IAU Division A
Fundamental astronomy – Astronomie Fondamentale

Annual report for 2020

Daniel Hestroffer (Paris obs.) – president
Norbert Zacharias (USNO) – vice president

April 2020

The steering committee of Division A is composed of:

Daniel Hestroffer (President)	FR
Norbert Zacharias (Vice-President)	US
Benoît B. Noyelles (Secretary)	FR
Anne Lemaître (Advisor)	BE
Alessandra Celletti (Commission A4 President)	IT
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Elisa Felicitas Arias	FR
Ralph A. Gaume	US
Andrzej J. Maciejewski	PL
Fernando Virgilio Roig	BR
Bonnie Alice Steves	UK

The working groups

The following are division's WGs that are *functional* working groups, with tasks achieved regularly, and one inter-division WG (with Division F).
Division A WG Numerical Standards in Fundamental Astronomy (NSFA)
Division A WG Standards of Fundamental Astronomy (SOFA)
Division A WG Time Metrology Standards
Inter-Division A-F WG Cartographic Coordinates & Rotational Elements

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Other WGs have been renewed at last General Assembly.
Division A WG Astrometry by Small Ground-Based Telescopes

Division A WG Multi-waveband Realisations of International Celestial Reference System

The following WG has been terminated:
Division A WG Third Realisation of the International Celestial Reference Frame

Functional inter-division working group WGCCRE is looking forward to include new members, with complementary expertise, in part to be able to respond to the increased needs and inquiries from the community. It also expressed the need of functional support to enable service and operational activities. It also expressed the need of having an operational service associated to - and ensuring - the WG tasks, and its need of having various communities following the IAU recommendations.

Functional working group Standards Of Fundamental Astronomy (SOFA) is looking to replace their current chair of the Board, C. Hohenkerk, who has been in post since 2010. Some of its member are associates. SOFA provides the astronomical community and others with authoritative software, and although currently it is mainly in "maintenance" mode, this will not necessarily continue, as new developments in fundamental astronomy and computing technology emerge. A new chair is needed to ensure that this valuable resource is able to address the needs of our Division.
The working group WGASGBT is also looking forward to replace their Chair.
Working group on Numerical Standards in Fundamental Astronomy has faced some difficulties with the hosting web-site, and it plans to end activities after bringing last changes to some reference values based on recent scientific results and resolutions.

Commission A2 'Rotation of Earth' has proposed 2 new Commission (joint) WGs:

- Joint IAU-IAG (International Association of Geodesy) - Improving Theories and Models of the Earth's Rotation (ITMER);
- Joint IAU-IAG-IERS on the Consistent Realization of TRF, CRF and EOP

There are ongoing discussions led by P. Charlot and F. Mignard to bring a new proposition of a working group under Division A to work on the realisation and maintenance of multiwavelength ICRS and ICRF.

Proposals for Symposia and Focus meetings

• For the 2020 edition
One IAU symposium proposal under Division A's coordination ; 3 proposals as secondary division.
One symposium IAUs364 was scheduled for July 2020, abstracts were collected and grants propositions established. But the event has been postponed during the final steps of its preparation because of the corona virus pandemic situation (see below).

• For the 2021 GA edition
Several proposals under Division A as coordinator
- 0 non-GA symposium
- 1 GA symposia
- 3 Focus meetings

Other 6 proposals as secondary division.

Division A has supported and/or commented 12 proposals.

Some commissions or groups would prefer to have an IAU label for holding regular meetings connected to commission tasks, instead of proposing an IAU symposium. The symposium format is not always adapted to the need of the community to discuss and work on specific tasks and progress the science.

Memberships

Division A reckons that the annual call for such individual memberships is benefiting to the IAU and division's dynamism. New junior members have joined the Division within the new scheme – it would be good to be able to identify junior members, and know the number of new-comers.
A call to the division members has been made to remind them on the possibility to joining Commissions. One senior member resigned from the Division, because of personal reason.
Some spam-fishing 'aggressive publisher' mail was sent to some of our Division members mentioning the IAU Division A. Action has been undertaken with the member colleague to avoid such fishing.

PhD Prizes

While the Division reckons this prize can motivate the young scientists to participate to IAU, there have been (very)few candidates proposed to Division A over the years, unfortunately (between zero and four). Actions to understand and correct this matter have been discussed, such broadening the call. Nevertheless it is unclear why the number of candidates is low ; actions directly to doctorate schools would be profitable, some offices and research centres also note that they are loosely connected to PhD candidates. Selection for year 2020 has been made with the entire SC, J. O'Leary (UNISA) has been selected.

Logistics – Others

Next GA Since last IAU GA the Division has settled down, and participated actively to the following EC#104 and discussions on the Divisions' implication for scientific meetings. Discussions on actions (new resolutions, topic on Division days) to prepare for the next GA – task groups should be established.
IAU label. Some commissions or groups would like to have an IAU label for holding regular meetings or colloquium connected to their commission tasks – no particular funding is requested.
Web-pages. There is no specific Division newsletter, this is left preferably to commissions. Updating of web-pages and inputs from information letters.
SC extended mailing list. Division A has decided that general e-mails sent to the steering committee (announcements, call for actions, reportings etc.) are also sent to the commissions vice-presidents and vice-chairs to ensure larger diffusion.
Situation due to Covid-19 pandemia. No colleague in critical situation has been reported. Apparently the Covid-19 has not hampered critical action from Division A. Many meetings and conferences around the globe have been cancelled, postponed, or transferred to videoconference. The IAU symposium #364 under Division A 'Multi-scale (time and mass) dynamics of space objects' (chair A. Gales & A. Celletti) has been postponed – announced on March 14th.

Commissions and Working groups reports.

Summary. Commissions A1, A2, A3, cross-division commission X2, and inter-division commission A4 ; Working groups SOFA, WGASGBT, WGTMS, WGNSFA, inter-division WGCCRE have provided their annual report. Reports have different formats but all are showing scientific and programmatic activities either as functional entities, and/or as holding meetings exchanging information, and supporting IAU plan.

IAU Commission A1 - Astrometry

Jean Souchay, Christopher Jacobs, Aletha de Witt, Anthony G.A. Brown, Alexandre H. Andrei, Jennifer Bartlett, François Mignard, Yoshiyuki Yamada

Annual Report 2019

Progress on the Celestial Reference Frame

The last few years saw the completion and adoption of the new generation of IAU official International Celestial Reference Frame. The ICRF-3 was adopted at the 2018 IAU general assembly and became official as of 2019 Jan 01. In the time since the March 2018 cutoff for ICRF3, observations for celestial frames have continued. At S/X-band (8 GHz) the geodetic observations provide a steady stream of data on the subset of sources observed by IVS. In addition the USNO and Goddard Space Flight Center are running a survey program using the VLBA to improve the positions about 5000 sources.

At K-band (24 GHz) observations have continued in the far south with HartRAO-Hobart baseline occasionally augmented with the Tidbinbilla 70-m. The VLBA's K-band program has also continued and was upgraded to dual-polarization 4 Gbps total data rate at the end of 2019. This both adds the new dimension of full polarization observations and increased sensitivity. Information can be found in https://ui.adsabs.harvard.edu/abs/2019aerr.confE...2D/ abstract and in (De Witt et al.,2019).

X/Ka (32 GHz) work continues with both NASA's Deep Space network and ESA's Malargüe, Argentina station. The big news is that the Japanese space agency (JAXA) is building a 54-m at Misasa near Usuda which will join the X/Ka effort. First fringes at X-band were achieved with the 54m in December. We also note that Ka-band has become more mainstream with NASA's Parker Solar Probe, ESA's Bepi-Columbo, and JAXA's Hayabusa-2 missions all making astrometric navigation measurements at Ka-band.

The plan is to combine all the above three bands of radio observations as well as Gaia optical observations into a multi-wavelength 4th generation ICRF. Patrick Charlot is the point of contact for organizing this future multi-wavelength ICRF (Charlot et al.,2020).

USNO has access to 50% of the observing time on the National Radio Astronomy Observatory's (NRAO) Very Long Baseline Array (VLBA). The USNO time allocation is used for the improvement and maintenance of the ICRF3. The USNO VLBA time allocation is also contributing 99% of data in the radio reference frame at 24 GHz (K-band). In addition to supporting the ICRF3 astrometry in the radio regime, the USNO is also using the VLBA for an imaging campaign designed to study source structure, spectral index, and flux densities at S,X, and K bands. These imaging data products will be made available through the USNO Fundamental reference Image Data archive (FRIDA).

Looking into the more distant future, an investigation of the potential of the Square Kilometre Array (SKA) for massively densifying the celestial reference frame was conducted. Due to its unsurpassed sensitivity, this instrument when used as an element of a VLBI array will make it possible to increase the number of sources in the ICRF by at least an order of magnitude. Its large field of view will also offer the possibility to make commensal observing, which is very attractive since observations for the celestial frame could then be acquired in the background of other programs, thus not requiring dedicated observing time on the SKA. Based on this study, a global astrometry use case with a goal to observe 50 000 Gaia counterparts was proposed.

Space astrometry

2.1 Gaia mission

July 16 2019 marked the end of Gaia's nominal five year mission. This date was chosen because it coincides with a major orbit maintenance manoeuvre, which is designed to keep Gaia out of the earth's shadow during the extended mission phase. The manoeuvre, having occurred on July 16th, was named the "Whitehead eclipse avoidance manoeuvre" in memory of Gary Whitehead from the Gaia Flight Control Team, who sadly passed away recently. It was executed without problem and is followed by one year of Gaia following a scanning law with a reversed precession direction (but the same spin direction) in order to aid breaking certain degeneracies in the astrometric solution. In addition slight optimizations of the scan law will be done in connection with catching high signal-to-noise ratio observations of stars near Jupiter in 2020 for the experiment aimed at measuring the light bending due to the quadrupole moment of Jupiter's gravitational field. The spin axis precession will go back to normal in the summer of 2020.

The estimated end-of-life for Gaia (when the micro-propulsion fuel runs out) is still end-2024. The process of extending the mission for the period 2023-2025 (thus covering end-of-life) started on February 27 with a technical review of the status of the spacecraft and payload. In June 2020 we hope to get the confirmation for the extension 2021-2022 and preliminary approval for 2023-2025.

The Gaia DR2 was available starting from April 2018 (Gaia collaboration, Brown A.G.A et al.,2018). It delivers a five-parameter astrometric solution [equatorial coordinates (α, δ), parallaxes, and proper motions] for more than 1.3 billion sources, with a limiting magnitude of G = 21 and a low limit at G $\approx$ 3. Parallax uncertainties are highly dependent on the magnitude, ranging from 0.04 mas (milliarcsecond) for sources at G < 15, to 0.7 mas at G = 20.

The data processing for Gaia EDR3 has finished and the release is being validated. The release date is unknown at the moment due to the Covid-19 crisis. This release will feature improved astrometry (positions, parallaxes, proper motions) and photometry (integrated G, G_BP,G_RP). For convenience the radial velocities from Gaia DR2 will be included as well. Many new data products will become available with Gaia DR3 in the second half of 2021. As listed on https://www.cosmos.esa.int/web/gaia/release

- Gaia EDR3 contents (see above)

- Object classification and astrophysical parameters, together with BP/RP spectra and/or RVS spectra they are based on, for spectroscopically and (spectro-photometrically) well-behaved objects.
- Mean radial velocities for stars with available atmospheric-parameter estimates.
- Variable-star classifications together with the epoch photometry used for the stars.
- Solar-system results with preliminary orbital solutions and individual epoch observations.
- Non-single stars.
- Quasars and Extended Objects results
- An additional data set, called the Gaia Andromeda Photometric Survey (GAPS), consisting of the photometric time series for *all* sources located in a 5.5 degree radius field centred on the Andromeda galaxy.

During the three years period (2018-2021), the GBOT (Ground Based Optical Tracking) group is in charge of the daily optical tracking of the Gaia satellite as it was the case from the beginning of the mission (Altmann et al., 2014). The aim was 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 1-2 meter class telescopes located at various places in the world. The requirements for the accuracy on the satellite position determination, with respect to the stars in the field of view is 20 mas, corresponding to 150 meters at the distance of 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 a group located at Paris Observatory in charge of the GBOT database and image reductions programs specifically adapted for tracking moving objects. Thus, during the three years period, about 10 000 frames containing the Gaia satellite have been reduced. A general technical study of the characterization of the astrometric precision limit within the GBOT project is developed exhaustively in (Bouquillon et al.,2017)

2.2 Jasmine mission

In Japan the development of JASMINE missions (Gouda 2011) has been continued. ISAS (science division of JAXA) has selected a mission candidate JASMINE, NIR astrometry mission into the central part of our galaxy that will reveal the evolution history of our galaxy, for a M-class slot. ISAS is determined to proceed to budget request for JASMINE to be launched in mid-2020s. Its capacity is also suited for detecting exo-planet in habitable zones of low mass stars. The conclusion and the plan have been notified to a governmental committee that oversees the space science activity in Japan on May 21. JASMINE has also been listed as one of large research program in Science Council of Japan.

JASMINE will determine positions and parallaxes with 25 microarcsec uncertainties 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 Hw = 12.5 mag (Hw-band: 1.1~1.7 micron). Proper motions with 25 microarcsec yr^{-1} uncertainties for stars brighter than Hw=12.5mag, and 125 microarcsec yr^{-1} for stars brighter than Hw=15mag can be measured. The survey will be performed with a single beam telescope with 30 cm diameter of the primary mirror (Yano et al. 2011). JASMINE is discussing with a USA team led by USNO about their contribution to the development of the detector box unit. We are also discussing with ESA their ground station contribution for science data down-link. The JASMINE Consortium, responsible for data analysis (Yamada et al. 2017) and science activities, was organized and a kick-off meeting was held in September 2019. We welcome the international

partners to join the consortium in near future. Development of data analysis software starts as an activity of consortium, and also international collaboration with ZAH-ARI. As one of the consortium's working groups, the team for investigating detecting exo-planet is organized.
A larger mission to observe the entire bulge region with infrared was planned. This plan is considered to require international collaborations.

2.3 Voyage 2050 Near-Infrared mission

During these last years, an ambitious proposal led by David Hobbs (Lund observatory) was elaborated. It concerns a space mission in the Near Infrared (NIR) domain. The leading argument for such a mission is that the combination of All-sky visible and NIR astrometry with a wavelength cut-off in the K-band will provide an additional foundation for all branches of astronomy from the solar and stellar systems to compact galaxies, quasars, binaries, neutron stars and Dark Matter (DM) substructures. Concerning the construction of reference frames starting from AGNs, the output of such a mission would be precious: it should allow the slowly degrading accuracy of the Gaia visible reference frame, which will be the future fundamental Celestial Reference Frame to be reinitialized back to a maximal precision. The degradation comes from the uncertainty in the spin of the frame, and the presence of small proper motion patterns which are not accounted for. In the stellar fields, the proposed mission could be combined with the older Gaia catalogue (~ 1.7 billion stars), with a 25-35 years baseline, in order to determine proper motions much more accurately than Gaia itself, with a factor of 14-20 for both components. At the same time, big improvement is scheduled in the determination of parallaxes, when astrometric measurements of both space missions will be combined.

Ground-based optical astrometry

USNO, working with the University of Hawaii's Institute for Astronomy (IfA); the Cambridge Astronomical Survey Unit of the Institute of Astronomy, Cambridge University; and the Wide Field Astronomy Unit at the University of Edinburgh, is continuing the 'USNO-UKIRT Hemispherical Survey' (U2HS), a near complete northern hemisphere survey from DEC = 0 + 60 deg, down to magnitudes H=19.0 a,d K=18.4. Observations have largely finished for the K-band survey, and the H-band survey is well under way. By end of June 2018 the USNO Robotic Astrometric Telescope (URAT) concluded observing at Cerro Tololo Interamerican Observatory (CTIO). An internal catalog was produced in early 2019, based on 159,000 URAT exposures over 3years. Results for bright stars (-1.5 to 4.5 Mag) were extracted and combined with UBAD observations and Hipparcos epoch data for a new solution of all 5 astrometric parameters (March 2020).

The Deep South Telescope (DST), a 1-meter aperture PlaneWave robotic telescope was installed at CTIO in March 2019 and began routine operation in Aug 2019. A 4k CCD camera and multiple filters are used for high cadence observations of about 200 compact, extragalactic sources (volume limited AGNs and ICRF sources) with emphasis on targets with discrepant optical and radio positions, as part of the Fundamental Reference Frame astrometric Monitoring Experiment (FRAMEx) collaboration between USNO and Paris Observatory.

Since 2015, Paris observatory is in charge of a project of 1-meter aperture robotic telescope to be installed in the French Alps (Saint-Véran, near the Italian border). The project is

currently well advanced, half of the budget was obtained in 2019, the second part being obtained between March and June 2020. The scientific program of this telescope concerns mainly the observation of quasars for the link of reference systems. It will observe the ICRF optical counterpart of extragalactic radiosources, the goal being to select by statistical methods (Allan variance) the more suitable targets for the link ICRF-Gaia CRF. In addition it will observe asteroids, exoplanets and optical counterpart of Gamma ray Burst in the framework of Gaia, CHEOPS and SVOM missions.

The U.S. naval Observatory Flagstaff Station (NOFS) continues its infrared parallax program, targeting brown dwarfs, on the 1.55 m Strand astrometric telescope at NOFS. Limited observations continue on the USNO Bright Star Astrometric Database (UBAD), a survey of bright ($V < 3$, $I < 3.5$) northern hemisphere stars, also with the Strand astrometric telescope. After an initial UBAD catalog was produced in 2019, a final catalog is expected in 2020.

LLR astrometry

The LLR community will continue to improve analysis model by implementing more and more small effects affecting the Earth-Moon dynamics like geocenter variations, non-tidal loadings, similar for the body of the Moon. As one result we will obtain better ephemeris of the Moon and of the Earth; therefore this leads to a better realization of the celestial reference system by the intermediary of the lunar orbit. As further result, we can determine many parameters of the Earth-Moon system with higher accuracy, including many quantities to verify Einstein's theory of Relativity, such as the equivalence principle, the constancy of the gravitational constant and metric parameters. Finally, we will also prepare our analysis package to include new differential measurements to the reflectors on the Moon as they are planned / prepared by agencies in USA.

Astrometry of the past sky : the NAROO project at Paris observatory

The NAROO project (New Astrometric Reduction of Old Observations) has been developed at Paris observatory to digitize, analyze and reduce old observations (Robert et al.,2019). A brand-new sub micrometric digitizing machine is now available at Paris observatory for this purpose. Thus, we intent to test the proper motion of stars modeled in the GAIA reference star catalogue for modeling the galactic dynamics, to make pre-discoveries of many comets and asteroids (NEO, TNO) on old photographic plates at a time they were not known but available on observations among stars, and also to observe the planets and natural satellites with the best accuracy on a large time span, allowing to quantify cumulative effects, signature of dissipation of energy as tides.

Catalogues of AGN and quasars

A new version of the OCARS (Optical Characteristics of Astrometric Radio Sources) catalog is completed (Malkin,2018). This compiled catalog includes radio sources observed in different VLBI programs and experiments that result in accurate source position determination, their redshift and photometry in the visible and near-infrared bands. A cross-identification with other catalogs in radio, optical, infrared, ultraviolet, X-ray, and gamma-ray bands is also provided.

The LQAC (Large Quasar Astrometric Catalogue) is a general compilation of all the recorded quasars, coming from large surveys (SDSS,2QF) as well as from small one. Its first aim is to give the a priori more precise and accurate values of the equatorial coordinates of each object, in priority those coming from the Gaia DR2. Moreover it contains various information (when available) as redshifts, multi-band magnitudes, radio-fluxes. Specific determinations resulting in complementary data concern the morphology index and the absolute magnitudes. A new up-date of the catalogue, the LQAC-5 was published recently (Souchay et al.,2019). It contains 592 809 quasars. This represents roughly a 34% increase with respect to the number of 443 725 objects recorded in the previous version, the LQAC-4 (Gattano et al.,2018). Among them, 398 697 objects were found in common with the Gaia DR2, within a 1" search radius. That corresponds to 67.26% of the whole population of the compilation. This is considerably more than the 248 788 objects found in common with the Gaia DR1 catalogue in the LQAC-4 with the same search radius.

The Wide Field Infrared Explorer (WISE) data are being reprocessed by USNO using a new reference star catalog based on 2MASS and Gaia data. In several iterations WISE frame-by-frame atlas images are processed with high order astrometric solutions. A final product is expected by early 2021.

Miscellaneous studies dealing with astrometry

- A full description of the statistics used to characterize the overall properties of the quasar sample has been done (Gaia coll., Mignard et al.,2018). It allows the construction of the Gaia-CRF2 which must be considered as the first realization of a non-rotating global optical reference frame meeting the ICRS prescriptions, in particular because it is based only on extragalactic sources. Gaia-CRF2 consists of the positions of a sample of 556 869 sources in Gaia-DR2 obtained from a positional cross-match with the ICRF3 and AllWISE AGN catalogues. The sample constitutes a clean, dense, and homogeneous set of extragalactic sources with accurate positions in the range $15 < G < 20$. The median positional uncertainty of the selected sample is 0.12 mas for $G < 18$ and 0.5 mas at $G = 20$, whereas large scale systematics are found in the range 20 to 30 μas.

- A careful investigation of 3413 ICRF3 extragalactic radio-loud sources was done (Makarov et al., 2019) with accurate positions determined by very long baseline interferometry in the S/X band, cross-matched with DR2 sources to study the radio-optical offsets. The distribution of normalized offsets was shown to be non-Rayleigh. After a suitable deselection, a lits of 2119 radio-loud quasars of prime astrometric quality was published. Dependence on redshift values and color were demonstrated.

- (Luri et al.2019) provided guidelines on how to use parallaxes more efficiently to estimate distances by using Bayesian methods, in particular by using DR2 data. Their conclusion is that to fully use the potential of such data it will be always necessary to pay careful attention to the statistical treatment of both parallaxes and proper motions.

- A new method SREAG (spherical rectangular equal-area grid) is proposed to divide a spherical surface into equal-area cells (Malkin,2019). It provides rectangular grid cells with latitude-and longitude-oriented boundaries, near-square cells in the equatorial rings. It is simple in construction and use and provides more uniform width of the latitudinal rings than other methods of equal-area pixelization of a spherical surface.

- A new way to estimate the distribution of the luminosity function of quasars by using the principle of Maximum Entropy was developed by (Andrei et al., 2019). The study was limited to apparent magnitude 15-19 with z < 3 to I =20.2 at z >3. They show that their results concerning the luminosity function compare well with previous works

- Geodetic / astrometric VLBI data obtained during nearly 40 yrs. Has produced more than 10 million baseline delay, phase and amplitude observables. They were used by Xu et al. (2019) to study, by means of closure rms (CARMS) analysis, the intrinsic source structures and their evolution over time. The overall structure effect magnitudes for 3417 ICRF radio sources are quantified. Among them the 30 most frequently observed sources, which constitute 40% of current geodetic VLBI observables, are studied in detail

- A comparison of Gaia DR2 parallaxes of stars with VLBI astrometry was done by Xu et al. (2019). Their sample was various, ranging from young stellar objects, evolved AGB stars to other radio stars. Their conclusion is that when they except AGB stars and stars in binaries systems, which shows significant discrepancies, they obtain an average, systematic parallax offset of +/- 29 μas for Gaia DR2, consistent with their estimate of a parallax zero-point between -100 and 0 μas.

- A quantitative analysis of systematic differences in the positions and proper motions of Gaia DR2 with respect to VLBI (Petrov et al.,2019) concerns 9081 sources matched between the two kinds of catalogues. According to that study the median position uncertainty is a factor of two larger than the median position uncertainty in Gaia DR2. They show both that the major contributor for significant offsets is the presence of optical jets, and that among the sources which present significant proper motions, the fraction of sources with proper motion directions parallel to the jets is a factor of three greater than on average.

- In the case of AGN targets observed assiduously by the TAROT telescopes the Allan time variance shows that the longest averaging period of the magnitudes is in the range 20−70d (Taris et al., 2018). The observation period by Gaia for a single target largely exceeds these values, which might be a problem when the magnitude variations exhibit flicker or random walk noises. Preliminary computations show that if the coordinates of the targets studied were affected by a white-phase noise with a formal uncertainty of about 1 mas (due to astrophysical processes that are put in evidence by the magnitude variations of the sources), it would affect the precision of the link at the level of 50 μas.

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IAU Commission A2 – Rotation of the Earth

Florian Seitz, Zinovy Malkin, Alberto Escapa, Jose Ferrándiz, Jolanta Nastula, Shuanggen Jin, Hadia Selim

Annual Report 2019

100th anniversary and Centennial Celebration of IAU Commission A2/Commission 19

July 28, 2019, marked the 100th birthday of Commission A2. Together with the IAU, which was created during the Constitutive Assembly of the International Research Council in Brussels (July 18-28, 1919), 32 Standing Committees were created on the last day of the Assembly. Among these was the "Standing Committee 19 on Latitude Variations" in order to study polar motion. In 1922 the Standing Committee was transformed into "Commission 19 on Variation of Latitude", and in 1964 it was renamed into "Commission 19 on Rotation of the Earth". In 2015, after the restructuring of the IAU, the Commission's designation was changed into "Commission A2 on the Rotation of the Earth".

Since 100 years, the Commission has been encouraging collaboration in observation and theoretical studies of Earth rotation, the development of new observation techniques and the development of strategies and methods for improving the accuracy of Earth rotation changes and reference frames. It has been ensuring the agreement and continuity of different (geodetic/astronomical) reference frames and their densifications, and it has been linking the astronomical community to international organizations that are responsible for providing Earth Orientation Parameters (EOP) and terrestrial and celestial reference frames (ITRF/ICRF), such as the International Association of Geodesy (IAG), the International Earth Rotation and Reference Systems Service (IERS), and the technique services IVS (Very Long Baseline Interferometry), ILRS (Satellite Laser Ranging), IGS (Global Navigation Satellite Systems), and IDS (Doppler Orbitography and Radio positioning Integrated by Satellite). Through a multitude of dedicated Symposia (among them various IAU Symposia and IAU Colloquia), Workshops, and through its Working Groups, the Commission has been fostering research and discussion on Earth rotation and reference frames within the international scientific community.

On the occasion of its 100th anniversary, the Commission held a **Centennial Celebration in Paris, October 7,** as part of the "*Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era"* (see below). During this celebration, Commission A2 looked back at its history and the developments in Earth rotation monitoring and research during the last century and provided an outlook into the future of Earth rotation research.

Co-organization of the "*Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era"* in Paris, France, October 7-9, 2019

The *Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era* were organized jointly by the IAU Commissions A1 (Astrometry) and A2 at the Observatoire de Paris (IAP amphithéâtre) from October 7- 9, 2019. It gathered 120 scientists from all over the world, for a large part members of Commissions A1 and A2. The meeting comprised dedicated sessions on the Gaia mission, Earth Rotation and Geodynamics (observations, analysis, models), ICRF and astrogeodesy, and Space navigation and solar system dynamics. In their presentations, the participants reported about exciting investigations and demonstrated the high scientific relevance of the topics covered by the Commissions. During the meeting, the 100th anniversary of Commission A2 was celebrated in the frame of a dedicated session, reviewing the enormous achievements in Earth rotation and reference systems/frames research over the past century and discussing prospective scientific challenges and potentials. The detailed meeting programme and proceedings can be assessed at:

https://syrte.obspm.fr/astro/journees2019/

Successful completion of the Joint Working Group on Theory of Earth Rotation and Validation (JWG TERV)

Joint WG of IAU Commission A2 and the International Association of Geodesy (IAG)

Chair: José Manuel Ferrándiz, Spain
Vice-Chair: Richard Gross, USA

After the IAU General Assembly 2018, Commission A2 kept in operation its IAU CA2/IAG JWG TERV until the General Assembly (GA) of the IUGG/IAG 2019 in Montreal, Canada, after which the JWG formally ended. The end-of-term reports of the JWG TERV and each of its three Sub-WGs/SWG) were presented in the IUGG/IAG General Assembly and can be accessed at *https://web.ua.es/es/wgterv/*. A summary of them is published in the IAG Travaux 2015-2019 (Drewes and Kuglitsch, 2019), as part of the IAG Commission 3 report, as well as in the IAG Symposia series (Ferrándiz, Gross, Escapa et al. 2020). The activity of the JWG was crucial to unveil that a significant part of the unexplained variance of the determined EOP series is due to systematic errors, inconsistencies, and need of updating old model components.

From all those findings and the research in progress, it was possible to conclude that at least a partial update of the Earth rotation theory was needed and feasible within a reasonable time span. On that basis, the JWG chair proposed a resolution, entitled "Improvement of the Earth's Rotation Theories and Models", that was adopted by the IAG at its General Assembly 2019 in Montreal (available at *https://iag.dgfi.tum.de/fileadmin/IAG-docs/IAG_Resolutions_2019.pdf*). It encourages the prompt improvement of the Earth rotation theory in regards to its accuracy, consistency, and ability to model and predict the essential EOPs; encourages consistency between reference frames and the definition of the EOPs including its theories, equations of motion, and models; and encourages the development of new models that are closer to the dynamically time-varying real Earth.

Proposal of two new Joint Working Groups under Commission A2

Joint Working Group on Improving Theories and Models of the Earth's Rotation (JWG ITMER)

Joint WG of IAU Commission A2 and the International Association of Geodesy (IAG)

Chair: José Manuel Ferrándiz, Spain
Vice-Chair: Richard Gross, USA

The main purpose of this JWG is proposing consistent updates of the Earth rotation theories and models and their validation. The associated tasks will contribute to the implementation of the **IAU Resolution B1 (2018)** on Geocentric and International Terrestrial Reference Systems and Frames, and the **IAG Resolution 5 (2019)** on Improvement of the Earth's Rotation Theories and Models. The last resolution is the most specific for the WG assignment, and mandates *(1) to encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential EOP, (2) that the definition of all the EOP, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG and its components, and (3) that the new models should be closer to the dynamically time-varying, actual Earth, and adaptable as much as possible to future updating of the reference frames and standards.*

Objectives and expected outcomes:

The JWG is committed to derive suplementary models for the celestial pole offsets (CPO) evolution, in part of semi-empirical and semi-analytical nature, and able to increase significantly the explained variance of the current theories and models. According to the recommendations of the 2019 GGOS-IERS Unified Analysis Workshop, the prioritary tasks of building such models will include:

- updating the amplitudes of the leading nutations of the IAU2000 theory and testing shortened series for certain operational purposes
- correcting the inconsistencies found in the precession-nutation models
- test the available FCN models (for explaining CPO variance) and consider whether the IERS should recommend FCN models or not

To develop and publish a fully dynamically consistent theoretical approach to support those models will require a continuation of the activity untill the end of the term. Theoretical developments must also address to advancing in all the aspects made explicit on Resolution 5, like using a consistent framework for all the Earth orientation parameters (EOP), with regard to reference systems and frames, background models, standards, and adaptation of the developments to the current knowledge of the dynamic Earth, from its inner components to its outer layers.

Joint Working Group on the Consistent realization of TRF, CRF, and EOP

Joint WG of IAU Commission A2, International Association of Geodesy (IAG) Sub-Commission 1.4, International Earth Rotation and Reference Systems Service (IERS)

Chair: Robert Heinkelmann, Germany
Vice-Chair: Manuela Seitz, Germany

The JWG addresses the requirements of the **IUGG Resolution 3 (2011)** urging, the **IAG Resolution 2 (2019)** recommending that *"highest consistency between the ICRF, the International Terrestrial Reference Frame (ITRF), and the Earth Orientation Parameters (EOP) […] should be a primary goal in all future realizations" and the **IAG Resolution 5 (2019)** resolving that "[…] the EOP, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG and its components,[…]"*.

Many applications, e.g. in geodesy, astronomy, or navigation, rely on the consistency between terrestrial (TRF) and celestial (CRF) reference frames and EOP, and they require a very high level of accuracy of the related parameters. Currently, TRF and CRF are determined independently of each other. The releases of the terrestrial and celestial frames do not happen at the same time. Individual Working Groups (CRF) or Combination Centers (TRF) compute the frames through reprocessing / combination efforts every five to ten years. In this way, the frames are computed based on different input data and on different analysis models in case of updates of the conventional models. For geodetic and astrometric data analyses and other purposes, the reference frames and the EOP are customarily applied in prediction mode. Accordingly, values have to be given beyond the data time span considered for the reference frame realization. The predicted EOP require consistency to the frames and to the reprocessed EOP at the same time. It is impossible to fulfill both requirements, when new reference frame releases become available.

The joint working group has the objectives to

- compute multi-technique CRF-TRF solutions together with EOP in one step, which will serve as a basis to
- quantify the consistency of the current conventional reference frames and EOP as well as to
- assess the consistency of reprocessed and predicted EOP.

The joint working group will further

- investigate the impact of different analysis options, model choices and combination strategies on the consistency between TRF, CRF, and EOP,
- study the differences between multi-technique and VLBI-only solutions,
- study the possible contributions to EOP and frame determination by the LLR technique,

- study the differences between EOP derived by VLBI solutions at different radio wavelengths in cooperation with the IAU Division A WG Multi-waveband Realisations of International Celestial Reference System,
- study the differences between EOP derived by VLBI solutions improved through Gaia (optical) data in cooperation with the proposed IAU Division A WG on VLBI-Gaia topics,
- study the effects on the results, when different data time spans are considered
- compare the practically achievable consistency with the quality requirements deployed by IAG GGOS
- derive conclusions about future observing systems or analysis procedures in case the quality requirements cannot be met with the current infrastructure and approaches.

Proposal for GA Symposium "Reference systems and their ties with the rotation of the Earth and other Solar System bodies" to be held in 2021 in Busan, Republic of Korea

By December 15, 2019, a proposal was submitted to hold an IAU Symposium "*Reference systems and their ties with the rotation of the Earth and other Solar System bodies"* as part of the XXXI IAU General Assembly in Busan, Republic of Korea, between August 18-22, 2021.

The proposal was prepared under the Lead of Commission A2 jointly together with Commission A1 (Astrometry) and the Inter-Division A-F WG Cartographic Coordinates & Rotational Elements (WGCCRE).

It is also supported by the coordinating Division A (Fundamental Astronomy), Commission A3 (Fundamental Standards), the IAU CA2/IAG/IERS JWG on Consistent Realization of TRF, CRF and EOP, and the IAU CA2/IAG JWG on Improving Theories and Models of the Earth's Rotation (ITMER).

The key topics of the proposed IAU Symposium are:

- 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

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.

Scientific conferences

During 2019 members of Commission A2 were deeply involved in the organization of scientific sessions dedicated to Earth rotation and Reference Frames in the framework of conferences and scientific meetings of various international organizations. In particular, Commission A2 members contributed strongly to the *EGU General Assembly in Vienna, Austria* (Session G2.2: The International Terrestrial Reference Frame: Elaboration, Usage and Applications; Session G3.1: Earth Rotation: Theoretical aspects, observation of temporal variations and physical interpretation), the *IUGG General Assembly in Montreal, Canada* (Session G01: Reference Systems and Frames; Session G04: Earth Rotation and Geodynamics; Session G06: Monitoring and Understanding the Dynamic Earth With Geodetic Observations), and the *AGU Fall Meeting in San Francisco, USA* (Session G11A/G23C: Reference Frames: Determination, Usage, and Application; Session G41A/G31B Fifty Years of Lunar Laser Ranging and Earth and Planetary Rotation).

IAU Commission A3 - Fundamental Standards
Annual Report 2019

James L. Hilton, Susan G. Stewart, Charles H. Acton, Steven A. Bell, Nicole Capitaine,
Demetrios N. Matsakis, & Dennis D. McCarthy

The purpose of IAU Division A Commission A3 is to facilitate advances in astronomy and other fields of science and engineering by developing, implementing, and communicating IAU-endorsed fundamental standards for fundamental astronomy. The Commission currently has 102 members. Our main effort continues to be to develop our website, which was first developed by Catherne Hohenkerk at the inception of Commission A3. We are grateful to for the hosting of this site (www.iaufs.org) by the United Kingdom Hydrographic Office (UKHO) and Steve Bell's serving as webmaster.

Loss of web services for the US Naval Observatory in the fall of 2019 demonstrated the need for an "institution free" solution for web services. It also has made the web site (http://maia.usno.navy.mil/NSFA/) for the Working Group on Numerical Standards for Fundamental Astronomy (NFSA) inaccessible. The requirements of the Commission A3 web site do not fit within the IAU's commissions web site template and allow for frequent maintenance of constants, so a new web site has been developed on GitLab by Susan Stewart (US Naval Observatory) accesed at https://iau-a3.gitlab.io/. The site includes a scrolling news window to keep the commission members aware of recent actions. The page of developing standards has been updated to prepare organizing committee members for discussion on current issues that need to be addressed in the near term. The web site is a first draft and is open for comments from the commission. Once formalized, it will replace to URL link currently listed on the IAU website. We would like to thank Susan Stewart who has agreed to continue to update the site and serve as webmaster.

The new web site includes a revised site for the NFSA. The chair of the NFSA WG has agreed to allow Commission A3 to maintain its web site. The NSFA pages can be accessed from the new A3 Commission web site pages or directly at the URL https://iau-a3.gitlab.io/NSFA/index.html. Changes to the NSFA pages include an update of the Best Estimates for the potential for the geoid as well as a reorganization of the constants to two list - estimates and fixed by convention - as suggested by the NSFA WG.

The commission supported the proposed General Assembly symposium on "Reference systems and their interaction with the rotation of the Earth and other Solar System bodies," with a letter of support. Two of the four co-chairs for the proposed symposium's SOC are members of Commission A3 and at least one other Commission member has agreed to serve on the SOC.

We continue to maintain contact with other standard-setting organizations to ensure the consistency of standards. Robert Heinkelmann is our contact with the Global Geodetic Observing System (GGOS) Bureau of Products and Standards. We assisted Heinkelmann in presentations for the International Union of Geodesy and Geophysics (IUGG) general assembly in Montréal and Journées 2019 in Paris.

In addition to NSFA we continue to maintain close contacts with the working groups Standards Of Fundamental Astronomy (SOFA) and Cartographic Coordinates & Rotational Elements (WGCCRE). Both of these working groups, like NSFA, are functional working groups dedicated to making improvements in particular sub-disciplines.

Annual Report of IAU Commission A4 - 2019

Activities promoted and/or carried out by IAU Commission A4 (Celestial Mechanics & Dynamical Astronomy) during 2019 are detailed below. These are part of the work plan included in the original proposal of Commission A4.

1. Since 2019, the Committee promoted the organisation of the IAU Symposium 364 titled "Multi-scale (time and mass) dynamics of space objects". The Symposium was scheduled in Iasi, Romania, 6-10 July 2020. Although the symposium had already a large number of registered participants, it has been canceled due to the current health situation. The Symposium will be postponed to a date when its activities can be carried out in a safe way.

2. Since 2019, some members of IAU Commission A4 organised the ìI-CELMECH Training Schoolî held in Milano, Italy, within the Italian National Project "New frontiers of Celestial Mechanics: Theory and Applications". Slides and videos of the lectures and talks are available at http://www.mat.unimi.it/I-CELMECH/index.php/training-school-lectures-talks/

3. Some members of IAU Commission A4 promoted a topical collection within the journal "Celestial Mechanics and Dynamical Astronomy":
- ì50 years of Celestial Mechanics and Dynamical Astronomyî (on-line at https://link.springer.com/journal/10569/topicalCollection/AC_099921925e89922029a852db7fbddfb9)

4. Information an updates on Celestial Mechanics and Dynamical Astronomy are spread by Alessandra Celletti through the ResearchGate Project: https://www.researchgate.net/project/Celestial-Mechanics-and-Dynamical-Astronomy

IAU Commission X2 - Solar System Ephemerides

Annual Report 2019

William M. Folkner (President)
Giovanni B. Valsecchi (Vice-President)
Agnès Fienga (Secretary)
Steven R. Chesley
Matthew Jon Holman
Marco Micheli
Elena V. Pitjeva

The commission was created in 2015, based on approval of a proposal to merge the functions of the previous Commission 4 on Ephemerides and Commission 20 on Positions and Motions of Minor Planets, Comets and Satellites.

The main purpose of the SSE commission is to support the development of high precision ephemerides, and the products/services that disseminate them, for all solar system bodies: planets, dwarf planets, asteroids, comets, trans-Neptunian objects, natural satellites (of planets and asteroids). The ephemerides will include position, velocity, and orientation for bodies other than Earth.

Unfortunately there is no ongoing meetings where many of the members of the former Commission 4 and Commission 20 come together. In the last triennium Commission X2 proposed a IAU Symposium to bring a broad range of experts on Solar System Dynamics together, but the proposal was unsuccessful, primarily because the expected number of participants was judged to be too low.

Following the 2018 General Assembly, it was tentatively agreed that commission could sponsor meetings outside the Symposium process. Plans were tentatively made to hold such a meeting in June 2019, but these failed to come to fruition due to medical issues of the leader of the local organizing committee.

The X2 Organizing Committee then discussed options for an alternate meeting in 2019. However the small-body representative preferred to concentrate on the AAS-DPS/EPSC and triennial Asteroid-Comets-Meteors meetings in 2020, and the planetary ephemerides representative prefer to stick with the Journees meeting series. So there was no date agreed to.

Given the triennial IAU GA planned for 2021, the next option might be the following year, 2022, if the Asteroid-Comets-Meteors meeting sticks to its triennial schedule, though that may change since the 2020 ACM meeting has been canceled due to the Covid-19 pandemic.

IAU Standards of Fundamental Astronomy (SOFA)
Annual Report 2019

SOFA Board/Working Group Members

John Bangert	United States Naval Observatory, retired
Steven Bell	HM Nautical Almanac Office, UKHO (Webmaster)
Nicole Capitaine	Paris Observatory
Mickaël Gastineau	Paris Observatory, IMCCE
Catherine Hohenkerk	HM Nautical Almanac Office, retired (Chair)
Li Jinling	Shanghai Astronomical Observatory
Brian Luzum	US Naval Observatory
Zinovy Malkin	Pulkovo Observatory, St Petersburg
Jeffrey Percival	University of Wisconsin
Wendy Puatua	United States Naval Observatory
Scott Ransom	National Radio Astronomy Observatory
Nicholas Stamatakos	US Naval Observatory (IERS Conventions)
Toni Wilmot	HM Nautical Almanac Office (Trainee)
Patrick Wallace	RAL Space, retired

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).

Currently SOFA is in a "maintenance" mode. Technical queries from users still occur, which were answered by Patrick Wallace, and there has been one release since the end of January 2018. Release 15, dated 2019 July 22, was a major release which, in summary, implements four new routines in the Star Catalog Conversion section, corrects a sign in one ANSI C routine, and enhances 17 routines to minimise rounding errors.

The four new routines that were added deal with the transformation between the FK4 and FK5 reference systems. These routines were included partly for completeness, but mainly so that positions in publications pre-1984 can be properly handled, and they cover conversions between B1950.0 FK4 and J2000.0 FK5, with and without proper motion. Following input from the Astropy group, enhancements were made to routines that compare the two components of the given date/time arguments to minimize rounding errors, so that optimum results are achieved even when one of the arguments is negative. SOFA is particularly grateful to the Astropy group and to all users for their comments and suggestions. The addition of new routines required updates to the *Astrometry Tools Cookbook*, the test program and the other supporting files. Many miscellaneous typographical corrections and improvements to various other documents were also made.

Since 2019 March it has been impossible to report the numbers of users studying the source code via our website, or the numbers of times the SOFA library (Fortran and/or ANSI C) has been downloaded, due to system changes at SOFA's host organisation. There are also many users of the SOFA software via various other implementations; Java from Jodrell Bank Centre for Astrophysics and C# available from the World Wide Astronomy library, and the thousands of users via the Essential Routines for Fundamental Astronomy (ERFA) version that is bundled with Astropy in Python. We encourage all our users to acknowledge their use of SOFA.

Considering the people on the SOFA Board, a new Chair is needed to take SOFA forward. To help both the current Chair and the Webmaster, Toni Wilmot from HM Nautical Almanac Office joins the board as a "trainee" member. Also joining the Board from 2019 November is Nicholas Stamatakos from the US Naval Observatory and the International Earth Rotation and Reference Systems Service (IERS) Conventions.

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; in particular for pointing out issues and making suggestions.

Catherine Hohenkerk
Chair IAU SOFA Board
2020 April 5

IAU Working Group -Astrometry by Small Ground Based Telescopes

M. Assafin -Chair
W. Thuillot -Vice-Chair

Annual Report 2019

The WGASGBT (Working Group on Astrometry by Small Ground Based Telescopes) was set up in 2006 during the XXVIth IAU General Assembly in Prague by the Division 1 (Fundamental Astronomy). Since then it has been successively extended. The last triennium extension by Division A occurred during the XXXth IAU General Assembly held in Vienna in 2018. The goal of this WG is to update and maintain information on astrometric programmes and activities carried out with small telescopes, to diffuse news through these 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 of D < 2 m. These telescopes are generally easier to access than larger ones and allow us to carry out observational programs on medium and long term. Thanks to that they are precious tools to contribute to the advance of our knowledge of the celestial bodies: many Solar System objects and some astrophysical objects. More generally, the small telescopes due to their number and their geographical spread, are very efficient for observation in network. This is a strength which is successfully applied for coordinated programs.

Here it follows a brief summary of our activities in 2019.

W. Thuillot reports that during he and his colleagues at IMCCE, Paris Observatory, France, worked in the validation and follow-up of the Gaia discoveries of Solar System Objects, acquisition and exploitation of astrometric observations of natural satellites and set up of a new astrometric project by exploitation of old photographic plates. The Gaia alerts Follow-Up Network, Gaia-FUN-SSO (Thuillot et al., 2018b), continued to react on alert when new Solar System Objects were detected by Gaia. An alert pipeline is operating since the end of 2016 and transforms the Gaia space data into propagated topocentric data which are diffused at the address https://gaiafunsso.imcce.fr. Around 1500 alerts per year (4 alerts/day) are triggered. The detection of more than 200 new objects have already been reported and their astrometric data have been sent to the Minor Planet Center in order to feed the asteroid orbital database. The most productive observatories are the 1m class

telescopes of the Las Cumbres Observatory Global Telescope network, Haute-Provence Observatory, Odessa-Mayaki, Terskol and Caussols (Thuillot et al., 2019; Carry et al., 2019; Thuillot & Dennefeld, 2018a). The data issued from the last campaign of observation of mutual events of the Galilean satellites, eclipses or occultations of satellites by each other, coordinated by IMCCE and the Sternberg Astronomical Institute in Moscow have been analyzed (Saquet et al., 2018; Zhang et al., 2019). This kind of photometric observations are made for astrometric purposes. They are performed by small telescopes and lead to very accurate astrometric measurements which are used in the dynamical development of the natural satellite models. New predictions have been made and new campaigns are foreseen (Arlot & Emelyanov, 2019). Besides, the NAROO project anticipated the use of the Gaia stellar catalogs to rereduce old photographic plates (Arlot, Robert & Lainey, 2018; Arlot & Robert, 2019; Robert et al., 2019). A sub-micrometric scanning machine has been set up in Paris Observatory for this goal and begun to operate in 2019. W. Thuillot also points out to a report from N. Mason, President of the Europlanet Society and coordinator of the Europlanet 2024 RI Section. N. Mason reported that Europlanet 2024 RI is establishing a network of small telescope facilities within Europe and beyond. A full-day virtual meeting was held in March 2020 to officially kick-off the activity. The web-conference was attended by 37 participants representing Europlanet 2024 RI and the Work Package team but also a diverse set of different telescope facilities from all over Europe. The main goal of the meeting was to discuss the aims and goals of the network activity for the upcoming four years. These contain the development of a central website for observational alerts and the organization of coordinated campaigns, amateur training workshops, and the establishment of the Europlanet Telescope Network itself.

N. Zacharias submitted a full report on US Naval Observatory activities for Comission A1 which does include topics for the WGASGBT. He recently released a public report about the 1-meter telescope of the USNO, the Deep South Telescope (DST), deployed at Cerro Tololo Interamerican Observatory (CTIO), Chile in March 2019. A 4k CCD camera will be used to image selected optical counterparts of ICRF sources which display significant radio-optical position offsets. This high cadence observing program is a joint effort between USNO and Paris Observatory. DST will also be used for other programs in the future, including near-infrared observations with a camera mounted at the 2nd Nasmyth focus.

F. Taris reports that quasar optical flux variations can alert us to potential changes in their source structure. These changes could have important implications for the position and time

evolution of the target photocenters with consequences for the link of the reference systems (ICRF-Gaia CRF). For some targets well observed by the TAROT telescopes, the Allan time variance shows that the longest averaging period of the magnitudes is in the range 20-70 days. The observation period by Gaia for a single target largely exceeds these values, posing a problem when the magnitude variations exhibit flicker or random walk noises. Preliminary computations show that if the coordinates of the targets were affected by a white-phase noise with a formal uncertainty of about 1 mas (due to astrophysical processes that are put in evidence by the magnitude variations
of the sources), it would affect the precision of the link at the level of 50 μas (Taris et al., 2018). To improve these first results the SYRTE department of Paris observatory is involved in photometry measurements of AGNs (quasars) in the frame of several projects. They are performed with small (or medium) class telescopes in close collaboration with Belgrade, Côte d'Azur and Montsec Astronomical observatories. Magnitude time series
are continuously acquired to improve our knowledge of the longest averaging period of the magnitude time series of AGNs. The laboratory is associated with the Fundamental Reference AGN Monitoring Experiment (FRAMEx) project lead by USNO. The goal is to observe the optical counterpart of radiosources at the same time than the VLBA and IR facilities. To observe a huge amount of targets on a daily basis, the laboratory initiated the construction of a 1 m robotic telescope. Half of the budget had already been obtained and the team plan to build the instrument before autumn 2021.

R. Teixeira reports local and remote (from Shanghai, China) observations of artificial satellites and space debris made with the MEADE 40cm of the Abrahão de Moraes Observatory of the University of São Paulo, Brazil. The observations are made with a CCD camera in drift scan mode coupled to a rotator developed by the Shanghai Observatory. These observations are part of a larger project in collaboration with colleagues from various institutions around the world for the astrometry of fast objects such as artificial satellites, debris and Near-Earth Asteroids. He also reports that the CCD Meridian Circle of that observatory is currently deactivated, but opened for public outreach.

T. Pauwels reports the activities at the Royal Observatory of Belgium. In 2017 the dome of the Ukkel Schmidt Telescope was restored, and during that period no observations were possible. After the telescope was available for observations again, the number of still to be discovered asteroids in the range of the equipment (magnitude limit 20-20.5) had decreased too much to justify the cost of the maintenance and to motivate the observers. No astrometric

observations have been performed since then, and it is quite unlikely that observations will be done in the future.

N. Maigurova and O. Shulga report astrometrical observations of small Solar System bodies, multiple stars and open clusters, GEO and LEO satellites and meteors carried out by small ground-based telescopes at the Research Institute Mykolaiv Astronomical Observatory, Ukraine. A total of 1229 topocentric positions of 40 NEAs and 112 ones of 5 comets were obtained during 2019 at the KT-50 telescope. The positions were sent to the IAU MPC database (code 089). Observations of 260 open cluster fields were made in 2019 at the KT-50 telescope resulting on a catalog of 357,000 star positions up to V magnitude 16 at epoch 2019.5. Observations of 398 multiple and double stars were obtained in 2019 at the Axial Meridian Circle. The results will enter the WDS database. Optical and radio observations of meteors are under way. The observations are presented on the RMOB (Radio Meteor Observing Bulletin) website. Optical observations of low-orbiting satellites were carried out in 2019 at the KT-50 telescope. There were 686 successful observations over 25 nights. A database of 8380 positions was obtained. Optical observations of the satellites on geostationary orbits were also performed in 2019. There were 748 successful observations over 72 nights. A database of 15618 positions was obtained. According to the Ukrainian Network of Optical Stations in 2019, the team succeeded in contributing with positions to obtain orbital elements for the satellites, which are placed on the website http://umos.mao.kiev.ua/eng/index.php?slab=slabid-12.

Anatoliy Ivantsov reports activities supported by the Akdeniz University, Antalya, Turkey. It hosted the international workshop meeting Dynamics and Physics of Asteroids, TNOs and Natural Satellites in the New Era of Gaia Data (https://asteroid2019.space) on September 4-6, 2019. There were three sessions: Dynamics of Small Bodies, Sky Surveys from Space and from the Ground and Observations of Small Bodies, where numerous achievements in astrometry, photometry, spectroscopy, polarimetry were presented and discussed. The SOC comprised of two members of this WG (W. Thuillot and A. Ivantsov). There were more than 30 participants with 60% from Austria, China, France, Italy, Russia, Ukraine, UK, and USA. An observational programme devoted to characterizing the potentially hazardous asteroids and study their dynamics was initiated at the UBT60 telescope (D=0.61 m, F=3.96 m) of the Akdeniz University located at the Tubitak National Observatory site (A84). The telescope operated remotely is equipped with standard Johnson-Cousins UBVRcIc and SDSS filters and a new FLI Proline 16803 CCD (4096x4096, 9µm x 9µm) installed in 2019.

M. Assafin and R. Vieira Martins report on the astrometric and photometric use of 0.6m to 2.2m class telescopes at Brazil, Chile, Australia, France and Spain. They report the first observation of a stellar occultation (SO) by Europa (Morgado et al., 2019a), the observation of mutual approximations between the main satellites of Jupiter (Morgado et al., 2019b) and Uranus (Santos Filho et al., 2019), a SO by the irregular satellite Phoebe of Saturn (Gomes-Júnior et al., 2020), and SOs by Trojan asteroids of Jupiter, Centaurs (including the ringed object Chariklo), dwarf planets and many other transneptunian objects (Camargo et al., 2018). Regular astrometric observations of natural and irregular satellites of giant planets were also done with these instruments. They also report an initivative to form an astrometric/photometric network of tens of small 40-50 cm aperture telescopes in Brazil and South America - ROSA (South America Occultation Network in english) - in support but not limited to the observation of SOs by Solar System bodies, education and scientific outreach.

G. Damljanovic from the Astronomical Observatory at Belgrade (AOB), Serbia, reports that his team established a local Serbian-Bulgarian mini-network of six telescopes (lead by G. Damljanovic) at three sites: Belogradchik AO and Rozhen NAO in Bulgaria, and Astronomical Station Vidojevica (ASV) in Serbia. They observe QSOs, objects from alerts by the Gaia-FUN-TO (Gaia Follow Up Network for Transients Objects) and blazars from alerts by the WEBT-GASP (Whole Earth Blazar Telescope Project), among other objects. Near 100 ICRF QSOs, about 20 WEBT objects and about 75 Gaia Alerts were observed. About the SANU-BAN cooperation (between the Serbian Academy of Sciences and Arts and Bulgarian Academy of Sciences), there are two joint research projects underway on the observation of ICRF and Gaia radio-sources and fast variable objects, lead by G. Damljanovic. The synergy between Gaia and ground-based observations is of big importance, and it is in line with the Serbian-Bulgarian astronomical cooperation and investigation using our mini-network of six telescopes. It is important to align the Gaia frame (based on optical data) and ICRF (VLBI data) through observations of QSOs in both visible and radio domains, with a compact radio/optical core but without complex structures. Using the mini-network, the team monitors some QSOs and check the optical data (position stability and structure) via photometry and morphology investigations. The 2 m Rozhen and 1.4 m ASV telescopes are used in the QSO morphology investigations, and other telescopes (60 cm ASV, 60 cm Belogradchik, 60 cm Rozhen, and Schmidt-camera 50/70cm) are used for photometry to investigate QSOs quasi-periodicities. The WEBT is a network for optical, near-infrared, and radio observations to obtain

continuously, high-temporal-density monitoring of blazars. The WEBT data are extremely useful to understand the continuum emission of blazars. Gaia Alerts have been issued by the Gaia Science Alerts group, and Gaia is now the largest provider of transients in the world (rare types of supernovae, cataclysmic variable, microlensing events, etc.) with about 2000 alerts per year. Using our telescopes for simultaneous observations we can get data for multi-color photometric light curves and investigate fast changes on the flux of the objects. The investigations involved the reduction of CCD images for photometry/morphology, calculation of BVRI magnitudes (photometry, quasi-periodicities), determination of QSOs parameters using GALFIT software (morphology), the improvement of some steps and methods (during reduction of raw CCD images) to remove systematic errors and to get accurate data as much as possible, the development of new methods to get precise results, and the analysis of these results. The team collaborates with the Observatoire de Paris, Torino Observatory, among others. Some of our results have been published in several journals: MNRAS, Astrophysical Journal, Astrophysical Journal Letters, Astronomical Journal, Serbian Astronomical Journal, Astronomy and Astrophysics, etc. Also, some results were presented at a few conferences, and published in the Bulgarian Astronomical Journal.

Please visit our refreshed web page at https://iau_wgnps.imcce.fr for more historic and updated reports on the activities of this WG.

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INTERNATIONAL ASTRONOMICAL UNION
DIVISION A AND F / WORKING GROUP
CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS

MEMBERSHIP B. A. Archinal (Chair), A. Conrad (Vice-Chair), C. H. Acton, T. Duxbury, D. Hestroffer, J. L. Hilton, L. Jorda, R. L. Kirk, S. A. Klioner, J.-L. Margot, K. Meech, J. Oberst, F. Paganelli, J. Ping, P. K. Seidelmann, D. J. Tholen, I. P. Williams

REPORT TO IAU FOR 2019

1. Introduction

The main activity of the IAU Working Group on Cartographic Coordinates and Rotational Elements (hereafter, WG) is to make recommendations regarding the creation and maintenance of cartographic planetary coordinate systems. The agreed-upon recommendations are produced roughly in conjunction with each IAU General Assembly and are published as a report in the journal *Celestial Mechanics and Dynamical Astronomy*. Our most recent report was published in February 2018 (Archinal et al. 2018a) with corrections published in 2019 (Archinal et al. 2019c).

We are beginning work to compile the next version of that report. We expect there will be routine updates (Archinal and WGCCRE, 2020a) to recommended orientation and size models resulting from processing or reprocessing of various planetary datasets, e.g. with improvements possible for various bodies such as Mercury, Venus, Jupiter, Saturn, Saturnian satellites, Ceres, 67P/Churyumov–Gerasimenko, Arrokoth, Bennu, and Ryugu.

Although lunar ephemerides currently seem to provide the orientation of the Moon with an accuracy of several meters, improved ephemerides solutions continue to be made based on new lunar laser ranging (LLR) from various groups. Therefore, changes in the lunar orientation model should be considered. Another issue is whether to finally base the mean Earth/polar axis lunar system directly on no-net rotation-based LLR solutions for retroreflector coordinates rather than on a specific lunar ephemeris as is done currently.

For Mars, the orientation model previously recommended by the WG could be updated to a newer model. However, a separate issue has been raised that the new models seem to have a ~100 m offset in longitude at the fundamental epoch of J2000.0 relative to the previous recommended system. Clarification is needed as to the cause of this offset and based on community input a decision must be made as to whether some correction in longitude is needed in these newer models.

2. Membership

The WG currently consists of 16 members from 5 countries, with membership lengths from 2 to 44 years. Brent Archinal (U. S. Geological Survey) serves as the current Chairman, and Al Conrad (Large Binocular Telescope Observatory) serves as the Vice-Chairman. The WG began operation in 1976. In recognition of the continued need for the WG, in 2016 it became a “Functional Working Group" of the IAU, with an institutional scope and purpose in providing a service that naturally extends beyond the IAU triennial cycle (IAU Exec. Committee, 2016).

The WG is always looking for volunteers to join, particularly to help with each new report. Our membership is open to all who wish to help with our work. Some individuals have recently expressed an interest in joining the WG and we plan to follow up with them and others likely interested, but additional members are welcome. This may help to increase our membership, expertise, and available time to work on our main report and community inquires.

3. Community Inquiries

The WG Chair and many of the WG members spend significant time answering questions from NASA, missions, mission instrument teams, journal editors, individual researchers, and the public, on various issues related to planetary coordinate systems. Because of new data and improvements in data returned from active missions, there are ongoing questions about the coordinate systems for the Moon and Mars, and regular questions from various NASA Planetary Data System personnel. Some of our members have provided information to international archiving organizations such as ESA's Planetary Science Archive, JAXA's and IKI's archiving arms, as well as the International Planetary Data Alliance; and to planning organizations such as the NASA Mapping and Planetary Spatial Infrastructure Team (MAPSIT) advisory group. The WG cooperates with other IAU components, such as IAU Commission A1 Astrometry and the X2 Cross-Division A-F Commission Solar System Ephemerides. More frequently relative to coordinate system issues, WG members also have been asked to review papers and plans for data archives.

4. Concern About Support as a Functional WG

In recent years there has been concern, particularly due to the greatly increasing number and complexity of community inquiries, that the WG is becoming overextended. The time needed to respond to such inquiries have resulted in delays of our most recent reports relative to the preferred triennial schedule of IAU activities. We plan to address this partly by increasing membership, especially as experienced personnel retire and are not replaced. However, it also may be necessary to consider whether an actual service (perhaps analogous to the International Earth Rotation and Reference Systems Service, even if not initially at the same scale) is needed to perform some of the community support functions of the WG. One of us (Archinal) receives NASA funding for a portion of his work, but it may be necessary to seek additional funding and help in planning, perhaps from sources such as international space agencies, to continue to address community requests and increased demands for input. The WG plans to consider this overall issue but community input is welcome as we proceed.

5. Publications and Meetings

The WG has continued to make its efforts and activities known via its website (http://astrogeology.usgs.gov/groups/IAU-WGCCRE) and by various publications and community presentations. Specifically:

- We will continue to publish our main report to the planetary community, to be published approximately triennially, following each IAU General Assembly. Since our previous report was delayed, we tentatively plan to issue our next report in late 2020.
- The WG will make brief annual reports to Divisions A and F on our 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 for submittal as an IAU News Announcement, such as that shown in IAU (2018).
- To make our work better known and encourage adherence to the recommendations in our main report, we will continue to submit abstracts to and make presentations at various planetary science meetings, describing the activities of the WG and our reports. Such events would include the Lunar and Planetary Science Conference and the Planetary Data Workshops (Archinal and WGCCRE, 2019a, 2020a; Conrad and WGCCRE, 2019), the Planetary Science Informatics and Data Analytics Conference (Archinal and WGCCRE, 2018c), various international meetings (Archinal and WGCCE, 2018b, 2019b, 2020b, 2020c; Heinkelmann et al. 2019), and possibly other meetings such as NASA MAPSIT and other Analysis Group meetings (http://www.lpi.usra.edu/analysis/).

- In 2019, the WG, along with other components of the IAU, submitted a proposal to hold an IAU Symposium at the 2021 IAU General Assembly on the topic of “Reference systems and their ties with the rotation of the Earth and other Solar System bodies.”

6. Closing remarks

We plan to complete a new version of our main report by late 2020. We will continue to address questions from the planetary community regarding planetary coordinate system issues and continue to further increase community awareness of our work with abstracts and presentations at appropriate scientific meetings. Inquiries from the community have increased greatly in recent years from individuals, editors, instrument teams, missions, and space agencies. We expect to accommodate this increased workload in part by moving forward with an increased WG membership.

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Division A Working Group on Time Metrology Standards

Annual Report on Activities for 2019

Chair: Elisa Felicitas Arias

Membership

At the date of this report the Working Group has 18 members, including the chairperson. A request for association to the IAU has been presented, with the support of the president of Division A to keep within the members a representative from the US Naval Observatory. This will increase the number of members of the working to 19.

Meetings

The working group had no meetings within the period, only communication by e-mail.

Issues under consideration

The International Telecommunication Union invited the IAU to contribute to the studies on a possible redefinition of UTC. This contribution should be submitted before the World Radiocommunication Conference in 2023. The working group is considering the content of this contribution and form in which it could be presented.