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COMMISSION 8 ASTROMETRY

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TRIENNIAL REPORT 2009–2012

1. Scientific Highlights

Gaia is continuing well with its development and construction and is expected to achieve parallax accuracies of about 10 to 300 μas for 6 to 20 mag. It is scheduled to launch in 2013.

The ICRF2 was adopted by the IAU in 2009 as the new fundamental celestial reference frame.

The UCAC project concluded with the publication of its 4th data release (all-sky, over 100 million stars).

The JASMINE project will launch the Nano-JASMINE satellite in 2012 and continues with the development of its other satellites which will complement the Gaia project.

The PPMXL (Heidelberg) and XPM (Ukraine) catalogues provide improved astrometric accuracies from new reductions of USNO-B (USNO-A) and 2MASS data.

It is disappointing that the SIM project was cancelled during this triennium. It would have further complemented the above two satellite projects and would have gone even beyond Gaia in astrometric accuracy.

2. Instrumentation and Reduction Methods

ARGENTINA: The instruments at the Complejo Astronómico El Leoncito continue to operate regularly and represent interesting resources for astrometric observations. Also the Estacion Astronomica Rio Grande continued the work on polar motion. The Facultad de Ciencias Astronómicas y Geofísicas of the Universidad Nacional de La Plat kept its research group on reference systems for astronomy and geodesy. Also the Observatorio Astronomico de Cordoba, worked on Galactic astrometry.

BELGIUM: At the Royal Observatory of Belgium a high-precision scanner, called Damian, has been built capable of digitizing astrophotographic plates up to 35×35 cm. It is described in De Cuyper *et al.* (2011). A report by Robert *et al.* (unpublished) shows a positional accuracy of better than 0.1 μm.

CHINA PR: Yanben Han (Beijing) reports that the San Juan SLR station, working in cooperation with National Astronomical Observatories of the Chinese Academy of Sciences (NAOC) and Universidad Nacional de San Juan (UNSJ) of Argentina, has operated for five years since the end of February 2006; the observations of the SLR station

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have made contributions to the ILRS and IERS. In June 2009, San Juan SLR station began to upgrade the system for daylight and kHz tracking. The San Juan SLR system upgrading will be completed in 2012. The 40-metre radio telescope project (VLBI) comes into operation in 2011. The San Juan Station will become an integrated observational station with SLR, GPS and VLBI in coming years (Han *et al.* 2008).

Zhenghong Tang (Shanghai) reports that a prototype of a rotating-drift-scan CCD has been developed and installed on a 300 mm (F = 250 mm, FoV=8.3° × 8.3°) telescope to observe faint space debris (Tang *et al.*, 2010). With 5s observations, it is possible to observe space debris as faint as 13 mag. The astrometric performance of this telescope has been analyzed in Yu *et al.* (2010).

A new method to determine real-time atmospheric refraction was presented by Yu *et al.* (2009). The method does not depend on strict local parameters and precise instruments. Observations were carried out with a simple telescope at Xinglong station of the National Astronomical Observatories, The atmospheric refraction from the zenith distance of 44.8° to 87.5° can be obtained by this method.

Zhenghong Tang (Shanghai) reports that the components included in the Time of Arrival (ToA) of pulses from millisecond pulsars are parsed by Zhao & Huang (2009). From this work, it is not necessary to calculate the differential ToA as well as differential gravitational delay between the observer and the Solar System Barycentre.

Zhenghong Tang (Shanghai) reports that the first successful CVN (Chinese VLBI Network) phase-referencing observation of the pulsar B0329+54 was carried out on October 16, 2008 in the S band (Guo *et al.*, 2010). The fitted position of the pulsar relative to the calibrator is accurate to the level of tens of μas, which is comparable with the present differential VLBI astrometric accuracy, proving that CVN will be a potential powerful tool for astrometry and astrophysics.

Zhenghong Tang (Shanghai) reports that a new station, 'Jiang-Nan-Tian-Chi station', of the Shanghai Astronomical Observatory (λ = 119.5978°, ϕ = 30.4694°, height = 958.409 m) has been established. The night sky brightness and atmospheric extinction at the station were determined by Yao & Tang (2009).

RUSSIA: Malkin (Pulkovo) reports about the investigation of the impact of the Galactic aberration on the precession-nutation model. It is estimated to be small, but not negligible: up to 20 mas per century. Thus, this effect should be modelled during processing of high-accuracy observations (Malkin 2011).

UKRAINE: Pakuliak (Kiev) reports that the digitization of observational archives has resulted in about 3,000 digitized images of the MAO NASU collection and about 2,000 digitized images of the AO Lviv NU collection, which are available from the search pages of the Ukrainian VO (`http://gua.db.ukr-vo.org`). On the basis of these two digitized archives, and in cooperation with Mykolaiv AO, the prototype of the Joint Digitized Archive as a core of the astrometric component of the Ukrainian VO has been created and is intended to present the tools for access to the digitized observational archives of all Ukrainian observatories.

UNITED STATES: The USNO Robotic Astrometric Telescope (URAT, Zacharias *et al.* 2012) has become operational. A single exposure with the "red lens" onto 4 large CCDs covers 28 sq.deg. with an astrometric precision below 20 mas. A new all-sky, astrometric survey has begun for the northern hemisphere at NOFS in 2011 to provide positions and proper motions for all stars in the R = 9 to 17.5 mag range and parallaxes of nearby stars without selection bias.

An astrometric pipeline has been developed for LSST (Monet 2011, LSST science book 2009).

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3. Space Astrometry

Prusti (ESA) reports on the Gaia astrometric mission in the science programme of the European Space Agency. The satellite is currently (September 2011) in the qualification and assembly phase since successfully passing the mission critical design review. Gaia is scheduled for launch in 2013.

The main scientific aim of Gaia is to reveal the structure and kinematics of our Galaxy. The science requirements deduced from the main goal and amended by many other science cases have resulted in a mission conducting an astrometric, photometric and spectroscopic survey of the full sky. Gaia is anticipated to detect and measure more than 1 billion objects astrometrically and photometrically. In addition, spectroscopy will provide radial velocities for an estimated 150 million stars.

All spacecraft sub-systems have been delivered to the prime industrial contractor, EADS Astrium in Toulouse, France. The scientific performance estimates have been calculated based on tests and measurements at sub-system level. In late 2011, the sub-systems will be integrated and the performances will be verified at the system level. Scientific performance estimates are for the bright stars (6–12 mag), sky-averaged parallax accuracy between 5 and 14 μas. Stars brighter than about 6 mag will not be detected by Gaia as they saturate the detectors. For stars fainter than 12 mag, the parallax accuracy degrades to about 25 μas at 15 mag and to about 300 μas at the limiting magnitude of 20 for Gaia. The accuracies of positions and annual proper motions are roughly at similar μas accuracy levels.

In addition to astrometry, Gaia will provide photometry for *e.g.* stellar classification and spectroscopy mainly for radial velocities. The scientific performances are compliant to the original science requirements. The current photometric and spectroscopic performance estimates, as well as those for astrometry, can be found on the Gaia web-pages (`http://www.rssd.esa.int/Gaia`).

The ground segment is also preparing for the operational phase of the mission. In addition to the ESA provided elements for the operations, there is a large consortium of scientists and engineers entrusted with the scientific data processing task. More than 400 individuals are providing on the average about half of their time to Gaia data processing and analysis tasks. Early preparations are needed to cope with the huge amount of astronomical measurements from Gaia. On average, Gaia will produce some 400 million measurements daily which need processing to catalogue values for use by the astronomical community. Although the final catalogue will appear only in the next decade, Gaia will early on provide science alerts and intermediate catalogues that are planned some two years after the start of operations.

FRANCE: Astrometric tests using the Planck satellite and asteroids, together with the development of an optical image database, are currently under progress to prepare the Ground Based Optical Tracking of the Gaia mission. Several 1m class telescopes are used to determine the best way to obtain the precise position (20 mas) of the satellite during its mission among the reference stars in the same field of view. Once launched, the celestial coordinates of Gaia will be used to improve the coordinates that will be given in the final catalogue of the mission.

The Bordeaux Group (Krone-Martins & Ducourant), together with the Sao Paulo group (Teixeira), have developed specific tools to analyze the morphology of the tiny galaxies (few arcseconds of extension) that will be observed by Gaia. The algorithms of morphological classification and profile fitting developed and deployed at the Data Processing Centre in CNES are based on support vector machines, genetic algorithms,

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cross-entropy methods and the Radon transform. About five million of these objects, that cannot be observed from the ground, are expected (Krone-Martins, PhD thesis).

NETHERLANDS: The Joint Institute for VLBI in Europe (JIVE), in cooperation with the European VLBI Network (EVN), EC FP7 EuroPlaNet and ESPaCE and other partners, continued developing VLBI applications for ultra-precise tracking of planetary and other space science missions. The technique enables determination of positional components of spacecraft state-vectors at distances of several astronomical units with metre-level accuracy. Such a high accuracy enables multi-disciplinary applications of this VLBI tracking technique, including celestial mechanics and astrometry of the Solar System, fundamental physics and studies of interiors and atmospheres of planets. In the reporting period, the activities focused at the Planetary Radio Interferometry and Doppler Experiment (PRIDE) which exploits the technique of near-field VLBI tracking and has been demonstrated for ESA's Venus Express (VEX) and MarsExpress (MEX) missions (Molera Calves *et al.* 2011, Duev *et al.* 2011).

JAPAN: JASMINE is an abbreviation of Japan Astrometry Satellite Mission for Infrared Exploration. Three satellites are planned in the JASMINE series as a step-by-step approach to overcome technical issues and promote scientific results (Gouda *et al.* 2010, Gouda *et al.* 2011). These are Nano-JASMINE, Small-JASMINE and (Medium-sized) JASMINE.

Nano-JASMINE is a small satellite of which the size and weight are $(50\text{cm})^3$ and about 35 kg respectively (Hatsutori *et al.* 2011). The diameter of the primary mirror is 5 cm. A fully depleted CCD is at the focal plane of the telescope (Kobayashi *et al.* 2010). The flight model of Nano-JASMINE has been fabricated and it will operate in the zw-band (0.6–1.0 μm). The target accuracy of parallaxes is about 3 mas at zw=7.5 mag (Kobayashi *et al.* 2011). Moreover, high-accuracy proper motions ($\sim$0.1 mas/year) can be obtained by combining the Nano-JASMINE catalogue with that of Hipparcos, as the decrease in the error of the proper motions is proportional to the inverse of the epoch difference between the two catalogues, which for the Hipparcos and Nano-JASMINE catalogues will exceed 20 years.

The observing strategy and methods used in the data analysis for Nano-JASMINE will be similar to what is planned for Gaia. Thus the use of Nano-JASMINE data is useful to check algorithms that are to be used in the Gaia data analysis (Yamada *et al.* 2011). Nano-JASMINE is scheduled to be launched in 2012 from the Alcantara space centre in Brazil by a Cyclone-4 rocket developed in Ukraine and will be put in a Sun-synchronized orbit with an altitude of about 800 km.

Small-JASMINE will determine positions and parallaxes accurate to 10–50 μas towards a $3^\circ \times 3^\circ$ region around the Galactic centre and other small regions which include scientifically interesting objects brighter than Hw=11.5 mag (Hw-band: 1.1–1.7 μm). Proper motion accuracies of between 10 and 50 μas/year are expected (Yano *et al.* 2011). The target launch date is around 2017. The JASMINE group aims at a proposal for the Small-JASMINE mission to JAXA, to get launch approval and the required budget from the Japanese government in the near future.

The main science objective of Small-JASMINE is to clarify the formation model of the Galactic bulge structure, star formation histories around the Galactic centre (Tsujimoto 2011) and the evolution of the super-massive black hole located at the centre of the Galaxy.

(Medium-sized) JASMINE is an extended mission of Small-JASMINE, which will observe towards almost the whole region of the Galactic bulge with accuracies of 10 μas in the Kw-band ($\sim$2.0 μm). The target launch date is the first half of the 2020s.

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UNITED STATES: During the development of the Space Interferometry Mission (SIM), key projects conducted numerous investigations relating to astrometry (Unwin 2008).

Makarov (2005) developed a theoretical framework for the astrometric grid that may be relevant also to Gaia. Geisler (2006) described spectroscopic and photometric monitoring of candidate grid stars suitable as astrometric references at the μas level. Shao (2010) showed the importance of astrometry as a major technique for low-mass exoplanet detection and Traub (2009) demonstrated SIM's ability to detect multi-planet systems astrometrically. Gould (2005) showed how the microlens parallax allows precision astrometric measurements by stellar microlensing events.

Henry (2006) and Benedict (2007) explored the many contributions to precision stellar astrophysics. Kenneth Johnston (2009), Zacharias (2009) and Unwin (2009) discussed astrometric measurements of quasar nuclei as science targets and as anchors for a fundamental reference frame. Majewski (2007), Shaya (2009) and Kathryn Johnston (2009) showed how SIM could contribute to understanding the formation of the Galaxy and the Local Group and the dynamical role of dark matter. See also the NExScI website: `http://nexsci.caltech.edu/missions/SIMPQ/SIMSciStudies/accepted.shtml`.

NASA cancelled SIM in December 2010.

The JMAPS programme (USNO) continued throughout this reporting period.

4. Reference Frames

CHINA PR: Zi Zhu (Nanjing) reports that Xie and Kopeikin overviewed a set of post-Newtonian reference frames for a comprehensive study of the orbital dynamics and rotational motion of Moon and Earth by means of lunar laser ranging (LLR). They employ a scalar-tensor theory of gravity depending on two post-Newtonian parameters and utilize the relativistic resolutions on reference frames adopted by the IAU in 2000. The theoretical advantage of this work is in a simpler mathematical description. They also derive the post-Newtonian coordinate transformations between the frames investigated and analyze the residual gauge freedom (Xie & Kopeikin, 2010).

Zi Zhu (Nanjing) reports that extensive analyses of two large catalogues (PPMX and UCAC3) have been made in order to determine the local and overall systematic biases. The regional and magnitude dependent differences in stellar position and proper motion are comparable to random errors. The global orientation bias vector between the two systems is also significant (up to 17 mas). However, the term for the global rotation vector ω is small (tenths of mas per year): it is reasonable to believe that the PPMX and UCAC3 reference frames do not rotate with respect to each other. Because of plate dependent and field-to-field errors in the UCAC3 catalogue, they suggest that positions and proper motions of UCAC3 stars in the northern hemisphere ($\delta > -20^\circ$) should be used with caution (Liu & Zhu, 2011).

Zi Zhu (Nanjing) reports that the Galactic coordinate system, initially defined by the IAU in 1958, was thereafter transformed in 1984 from the B1950.0 FK4-based system to the J2000.0 FK5-based system. In 1994, although the IAU recommended that the dynamical reference system FK5 be replaced by the ICRS, the definition of the Galactic coordinate system was not updated. They consider that the present Galactic coordinates may be problematic because of the unrigorous transformation method from the FK4 to the FK5 and of the non-inertiality of the FK5 system with respect to the ICRS. They suggest reconsidering the definition of the Galactic coordinate system which should be directly connected to the ICRS for precise observations at the μas level (Liu *et al.*, 2011).

FRANCE: A new version of the LQAC (Large Quasar Astrometric Catalogue), called LQAC-2, has been produced (Souchay *et al.*, 2011). It contains about 180,000 quasars

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compared to 110,000 in the first version (Souchay *et al.*, 2009) and contains more items such as a specific identification number, more precise coordinates from the LQRF (Andrei *et al.*, 2009) and morphological indices.

Souchay (Paris) reports on the use of extragalactic sources to materialize the current ICRF. In the optical domain, these sources exhibit variations of their luminosity. These variations, due to astrophysical phenomenon, could be correlated to astrometric variations of the photocentre. Different investigations are in progress to find such a correlation in a set of targets that could ensure the link between the ICRF and the future Gaia Celestial Reference Frame. These activities are carried out as part of the ICRS-PC activities.

RUSSIA: The Allan variance (AVAR) technique has been improved to allow the processing of unevenly weighted and multidimensional data. The proposed AVAR modifications are used to analyze radio source position catalogues and time series at the Pulkovo observatory (Malkin 2011).

UNITED STATES: The ICRF2 was released (IERS, Fey *et al.* 2009) containing accurate positions of 3414 compact, extragalactic radio sources on the system of the original ICRF.

The Navy Prototype Optical Interferometer continued with absolute observations of a sample of bright stars (Benson *et al.* 2010).

5. Positions and Proper Motions

ARGENTINA: The Yale/San Juan Southern Proper Motion Catalogue, SPM4, was published containing absolute proper motions, celestial coordinates and photometry for over 103 million objects between the south celestial pole and -20° declination.

CHINA PR: Qingyu Peng (Guangzhou) reports that following CCD observations of the open cluster NGC2168 using the newly-fitted 2k by 2k CCD attached to the 1-m telescope at the Yunnan Observatory with two different orientations, significant distortions in the observations were found using UCAC2 as reference. After correction, the positional measurement accuracy of a bright star is about 7 mas in each direction (60 s exposure and near the zenith) (Peng & Fan, 2010). Observations have also been taken of M67 (NGC2682) and a technique developed using many overlapping CCD frames to remove the distortions (Peng & Tu, 2011).

DENMARK: Høg reports that the Brorfelde Schmidt CCD Catalogue (BSCC) has been published in collaboration with N. Zacharias, USNO (arXiv:1006.4602). It contains about 13.7 million stars, north of +49° declination with precise positions and V and R photometry. The catalogue has been constructed from the reductions of 18,667 CCD frames observed with the Brorfelde Schmidt Telescope between 2000 and 2007.

GERMANY: Röser (Heidelberg) reports on the PPMXL catalogue of about 900 million objects with a new determination of mean positions and proper motions on the ICRS system by combining USNO-B1.0 and 2MASS astrometry. Typical individual mean errors of the proper motions range from 4 mas/yr to more than 10 mas/yr depending on the observational history. The mean errors of positions at epoch 2000.0 are 80–120 mas, if 2MASS astrometry could be used, 150–300 mas otherwise (Röser, Demleitner & Schilbach 2010).

UKRAINE: Pinigin and Maigurova (Nikolaev) report ecliptic zone observations with the Axial Meridian Circle of RSI MAO have been completed. The resulting catalogue of 141,927 stars has accuracies of 20–90 mas for the magnitude range 9–15.5. Observations of high proper motion stars with the AMC and Mobitel telescopes have been carried out since 2009.

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Also the reprocessing of observations of 171 extragalactic radio sources using UCAC3 as the reference catalogue was carried out. The average values of the differences (optical minus radio) are (-6 ± 4) mas and (11 ± 4) mas for RA and declination, respectively.

Pinigin (Nikolaev) and Ryl'kov (Pulkovo) presented a compiled catalogue (Pul-ERS) of reference stars down to 17 mag around 240 extragalactic radio sources. Comparisons with UCAC3 show average differences of 12 mas in RA and 7 mas in Dec.

Fedorov (Kharkiv) reports that the XPM catalogue of positions and absolute proper motions of 314 million objects in the magnitude range 10 < B <22 was derived from the 2MASS and the USNO A2.0 positions. The catalogue is available from the CDS (Fedorov+ 2010). The proper motion accuracies for the Northern and Southern hemispheres are 3–8 mas/yr and 5–10 mas/yr, respectively. The mean formal error of absolute calibration is less than 1 mas/yr (P. Fedorov *et al.* 2009, 2010).

Comparisons of the proper motions between XPM and HCRF showed that the coordinate axes defined by the XPM catalogue are non-rotating with respect to distant extragalactic objects to within ±0.20 mas/yr. It was concluded that the derived system of the XPM proper motions is an independent realization of the ICRS in the optical and near-infrared wavelength range (P. Fedorov *et al.* 2010, 2011).

Comparisons of the XPM proper motions with those of other catalogues show appreciable systematic errors of proper motions with magnitude in these catalogues (Yatskiv *et al.* 2010, 2011; P. Fedorov *et al.* 2011). Comparing the absolute proper motions from the XPM catalogue with Tycho-2, UCAC-3, XC1 and PPMXL, showed that the coordinate axes of these catalogues have a rotation: ω_x and ω_y are very small, but the ω_z differences are ∼2 mas/yr and are present up to 14 mag.

UNITED STATES: Yale University reports that the SPM catalogue was released in early November 2009 and covers $\delta < -20°$. The catalogue lists absolute proper motions, positions, and B,V photometry for over 103 million stars and galaxies. It is complete to roughly V=17.5. The final precision of the SPM positions and absolute proper motions is 30–150 mas, and 2–10 mas/yr respectively. Systematic errors in the proper motions are estimated to be of the order of 1 mas/yr (Girard *et al.* 2011).

A separate proper-motion catalogue (based on the same SPM material) for a 450-square degree area, that encloses the Magellanic Clouds, was released in 2009 for 1.4 million objects (Vieira *et al.* 2010). The proper motions of the Clouds are derived with an estimated error of about 0.27 mas/yr in the inertial system of the Hipparcos catalogue. This study also provides the best-ever estimate of the relative proper motion of one Cloud with respect to the other (accuracy of 0.15 mas/yr) thanks to the well-defined reference frame encompassing both Clouds in this large-area study.

UCAC4 (Zacharias *et al.* 2012) is the final release of the USNO CCD Astrograph Catalogue. Positions, proper motions, and photometry are given for over 100 million stars, all-sky to about magnitude R = 16.

The 7th and 8th data release of the SDSS project occurred in 2009 and 2011, respectively. Proper motion results were published by Munn (2010).

6. Trigonometric Parallaxes (nearby and high proper-motion objects)

CHILE: The exceptional quality of Chilean skies has led to several astrometric investigations in cooperation with astronomers from ESO, USNO and Latin American institutes. An example of this is the IPERCOOL project on the parallaxes of dwarf stars.

CHINA PR: Shulin Ren (Nanjing) reports that the kinematical parameters of dozens of spectroscopic binaries are determined, or improved, based on the revised Hipparcos

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Intermediate Astrometric Data by using an efficient fitting method which reduces the number of non-linear model parameters as far as possible. This method can also be used in the data processing of the Gaia binaries (Ren & Fu, 2010 & 2011). The statistical analysis shows that the classical double two-body model cannot be used to describe the kinematics of most hierarchical triple star systems with the precision of present day observations (1 mas). A new description of the kinematics of six hierarchical triple star systems with sufficient observations are discussed (Liu, *et al.*, 2010). A V-band Mass-Luminosity Relation is improved, based on the dynamical masses and luminosities of 203 main sequence stars by using a fitting method which can reasonably assign weights to the observational data including two quantities with different dimensions (Xia & Fu, 2010).

FRANCE: Parallax projects on targets of astrophysical interest are developed at Bordeaux (Ducourant & Teixeira). Brown dwarfs and very young associations are targeted to solve the questions of membership and kinematics of groups (Teixeira *et al.* 2009). The TW Hydrae association is the centre of a project developed at ESO/NTT aiming at the determination of parallaxes of 15 members. The idea is to determine the dynamical age of this association by back-tracing its members until they define a minimum volume.

GERMANY: Scholz (Potsdam) reports on a high proper motion ($\mu > 0.14$ arcsec/yr) survey for extremely faint ($i > 21$) objects in SDSS stripe 82 covering about 275 square degrees. The newly discovered objects were classified spectroscopically as L dwarfs (13), late-M dwarfs (8), and cool white dwarfs (4), all showing thick disk and halo kinematics (Scholz, Storm, Knapp, & Zinnecker 2009). A faint common proper motion companion of a nearby L dwarf was found serendipitously in UKIDSS and SDSS data. The companion's colour is typical of a late-T spectral type, the astrometric measurements are consistent with a physical pair (separation 75 AU) at a distance of 8 pc (Scholz 2010a). Eleven new late-T dwarf candidates with high proper motions ($0.1 < \mu < 0.8$ arcsec/yr), including two wide companions of Hipparcos stars, were discovered in a systematic search with UKIDSS and SDSS (Scholz 2010b). Two ultracool (T8–T10) brown dwarfs at spectroscopic/photometric distances of only 5 pc were discovered from their large proper motions of 2.5 and 1.5 arcsec/yr by combining the preliminary WISE data release with 2MASS and SDSS (Scholz, Bihain, Schnurr, & Storm 2011).

UKRAINE: Ivanov (Kiev) reports that a catalogue of more than 2,500,000 stars with high proper motions (>0.04″/year) was compiled from the FONAK1.1 catalogue (itself taken from 790 other published catalogues and sources). This catalogue will be placed at CDS.

7. Double Star Astrometry

UNITED STATES: Mason and Hartkopf report that considerable effort has been spent identifying known pairs as optical or physical. Of the 102,000 pairs in the last major release of the Washington Double Star Catalogue (2006.5), 1.3% were optical and 1.8% physical. For the current catalogue (n=115,000), 2.0% are optical and 7.8% physical. While the majority remain unknown, the statistics are improving.

The parallax programmes at the 61 inch NOFS reflector (Vrba *et al.* 2011) and the Allegheny Observatory (Gatewood, 2009) continued.

8. Solar System

The WG on Natural Planetary Satellites encouraged the making of astrometric observations of all planetary satellites. A campaign of observations of the mutual events

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of the main satellites of Jupiter and Saturn have been made in 2009. These photometric observations provide highly accurate astrometric positions. The WG encouraged also progress in astrometric reductions in order to prepare for the arrival of the Gaia star catalogue. Through a collaboration between USNO, IMCCE and the Royal Observatory of Belgium, the scanning of old photographic plates have been made using the Damian scanning machine, showing that new accurate astrometric information may be extracted from these plates.

BELGIUM: Damian has been used to digitise USNO plates spanning more than 30 years to determine very accurate ephemerides of the four Galilean satellites of Jupiter (results in De Cuyper *et al.* (2009) and Robert *et al.* (2011)), the natural satellites of Saturn and the major planets.

BOLIVIA: The Observatorio Astronomico Nacional Santa Ana is making developments on NEAs and asteroids including astrometric aspects for rapid orbit determination.

CHINA PR: Rongchuan Qiao (Xian) reports that they present 112 new CCD astrometric positions of Nereid, the second satellite of Neptune. They observed Nereid in 2006–2007 with the 1m and 2.16m telescopes of the Xinglong Station near Beijing, both equipped with large CCD detectors of 1340×1300 and 2080×2048 pixels, respectively. UCAC2 was used in the reduction so that a classical astrometric calibration could be used. They have shown that these observations appear to be of equal or higher precision (RMS=0.2″) than most of the previous CCD ones (Qiao, 2008).

Astrometric observations of Phoebe, the ninth satellite of Saturn (V=16.5 mag), were performed during the four successive 2005, 2006, 2007 and 2008 oppositions. A total of 1250 new observed positions of Phoebe were obtained in 30 nights involving six missions, by using three different telescopes. A comparison of these new observed positions with the latest JPL Phoebe ephemerides shows that the RMS of the residuals is better than 0.1 arcsec (Qiao, 2011). These observations have been made available to update Phoebe's orbit and represent 2994 positions, spread over a large time interval of 105 years, from 1904 to 2009. The accuracy of the updated orbit of Phoebe presented here is about 0.1 arcsec and has been significantly improved. The new orbit is in good agreement with reliable JPL ephemeris within less than 20 mas (Shen, 2011). Also, during this triennium, they have obtained more than 7,500 observations, which include the main satellites of Saturn and Uranus: Phoebe, Triton and Nereid.

FRANCE: The automatic Bordeaux meridian circle is still active and continues programmes of astrometry of solar system satellites and planets and photometric variability of blazars.

RUSSIA: L'vov (Pulkovo) reports that the tables of approaches of planets to extragalactic radio sources and occultations of radio sources by planets have been computed for the period till 2050 and are available at `http://www.gao.spb.ru/english/as/ac_vlbi`. These tables can be used for planning observations aimed at testing gravity theories and Solar system studies. (L'vov, Malkin, Tsekmeister, 2010, 2011)

UKRAINE: Filonenko (Kharkov) reports on DSLR observations of comets C/2006 W3 Christensen, 103P/Hartley 2 and C/2009 P1 (Garradd) using the 20 cm reflector AZT-7 and the 40 cm Baker-Schmidt telescope.

Ivantsov (Nikolaev) reports that for the collaboration "Observations and research of small Solar system bodies before Gaia" between institutions in Ukraine, Russia, Turkey and France, there were made 1834 astrometric observations of 61 asteroids at the RTT150 telescope (Tubitak National Observatory, Turkey) and 285 astrometric positions of 17 asteroids at the AZT-8 telescope (National Centre of Control and Test of Space facilities, Evpatoriya). The reductions were made using the UCAC3 catalogue. Standard deviations

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of the astrometric measurements for the asteroids were 0.19″ for the RTT150 telescope and 0.29″ for the AZT-8 telescope.

Shulga (Nikolaev) reports that the 0.5/3.0m Mobile Telescope (MBTL) equipped with a 3k×3k 12μ Apogee CCD and field rotator was installed and began test observations in 2010. Due to an original Combined Observation Method (electronic tracking technique) the MBTL can observe NEOs with apparent motion from 3 to 300″/min with a 90s exposure, as well as space debris on all orbit types with a 1s exposure for low Earth orbits. Following the tests, observations of asteroids and comets were taken in 2010–2011: 382 topocentric positions of 15 asteroids (11 of them with apparent motion from 3 to 140″/min) and 203 positions of 8 comets have been obtained; 304 positions of 10 asteroids reported to the MPC (under code 089). CCD observations of selected geosynchronous space debris were taken using the 0.3/1.5m FRT in 2009–2010 in order to maintain a catalogue of positions and orbital elements. The ephemerides accuracy is better than 0.15° on the prediction period of 200 days.

UNITED STATES: The International Occultation Timing Association (IOTA) reports that over the reporting period some 400 high-precision relative astrometric positions of asteroids derived from occultation observations were reported to the Minor Planet Centre.

Over the reporting period, profiles with a resolution of a few km were obtained for about 35 asteroids. This included the binary asteroid 90 Antiope, where the profiles of both components were well-resolved (`www.asteroidoccultation.com/observations/Results/Data2011/20110719_AntiopeProfile2.gif`).
Occultation results have been combined with light curve inversion models to obtain scaled 3-D models of 44 asteroids (Durech *et al.* 2011). All observations are archived with NASA's Planetary Data System (`http://sbn.psi.edu/pds/resource/occ.html`). The observers are located mainly in Australasia, Europe, Japan and North America.

Minor planet observations continued with the 8 inch automated transit circle at NOFS (Harris, Murison 2011).

URUGUAY: There is strong astrometry of solar system bodies at the Observatorio Astronomico Los Molinos with work focusing on NEAS, asteroids, and comets. The department of Astronomia of the Universidad de la Republica also works on satellites and asteroids.

9. Open and Globular Clusters and the Galaxy

CHINA PR: Li Chen (Shanghai) reports on investigations on the kinematics and chemical properties of star clusters based on the SDSS DR7 spectroscopic data (Gao & Chen, 2010). Further studies have been carried out on NGC7380 which included CFHT/MegaCam observations of its proper motion (Chen *et al.*, 2011).

Investigations of young star clusters, confirm that subvirial and fractal-structured clusters will dynamically mass segregate on a short timescale (within 0.5 Myr) (Yu *et al.*, 2011).

Zi Zhu (Nanjing) reports that the astrometric data and radial velocities of carbon stars near the Galactic plane were used to investigate the kinematics of the Milky Way. The intention is to study the Galactic rotation curve up to 15 kpc of carbon stars and carbon-rich Mira variables identified toward the anti-centre direction. For these tracers, a flat rotation curve of 210 ± 12 km/s was found (Liu & Zhu, 2010).

FRANCE: The Bordeaux PM2000 proper motion catalogue has been used by the Bordeaux group to analyze the kinematics of known or suspected open clusters (Krone-Martins *et al.*, 2010). A catalogue was produced comprising all open clusters in the Bordeaux PM2000 region including their kinematical parameters and associated membership

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probability lists. For five open clusters, this is the first determination of their proper motions. Also confirmed were the non-existence of two kinematical populations in 15 previously suspected non-existent NGC objects and 2 additional open clusters.

GERMANY: Röser (Heidelberg) reports on a new deep ($r' < 17$) all-sky census of the Hyades based on the PPMXL catalogue and the application of the convergent point method to determine probable kinematic members. 724 stellar systems co-moving with the bulk Hyades space velocity are identified, representing a total mass of 435 solar masses. The tidal radius is about 9 pc, and 364 systems (with 275 solar masses) are found to be gravitationally bound (Röser *et al.* 2011).

JAPAN: Since 2004 the Mizusawa VLBI observatory of NAOJ has been operating VERA (VLBI Exploration of Radio Astrometry) for conducting VLBI astrometry of Galactic maser sources associated with star-forming regions and AGB stars. It has monitored about 100 sources in the Galaxy, and parallax measurements are already available for more than 20 sources with distances ranging from a few 100 pc to 5 kpc. The most recent results are summarized in the PASJ special issue for VERA (2011), where 9 papers report parallax measurements. Among them, Honma *et al.* (2011) reported a parallax for IRAS 05137+3919 to be 0.086±0.027 mas, locating this source in the far outer region beyond a Galacto-centeric distance of 15 kpc. Also, Hirota *et al.* (2011) reported a distance of the Perseus molecular cloud to be 232±18 pc based on observations of L1448C. Niinuma *et al.* (2011) measured parallax and proper motions of IRAS 06061+2151 and located it in the Perseus arm. This source shows a considerable non-circular motion with respect to Galactic rotation, confirming previous findings for other Perseus-arm sources. In addition to papers in the PASJ special issue, Nagayama *et al.* (2011) determined the distance of G48.61+0.02 to be 5.03±0.19 kpc, indicating that this source is associated with the supernova remnant W51C and star-forming region W51M, probably as a consequence of sequential star-formation triggered by a supernova whose remnant is W51C. The observations with VERA will be continued in 2012, and accurate determinations of Galactic parameters (such as distance to the Galaxy centre and rotation speed of LSR) are expected to be conducted in the coming year.

UKRAINE: Kharchenko (Kiev) reports on an investigation of 650 open clusters using the ASCC-2.5 catalogue of 2.5 million stars. From this, a catalogue was formed of the astrometric and photometric data and probabilities of the membership of stars in the 650 sky areas with Galactic open clusters. Also in this catalogue are the characteristics of the open clusters: coordinates, core and corona radii, shape parameters, proper motions, radial velocities, distances, reddening, ages, tidal radii and masses, integrated luminosities and colours, which for many clusters were determined for the first time. A revision of kinematic, structural and evolutionary parameters of the Galaxy disk was carried out on this set of open clusters, as basic representatives of the population of the Galaxy.

Rybka and Yatsenko (Kiev) present the RCGP catalogue of more than 0.5 million candidate Red Clump giants brighter than Ks=9.5 mag. These stars were selected from the PPMX catalogue as the most probable Red Clump members on colour-reduced proper motion diagrams, constructed from PPMX proper motions and 2MASS J and Ks-photometry. Based on the reddening of the extracted stars, Ks-band extinction was determined and taken into account. Using a two-dimensional Galactic rotation model, generalized by Ogorodnikov, the tangential velocity field of selected Red Clump members (mostly thin disk) was investigated within 1.5 kpc of the Sun. The values of kinematic parameters and solar components were determined as a function of height above the Galactic plane and heliocentric distance.

Fedorov (Kharkiv) reports that using the three-dimensional Ogorodnikov-Milne model, the kinematic parameters of the Galaxy were obtained by means of the absolute proper

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motions of faint stars in the XPM catalogue. The Oort constants were found to be A=8.2±0.44 km/s/kpc, B=11.26±0.34 km/s/kpc and the angular velocity of the Galaxy $\omega = 4.11 \pm 0.29$ mas/yr (Akhmetov *et al.* 2010, 2011).

UNITED STATES: Absolute proper motions for nine globular clusters located in the inner regions of the Milky Way were determined by Yale University with errors ranging between 0.4 and 0.9 mas/yr. The velocity structure of the Thick Disk was analyzed (Casetti-Dinescu *et al.* 2011).

The Kapteyn Selected Area Proper Motion Programme (Yale University) provides absolute proper motions in some 50 40×40 arcmin fields located in three declination zones: 0° and ±15°. The programme has a limiting magnitude of V∼20 for a typical field, and V∼22 for a few specific deep fields. This is based on Du Pont photographic plates, POSSI plates, 60-inch Mount Wilson plates and a few 4-m Mayall plates, with an overall baseline of ∼80 years and typical errors of 1 to 2 mas/yr. Recent publications include results in the tidal streams and overdensities detected in SDSS.

The PanSTARRS programme has been observing with PS1 for over a year and first astrometric results have been obtained (Monet *et al.* 2011).

First astrometric results were obtained from the Kepler mission (Monet *et al.* 2010).

10. Education in Astrometry

The peer reviewed Scholarpedia project has established a section about "Astrometry" (`www.scholarpedia.org/article/Category:Astrometry`).

DENMARK: The history of astrometry during the past 2000 years has been studied by Erik Høg in a dozen reports which are available at `arXiv:1104.4554`.

Høg has written about the early years of Gaia development: "Astrometry history: Roemer and Gaia", placed at `arXiv:1105.0879`. The evolution of optics and detection in this period is the main subject of the report.

11. Symposia, Colloquia, Conferences

Summer School on Astrometry, 5–9 September, 2011, Antalya, Turkey.

Unresolved Galaxies, QSOs, Reference Frames, June 14–16, 2010, IAP, Paris, France (`http://www.oca.eu/rousset/EGSG`)

Journées 2010: New challenges for reference systems and numerical standards in astronomy, September 20–22, 2010, Meudon, France

Journées 2011: Earth rotation, reference systems and celestial mechanics: Synergies of geodesy and astronomy, September 19–21, 2011, Vienna, Austria.

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