital elements and ephemerides.

2.4 The Minor Planet Center model and special requirements

Normalization and centralized coordination will benefit from the existence of the IAU Centre for the study of satellite constellations. This center could host the servers that provide observation proposals to contributing observatories, together with (on-line or off-line) reduction tools, and the same service would gather and unify the resulting data, to make them available for later scientific processing. The IAU Minor Planet Center (MPC) provides a model. The MPC gathers data from thousands of observatories around the globe, and they work in a way very similar to what has been described: they make observation proposals or calls, they establish some normalization in terms of data reduction standards, they perform quality control of the data gathered and they have a rigorous protocol to admit contributing observatories. To get a MPC number that allows an observatory to provide data, they have to demonstrate their capabilities, undergoing a mostly automated examination, and this should be implemented in our satellite centre, too.

The MPC model may be good from the logistical point of view, but it is important to note the differences in the kind of data to be collected. Astrometry is straightforward: it can be successfully obtained from unfiltered images and, for normal work on minor planets, extreme precision in timing is not a must, and flatfielding is usually ignored. However, observations from amateurs or professionals for satellite photometry have to fulfill a series of minimum requirements: they have to be filtered, timing accuracy will need to be better than that for minor planet observations and careful flatfielding is absolutely a must. Knowledge of observatory location and elevation with, probably, sub-metre accuracy, will also be needed. The equipment used would benefit from real-time internet access (fiber or cable, never satellite-based!) for the selection / prescription of targets on the fly.

The software to analyze the data will have to be provided by the IAU Centre, not only because most observatories will not be in a position to produce their own tools but also for the sake of standardisation. This software has to include:

- Stellar photometry and astrometry database.
- Flatfielding tool (this is to be discussed, many strategies are possible).
- Target prescriptor (PassPredict based, but also taking into account: sats in need of data, observatory location, need of having enough photometric standard stars in the field of view)
- Automatic star and trail (TrailMask based) detection.
- Automatic WCS module for astrometric solution.
- Differential photometry and quality assessment on the basis of the results for the stars detected.
- Trail characterization leading to effective magnitude and trail location (of possible use for astrometry in the direction perpendicular to the trail).
- Given that the observed object is known beforehand, some information about its angular speed is already available and this allows transforming the trail brightness from effective magnitude to the true apparent magnitude of the point-like satellite. Most probably the uncertainties in angular speed due to unavoidable errors in orbital elements will not significantly affect the final result.

This approach is based on the currently most feasible observation mode: staring at a predefined point with sidereal tracking, and waiting for the satellite to pass through the field of view to leave a trail. Observations tracking on the satellite (to get more or less point-like satellite images, but trailed stars) is, by far, beyond the capabilities of most observatories, and the results would pose additional challenges to data processing.

This approach may be capable of gathering a considerable amount of observational material and, at the same time, may build a community of contributors and enthusiasts that would feel themselves as a part of a worldwide effort. If we want this idea to be a success, it will require:

- Existence of the IAU center for the study of the impact of satellite constellations on astronomy, and that this centre assumes this idea as a part of its activities.
- Setting up the servers (hardware and software) for all parts of the operations: customized observation proposals, data reduction tools, gathering of results, quality control, protocols to get (and maintain) the contributor status, database storage and availability of results to researchers for further scientific use.
- Establishing the standards: choosing the photometric system and defining the observation and data reduction protocols.
- Follow up, ancillary data (e.g., color characterization of satellites), change of strategy in case of need.

- International, regional or national scale schools to provide candidate observers with the knowledge and tools needed to become contributors.

3. Education of observers about satellite constellations

The development of an effective international network of observers and observatories requires a substantial program of education and outreach. Awareness of the issues in observations needs to be at different levels: regular citizens, amateur astronomers and professional astronomers. Hence, it would be planned to have a training program to cater to these groups.

A training program that contains all the basic knowledge about the space sector and the related sciences will be proposed to both the community of amateurs and professional astronomers. This curriculum will also help in establishing a uniform terminology and file formats that will be used within SatHub. As SatHub aims at unifying the whole community of sky users, the content of each module will be accessible independently of the learner's level.

There will be a core curriculum containing :

- All the elements to know in order to have a proper understanding of the space sector, its history, evolution and the legal framework (regional, national and international) of its activities.
- An introduction to how each means of observation (optical, radio astronomy, astrophotography) works and how it is impacted by the satellite constellations. For each means of observations, the mitigation and recommendations measures that have been developed will be included. The learner will have the opportunity to send his/her feedback about it.
- The instructions to follow for each type of observation to contribute to SatHub (e.g., software to use, how to do the report, etc…). As some worldwide observation campaigns will be organized, the trainee will be able to join by accessing an updated calendar.
- The data that can help in doing an astronomical activity such as the Two Line Elements, the different formats used in exchanging information about the artificial objects evolving in LEO within the space sector community, between the space sector and astronomical community and within the astronomical community. An explanation will be given on how to contribute properly and efficiently to SatHub.
- Elements to do outreach activities about dark sky preservation.

Each of these topics will be further discussed in detail in more advanced and/or specialized modules. The curriculum will be firstly provided in English and will be translated into other languages (depending on the languages spoken by the volunteers).

Temporary names of the core curriculum modules	**Sub-topics**	**Names of experts who will help in writing the materials**
Introduction to the Space industry		Jonathan McDowell
Optical observation		Meredith Rawls Olivier Hainaut David Galadí-Enríquez
Radio astronomy		Federico Di Vruno
Astrophotography		TBD
Space Law	International Space Law National Legal Frame (specify the country)	Tanja Masson-Zwaan Giuliana Rotola
Data	TLE How to contribute to SatHub Output coming from SatHub	Meredith Rawls Fatoumata Kebe David Galadí-Enríquez
Outreach		Connie Walker Priya Hasan

NB: Optical observations, Radio astronomy and Astrophotography will be part of a main module named "Introduction to astronomical means of observations".

4. Impact on observations

Simulation and end-to-end modeling of the impact on data analysis by satellite streaks are required to assess quantitatively and qualitatively the actual loss of science. Initial efforts along these lines are well underway, but substantial further investigations are needed, and require support.

4.1 Model simulations and general assessment

The number of satellite trails affecting an observation can now be simulated using various methods with different precision (from a simplified geometric approach, as in Hainaut & Williams 2020, a brute force calculation of the position of the satellites, or an exact analytical representation of the satellite numbers, as in Bassa et al. 2021). In summary, the contamination will be the highest during twilight, the number of illuminating satellites plummeting as the night gets darker and the satellites fall into Earth's shadow. Satellites on higher orbits remain illuminated for a longer time than those on lower orbit. At a given time, the number of satellite trails in an exposure scales with the area field of view of the instrument, and with the exposure duration, but is independent of the size of the telescope.

Taking into account a simple photometric model for the satellites (a precision of 1 mag is sufficient, see for instance Bassa et al. 2021), it is then possible to estimate the effect of these trails on the observations. An important parameter is the *effective magnitude* of the satellite, which modifies the photometric magnitude of a satellite to account for its trailing (via its apparent angular velocity spreading the light) and its dilution during the exposure (while the absolute quantity of light from a satellite is independent of the exposure time, the relative quantity of light to the total collected decreases for longer exposures). If the effective magnitude of a satellite is fainter than the limiting magnitude for the exposure, the satellite is not detected.

In summary,

- Most imagers mounted on essentially any professional telescope (of the order of 1 m and above) will be sensitive to all satellites.
- Ultra-wide-field small-aperture instruments (typically astrophotography and all-sky cameras) will be sensitive only to the very brightest satellites, but not to the typical constellation satellites.
- Low-resolution spectrographs on most telescopes and mid-resolution on large telescopes are affected by many satellites; mid-resolution on small telescopes and high-resolution on most telescopes (even 10-meter class) are not: because of the much lower rate of recorded photons per spectral resolution element, the effective magnitude of the satellites is too faint. The effect of a satellite on a spectrum is much more difficult to detect than on an image, as most spectrographs have no 2D spatial information (fiber and short slit spectrographs) or only 1D spatial information (long slit). Only integral-field spectrographs can rebuild 2D images. Therefore, the contamination appears as an additional solar-like spectrum on top of the data. If the effective magnitude of the satellite is comparable to that of the science target, that contamination will not be apparent until the data are analyzed — and even in that case, the contamination could be mistaken for a scientific object (e.g. study of stellar population).

In the near infrared ranges, the sensitivities to the satellites are about the same as in the visible. However, in the infrared, exposures tend to be much shorter than in the visible, and taken in longer series. Therefore, the overall effect on near-infrared observations tends to be smaller than on an instrument with similar field of view and spectral resolution in the visible.

A calculation was provided as an example in the Metrics Working Group report for SATCON1: Using the UKIRT WFCAM, and assuming solar colors, SDSS *g* mag = 7 will be about UKIDSS *J* mag = 5.49. At a speed of 0.5 degree/second, the centroid will spend about 0.22 ms on the 0.4-arcsecond pixel of

WFCAM. This will be like a 14.6 magnitude star crossing the array (and even fainter when we degrade the point spread function for seeing and focus), and will not leave any noticeable latency.

In the thermal infrared at wavelengths longer than ~8 µm, the satellites behave like emitters. They are, therefore, visible during the whole night, even when they are in the Earth's shadow. However, the field of view of thermal infrared instruments tends to be much smaller than in the visible, and the observations taken as series of very short individual exposures. Overall, the effect on thermal infrared observations is therefore much smaller than on visible instruments.

Observations such as fast photometry and exoplanet transit are essentially immune to the effect of occultation by a satellite: the duration of the "eclipse" is of the order of a millisecond.

Overall, the most affected instruments will be large-field imaging cameras on any telescope above 1 m diameter. Therefore, the worst case scenario is for an ultra-wide-field camera on a very large telescope like the LSST camera at Vera C. Rubin Observatory.

4.1.1 Example of Impact: the Zwicky Transient Facility

Regarding the incidence of streaks, the field of view of the telescope/camera system is a very relevant parameter, as well as the observation strategy of the system. Telescopes equipped with science cameras of large field of view and performing observations starting at nautical twilight are the most impacted. This is the case for the Zwicky Transient Facility (ZTF).

The ZTF telescope/camera system has recorded regular crossings of Starlink satellites through its science field of view (FOV). The ZTF consists of the Samuel Oschin telescope, a 122-cm (48-inch) aperture Schmidt-type design, equipped with a 47-square-degree FOV camera, located at the Palomar Observatory (Graham et al. 2019; Masci et al. 2019). Its camera is composed of 16 detectors, consisting of 6144 x 6160 pixels in each detector arranged in four quadrants, and is equipped with aspheric corrector optics and a robotically exchanged bandpass filter for three filters, in the *g*, *r* and *i* spectral bands. The ZTF survey conducts time-domain astrophysical research by surveying the sky, taking 30-second exposures with a 10-second overhead.

- The ZTF conducts regular observations starting as the Sun reaches 12 degrees below the horizon (i.e. starting at nautical twilight). The ZTF observes about 5000 images a month while the Sun is between 12 and 30 degrees below the horizon. This implies that the ZTF, in its regular operations, and especially because of its relatively large FOV, detects satellite trails resulting from satellites crossing its FOV while they are illuminated by the Sun. An example of a ZTF full image, with detection of satellite streaks, is shown in Figure 5.2.

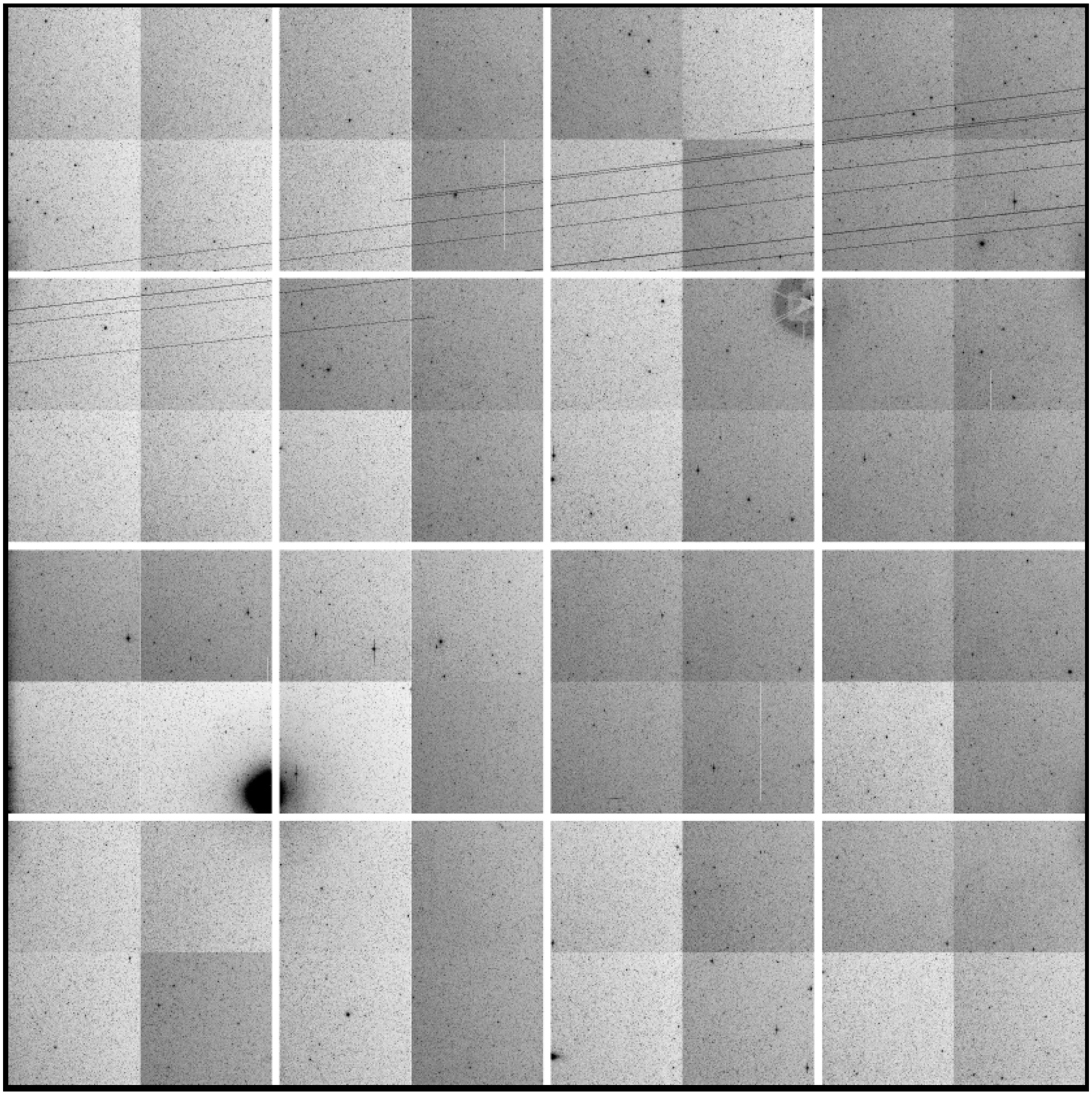

Figure 5.2. Zwicky Transient Facility science image, 30-second exposure. Satellite trails in the image are from Starlink satellites.

Since the start of deployment of Starlink satellites, the ZTF has detected an increasing number of satellite streaks. This is well illustrated by the histogram shown in Figure 5.3. The histogram shows the number of satellite streaks detected by the ZTF in periods of 10 days from early December 2019, until September 2021. The number of satellite trails went up from a few satellite trails in the early days of Starlink satellite deployments to about 230 streaks in images obtained in a 10-day period in more recent times. Figure 5.3 also includes a plot of the cumulative number of Starlink satellites that have been deployed into orbit (source: https://en.wikipedia.org/wiki/Starlink). The total number of satellite streaks detected in this period amounts to 5304.

Figure 5.3 is important because it shows that at any given time in each 10-day period, the ZTF has detected several satellite streaks equivalent to about 10% of the number of satellites currently in orbit. Consequently, the contamination of science images by satellite streaks has the potential to grow to large numbers as more satellites are deployed in orbit. Currently, there are about 1500 Starlink satellites with the potential to grow to about 42,000 of them (See Table 1 in Bassa et al. 2021) based on current plans. This implies a potential for a 30-fold increase in the number of satellite streaks detected in a 10-day period in science images observed by the ZTF, going from about 230 satellite streaks now to about 6500 of them once the Starlink constellation fulfills its current plans. This is a significantly large number of satellite streaks, in a 10-day period, considering that the ZTF obtains, in the same amount of time, about 1500 science images. The long-term potential is therefore for all the images to be contaminated with about 4 satellite streaks on average, accounting only for the contributions from the Starlink satellite constellation (Mroz et al. 2021).

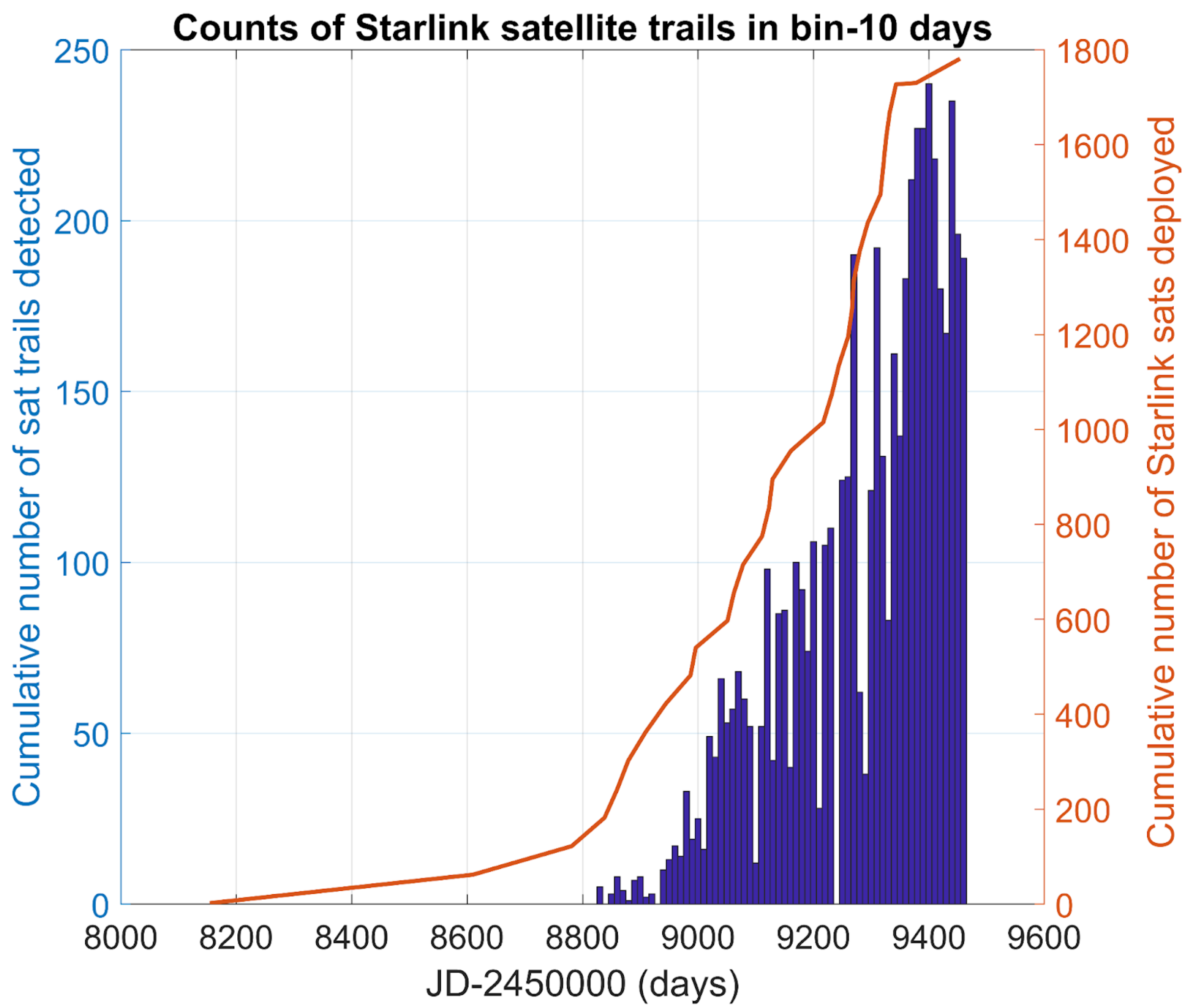

Figure 5.3. Histogram of the number of Starlink satellite streaks in the Zwicky Transient Facility science images in bins of 10 days. The line plot shows the cumulative number of Starlink satellites deployed from early 2019 until September 2021 (source: https://en.wikipedia.org/wiki/Starlink).

The satellite streaks in the ZTF images represent different satellites (i.e. different azimuth, elevation angle, and therefore range). The streaks have been analyzed to compute their apparent magnitudes scaled to a common range, that of the nominal orbital height of the Starlink constellation, H_{orb} = 550 km. Figure 5.4 includes scatter plots of the scaled satellite apparent brightness magnitude in the three ZTF science spectral bands (*g*, *r* and *i*). The difference in the dot color, in each subplot, is to show which of them are from visor-type (darker dots) and non-visor (lighter dots) satellites. In this study it is assumed that Starlink-1436 and Starlink-1522 and onward are visor-type satellites (Boley et al. 2021).

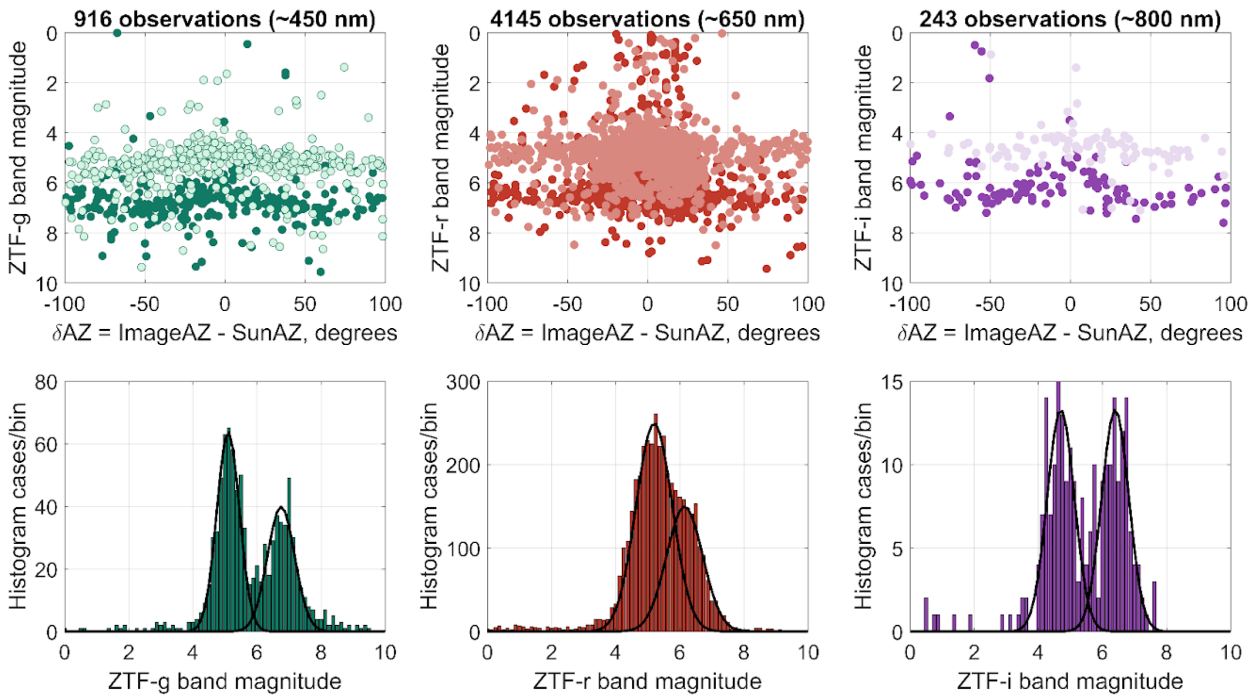

Figure 5.4. Starlink satellite apparent brightness, normalized to a range equal to the nominal orbital height of the Starlink satellites (H_{orb}=550 km). Left: ZTF-g spectral band (centered at around 450 nm), center: ZTF-r spectral band (centered at around 650 nm) and right: ZTF-i spectral band (centered at around 800 nm). Top: Apparent magnitudes plotted as a function of the difference in azimuth angle between that of the Sun and of the satellites at the time of imaging their streaks. Bottom: histogram of the satellite streaks normalized apparent magnitudes. The difference in the dot color, in each subplot, is to show which of them are from visor-type (darker dots) and non-visor (lighter dots) satellites. In this study it is assumed that Starlink-1436 and Starlink-1522 and onward are visor-type satellites. We find a smaller reduction in satellite brightness in the r band compared to g and i, but this is likely due to the majority of the ZTF survey being conducted in the r band (see text).

The distributions of satellite streak brightness are evidently bimodal as illustrated by the histogram of apparent magnitude in each spectral band. That bimodality is due to the fact the Starlink constellation includes two different type of satellites, the original (V1.0 type) of satellites and the visor-type satellites (satellites including a visor intended to prevent the sunlight from illuminating the surface of the satellite bus facing normal to Earth's surface, and intended to reduce the sunlight reflected by the satellites, making them fainter).

The statistics of the normalized apparent magnitude give the results shown in Table 1. The results illustrate that, indeed, the visor-type of the Starlink satellites are effectively fainter by 1.61, 0.97 and 1.64 magnitudes in the ZTF-*g*, ZTF-*r* and ZTF-*i* spectral bands, respectively. This corresponds to a brightness reduction by a factor of 4.4, 2.4, and 4.5, respectively. If, for the ZTF-*r* spectral band, we constrain the observations to Sun elevations higher than –20 degrees and relatively larger solar elongation angles, then the difference in magnitude (in *r* band) between non-visors and visors increases to a factor of 4.9, consistent with observations in the ZTF-*g* and ZTF-*i* spectral bands (Przemek et al., in preparation).

However, of the 916 normalized apparent magnitudes in the ZTF-*g* spectral band, 67% of them are brighter than what was recommended as the maximum brightness for mega-constellation satellites in Recommendation #5 of the SATCON1 Workshop (2020).

	ZTF-*g*	**ZTF-*r***	**ZTF-*i***
Non-visor satellites	5.16 ± 0.02	4.94 ± 0.01	4.58 ± 0.05
Visor satellites	6.77 ± 0.03	5.91 ± 0.02	6.22 ± 0.06
Difference in brightness magnitude	1.61 ± 0.04	0.97 ± 0.02	1.64 ± 0.08
Number of observations	916	4145	243

Table 1: Starlink satellite apparent magnitudes, normalized to 550 km range.

Last, and importantly, Figure 5.5 shows the distribution of the satellite streaks detected in the ZTF science images as a function of zenith angle and satellite range. The vertical red line shows the zenith angle corresponding to airmass 2. About 45% of the 5304 satellite streaks detected (2387), were imaged when the ZTF telescope was conducting observations in the nautical twilights and at large zenith angles. This is important for solar system science cases, follow-up of comets, asteroids or more interesting objects (such as the recently discovered interstellar object type) when those objects get relatively close to the Sun.

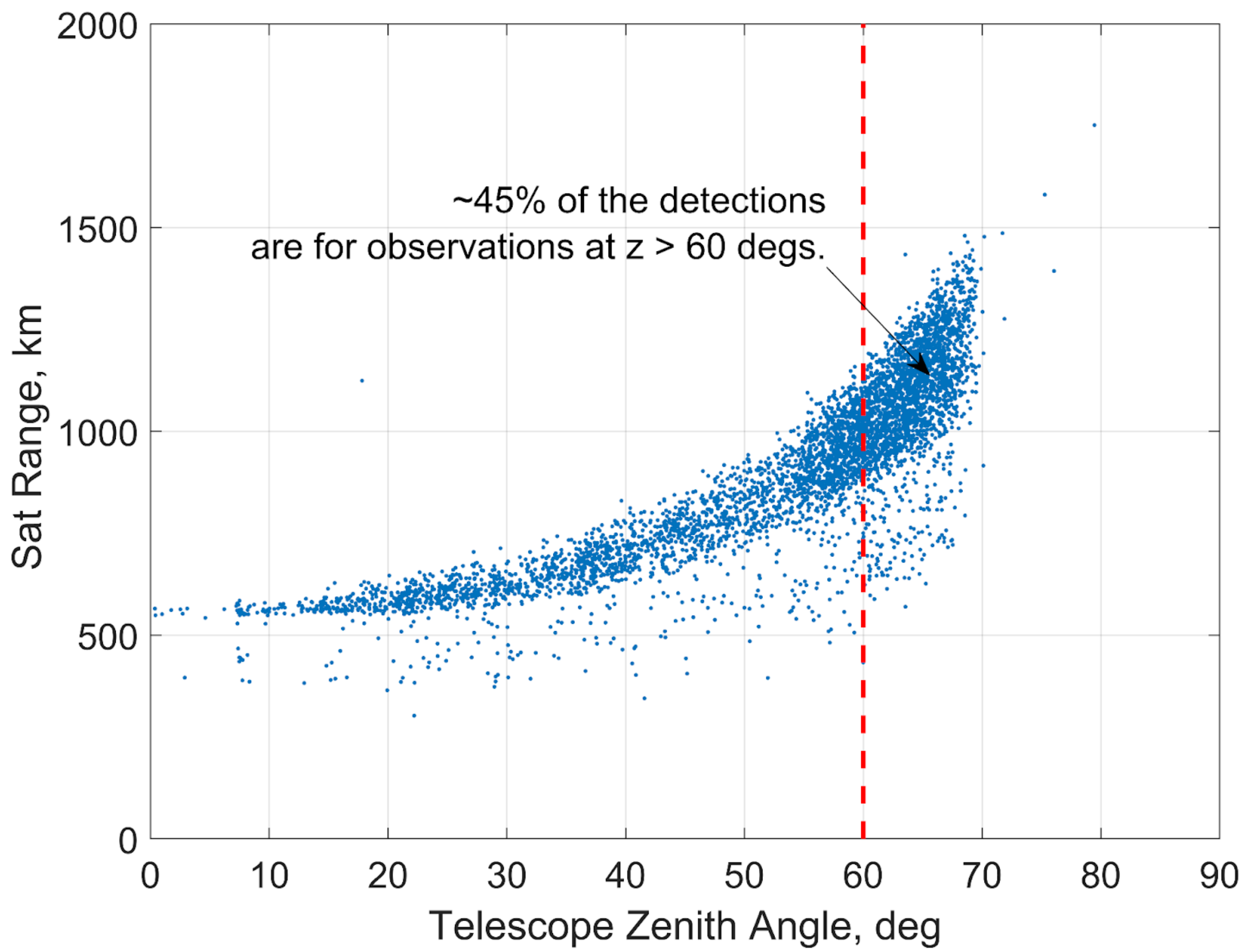

Figure 5.5. Scatter plot of the satellite streaks detected in the ZTF images as a function of telescope zenith angle and satellite range.

Based on the data of satellite streaks detected in science images by the ZTF telescope/camera setup, these are some relevant conclusions:

- The ZTF telescope/camera seems a great setup for the study of the effects of the LEO large constellations of satellites on wide-field-of-view astronomy.
- The number of observations and the span in time clearly show the rate of increase of satellite trails in science fields as a function of the increasing number of satellites being deployed in orbit. At any given time in each 10-day period, the ZTF has detected several satellite streaks equivalent to about 10% of the number of satellites currently in orbit. Currently, there are about 1500 Starlink satellites with the potential to grow to about 42,000 of them (See Table 1 in Bassa et al. 2021) based on current plans. This implies a potential for a 30-fold increase in the number of satellite streaks detected in a 10-day period in science images observed by the ZTF.

- The data illustrate the problem of a larger number of images impacted by satellite trails at high zenith angles, with particular relevance for Solar System observational astronomy. However, to date, ZTF Solar System observations have not been severely affected by satellite streaks, even at twilight, in terms of percentage area lost. But, as shown in this analysis, the number of satellite streaks impacting science images may increase by a factor of 30 accounting only for the current plans for satellite deployments from the Starlink satellite constellation.
- The data clearly show that the Visor-type satellites are dimmer. However, many of the observations are still brighter than stated in Recommendation #5 of the SATCON1 workshop. 67% of observations of Visor-type satellites are brighter than recommendation #5 of SATCON1.

5. Impact on scientific analysis

Satellite trails are most obvious when they cross imaging data, leaving a bright streak. Although the loss of information on any point-source object (such as a star) lying under the streak is clear, there are a number of less intuitive ways in which observations and analysis can be affected. To highlight a few examples:

- **Extended objects, such as galaxies, or the image arcs produced by strong gravitational lensing**. These objects may extend across many pixels in an image, and not all the objects will be directly affected by the satellite trail. Unfortunately, their properties are typically measured by summing across all pixels, so the loss of information in one region of the image effectively negates the value of the entire measurement, unless the trail can be properly masked. Further work is needed to accurately model and mask satellite trails in extended object data.
- **Systematic analysis of weak lensing distortions**. One of the main observational goals of the Rubin Observatory/LSST precision cosmology program is to determine the spatial distribution of dark matter through weak lensing distortions of background galaxies. This is a massive statistical study of billions of galaxy images, accomplished by filtering techniques to test for elongations of the galaxies' intrinsic shapes. A substantial simulation effort is required to assess the impact of masking the long linear region of a satellite streak on determining the weak linear distortions elsewhere in the image.
- **Near-Earth Objects (NEOs)**. Asteroids passing close to Earth are detected by the movement and/or trails they produce in imaging data. Often such objects are extremely faint, making it all the more difficult to distinguish them from the trails of satellites. It should be noted that some NEOs pose a potential risk of impact to Earth, and producing a complete catalog of potentially hazardous objects is a priority. NEO observations often use non-sidereal tracking to follow the motion of the target, which results in a point-source image of the target surrounded by trailed background stars. Any satellites in the data would appear as non-linear streaks, and more work is needed to simulate such satellite trails and model them accurately so that they can be masked.

- **Spectroscopy**. Spectroscopic measurements are essential to a great deal of astronomy, but satellite trails are intrinsically more difficult to detect in these data owing to the nature of the instruments. First, most spectrographs have no two-dimensional spatial information, so there is no tell-tale satellite trail in the data. Second, the light is spread out by wavelength and the exposure times tend to be much longer than for imagers, making spectrographs much less sensitive to satellite contamination. Overall, understanding the impact of the satellites on the spectroscopic data is more complex than for imagers. This is even more complex for multi-object spectrographs. It may not be possible to distinguish satellite-impacted spectra without costly instrument upgrades to install simultaneous imagers.
- **Occultations**. Remote objects in the outer Solar System are often so faint that the best way to study them from Earth is to measure their brightness at very high cadence while they pass in front of a background star, causing a momentary dip in its brightness. The rings of Jupiter were discovered through this technique. Accurate satellite ephemerides are required to avoid confusion with occultations caused by artificial objects, as well as to schedule observations so as to avoid satellites intersecting with the event.

We note that this list is not exhaustive, and a more comprehensive survey of all fields of astronomy has yet to be undertaken. All optical imaging and low-dispersion spectroscopy programs will be negatively impacted; the purpose of the survey is to identify those topics with losses to scientific analysis well in excess of the fraction of area or exposures lost to satellite streaks.

6. Advancing algorithm development and deployment

The SATCON2 Workshop report recommended the development of three main categories of software to assist the community to minimize the impact of satellite trails in their data as much as possible. The categories were: 1) TrailMask, to identify pixels within imaging data that were crossed by a satellite during the exposure, and (optionally) to replace affected pixel values with null entries; 2) PassPredict, to calculate what satellites are likely to intersect with an observation, given the observer's location, date and time and instrument field of view; and 3) Simulation tools, to enable scientists to model the instrumental signature of a satellite passing through an image produced by instruments with different characteristics, and to evaluate the corresponding impact of the satellite on the reduction and analysis of affected images.

The development of software in these three categories, together with the database of satellite ephemerides, is a clear priority for the IAU Centre. Data challenges have proven to be an effective means of stimulating software development and in cultivating partnerships between industry specialists (e.g. in machine learning) and academia. This would be complemented by hosting workshops to solicit input from the wider community on their requirements for the software, and the database user interfaces.

In each category, the SATCON2 report highlighted any software already available for the purpose together with their limitations and noted where further development will be required. In many cases, existing software packages were developed for specific instruments, and would need to be generalized before they will be usable by the general community. In particular, researchers have begun to explore the application of powerful machine learning techniques to satellite trail identification and this was considered to be an important area where further research is needed.

An initial simplified implementation of TrailMask might work on a single contiguous image (chip) with straight line trails (so no image chopping during the exposure), and return mask regions identifying the location of the trails. It should still be able to handle tumbling satellites, which generate brightness variations along the trail, as long as the minimum brightness is above some detection threshold. Current algorithms being tested in the Rubin Science Pipelinest use a Canny edge detection filter and a kernel Hough transform to find point clusters and fit lines to the results. The transverse profile of the streak can then be measured.

Our ability to accurately predict when and where satellites will intersect with observations is critically limited by the precision and timeliness of satellite ephemeris information from satellite operators. Astronomical observations with some narrow-field instruments can be scheduled to avoid satellite trails, but only if ephemerides of sufficient precision are made available, including uncertainty parameters. Information on the predicted brightness of satellites was considered to be highly desirable in this mitigation strategy, but likely to be much more difficult to produce.

In addition to developing the PassPredict algorithms themselves, it will be necessary to develop and maintain a publicly-accessible database of satellite ephemeris from all operators. The proposed SatHub system would be a natural host for this database and a centralized resource for the community. Further work is required to develop specifications for the database and user interfaces, which should include both human-facing and programmable options. The latter will be required to ensure that rapid response observations, designed to follow-up time-critical discoveries from modern surveys, can be planned and scheduled algorithmically.

The report particularly noted the need for long-term support for the maintenance of the ephemerides database, which will need daily updates from satellite operators.

To advance the algorithms effort, we should organize hackathons and possibly other contests to develop initial user versions of key algorithms. This will provide a good opportunity for a census of worldwide developments, in the service of closer coordination. To complement this, we will develop a prioritized development list for the professionals associated with the IAU Centre.

The limitation of these mitigation measures should be noted. The SATCON2 report focused primarily on imaging instruments only, and the PassPredict software will not enable wide-field instruments to avoid satellite trails; they will not be able to reschedule around trail predictions. More work is needed to understand the impact of satellite trails on other types of astronomical instrumentation and their data reduction, particularly fiber-fed spectrographs, where satellite trails are expected to be extremely difficult to distinguish.

In addition to observation-specific mitigation software such as TrailMask and PassPredict, there is a need for aggregate simulations to determine overall effects of future constellations on astronomy. As part of this infrastructure we need to be able to simulate trails from different kinds of satellites on different kinds of detector, and we need tools to automatically assess affected data for changes to sensitivity limits, photometric accuracy and point source detection efficiency. Existing source detection tools such as Source Extractor or those in the Rubin Science Pipelines may serve as a starting point for such a tool.

All the above are oriented towards the impact on astronomical observations. But we also have the need to observe the satellites themselves, and some specific tools are needed, for target prescription, data calibration and data processing. The observation and data reduction package would use modules from PassPredict and TrailMask, but it will have to incorporate additional databases (astrometric and photometric data on reference stars, for instance) and specific photometric and astrometric tools.

6.1 Standards from the Virtual Observatory for SatHub

The data tsunami in astronomy brings big challenges for research modes and global collaboration. The Virtual Observatory (VO) is a possible solution, initiated about 20 years ago by astronomers and IT experts. It is a data-intensive, on-line astronomical research and education environment, taking advantage of advanced information technologies to achieve seamless, global access to astronomical information. The VO aims to open up new possibilities for scientific research based on data discovery, efficient data access, and interoperability. The International Virtual Observatory Alliance (IVOA) was created in 2002 to facilitate international coordination and collaboration, and now there are 22 member organizations.

The VO closely integrates information technology and astronomy, and proposes a series of new technologies and standards, which are widely used in astronomical big data processing and astronomical observation practices.

Hierarchical Progressive Surveys (HiPS) is an IVOA standard widely used in astronomical big data release and publication. HiPS provides the hierarchical tiling mechanism which allows one to access, visualize and browse seamlessly image, catalog and cube data. It is increasingly popular in the community. Many sky survey projects have released datasets based on the HiPS standard, such as SDSS, 2MASS, AllWISE, etc. The HiPS standard has received extensive software support. Aladin, ESASky, and WorldWide Telescope can all support the processing and visualization of HiPS datasets. These features will make HiPS play an important role in SatHub, especially in the construction of Astronomical Data Repositories.

WorldWide Telescope (WWT) is a powerful tool for showcasing astronomical data and knowledge. It is “Google Maps for the sky,” a powerful data visualization tool, a 4D Solar System simulator, and a data-driven educational environment. Based on the features of HiPS supporting and powerful visualization features, WWT can realize satellite pass prediction and simulation, observation data visualization, data sharing and other functions. It can be used as one of the platform prototypes for data visualization in SatHub.

HiPS and WWT are just two of the many tools provided by VO. Through in-depth cooperation and development, VO will provide SatHub with more solutions.

7. Aggregate impact on diffuse night sky brightness

The issue of astronomical observations being affected by satellite trails has been discussed above. Because of their fast apparent angular velocity, the satellites are trailed over the detector, diluting their brightness. In the case of small telescopes or photographic cameras, in the case of spectrographs, and in the case of naked-eye observations, many, if not all, satellites will be below the detection limit. Nevertheless, these satellites still contribute to the diffuse sky background. This is true for all objects in orbit, from satellites all the way down to debris and dust.

Kocifaj et al. (2021) have studied in great detail the contribution of space debris to the sky brightness. They consider the size distribution of the debris, their vertical distribution, and the evolution of their total number until just before the start of Starlink’s launches. They present a rigorous analysis for light diffusion on these debris, and conclude that the sky brightness at zenith at the end of twilight (solar elevation from -18° to -22°) could reach ~20 µcd m^{-2}.

Bassa et al. (2021) performed simulations of constellations, including 65,000 satellites from Starlink, OneWeb, Kuiper and GuoWang. Their analytical method leads to an estimate of the satellite density (number per square degrees) over the full sky above an observatory, and of the brightness of each satellite, which they convert to surface brightness. At twilight (-18°), the satellites contribute ~0.5–1 µcd m^{-2} in the sunward half of the sky, and less than 0.3 µcd m^{-2} in the other direction. Interestingly, the edges of the constellations whose inclination is similar to the latitude of the observatory creates cusps where the sky brightness can reach 5 µcd m^{-2}.

Combining the works of Kocifaj et al. (2021) and Bassa et al. (2021), Hainaut (private communication) considered what would happen if the 65,000 satellites discussed above would be ground to debris with the same size distribution as the current debris population, assuming that the debris have the same reflectivity as the whole satellites. This results in an increase in the optical cross section by a factor ranging between 15 and 25, depending on the assumptions. This would result in a contribution to the sky brightness of 15–25 µcd m^{-2} in the sunward half of the sky, and 60–100 µcd m^{-2} in the cusps.

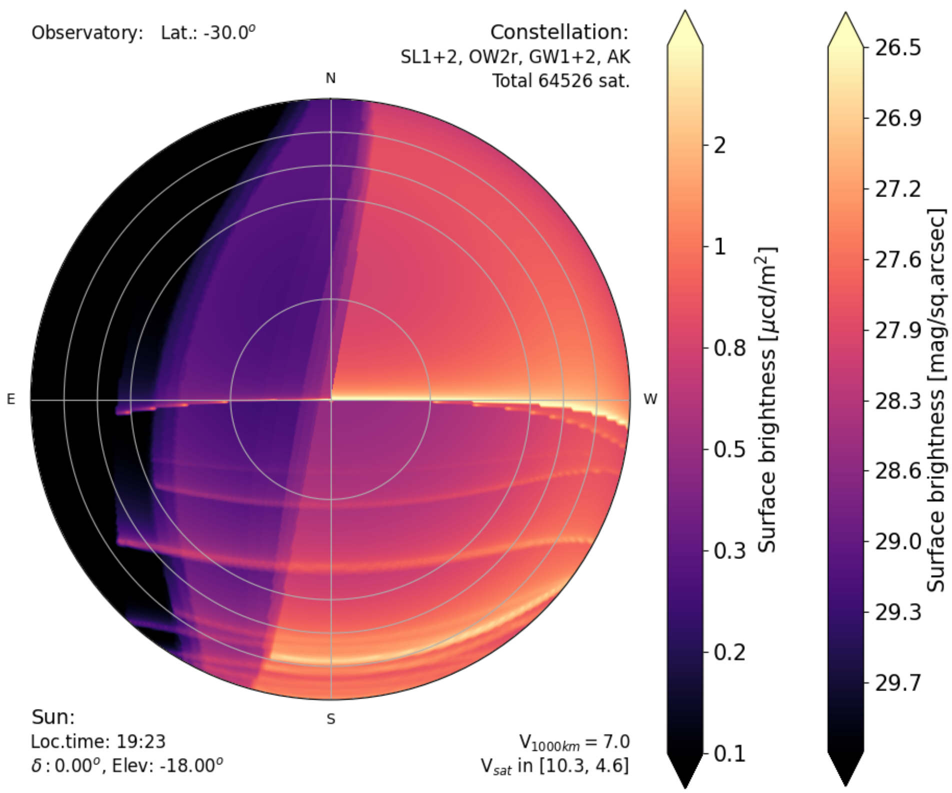

Figure 5.6 Sky map of the surface brightness contribution from the mega-constellation satellites.
The dark sky surface brightness from a good site can be as low as ~200 µcd m^{-2}. Therefore, the contribution from the satellite is ~1% on the right-hand side (where the satellites are illuminated) and ~0.1% on the left side (where most satellites are already in the shadow of the Earth). The bright cusps can reach 5%. This simulation is for astronomical twilight, when the effect is the strongest, and includes 65,000 satellites from Starlink, OneWeb, GuoWang and Kuiper, seen from an observatory at latitude 30°S at equinox (Hainaut, private communication, using algorithms in Bassa et al. 2021).

The sky brightness has been measured at many observatories; for instance, the dark sky above ESO's Paranal observatory (Chile, 23°S, altitude 2600 m) is V = 21.86 mag arcsec^{-2} at the zenith (Patat 2008) which corresponds to ~220 µcd m^{-2}. This value varies across the sky (airglow can have strong spatial variability with a scale of ~10–20°, and during the night, with an amplitude of up to 60 µcd m^{-2}. Additionally, the zodiacal light can contribute up to ~400 µcd m^{-2}, and the Milky Way even more. Moonlight will increase the sky background up to 2000 µcd m^{-2}. And last, but not least, ground-based light pollution can be of the order of 300,000 µcd m^{-2}.

Therefore the contribution of the satellite constellations, even considering 65,000 satellites (which is a plausible number for 2030), is of the order of 0.5% of the dark sky background with narrow cusps reaching 3%. This is much smaller than the spatial and temporal variations, even in the darkest, best conditions, and will not be detectable. Current space debris, however, plausibly already contributes an increase of ~10% at zenith, which is approaching the limit of detectability. Finally, grinding the upcoming satellites from the mega-constellation into debris would create an additional ~10% over the dark sky brightness, with narrow cusps that could reach a ~40% increase. These would be detectable, and might be even visible by naked eye in optimal conditions, at the level of the gegenschein.

These results are based on the debris size distribution from Kocifaj et al. (2021), which is likely to exaggerate the contribution from small fragments, and therefore to overestimate the level of pollution. Further investigation will be needed to better determine the size distribution of the debris.

While the debris are a deep concern in terms of Space Traffic Management, it is important to note that their contribution to the sky brightness is orders of magnitudes smaller than ground originated light pollution. The mega-constellation satellites themselves do not significantly contribute to the diffuse sky background — provided they remain in one piece and are not ground to dust by collisions. It is therefore critical to avoid major collisions in the satellite constellations, not only because of the disastrous effects that would have in orbit, but also to avoid sky brightness pollution issues.

A more accurate estimate of the mega-constellation satellites' diffuse sky background may be inferred by using a detailed radiative transfer model like Illumina v2.1 (Aubé et al. 2020; Aubé & Simoneau 2018). Illumina v2.1 accounts for first- and second-order scattering, which is clearly enough for such a determination. Calculations would need a detailed distribution of satellites in the sky at a given moment. This includes the viewing angle toward the satellite, its intrinsec radiance and of course the aerosol content of the atmosphere. But given that the rapid estimate indicates this satellite induced sky brightness to be orders of magnitude lower than typical light pollution levels, such a modeling task is not a priority unless the satellites degrade into debris.

8. Afterword: future threats beyond satellite constellations

The satellites considered here are all illuminated by the Sun in order to be detected in a telescope or by the human eye. There are satellites now on orbit and being planned that will have their own illumination source on board, and thus could be detected even if in Earth's shadow. Examples include satellites with LIDAR and satellites with LEDs on board for tracking during Earth eclipse. First, these are monochromatic signals, not reflected sunlight so unless one is observing in a filter that passes that wavelength, they will not be a problem. For all launched LEDSATs to date, their maximum brightness is $V \sim 8$ magnitude, not detectable by the human eye but certainly by many telescopes. Second, the times when the signals are on are controlled by ground stations, and are unlikely to be on all the time due to power constraints.

For the moment, the number of such satellites is small and unlikely to be a problem. The situation should be watched, because if 100,000 satellites all have LEDs on board all the time, this is a very different situation.

Next, the industry is rapidly moving towards the use of lasers for satellite-to-satellite communications and satellite downlinks. The amount of data that can be sent is much larger than over radio-frequency links. This is great news for radio astronomy, but perhaps less so for optical astronomy. The lasers are all monochromatic, not broad solar spectra. The satellite-to-satellite links are unlikely to be detected by telescopes on the ground, but it is not known whether the laser uplinks and downlinks could leave detectable streaks in astronomical images. The power levels are different from laser adaptive optics systems. The situation is worthy of further study, as 100,000 satellites with downlinks is a very different situation than just a few satellites. One should note that the ground stations would likely be located in areas with few clouds, raising concern about proximity to existing astronomical sites.

Finally, there are plans to launch very large structures (of order 1-km diameter) into orbit primarily for solar power stations (e.g., Caltech News 2021). These satellites could be brighter than the International Space Station, and even a small number would change the appearance of the night sky. The astronomy community will need to be proactive in expressing concern about strongly negative impacts of reflected sunlight to these projects under development.

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Part 4. Radio Astronomy Working Group

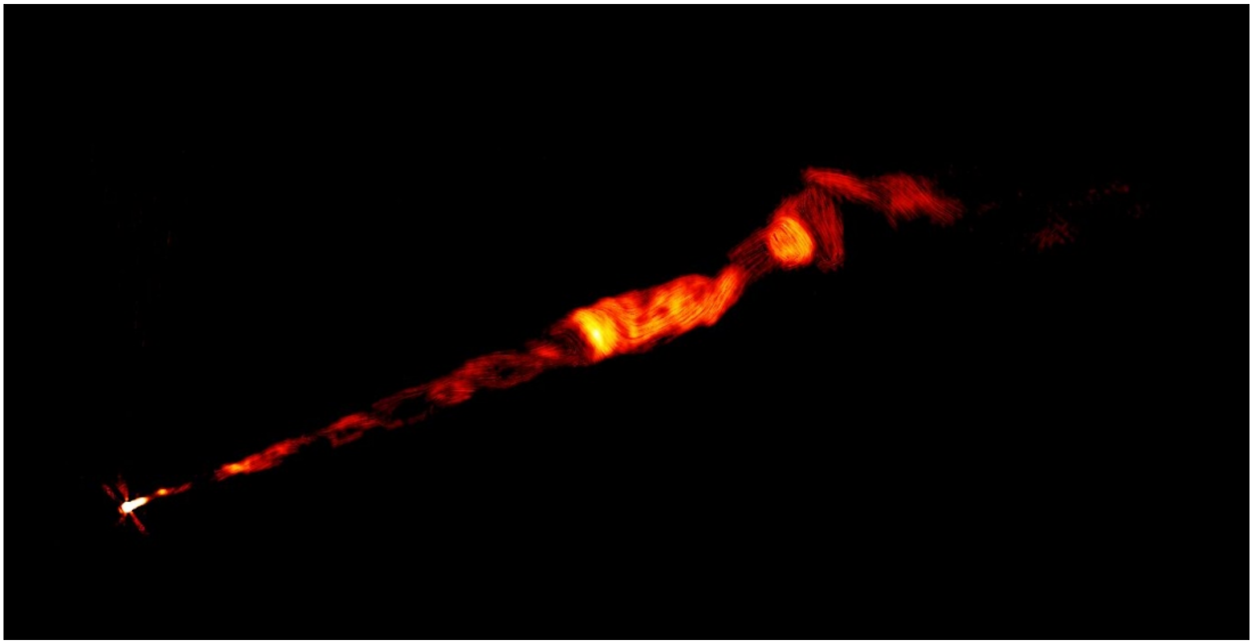

Figure 1.1: Radio image of the galaxy Messier 87 made with the Karl G. Jansky Very Large Array (VLA) revealing the 3-dimensional double-helix structure of the magnetic field in its jet. This image was possible observing in several bands of the VLA radio telescope: 4–8 GHz at the C band, 8–12 GHz at the X band, and 12–18 GHz at the Ku band resulting in a combined total observed bandwidth of 14 GHz. Credit: Pasetto et al., Sophia Dagnello, NRAO/AUI/NSF.

"Until now, radio astronomers have been able to conduct observations in the frequency ranges used by satellite operators, thanks to the relatively small number of satellites and the development of innovative techniques to cope with these. Over the last decades, radio astronomy as a research discipline has not only delivered ground-breaking discoveries — some of which have been rewarded with a Nobel Prize — it has also been a catalyst for innovation, intimately linked to many technological breakthroughs with wider impact on society. The deployment of thousands of satellites in low earth orbit in the coming years will inevitably change this landscape by creating a much larger number of fast-moving radio sources in the sky, which will interfere with humanity's ability to explore the Universe. This is a global challenge and mitigating this impact will require unprecedented cooperation between astronomers, satellite operators and regulators through national, regional and international bodies."

— Philip Diamond, SKAO Director-General

Chapter 1. Executive Summary

Radio astronomy has co-existed with radio interference since its very beginnings. The need to observe signals whose frequencies are defined by natural processes and the fact that real antennas can receive electromagnetic radiation from all directions as well as the intended one (referred to as sidelobes) render radio telescopes very sensitive to interference. This requires some narrow frequency bands allocated by the International Telecommunication Union (ITU) to be protected by national radio agencies; a small number of radio telescopes are protected by national legislation as radio quiet or coordination zones. On the telescope side, the continuous development of hardware and software techniques is needed to mitigate the effect of man-made radio transmissions.

The rapid industrialization of space, especially in low Earth orbits (LEOs) threatens to drastically change our view of the radio sky. Large LEO satellite constellations are exponentially increasing the satellite density per sky area with planned constellations that could lead to a high probability of having a satellite in the main beam of an antenna for a large fraction of the time in any direction in the sky. Constellations of high-power satellite radars are also increasing in numbers; this is especially worrisome given their ability to destroy a radio astronomy receiver in the case of direct beam-to-beam coupling. Other recent developments, such as the proposed studies of “in-orbit” solar power plants, revive concerns raised decades ago by radio astronomers about the impact of such an application beaming large amounts of energy towards Earth.

Even the radio-quiet zone in the shielded zone of the Moon, protected by the ITU Radio Regulations, is under threat by proposed missions aimed at the establishment of lunar communication networks. This area on the surface of the Moon is especially suitable for very sensitive low-frequency radio astronomy that, given our atmosphere and radio environment, is just not possible from the surface of our planet.

Spectrum management organizations dedicated to the protection of radio astronomy work continuously within the ITU-R framework and in some cases directly with agencies operating satellite platforms. A recent successful example is the agreement between the Scientific Committee on the Allocation of Frequencies for Radio Astronomy and Space Science (IUCAF) and the European Space Agency (ESA) to protect radio astronomy stations from very powerful emissions from the EarthCare radar satellite at 95 GHz.

The ITU has played a major role in the protection of radio astronomy since 1959; the frequency bands allocated to radio astronomy are vital for the observation of certain cosmic radio emissions, and to ensure the correct calibration of observations. But the rapid escalation in the density of space transmitters requires further protections to minimize the impact on wideband observations; although not as visual as the impact on optical observations, radio astronomy can be impacted equally, or even more. Awareness of these issues must be raised in international forums dealing with space activities, such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS), to urge states to consider the wider potential impacts in radio astronomy while planning, deploying and operating satellites in LEO. The recommendations of the 2020 Dark and Quiet Skies for Science and Society conference (see Section 2.1) serve as a guide for this purpose, but they need to be accompanied by discussions of the sustainability of activities in space and how these can impact space exploration conducted from the surface of the Earth.

Chapter 2. Addressing the Impact of Satellite Constellations on Radio Astronomy

1. The radio astronomy recommendations

The report of the Dark and Quiet Skies Workshop held in October 2020 (D&QS1) introduced radio astronomy as a discipline and described radio astronomy's use of radio spectrum. It described the radio spectrum regulatory regime that protects radio astronomy in specific allocated frequency bands and it assessed a wide range of risks to radio astronomy observations resulting from existing and emerging uses of the radio spectrum by a broad range of transmitters. The end-user service levels of transmitters employed by radiocommunication systems are billions of times (or more) stronger than the cosmic radio waves studied by radio astronomy.

Special care was taken throughout the D&QS1 report to explain and account for radio astronomy's particular vulnerabilities, including the use of wideband receivers and the need to observe cosmic phenomena outside allocated frequency bands as discussed here in Section 2.

Of particular concern with respect to radio astronomy interference, was the unavoidable presence of antenna sidelobes. Even the largest radio astronomy antennas are sensitive to radiation arriving in directions away from where their peak response, the so-called main beam, is pointed. Conversely, transmitting antennas unavoidably radiate in directions away from their main beam.

Interference can result from all combinations of interactions between the main beams and sidelobes of receivers and transmitters. Careful design of antennas and transmitters minimizes the potential for interference, in the best case enabling compatible spectrum use through a combination of engineering, regulation and operating rules.

When all factors were accounted for, and in the specific context of concerns relevant to COPUOS, the greatest risk to radio astronomy was judged by D&QS1 to arise from satellites orbiting below the geosynchronous satellite orbit, the so-called non-GSO satellites, especially those in low Earth orbit (LEO) at altitudes between approximately 300 and 1200 km. Risks from two kinds of satellites were identified: from the main beams and sidelobes of very large numbers of radio communication satellites in so-called mega-constellations providing global broadband connectivity, and from the beams of hundreds of high-power radars that will be used to map Earth and study its climate and cloud cover. Radars are individually capable of burning out a radio astronomy receiver in the worst case; while communication satellites generally use lower power, they can still interfere with or saturate a radio astronomy receiver, blinding but not destroying it.

Radio astronomers at D&QS1 produced two recommendations for the design and operation of non-GSO satellites that would allow satellite operators to mitigate potential interference and allow radio astronomy to continue to operate in the presence of multitudes of satellites. The two recommendations are an expression by radio astronomers of the means to protect the science of radio astronomy that is responsible for so much discovery and innovation.

> The following two recommendations distill the discussion and the experience of radio astronomers and radio astronomy spectrum managers into two practical tools that are needed to allow radio astronomy to continue to operate:
>
> - **RAS1**: Non-GSO satellites should be required to be able to avoid direct illumination of radio telescopes and radio quiet zones, especially the radar and other high-power satellite applications that are capable of burning out radio astronomy's receivers;
> - **RAS2**: Non-GSO satellites should be required to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio quiet zones do not interfere, individually or in the aggregate.

Figure 2.1: The radio astronomy recommendations from the D&QS1 workshop held in 2020.

The recommendations were driven by considerations of the burgeoning satellite population. There are currently some 2000 satellites in LEO, up from approximately 100 as recently as 2018. Because they are so close to Earth at altitudes of 500–1200 km, only about 5% of LEO satellites now orbiting are above the horizon at any time in one place. If we imagine the 2π steradians or approximately 21,000 square degrees of sky above the horizon as being homogeneously filled with about 2000 x 0.05 = 100 satellites, each satellite can be assigned an area of radius sqrt(21,000/100/π) = 8.2°. A randomly pointed radio telescope beam would on average fall within 8.2° of a satellite.

This is much wider than the typical radio telescope main beam, but still close enough to the axis of the main beam (the "boresight") to ensure that a satellite signal would be substantially boosted by the radio telescope. A vivid example of such considerations is given in Section 3 where an actual proposed constellation of 30,000 LEO radiocommunication satellites was mapped on the sky.

2. Radiofrequency spectrum management regulatory protection for terrestrial radio astronomy

The radio astronomy recommendations exist parallel to and outside the spectrum management regime that protects radio astronomy's frequency allocations from receiving harmful interference. To understand the difference and why radio astronomers felt it necessary to produce the recommendations, an explanation is warranted.

Terrestrial users of radio spectrum, including radio astronomy, are protected from harmful interference within their allocated frequency bands by the Radio Regulations, an international treaty that is promulgated internationally at the ITU-R and renewed every four years at the World Radio Conference. National regulators try to harmonize the allocations within the borders of their administrations with the Radio Regulations as much as possible, to allow cross-border interoperability and to protect spectrum use within their borders from interference generated by incompatible spectrum use in other administrations.

The report of the Radio Astronomy Working Group discussed the use of radio spectrum by terrestrial radio astronomy and described the extent to which this use is protected by regulation. Radio astronomy is one of a handful of so-called “passive” services that do not produce emissions, alongside a much larger group of “active” services that do. Radio astronomy’s use of spectrum is unique even among the passive services because cosmic radio waves are so exceptionally weak and the frequencies at which they occur in the spectrum are determined by conditions extending back to the beginning of time, irrespective of human convenience.

Detecting cosmic radio waves requires tuning the receiver to compensate for the Doppler frequency shifts induced by the expansion of the Universe, the motions of the Sun and Solar System within the Milky Way, the revolution of Earth about the Sun and the daily rotation of Earth about its own axis. Detecting signals originating within the Milky Way requires modest fractional bandwidths (tuning range) of +/–0.1%, but signals from the very early Universe are received at frequencies some 10 times smaller than those at which they were emitted. The same spectral line of neutral atomic hydrogen that is observed within our Galaxy with small deviations from 1420.40575 MHz, is shifted to frequencies below 200 MHz when seen in the early Universe. Observation of the Milky Way and the nearest galaxies may fit neatly within narrow frequency allocations, but observing the Universe at large does not.

The scheme of protecting allocated spectrum was designed for active services that can arrange their operation to make the best use of technology within sharply-defined spectrum bands (of course they would all like to have the use of more spectrum!). It also suits a limited subset of radio astronomy observations of the Milky Way and the very nearby Universe, which radio astronomers use as templates to interpret phenomena observed more distantly with poorer spatial resolution. It is a poor fit for observing the majority of natural cosmic phenomena that do not fall in spectrum bands allocated to radio astronomy, and it is a poor fit when the more distant Universe is observed. Radio astronomy is necessarily performed at frequencies that are not allocated to radio astronomy, and this is allowed by the Radio Regulations because radio astronomy cannot cause interference to other radio services no matter what it observes.

Although use of unallocated spectrum may be tolerated or mentioned at ITU-R in some limited contexts, it is not encouraged and cannot be protected. As noted in the D&QS1 report, regulators in some individual administrations have adopted alternatives like national radio quiet and coordination zones that limit potential interference by isolating observatories from transmissions, even at frequencies not allocated to radio astronomy. However, these radio quiet and coordination zones lack international regulatory recognition and in most cases apply only to fixed terrestrial transmitters, not to satellites. This situation was discussed in detail in the Radio Astronomy Working Group Report to the D&QS1 workshop.

Radio quiet and coordination zones are effective in keeping portions of the spectrum clear because the same frequencies have, until now, generally not been used by transmitters on the ground and by downward-pointing airborne or spaceborne transmitters overhead. But even radio telescopes in radio quiet and coordination zones cannot avoid seeing emissions from satellites when they are above the horizon, independent of whether the satellite is licensed to operate in the administration operating the telescope, or whether the telescope and satellite are pointed at each other. In this case, neither the radio quiet and coordination zone created by the national authorities, nor the radio spectrum regulatory regime hosted at ITU-R, protects radio astronomy. Other means of protection are required and the radio astronomy recommendations were created to meet this need.

3. Mega-constellations and the growth in satellite numbers

Lately we are experiencing a phenomenon like a "space-race", where operators are filing plans to build (and are already launching) more and ever-larger constellations in LEO. While the capacity of LEO orbits, meaning how many satellites can "fit" in orbital shells[615], is a three-dimensional problem, from an observer's point of view the sky is just not that vast. A radio astronomy antenna only sees a two-dimensional sky, where different orbital shells are seen as "stacked together", effectively increasing the apparent satellite density per sky area, as in the simple example discussed in Section 1.

To illustrate this, the orbital parameters of the Starlink Phase 2 constellation (see Table 1) were used to illustrate the mean probability that a satellite appears within 0.25° of the boresight of a radio telescope in one second at four observatory sites over a wide range of geographic latitudes (Figure 2.2). Just for this one constellation of 30,000 satellites, some areas of the sky show 40% probability, where satellite transmissions would be amplified by a 38–44 dBi antenna gain. These gains result from 12-m to 100-m radio astronomy antennas according to Recommendation ITU-R RA.1631 (https://www.itu.int/rec/R-REC-RA.1631/en) that is used in such compatibility studies at ITU-R.

[615] An orbital shell is a collection of orbital planes at a certain altitude.

	Shell 1	Shell 2	Shell 3	Shell 4	Shell 5	Shell 6	Shell 7	Shell 8
Altitude	328	334	345	360	373	499	604	614
Inclination	30	40	53	96.9	75	53	148	115.7
Number of planes	7178	7178	7178	40	1998	4000	12	18
Satellites per plane	1	1	1	50	1	1	12	18
Total satellites	7178	7178	7178	2000	1998	4000	144	324

Table 3.1: Starlink Phase 2 parameters from FCC filing SAT-LOA-20200526-00055.

The constellation of a single operator that was used in this calculation represents a small fraction of the total number of satellites that is expected. If this and other mega-constellations do not follow the radio astronomy recommendations to effectively minimize their emissions toward radio observatories, radio astronomy receivers will be constantly saturated (or blinded) by satellite radio communication signals that are intrinsically billions of times stronger than the cosmic radio waves studied by radio astronomy.

The radio astronomy recommendations are an attempt to render an artificial atmosphere of non-GSO satellites transparent to radio astronomy observations. The recommendations are firstly relevant to satellite design and operation because nothing can compensate for imperfectly designed or operated satellites: even a relatively small existing constellation of 66 satellites causes harmful interference in frequency bands adjacent to the satellite operator’s own frequency allocation. That said, the need to preclude aggregate effects may eventually overwhelm the ability of even the best engineering and operating practices. At that point, only a very drastic reduction in the numbers of satellites might suffice.

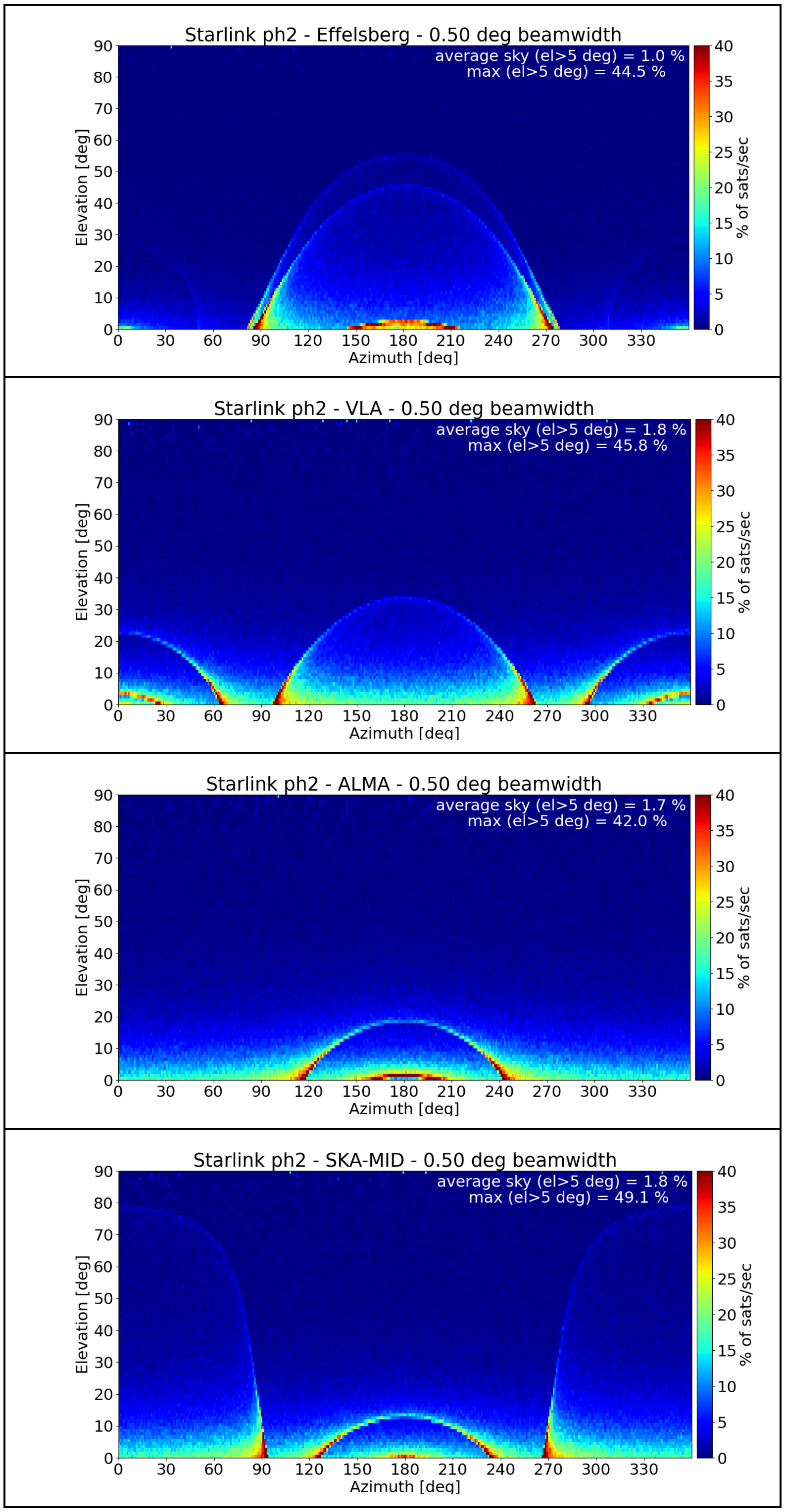

Figure 2.2: Mean probability of a satellite encounter within 0.25° in one second for Effelsberg (latitude=53°), VLA (34°), ALMA (–23 °) and SKA-MID (–30°).

4. Other recent developments reinforcing the need for additional protection from satellite emissions

4.1 Unregistered satellite transmissions

Administrations representing satellite operators have recently registered large fixed-satellite service[616] or mobile-satellite service[617] constellations in LEO at ITU-R without providing complete details of their operation. As registered at ITU-R, these incompletely-specified constellations have the properties of the fixed-satellite and/or mobile-satellite services, using the frequencies allocated to those radiocommunication services. The fixed-satellite service provides wireless broadband from satellites to home user terminals, among other uses, and the constellation modeled in Section 3 is an example. The mobile-satellite service provides communications between satellites and specially designed satellite phones or larger mobile terminals used on vessels and larger vehicles of various kinds.

However, when the commercial operators of these constellations subsequently applied for operating licenses in various administrations, they asked permission to communicate between their satellites and ordinary terrestrial mobile phones (i.e., cell phones), in mobile service frequency bands that cell phones use to communicate with each other on the ground. Terrestrial emissions at such frequencies are kept out of radio quiet or coordination zones, but would be re-introduced when seen from the satellites. The protection afforded by a local radio quiet or coordination zone will have been rendered ineffective.

There is no spectrum allocated for communication between satellites and mobile service cell phones: the mobile service spectrum that *is* allocated for use by cell phones is proscribed for use in direct communication with satellites. But the situation is complicated in a regulatory sense because neither the satellite nor the radio telescope is using spectrum that is allocated to it in this case.

The Radio Astronomy Working Group recommendations would protect radio astronomy, but it would be better if satellite and radio spectrum regulators did not condone such practices. Radio astronomy observatories have filed objections to this practice with their national spectrum regulator, for instance in the case of the USA: https://licensing.fcc.gov/myibfs/download.do?attachment_key=2862535 and https://licensing.fcc.gov/myibfs/download.do?attachment_key=9507364.

[616] Communication between a satellite and a ground station whose location is fixed.
[617] Communication between a satellite and a ground station whose location moves.

4.2 Electromagnetic radiation from mega-constellation satellites

Radio transmissions by mega-constellation satellites are regulated by the ITU-R and its member states. This includes the wanted emission in assigned frequency bands and the unwanted emissions in adjacent and harmonically-related bands, which are intrinsically related to the signal generation and transmission processes (signal amplification, modulation scheme, etc). However, electronic circuitry can also generate electromagnetic radiation (EMR), for instance from a CPU clock signal on printed circuit board traces that act as antennas for radiation that escapes the satellite.

Unfortunately, EMR is usually not subject to ITU-R procedures associated with the satellite notification process. While the power levels associated with EMR are normally considered negligible for communication systems in space and on Earth, radio astronomy receivers are sensitive enough to detect them. These emissions may be exacerbated by faults and with the large numbers of satellites in mega-constellations, a non-negligible number of satellites could experience malfunctions during their lifetime. This could lead to an excess in EMR which can take years to be removed from orbit.

4.3 Solar power satellites for beamed energy transmission

Solar power satellites would convert sunlight to microwaves or optical laser light and beam the converted energy from orbit to satisfy Earth's energy needs, which according to their proponents will not damage the environment. Radio astronomers have been arguing against the hazards of solar power satellites for 40 years. While such systems have remained entirely hypothetical, CalTech in the USA recently announced an infusion of $100,000,000 to advance them (https://www.caltech.edu/about/news/caltech-announces-breakthrough-100-million-gift-to-fund-space-based-solar-power-project)

The original radio astronomical paper discussing the external effects of solar power satellites is by Thompson (1981, Radio Science, 16, 35). The International Union of Radio Science (URSI) published a White Paper and Inter Commission Working Group Report in 2006 and 2007, respectively, only the latter of which received much contribution from radio astronomers (see http://www.ursi.org/files/WhitePapers/WPSPS-ReportMin.pdf).

Radio astronomy is not by any means the only existing use of radio spectrum that stands to be disrupted by the advent of large-scale energy generation using solar power satellites to beam energy down to Earth as microwaves. Microwave power beams would wreak havoc with communication services and present extreme biohazards in the vicinity of the rectifying antennas receiving and converting the radio waves to electricity on the ground. The vast collecting areas and large numbers of satellites required to collect solar energy at gigaWatt scales would present extreme hazards to optical and infrared astronomy.

An example of one of the proposed solar power satellites would have a solar panel with a size of 10 x 10 km. Its angular size would be about one arcminute, much larger than Jupiter, and the reflected solar light would be very bright. For a much smaller satellite with a transmitting surface area of 1 km^2 in geo-synchronous orbit at a distance of 30,000 km and an albedo (reflectivity) of 7.5% typical of untreated StarLink satellites (Horiuchi, Hanayama & Ohishi 2020, ApJ, 905, 3, https://iopscience.iop.org/article/10.3847/1538-4357/abc695) the visual *V*-magnitude would be 1.8 (half the brightness of the brightest stars), and the peak brightness would be *V*-magnitude 1.5 at a wavelength of 950 nm.

Solar power satellites are just one aspect of beamed wireless power transfer that is discussed more generally in Report ITU-R SM.2392 https://www.itu.int/pub/R-REP-SM.2392-1-2021. Non-beam inductive methods of transferring power over short distances for such uses as electric vehicle charging are also capable of generating harmful interference across a broad swath of spectrum. The regulatory status of wireless power transfer is ambiguous.

5. Protections for radio astronomy in the shielded zone of the Moon

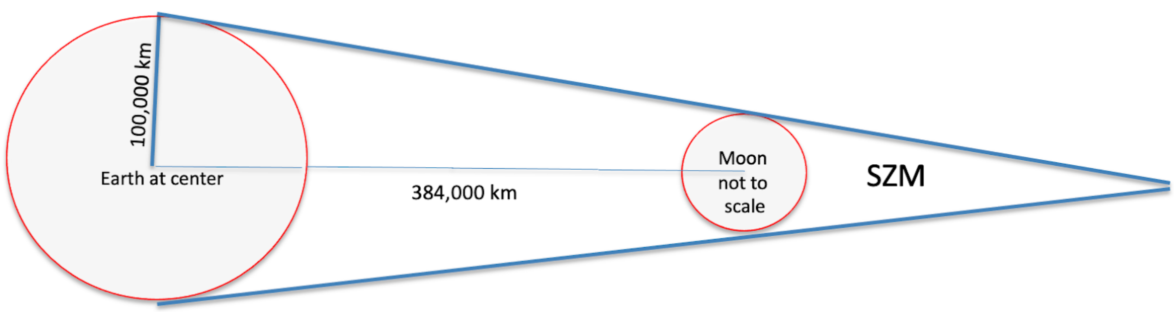

Figure 2.3 Schematic representation of the shielded zone of the Moon.

Regulatory protection in the Radio Regulations for radio astronomy and passive science in the shielded zone of the Moon stands in sharp contrast to that afforded to the terrestrial radio astronomy that has been discussed in the Dark and Quiet Skies conferences. The ITU-R is capable of formulating rules that protect science by avoiding completely narrow concerns of frequency allocation in the case of lunar radio astronomy and passive science.

As noted in RR 22.22.1 "T*he shielded zone of the Moon comprises the area of the Moon's surface and an adjacent volume of space which are shielded from emissions originating within a distance of 100,000 km from the center of the Earth*." Articles 22.22–22.25 of the Radio Regulations prohibit emissions that would cause harmful interference to radio astronomy and other passive services in the shielded zone of the Moon at *all* frequencies, except those in bands allocated to a few radio services that support lunar and space operations:

22.22 § 8 1) In the shielded zone of the Moon[31] emissions causing harmful interference to radio astronomy observations[32] and to other users of passive services shall be prohibited in the entire frequency spectrum except in the following bands:

22.23 *a)* the frequency bands allocated to the space research service using active sensors;

22.24 *b)* the frequency bands allocated to the space operation service, the Earth exploration-satellite service using active sensors, and the radiolocation service using stations on spaceborne platforms, which are required for the support of space research, as well as for radiocommunications and space research transmissions within the lunar shielded zone.

22.25 2) In frequency bands in which emissions are not prohibited by Nos. **22.22** to **22.24**, radio astronomy observations and passive space research in the shielded zone of the Moon may be protected from harmful interference by agreement between administrations concerned.

[31] **22.22.1** The shielded zone of the Moon comprises the area of the Moon's surface and an adjacent volume of space which are shielded from emissions originating within a distance of 100 000 km from the centre of the Earth.

[32] **22.22.2** The level of harmful interference is determined by agreement between the administrations concerned, with the guidance of the relevant ITU-R Recommendations.

Figure 2.4 An extract from the ITU-R Radio Regulations, Articles regarding the protection of the shielded zone of the Moon.

These Articles are striking because they prohibit harmful emissions throughout the entire frequency spectrum up to 3000 GHz, including frequencies that are not allocated to radio astronomy and frequencies above 275 GHz that are not allocated to any service. The only spectrum uses that are allowed to cause harmful interference are those using the limited frequency bands of radio services needed for support of lunar missions.

This is much broader and more protective than any regulation of terrestrial radio astronomy. Unfortunately, lunar missions are now being readied that use frequencies subject to Articles 22.22–22.25 but have not been coordinated with radio astronomers.

6. 94 GHz coordination agreement between ESA and IUCAF

Since 2005, the Jet Propulsion Laboratory in the US has operated the 94.05 GHz CloudSat cloud profiling radar in the middle of a broad swath of spectrum that is allocated to and heavily used by radio astronomy. The powerful beam of this nadir-pointing radar saturates any receiver over which the satellite passes during its 16-day repeating orbital cycle, no matter where a radio astronomy antenna points. More seriously, the radar could burn out a radio astronomy receiver in the worst case. A variety of modifications to radio astronomy operations and instruments have been made on this account, especially for moveable array antennas that are transported in a zenith-pointing orientation with their supercooled electronics operating.

Figure 2.5 EarthCare radar system. Credit: NASA.

To forestall a repetition of this unfortunate situation when ESA launches its EarthCare mission in 2023 (Figure 2.5) with an even higher-power 94.05 GHz JAXA-designed radar, IUCAF has for 15 years participated in meetings of the Space Frequency Coordination Group where EarthCare and other Earth-sensing radars were discussed. This effort bore fruit in April 2021 when ESA and IUCAF signed a Memorandum of Understanding under which the nadir-pointing EarthCare radar will be silenced when its beam passes close enough to a radio astronomy antenna that the radio astronomy receiver could be damaged.

IUCAF notes that ESA agreed to modify the EarthCare radar's operation; JAXA designed the radar in such a way that an accommodation was possible; and NASA provided for calculations of radar characteristics, continual encouragement and assistance at meetings of the Space Frequency Coordination Group since 2004. See https://www.sfcgon-line.org.

7. Scientific access to sky and spectrum

Scientific access to sky and spectrum is eroding under the relentless pressure of commercial development of radio communication technology. Meanwhile, radio spectrum regulators are focused on the protection of frequency allocations and have no obvious means to address the biological, environmental, and broader scientific concerns that are the subject of the Dark and Quiet Skies conferences. Radio spectrum regulators authorize vast mega-constellations that occupy wide swaths of the radio spectrum used by radio astronomy while inadvertently reflecting sunlight at levels visible to the naked eye, disrupting optical astronomy. The dark and quiet sky threatens to become a nightly theater of artificial objects and artificially generated radiation that isolates us from the cosmos.

The common lesson of all the studies conducted for the Dark and Quiet Skies effort, whether in regard to artificial light at night, to reflection of solar radiation by satellites, or to use of satellites for radiocommunication, is the principle that **artificial radiation of whatever kind should not be produced if it is not needed and should not be detectable where it is not used**. The radio astronomy recommendations embody this principle in the context of radio astronomy and implementing them is a critical step in maintaining scientific access to sky and spectrum and the Universe.

8. Towards implementation of the recommendations

Radio astronomy requires portions of the radio spectrum (not constrained to the protected radio astronomy bands) to be interference-free, for sufficiently long periods of time, to enable scientific discoveries that can advance the human knowledge of the Universe, contribute to planetary defense, and create terrestrial reference frames used for global positioning, among many other applications. The invaluable work done by administrations and radio astronomy protection groups at the ITU-R, should be complemented by the Dark and Quiet Skies proposed work at COPUOS to raise the awareness on the vulnerability of radio astronomy to activities in space. The significant effect that satellite systems (as a space activity under the mandate of COPUOS) can have on radio astronomy, at all frequencies of the radio spectrum, requires urgent attention in this new era of unprecedentedly fast developments.

The radio astronomy working group recommends that the potential impacts of space activities on radio astronomy are presented at COPUOS and national delegations are urged to consider these as part of the general assessment of environmental impact of any proposed space activity.

9. Acronyms

- ALMA: Atacama Large Millimeter/submillimeter Array
- ESA: European Space Agency
- FCC: Federal Communication Commission (US)

- GSO: Geo-Synchronous Orbit
- ITU-R: International Telecommunication Union — Radio Sector
- JAXA: Japanese Aerospace Exploration Agency
- MOU: Memorandum of Understanding
- NASA: National Aeronautics and Space Administration (US)
- PNT: Position, Navigation and Timing functionalities
- RAS: Radio Astronomy Service at ITU-R
- SFCG: Space Frequency Coordination Group
- SatCon1: Satellite Constellations 1 Workshop
- SZM: Shielded Zone of the Moon
- VLA: Very Large Array Telescope


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