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DIVISION F PLANETARY SYSTEMS AND ASTROBIOLOGY

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PARTICIPATING COMMISSIONS

Commission F1	**Meteors, Meteorites and Interplanetary Dust**
Commission F2	**Exoplanets and the Solar system**
Commission F3	**Astrobiology**
Commission F4	**Asteroids, Comets and Transneptunian Objects**
Cross-Division A-F	**Commission X2 Solar System Ephemerides**

INTER-DIVISION COMMISSIONS AND WORKING GROUPS

Inter-Division A-F	**WG-Cartographic Coordinates & Rotational Elements**
Inter-Division A-F	**WG Near-Earth Objects**
Inter-Division A-F	**Commission Celestial Mechanics and Dynamical Astronomy**
Inter-Division E-F-G	**Commission Impact of Magnetic Activity on Solar and Stellar Environments**

TRIENNIAL REPORT 2021-2024

1. Organization and activities

The Division F, with 2626 members and 233 junior members is focused on the study of the solar and extrasolar planetary systems, their constituents and astrobiology. In particular, the members dedicate their activities on observational, theoretical and experimental studies of a large variety of objects: exoplanets, planetary systems, interplanetary dust, planets, asteroids, comets, transneptunian objects, interstellar objects, satellites, meteors, meteorites, and a large set of topics in the interdisciplinary astrobiology field. Within the Division, there are four Commissions, and one Cross Division Commission and Working Groups. The creation, in 2021, of the new Commission F4 (Asteroids, Comets and

Transneptunian objects), increased the synergies and activities in this growing theme. This triennium was particularly exciting with the amazing new discoveries thanks to results by JWST, space missions, and pristine samples returned to Earth.

Several resolutions were proposed and discussed among our community, with particular attention to "*Definition of a Planet in the Solar System*".

2. PhD Prizes

Following the increased number of excellent proposals for PhD prizes, we promote the decision of honorable prizes. Consequently each year we selected 1 PhD Prize and 2 honorable Prizes:

The winners are for 2022:

Megane Weiner Mansfield, USA: *Revealing the Atmospheres of Highly Irradiated Exoplanets: From Ultra-Hot Jupiters to Venus Analogues*

Honorable Prizes :

Chloe Fisher, Switzerland: *Characterising Exoplanet Atmospheres using Traditional Methods and Supervised Machine Learning*

Rafael Luque, Spain: *Planetary systems around red dwarfs and activity of their host stars*

For 2023:

Malena Rice, USA: *A Dynamical Synthesis of Planetary Systems*

Honorable Prizes :

Tyler Garden, UK: *Probing Unique Regimes of Exoplanet Science with Long Baseline Interferometry*

Misako Tatsuumo, Japan: *Material Strength of Dust Aggregates in Planet Formation*

For 2024:

Mohammad Farhat, France/Lebanon: *Dissipation in the Earth-Moon System*

Honorable Prizes :

Adina Feinstein, USA: *A Multi-Wavelength Investigation of Young Stellar and Planetary Systems*

Andres Felipe Izquierdo Cartagena, Netherland: *Mining the kinematics of discs to hunt for planets in formation.*

3. Highlights

One of the most exciting developments that has happened over the last triennium in Division F, are the samples returned to Earth from two primitive asteroids (Ryugu and Bennu), which are under analysis all around the world. The analysis from the Ryugu sample (5.4 g) returned by the JAXA Hayabusa2 mission revealed the most chemically pristine solar system material ever analyzed. A variety of major pre-solar grains and organic molecules have been identified, as well prebiotic molecules. The NASA OSIRIS-REx mission has successfully brought back, just few months ago, about 122 g of material from the pristine asteroid Bennu. The preliminary analyses show a hydrated, organic-rich sample from the early solar system. The results already obtained plus the ones to come will be of fundamental importance for planetary systems models.

In the Solar system, a clumpy ring beyond the Roche limit has been discovered around the dwarf planet Quaoar, making a revolution in the field. Dozens of new moons of Saturn have been discovered, making Saturn the planet with the most moons of any planet in the solar system. The Mimas Saturnian moon has been suspected to have an ocean 20-30

km under its surface. NASA's Lucy mission discovered that the small asteroid Dinkinesh has a satellite that itself is a contact binary.

The NASA DART (Double Asteroid Redirection Test) mission which impacted (September 26, 2022) the asteroid moonlet Dimorphos, was the first-ever mission dedicated to investigating and demonstrating one method of asteroid deflection by changing an asteroid's motion in space through kinetic impact. The outcome will be investigated in detail by the ESA Hera mission that will be launched in October 2024, as part of the Asteroid Impact and Deflection Assessment (AIDA) international cooperation.

For exoplanets, discoveries have continued at a pace of one to a few per week (see Fig.1).

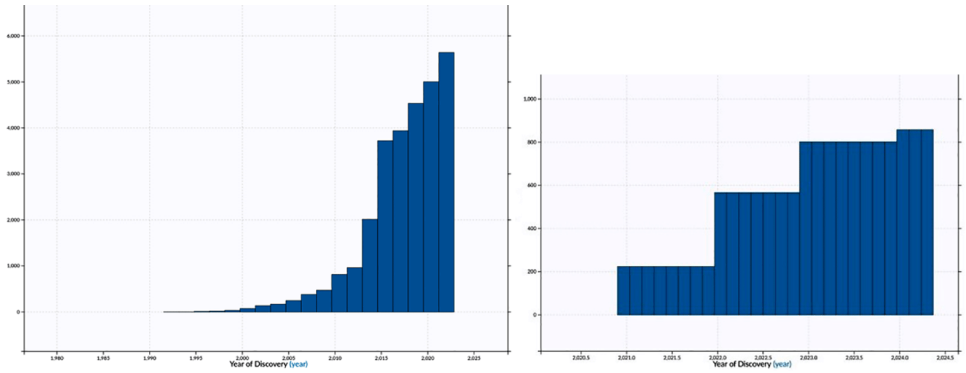

Figure 1. Cumulative detections of exoplanets per year with a zoom on the right for the last three years

New insights into planetary system formation have been obtained with NASA's James Webb Space Telescope with the characterization of the chemical composition of several exoplanet atmospheres. Among its many discoveries, JWST has detected signs of methane, carbon dioxide and dimethyl sulfide in the atmosphere of K2-18 b, a rocky world in its star's habitable zone, hinting that it could harbor a water ocean on its surface.

Data from the TESS spacecraft have been used to discover and characterize the exceptional planet TOI-1853 b, which is smaller than Neptune but about five times as massive. TOI-1853 b is very hot and models imply that more than 90% of its mass is in the form of elements heavier than helium. Two planetary systems, TOI-178 and HD 110067, have been found with 6 planets in Laplace resonance.

4. Conference participation & diffusion

The Division F members organized and participated in many IAU symposia, Focus meetings and general International meetings and workshops. For the Division day (GA2024) 65 abstracts have been obtained allowing to organize a well intense and interdisciplinary meeting.

Many important meetings with large participation, just to a quote few recent ones :

- AGU Fall Meeting, Dec 12-16 2022, Chicago, USA
- White Dwarfs as Probes of the Evolution of Planets, Stars, the Milky Way and the Expanding Universe, Oct 16 - Dec 17 2022, Santa Barbara, USA
- Meteoroids 2022, June 13-17 2022, Huntville, USA (online)

- SKA/MSE and multiwavelength synergies workshop, Jan 9-13 2023, Bengalore, India
- Asteroids, Comets, Meteors (ACM) Conference, June 18 - 23 2023, Flagstaff, USA
- 2023 Kavli-IAU Astrochemistry Symposium. Astrochemistry VIII - From the First Galaxies to the Formation of Habitable Worlds, July 10-14 2023, Traverse City, MI, USA
- Complex Planetary Systems II – Kavli-IAU Symposium 382, July 3-7, 2023, Namur, Belgium
- Origins 2023, July 30 -Aug 4, jointly sponsored by ISSOL and Commission F-3, Quito, Ecuador
- AGU Fall Meeting, Dec 11-15 2023, San Francisco, USA

5. Participating Commissions

Commission F1 Meteors, Meteorites and Interplanetary Dust

Commission F1 of the IAU has historically been the international focal point of the meteor community since 1922 (previous Commission 22). The Commission fosters scientific cooperation not only among different nationalities, but also links scientific communities; obviously meteors, meteorites and dust, but also the comet and asteroid communities. This is fostered with the Commission's triennial Meteoroids conference.

One major area of interest in the past three years has been pre-atmospheric detection of large meteoroids, which have then been observed. In 2022, asteroid 2022 WJ1 impacted the atmosphere over Ontario, Canada and was observed by a handful of notified observers. In 2023, 2023 CX1 was widely observed over the UK and France when it impacted about 7 hours after being discovered. On a similar note, two new predicted meteor showers were observed during the triennium. The Arids from Comet 15P/Finlay were observed for the second time, and there was a first observation of the lambda-Sculptorids from Comet 46P/Wirtanen. The showers were observed by the GMN and CAMS optical meteor networks, and the SAAMER meteor radar. An outburst of the established τ Herculid shower, caused by a breakup of comet 73P/Schwassmann Wachmann 3 in 1995, was also observed in 2022. Dynamical modelling, in addition to predicting new meteor showers and modelling meteor shower outbursts, address the problem of the dust environment in near Earth space and the influx of interplanetary material on the Earth. The Commission is already preparing for the next major event of the coming triennium: the Meteoroids 2025 conference in Perth, Australia.

Commission F2 Exoplanets and the Solar system

The Commission "Exoplanets and the Solar System" resulted from the merging of the previous commissions C16 (Physical study of planets and satellites) and C53 (Extrasolar planets). Although extrasolar planets are detected and observed with different instruments and different techniques than the planets of the Solar System, the physical properties of these objects have many aspects in common. The Commission promotes exchange and interaction between the two communities. As described in the Division Report of the previous triennium, Commission F2 held a plebiscite on amending the Working Definition of an exoplanet in 2018. An article presenting the current definition and motivations therefore has now been published: `https://ui.adsabs.harvard.edu/abs/2022NewAR..9401641L/abstract`.

Commission F3 Astrobiology

Hayabusa 2 returned samples from the carbonaceous asteroid Ryugu in December 2020.

The samples were examined and opened for proposals for analysis from qualified experts early in the triennium and a treasure trove of data has been the result. Twenty different amino acids, uracil and even vitamin B3 have been detected in the returned samples, yet because these samples were collected directly from Ryugu, there is little concern that such biomolecules are due to terrestrial contamination. These analyses should shed light on the role primitive bodies may have played in the origin of life on Earth, throughout the solar system, and in extrasolar environments. In September 2023, the OSIRIS-REx spacecraft successfully returned 122 grams of sample from the water- and carbon-rich asteroid Bennu. Preliminary analyses of these samples have just begun, and a catalog of samples should soon be available to the world-wide scientific community early in the triennium that can be requested by qualified investigators for detailed scientific analysis. Asteroid (and comet) sample return has been, and will continue to be, the only method that can provide contaminant free samples of organic processes that occurred prior to the origin of life on Earth, and this age of sample return is thus a watershed opportunity for Astrobiology. The study of Astrobiology has become much more popular over the last several triennia thanks to regional and national Astrobiology Centers and Institutes. In particular, the European Astrobiology Institute under the leadership of Prof. Wolf Geppert has established a series of well-attended seminars that are advertised and open to the worldwide scientific community and serve to promote interest in all aspects of Astrobiology from philosophical and ethical issues to intricate details of biochemistry and chemical evolution. These compliment other efforts to support the Astrobiology Community with seminars and discussion forums such as those of the Astrobiology Science Communication Guild. Finally, IAU Commission F-3 joined with the International Society for the Study of the Origin of Life (ISSOL) to hold a very successful meeting in Quito Ecuador in August 2023. The next joint IAU Commission F-3/ISSOL meeting will occur in Paris, France in 2026.

Commission F4 Asteroids, Comets and Transneptunian Objects
The Commission F4 was approved in August 2021 and brings together the international scientific community involved in the study of small bodies. Although this commission is considered new, it resumed the activities of the previous Commission 15 (1935-2015), which was dissolved under the reorganization of the IAU structure. The main responsibility of the Commission is to promote progress on the physical studies of asteroids, comets, TNOs and to support synergy and collaboration of observational, experimental, and theoretical research across groups studying small bodies. During the triennium the research activity has been extremely productive as demonstrated by over 1200 peer-reviewed papers published each year. The Commission members have significantly contributed to ongoing and future space missions to small bodies. Telescopes around the globe and in space monitored the binary asteroid Dimorphos before and after the DART impact. The analysis of samples of two near-Earth asteroids returned by JAXA Hayabusa2 and NASA OSIRIS-REx missions opened a new era in the study of the early Solar system's pristine material and its evolution. The ESA Gaia mission data has significantly increased the accuracy of asteroid orbits, mass determinations, and predictions of stellar occultations. The obtained new results were broadly discussed among OC and Commission members to highlight and promote the most important findings. The highlights have been posted on the IAU Commission F4 webpage.

Commission X2 Cross-Division A-F Commission Solar System Ephemerides
Members of Commission X2 are constantly improving mathematical methods and using the ever-increasing database of observations to produce precise ephemerides for future

lunar and planetary missions, study physical properties of celestial bodies, and theoretical studies in general relativity. Updated versions of planetary ephemerides were released: DE440, EPM2021, INPOP21a. Notable improvements include better accuracy of Jupiter's orbit thanks to new Juno spacecraft ranging observations; better accuracy of Moon's orbit and physical libration model thanks to continuing lunar laser ranging observations from Grasse, Apache Point, Wettzell, and Matera; better estimate of Sun's gravitational parameter thanks to in situ electron density measurements used for estimating the delay of signal in solar plasma (EPM); better estimate of the mass distribution in the outer solar system; an important update of the Saturn dynamical environment (planet and satellites, spin, gravity field,...) thanks to Cassini in situ data; more accurate orbit of Pluto thanks to stellar occultations data from Gaia DR3 (DE, INPOP). Also, a completely new lunar-planetary ephemeris, PETREL19, was developed in China. Regarding the small bodies, huge progress in exchanging astrometric data has been made thanks to the adoption of the ADES format. Gaia mission results were of paramount importance for improving the accuracy of astrometric observations of small bodies, thanks to the astrometric catalogue data product, but also through direct observations of nearly 160,000 small bodies. Progress on the demonstration of deflection capabilities has been made thanks the DART mission to Didymos and Dimorphos.

Division A-F Working Group on Cartographic Coordinates and Rotational Elements

The Working Group on Cartographic Coordinates and Rotational Elements makes recommendations on the latitude and longitude coordinate systems and orientation, size, and shape models used for mapping of all Solar System Bodies other than the Earth. Various groups have proposed making a major change in the cartographic lunar coordinate system, a topic that will be discussed. In any case, small but important changes will likely be recommended for the systems for the Moon and Mars. Updates are also likely due to new results from processing or reprocessing of various planetary datasets. These include the models for various bodies, such as Mercury, Venus, Jupiter, Saturn, the Saturnian satellites, the dwarf planet Ceres, Comet 67P/Churyumov–Gerasimenko, and the asteroids Arrokoth, Bennu, and Ryugu.

Division A-F Near-Earth Object Working Group

The NEO Working Group is a functional inter-Division A-F WG. It continues its task of monitoring and participating to the international activities focused on planetary defense, of representing the IAU in international groups, such as the UN-endorsed International Asteroid Warning Network (IAWN; see: `https://iawn.net`). It also highly contributes to public outreach efforts, noting that NEOs and planetary defense are of high interest for the public. The media interest was at its maximum for the DART impact and is especially high when a new NEO is discovered. This is part of the reason why a committee is working on a proposal to the UN to define 2029, which is when Apophis will come close to Earth, as the International Year of Planetary Defense, which will trigger a big amount of public outreach activities along the year on this topic, noting that UN already endorsed June 30 as the Asteroid Day of each year. The NEO WG will continue its task during the next triennial and is looking forward to the next discoveries and space projects to be launched, starting with the ESA Hera mission in 2024!

M. Antonietta Barucci
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