

Reference systems and their ties with the rotation of the Earth and other Solar System bodies

A proposal for an IAU General Assembly Symposium for 2021

Location: Busan, Republic of Korea

Dates: August 18–22, 2021

Coordinating Division: Division A Fundamental Astronomy

Jointly proposed by:

(1) Commission A2 Rotation of the Earth (Lead)

(2) Commission A1 Astrometry

(3) Inter-Division A/F WG on Cartographic Coordinates and Rotational Elements (WGCCRE)

In addition, the chairs of the following IAU bodies are involved either in the SOC and as session conveners or as invited speakers:

- Commission A3 Fundamental Standards
- IAU CA2/IAG/IERS JWG on Consistent Realization of TRF, CRF and EOP
- IAU CA2/IAG JWG on Improving Theories and Models of the Earth's Rotation (ITMER)

Formal endorsements have been received from:

- Division A
- Commission A3 Fundamental Standards
- Commission A1 Astrometry
- Commission A2 Rotation of the Earth including
 - IAU CA2/IAG/IERS JWG on Consistent Realization of TRF, CRF and EOP
 - IAU CA2/IAG JWG on Improving Theories and Models of the Earth's Rotation (ITMER)
- Inter-Division A/F WG on Cartographic Coordinates and Rotational Elements (WGCCRE)
- (Division F formal support could not be given by the time of submission due to Division F scheduling reasons)

Scientific Organizing Committee Co-Chairs:

Florian Seitz, Technical University of Munich, Germany (President of CA2, contact)

Jean Souchay, Observatoire de Paris, France (President of CA1, ex-officio)

Brent Archinal, U.S. Geological Survey, United States (Chair of WGCCRE)

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Proposed Editors:

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Jean Souchay, Observatoire de Paris, Paris, France

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Key Topics:

- State of the art, new developments and scientific challenges in Gaia and VLBI observations
- Next generation Celestial Reference Frame: towards a combined radio and optical multi-band CRF
- Practical aspects of defining and maintaining reference systems and frames for Solar System bodies (planets, moons, asteroids, comets)
- Relating and combining celestial and planetary reference frames
- Rotation of the Earth and other Solar System bodies: theories, models, and analysis
- Internal structure of planetary bodies and its connection with their rotation
- New and emerging measurement systems
- Future space astrometry and its ties with astrophysics

Abstract:

Celestial and planetary reference systems provide the fundamental framework for referencing astronomical and space-geodetic observations. Precise realizations of these systems, the so-called reference frames, are of paramount importance for positioning and navigation on Earth and across the Solar System as well as for the measurement of time. Celestial and planetary reference frames are connected through orientation and spin of the planetary bodies. Thus, precise reference frames fundamentally require precise knowledge of the rotation of the Solar System bodies both in a theoretical and observational point of view. Besides, the knowledge of the rotation of Solar System bodies is precious for studying their internal structure and geophysical phenomena.

Emerging observation technologies, such as planetary probes and the astrometric Gaia mission, contribute to new data types for the determination of celestial reference frames and rotation models. The Symposium will address challenges and opportunities related to the analysis and combination of well-established and new observation techniques leading to next generation reference frames and rotation series at the highest level of consistency and accuracy. Therefore topics include new scientific results from astrometric observations and rotation series in astronomy, geodynamics and internal structure modeling.

Rationale:

During recent years, great progress has been made in the construction of the Celestial reference frames. In 2018, the IAU adopted the Third realization of the International Celestial Reference Frame (ICRF-3) determined from VLBI observations as the fundamental realization of the ICRS. In 2013 ESA launched the Gaia space mission to determine a new highly-accurate celestial reference frame in the optical domain (Gaia Celestial Reference Frame). The proposed Symposium will be a forum to discuss the new developments, scientific challenges and the consistency of the link between the radio and optical frames focusing on their mutual orientation and rotation. Furthermore, we will discuss how a next generation multi-band CRF combining both frames at micro-arc second level accuracy could be realized. It will in particular benefit from the expertise generated in the Division A WG Third Realization of the ICRF.

In addition, the quasars observed both by VLBI and by Gaia DR2 (and in the future DR3) are of particular interest. Their radio and optical data lead to challenging questions which will be addressed during this symposium, such as: how can we explain their positional offset? How well can we model the source structure in radio and optical wavelengths to mitigate these offsets? Is there a correlation between radio flux and optical magnitude variability? What is the link between the positional uncertainty/instability in both domains? Some of these questions involve the astrophysical models of the quasars, and the ties between astrometric and astrophysical constitutes a new exciting field of interest.

For defining planetary coordinate systems, the IAU and the Working Group on Cartographic Coordinates and Rotation Elements (WGCCRE) established fundamental principles primarily in the 1970s. Related to these definitions, the Symposium shall address the following questions: Are these principles still adequate? Are changes needed? E.g. for bodies where a

longitude definition has been previously defined based on ground-based observations, how should that (or should it) be maintained for spacecraft observations? What are the best methods for recording the fundamental parameters defining cartographic coordinates and rotational elements for well-studied bodies? What procedures need to be further recommended for establishing and updating these coordinate systems and frames? Does it make sense to switch from the existing widespread use of planetographic systems for planets and satellites to planetocentric coordinate systems?

The Celestial reference frame and the respective reference frame of a Solar System body form an interconnected trio with its rotation, because the latter is defined as the link between the orientations of the two frames. One key topic of the Symposium will be the discussion of theoretical concepts for the realization of consistent frames and rotation parameters as well as the practical implications of this goal. In particular, for the Earth's rotation the consistency between ICRF, ITRF (International Terrestrial Reference Frame) and the Earth Orientation Parameters is requested by two resolutions of IUGG and IAG and subject of a new IAU CA2/IAG/ IERS Joint WG to be established in early 2020.

The Symposium will be a forum to discuss the theories, models, and the analysis of the rotation of the Earth and other Solar System bodies. For the Earth, dedicated observations of its polar motion and spin are available since the end of nineteenth and mid-twentieth century respectively with constantly increasing accuracy. However, the accuracies at the millimeter level on the surface of the Earth required by IAG's Global Geodetic Observing System GGOS for the reliable determination of global change impacts can still not be met as has been recognized in the final reports of recent IAU CA2/IAG Joint WGs on the Theory of Earth Rotation (2013-2015, 2016-2019). This challenge requires further improvement of theories and models of Earth rotation (which is subject of the newly established IAU CA2/IAG Joint WG on Improving Theories and Models of the Earth's Rotation) as well as new and refined approaches for the combination of different space-geodetic observations. Concerning other planets, satellites, asteroids, and comets, observational data on their rotation are presently limited. In the future, we anticipate a dramatic improvement in our knowledge on the rotation states of Mars (from NASA's InSight mission), the Galilean satellites (ESA's JUICE and NASA's Europa Clipper missions), and of several asteroids (e.g. from the Dawn, Hayabusa, OSIRIS REx, and Psyche missions). Planets, moons, and small bodies experience a variety of forcings that produce a rich array of rotational modes.

Another fundamental point is that the theoretical framework for rotational models used by the WGCCRE was established about 40 years ago, when space exploration had just begun. It is appropriate to now consider revising this framework and to adapt it as needed to the new knowledge on the rotation states. To achieve this goal, much can be learned from the theoretical framework already in use for Earth's rotation.

Observations of the rotation of Solar System bodies – encompassing the rate of rotation, the position of the rotation axis with respect to the planetary reference frame (polar motion), and with respect to the CRF (precession and nutation) – show changes on multiple observable timescales, reflecting a wide variety of the exogenous and endogenous processes. The Symposium will provide a forum to discuss analyses of the observed changes for the Earth and other Solar System bodies. With respect to the later, there is great interest in research related to their internal structure, including the “Ocean Worlds” of Europa, Titan, Enceladus, and others. Related questions will be: What information on this structure has been derived or can be derived in coming years with current or future datasets, via analysis of body orientation parameters, e.g. for libration and tides? What types of new datasets need to be collected? What types of analysis techniques are useful for deriving such information? We aim at getting new insight on these topics.

Finally, the Symposium seeks contributions discussing new or improved astrometric and geodetic observation techniques and networks for the determination of reference frames and rotation series, including combinations of different observing techniques.

Important information:

A colloquium “Journées 2019: Astrometry, Earth Rotation and Reference Systems in the Gaia era” was held recently in Paris (2019, Oct. 7-9) gathering 120 scientists from all over the world, for a large part members of Commissions A1 and A2. This large participation **constitutes the proof that the proposed topics for discussion during the Symposium are of high scientific relevance** and comprise exciting investigations. Thus, it is appropriate that the Journées 2019 meeting will be followed within two years by an IAU Symposium including (but not exclusively) its common topics. We expect an attendance of about 125-150 people.

In this regard, it is worth pointing out that the last official IAU meetings related to the fundamental topics considered in this proposal **were held more than twenty years ago**, and even then, none included Solar System issues as a topic. None were done as a Symposium:

- IAUC 56 “Reference Coordinate Systems for Earth Dynamics”, 1980
- IAUC 128 “The Earth’s Rotation and Reference Frames for Geodesy and Geodynamics”, 1986
- IAUC 178 “Polar Motion: Historical and Scientific Problems”, 1999
- IAUC 180 “Towards Models and Constants for Sub-Microarcsecond Astrometry”, 2000

As regard to astrometry, some previous IAU Symposia (e.g., IAUS 348: 21st Century Astrometry: crossing the Dark and Habitable frontiers) targeted different goals than those considered here. In particular, the proposed Symposium aims at integrating astrometry from the perspective of serving as a fundamental tool in the realization of the reference frames defining the orientation of the Earth and other celestial bodies of the Solar System.

Program Outline:

We plan a Symposium comprising a Plenary Session and 9 oral sessions (1:30 h each). They can be arranged in 4 days in coordination with the organization of the GA. The Plenary Session will highlight the key topics of the Symposium by three invited talks (30 minutes each). Each of the regular sessions will be opened by a Keynote Talk (30 minutes) and followed by up to 4 contributed talks (15 minutes). Posters related to the topics of the sessions may be on display during the whole duration of the Symposium and may be presented during one or two dedicated time slots outside of the oral sessions.

Plenary Session:

François Mignard (OCA, France)

Optical and radio Celestial Reference Frames: state of the art and future prospects

Richard Gross (NASA/JPL, USA):

Earth Rotation: Connecting the Earth to Space

Al Conrad (Large Binocular Telescope, USA)

Sizing up small bodies: New technologies - New challenges

Topic 1: Reference systems

Session 1:

New developments and scientific challenges in Gaia and VLBI observations for the determination of radio and optical Celestial Reference Frames

Convener: Patrick Charlot (Université de Bordeaux, France)

Keynote talk: Aletha De Witt (SARAO, South Africa)

Session 2:

Next generation Celestial Reference Frame: Towards a combined radio and optical multi-band CRF

Convener: Zinovy Malkin (Pulkovo Observatory, Russia)

Keynote talk: Nathan Secrest (US Naval Observatory, USA)

Session 3:

Consistent realization of celestial reference frame, terrestrial reference frame and the Earth orientation parameters

Convener: Daniela Thaller (IERS Central Bureau, Germany)

Keynote talk: Robert Heinkelmann (GFZ, Germany)

Session 4:

Defining and maintaining reference systems and frames for Solar System bodies

Convener: Brent Archinal (USGS, USA)

Keynote talk: Randolph Kirk (USGS emeritus, USA)

Topic 2: Observations and emerging measurement systems

Session 5:

Current and emerging technologies for the determination and dissemination of reference frames and rotation series

Convener: Flora Paganelli (SETI Institute, USA)

Keynote talk: Charles Acton (NASA/JPL, USA)

Session 6:

Future space astrometry and its ties with astrophysics

Convener: Sergei Klioner (Lohrmann Observatory, Germany)

Keynote talk: David Hobbs (Lund Observatory, Sweden)

Topic 3: Rotation of the Earth and other Solar System bodies: Theories, models, analysis and application

Session 7:

Improving Theories and Models of Earth rotation

Convener: Cheng-Li Huang (Shanghai Astronomical Observatory, China)

Keynote talk: Jose Manuel Ferrándiz (University of Alicante, Spain)

Session 8:

Analysis and prediction of Earth rotation and its ties with geodynamic processes

Convener Jolanta Nastula (Space Research Center, Poland)

Keynote talk: Sigrid Böhm (Vienna University of Technology, Austria)

Session 9:

Rotation and internal structure modeling of Solar System bodies

Convener: James L. Hilton (US Naval Observatory, USA)

Keynote talk: Rose-Marie Baland (Royal Observatory of Belgium, Belgium)

Inclusion of young researchers and dissemination to students:

The SOC particularly welcomes contributions from young researchers which will be given room in the regular oral and poster sessions. This way the young researchers will be able to present their research and ideas to experienced colleagues, receive valuable feedback and networking possibilities. Various SOC members have longstanding experience in teaching and in organizing actions towards young researches and students, like summer schools, seminars, tutorials, etc. We are eager to collaborate with GA local organizers in order to develop such activities if they can be accommodated during the time of the Symposium.