Division A GA-2022 — Division Days

– 5 & 8 August 2022 –

Rationale

The purpose of this Division Days meeting is to provide a summary of the most recent and relevant results for our Division A Fundamental Astronomy – Astronomie fondamentale. In addition to presentations of PhD prizes and recent WG topics, we will have a special focus on: a) Gaia DR3 and eDR3, and b) Reference frames and Rotations.

https://www.iau.org/science/scientific_bodies/divisions/A/meeting2022/

SOC : D. Hestroffer (DP, France), B.A. Steves (DVP, United Kingdom), N. Zacharias (Advisor, United States), F. Bernardi (Italy), C. Efthymiopoulos (Greece), C.S. Jacobs (United States), Z.M. Malkin (Russian Federation), S.G. Stewart (United States), M. Assafin (Brazil), A.G.A. Brown (Netherlands), A.J. Maciejewski (Poland), E. Pilat-Lohinger (Austria), V. Sidorenko (Russian Federation).

Programme and Abstracts booklet

Div.A Programme

Times in KST local time = UTC+9h

Friday 5 | 10:30–12:00 + 13:30–16:45

09:45–10:30 Morning ePosters and pre-recorded contributions

10:30–12:00 [90min] DivA-1

10:30 Division.A Days - Plenary introduction (Daniel Hestroffer)

Session 1 - PhD prizes talks (chair Norbert Zaccharias +DH)

10:40 **Joseph O'Leary** (2019) - A new general relativistic planetary orbitography platform [in room]

11:00 **Etienne Savalle** (2020) - Searching for scalar field dark matter with the DAMNED experiment [remote]

11:20 **Chris Hamilton** (2021) - Secular Dynamics of Binaries in Stellar Clusters [in room]

11:40 **Lei Zhang** (2020) (Honorary mention from the Division) - Pulsar Observation and Study with FAST and Parkes Radio Telescope [remote]

12:00 Lunch

13:30–15:00 [90min] DivA-2

Session 2 - Gaia eDR3 and DR3 (chair Anthony Brown + DH)

13:30 **Steve Durst** – Astronomy from the Moon Surface and ILOA Hawaii [in room]

13:50 **Anthony Brown** – Mission status and DR3 overview [in room]

14:20 **David Hobbs** – The Hidden Regions – Future Space Astrometry in the Near Infrared [in room]

14:40 **François Mignard** – Gaia Celestial Reference Frame Gaia-CRF3 [remote]

15:00 Coffee break

15:15–16:45 [90min] DivA-3

Session 3a - News from Commissions and WGs (chair Norbert Zaccharias +DH)

Introduction of new working groups (2021-2024)

15:15 **Patrick Charlot** – The new Division A Working Group on Multi-waveband ICRF [remote]

15:25 **José Manuel Ferrándiz** – Report of the IAU/IAG Joint Working Group on Improving Theories and Models of the Earth's Rotation to the IAU General Assembly (2022) [in room]

Scientific reports from the Division's Commission and Working groups

15:35 **Christopher Jacobs** – Commission A1 Astrometry scientific report [in room]

15:45 **Zinovy Malkin, Alberto Escapa** – Commission A2 Rotation of the Earth: Current activities and outlook [in room]

15:55 **Susan Stewart** – Commission A3 Fundamental Standards Update [in room]

16:05 **Steve Bell** – The Standards of Fundamental Astronomy (SOFA) WG [in room]

16:15 **Felicitas Arias** – Division A Working Group on Time Metrology Standards (TMS) [remote]

16:25 **Fabrizio Bernardi** - X2 Cross-Division A-F Commission Solar System Ephemerides [remote]

16:35 **Brent Archinal** - WG on Cartographic Coordinates & Rotational Elements (CCRE) [remote]

16:45–17:30 Afternoon ePosters and pre-recorded contributions

« E-talks/e-posters will be available to watch at the web-based galleries all the time. »

Times in KST local time = UTC+9h

Monday 8 | 10:30–12:00 + 13:30–15:00

09:45–10:30 Morning ePosters and pre-recorded contributions

10:30–12:00 [90min] DivA-4

Session 4 - Reference Frames and Rotations (chair Alberto Escapa + DH)

10 :30 **José Manuel Ferrándiz** – Advances and prospects in the accurate modelling of precession-nutation from VLBI solutions [in room]

11 :00 **Richard Gross** – Sequentially Estimating and Updating Terrestrial Reference Frames [in room]

11 :20 **Jolanta Nastula** – Preliminary study on the consistency among hydrological angular momentum estimates determined from CMIP6 historical simulations [in room]

11:40 **Alberto Escapa** – Effects of the mass redistribution on the rotation of the Earth [in room]

12:00 Lunch

13:30–15:00 [90min] DivA-5

Session 5 - Highlights of Focus Meetings (chair Daniel Hestroffer +NZ)

13:30 **Masateru Ishiguro** – Highlights of IAU Focus Meeting FM8 Planetary astronomy via telescopic and microscopic approaches [remote]

13:50 **Anatoliy Ivantsov** – Highlights of IAU Focus Meeting FM10 Synergy of Small Telescopes and Large Surveys for Solar System and Exoplanetary Bodies Research [remote]

14:10 **Anthony Brown** – IAU Focus Meeting FM7 Astrometry for 21st Century Astronomy [in room]

14:20 10 minute Break

Session 3b - News from Commissions and WGs (chair DH+NZ)

Scientific reports from the Division's Commission and Working groups

14:30 **Anatoliy Ivantsov, Marchelo Assafin, William Thuillot** – Division A Working Group on Astrometry by Small Ground-Based Telescopes (ASGBT) [remote]

14:40 **Patrick Michel** – NEO Working Group : some new knowledge regarding NEOs, current projects and perspectives. [remote]

14:50 **Christos Efthymiopoulos, Giovanni Gronchi** – Commission A4 Celestial Mechanics and Dynamical Astronomy [remote]

15:00 End of Division Days

---

e-posters and pre-recorded contributions

Div.A Abstracts

(in chronological order)

Friday 5 | 10:30–12 :00 + 13:30–16:45

10:30–12:00 [90'] DivA-1 - Session 1 - PhD prizes talks

Abstract 2612

A new general relativistic planetary orbitography platform

Joe O'Leary[1], Jean-Pierre Barriot[2]

[1]*Astrodynamics, EOS Space Systems, Australia*
[2]*Geodesy Observatory of Tahiti, University of French Polynesia, Polynesia*

Through a series of resolutions, the International Astronomical Union suggest that all problems in the field of astronomy or astrodynamics be formulated within the framework of Einstein's general theory of relativity.

Orbitography software such as the French space agency GINS or NASA's MONTE platforms currently describe the motion of interplanetary spacecraft using a classical Newtonian framework linearly corrected with effective forces, accounting for the *effects* of general relativity with the so-called n-body Einstein-Infeld-Hoffmann (EIH) equations of motion. Given the stringent accuracy requirements associated with fields such as astrometry, metrology and geodesy, spacecraft propagation platforms based on the so-called ``Newton $+$ correction'' framework need to include subtle relativistic effects in order to reflect the rapid improvements in modern measurement technology. We argue that this approach is now reaching its limits in terms of complexity.

Recently [1,2] we presented the first results of a prototype software titled General Relativistic Accelerometer-based Propagation Environment (GRAPE) which describes the motion of interplanetary probes and spacecraft using the complete framework of general relativity. GRAPE employs extended relativistic equations of motion which account for non-gravitational forces using either end-user supplied accelerometer data or approximate dynamical models.

In this talk, we extend GRAPE for operational mission planning within the Solar System, describe the approach adopted to interface it with NASA's SPICE kernels and verify our results by comparing the Doppler residuals using GRAPE *and* SPICE with high-precision Ka/Ka band Doppler data obtained from the gravitational-wave experiments performed by the Cassini probe during its cruise phase.

[1] O'Leary, J. and Barriot, J.P., 2021. An application of symplectic integration for general relativistic planetary orbitography subject to non-gravitational forces. *Celestial Mechanics and*

Dynamical Astronomy, *133*(11), pp.1-22.
[2] O'Leary, J., 2021. *General Relativistic and Post-Newtonian Dynamics for Near-Earth Objects and Solar System Bodies*. Springer Nature.

Keywords: General Relativity, Planetary Orbitograhy, Non-gravitational Forces, Interplanetary Navigation

Abstract 2939

Searching for scalar field dark matter with the DAMNED experiment

Etienne Savalle

DPHP, CEA, France

DArk Matter from Non Equal Delays" (DAMNED) is a new experiment that aims to detect dark matter. This 3 arms Mach-Zender experiment allows us to compare an ultra-stable cavity to itself in the past through the delay created by a multi kilometer long optical fiber. We present the results of this new experiment and put competitive constraints on the DM coupling constants.

Keywords: Dark matter, Interferometry, experiment

Abstract 3456

Secular Dynamics of Binaries in Stellar Clusters

Chris Hamilton

School of Natural Sciences, Institute for Advanced Study, Princeton, United States of America

Why do black holes collide? Where are massive planets formed? How are ancient comets able to penetrate the inner Solar System? To address these questions requires a detailed understanding of the orbital evolution of gravitationally bound two-body systems — usually known as binaries.

Despite the great diversity of astrophysical binaries, many of them share the common feature that they are not isolated, but are instead continually perturbed by their environment, such as their host star cluster or galaxy. Here I derive a general theory that describes the orbital evolution of any

binary system perturbed by an external gravitational field. When applied to black hole binaries in star clusters the theory explains how the force from the cluster can ultimately drive the black holes to merge. Furthermore, the theory constitutes a generalisation of the classical three-body problem, and despite centuries of work on that topic, in almost every Chapter of the thesis I reveal some new insight into it.

In summary, then, the purpose of this thesis is three-fold: to formulate a unified theory of binary dynamical evolution; to propose an origin for black hole mergers and other astrophysical exotica; and to uncover a range of new, important and beautiful dynamical phenomena.

Abstract 3457

Pulsar Observation and Study with FAST and Parkes Radio Telescope

Lei Zhang

Radio, National Astronomical Observatories, Chinese Academy of Sciences, China

Lei Zhang obtained her PhD degree in July 2020 from National Astronomical Observatories, Chinese Academy of Sciences (NAOC). During her Ph.D., she led pioneering work with two major new instruments for radio astronomy, namely the Five-hundred-meter Aperture Spherical radio Telescope (FAST) that is the largest single-dish antenna in the world and new Ultra-Wideband Low (UWL) receiver installed on the Parkes telescope that is the first such receiver to be regularly operated on a major telescope. With only a un-cooled commissioning receiver on FAST, she discovered a new pulsar, J1926-0652, and led the e↵orts to follow it up with Parkes, GBT, and FAST. Her work revealed a plethora of unexplored complex single-pulse behaviors

and “pose challenges for the classic carousel-type models”, as stated in the last sentence of the abstract of the resulting publication (Zhang et al. 2019 ApJ), which was the first international journal paper from FAST. She then focused pulsars in globular clusters (GC). Aided by the then newly installed Parkes UWL, she obtained the most accurate measurements thus far of DM and for the first time RM toward three bright pulsars in 47 Tucanae. This work is a nice example of how to probe GC pulsars with highly-sensitive, well-calibrated observations made available by the UWL. Her work result in one of the first science papers from the Parkes UWL.

Abstract 1288

Astronomy from the Moon Surface and ILOA Hawaii

Steve Durst

Hawaii, International Lunar Obsevatory Association, USA

The Moon's thin exosphere, radio quiet farside, stabile surface, 1/6th gravity, extractable volatiles for ISRU and near-term human settlement allowing for instrument services/upgrades make the Moon an attractive environment for a wide-range of astrophysical observation including long duration, high resolution Earth observation, parallax astrometric measurement, interferometry / VLBI, and classical refractor and reflector telescopes.

International Lunar Observatory Association (ILOA) is preparing its first lunar payload, precursor ILO-X, to land on the Moon near 24.5°N, 50.5°W / Vallis Schröteri aboard Intuitive Machines IM-1 Nova-C lander in 2022 via SpaceX Falcon 9 rocket.

The <600g ILO-X dual instrument astronomy lenses, one narrow and one wide FoV built by Canadensys of Ontario, Canada, will conduct optical First Light images of the Milky Way Galaxy Center, and other observations, while serving as technology demonstrators. To date 7 Invited Observations for global collaboration with ILO-X are in place, and ILOA hopes to enable global outreach of its observations with the nearly 8 Billion people of Earth.

ILOA Flagship ILO-1 planning is underway, possibly involving radio and other astronomical spectroscopy instruments. Malapert Mountain, near the Moon South Pole is the ideal location for ILO-1. It's backup, ILO-2 is likely destined for Shackleton Rim or Malapert Mountain. Other 2022 missions are CAPSTONE, Artemis 1 / SLS, Astrobotic Peregine-1, India Chandrayaan-3, Russia Luna-25, Korea Pathfinder Lunar Orbiter (KPLO), Japan ispace, JAXA SLIM and IM-2.

ILOA Hawai'i continues collaborations with China 2013 Chang'e-3 Lunar-based Ultraviolet Telescope (LUT), is planning for at least 5 Galaxy Forum 21st Century education events in 2022, and advocates for a peaceful, aloha-spirit human return to the Moon / First Woman on the Moon – who will undoubtably 'look up' to observe the sky, performing amateur astronomy from their first steps on Luna.

Keywords: Astronomy, Moon, Milky Way Galaxy, Observation

Abstract A9

Gaia mission status and Gaia DR3 overview

Anthony Brown

Leiden observatory, The Netherlands

I will briefly summarize the status of the Gaia mission and its extended operations and then provide an overview of the contents of Gaia DR3.

Abstract A10

The Hidden Regions – Future Space Astrometry in the Near Infrared

David Hobbs

Lund observatory, Sweden

Our Galaxy contains many different types of stars and planets, interstellar gas and dust, and dark matter. These components are widely distributed in age, reflecting their formation history, and in space, reflecting their birth place and subsequent motion. Objects in the Galaxy move in a variety of orbits that are determined by the gravitational force, and have complex distributions of different stellar types, reflecting star formation and gas-accretion history. Understanding all these aspects in one coherent picture is being partially achieved by Gaia, which surveys around 1% of the Galaxy and is still ongoing today. However much more could be done by using Near InfraRed light to peer through the dust and gas to reveal the hidden regions of the Galaxy.

A new all-sky Near InfraRed astrometric mission will expand and improve on the science of Gaia using basic astrometry. Near InfraRed astrometry is crucial for penetrating obscured regions and for observing intrinsically red objects. The new mission is aimed at surveying around 12 billion stars in the Galaxy, revealing important new regions obscured by interstellar gas and dust while also improving on the accuracy of the previous results from Gaia. The mission will explore the Galaxy, particularly the very important hidden regions, to reveal nature's true complexity and beauty in action.

In 2019 ESA announced the next planning cycle for their long term Science Programme, called Voyage 2050. The program called for White Papers outlining new ideas for future space mission themes. In June 2021 Voyage 2050 finally set sail, with ESA having chosen its future science mission themes. Our proposal on All-Sky Visible and Near Infrared Space Astrometry has been selected as one of two possible themes for a future Large category mission for ESA or as a Medium class mission with international partners. This talk will give an update on the science goals, the mission design and its current status.

Astrometry, Galactic Astronomy, Dynamics, Parallaxes, Proper Motions, Survey Mission.

Abstract A1

The new Division A Working Group on Multi-waveband ICRF

P. Charlot (chair)

Laboratoire d'Astrophysique de Bordeaux, France

A new Division A working group entitled "Multi-waveband ICRF" has been established in 2021. This working group takes over two former working groups: (i) the working group on the "Third Realization of the International Celestial Reference Frame (ICRF3)", terminated in 2018 with the realization and adoption of the ICRF3 (IAU Resolution B2, 2018), and (ii) the working group entitled "Multi-waveband realizations of the International Celestial Reference System (ICRS)", terminated in 2021 after the adoption of the Gaia-CRF3 as the optical realization of the ICRS (IAU Resolution B3, 2021). The objective of the new working group is to work toward the realization of a fully integrated multi-waveband celestial reference frame, incorporating positions in both radio and optical bands and ensuring their consistency over the various bands. The end goal of the working group will be to produce the next generation VLBI frames at the S/X, K, and X/Ka bands, or at any other radio band that may emerge in the coming years, to match these with the optical realization from the Gaia space mission, and to place all such positions on a common grid guaranteeing consistency of the source positions over the different bands comprised in the frame. Before this can be accomplished, a number of questions relating to the construction of such a multi-waveband frame are to be addressed. These include dealing with non-uniform sky distributions, agreeing on common values for the amplitude and direction of the Galactic acceleration vector, establishing common practices to align reference frames in different bands and to treat wavelength and time-dependent source positions, and defining a proper terminology for referring to individual (per wavelength) components of the reference frame. This future multi-waveband ICRF should be a valuable asset to further improve our understanding of the physics of the underlying objects.

Abstract A2

Report of the IAU/IAG Joint Working Group on Improving Theories and Models of the Earth's Rotation to the IAU General Assembly (2022)

José M. Ferrándiz[1] *(Chair) and Richard S. Gross*[2] *(Vice-Chair)*

[1]*Universidad de Alicante, Spain*
[2]*JPL, Caltech, USA*

This Joint Working Group (JWG) on Improving Theories and Models of the Earth's Rotation (ITMER) depends on the IAU Commission A2, Rotation of the Earth, and of the International Association of Geodesy (IAG) and was created after the 2019 General Assembly of the latter. According to its Terms of Reference, its main purpose is proposing consistent updates of the Earth rotation theories and models and their validation. Taking into account the different methods and expertise required for the treatment of the different kinds of EOP and that their theoretical treatment must be as consistent as their determination from observations, this JWG adopted a functional structure similar to that of the former IAU/IAG JWG on Theory of Earth rotation and validation (TERV), which may be summarized by the distribution of different kinds of tasks among three sub-WGs (SWG) that work in paralel. These SWG (official within the IAG) are: (1) Precession/Nutation, chaired by Alberto Escapa; (2) Polar Motion and UT1, chaired by Aleksander Brzezinski; and (3) Numerical Solutions and Validation, chaired by Robert Heinkelmann.

This report outlines the main outcomes and activities developed by the JWG in the last years or planned.

Abstract A7

Commission A1 Astrometry scientific report

Christopher S. Jacobs

JPL, Caltech, USA

Commission A1 on Astrometry is pleased to share that the 2021–2022 year has been a year full of successes in the field of astrometry. We report here progress in both global and differential astrometry at optical/IR and radio wavelengths.

The Gaia mission continues to revolutionize optical astrometry with the positions, motions, and physical properties of 1.8 billion objects over a vast range of scales from the solar system, to the galactic, to the extra-galactic. The third data release is scheduled for 13 June 2022 (Gaia, 2022) and will doubtless stimulate progress in numerous areas in- cluding celestial mechanics, galactic kinematics, cepheids, dynamics of open and globular clusters, quasars.

A fundamental ongoing task in the scope of commission A1 is the construction of celestial frames, in particular, at radio wavelengths with the Very Long Baseline Inter- ferometry (VLBI) technique and at optical wavelengths with Gaia.

A robust set of VLBI surveys is underway to increase the number of sources available for reference frame work. Differential VLBI astrometry such as the BeSSeL project to map the structure of the galaxy and ΔDOR spacecraft tracking are producing valuable scientific results. Work continues on the planetary ephemeris.

Ground based optical work ranging from surveys to speckle observations to Lunar Laser Ranging have added to our scientific knowledge during 2021-2022.

We look forward to new instruments such as the LSST, SKA, JASMINE, and Voyage 2050 which in combination with Gaia will invigorate the activities of the commission for many years. For all these reasons we are thankful for the accomplishments of the past year and are looking forward to the work of commission A1 in the coming year.

Abstract A3

IAU Commission A2 "Rotation of the Earth": Current activities and outlook

Zinovy Malkin (President) - Pulkovo Observatory, Russia
Alberto Escapa, (Vice-President) - University of Alicante, Spain

The main activities of the IAU Commission A2 (CA2) include coordination of scientific studies on Earth's rotation and related celestial and terrestrial reference frames; improving the theory of Earth's rotation and reference systems and frames; improving the accuracy and understanding of the observed Earth's rotation variations. The CA2 also serves the astronomical community by linking it to the organizations that provide the International Terrestrial and Celestial Reference Systems and Frames and Earth orientation parameters (EOP): the International Association of Geodesy (IAG), the International Earth Rotation and Reference Systems Service (IERS), the International VLBI Service for Geodesy and Astrometry (IVS), the International GNSS Service (IGS), the International Laser Ranging Service (ILRS), and the International DORIS Service (IDS), as well as analyzing and improving consistency between the results delivered by these services. As a result of these studies, several IAU Resolutions were proposed since 2018 and accepted by the IAU, and practical implementation of these Resolutions is underway. In this presentation, we describe and discuss the current activity of the CA2 in these fields and our plans for the nearest future.

Abstract A8

The Standards of Fundamental Astronomy (SOFA) WG

Steve Bell

HMNAO, UK

This short talk covers the current status of the SOFA WG and the availability of materials within the SOFA Libraries, in both Fortran 77 and ANSI C. It also covers the range of subject areas that SOFA currently addresses and the documentation and cookbooks that accompany the downloadable tarballs and zip files. The talk describes how potential users can download these routines and describes the conditions under which they may be used and other potential sources of this material using other languages.

Abstract 3461

Division A Working Group on Time Metrology Standards (TMS)

Felicitas Arias, and TMS WG members

Observatoire de Paris, France

The Working Group on TMS has been created as a functional Working Group of Division A in 2015, with the aim of providing a link between astronomers and the time metrology community that provides the reference timescale. The membership of the WG consists on 18 scientists, experts in the fields of astronomy and time metrology.

Time metrology is going along fundamental changes that will certainly impact on astronomy; the redefinition of Coordinated Universal Time and the redefinition of the SI unit. This talk will present their progress and potential impact on the astronomical science.

Abstract A4

X2 – Cross-Division A-F Commission Solar System Ephemerides

Fabrizio Bernardi

Space Dynamics Services S.r.l, Navacchio di Cascina, Italy

During this period, optical observers and data processing centers (MPC, NASA, ESA, NEODyS) consolidated the adoption of the ADES format. The next major challenge is preparing to process the increased flow of astrometric data due to the start of big surveys such as the Vera Rubin Telescope, the NEO Surveyor mission, and the Fly-Eye Telescope. In view of this increased data volume, the MPC is making the necessary preparations and major SW and data flow architecture reviews are undergoing. Similar adaptations are necessary for the other data processing centers. On the planetary side, the next-generation, general-purpose planetary and lunar ephemerides called DE440/DE441 were delivered in 2020 by JPL. Compared to the previous DE430, seven years of new data have been added with improved dynamical models and data calibration.

Since 2016, three new versions of INPOP planetary and lunar ephemerides have been delivered by the IMCCE team: INPOP17a, INPOP19, and INPOP21a. They benefit from an improved modeling of the Moon rotation and orbit (INPOP17a), the introduction of Bayesian methods for the asteroid mass determination and the regular inputs of Juno, Mars Express and ExoMars data (INPOP19a, INPOP21a). Perturbations by TNOs have been included since 2020. Constraint on the size of the Moon core has been obtained, INPOP21a gave a better description of the distribution of the mass for the outer solar system and new constraints on dilaton and graviton theories have been published using INPOP19a and INPOP20a.

In 2021 the IAA - Russian Academy of Sciences released a new version of planetary ephemerides, EPM2021, after 4 years since last release.

In 2021 the JPL-Sentry team announced the implementation of a new impact monitoring method that replaces the Line-of-Variations method. This development is important because the new method is fully independent of the previous ones, thus improving the reliability of the results and of the cross-check validation with NEODyS and ESA.

Abstract A5

Division A & F Working Group on Cartographic Coordinates and Rotational Elements (CCRE)

Brent Archinal[1] and the IAU WGCCRE
,
[1]U. S. Geological Survey, Astrogeology Science Center, USA

We report on the activities of the International Astronomical Union (IAU) Working Group (WG) on Cartographic Coordinates and Rotational Elements. Our main work is to make recommendations regarding the creation and maintenance of cartographic planetary coordinate systems. The recommendations are included in our main report produced approximately in conjunction with each General Assembly.

Our most recent such report was published in February 2018, and we are beginning work to compile the next version of that report. We expect routine updates to recommended orientation and size models resulting from processing or reprocessing of various planetary datasets. These include the models for various bodies, such as Mercury, Venus, Jupiter, Saturn, the Saturnian satellites, Ceres, Comet 67P, Arrokoth, Bennu, and Ryugu. Improvements to the reference frames and orientation models for the Moon and Mars are also under consideration.

Our presentation will describe the current membership and operation of the WG, our ongoing invitation for new members to join, the numerous types of community requests that we respond to, and our increasing cooperation with other groups.

In recent years, the WG has been concerned that it is becoming over-extended, partially due to the increasing number and complexity of community inquiries, but also due to the increasing complexity of the rapidly expanding number of planetary datasets. Community input on that topic and on the topic of our recommendations is welcome. A discussion of the overall issues involved has been presented to the NASA Planetary Science “Decadal Survey” and at other venues. In the meantime, the WG has continued to make its efforts and activities known via its website (https://astrogeology.usgs.gov/groups/IAU-WGCCRE) and by various publications and community presentations. Further information on the WG’s activities and publications are given in our triennial and annual reports to the IAU, available from the main IAU WG website.

Monday 8 | 10:30–12:00 + 13:30–15:00 KST time

10:30–12:00 DivA-4 Session 4 - Reference Frames and Rotations

Abstract 1984

Advances and prospects in the accurate modeling of precession-nutation from VLBI solutions

Jose Manuel Ferrandiz[1], Santiago Belda[1], Maria Karbon[1], Sadegh Modiri[2], Alberto Escapa[1], Robert Heinkelmann[3], Daniela Thaller[2], Harald Schuh[4]

[1]UAVAC, University of Alicante, Alicante, Spain
[2]Department of Geodesy, Federal Agency for Cartography and Geodesy, Germany
[3]Department of Geodesy, GFZ German Research Centre for Geosciences, Germany
[4]GFZ German Research Centre for Geosciences, and Technische Universitat Berlin, Institute for Geodesy and Geoinformation Science, Germany

The celestial pole offsets (CPO), or deviations of the observed celestial intermediate pole with respect to the nutation IAU2000 and precession IAU2006 current theories, can be accurately determined only from VLBI data. Most CPO solutions compute the pair dX, dY, using a session-wise approach from each 1-day long observation “R” session. The weighted root mean squared (WRMS) of CPO time series is the most common measure of the accuracy of the a priori models.Improving such accuracy was urged by IAU Resolution B2 in 2021, and we address how that requirement may be implemented at short-term.

This presentation intends to exemplify to which extent the unexplained variance of CPO observed by VLBI can be reduced by the option of using some corrections to the precession and forced nutations models, including modifying the a priori in the solution computation. As an example, a suitable update of the precession offsets and rates of IAU2006 allows to reduce the WRMS of dX and dY from the IVS ivs19q4X combined solution in 1984-2021 from 173 and 174 μas to 153 and 159 μas, respectively. This is not the only chance of improving the accuracy of this precession theory. Moreover, the unexplained variance may be further reduced by introducing a suitable set of corrections to the IAU2000 nutation models, whose fit is over 20 years old but still provides the a priori standard to compute the nutations when analyzing VLBI data.

A complete revision of the nutation theory seems to be the best way of increasing accuracy and consistency with all the IAU current standards, but it is not feasible at the short term, given its complexity. The possibilities explored so far include partial re-fitting of the IAU2000 theory, meant as updating the MHB2000 transfer function but not second-order or oceanic effects among others, derivation of empirical corrections to the amplitudes of selected sets of astronomic periods, and also combinations of theoretical and empirical corrections.

Keywords: Precession-nutation, VLBI solutions, Earth rotation, reference systems

Abstract 1242

Sequentially Estimating and Updating Terrestrial Reference Frames

Richard Gross

Geodynamics and Space Geodesy Group, JPL, USA

The terrestrial reference frame (TRF) is the foundation for virtually all space-based and ground-based Earth observations. Positions of objects are determined within an underlying TRF and the accuracy with which objects can be positioned ultimately depends on the accuracy of the TRF.

The terrestrial reference frame is determined and maintained though a global network of ground sites with co-located SLR, VLBI, GNSS, and DORIS stations and is realized as the international standard through the ITRF (International Terrestrial Reference Frame). Requirements for the ITRF have increased dramatically since the 1980s. Today, the most stringent requirement comes from critical sea level programs: a global accuracy of 1.0 mm, and 0.1 mm/yr stability is required. This is a factor of 5 to 10 beyond current capability. Current and future satellites will have ever-increasing measurement capability and should lead to increasingly sophisticated models of the processes that they are observing. The accuracy and stability of the terrestrial reference frame needs to dramatically improve in order to fully realize the measurement potential of the current and future generation of Earth observing satellites.

Recent ITRFs have been produced at intervals of 3-6 years (ITRF2000, ITRF2005, ITRF2008, ITRF2014, ITRF2020). Between these realizations, users must rely on predictions of the motions of the reference stations that make-up the ITRFs. However, these predictions degrade with time leading to errors in products that depend on the ITRF. Updating the TRF more frequently would eliminate the need for multi-year predictions and hence eliminate this source of error in the TRFs.

JPL is developing a sequential estimation approach to realizing terrestrial reference frames. This approach, which was used at JPL to produce JTRF2014 and which is being used to produce JTRF2020, and which is particularly well-suited to the task of updating the TRF in a timely manner, will be described in this presentation.

Keywords: Terrestrial Reference Frame, VLBI, GNSS, SLR, DORIS

Abstract 694

Preliminary study on the consistency among hydrological angular momentum estimates determined from CMIP6 historical simulations

Jolanta Nastula[1], Justyna Śliwińska[1], Malgorzata Wińska[2], Tomasz Kur[1], Aleksander Partyka[1]

[1]ZGP, CBK PAN, Poland
[2]Faculty of Civil Engineering, Warsaw University of Technology, Poland

Polar motion (PM) is an essential parameter needed to transform coordinates between celestial and terrestrial reference frames, thus playing a crucial role in precise positioning and navigation. Geophysical interpretation of PM variations is an important, but still challenging task. Hydrological signals in particular are a source of uncertainty in the estimation of geophysical excitation of PM.

In this study, we use data obtained from sixth phase of the Coupled Model Intercomparison Project (CMIP6) to assess the impact of the continental hydrosphere on PM excitation. To do so, we exploit soil moisture and snow water variables taken from historical simulations of CMIP6 to estimate hydrological angular momentum (HAM) series. There is a wide variety of climate models delivered in the frame of CMIP6, which differ in terms of initial conditions, physical properties of atmosphere, oceans, hydrosphere, and climate forcing. Such divergences obviously contribute to the differences between various CMIP6-based HAM series. In order to determine how large the spread of results obtained from climate models can be, we study the consistency among CMIP6-based HAM with respect to the mean of all considered models. We will split initial set of 99 models into groups taking into account the course and amplitudes of estimated HAM series. We also evaluate various CMIP6-based HAM series with the use of hydrological signal in geodetically observed PM excitation. The general conclusion is that despite the large differences between the HAM series obtained from CMIP6, it is possible to choose the models that allow for quite reliable determination of HAM.

Keywords: Polar motion, Climate, EOP

Abstract 1254

Effects of the mass redistribution on the rotation of the Earth

Alberto Escapa[1], Tomas Baenas[2], Jose Manuel Ferrandiz[1]

[1]University of Alicante, Spain
[2]University Centre of Defence at the Spanish Air Force Academy, Spain

As a consequence of the tidal attraction of the Moon and the Sun the Earth suffers a redistribution of mass. In turn, such redistribution gives raise to an additional contribution to the Earth gravitational potential energy: the redistribution potential. In the last few years we have performed a comprehensively study of the influence of that effect on the Earth rotation — Baenas, Escapa, & Ferrandiz 2019, 2020, 2021 (published in A&A). These works address the precession, nutation, and secular changes in length of day.

In this talk, we present the framework employed to derive all such effects stemming from the redistribution potential. It is based on the Hamiltonian formalism and presents the advantage of leading to analytical formulae of the induced contributions. That is especially useful, since it facilitates the evaluation of the effects of different sets available for frequency-dependent Love numbers corresponding to solid and oceanic tides.

In this way, we compute the derived formulae using IERS Conventions 2010 frequency-dependent Love number set for solid tides (with oceanic load), and Williams & Boggs (2016) correction to account for the direct contribution of the oceans. Secular length of day variation is in very good agreement with recent observational values.

The obtained numerical values for precession and nutation, however, show significant discrepancies with those of IAU2006 and IAU2000 standard models. This fact must be considered in the revision of IAU models of precession and nutation. In addition, due to the magnitude of the contribution related to the ocean and for keeping consistency, the ocean model adopted in IERS and GGOS Conventions should be the same as that used in the development of precession and nutation theories.

Keywords: Precession, nutation, length of day, rotation of the Earth, celestial mechanics, reference systems

13:30–14:20 DivA-5 Session 5 - Highlights of Focus Meetings

Abstract A6

Highlights of IAU Focus Meeting FM8:
"Planetary Astronomy via Telescopic and Microscopic Approaches"

Masateru Ishiguro (Seoul National University, Korea), Hong-Kyu Moon (KASI, Korea), Maria Antonella Barucci (Observatoire de Paris, France), Ricardo A. Gil-Hutton (UNSJ, Argentina), Makoto Yoshikawa (ISAS/JAXA, Japan), Beth Ellen Clark (Ithaca College, USA), Karri O. Muinonen (Univ. Helsinki, Finland), Hikaru Yabuta (Hiroshima Univ., Japan), Amanda A. Sickafoose (SAAO, South Africa), Young-Jun Choi (KASI, Korea), and Jeong-Eun Lee (Kyung Hee Univ., Korea)

We have 12 invited and 31 contributed presentations on the planetary systems, from planet formations to the present solar system, using various techniques.

There are three invited talks on the link between star-forming regions and the present planetary systems. Dr. Y. Aikawa talks about the chemical link between protostellar cores, protoplanetary disks, and the Solar System's small objects based on theoretical studies of chemical reactions. Dr. Maria Drozdovskaya describes her picture of the origin of cometary volatiles and their implications for the chemical processes during star formation based on the recent findings of complex organic molecules in several comets. Dr. W. Kwon introduces their research on grain growth at the early stage of YSOs.

Three invited talks report on space explorations. Dr. D. Lauretta presented scientific findings from the OSIRIS-REx mission to the asteroid Bennu. Dr. S. Watanabe reports on the recent findings of Hayabusa2 and suggests that the parent body of the target asteroid Ryugu may have originated beyond the CO2 and NH3 snow line. Dr. T. Arai introduces the scientific importance of the near-Sun asteroid Phaethon, which will be explored in the late 2020s.

Three invited talks focus on the evolutionary processes in Solar System. Dr. P. Michel reviewed the impact process on small bodies based on recent spacecraft observations and numerical simulations. Dr. B. E. Clark overviews the space weathering process on the dark C-complex asteroid Bennu. Mr. J. Beniyama introduces their recent study of tiny asteroids and their evolution of physical status.

Three invited talks review research by a variety of methods. Dr. M. A. Barucci reviews the observational history of small solar-system objects from light points to micro-particles and summarizes various recent findings. Dr. I. Belskaya provides a comprehensive review of asteroid polarimetry. Finally, Dr. Tachibana provides an overview of the initial analysis results of the Ryugu sample.

Abstract 3459

Highlights of IAU Focus Meeting FM10: " Synergy of Small Telescopes and Large Surveys for Solar System and Exoplanetary Bodies Research"

Anatoliy Ivantsov[1], William Thuillot[2]

[1]*Royal Observatory of Belgium, Belgium*
[2]*Paris Observatory, France*

This Focus Meeting is promoting the complementarity of large astronomical surveys and astronomy performed with small telescopes (up to 2 m in diameter). It concerns, in particular, the application of big data methods to modern and past sky surveys, to data archives of small telescope. Machine learning and, in particular, deep learning are used for the classification of exoplanets, enhancing and optimising their follow up observations (TESS). Contemporary and prospective sky surveys (Gaia, LSST, etc.), radar, space-borne data allow to use these highly accurate measurements for calibrating data measured at the small telescopes, revealing their potential in planetary science in the time-domain. We discuss the differential method used at the small telescopes in astrometry, photometry, polarimetry, spectroscopy to complement the scientific output of the sky surveys, e.g., to follow up the newly discovered Solar System objects and exoplanetary systems, expand their physical characterization to different wavebands and properties. Extension of observational histories will positively affect checking the adequacy of various physical and dynamical models, e.g. finding a single solution for the rotation parameters of asteroids that satisfies different observational datasets. The big data methods applied to the sky surveys and small telescope archives have the potential to detect new objects, and to improve classification and data analysis. Data mining sky surveys, astrophotographic plates, and the small telescope archives should substantially increase the completeness of search for the time-domain events. Sharing this experience and advanced observational techniques will enlarge efficiency and facilitate using the small telescopes in conducting the present-day research in Astronomy.

Abstract 3458

IAU Focus Meeting FM7: “Astrometry for 21st Century Astronomy”

Anthony Brown

[1]*Leiden Observatory, Leiden University, The Netherlands*

High accuracy astrometry has made spectacular progress over the past decade thanks to developments in VLBI techniques, the appearance on the scene of the GRAVITY instrument, and the giant step taken with the Gaia mission in the quality and depth of its astrometric survey. High accuracy astrometric data is now indispensable across astronomy disciplines and in solar system science. With this focus meeting we wish to highlight the scientific progress based on these astrometric data and bring together the various astrometry and sky survey communities; to learn from each other, explore opportunities for coordination and map out the synergies between astrometry and other techniques and surveys, aiming to maximize the scientific outputs. The IAU GA is the natural venue to bring the communities together and the timing is right, one year after the appearance of the early part of the third Gaia release, three years after the adoption of the ICRF-3, five years into GRAVITY operations, and on the eve of the era of LSST and extremely large telescopes.

Topics are:

Review of modern astrometry and its science applications

Astrometry science highlights, including from Gaia DR2 and Gaia (E)DR3

Future ground and space-based astrometric surveys

Dense and accurate reference frames to optimize the science return from extremely large telescopes and large sky surveys

Astrometric techniques; opportunities for cross-fertilization

Synergies between astrometric, photometric, and spectroscopic surveys

Abstract 3460

Division A Working Group on Astrometry by Small Ground-Based Telescopes (ASGBT)

Anatoliy Ivantsov[1], Marcelo Assafin[2], William Thuillot[3], Working Group ASGBT members

[1] *Royal Observatory of Belgium, Belgium*
[2] *Federal University of Reo de Janeiro, Brazil*
[3] *Paris Observatory, France*

Since the Working Group setup 2006 its goal is disseminating information about the current astrometric programmes and activities carried out with small telescopes (up to 2 m in diameter), distribute the related news, facilitate collaboration and help for coordination of the activities in astrometry from ground-based telescopes. The small telescopes being numerous and geographically widely spread are easily accessible and efficient for observation in networks. The WG members are currently focused on the various projects that get benefits from both direct astrometric measurements of Small Solar System bodies and indirect measurements via photometry of mutual events of natural satellites. Follow up observations of asteroids discovered by the Gaia satellite (Gaia Follow Up Network) are highly necessary for improving their initial orbits and maintaining the discoveries. Astrometry of the optical counterparts of ICRF sources measured at the long-focal telescopes points at the structure, variability of these sources. Digitisation of the photographic archives with high resolution and accuracy supported by the Gaia catalogue data allows to redo the past measurements limited only by the instrument specific errors. We emphasise the efficiency of small telescopes for making astrometric measurements that satisfy the contemporary requirements for getting new discoveries, and encourage visiting the dedicated webpage at https://iau_wgnps.imcce.fr .

Abstract A11

Commission A4 Celestial Mechanics and Dynamical Astronomy

Christos Ephtymiopoulos[1], Giovanni F. Gronchi[2]

[1]*University of Padua, Italy*
[2]*Università di Pisa, Italy*

In recent years, the commission A4 on "Celestial Mechanics and Dynamical Astronomy" has focused on supporting activities and events which underline the links between the historical theoretical development of Celestial Mechanics and modern applications in our Solar System dynamics, the understanding of extrasolar planetary systems, astrodynamics and dynamical systems theory. The presentation will give a short summary of these activities as well as of future prospects of collaboration between A4 and the other commissions of Division A.