

Division A – Annual report 2016

Anne Lemaitre – president

Daniel Hestroffer – vice-president

The Committee: rules and roles

The year 2016 was the opportunity for Division A to settle down, to organize the work and the duties in the new context established in August 2015 by the General Assembly. The committee started discussing, exchanging requests or information, protesting or claiming against the new rules. A part of these discussions was reported at the EC meeting at Mexico in May 2016 to clarify and optimize some of the new procedures.

The committee is composed of:

Anne Lemaître (President)

Daniel Hestroffer (Vice-President)

Susan Stewart (Secretary)

Sergei Klioner (Past-president)

Anthony Brown (Commission A1 President)

Richard Gross (Commission A2 President)

Catherine Hohenkerk (Commission A3 President)

Cristian Beaugé (Commission A4 President)

William Folkner (Representative Commission X2)

Felicitas Arias

Nicole Capitaine

Sylvio Ferraz-Mello

Ralph Gaume

Fernando Roig

The committee is now very receptive about the different strategies of the division, and most of the members take an active part to the discussions, choices or selections of projects.

The Working Groups: creation, types, statutes, membership

In the IAU new rules of 2015, the status of the Working Groups, in particular, has changed; they are now created for 3 years, automatically dissolved after, and have to be recreated or renewed if necessary after a new proposal by the concerned division(s).

However, besides this dynamical creation and disappearance of WGs with a specific short mission, a particular class of Working Groups has appeared, called *Functional Working Groups* with a permanent mission, with constant objectives, collecting and controlling data, improving unities or constants knowledge, establishing standards, and certainly not linked to a specific period of time. In Division A, these tasks are well present and numerous, and most of the members of the committee estimated that four (at least) of the WGs depending on Division A had to become Functional.

The first two functional WGs selected by Division A concerned the standards (SOFA, NSFA) and the third one has been created in 2016 to compensate the disappearance of the ex-commission responsible for the Time. It was proposed as a new Functional Working Group, called Time Metrology Standards, and approved in the EC Meeting of May 2016 at Mexico. The Working Group shared with Division F (called WGCCRE) was again approved by both divisions, after several exchanges about its missions, specificity and exact competences, and also recognized as *Functional*.

Proposals for IAU symposia and focus meetings

In September 2015, just after the 2015 General Assembly, it was very difficult for the committee to stimulate the scientific community of Division A to propose Symposia for 2017. After several contacts, the projects were postponed or forgotten, and Division A was reduced to a few supports of symposia, proposed by the other divisions, without any proposal as coordinating division.

In September 2016, two symposia and a focus meeting were proposed for the 2018 GA, and several projects were discussed for future years. These projects were officially confirmed in December 2018 in the final call for symposia and cover several of the main interests of the division. Several discussions could lead to new proposals for 2019.

Division A was also contacted as supporting division by about ten applicants (6 symposia and 4 FM), and for each proposal, a debate and a discussion in the committee followed and the decisions were taken collegially.

New organization of IAU bodies

The project of creating a Division Newsletter was discussed in the committee, with very different positions. Some of the commission presidents preferred to create this newsletter in the commission itself with a more restrictive but targeted public, than in the division, with a too large scope. This was the decision taken for 2016, to push the local initiatives, as Commission A4 project, which is now effective. The fact that everyone now belongs at least to a division but also at least to a commission, should reinforce this choice of commission newsletters. The system is new, not yet integrated in all minds, but is evolving in the right direction.

Let us also mention that the communication with the Division A members should be improved. More information could be sent, more advices or comments could be encouraged, directly from the division, and not only from the commissions.

Mandates and representatives

Several commissions (A2 and A3 for example) have to designate quite a lot of IAU representatives for different associations, out of IAU but with close interests. With the limited number of scientists in the committees of the commissions, it is almost impossible to answer to all these requests. A first idea was to extend the number of officers, but it was not accepted. The only solution is to choose those representatives in the commission as a whole, and not necessary among its officers.

The list of these representations for IAU is very long, and sometimes obsolete. A few representatives have to be recognized, or changed, or purely forgotten. The EC meeting of May 2016 pointed out this problem, and the list should be checked and improved before the next EC meeting of 2017.

PhD Prizes

The idea of a PhD prize to motivate the young scientists to participate to IAU meetings and bodies was very well received by Division A. However, the publicity about the prize was not efficiently performed by the committee members, and very differently announced in the national committees. This first year was not productive, and no application was retained for the prize. The challenge for 2017 is to communicate directly with the whole scientific community in a more efficient way, with several calls and reminders.

Political discussions

At least twice in 2016, a debate exploded in the committee, to qualify a political position or to select an appropriate answer to an international event. The main question is always the same: should a scientific organization react to political chocking events or should it keep its total neutrality? Of course, there is no answer and the committee decided to follow IAU official position.

Summary of the commissions and WG reports

The Commissions A1, A2, A3 and A4 sent their annual reports 2016, annexed to the present report, in different styles and presentations, but all showing their dynamism and excellent scientific results. Their objectives are very different, and not directly comparable, but the important point is their achievement. Commission X2, shared with Division F, has not sent any report in Division A, but probably did to Division F.

For the WG, depending on Division A, SOFA, NSFA, ASGBT and CCRE (shared with Division F) sent their annual reports, again with different styles, detailed or synthetic, but all active. The WG TMS and MWR-IRCS were created in 2016, and they needed some time to list their members and organize their tasks. No report was available for 2016.

IAU Commission A1 - Astrometry

Anthony Brown, Norbert Zacharias, Yoshiyuki Yamada, Jean Souchay, Alexandre Humberto Andrei, Dafydd Evans, Stephen Unwin

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Gaia mission

The first release of Gaia data (Gaia DR1, Gaia Collaboration et al 2016) took place on September 14 2016. This first Gaia catalogue consists of 1.1 billion sources to magnitude 20.7 for which positions are provided with typical uncertainties of 10 milliarcsec. For a subset of about 2 million sources from the Hipparcos and Tycho-2 catalogues proper motions and parallaxes are provided with a typical uncertainty of 1 milliarcsec/yr and 0.3 milliarcsec, respectively.

Gaia DR1 represents a large step forward in the densification of the astrometric reference frame in the optical at faint magnitudes, and has consequently already been employed as the reference positional catalogue for several other large surveys (see below). The radio positions of around 2000 ICRF2 sources were compared to the optical positions from Gaia (Mignard et al 2016). No systematic differences larger than a few tenths of a milliarcsec were found. For most sources the true offsets are likely to be less than 1 mas. This is a very encouraging result in connection with the efforts to develop multi-wavelength realizations of the ICRS.

The optical tracking of the position of Gaia on the sky was continued throughout 2016 by the GBOT (Ground Based Optical Tracking). The aim is to get an optimized position of the satellite with respect to the surrounding stars. The observations are made with the help of CCD frames taken at the focus of T1-2m class telescopes located at various places in the world. The requirements for the accuracy on the satellite position determination, with respect of the stars in the field of view, are 20 mas (corresponding to 150 meters at the distance to Gaia). This accuracy is necessary to correct at best the relativistic aberrations as well as the parallax effects of solar system objects. More specifically the "Data Storage and Processing center of Gaia - GBOT" is sub-group located at Paris Observatory in charge of the GBOT database and image reductions programs specifically adapted for tracking moving objects. In 2016, about 3200 frames of Gaia satellite have been reduced

Reference frame sources

The LQAC (Large Quasar Astrometric Catalogue) is a general compilation of all the recorded quasars, coming from large surveys (SDSS, 2DF, ...) as well as from small ones. It contains various original information (when available) such as the most accurate equatorial coordinates, the red-shifts, multi-band magnitudes, radio-fluxes. Moreover, it provides supplementary data such as absolute magnitudes and morphology index. A new up-date of the catalogue, the LQAC-4 was in preparation in 2016, following on from the LQAC-2 (2012) and the LQAC-3 (2015). As a new important input this update will contain the cross-

identifications with the Gaia DR1 catalogue. The publication of the LQAC-4 is scheduled for 2017. It will contain 443725 objects with 248788 cross-matched with Gaia DR1.

A specific photometric study of ICRF quasars in R and V bands (Taris et al., 2016) was done in order to determine the flux variability of a set of 14 ICRF quasars pre-selected for the link between the ICRF and the future Gaia Celestial Reference Frame. High frequency light-curves of each quasar of the set were constructed, together with a periodogram analysis proving periodic or quasi-periodic phenomena. This variability should be accompanied with displacements of the photocentre and thus should have consequence on the astrometric quality. This deserves further investigation.

Ground based astrometry

Altmann et al. generated a new proper motion catalogue of 580 million stars (HSOY) by combining Gaia DR1 data with re-reductions of PPMXL (arXiv:1701.02629).

The URAT Parallax Catalog (UPC) by Finch and Zacharias was published (arXiv:1604.06739, CDS I/333). It contains first trigonometric parallaxes of over 53,000 nearby stars along with URAT parallaxes of over 58,000 previously known nearby stars.

A re-reduction of the UCAC data was performed to obtain new proper motions of over 107 million stars (UCAC5) by combining with Gaia DR1 data (Zacharias, Finch, Frouard 2017 submitted). This extends Gaia DR1-level precision of proper motions to about magnitude 14, with somewhat poorer data to R=16.

The USNO redlens astrograph (URAT project) continues to observe from Cerro Tololo, focusing on bright stars (Sirius to 6th mag). UCAC5 is used as reference star catalogue, which in turn is based on Gaia data.

The first Pan-STARRS data release (PS1) was prepared during 2016. The data are available through the MAST Portal of the Space Telescope Science Institute (STScI) since Feb 2017. The survey is described by Chambers et al. (arXiv:1612.05560), <http://panstarrs.stsci.edu/>.

Regular operation of the VLBI Exploration of Radio Astrometry (VERA) array continued in 2016. Astrometric observations of Galactic masers were conducted for approximately 1800 hrs. Astrometric observations for 150 maser sources were completed, and parallaxes were derived for 86 maser sources (71 star-forming regions and 15 late-type stars). In 2016, the parallaxes and proper motions have been reported for several Galactic maser sources such as S255 (Burns et al. 2016), M17 (Chibueze et al. 2016), FV Boo (Kamezaki et al. 2016a), U Lyn (Kamezaki et al. 2016b), and R UMa (Nakagawa et al. 2016). Also, Yamauchi et al. (2016) demonstrated that even for sources at a distance of ~ 20 kpc, a relatively accurate distance can be estimated based on proper motions when combined with the Galactic rotation law. This new approach will be of help to explore the structure of the Galaxy where parallax measurements are not currently available. Oyama et al. (2016) demonstrated the capability of simultaneous observations of SiO ($J=1-0$) maser lines at four transitions (28SiO $v=1,2,3$ and 29SiO $v=1$).

The resources of the Korea-Japan joint array (KaVA: KVN and VERA Array) and East Asian VLBI Network with participation of China, Korea and Japan were joined. Test observations have been conducted with these arrays including evaluation of astrometric performance with an eye toward future astrometric with this extended array.

Steps toward future astrometric observations with SKA were taken through the demonstration of high precision radio astrometry at low frequency bands using the existing VLBI arrays such as the VLBA (Rioja et al, arXiv:1612.02554). It was confirmed that astrometry with an accuracy of at least a 100 microarcsec level is technically feasible for astronomical maser sources and that reaching the 10 microarcsec level accuracy is feasible.

Space astrometry missions

A proposal for the extension of the Gaia mission beyond its nominal five years' duration (to mid-2019) was submitted to ESA. Current estimates are that Gaia can continue collecting observations until the end of 2023, the only limitation being the propellant for the micro-thrusters that are used to accurately maintain Gaia's attitude and spin-rate.

The proposal for the Theia mission was submitted to the ESA/M5 call for missions. It aims at differential microarcsec astrometry with the goals of studying the nature of dark matter and the equation of state of matter in extreme environments, and finding habitable Earths (<http://www.obs.u-bordeaux1.fr/m2a/krone/Theia/>).

A proposal was submitted to ESA to initiate industrial scientific studies into the developments needed to realize a future Gaia-like mission operating in the near-IR (in particular operating infrared sensitive detectors in TDI mode). The goal is to open up the large discovery space accessible through high accuracy astrometric measurements in the infrared (Hobbs et al, arXiv:1609.07325).

In Japan, the efforts on the JASMINE mission continued. JASMINE is an abbreviation of Japan Astrometry Satellite Mission for Infrared Exploration.

Three satellites are planned as a series of JASMINE projects, as a step-by-step approach, to overcome technical issues and promote scientific results (Gouda 2011, Gouda 2012). These are Nano-JASMINE, Small-JASMINE and (medium-sized) JASMINE. Nano-JASMINE will operate in the z_w-band (0.6-1.0 micron). The target accuracy of parallaxes is about 3 milliarcsec at z_w=7.5 mag (Kobayashi et al. 2011). By combining Nano-JASMINE measurements with Hipparcos positions accurate proper motions (to about 0.1 milliarcsec/yr) can be derived. Although the flight model of Nano-JASMINE is ready, the search for a suitable launch opportunity is still ongoing.

Small-JASMINE will determine positions and parallaxes accurate to 20 microarcsec for stars towards a region around the Galactic nuclear bulge and other small regions which include scientifically interesting target stars (e.g. Cyg X-1), brighter than H_w=11.5 mag (H_w-band: 1.1-1.7 micron). Proper motions of between 10 and 50 microarcsec/yr are expected. The survey will be done with a single beam telescope of which the diameter of the primary mirror is about 30 cm (Yano et al. 2011). The target launch date is around 2021. The

proposal for Small-JASMINE was ranked highest by JAXA in terms of scientific quality and technical feasibility.

The outcome of the mission design review is expected in 2017.

(Medium-sized) JASMINE is an extension of Small-JASMINE, which will observe almost the whole region of the Galactic bulge with accuracies of 10 microarcsec in Kw-band (1.5-2.5 micron). The target launch date is the 2030s.

Additions

- Two major meetings draw together the astrometric community in South America, the LARIN 2016 (XV Latin American Regional IAU Meeting; October 3-7) and the AdeLA2016 (Astronomía Dinámica en Latino América; September 28-30. Both were held in Colombia, the first in Cartagena, and the second in Bogota.
- The relatively rare transit of Mercury over the Sun, 09 May 2016, was full visible across most South-America, and followed by many teams of the region.
- Including several countries in South America (Argentina, Bolivia, Brazil, Uruguay) independent cooperations, with groups from Russia, Europe, and China are increasingly using existing small telescopes, or new, dedicated ones for programs of Space Debris discovering and surveying.
- Brazil – In Brazil, a cooperation between Observatorio Nacional and the Shanghai Astronomical Observatory is conducting a double program aiming not only at Space Debris, but also to the BEIDOU Chinese GNSS cloud. Beyond the existing RIOS iGMAS/BEIDOU station, studies were concluded to install a fundamental station over the Equator line, in the Brazilian state of Para.
- Also including several South America researchers, including the support of the most committed amateur groups, the program of asteroid occultation continued very strong. The program uses the GDR1 positions and the Gaia early announcements.
- Chile - Astrometry played the key part in the Pale Red Dot program, which includes a team from several institutions around the world. The most publicized result was the discovering of the signature of an Earth-like planet around Proxima Centauri.
- Chile – Further analysis of the Bayesian Cramér-Rao lower bound in astrometry, by a team from Universidad de Chile, keep bringing forth what can be actually expected from ground base astrometry.
- Argentina – Directly related to one of the major astrometry achievements in 2016, the Gaia GDR1, it must be highlighted the Malargüe (Argentina) is one of the two stations used to communicate with Gaia, and also used to receive the data packets.

IAU Commission A2 - Rotation of the Earth

Richard Gross, Florian Seltz, Alberto Escapa, José Manuel Ferrandiz, Daniela Thaller, Vladimir Zharov

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Co-Organized Symposium, Geodesy, Astronomy, and Geophysics in Earth Rotation - 18-23 July 2016; Wuhan, China

This joint science symposium, organized by Commission A2 (Rotation of the Earth) of the International Astronomical Union (IAU), Commission 3 (Earth Rotation and Geodynamics) of the International Association of Geodesy (IAG), and the International Earth Rotation and Reference Systems Service (IERS), and hosted by Wuhan University, Shanghai Astronomical Observatory and the Institute of Geodesy and Geophysics, was a forum for assessing our current ability to observe the Earth's time varying rotation, for assessing our current understanding of the causes of the observed variations, for assessing the consistency of Earth rotation observations with global gravity and shape observations, for exploring methods of combining Earth rotation, gravity, and shape observations to gain greater understanding of the mass load acting on the surface of the solid Earth, and for identifying improvements in the global geodetic observing system needed to further our understanding of the Earth's variable rotation.

Co-Organizing Symposium, Journées des Systèmes de Référence et de la Rotation Terrestre - 25-27 September 2017; Alicante, Spain

In the interest of enhancing the interactions between astronomy and geodesy, the Journées are devoted to the study of the space-time celestial and terrestrial reference systems and their evolution with time with the emphasis on the rotation of the Earth. The scope of the Journées will range from concepts and theoretical solutions to observational techniques and data analysis. The sub-title of this meeting is "Furthering our Knowledge of Earth Rotation" and our discussions will help to develop the tasks of the IAU/IAG Joint Working Group on "Theory of Earth rotation and validation" among others.

The topics to be discussed at the Journées include, but are not limited to:

1. Theory of Earth rotation variations: precession/nutation, polar motion, LOD/UT1
2. Observation methods of Earth rotation variations
3. Celestial and terrestrial reference systems and frames
4. Modelling of Earth rotation variations: solar system dynamics and global geophysical fluid mass transports
5. Relativity and new concepts in Earth rotation theory

Began Planning for Centennial Anniversary Celebration of Commission A2 June or July, 2019; Brussels, Belgium

The 100th anniversary of the IAU and of Commission A2 will be on July 28, 2019. The Constitutive Assembly of the International Research Council was held in Brussels during July 18-28, 1919. On the last day, July 28, the Assembly adopted a Statute creating the IAU. So, July 28, 1919 has been taken to be the birth date of the IAU (see <https://www.iau.org/about/90years/>) and July 28, 2019 will be its 100th anniversary. Along with creating the IAU, 32 Standing Committees were also created on July 28, 1919. One of these was Standing Committee 19 on Latitude Variations. In 1922, all the Standing Committees became Commissions. So, Standing Committee 19 on Latitude Variations became Commission 19 on Variation of Latitude. In 1964, this was renamed Commission 19 on Rotation of the Earth. In 2015, this became Commission A2 on Rotation of the Earth. So, July 28, 2019 also marks the 100th anniversary of Commission A2. To celebrate the centennial anniversary of Commission A2 a Symposium on Earth Rotation will be organized in June or July 2019 in Brussels. In addition, a full-length article describing the history of Commission A2 is being planned. Besides a general historical overview of the Commission, the article will include discussions of the Commission's involvement in the study of UT1/polar motion, precession/nutation, geodetic/astronomical constants, and reference frames. The article will also include a discussion of the Commission's relationship with other bodies such as the ILS, IPMS, BIH, IERS, and IAG and its Services (IVS, ILRS, IGS, IDS). And it will include a discussion of the Commission's involvement in satellite missions such as Hipparcos.

Prepared Proposal for GA Symposium, Reference Systems and Frames 20-31 August 2018; Vienna, Austria

Reference systems and frames are fundamental to positioning and navigating objects in space and on the Earth. Celestial reference frames are used to measure the passage of time, for navigation, and for studying the dynamics of the solar system. Most recently, celestial reference frames have become essential for studying the dynamics of more distant objects and for studying geophysical phenomena on the Earth. Terrestrial reference frames provide the fundamental framework and metrological basis for Earth observations. Since terrestrial reference frames are attached to the Earth, transforming the position of objects between the celestial and terrestrial reference frames requires knowledge of the Earth's changing rotation. Celestial reference frames, terrestrial reference frames, and the Earth's rotation therefore form an interconnected trio. Reference frames, either celestial or terrestrial, are represented by the positions of defining objects. For celestial reference frames these are the positions of radio sources or stars. For terrestrial reference frames these are the positions of fundamental observing stations on the ground. Reference frames need to be maintained and updated as observing systems improve and as the defining objects change their appearance and positions. This Symposium is meant to be a forum for discussing celestial and terrestrial reference systems and frames, the Earth orientation parameters that connect them together, and the fundamental standards needed to determine the reference frames and Earth orientation parameters.

IAU Commission A3 - Fundamental Standards

Catherine Hohenkerk, Brian Luzum, Nancy Oliverson, Charles Acton, John Bangert, Nicole Capitaine, Dennis McCarthy

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The purpose of this IAU Division A commission is to facilitate advances in astronomy and other fields in science and engineering by developing, implementing, and communicating fundamental IAU-endorsed standards for fundamental astronomy. The Commission currently has 101 members. The main effort has been to develop our website (www.iaufs.org), hosted by the United Kingdom Hydrographic Office (UKHO), to whom we are grateful. Steve Bell of HM Nautical Almanac Office, with the OC's agreement, was formally named as the webmaster, as at UKHO he is actually responsible for all the underlying web support.

During 2016, the website was updated with more information. In the section on "Various Standards ..." there is now a link to a summary covering the 2000-2012 IAU resolutions in the context of reference systems. The section on SI units has changed and there is now a sub-menu at the top of this page, showing what is available. In the next year, there will be more additions and changes. One goal is to update the information on SI units to ensure that it and the IAU main website are in line with the BIPM information on this topic.

We have supported, with a letter of support, the proposed symposium on "Reference Systems and Frames", where Division A is a coordinating division. Currently, the President of Commission A2 (Earth Rotation) is leading this. However, the other co-chairs of the SOC are the Presidents of Commissions A1, A3, and the Chair of the WG on ICRF3. We have also supported a focus meeting on "Understanding historical observations to study transient phenomena", where Division A is a supporting division.

We have been in contact with other standard-setting organizations in order to ensure consistency of standards. Through Robert Heinkelmann we are in communication with the Global Geodetic Observing System (GGOS) Bureau of Products and Standards. I was also contacted by Dr Urs Marti, Chair of the WG on Global Geodetic Reference Frame (GGRF). The WG is working towards bringing consistency to the various parameters and standards used by all. I am sure Commission A3 can assist with this effort.

A joint poster promoting "standards" with working groups Standards Of Fundamental Astronomy (SOFA), Numerical Standards for Fundamental Astronomy (NSFA), Cartographic Coordinates and Rotational Elements (CCRE) was displayed at the Workshop on Understanding the Earth core and nutation at the Royal Observatory of Belgium in September.

Acknowledgments and thanks to the Organizing Committee and all those who have helped with the poster and the website.

IAU Commission A4: Celestial Mechanics and Dynamical Astronomy

Cristian Beaugé, Alessandra Celletti, Bonnie Steves, Douglas Hamilton, Elichiro Kokubo, Jacques Laskar, Daniel Scheeres

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Activities within the OC have focused on two objectives. These were part of the work plan included in the original proposal for A4.

1. Newsletter. A Bulletin is sent to all commission members with information relevant to our community. It also helps to establish a communicational link between the OC and its members.
2. School of Celestial Mechanics. Together with Commission X2, we are organizing a one-week research school in Celestial Mechanics, which will take place in Viterbo (Italy) next September, the week prior to the CELMEC meeting. We hope this school will be the first of many editions, each devoted to a different topic within our area.

IAU Commission X2: Solar System Ephemerides

Andrea Milani Comparetti, William Folkner, Jean-Eudes Arlot, Steven Chesley, Elena Pitieva, Paolo Tanga.

2016 Annual Report

This commission belongs to divisions A and F.

1. Data Exchange Standard.

At the Honolulu IAU the Commission 20 has approved the new Astrometric Data Exchange Standard, with the purpose of significantly enhancing the information content of the databases of astrometric information on asteroids, comets, natural satellites (the standard also includes the radar astrometry and the photometric information available with the astrometry). The practical adoption of the new standard, which would result in a very significant improvement in the quality of the orbits determined for all these bodies, depends upon the availability of certified software to ensure the integrity of the database when stored at the MPC and other interested institutions, when transmitted to orbit computers, and when actually used. Note also that the standard includes two formats, a machine readable XML and a human-readable version in Pipe Separated Variables (PSV) format; the conversion among these two needs also to be guaranteed. The process of development of this software is slow, mostly because it is done as voluntary work, without a systematic source of funding. Prototypes are now available, but not yet for all the functions and for all the languages in which the software was planned to be available. Commission X2 needs to continue to follow this process, with the goal of a full implementation before the next general assembly.

2. Organization of meetings. Commission X2 has taken part in two initiatives, one successful and one (so far) not successful.

- In collaboration with Commission A4 (CMDA) we started immediately after the Honolulu GA to promote the first of an intended series of meeting for the formation of young astronomers to the principles and methods of Celestial Mechanics, because without a diffused expertise in this field both the activities of comm. X2 and A4 would become very difficult. This was meant to follow the example of the "Cortina school" organized every 3 years between 1972 and 2003. This initiative has been successful, and the school shall take place in San Martino del Cimino (near Roma, Italy) between 27 August and 2 September 2017 (95 applications for participation have been received). The school shall be followed by the CELMEC 7 international congress, in the same location from 3 to 9 September 2017.
- The OC of the commission X2 worked somewhat, between September and December 2016, to the proposal of a Symposium to be held at the Wien GA, with the provisional title "New challenges in our Solar System ephemerides". Although a Letter of Intent was presented, the SOC was intimidated by the horrendous competition for symposia at the next GA. Moreover, we were convinced that our proposal was not

yet fully defined, essentially because of the need to reconcile the two different points of view which can roughly be traced to the previous commissions 20 and 4 (which have been unified in commission X2). We are still convinced that a unified approach is possible and would be very fruitful, but in December 2016 we have decided to give up the proposal for 2018 and prepare with a more timely effort a proposal for a symposium to be held in 2019.

3. Collaboration with Working Groups. Although there are no WG directly under commission X2 supervision, there are of course interactions with some of them:

- Numerical Standards in Fundamental Astronomy (NSFA) - Division A: The WG is considering a proposal (by Folkner) to adopt an updated GM of Ceres determined by the DAWN mission.
- Cartographic Coordinates & Rotational Elements - Divisions A & F: The WG is working on publishing the current standards. Changes include adoption of a new rotation model for Mars consistent with spacecraft radio tracking, and adopting a fixed longitude for Viking Lander 1 that defines the coordinate system on Mars, agreeing with previous definition of the center of crater Ares-0 within uncertainties.

IAU WG - Standards of Fundamental Astronomy (SOFA)

Catherine Hohenkerk - Chair

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SOFA is a Functional Working Group of Division A. The IAU SOFA service continues its task of establishing and maintaining an accessible and authoritative set of algorithms and procedures that implement standard models used in fundamental astronomy. This is achieved via the expertise of Board members and the SOFA website (www.iausofa.org).

During 2016, there has been one major release (number 12) in May, and minor releases in July (12a) and December (12b & c).

SOFA release 12 added ten new routines, making a total of 231 astronomy routines. Thus, there are now four more routines in the Precession / Nutation / Polar Motion section, which deliver long-term (+/-200,000 years) precession using the model of Vondrák, Capitaine and Wallace (2011, 2012). A new section was added, entitled Ecliptic Coordinates, consisting of six routines dealing with the transformation between equatorial and ecliptic coordinates using either the IAU 2006 or the long-term precession model. Also, the Earth Attitude Cookbook was separated for Fortran and C users. It should be noted that this was the first of the three cookbooks, and at that time there were no ANSI C routines.

Release 12a in July took account of the leap second due at the end of December 2016. The routine that calculates the deflection of starlight by the Sun was modified, without affecting the results for normal use. The formally fixed threshold value was changed to a value that depends on the observer location, which means the change is less abrupt and it improved the round-trip closure even for impossible (i.e. occulted) cases.

It was demonstrated that when using a particular combination of processor, compiler and other conditions, the ANSI C routines for Julian to calendar date conversion were giving incorrect results, and thus it was necessary to promptly issue another minor release. At the same time, we took the opportunity to update the STARPV routine to improve numerical efficiency. In all releases, there were various minor corrections to the documentation.

It is impossible to say how many users actually use SOFA. However, there are now some 793 registered users. Each month during 2016, there were between 1 806 and 3 028 unique visitors to the website. For release 11a (April 2015 to May 2016) there were 4 567 downloads of the ANSI C library, while there were 11 055 for the Fortran library. There are also many other users of the SOFA software via other implementations; Java from Jodrell Bank Centre for Astrophysics and C# available from the World-Wide Astronomy library. There are also the thousands of users via the Essential Routines for Fundamental Astronomy (ERFA) version that is bundled with Astropy for Python. We encourage all our users to acknowledge their use of SOFA.

Posters promoting SOFA have been displayed at the Science of Time symposium held at Harvard in June and as well as a joint poster with working groups Numerical Standards for Fundamental Astronomy (NSFA), Cartographic Coordinates and Rotational Elements (CCRE), and Commission A3, Fundamental Standards at Understanding the Earth core and nutation at the Royal Observatory of Belgium in September. At the latter meeting I also gave a review talk about SOFA over the last 20 years.

Finally, we acknowledge and thank the members of the Board and their institutes. The Board thanks the United Kingdom Hydrographic Office for hosting the SOFA website. We also thank our users, and in particular for pointing out various issues and making suggestions.

IAU Working Group - Astrometry by Small Ground Based Telescopes

M. Assafin - Chair

W. Thuillot - Vice-Chair

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This Working Group belongs to the IAU Division A on Fundamental Astronomy. It has been initiated during the XXVIth General Assembly of the IAU in Prague, in August 2006 by the Division 1 (Fundamental Astronomy). It has been extended for a new triennium at the XXVIIth IAU General Assembly held in Rio de Janeiro in August 2009, then in 2012 during the XXVIIIth IAU GA held in Beijing and during the XXIXth IAU General Assembly held in Honolulu in 2015.

The goal of this continuously active WG is to update and maintain information on astrometric programmes and activities carried out by small telescopes, to diffuse news through web pages and by e-mails, to facilitate the collaborations and to help for the coordination of the activities, when possible, in astrometry from ground-based telescopes.

Here it follows a brief summary of our activities in 2016.

We welcome Nadiia Maigurova from the Nikolaev Observatory, Ukraine, as a new member of our WG. Dr. Damjanovic Goran reported the establishment of a new site, the Astronomical Station Vidojevica - ASV (of Astronomical Observatory in Belgrade, Serbia), with a new 1.4 m telescope (made by ASA, Austria) under the scope of the BELISSIMA FP7 project. More about it can be seen at belissima.aob.rs web site. It was also put into operation the Serbian-Bulgarian mini-network telescopes (now, 6 telescopes). All these instruments are collecting useful data for Gaia astrometry, GAIA-FUN-SSO, GAWEBT, etc.

In USA Dr. Norbert Zacharias continues with the URAT project and with astrometric observations from USNO supporting the observation of stellar occultations by Pluto and other transneptunian objects. William Van Altena's recent book "Astrometry for Astrophysics: Methods, Models, and Applications" keeps being a valuable resource for graduate students as well as for astronomer researchers.

Brazilian astronomers Dr. Roberto Vieira Martins and Dr. Marcelo Assafin report on the astrometric use of 0.6m to 2.2m class telescopes at Brazil, Chile, Australia, France and Spain in supporting the observation of stellar occultations by Pluto and other transneptunian objects and Centaurs, and also in the astrometry of natural and irregular satellites.

Dr. Jean-Eudes Arlot continues with his project of digitizing old photographic plates of natural satellites with a new precise scanner machine under the auspices of the IMCCE - Observatoire de Paris, France. Dr. Dan Pascu made a huge contribution on this respect allowing for the use of the USNO collection of Martian and Jovian satellites.

Dr. William Thuillot reports on the effective beginning of the Gaia-FUN-SSO activities of following up solar system objects, mostly asteroids. These astrometric observations are triggered by GAIA-FUN-SSO alerts for a broader community of registered observers throughout the world (<https://gaiafunssso.imcce.fr>). He also reports on the continuity of the GBOT activities, which collects astrometric observations of the GAIA probe in support for the ESA mission. The GAIA-FUN-SSO and the GBOT activities involve many of our members and constitute an important part of the activities supported by this WG.

Please visit our refreshed web page:

at http://www.imcce.fr/hosted_sites/iau_wgnps/astrom.html for more historic and updated reports on the activities of this WG.

IAU Working Group - Cartographic Coordinates and Rotational Elements

Brent Archinal - Chair

Annual Report 2016

Following is a summary of the activities of the IAU Working Group on Cartographic Coordinates and Rotational Elements for 2016.

- The main activity and product of the WG is the production of a report, produced roughly in conjunction with each IAU General Assembly, making recommendations regarding the creation and maintenance of cartographic planetary coordinate systems. This is an effort the WG began upon its creation in 1976. Our “2015” report has been delayed further than we would like, but we are closing in on an expected publication in the spring of 2017. Significant changes from our last report planned so far include:

- A procedure is described for submitting questions about the recommendations given or the application of the recommendations for creating a new or updated coordinate system for a given body.

Regarding body orientation, the Mercury orientation model has been updated based on MESSENGER results, approximate expressions for the Earth have been removed in order to avoid confusion; the Mars orientation model will be improved using new modeling; the expression for the rotation of Neptune has been updated; the previously on-line only recommended orientation model for (4) Vesta is repeated and an explanation of how it was updated given; an orientation model is given for (52) Europa, the orientation model for (2867) Šteins has been improved; and corrections have been made for the rotation model for Pluto and its satellite Charon, and the orientation model has been corrected for (243) Ida. Information has been added on the rotational states of Comets 9P/Tempel 1, 19P/Borrelly, 67P/Churyumov-Gerasimenko, and 103P/Hartley 2, noting that such information is valid only between specific epochs. The difficulty of mapping 67P/Churyumov-Gerasimenko is discussed. Regarding body shape, text has been included to explain the expected uses of such information, and the relevance of the cited uncertainty information.

The radius of the Sun has been updated and notation added that the size and the ellipsoidal axes for the Earth and Jupiter have been recommended by an IAU Resolution. The distinction of a reference radius for a body (here, the Moon and Titan) is made between cartographic uses, and for ortho-projection and geophysical uses. The recommended radius for Mercury has been updated based on MESSENGER results. The recommended such radius for Titan is returned to its previous value. Size information has been given for (16) Psyche and (52) Europa. The size of (25143) Itokawa has been corrected. In addition, the discussion of terminology for the poles (hemispheres) of small bodies has been modified and a discussion on cardinal directions added.

- The current citation for this publication is: B. A. Archinal, C. H. Acton, M. F. A’Hearn, A. Conrad, G. J. Consolmagno, T. Duxbury, D. Hestroffer, J. L. Hilton, L. Jorda, R. Kirk, S. A. Klioner, D. McCarthy, K. Meech, J. Oberst, J. Ping, P. K. Seidelmann, D. J. Tholen, P. C. Thomas, I.P. Williams (2017). “Report of the IAU Working Group on Cartographic

Coordinates and Rotational Elements: 2015,” in preparation, to be submitted to Celestial Mechanics and Dynamical Astronomy.

- The WGCCRE continues to maintain its website at <http://astrogeology.usgs.gov/groups/IAU-WGCCRE>. Given there is a brief history of the WG and links to all our (major) reports, from 1979 to 2011, and a special statement on the recommended coordinate system for Vesta (2013).
- The WG currently consists of 19 members, from 6 countries, with membership lengths from 4 to 40 years. Brent Archinal (U. S. Geological Survey) serves as the current chairman, and Al Conrad (Large Binocular Telescope Observatory) serves as the acting Vice-Chairman.
- The WG chair and some of the WG members spend significant time answering questions from NASA, missions, mission instrument teams, individual researchers, and the public, on various issues related to planetary coordinate systems. There are ongoing regular questions about the coordinate systems for the Moon and Mars, and regular questions from the various components of the NASA Planetary Data System. Some of our members have also provided information to the various archiving organizations such as ESA’s Planetary Science Archive, to JAXA’s and IKI’s archiving arms, as well as to the International Planetary Data Alliance.
- The WG, in response to queries from the Division A and F Presidents, in 2016 developed a policy for soliciting new members and having an open membership. The WG agreed to make it clear that it was open to anyone applying for membership, and that we would fairly regularly (e.g. yearly at least) make a significant effort to make announcements that new members would be welcome to apply. That would likely be done via announcements in appropriate newsletters, mass e-mail to Division members, and via presentations at meetings (more below). It could also be done by regularly directly contacting experts in the field and any others who would likely be interested and could help. We also plan to ask applicants and periodically current members what expertise they feel they are bringing to the WG and how they plan to contribute to our main report. Only in highly unusual cases and with the approval of the Division A and F Presidents as well would an applicant be turned down. Announcements to solicit new members are planned for mid-2017.
 - The WG also agreed to continue to its various efforts to make its efforts known by various publications and community presentations. Specifically:
 - We will continue to publish our “main” WG report, to be published approximately triennially, following each IAU General Assembly.
 - If requested/desired from the Divisions or editors, a triennial report on WG operations could be made available for publication in the IAU Transactions.
 - The WG will also make a brief annual report (i.e. this document) to Divisions F and A on the WG’s activities. We are also willing to continue to make oral reports at the General Assembly Division meetings.
 - We will provide occasional reports, on items of interest (e.g. a new main WG report), for submittal to the IAU News.
 - To make our work better known, we will continue to submit abstracts and presentations to various planetary science meetings, describing the activities of the WG and our reports. These would include occasional presentations at the Lunar and Planetary Science Conference and the Planetary Data Workshop (2017 June), and possibly other meetings such as NASA Analysis Group meetings

(<http://www.lpi.usra.edu/analysis/>), the AAS Division of Planetary Sciences meeting, COSPAR (2018 July), etc. Publications from 2016 along these lines are listed following:

WG Publications, 2016

- M. F. A'Hearn (2016). "Small Solar System Bodies: Products and Standards," Proceedings of the 47th Lunar and Planetary Science Conference, 2016 March 21-25, The Woodlands, Texas, abstract no. 2739. Available as <http://www.hou.usra.edu/meetings/lpsc2016/pdf/2739.pdf>. Presentation available as <http://www.lpi.usra.edu/mapsit/meetings/lpsc-2016/AHearn.pdf>.
- (Aside from the above paper, other papers from the LPSC session "Planetary Spatial Infrastructure: At the Intersection Of GIScience and Planetary Science", may also be of interest. These are not really papers from the WG, but this session was partially organized and supported by WG members (A'Hearn, Archinal, and Kirk). See <http://www.lpi.usra.edu/mapsit/meetings/archive/> for access to abstracts and presentations.)
- B. A. Archinal and the IAU Working Group on Cartographic Coordinates and Rotational Elements (2016). "Update on the IAU Working Group on Cartographic Coordinates and Rotational Elements and its Upcoming 2015 Report," Proceedings of the 47th Lunar and Planetary Science Conference, 2016 March 21-25, The Woodlands, Texas, abstract no. 2963. Available as <http://www.hou.usra.edu/meetings/lpsc2016/pdf/2963.pdf>.
- Catherine Hohenkerk, Brent Archinal, and Brian Luzum (2016). "IAU Division A— Fundamental Standards," Workshop on "Understanding the Earth core and nutation", Royal Observatory of Belgium, September 19-21. Abstract. To be available(?) on-line at <https://register-as.oma.be/rotanutWS/>.

IAU Working Group - Numerical Standards for Fundamental Astronomy

Brian Luzum – Chair

2016 Annual Report

Following the meeting at the 2015 IAU General Assembly, several topics for discussion during the next triennium were proposed. These include: the “defining” constant a_u be moved to the “other” constants; the “other” constant L_c be eliminated; the NSFA Current Best Estimate value for the “measurable” constant G always point to the CODATA value for G ; the NSFA Current Best Estimate for the “body” constant GM_E point to the latest geophysical value for GM_E ; the NSFA Current Best Estimate for “body” constants J_2 and W_0 point to the latest geophysical values for J_2 and W_0 ; issuing NSFA Reports with the latest values instead of proposing IAU Resolutions; and that the NSFA WG should consider the possibility of disbanding after the 2018 IAU General Assembly.

The WG created a joint poster with the Standards Of Fundamental Astronomy (SOFA) and Cartographic Coordinates and Rotational Elements (CCRE) promoting “standards”. The poster was presented at the “Understanding the Earth core and nutation” Workshop at the Royal Observatory of Belgium in September, 2016.

In addition, the Chair of the NSFA Working Group provided a letter of support for the proposed IAU Symposium on “Reference Systems and Frames”, which if approved, would be held during the IAU 2018 General Assembly.