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COMMISSION A1 ASTROMETRY

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Triennal Report 2015-2018

1. Recommendation to continue Commission A1

We recommend the continuation of commission A1. The discipline of astrometry traditionally benefited from international collaboration and will continue to do so as efforts to refine and align the optical (Gaia-CRF2, see below) and radio reference frames continue. The community represented by Commission A1 remains the natural partner for identifying the need for and assisting in the creation of working groups, such as the 'Multiwaveband Realisations of International Celestial Reference System' and 'Astrometry by Small Ground-Based Telescopes' working groups.

As a goal for the next triennium we believe commission A1 should become more active in communication and outreach toward the astronomical community, in particular where it concerns astrometric techniques and the proper use of astrometric data, as well as keeping our community better informed in general about astrometry-related initiatives and activities.

2. Space astrometry

2.1. *Gaia mission*

Following the first Gaia data release in 2016 the Gaia Data Processing and Analysis Consortium (DPAC) concentrated on the data processing for and production of the second Gaia data release. Gaia DR2 will appear on April 25 and represents a major step with respect to the first release, expanding the availability of high precision proper motions and parallaxes to a sample of over 1.3 billion stars and also adding a large radial velocity survey at the bright end (below 13th magnitude), containing over 6 million radial velocities. These data are complemented with stellar astrophysical parameter estimates for more than 150 million stars, light curves for some 0.5 million stars, and the first Gaia epoch astrometry for a sample of about 14 000 minor planets in the solar system.

Gaia DR2 also represents a new materialisation of the celestial reference frame in the optical, the Gaia-CRF2, which is the first optical reference based solely on extra-galactic sources.

During the three year period 2015–2018, the GBOT (Ground Based Optical Tracking, Altmann et al. 2014) group was in charge of the daily optical tracking of the Gaia satellite as it is the case for the whole duration of the mission. 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 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 optimally correct 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. During the three year period, about 10 000 frames of Gaia satellite have been reduced. A general technical study of the characterization of the astrometric precision limit for moving targets observed with digital-array detectors was carried out within the GBOT program (Bouquillon et al., 2017)

2.2. *JASMINE missions*

In Japan the development of JASMINE missions has been continued. JASMINE is an abbreviation of Japan Astrometry Satellite Mission for Infrared Exploration. Three satellites are planned as a series of JASMINE projects, in 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 zw-band (0.6–1.0 micron). The target accuracy of parallaxes is about 3 milliarcsec at $zw = 7.5$ mag (Kobayashi et al. 2011). By combining Nano-JASMINE measurements with Hipparcos catalogue, precise proper motions (to about 0.1 milliarcsec/yr) can be derived. Although the flight model of Nano-JASMINE has been accomplished, the launch opportunity has never been officially determined. However, recently a suitable candidate was found and we proceed to conclude a launch service agreement with a company.

Small-JASMINE will determine positions and parallaxes with 20 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 20 microarcsec yr^{-1} uncertainties 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). The target launch date is around 2024. Small-JASMINE successfully passed MDR (Mission Definition Review) in April 2017. As a part of the management review planned by ISA/JAXA for acceptance of the upgrade to the next development phase, we had an international review in December 2017. The review committee has concluded that Small-JASMNE has high scientific significance because scientific objectives on the Galactic nuclear bulge are potentially unique and compelling for the era of mid-2020's. Furthermore the review committee concluded that the error budgets of the observation and the ground analysis methods are extensively studied and no technical showstopper was found at the present phase.

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

3. Ground based astrometry

3.1. *Optical/infrared astrometry*

The US Naval Observatory (USNO) Robotic Astrometric Telescope (URAT) was successfully moved to Cerro Tololo Interamerican Observatory (CTIO) in October 2015 and since then has taken over 188 000 exposures (each 28 square degrees). The main goal is to supplement Gaia with observations of bright stars (up to Sirius) through a neutral density spot filter.

The URAT Parallax Catalog south (UPCs) was completed based on 2 years of observing at CTIO, giving trigonometric parallaxes of 916 newly discovered stars within 25 pc (Finch, Zacharias & Jao, submitted),following the UPC north data release (Finch & Zacharias 2016). The UCAC5 catalog (Zacharias, Finch & Frouard 2017) was published as CDS catalog I/340 combining UCAC data with Gaia Data Release 1 (DR1) to obtain new proper motions.

USNO is acquiring a new 1.0-meter, fully robotic telescope (DST = Deep South Telescope) to be used for deep astrometric observations at CTIO beginning in late 2018. The DST will replace URAT, which will be shutdown after completing both norther and southern hemisphere surveys.

The Naval Observatory Flagstaff Station (NOFS) completed its decades-long optical, trigonometric parallax program in light of Gaia DR2. The subdwarfs from that program were published (Dahn et al. 2017), and more papers regarding white dwarfs and carbon stars are in preparation. Observations of bright stars in the northern sky are ongoing with the USNO Bright-star Astrometric Database (UBAD) project using the 1.55-meter Strand astrometric telescope at NOFS.

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 conducting the 'USNO-UKIRT Hemispherical Survey' (U2HS), a complete northern hemisphere survey from DEC =0 to +60 deg in K-band down to magnitude K ¿ 18. U2HS will complement the soon-to-be-released UKIRT Hemispherical Survey (UHS), a recently completed J-band survey of the northern hemisphere up to DEC +60 deg.

3.2. *Radio astrometry*

The Bar and Spiral Structure Legacy (BeSSeL) Survey conducted VLBA maser-astrometry observations for a total of $\sim 3\,500$ hours from 2010 to 2016. In 2017, the BeSSeL results have been published in Sanna et al. (2017), Zhang et al. (2017), Reid et al. (2017) and so on. Sanna et al. reported the smallest parallax ever measured(0.049 ± 0.006 mas, corresponding to $20.4 + 2.8/-2.2$ kpc). The result sheds light on Galactic structure far behind the Galactic center, locating the source at a distance of 12 kpc from the center.

In Japan, regular operation of the VLBI Exploration of Radio Astrometry (VERA) array continued in 2017. Astrometric observations of Galactic masers were conducted for approximately 1800 hrs. As of August 2017, astrometric observations of about 200 maser sources were completed, and parallaxes were derived for 97 maser sources (75 star-forming regions and 22 late-type stars). In 2017, the parallaxes and proper motions have been reported for several Galactic maser sources such as AFGL 5142 (Burns et al. 2017), CO-0.40-0.22 (Iwata et al. 2017), and IRAS 20231+3440 (Ogbodo et al. 2017). Also, Sakai et al. (2017) disentangled a puzzle of Sgr D complex (consisting of Sgr D HII, Sgr D SNR and Sgr D new SNR) where the location of the complex relative to the Galactic center had not reached in a consistent result (i.e. in or near-side/outside of the Galactic center). They derived a trigonometric distance of Sgr D HII to be $2.36(+0.56/-0.39)$

kpc, placing it in the Scutum arm instead of the Galactic center. It is revealed that Sgr D HII is seen in the direction of the Galactic center just by chance projection effect.

USNO has access to 50% of the National Radio Astronomy Observatory (NRAO) Very Long Baseline Array (VLBA) observing time. Under the USNO time allocation, the 10 radio telescopes of the VLBA are being used for maintenance of the International Celestial Reference Frame 2 (ICRF2) through a series of observing sessions designed to re-observe previously poorly observed ICRF2 sources, e.g., sources previously observed in only a single session (such as the VLBA Calibrator Survey sources) or sources with only a few successful observations in previous observing sessions. The USNO VLBA time allocation is also being used to support the extension of the ICRF2 to higher radio frequencies through a series of observing sessions of ICRF2 sources at a radio frequency of 24 GHz (K-band).

3.3. *Astrometry with SKA*

The activity of the Astrometry sub-Working Group of the Japanese SKA Consortium (SKA-JP) has yielded publications of two refereed papers on the technique of low frequency astrometry for 1.6 GHz hydroxyl masers (Rioja et al. 2017, AJ, 153, 105; Orosz et al. 2017, AJ, 153, 119) on the basis of the basic idea described by Imai et al. (2016, arXiv1603.02042). The sub-WG activity is currently focusing its important role on designing the strategy of ultra-wide band VLBI astrometry and geodesy, in which astrometric error contributions from the troposphere and the ionosphere will be directly measured. This activity includes designing a new front-end and a signal transmission system, which will correspond to the development of the SKA MID Band 5c receiving system as one of possible Japanese contributions to the SKA1 construction.

4. Astrometric data bases

A specialized PostgreSQL database (the Celestial Database, or CDB) has been developed at USNO comprising the best astrometric and photometric data on nearly 2 billion stars and compact sources. The CDB currently includes some 50 catalogs and surveys in different schemas, ranging from X-rays to mid-IR in wavelengths and from $G \sim 21$ mag to the brightest stars in magnitude. The architecture is flexible and dynamic permitting frequent updates and modifications, with the intent of providing only the most accurate, up-to-date, and verified astrometric information. DCDB has been used as the main platform for the services provided by USNO as an affiliated Gaia Data Center, as well as in a number of dedicated investigations, such as the tentative global astrometric solution for Pan-STARRS anchored in the ICRF2 (Berghea et al. 2016), and the origin of radio-optical position offsets of ICRS sources detected in the Gaia DR1 and ICRF2 (Makarov et al. 2017).

5. Reference frame

5.1. *LQAC catalogue*

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) as the most accurate equatorial coordinates, the redshifts, multi-bands magnitudes, radio-fluxes. Moreover it gives supplementary data as absolute magnitudes and morphology index. A new up-date of the catalogue, the LQAC-4 was achieved in end-2017 (Gattano et al., 2018), in the continuity of the LQAC-2 (Souchay et al.,2012) and the LQAC-3 (Souchay et al.,2015). As a new important input this last up-date contains the cross-identifications with the GDR1 (Gaia data release 1) catalogue. A total number of 443 725 objects are compiled with 248788 of them cross-matched with the GDR1, by adopting a 1 arcsecond search radius.

5.2. *Photometric monitoring of ICRF quasars*

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 preselected for the link between the ICRF and the Gaia-CRF (Gaia Celestial Reference Frame). High frequency light-curves of each quasar of the set was given, together with a periodogram analysis proving periodic or quasi-periodic phenomena. This variability should be accompanied with displacements of the photocenter and thus should have consequence on the astrometric quality. A statistical study of the photometric variability, based on the Allan variance, was undertaken recently (Taris et al., 2018)

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