Book of Abstracts

IAU

IAU Symposium 401

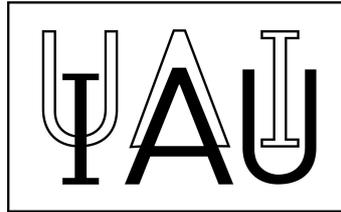# Advancing Reference Systems, Ephemeris, and Standards

From the Earth and the Moon to Solar System Bodies

August 4-9, 2025

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Preface

The International Astronomical Union (IAU) symposium "Advancing Reference Systems, Ephemeris, and Standards: from the Earth and the Moon to Solar System Bodies" —IAUS 401 (https://iaus401.fcaglp.unlp.edu.ar)— was held in a hybrid format on August 4 to 9, 2025 at the National University of La Plata (UNLP), La Plata (Argentina).

It was a joint proposal of IAU Commissions A2 Rotation of the Earth, A3 Fundamental Standards, and X2 Solar System Ephemerides; and the Working Groups Time Metrology Standards and Cartographic Coordinates & Rotational Elements.

Reference systems and their standardization are of paramount importance to many fields of astronomy. Some examples are the reduction of ground-based observations, space astrometry, astrophysics missions, and space missions to solar system planetary bodies and beyond.

The concept of a reference system and its realization requires the convergence of reference frames, ephemeris, and time scales to be developed respecting associated standards, thus fulfilling one of the IAU strategic goals as the provider of astronomical standards and their use.

The outlined subjects were structured in the science sessions: (1) Earth rotation models and Earth Orientation Parameters (EOP); (2) Celestial and terrestrial reference systems/frames; (3) Reference systems/frames for the Moon and other solar system bodies; (4) Time scales and time metrology; (5) Ephemerides of solar system objects; and (6) Astronomical standards.

In this Book of Abstracts, we have compiled the abstracts of the plenary lectures, invited contributions, and oral and poster presentations that were contributed to IAUS 401.

Finally, we would like to give special thanks to all the participants of IAUS 401, as well as the organization of the Scientific Organizing Committee; the Local Organizing Committee; and the support of IAU, Faculty of Astronomical and Geophysical Sciences (FCAG), UNLP, CONICET, Asociación Argentina de Astronomía, Fundación Williams, and Kavli Foundation.

Alberto Escapa and Laura Fernández

Contents

PLENARY TALKS

Earth rotation and reference frames

Schuh H.[1][*], *Heinkelmann R.*[2]

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Since the late 1970s, space geodetic techniques have been used to measure Earth orientation parameters (EOP). VLBI (Very Long Baseline Interferometry) is the only method capable of observing all five EOP in terms of polar motion, UT1-UTC, and celestial pole offsets without external information. The EOP link the station coordinates given in the ITRF (International Terrestrial Reference Frame) to the sky-fixed system of extragalactic radio sources, the ICRF (International Celestial Reference Frame), which is typically implemented using VLBI observations of AGN (Active Galactic Nuclei). All satellite techniques, such as SLR (Satellite Laser Ranging), GNSS (Global Navigation Satellite Systems) and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) are suitable for highly accurate measurements of pole coordinates and length-of-day (lod) that corresponds to the temporal rate of UT1-UTC. Today, EOP are determined using combined solutions of the above-mentioned space geodetic techniques, with various approaches possible: combining the results of the individual techniques, combination at the normal equation level, or combination at the observation equation level. The operational results of EOP can be compared with more recently developed and established methods such as LLR (Lunar Laser Ranging) and ring laser measurements. The latter use a completely different concept: instead of being connected to targets outside of the solid Earth, as with VLBI and satellite techniques, local sensors are used to measure the Earth's variable rotation rate via laser beam and the Sagnac effect. New developments in Earth rotation observation will be presented such as current ring laser observations and future satellite missions as for instance the ESA satellite GENESIS, which will enable the co-location of the main four space geodetic techniques (VLBI, SLR, GNSS, DORIS) in space. This will be complemented by simulations of satellite constellations and network configurations.

Acknowledgements

(EOP) and international reference frames

Participation: In person

Challenges of time metrology

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on behalf of the CCTF task force and task groups dedicated to presented topics

In close cooperation with the BIPM Time department, the Consultative Committee for Time and Frequency (CCTF) is working on "hot topics" corresponding to current and future challenges of time and frequency metrology. The presentation will provide an overview of the CCTF activities and will address especially the following topics:

- Redefinition of the second - Since 1967, the definition of the second is based on a transition of the caesium atom. The best accuracy of primary frequency standards realizing the second is today at 10-16 but, in the last 10 years, optical frequency standards demonstrated a relative frequency accuracy of 10-18. The debate on the possible options for the redefinition of the second is thus very much alive and mandatory criteria (on optical frequency standards and their contribution to international time scales, on time & frequency transfer techniques, etc.) to be fulfilled before the redefinition have been fixed [1].

- Continuous UTC - The CCTF is strongly involved in an important evolution of the international time standard UTC to enlarge the maximum limit of UTC-UT1 beyond one second, in order to ensure the continuity of UTC for at least 100 years. This new process is expected to come into force in or before 2035, with a current evaluation of the probability for the occurrence of a negative leap second in the next decade, leading to an exceptional situation that has never been experimented before [2].

- Promotion of the mutual benefit of UTC and GNSS - The aim is to improve the collaboration with the providers and users of GNSS highlighting the mutual benefits for navigation and time metrology in applications such as time transfer, interoperability, and traceability to UTC through the GNSS broadcast information [3].

- Reference time for the Moon – Current discussions and activities aim at defining a Lunar reference time, traceable to UTC, to ensure the

interoperability of the systems for Positioning, Navigation and Timing (PNT) in a cislunar environment.

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[3] Defraigne, P. et al (2022). Achieving traceability to UTC through GNSS measurements. Metrologia, 59 064001.

Participation: In person

The importance of high-precision astrometry in the orbit determination and ephemeris computation for small bodies

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The orbit determination process for natural Small Solar System Objects relies for the most part on optical astrometry obtained by ground-based telescopes. In this context, the word "astrometry" is typically intended as the determination, from astronomical images, of four basic sets of quantities: the absolute coordinates of an object in the plane of the sky, the time corresponding to that observation, the spatial location of the observer, and an estimate of the uncertainties on all the numbers above.

Although the basic process behind these measurements has remained nearly unchanged for decades, recent developments have greatly improved the quality of the astrometric data that we can produce, enabling new applications for this information.

In this talk, we will briefly present some of these recent techniques and resources, discuss how they are being adopted in the community of small body observers, and highlight some challenges that still remain in the field.

We will also present a few recent cases where high-precision astrometry has played a significant role in our understanding of small bodies, both from a scientific perspective and as a basis for understanding the impact threat to our planet posed by these objects.

Participation: In person

Building on the Legacy of Astronomical Standards

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International cooperation and collaboration on astronomical projects of various kinds followed the improvements in communication and travel that rapidly advanced during the late 19th and early 20th centuries. The history of international astronomical standards probably dates to the International Meridian Conference in 1884 in Washington and the Paris Conference of 1896. The formation of the IAU in 1919 institutionalized international cooperation in astronomy.

Before the midpoint of the 20th century, only a few organizations worldwide, mostly the national observatories, had the capabilities to compute and distribute the data for fundamental astronomy, such as the celestial coordinates of the Sun, Moon, and planets; sidereal time; eclipse circumstances; apparent places of stars; the data needed for celestial navigation; and precise time. The situation changed after World War II as electronic computers became available at scientific institutions and more precise observational techniques were invented, some involving spaced-based instruments. As many common astronomical computations became more "democratized" in the latter part of the 20th century, IAU standards, as well as those from other institutions, such as the IUGG and IERS, of necessity became more comprehensive and detailed, covering time scales, constants, reference systems, Earth orientation models, and the implementation of relativity in various astronomical computations.

Thus, the evolution of astronomical standards traces the major advances in observational technology, theoretical sophistication, and computing power that have defined our science for the last century.

Participation: Online

SESSION 1: Earth rotation models and Earth Orientation Parameters (EOP)

INVITED CONTRIBUTION

Lights and shadows on the resonant modes of the Earth rotation axis

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Resonant free modes are of primary important for understanding the terrestrial and celestial oscillations of the rotation axis of a non-rigid Earth. In this talk we present the state of the art of their observation and modeling. We show how mass transports taking place in the hydro-atmospheric layer allows to reconstruct Chandler wobble from the 1950's, and account in particular for its minimum observed since the 2020. In contrast, the irregularities of the free core nutation remains largely unexplained. Until now, diurnal circulation in the atmosphere and oceans seems to have been powerless, and we shall give the last results in this respect. Finally we shall explore the existence of a supplementary polar motion resonance caused by the inner core.

Participation: Online

INVITED CONTRIBUTION

Interannual changes in length-of-day driven by a hydromagnetic core waves inside the fluid outer core

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Variations in Earth rotation rate defined by length-of-day (LOD) on the intradecadal scales present two primary period (i.e., 6yr and 8.6yr) oscillations, the physical mechanisms for them are still uncertain. Based on the core surface flow data inferred from modern satellite magnetic observations for 1999 to the present, we calculate the electromagnetic torque exerting on the mantle from core flow motions and show that the torque also presents the same two period oscillations, providing new evidence to show that intradecadal LOD oscillations are driven by the core motions. Using the purely geostrophic core flow model described in the framework of torsional waves, this work shows that the predicted 6yr LOD result coincides well with the observation, while the observed 8.6yr LOD oscillation cannot be satisfactorily explained by this model due to the existing phase difference with ~ 2 years. This work further develops the novel model of LOD changes attributed to the quasi-geostrophic magneto-Coriolis (QG-MC) waves, suggesting that the QG-MC wave modes with cylindrical radial wave number ~ 4.8 and quality factor $Q \sim 16$ can provide a nice explanation for the 8.6yr LOD oscillation (including both amplitude and phase) and providing a new approach to infer the information of core dynamics via LOD changes.

Participation: In person

INVITED CONTRIBUTION

Achievements, needs and prospects of updating the standards, theories and models of the Earth's rotation

Ferrándiz J. M.[1*]*, Escapa A.*[2]*, Karbon M.*[1]*, Belda S.*[1]*, Baenas T.*[3]*, Huang C.-L.*[4]*, and Liu J.-C.*[5]

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Over the last decade, the IAU and the International Association of Geodesy (IAG) have organised successive Joint Working Groups (JWGs) to improve the theories and models of the Earth's rotation. Their reports revealed inconsistencies and obsolescence of the standard theories and models, and some of underlying concepts, and led to the 2019 IAG and 2021 IAU Resolutions [1] encouraging their improvement in terms of accuracy, consistency, and better adaptation to present knowledge of the actual Earth.

The current IAU/IAG JWG on Consistent Improvement of Earth's Rotation Theory (CIERT) is addressing this problem with a particular focus on the theories of precession and nutation (PN). Improving consistency requires that all components of theories and analyses of observational data refer to and use identical reference frames, basic and ancillary Earth models and parameters. In contrast, these in the official PN theories are over 20 years old and do not meet the current standards. Worse, the three main components of these theories are inconsistent with each other regarding underlying geophysical models, free Earth oscillation modes, and some fundamental parameters: e.g. the dynamical ellipticity in IAU2006 is a linear function of time, while in IAU2000 it is a constant whose value needs updating; moreover, the planetary nutations are still a rigid-Earth solution, unlike the lunisolar ones.

This presentation reports on the main achievements of several JWG mem-

bers and their advantages and limitations, focusing on those more consistent and capable of drastically reducing the unexplained variance of the determined celestial pole offsets in the short term.

References

[1] 2021 IAU Resolution B2: "on the improvement of the Earth's rotation theories and models"

Participation: In person

INVITED CONTRIBUTION

Prediction of Earth Orientation Parameters – achievements, challenges, and future perspectives

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Accurate observations of Earth orientation parameters (EOP) are essential for carrying out various operational tasks, including communication with spacecraft, orientation of astronomical instruments, and ensuring precise navigation and positioning. Many operational tasks require real-time knowledge of EOP, but such information is impossible to obtain due to delays caused by the time needed to process observational data from various techniques. Therefore, many institutions worldwide, including the International Earth Rotation and Reference Systems Service (IERS), develop EOP forecasts and make them available to the community.

Over the last decade, significant progress has been made in processing EOP observations, developing new forecasting methods, and understanding the role of Earth's surface fluid distribution in EOP variability. The number of teams involved in EOP prediction has also increased, with different teams applying various input data, forecasting algorithms, and prediction horizons. As a result, clear differences have emerged in the accuracy of individual predictions.

This presentation will summarize the latest achievements in EOP forecasting, particularly the outcomes of the recently concluded 2nd EOP Prediction Comparison Campaign, conducted under the auspices of IERS. We will show the current accuracy achievable in EOP forecasting and highlight the most optimal forecasting approaches (prediction methods and observational data). The challenges and future perspectives for obtaining more reliable and timely forecasts will also be discussed.

Acknowledgements

Participation: In person

Contributions to the Earth's rotation due to tidal mass redistribution

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The mass redistribution of tidal origin is due to the gravitational attraction exerted by the Moon and the Sun on the Earth. This redistribution modifies the potential energy of the mechanical system, thereby affecting the Earth's rotation. In recent years [1–3] we have derived analytical formulae to quantify and describe the contributions of this process to precession and nutation motions, as well as to the secular changes in the length of day (LOD).

A key component of this calculation is the modeling of the Earth's deformation. It relies on the Love numbers theory —more specifically, on complex Love functions—, which depend on the frequencies arising from a Fourier-type decomposition of the Earth's anelastic response. Consequently, the numerical evaluation of our formulae requires standardized datasets that provide the corresponding Love numbers for each perturbing frequency.

We review the procedure necessary to obtain analytical expressions for the precession, nutation, and secular changes in LOD. This is accomplished through the Hamiltonian formalism of the non-rigid Earth rotation. The numerical value of the amplitudes and rates are obtained by using the Love number sets corresponding to solid Earth tides (IERS Conventions 2010) and direct ocean tides [4]. The results show that both sets must be considered given nowadays current accuracy requirements. These findings underscore the importance of integrating all relevant tidal contributions into a unified and updated framework.

Acknowledgements

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[3] Baenas, T., Escapa, A., Ferrándiz, J.M. (2021). Secular changes in length of day: Effect of the mass redistribution, A&A 648, A89.

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Contribution type: Poster presentation
Participation: Online

Next-Generation Celestial Pole Offset Prediction

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The growing reliance of modern society on geodetic applications—with stringent demands for precision and long-term stability—underscores the critical role of accurate Earth Orientation Parameter (EOP) predictions. These parameters form the backbone of the Global Geodetic Observing System (GGOS) under the International Association of Geodesy (IAG), enabling reliable alignment between the International Celestial Reference Frame (ICRF) and the International Terrestrial Reference Frame (ITRF). Accurate EOP predictions are thus vital for a wide range of applications including satellite orbit determination, autonomous navigation, precision agriculture, and timing systems.

Among EOPs, the Celestial Pole Offsets (CPO) remain a challenge, as their accurate determination relies exclusively on Very Long Baseline Interferometry (VLBI) observations. CPO comprise the Free Core Nutation (FCN), long-term trends, harmonics induced by deficiencies in the IAU 2006/2000A precession–nutation model, geophysical excitations, and observational noise.

In this work, we advance the prediction of CPO by integrating updated precession-nutation models, newly estimated FCN representations, and modern machine learning techniques. The FCN models are derived from high-precision VLBI observations using refined parametrization strategies that capture the complex geophysical dynamics more accurately. Furthermore, machine learning algorithms are employed to model residual patterns and nonlinear behaviors in the CPO time series, enhancing short- and mid-term predictive capabilities. This hybrid approach bridges empirical modeling with data-driven insights, resulting in substantial improvements in prediction accuracy and contributing to the long-term stability and precision goals set by GGOS.

Acknowledgements

Contribution type: Poster presentation
Participation: Online

EOP determination using VLBI at IGN ARGENTINA

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Very Long Baseline Interferometry (VLBI) is an important technique in Space Geodesy, making innovative use of radio telescopes to observe distant quasars that emit strong radio waves. The signals received at multiple antennas are recorded and compared to determine time delays, which, combined with geometric models, allow precise calculation of the baseline between them. Multiple observations improve the accuracy of antenna positions and enable real-time determination of Earth Orientation Parameters (EOP). With the establishment of the Argentine-German Geodetic Observatory (AGGO), Argentina has acquired the infrastructure to contribute to the global VLBI network. In this context, the Center for Research in Applied Geodesy (CIGA) of the National Geographic Institute (IGN) incorporated VLBI into its core geodetic activities. Since April 2020, IGN has served as an associated analysis center of the International VLBI Service for Geodesy and Astrometry (IVS). It delivers daily SINEX files containing 24-hour EOP estimates and station coordinates. These contributions adhere to international standards for integration into IVS combinations and are produced using the scientific software VieVS, developed by the University of Vienna. In this presentation, we provide a comparative analysis of our EOP estimates with respect to those from other recognized IVS Analysis Centers and the International Earth Rotation and Reference Systems Service (IERS). The comparison includes daily solutions from 2014 onward, and global solutions based on this extended time series. The main objective of this analysis is to perform quality control on our products and to validate the accuracy and consistency of our results.

Contribution type: Oral presentation
Participation: In person

Non-rigid contributions to the value of the dynamical ellipticity of the Earth

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The dynamical ellipiticity of the Earth H plays a central role in the Earth precession and nutation motions. Its current standard value comes from IAU 2006 precession model and is incorporated in IERS Conventions (2010).

A common approach to determine H numerically relies in consider just the precession of the Earth, since the available analytical models are more complete than the nutation ones. It entails that it is required to determine the second order contributions to the general precession in longitude, as done originally in Kinoshita & Souchay (1990).

A part of such precession contributions is due to the non-rigid nature of the Earth. Specifically, nutation-nutation crossed terms —second order terms in the sense of perturbation theories — comes from the lunisolar torques and are sensible to the fluid core and elasticity of the Earth [1]. In turn, mass redistribution of tidal origin contributes to the precession, also depending in the Love numbers values for the solid Earth and the oceans [2]. Both of them are absent in the derived value of H in IAU 2006 precession model.

Following the Hamiltonian approach, we present the basic guidelines in computing H considering those non-rigid effects [3] and provide an updated value. Our approach also allows to fix neatly the tidal system tide-free, zero-frequency, and mean tide in which H is provided, a question hitherto omitted but necessary considering nowadays needs of consistency.

Acknowledgements

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Contribution type: Oral presentation
Participation: In person

Effect of a Non-Hydrostatic Core-Mantle Boundary on Earth's and Mars'Rotational Dynamics

Folgueira-López M.[1*], *Dehant V.*[2,3], *Puica M.*[4], *Brekier J.*[2], *and Van Hoolst T.*[2]

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Dynamic loads within planetary mantles can deform the core-mantle boundary (CMB). On Earth, subducting slabs primarily induce degree-2, order-2 deformation of the CMB, though additional degrees arise when expanded in spherical harmonics [3]. Nutations, observed through Very Long Baseline Interferometry (VLBI), and variations in the Length of Day (LOD) are measured with high precision. While the first-order effect of Earth's non-hydrostatic flattening significantly contributes to nutation amplitudes, we focus here on second-order effects.

We compute the pressure torque acting on an irregular CMB, which can perturb both nutations and LOD. For nutations, topographic effects are generally small, as they are proportional to the product of two topography coefficients—except in cases of resonance, where the tidal frequency is close to an inertial wave frequency. We identify three such cases, though none lead to nutation amplifications exceeding 2 microarcseconds. This finding definitely excludes topographic pressure as an efficient mechanism to explain nutations. For LOD, we find significant amplification near specific resonances: the tide at 13.633 days is quite close to an inertial wave at 13.614 days, and the tide at 27.555 days to an inertial wave at 27.666 days, both resulting in an amplification of 0.06 milliseconds, at the level of the observed residuals.

We also assess the effects on Mars but find that its tidal and nutation frequencies do not come sufficiently close to the determined inertial wave frequencies, leading to negligible resonance effects.

Acknowledgements

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Contribution type: Poster presentation
Participation: In person

Assessment of Earth orientation parameters from K-band VLBA sessions until 2025

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The K-band Astro2Geo Very Long Baseline Interferometry project has initiated regular 24-h sessions conducted by the Very Long Baseline Array (VLBA) at 24 GHz since 2016, with the primary goal to refine the precision and accuracy of the celestial reference frame at K-band frequency. Each of the ten VLBA telescopes consists of a 25 meter parabolic dish antenna, and is strategically placed on the US territory. Therefore, the observing sessions are generally suitable for estimation of all five Earth orientation parameters (EOP).

Based on our previous studies, for example, [1, 2], we present an update of the EOP estimates that includes the most recent K-band sessions. We carry out comparisons with EOP estimated from traditional S/X measurements divided into separate groups based on the station network geometry and project purpose. We show, that the precision of the EOP estimates from VLBA sessions observed within the K-band Astro2Geo project is comparable with astrometric USNO-CRF sessions observed with VLBA at S/X band since 2018.0. In addition, a comparison is made with the combined IERS C04 series and extensive statistics are presented.

Acknowledgements

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Contribution type: Poster presentation
Participation: Online

Re-Understanding of the Earth Polar Motion with Complete Solution of Liouville Equation

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The traditional solution of the Liouville equation which defines the relationship between the variation of Earth's polar motion and the excitations is only an approximation and not valid for high frequency (e.g., sub-diurnal band) polar motion. Here, we present a new and complete solution of the Liouville equation (CLE), from which we try to re-understand the geophysical excitations on the polar motion in whole frequency band. We will also present some new insights into the characteristics and excitation mechanism of the Chandler wobble derived from CLE, which is important for polar motion prediction.

Acknowledgements

Contribution type: Oral presentation
Participation: Online

A data – driven multichannel prediction of celestial pole offsets

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In this contribution, we introduce a methodology aimed at improving the accuracy of Celestial Pole Offsets (CPO; dX, dY) predictions, with a particular focus on short-term forecasts (up to 30 days). The prediction algorithm is tailored for the simultaneous analysis of multichannel data, meaning the data collected from multiple sources (e.g., several sensors measuring the same parameter; here CPO time series provided by different institutions). We use IERS EOP final data, along with data published by JPL, as the input for the prediction procedure. The core of the prediction algorithm is based on the principle of Dynamic Mode Decomposition (DMD), but due to the multidimensional character of the algorithm all operations are tensor-based.

The prediction procedure is consistent since it does not depend on external data to fill any latency gaps in the IERS and JPL products. Instead, this is managed within the prediction routine by extending the forecast horizon to include both the gap-filling and proper forecast horizons. As a result, the methodology is fully operational and well-suited for real-time applications.

We evaluated this approach against the results obtained within the course of the 2nd EOPPCC as well as in 100 successive yearly trials covering 10 years (01.01.2014 – 01.01.2024) to assess prediction capabilities of the newly introduced methodology in a long run. The latter mentioned was performed for series consistent with different reference frames, i.e., IERS EOP 14 C04 and IERS EOP 20 C04. The results indicate that the method is at the forefront of current CPO forecasting methods.

Acknowledgements

Contribution type: Oral Presentation
Participation: Online

Improvement of the IAU 2006 precession model with an updated Earth's J_2 long-term variation

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At its 2006 General Assembly, IAU has adopted a standard precession theory, called the "IAU 2006 precession". The linear variation of the Earth's dynamical flattening J_2 was considered for the precession rate in longitude. However, the uncertainty in the J_2 model is one of the greatest sources of uncertainty in this precession theory. In this report, we use the latest observational data from the satellite laser ranging (SLR) to investigate the effect of J_2 long-time variations in solving the precession of the equator. The polynomial expressions for precession quantities are developed with a method similar to the IAU 2006 approach and are checked using the latest VLBI observations. The newly developed precession solution is clearly more consistent with VLBI observations and can reduce most of the curvature signals in the CPO series. Since the improvement relative to the IAU 2006 precession model is quite significant, we propose that a serious study for updating the IAU precession be carried out by relevant IAU Working Groups.

Acknowledgements

Contribution type: Oral presentation
Participation: In person

Analysis of polar motion excitation using C21 and S21 coefficients from GRACE, SLR and hybrid solutions

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Hydrological angular momentum (HAM) is used to quantify the effect of mass changes in the continental hydrosphere on variations in polar motion (PM). It plays a key role in understanding the links between Earth system processes and changes in the planet's rotation. In this study, we analyze HAM time series computed from various Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) solutions, satellite laser ranging (SLR) data, as well as hybrid datasets combining SLR and GRACE/GRACE-FO solutions. Our results show that most HAM series derived from hybrid solutions closely match the hydrological signal observed in geodetic PM excitation (GAO). HAM derived from hybrid solutions generally performs similarly to, or better than the series based on single GRACE/GRACE-FO or SLR solutions. For seasonal oscillations, the agreement between HAM and GAO is similar for both combined and single-technique solutions, while hybrid datasets show greater consistency in the non-seasonal spectral band. We find strong correlations between GAO and HAM from combined solutions for non-seasonal short-term variations (around 0.6) and non-seasonal long-term variations (around 0.9). These results highlight the significant potential of hybrid data for analyzing PM excitation, especially in the non-seasonal spectral band. The undeniable advantage of hybrid solutions compared to GRACE/GRACE-FO data is their significantly longer observation time series and the fact that their quality does not experience periodic declines as significant as those observed for GRACE/GRACE-FO.

Acknowledgements

Contribution type: Oral presentation
Participation: In person

Length of Day and geomagnetic field asymmetry: an observed correlation for the last three millennia.

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The length of day (LOD) and the geomagnetic field are two geophysical phenomena closely linked to the dynamics of Earth's outer core. Fluid motion in the Earth's outer core drives variations in both the geomagnetic field and the core's angular momentum [1]. While this relationship has been extensively studied at decadal and interannual scales, the evolution of the geodynamo unfolds over much longer periods [2]. This study focuses on the millennial scale variations. Reconstructed LOD changes from ancient records of eclipses [3,4] reveal an oscillatory component with a periodicity of approximately 1300 years and 4 ms of amplitude which cannot be explained by tidal effects, glacial isostatic adjustment or the ocean and atmospheric dynamics [5]. Our analysis indicates that the non-tidal fluctuations in the LOD are correlated with the paleosecular variation of the Earth's magnetic field over the last three millennia. In particular, LOD maxima occur when the eccentric dipole shifts towards the Pacific region, signature of a more asymmetric geomagnetic field, while the geocentric dipole becomes more axial. Conversely, LOD minima correspond to a more centred eccentric dipole and a more tilted geocentric dipole towards Atlantic region. These results provide new insights into the coupling between Earth's rotation and geomagnetic field variations on millennial timescales.

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Contribution type: Poster presentation
Participation: In person

A novel approach for direct estimation of the instantaneous Earth rotation velocity

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Very Long Baseline Interferometry (VLBI) measures two standard observables: group delay and fringe frequency (delay rate). While the group delay is widely used to estimate a large set of geodetic and astrometric parameters, the fringe frequency has been largely ignored to date. However, the fringe frequency is a unique tool for direct estimation of the instantaneous Earth angular rotation velocity which is not accessible with the group delay alone. This study aims to estimate the magnitude of the Earth angular rotation velocity and, in addition, daily estimates of X and Y angles (celestial pole offset) linking the Celestial Instantaneous Pole (CIP) and the International Celestial Reference System (ICRS) pole. Least squares method is applied for analysis of the fringe frequency from the routine geodetic VLBI observations since 1993 (IVS-R1, R4 programs). Three components of the Earth rotation vector are estimated with a formal error of 1 $prad/s$ or 10^{-8} in relative units, or even better, if a large international VLBI network is at work. Using the newly obtained values one could 1) monitor the Earth rotation irregularity in parallel to the traditional length-of-day (LOD) values; and 2) assess the modern precession-nutation theory directly.

Contribution type: Oral presentation
Participation: In person

NTSC's activities on UT1 measurements and Earth Rotation Studies

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The Earth Orientation Parameters are a set of parameters that describe the Earth rotation's statement and bridge the Celestial and Terrestrial Reference frame. EOP services are of importance for a wide range of applications in astronomy (astrometry and astronnomical instruments orientation), in geodesy (Positioning and navigation on the Earth's surface and in space), and in operation of deep space missions (Lunar and Mars explorations). 3 out of 5 EOP parameters, including the Universal Time (UT1) and the Celestial Pole Offsets (dX, dY), can only be determined by very long baseline interferometry (VLBI) observations. The Length of Day variations (ΔLOD) and Polar motions (PMX, PMY) can also be determined by other 3 space geodetic techniques, including the satellite laser ranging (SLR), the Global Navigation Satellite System (GNSS), and the Doppler orbitorgraphy and radiopositioning integrated by satellite (DORIS), all of which use artificial satellites as target.

In the aim to keep the Earth Rotation time scale UT1, recently, the national time service center of Chinese Academy of Sciences built a team dedicated for UT1 measurements and services [3]. Currently, we operate a domestic VLBI network [1], data center and analysis center of the international GNSS Monitoring and Assessment System (iGMAS), and 3 SLR stations. Studies on software development, EOP combinations [4], EOP predictions [2] and Earth Rotation variation theory are also in progress. Here we report our recent activities on UT1 measurements and Earth rotation studies.

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Contribution type: Oral presentation
Participation: In person

SESSION 2: Celestial and Terrestrial reference systems/frames

INVITED CONTRIBUTION

The International Terrestrial Reference System (ITRS) realization ITRF2020 and its update

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According to the International Union of Geodesy and Geophysics (IUGG) 2007 and 2019 resolutions, the International Terrestrial Reference System (ITRS) is the preferred Geocentric Terrestrial Reference System (GTRS) for scientific applications. Its realizations, the International Terrestrial Reference frames, are the standards for positioning, satellite navigation and Earth Science applications. They are built on international cooperation over more than three decades for the benefit of global geodesy, geodynamics as well as astronomy. Substantial improvements have been constantly made in the data analysis strategy, at the level of both individual geodetic techniques, as well as the ITRF combination, with the aim to improve the ITRF accuracy and reliability.

Since 1990, 14 realizations of the ITRS, named ITRFyy, have been published, from ITRF88 to ITRF2020. A short history of the ITRF series will be presented highlighting how the orientation of the latest ITRFs was defined, which impacts long-term polar motion and UT1-UTC trends. The ITRF2020 products will be described and an evaluation of the uncertainty of the frame parameters presented.

More recently, the ITRS Center decided to regularly update the ITRF2020 [1], with its first update, ITRF2020-u2023 released in December 2024. Although individual station coordinates have changed, the ITRF2020-u2023 frame parameters are identical to those of ITRF2020 within the uncertainty of a 14-parameter similarity transformation. The main differences between ITRF2020 and its update, in terms of both individual station coordinates and EOPs will be discussed. Future plans for ITRF updates will conclude the presentation.

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Participation: Online

INVITED CONTRIBUTION

Building the Celestial Grid: The ICRF and Global VLBI Collaboration

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The International Celestial Reference Frame (ICRF) is the fundamental realization of the International Celestial Reference System (ICRS), providing a quasi-inertial coordinate system anchored by precise positions of extragalactic radio sources. Realized through Very Long Baseline Interferometry (VLBI), the ICRF underpins all high-precision astrometry, Earth orientation studies, geodesy, and spacecraft navigation. This talk provides an overview of the evolution of the ICRF from its first realization in 1998 to the current multi-frequency ICRF-3, adopted by the IAU in 2018. ICRF-3 incorporates nearly 40 years of dual-frequency S/X VLBI data, as well as independent realizations at K-band and X/Ka-band, achieving positional accuracies at the 30 micro-arcsecond level. Key challenges -such as source structure effects, Southern Hemisphere coverage, and frequency-dependent offsets - are addressed through global collaboration, targeted observations, and improved modeling. The ICRF is also increasingly integrated with the optical Gaia reference frame, and future efforts are focused on developing a multi-wavelength realization. Particular attention will be given to the growing role of Africa in VLBI and its contributions to the celestial reference frame.

Acknowledgements

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Participation: Online

INVITED CONTRIBUTION

Consistency Between Celestial and Terrestrial Reference Frames and Earth Orientation Parameters: A Geodetic Perspective

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The consistency between the International Celestial Reference Frame (ICRF), the International Terrestrial Reference Frame (ITRF), and Earth Orientation Parameters (EOPs) is essential for precise space geodesy and astronomy. While the ITRF and EOPs benefit from established multi-technique combination strategies, the current celestial realization, ICRF3, is based on independent catalogs at different frequencies and remains disconnected from the Gaia-CRF. Moreover, discrepancies among ITRF realizations (e.g., ITRF2020 and its update, DTRF2020, JTRF2020) due to differing combination strategies, and the aging IAU 2000/2006 Earth rotation models, further complicate the transformation between terrestrial and celestial systems.

In this contribution, we assess systematic inconsistencies within and between these reference frames, examine the transparency and reliability of reported uncertainties in official geodetic products, and evaluate the impact of TRF choice on CRF determination. We also review recent recommendations for updating Earth rotation theory and IERS Conventions, highlighting the need for a harmonized framework that ensures mutual consistency among reference frames and EOPs, aligned with current precision requirements.

Acknowledgements

Participation: In person

INVITED CONTRIBUTION

The International VLBI Service in its transition to VGOS

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The International VLBI Service for Geodesy and Astrometry (IVS) coordinates global VLBI observations for the main products of the terrestrial and celestial reference frame as well as Earth orientation parameters. Driven by the need for higher accuracies as well as an increasingly crowded frequency spectrum in the S-band, the IVS is currently transitioning to its new VLBI Global Observing System (VGOS). VGOS encompasses new frequencies (3-14 GHz) and largely new infrastructure, ultimately aiming for one order of magnitude improvement in the results compared to the legacy S/X system.

This contribution features the status of the VGOS roll-out, current and future operations and results. IVS products will be discussed, in particular, in terms of cadence and turn-around times as well as their incorporation into wider geodetic and astrometric products.

Participation: Online

A global worldwide VLBI network to strengthen the celestial reference frame at K band for ICRF4

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The next realization of the International Celestial Reference Frame, namely ICRF4, is planned for 2027. Like its predecessors, the frame will be built by a working group of the IAU that was formed in 2021 for this purpose. A novel feature of ICRF4 is that it will be multi-waveband, meaning that it will include an optical component (based on the Gaia Data Release 4 data) besides the three radio components (at the S/X, K and X/Ka frequencies) that were the basis of ICRF3. The issues involved in generating such a multi-waveband frame have been investigated by the working group and are discussed in [1]. At the same time, the VLBI observing programs are being strengthened to correct previous deficiencies and improve over ICRF3.

At K band, a large worldwide VLBI network consisting of the Very long Baseline Array (in the United States), the European VLBI Network (which includes telescopes in Europe, South Africa, China and South Korea), and antennas in Australia, has been assembled, for a total of up to 27 telescopes, with correlation to be carried out at the Joint Institute for VLBI ERIC. The aim of the project is three-fold: (i) increase the intrinsic source position precision by observing with longer baselines than achieved so far, (ii) reduce the North-South asymmetry of the frame by incorporating long baselines between South Africa and Europe and between Australia and Asia, and (iii) image the sources at high resolution and with high dynamic range.

A total of 10 observing epochs (to take place before 2027), each 24-hour long, have been granted to cycle over the 1200 sources in the frame and

achieve these goals. The presentation will give an overview of the program and discuss initial results according to availability.

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Contribution type: Oral presentation
Participation: In person

A Catalog of Variability-selected, VLBI-detected Blazars for Construction of the ICRF

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Several studies have highlighted the presence of statistically significant offsets between Gaia and VLBI positions [1–5], and additional studies helped determine possible astrophysical causes for these differences [5–8]. As we draw nearer to the next realization of the International Celestial Reference System (ICRS), it is important to address these challenges and others, which affect not only the individual reference frames but also the multi-wavelength tie between them. This is also of particular importance as long-term maintenance of the principal radio frame at S/X-band (2.3/8.4 GHz) gives way to K or Ka (22 GHz, 32 GHz). Recently, Secrest [9] showed that offsets between source positions could be mitigated by selecting photometrically variable sources, showing that the most highly variable sources have properties consistent with blazars, such as counterparts in the Fermi catalog. Lambert & Secrest [10] then expanded upon these findings, showing photometric and astrometric variability are inversely correlated. Therefore, selecting on or weighting by photometric variability presents the clearest path to a stable and rigid reference frame. A sample of bona fide blazars selected on photometric variability may be key to the creation of a truly wavelength-independent frame. To this end, we have created a catalog of VLBI-detected sources likely to be blazars based on variability properties derived from time-domain, photometric surveys such as ZTF and WISE. Here we present this catalog and discuss the sample and metrics used to create it.

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Contribution type: Oral presentation
Participation: In person

The Fundamental Reference Image Data Archive (FRIDA)

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The International Celestial Reference Frame (ICRF) is defined by making precise astrometric measurements of active galaxies (AGN) using very long baseline interferometry (VLBI). Astrometric VLBI measurements simply measure the position of the brightest point in the observed field on the sky. This position is then reported as the position of the galaxy and is used to build the ICRF. However, a large problem with this is that AGN are highly variable, especially on the physical scales which VLBI is sensitive to. VLBI is capable of resolving structure in many of the ICRF sources which can change in brightness or even move position on the sky. If this structure is either not accounted for or not well understood, it will obscure the precision of astrometric measurements. Imaging ICRF sources allows for these bright components to be separated and monitored using photometric and morphological techniques. The US Naval Observatory (USNO) has been consistently imaging ICRF sources since 1997. The data are available through a web–accessible data archive known as the Fundamental Reference Image Data Archive (FRIDA). In recent years, USNO has been supporting monthly dedicated imaging observations on the Very Long Baseline Array (VLBA) at S–, X–, and K–bands. These observations are part of our 50% time allocation on the VLBA in agreement with the National Radio Astronomy Observatory (NRAO). A calibration and imaging pipeline has been developed using the Common Astronomical Software Application (CASA). A new major overhaul of both the imaging pipeline and the FRIDA user interface is underway. We present on the current status of FRIDA and look towards the future, focusing on what data products it can offer to the astrometric, geodetic, and the astronomical communities.

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The contribution of South American VGOS sites to EOP and reference frames determination

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We analyzed the impact of different network configurations with VGOS antennas. Up to 2025, the inhomogeneous distribution of Very Long Baseline Interferometry (VLBI) sites with VGOS technology shows more VGOS antennas in the Northern than in the Southern hemisphere. We simulated additional VGOS sites in South America and studied their impact on Earth Orientation Parameters (EOP), as well as station and source coordinates. The selection of fictitious sites was made on the presence of existent and needed infrastructure. Different fictitious network configurations were compared by their performance with respect to the real situation. It was concluded that a more uniform distribution with additional sites in South America would significantly improve the EOP and source coordinates, but not on station coordinates.

Acknowledgements

Contribution type: Oral presentation
Participation: In person

Characterizing the astrometric quality of AGNs in Gaia-CRF3

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AGNs, due to their vast distances and small apparent sizes, play a crucial role in defining the celestial reference frame. With approximately 1.9 million AGNs observed in the visible spectrum in Gaia DR3 and a precision comparable to radio wavelengths, Gaia's astrometric measurements provide a foundation for constructing the next-generation kinematically non-rotating reference frame in optical wavelength, using AGNs as primary reference sources [1].

Accurately assessing the systematic residuals in quasar astrometry is essential for fundamental astronomy. Therefore, refining the AGN catalog from Gaia is crucial. This study aims to characterize systematic errors in the parallaxes and proper motions of AGNs in Gaia DR3, exploring correlations between these errors and various AGN properties reported by Gaia and other sources [2].

Additionally, a substantial number of AGNs in Gaia-CRF3 exhibit significant astrometric offsets despite their confirmed extragalactic nature. Our analysis reveals that these anomalies primarily stem from dual AGNs and lensed quasars, where structural variations cause photo-center jitter, mimicking parallax and proper motion [3]. With milliarcsecond-level precision, such sources must be rigorously identified and excluded from reference frame construction. To address this, an astrometric quality index is introduced for each source. Our preliminary results demonstrate a clear correlation between declining astrometric index values and increasing positional, proper motion, and parallax errors, validating this classification as a key metric for identifying high-quality primary reference sources.

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Contribution type: Oral presentation
Participation: Online

Secular aberration drift in stellar proper motions and their implication on the stellar reference frame

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The motion of the Solar System barycenter (SSB), which is the spatial origin of the International Celestial Reference System, causes a directional displacement known as secular aberration. The secular aberration drift caused by the galactocentric acceleration of the SSB has been modeled in the third generation of the International Celestial Reference Frame. In this talk, we will address another secular aberration drift effect, which is due to the change in the line-of-sight direction, and study its implications for stellar proper motions. To this end, we derived a complete formula for the secular aberration drift and computed its influence on stellar proper motion based on the astrometric data in Gaia Data Release 3. We found that the secular aberration drift due to the change in the line-of-sight direction tended to decrease the observed proper motions for stars with galactic longitudes between 0 and 180 degrees, and increase the observed proper motion for stars in the remaining region. If this secular aberration drift effect is ignored, it will induce an additional proper motion of $> 1\,\mathrm{mas\,yr^{-1}}$ for 84 stars and $> 0.02\,\mathrm{mas\,yr^{-1}}$ for $5\,944\,879$ stars, which is comparable to or several times greater than the typical formal uncertainty of the Gaia proper motion measurements at $G < 13$. Furthermore, we used the intermediate astrometric data from the Hipparcos-2 catalogue to study the implication of ignoring the secular aberration drift on the determination of stellar trigonometric parallaxes. We recommend that the secular aberration drift due to the change in the line-of-sight direction and the acceleration of the SSB should be modeled to make the stellar reference frame.

Acknowledgements

Contribution type: Oral presentation
Participation: In person

Topological-geometrical incursion into the internal structure of the Pleiades open cluster and its relationship with some astrophysical parameters

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The release of successive versions of the Gaia data [1] has inspired numerous studies on the Pleiades, with objectives ranging from identifying new stars to exploring cluster dynamics. Our research, however, adopts a distinct approach. We identify a subset of data by imposing geometric constraints on the M45 file obtained from the Gaia website.

Specifically, we focus on the 2MASS stars within the file and utilize the stellar distances provided in EDR3, applying criteria that emphasize high spatial density and minimal distances between stars. With this denser core established, we analyze the three-dimensional point cloud using Topological Data Analysis (TDA) techniques. We investigate its topological and geometrical structure through two TDA methods [2, 3] that yield different insights. To enhance our understanding of these discrepancies provided by both methods, we introduce a dual approach over a point network that reveals null densities, which will aid in discussing the identification of loops and voids, after having obtained compatible results between the introduced dual method and the alphashape method. Additionally, we identify connected components and subsequently relate the astrophysical properties of these stars within each connected component to the topological and geometrical findings we have derived. Our smaller dataset may later be expanded to include stars from DR2, excluding those from 2MASS [4].

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Contribution type: Poster presentation
Participation: Online

Effect of negative parallax in VLBI

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Extragalactic radio sources, observed with Very Long Baseline Interferometry (VLBI), are used to define the International Celestial Reference System (ICRS). Its latest realization, ICRF3, based on observations from 1979 to 2018, includes coordinates for 4,536 sources, 303 of which are "defining" and determine the ICRS axes with an accuracy of 30 μas. Otherwise, the Gaia optical astrometry mission has measured precise positions of millions of objects, including QSOs also observed by VLBI.

In Gaia EDR3, a negative parallax effect for QSOs having a median amplitude of -17 μas was reported, likely caused by technical reasons. We analyzed the full set of VLBI observations spanning from 1993 to 2025 and discovered the similar parallax effect using two methods: global parameter estimation [1], and through positional time series analysis.

We compared the parallactic effect in VLBI and Gaia EDR3 for the same period of time (2014 - 2017). The results showed that the parallax estimated as -16.8 ± 2.5 μas in VLBI is in good agreement with the Gaia EDR3 value.This consistency suggests that both effects may share a common origin.

Also, time series of individual sources reveal an annual signal in the periodograms. Cross-spectral analysis indicates a strong correlation between the right ascension and declination components of this signal. The amplitude of the annual variation ranges approximately from $+20$ to -70 μas. We assume that this parallax effect may originate due to the deformation of the fundamental axes, possibly caused by the positional instability of the ICRF3 «defining» sources.

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Contribution type: Oral presentation

Participation: In person

Participation: In person

70 Years of Astrometry at the Félix Aguilar Astronomical Observatory in San Juan

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Since its inauguration on September 28, 1953, the Félix Aguilar Astronomical Observatory (OAFA), currently affiliated with the National University of San Juan (UNSJ), has carried out more than seventy years of fruitful work in the field of astrometry.

This document synthetically describes the observatory's humble beginnings, narrates its evolution, and the successful international cooperation agreements developed with scientific organizations in countries in North America, Europe, and Asia. It also provides a brief glimpse into its future.

Contribution type: Poster presentation
Participation: In person

Polarimetric Reference Frames for Exoplanetary Atmosphere Characterization

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The characterization of exoplanetary atmospheres through polarimetric observations requires precise reference frames and ephemerides to accurately model the planet-star system. Upsilon Andromedae b, a hot Jupiter orbiting a main-sequence star, serves as an excellent test case for studying the role of reference systems in exoplanetary research. This work presents a refined approach to defining celestial reference frames for polarimetric studies, ensuring consistency with Earth-based and space-based observatories.

We utilize time-resolved polarimetry to track the planet's atmospheric scattering properties, necessitating rigorous alignment with the International Celestial Reference Frame (ICRF) and local terrestrial observatory frames. The impact of orbital ephemeris precision on derived polarization signals is explored, highlighting the need for updated planetary system parameters. Our study also addresses the transformation of reference systems to mitigate observational biases and improve consistency across different datasets.

The findings demonstrate the importance of accurately calibrated reference frames in enhancing polarimetric measurements of exoplanets, with implications for future missions and ground-based monitoring programs. By integrating celestial reference systems with exoplanet observation techniques, we contribute to the broader effort of standardizing astronomical methodologies in planetary sciences.

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Contribution type: Poster presentation
Participation: In person

Blazars as Ideal Reference Frame Objects

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Despite achieving sub-milliarcsecond per-source position accuracies and an overall celestial reference frame (CRF) stability of a few tens of micro-arcseconds, consistent source positions and frame orientations across wavelengths has not yet been achieved, hampering the goal of producing a wavelength-independent CRF. Source position discrepancies are seen both between radio frequencies (e.g., X and K) and between the radio and the optical CRFs (i.e., ICRF3 and Gaia-CRF3), with about 15% of ICRF3 sources having statistically significant optical-radio position offsets. It has recently been shown by the U.S. Naval Observatory that the prevalence of optical-radio position offsets is inversely correlated with photometric variability, strongly indicating blazars as astrometrically stable sources. In this presentation, I review important recent results on the relationship between blazars and multi-wavelength astrometric stability and argue that blazars should be the object of choice for the next ICRF and future geodetic observations.

Contribution type: Oral presentation
Participation: In person

CART: history, current status, development and future collaborations

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On this work we will show the past 10 years of CART (China Argentina Radio Telescope) evolution, especially related to construction activities. We explain current assembly status and receiver integrations. Finally, we detail the development of digital wide band back end to be integrated with the future receivers.

Contribution type: Oral presentation
Participation: In person

Spatial Geodesy from Colombia: Starting Contributions from Academia

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The peace process in Colombia promoted the strengthening of the national geodetic network, which has been densified thanks to the coordination of the active networks of the IGAC and the Colombian Geological Service (Conpes 3958, 2019) allowing in a few years to go from 46 to more than 260 CORS stations, which shows sufficiency at the country level in GNSS development and its different technical and geoscientific applications.

However, current Geodesy-related curricula in Colombia, as well as research groups at universities, institutions, and companies in the geospatial sector, do not include R&D&I development nor projects related to processing in other spatial geodesy techniques. For this reason, the NIDE research group has created a space geodesy research line. The first stage of this work was the development of a methodological guide in Spanish for processing VLBI data using Vienna VLBI and Satellite Software (VieVS). This was followed by GGRF outreach programs, such as the development of a dashboard to provide a practical and graphical display of the global VLBI infrastructure and GitHub resources with complementary information on the applied processing methodology. An intrinsic elective program is currently being planned to articulate undergraduate and graduate research, allowing for national academic mobility for programs related to the Geosciences. The goal is to formalize and promote research, development, and interaction activities with the international community. Finally, the plan is to include teaching SLR and LLR techniques in the syllabus.

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Contribution type: Poster presentation
Participation: In person

Global VLBI solutions: advancing the realization of reference frames IAA2025

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The realization of celestial and terrestrial reference frames requires processing extensive VLBI data. At the Institute of Applied Astronomy, we use the QUASAR software to compute global solutions refining source and station coordinates [1]. We processed 6,605 sessions from 1979 to 2024, including sessions from the VLBI Global Observing System, which, to the best of our knowledge, have been considered for the first time in a global solution. The a priori catalogs used are ICRF3 for celestial sources and ITRF2020-u2023 for terrestrial stations.

To define the orientation of the terrestrial reference frame and compute Helmert trans-formation parameters, a dedicated set of reference stations was carefully selected. These stations serve to enforce the no-net-rotation and no-net-translation conditions. The selected stations are required to exhibit long-term stability and continuity in their coordinate time series, with no significant jumps or discontinuities. To ensure these criteria are met, we developed a specialized algorithm for detecting coordinate jumps. Based on its output, corrections were introduced into the a priori ITRF2020-u2023 catalog for affected time intervals. The final terrestrial reference frame, IAA2025-TRF, consists of 161 stations, including 31 stations where coordinate discontinuities were identified and corrected. We also analyzed how the accuracy of the Helmert transformation parameters depends on the weighting and transformation parameters choices [2].

For the celestial reference frame, we selected 295 defining sources from ICRF3, enforcing no-net-translation. Other sources may exhibit coordinate jumps [3], necessitating detection and correction. Currently, such sources are artificially treated as two independent sources. The resulting IAA2025-CRF catalog includes 4,638 sources.

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Contribution type: Oral presentation
Participation: In person

Investigation of the Effect of Different Crustal Density Models on the Gravimetric Geoid

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The geoid is a closed surface representing the Earth's true shape, coinciding with mean sea level. It is used in geodesy to determine the orthometric heights of points.

In this study, the effect of different density models on the gravimetric geoid was investigated using the UNB Global Topographical Density Models at 1 arc-degree grid spacing and 30 arc-seconds grid spacing, as well as a constant density value of 2670 kg/m³. The computation of the geoid was based on the ITU_GGC16 global geopotential model. The SRTM model with 1 arc-second resolution was used as the digital elevation model. Other terrestrial data were obtained from the Colorado region in the western United States.

The geoid model was determined using the Least Squares Modification of Stokes' Formula based on the KTH (Royal Institute of Technology) method [1] [2]. Various gravimetric geoid models were produced using different density models and other data, and these models were compared both among themselves and with the GNSS/Levelling geoid. A five-parameter corrective surface was applied to eliminate systematic errors during model comparison [3].

Acknowledgements

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Contribution type: Poster presentation
Participation: Online

SESSION 3: Reference systems/frames for the Moon and other solar system bodies

INVITED CONTRIBUTION

Lunar and Planetary Coordinates and the IAU Working Group on Cartographic Coordinates and Rotational Elements

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The International Astronomical Union (IAU) Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE) has been tasked by the IAU to make recommendations regarding the coordinate systems for all Solar System bodies other than Earth [1]. An example is the WGCCRE's

past recommendation to use the JPL DE 421 frame products in the mean Earth/polar axis (ME) system to define the Moon's surface reference frame. We are now considering recommending using the surface frame-matching JPL DE 440 new products [2] for that purpose. We emphasize the need to use such a frame for the Moon and other Solar System bodies, as is done with the International Terrestrial Reference Frame for the Earth. This is as opposed to axis of figure or gravity field frames, such as the Principal axis system for the Moon, which at the highest level of accuracy are not tied to the body surface, which can be substantially different from a surface frame. Our primary goal is to make recommendations that support mapping, i.e., the positioning of lunar and planetary data. In practice, such recommendations have been internationally adopted for other positioning and navigation purposes, and we know of no reason such a practice would not continue.

The WGCCRE is currently preparing our next report with such recommendations. We will review updates being considered for several bodies, including the Moon and Mars [3]. We are always seeking input for planning our recommendations and welcome those interested in our work to apply to join the IAU and the WGCCRE.

Acknowledgements

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J., Paganelli, F., Park, R. S., Ping, J., Seidelmann, P. K., Stark, A., Tholen, D. J., and Williams, I. P. (2025). Working Group on Cartographic Coordinates and Rotational Elements Annual Report to the IAU for 2024-2025, International Astronomical Union. To be available from `https://iau.org/WG100/WG100/Home.aspx`.

Participation: In person

INVITED CONTRIBUTION

Variety of relativistic time scales in the Solar system

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Given recent plans of several space agencies to bring high-precision atomic clocks both in space around the Moon and to the Moon surface within several years from now, it necessary to discuss and fix the relativistic definition coordinates for the Moon and in particular, to carefully discuss all aspects on the relativistic time suitable for the Moon and its surrounding. The IAU 2000 framework for relativistic reference systems establishes the fundamental principles for physically adequate reference systems and should be used to define the adequate relativistic reference systems for each solar system body. The IAU Resolution II in 2024 https://iau.org/Iau/Publications/List-of-Resolutions has already suggested to use this framework for the relativistic reference system of the Moon. As usual that relativistic reference system contains both spatial coordinates and a coordinate time scale. The same definition can and should be used for all other Solar system bodies, e.g. for Mars and Mercury. After a brief introduction into the IAU 2000 framework, I will show the properties of the relativistic time scales for various celestial bodies and describe a simple and robust numerical procedure to compute the relations between them. I will argue that no analytical approximative formulas are needed to work with those relativistic time scales. Then I will discuss the remaining freedom of those relativistic reference system: the orientation of the spatial axes and an arbitrary scaling of the time and spatial axes (e.g. TDB-compatible vs. TCB-compatible quantities) and also demonstrate pros and contras of different options for the scaling.

Participation: In person

INVITED CONTRIBUTION

MoonLIGHT+MPAc on the Moon for Precision Tests of General Relativity

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Over the past 56 years, Lunar Laser Ranging (LLR) has kept providing accurate and precise (down to about 1 cm RMS) measurements of the Moon orbit thanks to the Apollo and Lunokhod Cube Corner Retroreflector (CCR) Laser Retroreflector Arrays (LRAs) deployed on the Moon during the Space Race Era. Nowadays, such lunar POD (Precise Orbit Determination) measurements are largely limited by the lunar librations affecting the old generation of LRAs hence, next generation libration-free retroreflectors are necessary.

The SatellitelunarGNSS laser rangingaltimetry and cubemicrosat Characterization Facilities Laboratory (SCF_Lab) at the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati (INFN-LNF), supported by the Italian Space Agency (ASI), designed, developed, and refined Moon-LIGHT (Moon Laser Instrumentation for General relativity High-accuracy Tests), a single large CCR of 100 mm of front face diameter, nominally unaffected by librations, and whose optical performances are comparable to the ApolloLunokhod LRAs of CCRs.

Such a big CCR (hereafter, ML100), is housed into a specifically devised, designed, and manufactured robotic actuator, funded by the European Space

Agency (ESA), the so-called MoonLIGHT Pointing Actuator (MPAc), that, once its host lander will be on the Moon, will finely align the front face of ML100 towards the Earth. The (optical) performances of such a hardware, MoonLIGHT+MPAc, were tested inby the SCF_Lab, in order to get it accepted for space flight before its integration onto the deck of the host craft. After successful deployment on the Moon, additional and better quality LLR data (down to about 1 mm RMS or better for the Moon orbit) will be available to the community for future and enhanced tests of gravitational theories.

While mainly devoted to the hardware development aspects, the tests of gravitational theories attainable thanks to LLR and subsequent data analysis will be shown, with emphasis on ongoing activities carried on by the coauthors. Several other topics will be covered, including, yet not limited to, the family of INFN's microreflectors for lunar and planetary sciences, and their applications.

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Participation: Online

INVITED CONTRIBUTION

Reference Systems and the Rotation of Celestial Bodie: Insights from the Moon and beyond

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The definition of reference systems attached to a celestial body is essential for studying their dynamics and cartography. It is also crucial for future application, such as planned global space navigation system for the Moon. At present, two systems are defined: the PA-system based on the principal axis direction of Moon's inertia tensor, and the ME-system based on the mean Earth direction. In this talk, we describe the methods used to transform the PA-system into ME-system, and discuss the varying level of precision associated to these methods. Then, we conclude by addressing the challenges of defining reference systems for other bodies in the Solar system.

Participation: Online

Implementation of Lunar Celestial Reference System (LCRS) for Practical Use and Interoperability

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With the standardization of an inertial lunar reference system, the Lunar Celestial Reference System (LCRS) and the accompanying Lunar Coordinate Time TCL) [1] it becomes an important next step to consider the practical applications and use of LCRS. LCRS and the accompanying necessary, but not yet standardized, body-fixed lunar reference system (LRS) that enable operations on and near the surface of the Moon, require interoperability with Earth reference systems. TCL is a coordinate time centered on the Moon analogous to Geocentric Coordinate Time (TCG). Currently there is not a connection between practical times like Barycentric Dynamic Time (TDB), or UTC, or a defined lunar surface time analogous to TT and UTC. Computations using LCRS and TCL remain in the theoretical realm until they can be tied to measured time scales. Current practice for computing position and motion using coordinate systems around the Moon use TDB as a default to connect to UTC for spacecraft and observations that move from Earth to the Moon. Furthermore, current calculations of the lunar orientation angles between LCRS and LRS for body-fixed systems like Mean Earth (ME) and Principal Axis (PA) also use TDB as this is dependent on the rotation rate of the Moon.

The practical use of LCRS is to create tracking capabilities, define a lunar oriented position to find celestial objects and to support a lunar-based navigation system. While many missions have successfully traveled from the Earth to the Moon prior to the adoption of the LCRS, more and more missions are being planned and a standardized coordinated system and time for all the missions to use is becoming necessary. Since missions are initially launched from Earth and then transition to the lunar sphere of influence it is critical to: a) have a defined practical time for LCRS either by determining the relationship between TCL and TDB or UTC/TT, or defining a local lunar surface time (e.g. Lunar Time TL or LTC etc.) that can be defined by a real or measured time and/or has some connection to terrestrial time; b) determine a crossover point between the sphere of influence of Earth and the Moon, and c) determine the relationship between LCRS and the body

fixed system LRS. With all this in place it is possible to have a standardized system of navigation for the surface and lunar orbit, the ability to track celestial references like navigation stars and planets, and the data necessary to create a lunar navigation system. We will illustrate practical uses for the LCRS, ensuring they are consistent with IAU standards and interoperable with other reference systems. Such uses could include navigation for locations on the surface of the moon using celestial objects (stars and planets), precise coordinates (of stars and planets) in LCRS, and transformation parameters from LCRS to LRS.

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Contribution type: Oral presentation
Participation: Online

Report from the IAG JWG 1.1.3 about Lunar reference frames

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In this presentation, we will provide a comprehensive overview of the activity conducted by the IAG JWG 1.1.3, which is specifically focused on the definition of future lunar reference frames. The presentation will address the four primary inquiries that the JWG has been engaged in. Firstly, we will present the properties that should be employed in order to define the lunar-fixed reference frame (ILRF). Secondly, the current limitations of the lunar physical libration models will be examined. Thirdly, we will discuss how the new lunar reference frame can be tied to ITRF and how GNSS direct observations by a lunar lander can help to increase the accuracy of such a tie. Fourthly, we will address the interconnection between lunar time and lunar-fixed frame realizations. Finally, we also provide some recommendations for the first ILRF realization and for the definition of the lunar geoid.

Contribution type: Oral presentation
Participation: Online

Lunar Laser Ranging calibrated analytical representation of lunar physical librations

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The study of lunar physical librations is a significant branch of planetary science, like the free modes of the librations are closely related to the Moon's internal structure, making their study crucial for understanding the Moon's formation and evolution [1]. Existing analytical representation method merges spectral analysis of numerical ephemerides with an analytical ephemerides framework, providing a compact solution with greater long-term stability than numerical approaches and higher accuracy than analytical methods [2]. This work refines analytical representation method by incorporating lunar laser ranging data, enabling adjustments of quasi-periodic components and achieving observational residuals at the centimeter scale. This enhancement brings the analytical representations closer to actual observations. Looking ahead, the advanced analytical representation method provides novel perspectives and data support for research on the Moon's internal structure.

Acknowledgements

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Contribution type: Oral presentation
Participation: In person

Mars orientation and rotation angles

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We present recommendations for building an orientation and rotation model for Mars for the right ascension, declination and rotation angle with respect to the ICRF equator. Main recommendations are:

- Replace the artificial very long period terms (present in the last report of the IAU WG on Cartographic Coordinates and Rotational Elements) with a quadratic polynomial and update epoch value and rate accordingly [3, 4].

- The rotation rate $\dot{W}$ relative to the ICRF equator should not be confused with the rotation rate $\dot{\phi}$ relative to the J2000 mean orbit of Mars. Their difference causes a 1900 m longitude shift after 30 years [3].

- The Euler angles (obliquity, node longitude relative to the J2000 Mars orbit plane), commonly used by the radioscience community to orient the spin axis of Mars, should be transformed into ICRF-based angles using analytical relations. This transformation preserves the physical meaning of Mars' rotational dynamics, which follows well-defined periodicities governed by celestial mechanics.

- An accurate rotation model should incorporate up-to-date rigid [3] and liquid [2] nutation models, relativistic corrections in rotation [1], and polar motion induced by the external torque [3].

- Since the Poisson terms (a periodic series with amplitudes changing linearly with time) can reach 4 milliarcseconds 30 years away from J2000, we recommend adding them if a precise model is targeted on a long time interval.

We compare different models from the literature, with a particular focus on the prime meridian's position. Differences between models can lead to discrepancies of up to 100 meters in meridian location.

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Contribution type: Oral presentation
Participation: In person

Spin Orientation of the Galilean Satellites

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The Galilean satellites are locked in a 1:1 spin-orbit resonance. Their rotation axis is assumed to be in a Cassini state and to follow the long-term precession of the orbit normal. The obliquity, which is the angular separation between the rotation axis and the orbit normal, is expected to be small.

The orientation/rotation angles can be described using two different sets of angles:

- The Euler angles with respect to the Laplace plane: obliquity, node longitude and rotation angle (giving the direction of the prime meridian). They are regularly used for the physical modeling of the torques [2].

- The equatorial coordinates with respect to the ICRF equatorial plane: right ascension, declination and the rotation angle W. They are used in the IAU reports [1]

Based on geometrical considerations, we computed analytical expressions to transform these angles between the Laplace and the ICRF planes, up to the first order in small parameters like obliquity. This method is an improvement with respect to zero obliquity models. Our method is similar to [3] that converts Martian angles. It does not require any fit of the amplitudes and frequencies on numerical series and the physical meaning of the frequencies is kept from the input series.

Observations and/or well-informed dynamical model are required to provide with a recommended numerical solution for the orientation/rotation. This study is useful for the interpretation of future Earth based observations or JUICE data. The link between the interesting geophysical parameters and the equatorial coordinates angles is more direct.

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Contribution type: Poster presentation
Participation: In person

SESSION 4: Time scales and time metrology

INVITED CONTRIBUTION

Continuous Coordinated Universal Time adopted by the ITU

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The work reported here is one of the activities of the International Telecommunication Union - Radiocommunication Sector (ITU-R) Study Group 7 (SG 7) (Science Services), Working Party 7A (WP 7A) (Time Signals and Frequency Standard Emissions). As a result of technical time scale issues raised by Sector Members of the ITU-R about thirty years ago and a letter from the Director of the Bureau international des poids et mesures (BIPM) to the Secretary General of the ITU in 2000, a new question ITU-R 236/7 on The Future of the Coordinated Universal Time UTC time scale was generated by WP 7A in 2001. Question 236/7 was structured to address the future definition and use of UTC in the ITU-R recommendations, and was updated over time [1]. Major technical changes to UTC clearly have a potentially significant impact on communications networks, navigation systems, time/frequency distribution systems and virtually all aspects of civil/military timekeeping [2].

In order to better conduct the often-difficult discussions, several events have taken place in the past, coordinated by the ITU, starting with a meeting at the BIPM in Sèvres in 2002, followed by a Colloquium on UTC in Turin in 2003. Then a draft revision of recommendation TF.460 [3] submitted to Radiocommunication Assembly in 2012 (RA-12), which was unsuccessful due to lack of consensus. These were followed by the holding of an ITU-BIPM workshop in Geneva in 2013 [4], preceded by the publication the same year in an ITU News magazine [5], of various opinions on the question of whether to abolish or not to abolish the leap second in UTC. As a result, divergent views on the evolution of UTC were clearly reflected in the Conference Preparatory Meeting (CPM) report to the World Radiocommunication Conference of 2015 (WRC-15). Things began to evolve in a convergent way after WRC-15, notably with the adoption by the Conférence générale des poids et mesures (CGPM) of two resolutions, one in 2018 On the definition of time scales [6]

[7] and one in 2022 On the use and future development of UTC [8, 9]. In the meantime, a MoU was signed by the BIPM and the ITU in 2020 [10]. The work was complemented by the release of a substantial report on Time signals to be disseminated by radiocommunication systems [11], followed by the organization of a Special session with the BIPM on Resolution 655 (WRC-15) during the 2nd ITU Inter-regional Workshop on WRC-23 Preparation, held in Geneva in 2022 [12]. Resulting from close collaboration between the BIPM and the ITU, key articles on the future of UTC were published in ITU News magazine in 2023 [13].

Indeed, the year 2023 was a significant and decisive year as the ITU unanimously succeeded in achieving the main objective of moving towards a continuous UTC when WRC-23, held in Dubai from 20 November to 15 December, endorsed the BIPM decision on this matter. This led to the revision of Resolution 655 (WRC-15), paving the way for further studies to be carried out by WP 7A, with a view to a possible revision of Recommendation TF.460 that is incorporated by reference in the Radio Regulations [3].

It could potentially include a new code format for the continuous UTC signal to be disseminated and thus be able to end the process of inserting leap seconds into UTC at a date and for a maximum value of the UT1 - UTC difference that will both be defined in a CGPM Resolution in 2026. The medium-term objective of WP 7A on this topic is to complete the draft revision of Recommendation TF.460 and submit it to Study Group 7 for further consideration and approval, with a view to its subsequent adoption by the RA-27 and then by the WRC-27 to be held in 2027, thus implementing Resolution 655 (Rev.WRC-23) [14].

Acknowledgements

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Participation: In person

INVITED CONTRIBUTION

Lunar Time

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These last years have seen a renewed interest for lunar missions. Would it be for scientific applications, navigation, or communication on the Lunar surface, a lunar standard reference time scale should be defined. Considering the difference of gravitational potential around the Moon or around the Earth, as well as their different motions in an inertial frame, the Einstein general relativity theory predicts of course that the time measured on Earth and that measured on the Moon will not coincide. For example, an ideal clock on the Moon surface, when compared to an ideal clock on Earth surface, would exhibit a 58.7 $\mu s/d$ drift plus some pseudo-periodic variations, which will be impossible to ignore for most practical purposes. It is therefore difficult to use UTC directly as the reference time scale in the cislunar environment, and space missions' designers are asking for a practical time scale that would be used as the reference time scale in this environment.

The IAU resolution II (2024) recommends constructing a Lunar Celestial Reference System (LCRS), with its time coordinate designated Lunar Coordinate Time (TCL), using the same techniques as to construct the GCRS and TCG, and keeping the unit of measurement of TCL consistent with the SI second. In its resolution III (2024), the IAU also recommends that "the relationships between the possible versions of a lunar reference time scale and other time scales, in particular a lunar coordinate time and UTC, are pursued in a collaborative agreement among the relevant international organizations". One of these is the Consultative Committee for Time and Frequency (CCTF), a sub-committee of the International Committee for Weight and Measures (CIPM).

CCTF experts and members of the national metrological institutes in close contact with space agencies started elaborating a strategy to work actively towards a consensus.

In this presentation, we will provide a review of the relativistic time scales

in the Solar System, and how a new reference scale should be considered for lunar applications considering the IAU recommendations. In particular, we will investigate the possibility of scaling TCL which would allow to remove secular deviation between the lunar time reference and UTC, or between the lunar time reference and the natural time of a clock at the lunar surface. We will analyse the theoretical and practical advantages and drawbacks of the different options for a lunar reference time scale.

We will then propose a scheme for the realisation of a lunar reference time, for both the situation where only Earth clocks are available to provide this reference, and the situation where one or more clocks are on the Moon. And we will propose some practical implementation to maintain the traceability of a lunar reference time to UTC.

Participation: In person

INVITED CONTRIBUTION

Current status of frequency standards toward the redefinition of the SI second

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In 1967, the SI second was defined as the duration of 9,192,631,770 cycles of the microwave transition between hyperfine levels of the ground state of the cesium-133 atom. A primary frequency standard realizes this definition using cesium atoms while rigorously evaluating all sources of systematic bias to achieve a well-characterized, low-uncertainty realization of the second. Currently, the best cesium-based standards achieve systematic uncertainties at the level of 1-2 $\times$ 10^{-16}; however, this performance has plateaued over the past 15 years. In contrast, optical frequency standards have made rapid progress since around 2005, with state-of-the-art systems now demonstrating systematic uncertainties in the 10^{-19} range. This substantial improvement has sparked active discussions about redefining the SI second based on optical transitions [1].

Two major issues are currently under consideration. The first is the choice of how to define the new SI second, with two principal options being proposed. The second is whether a redefinition would yield clear benefits under present technological and operational conditions. In this presentation, I will begin with a brief overview of the current status of optical frequency standards. I will then introduce the two main redefinition options using a graphical representation [2]:

- Option 1: Select a single optical transition to replace the current cesium hyperfine transition.

- Option 2: Define the second based on a weighted geometric mean of multiple optical transition frequencies [3].

I will discuss the ongoing debates regarding the relative merits and challenges of each approach.

To assess the benefits and feasibility of redefinition, the Consultative Committee for Time and Frequency (CCTF) has established a set of criteria that

must be satisfied. This presentation will provide an update on the current progress toward meeting these criteria and outline future strategies to ensure their full achievements.

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Participation: Online

Simplified Evaluation of CGGTTS Generation Without Navigation RINEX Corrections: Impact on UTC (INXE)

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The contribution to UTC by time and frequency laboratories is commonly achieved through RINEX and CGGTTS files derived from GNSS measurement data [1]. These text-based files are typically generated from continuous binary streams, from which partial extracts can be obtained. CGGTTS files conforming to the BIPM standard are produced by dedicated software using two preceding days of RINEX streams, where the navigation RINEX file provides critical ephemeris corrections, including precise orbital position coordinates for GNSS constellation satellites.

Based on our UTC (INXE) generation experience, we observed that the requirement for a two-day data window imposes limitations when significant time transfer drifts occur over shorter intervals (< 48 h). In this context, we present a simplified study of the impact of generating CGGTTS files directly from raw binary GNSS data, which lack RINEX-derived navigation corrections.

The preliminary results of 350 UTC (INXE) CGGTTS files over a one-year period show sigmas ~ 0.25 ns and 5 ns for All in View and Common View modes, respectively. However, as expected, the frequency of outliers increases in the absence of ephemeris correction data.

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Contribution type: Oral presentation
Participation: In person

Ground-space VLBI Near-field Delay Model for LOVEX Project

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The Queqiao-2 relay satellite of the Chang'e-7 mission is equipped with a 4.2-meter radio telescope, which has successfully carried out a number of joint lunar-Earth ultra-long baseline VLBI observations with ground-based VLBI stations.

For these observations, we computed both the ground-space VLBI-defined and DOR-defined geometric delay model. These models were used to obtain VLBI fringes, perform Delta-DOR local correlation processing and extract Doppler frequency measurements. After applying relativistic effect corrections to both delay models, VLBI fringes for CE-6 observations were successfully obtained within the main carrier frequency band for ground-space baselines. The fringe fitting results demonstrate that the DOR delay accuracy is on the order of nanoseconds, while the delay rate accuracy is on the order of 10 ps/s, corresponding to a fringe rate of approximately 0.15 Hz in the X band.

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Contribution type: Oral presentation
Participation: Online

UTC updates

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The Bureau International des Poids et Mesures (BIPM) Time department is in charge of the monthly calculation of Coordinated Universal Time (UTC), and its weekly rapid version UTCr.

UTC is based on the contribution of about 450 atomic clocks maintained in about 85 time laboratories all over the world compared by means of GNSS, and in some cases by Two-Way Satellite Time and Frequency Transfer.

The first step in the computation of UTC is a sort of weighted average of all the clocks to optimize long-term stability. Then the frequency of this average is compared versus the most accurate realization of the second obtained by Primary and Secondary Frequency Standards and a frequency steering is introduced. This process realizes the international atomic time TAI which is a realization of TT as currently defined by IAU in Resolution 4 of its XXIst General Assembly.

The last step originated from several discussions taking place in the early '70s at the IAU (XIVth General Assembly 1970), the Bureau International de l'Heure, the Consultative Committee for the Definition of the Second, and the International Telecommunication Union, which decided to maintain UTC and UT1 in pace within one second with the mechanism of the leap seconds : Since the 1st of January 1972, UTC and TAI differ only by an integer number of seconds, chosen so that it remains within 1 second versus the rotational angle of the Earth UT1. This relies on data communicated by the International Earth Rotation and Reference Systems Service (IERS) through its Bulletin C, and finally enables the publication of UTC.

In this presentation, we will summarize the main steps in the computation of UTC, the type of clocks used and the techniques for clock comparisons and the ongoing developments based on the research on new optical frequency standards, as well as new clock comparison techniques.

Some recent enhancements on the way UTC is disseminated (i.e. the Circular T, as well as downloadable data available from BIPM's web server, and the effort towards digitalization) will also be presented.

Contribution type: Oral presentation

Participation: In person

Participation: In person

Modernizing the Time and Frequency Laboratory of the Observatorio Naval de Buenos Aires (ONBA): Advancing Precision and Global Integration

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The Time and Frequency Laboratory of the Observatorio Naval de Buenos Aires (ONBA) has been responsible for maintaining Argentina's official time [1] since 1923 and began contributing to international time standards following the adoption of the atomic second at the 13th CGPM in 1967 and the incorporation of its first atomic clock. It has since collaborated with the Bureau International des Poids et Mesures (BIPM), which succeeded the Bureau International de l'Heure (BIH) in 1987, following the incorporation of its first atomic clock. With 144 years of history, ONBA continues to play a key role in Coordinated Universal Time (UTC), reinforcing its position in global time metrology.

As part of an ongoing modernization effort, ONBA has integrated a new generation of atomic clocks and GPS receivers to enhance the accuracy, stability, and reliability of its timekeeping systems. This study examines the impact of these technological advancements by analyzing time data from the upgraded system and modeling its expected performance. Additionally, machine learning techniques are being explored to optimize data processing and improve predictive capabilities for synchronization adjustments.

This poster contribution presents the impact of ONBA's modernization efforts on time dissemination and its alignment with the synchronized time infrastructure required by Industry 4.0. By refining measurement processes and optimizing data analysis, this work strengthens Argentina's role in time signal synchronization and enhances its contribution to global reference systems.

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Contribution type: Poster presentation
Participation: In person

Revitalizing the Observatorio Naval de Buenos Aires (ONBA): Modernization, Outreach, and New Challenges

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The Observatorio Naval de Buenos Aires (ONBA) is undergoing a comprehensive modernization to strengthen its role as a public service institution, aligned with the mission of national defense, scientific development, time dissemination, and calibration. ONBA has upgraded its Time and Frequency Laboratory, ensuring the accuracy of Argentina's official time [1] and contributing to the Bureau International des Poids et Mesures (BIPM). Since 1934, ONBA has maintained the uninterrupted publication of the Almanaque Náutico, providing precise astronomical and navigational data. Additionally, it continues to offer expertise in judicial inquiries requiring astronomical analysis.

In parallel, ONBA is expanding its public engagement initiatives. In 2024, it participated for the first time in La Noche de los Museos (Night of the Museums, Buenos Aires' annual citywide cultural event) at the Ministerio de Defensa (Ministry of Defense), reinforcing its commitment to science communication. As a result, ONBA is now joining the Red Nacional de Museos de Defensa (National Defense Museums Network) meetings, with the aim of becoming an official member. It is also advancing the digitization of its historical archives and improving accessibility to its library and museum collections.

A key initiative in this renewal effort is the Antarctic Project on Deception Island [2], which integrates historical research, scientific measurements related to the transmission of its time signal, and site surveys for other astronomical projects on the island. The project also includes the development of a Sustainable Astronomical Park, designed to engage researchers and visitors through educational installations.

This work highlights ONBA's evolving role by integrating scientific knowledge, precision time synchronization, and public outreach. It ensures the observatory remains relevant within both national and international scientific communities.

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Contribution type: Poster presentation
Participation: In person

Earth Rotation: Measurement of TT-UT, −720 to +1950

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We present figures and tables of our results for DT=TT–UT in the period −720 to +1950 obtained principally from analyses of historical records of solar eclipses (−720 to +1600) and timings of lunar occultations (+1600 to +1950) [1].

These show changes in the Earth's rate of rotation as measured in changes of the length of the day (lod). There is a long-term deceleration producing an increase in the lod of +1.72 ms cy^{-1}. There are also centennial fluctuations in the lod of amplitude 3 ms. After +1600 the data are precise enough to reveal decade fluctuations of up to an amplitude of 4 ms.

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Contribution type: Poster presentation
Participation: Online

A numerical realization of Lunar time ephemeris and its harmonic decomposition

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Similar to time ephemeris of the Earth, Lunar time ephemeris (LTE) representing the difference between TDB/TCB and lunar time scales, such as, TCL (Lunar Coordinate Time) recommended in Resolution II at the IAU2024 General Assembly, will play essential roles in time-keeping on the Moon. In this talk we will report a numerical realization of LTE which is consistent with the planetary and lunar ephemeris PETREL19 [1]. For practical use, a harmonic decomposition of LTE is implemented with the method of Kudryavtsev(2004) [2]. At last, the lunar time scales (implicitly) adopted by different LLR (Lunar Laser Ranging) analysis groups will be reviewed, and the impact of selecting different lunar time scales on the realization of lunar reference frames will be discussed.

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Contribution type: Oral presentation
Participation: In person

SESSION 5: Ephemerides of solar system objects

INVITED CONTRIBUTION

New views of the Oort Cloud

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The existence of the Oort Cloud, the source of long-period comets (LPCs), was proposed in 1950. Until recently, most LPC discoveries were of comets that passed within 3 au of the Sun, where water ice sublimates vigorously. LPCs are now being discovered with perihelion distances beyond 10 au, and five have shown activity beyond 20 au on the inbound legs of their orbits (four listed in [1], plus C2025 D1 (Groeller)) . I will review models of the formation of the Oort Cloud [2]; describe comets active far from the Sun and determinations of nongravitational forces in their orbits [3]; report on a prediction of a spiral structure in the inner Oort Cloud [4]; and discuss prospects for the Legacy Survey of Space and Time of the Vera Rubin Observatory to discover many distant LPCs.

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Participation: In person

INVITED CONTRIBUTION

The Astrometric Observing Campaign for the First Interstellar Object, 'Oumuamua

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The first interstellar object, 1I/'Oumuamua, was discovered by the Pan-STARRS telescope on 2017 Oct. 19, with 4 images obtained in poor seeing conditions. Pre-recovery data from 18 Oct. gave equally good fits to an elliptical or parabolic orbit. Additional observations up through 22 Oct. showed that the object had a hyperbolic orbit [1]. 1I was moving very fast when it was discovered, and many objects like this can be lost without immediate follow up. In addition to physical and compositional studies our team continued to image 'Oumuamua to constrain its trajectory with astrometric measurements, with the last observations made on 2018 Jan. 2, when it was fainter than $V \sim 27$ mag at a heliocentric distance of 2.9 au with the Hubble Space Telescope. This talk will present the observational campaign, including the decision to use HST for an astrometric experiment rather than physical characterization. The full observational ground and space-based dataset combined from multiple teams was used to demonstrate that the orbit could not be fit by a gravity-only solution, in spite of the lack of observed activity [2]. The astrometric data were then used to attempt to trace the path of 'Oumuamua back to its home solar system. This talk will present some of possible ways that the discovery rate of ISOs can be improved [3]. With the advent of the LSST survey beginning soon, and the predictions that it may discover several new ISOs per year [4], this talk will present some discussion about the coordination that will be needed to efficiently characterize these objects.

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Participation: Online

INVITED CONTRIBUTION

A statistically sound model for astrometric uncertainties to improve minor planet orbit accuracies

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Astrometric uncertainties are central to any orbit-fitting procedure. The result of a fit is a *nominal solution*, which represents the single orbit that best matches the observations, and a *confidence region* describing the orbital uncertainty, which includes the set of orbital elements statistically compatible with the data and the error model. For well-observed asteroids, the region is well approximated by a multidimensional ellipsoid. In contrast, for short-arc objects (e.g. objects on the NEO Confirmation Page), the uncertainty region appears as a cloud of admissible orbits.

The confidence region depends on a realistic statistical model of observation errors: accurate error statistics determine both the shape of the region's boundary and the probability distribution of orbits within it.

Astrometric errors are the result of several instrumental and observational factors, including but not limited to the pixel scale and the aperture of the telescope, the astrometric catalog used for reducing the observations, the brightness of the observed objects, the observer. This yields a heterogeneous error distribution across the astrometric dataset. A preliminary analysis of post fit residuals for ground based observations of numbered objects indicates uncertainties ranging from –1 to +1 arcseconds. These inhomogeneous uncertainties pose a significant challenge to deriving precise orbital solutions.

To address this, we present a review of the statistical performances of all the observations available for numbered objects and our preliminary study to create a statistical error model that defines consistent weighting and validation rules, streamlining the orbit fitting process for datasets with diverse error characteristics.

Acknowledgements

Participation: In person

Near-Earth Asteroid Orbit Determination with Physics-Informed Extreme Learning Machine

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Despite the growing enthusiasm for AI in space applications, AI-based orbit determination is still a relatively new field with limited practical implementations [1–3]. A promising new development is Physics-Informed Extreme Learning Machine (PIELM) [4]. It combines the rapid training capabilities of Extreme Learning Machines (ELM) with the physics-informed strengths of Physics-Informed Neural Networks (PINN), which ensures solutions consistent with physical laws and actual measurements. This synergy makes PIELM well-suited for solving the complex orbit determination problem.

PIELM was first used to determine the orbits of Earth-orbiting objects [5]. In this study, we extended PIELM's application to Near-Earth Asteroid (NEA) orbit determination. Our approach is specifically designed to account for unique NEA characteristics, incorporating a light-time correction into the measurement model and adding an N-body constraint into the loss function. A statistical analysis based on numerous real NEA observations was conducted to assess PIELM's accuracy in orbit determination. The results show that PIELM can effectively provide initial NEA orbits for subsequent refinement, or directly acquire orbits with competitive accuracy in most cases. Although PIELM's accuracy is inferior to the traditional least squares method, it offers a valuable alternative for NEA orbit determination, particularly with the advantage of not requiring any initial guess. With continued optimization of the neural network to improve its accuracy and training speed, PIELM will become a promising and powerful approach for NEA orbit determination, addressing the opportunities and challenges of this new big data era.

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Contribution type: Poster presentation
Participation: In person

Dynamical evolution of Inner-Earth objects (IEO)

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Inner-Earth objects are a subgroup of near-Earth objects (NEOs) whose orbits are entirely contained within Earth's orbit. Within this group, Atira asteroids have aphelion distances (Q) in the range $0.718AU < Q < 0.983AU$, Vatiras have orbits completely interior to Venus ($0.307AU < Q < 0.718AU$), and Vulcanoids are hypothesized to have orbits interior to Mercury. Very few of these objects have been discovered due to their proximity to the Sun, which makes observation challenging. In this study, we investigate the dynamical evolution of the observed Atira and Vatira asteroids (no Vulcanoids have been observed to date) using numerical simulations, building upon the initial work of [1]. Our dataset consists of 28 observed objects obtained from the JPL database as of October 2022, supplemented with 99 clones of each. We perform numerical integrations of all the particles over 10^9 years, considering classical and relativistic theory. By mapping population occupancy, we identify regions of varying dynamical stability, revealing where these objects are most likely to be found. Our results show that nearly all particles eventually collide, primarily with Venus and the Sun, and to a lesser extent with Earth and Mercury. Most close encounters occur with Venus and Earth, followed by Mercury and Mars. We estimate the half-life of each subpopulation and track their long-term evolution across the solar system. Additionally, we analyze the differences between simulations that include general relativity versus those that rely on classical mechanics. This study allows us to assess where these objects can be found, estimate how many we might expect, and whether we can expect to find Vulcanoids.

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Contribution type: Poster presentation

Participation: In person

Participation: In person

Evolution of INPOP planetary ephemerides

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In this presentation, we will review the major upgrade of the INPOP planetary and lunar ephemerides since INPOP21a. A special focus on asteroid perturbation modeling will be done as well as the impact of new data implemented in the INPOP adjustement. We will also describe how INPOP has been used for the JUICE mission navigation. And finally, we will also give a brief description of the results obtained in terms of tests of fundamental physics obtained in the past years. In conclusion of this presentation we will introduce the future perspectives open by the arrival of the Bepi-Colombo mission at Mercury in 2026-2027.

Contribution type: Oral presentation
Participation: Online

The SORA package for Stellar Occultations: sub-mas precision technique

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Stellar occultation is an event that happens when a Solar System Object passes in front of a background star. It is a unique and powerful technique to probe rings [1–3], satellites [4], topography [5], atmospheres [6], and other physical characteristics of the occulting body. The technique translates temporal resolution into spatial resolution, achieving sub-milliarcsecond (sub-mas) accuracy in the relative position of the object and star when supported by high signal-to- noise observations. However, the absolute position remains limited by the star's cataloged coordinates.

More recently, combining stellar occultations with rotational light curves has enabled the derivation of 3D shapes and spin parameters of Solar System objects. In [7], the combination of the 3D shape of Phoebe, derived from the Cassini spacecraft, and stellar occultations could improve the rotational period of the satellite by an order of magnitude.

To support such analyses, we developed the Stellar Occultation Reduction and Analysis (SORA) tool [8], designed for high-precision modeling and astrometry. To achieve this goal, we are developing techniques to allow mas to sub-mas accuracy in the determination of the object's position, pushing the limits of occultation science. Among the features are: 2D diffraction of asymetric shape models, simultaneous light deflection by multiple massive bodies, determination of rotational parameters, and astrometric positions. This work highlights the most recent progress and innovations achieved in the project.

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Contribution type: Oral presentation
Participation: In person

The invariable plane of the solar system based on modern long-term ephemerides of the major, dwarf and minor planets

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The invariable plane of a dynamical system is a plane perpendicular to the total angular momentum vector of the system and it passes through the system's barycenter. The invariable plane of the solar system is one of the most "natural" reference planes used in many applications (e.g., [1]). In [2] the orientation parameters of such the plane were earlier derived. They are inclination and ascending node of the invariable plane w.r.t. either ICRS or equinox-ecliptic of the epoch J2000. To calculate the instantaneous angular momentum vector of the solar system, study [2] used the positions of the major planets from the DE405/406 and INPOP10a numerical ephemerides. Additionally, the input from Pluto, (1) Ceres, (4) Vesta and (2) Pallas was taken into account.

The present study updates the results of that work. Here we employ the latest long-term planetary/lunar ephemerides DE430/431 and DE440/441 and the complete set of attracting bodies used by the corresponding ephemeris. In particular, when dealing with DE440/441, the input to the angular momentum vector was calculated from the barycenters of all major planets (where the effect from Earth and the Moon was taken into account separately, unlike in [2]), Pluto, 343 asteroids/dwarf planets, 30 Kuiper Belt Objects (KBO) and a KBO ring. The orientation of the invariable plane was determined over 14,000 years: 5000 BC – 9000 AD (cf., in [2] the longest solution was built over 6000 years: 3000 BC – 3000 AD). We have a noticeable improvement in the short term accuracy as well (in [2] defined as the pick-to-pick temporal variations in the orientation parameters over 1950-2050 after removing the secular part).

Updated values of the orientation parameters of the solar system invariable plane are suggested.

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Contribution type: Oral Presentation
Participation: In person

Three-Dimensional Shape of (50000) Quaoar and Orbit Refinement Using Data from 29 Stellar Occultations

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Since the discovery of (15760) 1992 QB1 [6], the number of trans-Neptunian objects (TNOs) identified has grown significantly. By February 2024, more than 4800 TNOs were known, with only about 210 of them with measured diameters. With the new data from the Legacy Survey of Space and Time (LSST), this number will grow significantly, deepening our understanding of the origin and evolution of the Solar System [1]. However, due to their distance, knowledge about their sizes, shapes, albedos, densities, and atmospheres remains sparse [2]. Stellar occultations allow for precise determinations of these parameters. A stellar occultation occurs when a Solar System object passes in front of a star, casting a shadow on Earth. This shadow reflects the object's projection at the moment of occultation [5]. Quaoar, a TNO with a semi-major axis of 43 au and an inclination of 8 degrees is classified as a hot classical TNO [4]. It has a satellite, Weywot, and two rings beyond the Roche limit [8]. These rings suggest alternative mechanisms for their formation and stability [7]. From 21 observed stellar occultations, 16 unpublished, an ellipsoidal model for Quaoar was obtained with dimensions 599.6 ± 24.3 km, 560.5 ± 4.0 km, and 506.9 ± 5.2 km. This model considers

its rotational period to be 17.8938 ± 0.0004 hours, with the pole orientation matching the rings' [8]. The occultations also provided 29 new astrometric positions, leading to an accurate orbit, with an error of about 2 milliarcseconds, derived using the NIMA integrator [3]. We will present the methods used to derive Quaoar's 3D shape from a joint analysis of all the occultation detections and its rotation light curve.

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Contribution type: Poster presentation
Participation: In person

Boosting decision trees for Main Belt Asteroid selection in planetary ephemerides

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One of the main bottleneck in assessing the accuracy of Mars orbit during planetary ephemerides construction, is the unknown value of the asteroids masses in the Main Asteroid Belt. Nowadays modern planetary ephemerides use a modeling with 343 asteroids as point masses, with the relative masses fitted to observational data. In the current work we propose an innovative methodology to reduce the number of asteroids implemented as point masses, thus reducing the number of parameters to be fitted, without a significant degradation of the postfit residuals. By mean of supervised learning, using boosting decision trees, we are able to provide a ranking by relative importance of the point masses used for the asteroids, reducing the list of more than 100 objects without degradation of the observational residuals and improving the extrapolation capability of the dynamical model. The main results of this work can be found in [4].

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Contribution type: Oral presentation
Participation: In person

Refining the Ephemeris of Solar System Objects through Observational Data using Kottamia Telescopes, Egypt

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Ground-based optical telescopes are essential tools for developing accurate ephemerides of solar system objects by providing precise astrometric and photometric data. This study highlights the contributions of the Kottamia Astronomical Observatory's 1.88-meter and 0.28-meter telescopes in refining the orbital parameters and positional predictions of asteroids, comets, space debris, and satellites. The telescopes are employed for differential astrometry and multi-band photometry, leveraging their capabilities for long-term monitoring and high-precision measurements. Challenges such as atmospheric effects, light pollution, and observational biases are addressed, focusing on how these are mitigated using advanced calibration methods and image processing techniques. The study underscores the pivotal role of the Kottamia telescopes in supporting international observation campaigns and advancing the accuracy of solar system ephemerides.

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Contribution type: Oral presentation
Participation: In person

A PCA based effective model for asteroid accelerations

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Fitting asteroid masses using planetary ephemerides is a well-studied technique, but traditional implementations face challenges such as correlations between asteroid masses, poorly characterized systematic errors, and overfitting. We present a method that applies linearization and principal component analysis (PCA) to the accelerations induced by unmodeled asteroids on solar system bodies. We investigate how the number of principal components relates to uncertainties in the Earth-Mars distance and demonstrate how these components respond to new high-precision constraints, such as those expected from Bepi-Colombo. Finally, we explore what constraints these components place on individual asteroid masses.

Contribution type: Oral presentation
Participation: In person

Astrometric Precision of Light Deflection in Stellar Occultations: Gravitational Effects of Multiple Solar System Bodies

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Stellar occultations provide a crucial method for obtaining precise astrometric positions of Solar System objects. This precision primarily hinges on the temporal resolution of observations and the magnitude of the star. However, gravitational effects by massive bodies like the Sun and planets introduces systematic deviations, complicating astrometric measurements. This research investigates such astrometric effects during stellar occultations, considering the simultaneous gravitational influence of multiple Solar System bodies.

Astrometric measurements from occultations directly impact the determination of ephemerides for Solar System bodies [1]. Accuracies of 1 milliarcsecond or better are achievable, where light deflection becomes significant. With advancements in technology and precise measurements from missions like Gaia, even higher accuracies are anticipated. We aim to enhance the precision of astrometric measurements from occultations by understanding the limitations posed by light deflection, especially in scenarios involving multiple bodies.

This work examines the stellar occultation by Ganymede, one of Jupiter's largest moons, on December 21, 2020, as a proof of concept. During this event, the starlight traversed the gravitational fields of Ganymede, Jupiter, Saturn, and the Sun. The methodology consider the gravitational contributions of these bodies and their influences on astrometric observations, aiming for precise estimation of the occulting object's position.

To achieve this, we employ tools such as the SORA package [2] and the parametrized post-Newtonian relativistic model for microarcsecond astrometry [3]. By combining theoretical analysis and numerical simulations, we assess gravitational light deflection in stellar occultations. Addressing these challenges contributes to refining astrometric precision, improving ephemerides, and advancing space navigation and planetary studies.

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Contribution type: Poster presentation
Participation: In person

Determination of the MESSENGER spacecraft orbit and calculation of Earth-Mercury range points by processing raw range and doppler data

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Precision interplanetary ranges (range points) are essential for building modern planetary ephemerids. In particular, Earth–Mercury range points allow not only to determine the orbit of Mercury, but also to study physical properties of the Sun and test General relativity [1]. While there exist publicly available range points derived in JPL [2,3] from raw MESSENGER radio science data, we aim to provide an independent analysis.

We processed the X-band raw radio data—range and Doppler delay in the timespan of April 2011 – March 2015. The raw data are in the Orbit Data File (ODF) format, produced by the Radio Metric Data Conditioning Team (RMDCT) at NASA's Deep Space Network (DSN). Data processing was carried out taking into account the action of solar plasma, calibration corrections and a relativistic model of signal propagation.

The integration of the MESSENGER spacecraft orbit was carried out taking into account the non-uniform gravitational potential of Mercury and the disturbances caused by the Sun and planets. After fitting the orbit to raw radio observation data (Doppler and range data) and then reducing the raw ranges to the center of Mercury, range points between DSN stations and the center of Mercury were obtained.

Similar work is planned with radio science data of Mars orbiters—Odyssey and MRO, which are still producing new data.

Work was done under guidance of Dmitry Pavlov.

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Contribution type: Oral presentation
Participation: In person

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Rotating-drift-scan observation and orbit determination of near-Earth asteroids

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Precise observations of near-Earth asteroids (NEAs) are critical for extending observational arcs, refining their orbits, and ensuring Earth's safety through accurate impact prediction. However, their high apparent motion during close Earth encounters presents a significant challenge to precise observation. The rotating-drift-scan (RDS) charge-coupled device (CCD) technique offers a promising solution for observing these fast-moving NEAs during close approaches. By rotating the telescope camera, time delay integration is enabled, allowing the NEA to be imaged as a point source despite long exposure times. Here, we make RDS follow-up observations and perform orbit determination to conduct a detailed statistical analysis of astrometric errors. It reveals that RDS observation achieves competitive accuracy with a root-mean-square (RMS) error of 0.24 arcseconds in right ascension and 0.32 arcseconds in declination [1]. Telescope instability is likely to be the main reason affecting the precision. Moreover, the RDS technique excels at observing fast-moving NEAs. For NEAs with rates of motion exceeding 10 deg/day, the RMS of RDS observation residuals is 0.35 arcseconds in the along-track direction and 0.23 arcseconds in the cross-track [1]. Therefore, a network of small-aperture telescopes using the RDS technique would be a significant asset to the global NEA monitoring system.

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Contribution type: Poster presentation
Participation: In person

Radar astrometry of near-Earth asteroids from the Arecibo Observatory

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The Arecibo Observatory had the world's most powerful planetary radar system until December 2020, which provided ground-based observations whose quality could only be exceeded with a spacecraft flyby. Radar allows one to characterize near-Earth asteroids (NEAs) in terms of size, shape, spin, and surface properties, and to discover natural satellites that form binary and triple asteroid systems. In addition, radar astrometry is a valuable tool for orbit refinement, providing precise measurements that can significantly improve the accuracy of orbit determination [1]. Every year about 40-60 recently discovered NEAs were observed at Arecibo.

Radar offers the great advantage of controlling the properties of the transmitted signal. The changes in the received echo compared to the transmitted signal provides clues about the characteristics of the object. The time delay gives information about the distance to a target with precision as fine as meters, and the Doppler-shifted frequency of the echo provides the radial velocity with precision as fine as mm/s, making it possible to detect even small changes in the orbit due to perturbations, such as the nongravitational acceleration generated by the Yarkovsky effect. Radar astrometry can also quickly eliminate impact false alarms with the improvement of estimates of an asteroid's orbital elements. Therefore, radar astrometry is crucial for planetary defense.

We will present an overview of radar astrometric observations of NEAs obtained using the Arecibo planetary radar system during nearly 60 years of operations and how their orbits were secured after radar observations. Especially for newly discovered objects, that usually have large orbit uncertainties, Doppler and/or range measurements can prevent the object from being lost and requiring re-discovery in the future.

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Contribution type: Poster presentation
Participation: In person

Analytical Representation of Saturnian Satellite Numerical Ephemerides over Limited Time Spans

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Numerical integration ephemerides are highly valued in both research and engineering due to their exceptional precision. However, their application in theoretical studies, particularly in the investigation of rotation and evolution, is constrained by their finite available time spans. In our previous work [5], we effectively explored an analytical representation of the mean longitude of Titan from the Jet Propulsion Laboratory (JPL) ephemerides. We established this representation as a function of combinations of proper frequencies and compared the results with those obtained from the synthetic ephemerides of the Théorie Analytique des Satellites de Saturne (TASS) [3, 4].

Building upon this, we have extended our analytical representations beyond the mean longitude to the other osculating elements of the Titan ephemeris [6]. This enables us to develop new synthetic representations that combine the strengths of both approaches: the long-term stability and system complexity inherent in TASS.

In our current work, we have shifted our focus to the NOE ephemerides from the Paris Observatory. Unlike the JPL ephemerides and the synthetic TASS ephemerides, the NOE ephemerides account for Saturn's tidal effects and long-period solar terms within their perturbation calculations. This results in a more complex analytical representation of the NOE ephemeris compared to the JPL ephemeris. Notably, these representations encapsulate crucial dynamical information, including proper frequencies, which are invaluable for theoretical research.

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Contribution type: Oral presentation
Participation: In person

SESSION 6: Astronomical standards

INVITED CONTRIBUTION

Role and Activities of the GGOS Bureau of Products and Standards

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The Bureau of Products and Standards (BPS) is a key component of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). It supports GGOS in its goal to provide consistent geodetic products needed to monitor, map, and understand changes in the Earth's shape, rotation, and gravity field. A major objective of the BPS is to keep track and foster homogenization of adopted geodetic standards and conventions as a fundamental basis for the generation of consistent geodetic products, such as the celestial reference frame, the terrestrial reference frame, Earth Orientation Parameters, satellite orbits, gravity field models and heights. This requires a close collaboration across all IAG components, as well as with other bodies dealing with standards and conventions, such as the IAU Commission A3 "Fundamental Standards", the International Organization for Standardization (ISO) and the Committee on Data for Science and Technology (CODATA).

This contribution presents the role of the BPS and it highlights some of the recent activities. A key issue is the regular update of the BPS inventory of standards and conventions used for the generation of geodetic products to incorporate the latest developments in the field. Further activities focus on the description and promotion of geodetic products to make other disciplines and society aware of geodesy and its beneficial products, and on the definition of Essential Geodetic Variables (EGVs).

Participation: Online

Status of the IERS Conventions

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The International Earth Rotation and Reference Systems Service (IERS) Conventions describes the reference systems realized by the IERS, in addition to developing and maintaining the models and procedures used to support this endeavor. The IERS Conventions Centre has been preparing to release an updated conventions from the current Conventions (2010). This presentation will give an overview of the IERS Conventions as well as discuss the proposed changes to the chapters and their technical content including the changes in the associated experts and editors. A timeline for the proposed release of the updated conventions will also be discussed. Additionally, we will give an overview of the procedure and criteria for requesting and releasing minor and moderate updates to the conventions that happen in between major releases.

Participation: Online

INVITED CONTRIBUTION

Standard of Fundamental Astronomy

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Standards of Fundamental Astronomy (SOFA) is a functional working group in Division A which continues to provide an accessible and authoritative set of algorithms and procedures that implement standard models used in fundamental astronomy. This talk reports the current status of the SOFA WG and gives an overview of the services that it provides, in particular the SOFA software collection, which covers a variety of topics including astrometry, Earth orientation, and time scales, together with angle/vector/matrix tools. It also includes the documentation and cookbooks that accompany this software and current usage of SOFA software.

Participation: In person

Constellation Boundaries Update - 21st Century Complete

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For millennia, humans used asterisms to track seasons, tell cultural stories, and measure time, as seen in artifacts like the Dendera Zodiac (circa 50 BCE) [1] and the Babylonian MUL.APIN [2]. John Flamsteed's Atlas Coelestis (1729) [3] reflects this, mapping stars within traditional asterisms while including some telescopic stars. Flamsteed preserved overlaps, such as Capricornus' stars in Aquarius' arm [4]. However, Eugène Delporte's 1930 IAU standardization introduced 88 constellation boundaries using straight lines of right ascension and declination, aligned to the B1875.0 and B1900.0 epochs [5, 6], fundamentally changing this system. Using Carte du Ciel software to observe existing constellation boundaries [7] and Flamsteed's charts, we identified discrepancies in the Pisces-Aquarius-Capricornus-Cetus region. Stars like 11 Peg, HD 209522, HD 210848, and Eta Psa were reassigned by Delporte's lines disrupting cultural coherence [8]. Today, celestial maps' original roles—seasonal prediction, storytelling, and timekeeping—are obsolete, replaced by digital age technologies like meteorology and atomic clocks [9]. Delporte's Earth-centric boundaries also face obsolescence due to precession and stellar motion [10, 11]. We advocate for a dual framework to preserve cultural heritage while advancing astronomical precision, archiving cultural asterisms as borderless to preserve their historical significance, while adopting a universe-centric system using the International Celestial Reference System (ICRS) [12] and Gaia's 3D stellar data [13, 14], balancing heritage with future astronomical precision. This approach not only honors our astronomical heritage but also embraces the precision required for future celestial exploration.

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Contribution type: Poster presentation
Participation: Online

Reconsidering the Definition of the Galactic coordinate system

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The definition of the Galactic coordinate system (GalCS) in the FK4 reference frame was announced by the IAU in 1958. For nearly 70 years, the definition of the GalCS has remained unchanged from the initial IAU1958 version, and there may exit some misunderstandings in the transformation and application of the GalCS.

We re-determine the position of the Galactic plane based on modern all-sky infrared catalogs. After removing their systematic errors with respect to the Gaia-CRF3, the AllWISE and the CatWISE2020 are used for this purpose. We also propose an updated definition of the GalCS by adopting the ICRS position of the Sgr A* at the Galactic center. We find that the obliquity of the Galactic equator with respect to the ICRS principal plane is about larger than the J2000.0 value given by the Hipparcos team. The new transformation matrices and parameters describing the orientation of the Galactic coordinate systems in the ICRS are derived at 1 milliarcsecond level to match the precision of modern observations. For practical applications, we propose that a revised definition of the Galactic coordinate system should be adopted in the near future.

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Participation: In person

Thank you to all participants!