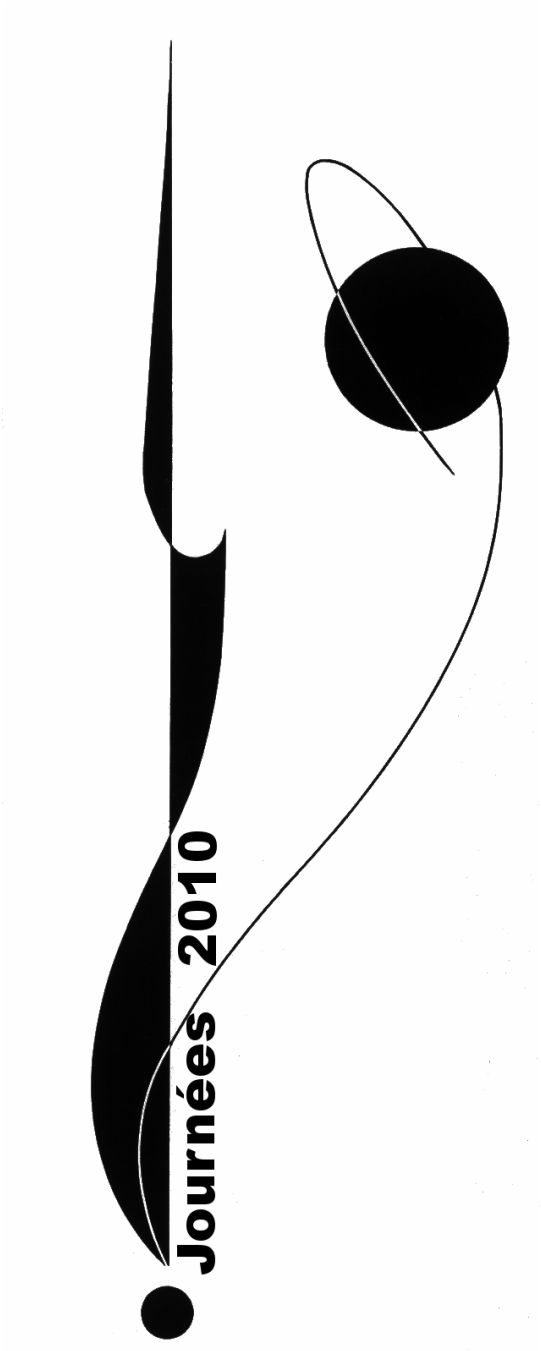
Rencontres de l'Observatoire

Journées 2010

« Systèmes de référence spatio-temporels »



New challenges for reference systems and numerical standards in astronomy

BOOK OF ABSTRACTS

Observatoire de Paris
Ecole Normale Supérieure
20-22 September 2010

Journées 2010

« Systèmes de référence spatio-temporels »

New challenges for reference systems and numerical standards in astronomy

Sessions

Session 1: *The astronomical constants, SI units and future developments in numerical standards*

Session 2: *Solar system ephemerides and their comparison*

Session 3: *Progress in astrometric catalogs in optical and radio wavelengths*

Session 4: *Recent developments in theory and observation of Earth rotation and related reference systems*

Session 5: *Pulsars timing, relativity and time transfer*

Abstracts for the oral sessions

(in the order of the oral sessions)

Session 1 - The astronomical constants, SI units and future developments in numerical standards

IAU Working Group on Numerical Standards for Fundamental Astronomy: the second triennium (invited)

Luzum B., Hilton J.[(1)] and the IAU NSFA Working Group[(2)]

(1): *U.S. Naval Observatory*, USA ; (2): see at http://maia.usno.navy.mil/NSFA.html

The Working Group (WG) for Numerical Standards of Fundamental Astronomy (NSFA) was initiated at the 2006 International Astronomical Union (IAU) General Assembly (GA). At the 2009 IAU GA, Resolution B2 adopted the Current Best Estimates (CBEs) assembled by the NSFA WG as the IAU (2009) System of Astronomical Constants. With the initial task completed, the WG has turned its attention to other tasks of importance to the long-term success of the WG. These tasks include identifying the best methods for maintaining an IAU list of CBEs as well as setting up an archival system for past values of CBEs. Addressing these issues will standardize the task of maintaining a documented list of CBEs allowing this task to be provided as an IAU service. An update on these activities will be provided. In addition, unresolved questions regarding the Gaussian gravitation constant and the use of the astronomical unit and the mass of the Sun will be discussed.

The new edition of the IERS Conventions: conventional reference systems and constants (invited)

Petit G.

Bureau International des Poids et Mesures (BIPM), France

A new reference edition of the IERS Conventions is reaching completion, the Conventions (2010) due to replace the Conventions (2003). The paper presents the main features of this new edition for what concerns the conventional reference systems and the set of adopted constants, including the associated relativistic issues. Changes vs. the Conventions (2003) and other past editions will be highlighted. It is shown how the Conventions implement the framework set by the Resolutions adopted by the scientific unions (IAU, IUGG and IAG), and also try to keep consistency as much as possible with the conclusions drawn by the Unions' working groups and bodies.

Planetary System GMs in the JPL Planetary Ephemerides

Jacobson R., Folkner W., Taylor A., Konopliv S., Williams J. G., Brozovic M.

Jet Propulsion Laboratory, USA

Fundamental to JPL planetary ephemeris development are the values of the planetary system GMs. With the exceptions of Mercury and Venus, the ephemerides actually give positions of the planetary system barycenters. Consequently, the relevant GMs are the sum of the planet and planetary satellite GMs. Smith et al. (2010) and Taylor (2010) independently estimated the Mercury GM using the radiometric tracking acquired during the recent flybys of the Messenger spacecraft. Analysis of an extensive set of Magellan and Pioneer Venus Orbiter Doppler tracking data by Konopliv et al. (1999) produced a high degree and order gravity field and associated GM for Venus. The Earth-Moon system GM was determined along with the lunar orbit using Lunar Laser Ranging measurements (Williams et al. 2009). Konopliv et al. (2006) estimated the Mars planet GM while developing the Mars gravity field using data from several orbiting spacecraft, and Jacobson (2010) obtained the satellite GMs by fitting Viking and Phobos 2 spacecraft data. The Jovian system GM was determined as part of the development of the Jovian satellite ephemerides

in support of the Galileo mission (Jacobson 2001). Similarly, the Saturnian system GM was determined in conjunction with the Saturnian satellite ephemerides using data from the Cassini mission (Jacobson 2006). Analysis of the data acquired during the Voyager flybys of Uranus and Neptune yielded their system GMs (Jacobson et al. 1992; Jacobson 2009). Brozovic and Jacobson (2010) estimated the GM of the Plutonian system from observations of the motions of Pluto's satellites.

SOFA – status report, a review and a look to the future

Hohenkerk C.

HM Nautical Almanac Office, UK

Standards of Fundamental Astronomy - SOFA is an IAU initiative that provides accessible and authoritative algorithms and procedures that implement standard models used in fundamental astronomy. SOFA consists of a dedicated website from which the SOFA Software Collections may be downloaded and a Board that provides and checks the material. At present this IAU Division 1 activity reports to Commission 19; however the members of the international Board are selected from various Commissions. This presentation looks at SOFA's development, in particular over the last few years. For the future we consider what SOFA needs to provide and its place within the IAU.

Proposal for the re-definition of the astronomical unit of length through a fixed relation to the SI metre

Capitaine N.(1), Guinot B.(1), Klioner S.(2)

(1): *Observatoire de Paris/SYRTE,* France; (2): *Lohrmann Observatory, TU Dresden,* Germany

As already suggested before the 2009 IAU General assembly, it is proposed to re-define the ua as a fixed number of SI metres through a defining constant. Such a change of status for the ua would limit its role to that of a unit of length of "convenient" size for some applications. Consequently, GMSun which would cease to have a "fixed" value in astronomical units and will have to be determined experimentally, which is shown to be desirable for modern dynamics of the solar system. The defining number to be adopted for the conventional definition of the ua should be, for continuity reason, the value for the current best estimate of the ua in m as adopted by IAU 2009 Resolution B2 (i.e. ua= 1.495 978 707 00 x 10^{11} m). Such a change of status of the ua would be a great simplification for the users of the astronomical constants, will let possible variations of the mass of the Sun (and/or G) appear directly, and would avoid an unnecessary deviation from the SI.

Some new thoughts about long-term precession formula

Vondrák J.(1), Capitaine N.(2), Wallace P.T.(3)

(1): *Astronomical Institute, Acad. Sci. Czech Rep.,* Czech Republic; (2): *Observatoire de Paris/SYRTE,* France ; (3) : *Rutherford Appleton Laboratory,* UK

In our preceding study (Vondrak et al., Journees 2008) we formulated developments for the precessional contribution to the CIP X, Y coordinates suitable for use over long time intervals. They were fitted to P03 in a close vicinity of J2000 and to the numerical integration of the ecliptic (using the integrator package Mercury 6) and of the general precession and obliquity (using Laskar's solution LA93) for more distant epochs. Now we look at how best to define the boundary between precession and nutation (both are periodic). We use the JPL planetary ephemerides to represent the precession of the ecliptic close to J2000, Mercury 6 for more distant epochs, and the LA93 solution to represent general precession and obliquity. The goal is to obtain new developments for different sets of precession angles that would fit to modern observations near J2000, and at the same time to numerical integration of the translatory-rotatory motions of solar system bodies in the scales of several thousand centuries.

Session 2 - Solar system ephemerides and their comparison

Session 2 Introductory remarks

provided by G. Kaplan, President, IAU Commission 4

INPOP, Intégration Numérique Planétaire de l'Observatoire de Paris (invited)

Fienga A., Manche, H., Kuchynka, P., Laskar, J., Gastineau, M.

IMCCE, *Observatoire de Paris,* France

We will present the new version of INPOP obtained with an extended set of observations and new fitted parameters: GM of the sun (instead of AU), new asteroid masses.

Recent developments in planetary ephemeris observations (invited)

Folkner W.

Jet Propulsion Laboratory, US*A*

The uncertainty in the planetary orbits is determined more by the data accuracy than by the dynamical modeling. The orbit uncertainty of the inner planets is dominated by the uncertainty in the overall orientation with respect to the ICRF. VLBI observations of Mars-orbiting spacecraft have recently been adjusted to align with the ICRF2.0 somewhat improving the overall tie of the inner solar system to the ICRF. Ranging measurements to Mars-orbiting spacecraft and to Venus Express provide extremely accurate determinations of the shapes of the orbits of Venus, Earth, and Mars, and their relative orientation. Information from three encounters of the MESSENGER spacecraft have improved the orbit of Mercury somewhat, with better data expected after the spacecraft enters orbit about Mercury in March 2011. VLBA observations of the Cassini spacecraft at Saturn have the best internal consistency of any planetary observations, limited primarily by the radio source uncertainty in the ICRF. Ranging measurements to the Cassini spacecraft are also of interest but show correlations due to the way the spacecraft orbit is processed. The status of these and other recent observations will be described.

EPM - Ephemerides of Planets and the Moon of IAA RAS: their model, accuracy, availability (invited)

Pitjeva E., Bratseva O., Panfilov V.

Institute of Applied Astronomy of Russian Academy of Science, Russia

The current state of the last version of the planet part of EPM's ephemerides of IAA RAS (EPM2010) integrated in the PPN metric over the 1800 - 2200 time interval is presented. The updated dynamical model includes perturbations from all Trans-Neptunian Objects being on the mean distance of 43 AU in addition to the perturbations from the major planets, the Moon, the Sun, and asteroids of the main belt. EPM2010 ephemerides have resulted from a least square's adjustment to observations data totaling about 600 000 position observations of different types including recent CCD Flagstaff and TMO data of the outer planets and their satellites, VEX and Cassini spacecraft ranging and VLBI measurements. EPM2010 have been oriented onto the ICRF by the inclusion of the ICRF-base VLBI spacecraft observations into the fitting. The uncertainty of EPM ephemerides is controlled by comparison with a prior accuracy of observations and the independent DE423 ephemerides. The differences between the times TT and TDB have been constructed for EPM2004 (that is the basis for the Russian Astronomical Yearbook) and EPM2008 ephemerides. The access to these ephemerides with their TT-TDB are available via ftp://quasar.ipa.nw.ru/incoming/EPM/. This package allows a competent user to obtain the rectangular coordinates of the Sun, Moon, and nine major planets by means of a subroutine written in standard languages Fortran, C, Pascal, Java. Moreover this package gives a possibility to obtain access to ephemeredes of the other seven bodies code named "planets – dwarfs" Ceres, Pallas, Vesta, Eris, Haumea, Makemake, Sedna, obtained simultaneously with the main EPM ephemerides.

INPOP, a 1 Million year planetary ephemeris

Laskar J., Fienga A., Gastineau M., Manche H.

IMCCE, Observatoire de Paris, France

In the INPOP ephemeris, we integrate the Earth spin evolution at the same time as the planetary orbits. This allows to extend the ephemeris over extended time span. The outcome of these integrations over 1 Myr will be presented.

Development of long-term numerical ephemerides of major planets to analytical series

Kudryavtsev S.

Sternberg Astronomical Institute of Moscow State University, Russia

We make development of the long-term numerical ephemerides of the major planets DE-406 (Standish 1998) to compact Poisson series. A new modification of the spectral analysis method (Kudryavtsev 2007) is used. The expansion of either rectangular coordinates or orbital elements of the planets can be done. In the latter case we develop to analytical series the differences between the osculating orbital elements (calculated from numerical ephemerides) and the mean planetary elements by Simon et al. (1994). This approach is more effective. The orbital longitude of, e.g., Mercury is represented to accuracy of a few 0.1" over the time interval 3000BC-3000AD by compact Poisson series of a few hundreds terms. Research supported in part by the Russian Foundation for Basic Research under grant no.10-02-00234-a. References: Kudryavtsev, S. (2007): A&A, 471, 1069-1075. Simon, J.L. et al. (1994): A&A, 282, 663-683. Standish, E.M. (1998): JPL IOM 312F-98-048.

New version of EPM-ERA Lunar theory

Yagudina E., Krasinsky G.A., Prokhorenko S.O.

Institute of Applied Astronomy, Russia

The numerical Lunar theory EPM-ERA has been constructed in IAA RAS [1,2]. The dynamical model of the Moon motion has been constructed by simultaneous numerical integration of the equations of orbital and rotational motions of the Moon, major planets, five biggest asteroids. Potential of the Moon is calculated up to the 4-th order of zonal index, that of the Earth includes the 2th harmonics C20 and C22. Tidal perturbations in the lunar orbital motion caused by tidal dissipation on the Earth`s body is computed by the model with a constant lag. The effects of elasticity of the lunar body has been also taken into account. In the paper [3] 16 320 LLR data (1970-2008) has been included in the processing for improving ephemeris of the Moon and obtaining some selenodynamical parameters . New version of EPM-ERA Lunar theory was corrected by an improved model of dissipative effect of the lunar rotation by integration orbital and rotational motions with retarded argument. The comparison of the improved dynamical model with 17 131 LLR data from 1970 till 2010 have been made. The LLR-observations were also processing have been compared with three versions of DE ephemeredes. [1] Aleshkina E.Yu., Krasinsky G.A., Vasiliev M.V., "Analysis of LLR data by the program ERA", Proceedings of IAU Colloquium 165,1996, Poznan, pp. 228-232. [2] Krasinsky G.A., 2002, Selenodynamical parameters from analysis of LLR observations of 1970-2001", Communications of the IAA RAS, N 148,2002,pp 1-27. [3] Yagudina E.I. 2008,"Lunar numerical theory EPM2008 from analysis of LLR data", Journées 2008, Dresden,22-24 September, pp 61-64.

LLR residuals of the latest INPOP solution and constraints on post-Newtonian parameters

Manche H.[(1)] , Fienga A.[(1) (2)], Laskar J.[(1)], Gastineau M.[(1)], Bouquillon S.[(3)], Francou G.[(3)], Kuchynka P.[(1)]

(1): *IMCCE, Observatoire de Paris*, (2): *observatoire de Besançon,* (3): *SYRTE, Observatoire de Paris,* France

Among all parameters involved in Lunar Laser Ranging computations (dynamical and reduction model), only some of them can be fitted to observations. We will present the method of their selection used for INPOP solutions and the residuals obtained. Finally, adding the parameterized post-Newtonian parameters beta and gamma to the list of fitted parameters gives some constraints on their values and uncertainties.

Geodesy instrument package on the Moon for improving our knowledge of the Moon and the realization of Reference Frames

Dehant V.[(1)], Oberst J., Nadili R.

(1): *Royal Observatory of Belgium*, Belgium

The use of passive Laser reflectors on the lunar surface appeared to be the most attractive in the Apollo era, but the next generation of LLR experiment should therefore aim at a substantial improvement thanks to a one way ranging concept. A particular strength of this proposed experiment is given when several stations are ranging to the Moon simultaneously and/or when several geodetic stations on the Moon are used simultaneously, as this is expected to improve the modelling geometry and data quality. The proposed experiment may well initiate the installation of new observing stations on Earth – perhaps within the infrastructure of existing astronomical observatories. In the case of the beacon mode, only passive optical receivers are needed on the ground. We explore the requirements for the instrumentation of such a ground station. We propose to deploy and operate a microwave receiver/transmitter with precisely known mechanical local ties to the Laser beacon, which will permit observations of the tangential position of the moon with respect to the celestial frame. We propose to include a GNSS microwave transmitter into the proposed equipment realizing a "GPS/Galileo satellite on the Moon" that is tracked together with GNSS satellites by receivers on the ground and possibly on the future generation of GNSS satellites. The ultimate objectives of our proposal are twofold, the improvement of the reference frames for the Earth and a better understanding of the Moon's interior.

Application of the spectral analysis methods for the investigation of the Moon rotation

Pashkevich V., Eroshkin G.I

Central (Pulkovo) Astronomical Observatory, Russian Acad. Sci., Russia

Dynamics of the rotational motion of the Moon is investigated numerically. Very convenient Rodrigues-Hamilton parameters are used for high-precision numerical integration of the rotational motion equations over a 400 yr time interval. The results of the numerical solution of the problem are compared with the contemporary semi-analytical theory of the Moon's rotation. The semi-analytical theory of the Moon's rotation (SMR) consists of the so-called Cassini relations and the semi-analytical solutions of the lunar physical libration problem (Eckhardt D.H., 1981), (Moons M., 1982), (Moons M., 1984), (Pešek I., 1982). The comparisons reveal residuals both of periodic and systematic character. The investigation of the discrepancies between the high-precision numerical solutions of the Moon rotation and the semi-analytical solutions SMR is carried out by the spectral analysis methods in order to choose and compare the optimal spectral analysis schemes for the investigations of the rotational motion of the Moon. All the secular and periodic terms representing the behavior of the residuals are interpreted as corrections to the mentioned semi-analytical theory. Construction of the new high-precision Moon Rotation Series (MRS2010), which is dynamically adequate to the DE200/LE200 ephemeris over 400 year time interval.

A Comparison of the High Accuracy Planetary Ephemerides DE421, EPM2008, and INPOP08

Hilton J.[(1),] Hohenkerk C.[(2)]

(1): *U.S. Naval Observatory,* USA; (2): *HM Nautical Almanac Office*, UK

At the heart of many astronomical applications lies a planetary ephemeris. Since the 1980s the de facto world standard has been the Jet Propulsion Laboratory's DE (Development Ephemeris) series ephemerides. Recently, ephemerides from the Paris Observatory (Integration Numerique Plantaire de l'Observatoire de Paris, or INPOP) and the Institute of Applied Astronomy in St. Petersburg (Ephemerides of Planets and the Moon, or EPM) have become available which provide accuracies similar to those from JPL. Here we compare the constants, initial conditions, and planetary positions produced by DE421, INPOP08, and EPM2008, the most recent ephemerides released for general use from these three groups. Ultimately, the true test of any ephemeris is how well its predictions compare with actual observations. Other considerations, such as ease of use, shall be discussed as well.

Session 3 - Progress in astrometric catalogs in optical and radio wavelengths

UCAC and URAT: optical astrometric catalog observing programs (invited)

Zacharias N., Gaume R.

U.S. Naval Observatory, USA

The third USNO CCD Astrograph Catalog (UCAC3) all-sky catalog was released in August 2009. The final release, UCAC4, is in preparation which will include corrections and improvements to positions and proper motions as well as publication of intermediate data. Properties of UCAC products and information for users will be presented. The USNO Robotic Astrometric Telescope (URAT) project will be outlined. It uses the optics of the UCAC with a new, wide-field camera to cover 28 sq.deg per exposure. First light is expected in October 2010 and a new all-sky survey to R=17.5 mag will be undertaken from Arizona and Chile sites. Neutral density spots on the single filter allow observation of bright stars. URAT will will be able to directly link Hipparcos stars and extragalactic sources of the ICRF. Multiple sky overlaps per year allow to derive mean positions, proper motions and parallaxes from these CCD observations. An accuracy level of 10 mas is expected for high signal-to-noise stellar observations. Test areas along the path of Pluto have been observed with UCAC and observing will continue with URAT to assist in occultation predictions. Results from observed occultations confirm the high accuracy of UCAC data.

The Large Quasar Astrometric Catalog (LQAC) and the densification of the ICRF through the LQRF (Large Quasar Reference Frame) (invited)

Souchay J.

Observatoire de Paris/SYRTE/CNRS, France

After summarizing the various astrometric programms already achieved bothg at radio and optical wavelengths and still on the way, we show the principles of construction of the LQAC (Large Quasar Astrometric Catalog) in its original version (Souchay et al.,2009) and the up-coming one, together with the elaboration of the LQRF (Large Quasar Reference Frame) (Andrei et al.,2009). Then we explain what should be the future prospects for the densification of the ICRS in the scope of the GAIA mission.

Parallaxes of Southern Extremely Cool objects I: Targets, proper motions and first results

Andrei A.H.[(1)], Bucarelli B.[(2)]

(1): *Observatorio Nacional/MCT*, Brasil; (2): *INAF - Astronomical Observatory of Turin*, Italy

We present results from the PARallaxes of Southern Extremely Cool objects (PARSEC) program started in 2007 to determine parallaxes for 122 L and 28 T southern hemisphere dwarfs using the ESO 2.2 m telescope Wide Field Imager. We present parallaxes of 10 targets from observations over 18 months and a first version proper motion catalog. The proper motions have been obtained by combining PARSEC observations and the 2MASS positions. The proper motion precision is at 5 mas/yr, for 195 700 sources. The 140 0.3deg^2 fields are unbiasedly spread, except for the galactic plane where the number of known L/T dwarfs is small. We will continue to update this catalog until the end of the program and improve it by including also observations from the GSC2.3 database. The preliminary parallaxes have precision at 4.2mas, and increase by 11% the present number of L dwarfs with published values. Two of the objects are within 10pc, while three of them had no previous discussion in the literature. Of the latter, two were thought to be binary but the PARSEC observations show them to be single, whilst one is found to be part of a binary system instead of a single object. The PARSEC program ends in 2011. Its main expected outputs are: more than a 100% increase of the number of L dwarfs with parallaxes; to increment to at least 10 the number of objects per spectral subclass up to L9; and to put limits on the general binary fraction of brown dwarfs.

Towards a VLBI catalog of optically-bright extragalactic radio sources for the alignment of the radio frame with the future Gaia frame

Bourda G.(1), Charlot P.(1), Collioud R.(1), Porcas R.(2), Garrington S.(3)

(1): *Laboratoire d'Astrophysique de Bordeaux*, France; (2): *MPIfR*, Germany ; (3): *Jodrell Bank Observatory*, UK

The space astrometry mission Gaia will construct a dense optical QSO-based celestial reference frame. For consistency between optical and radio positions, it will be important to align the Gaia and VLBI frames with the highest accuracy. In this respect, it was found that only 70 sources from ICRF were suitable to establish this link, either because they are not bright enough at optical wavelengths or because they show extended radio emission which precludes reaching the highest astrometric accuracy. In order to improve the situation, we initiated a multi-step VLBI observational project, dedicated to finding additional suitable radio sources for aligning the two frames. The sample consists of ~450 optically-bright radio sources, typically 20 times weaker than the ICRF sources, which have been selected by cross-correlating optical and radio catalogs. The initial observations, aimed at checking whether these sources are detectable with VLBI, and conducted with the European VLBI Network in 2007, showed an excellent 90% detection rate. This paper reports on global VLBI observations carried out in March 2008 to image 105 from the 398 previously detected sources. All sources were successfully imaged, revealing point-like VLBI structures for about half of them, which is very promising for the future. While the remaining ~300 detected sources from our initial sample will be imaged in the same way, the next step, dedicated to measuring accurately the position of these sources, will be engaged in the near future.

Comparison of the proper motions in declination of four catalogues via 807 Hipparcos stars

Damljanovic G.

Astronomical Observatory, Serbia

We can combine the Hipparcos coordinates and proper motions of stars, and astrometric observations of latitude and universal time variations (via observed stars referred to Hipparcos Catalogue) to get more accurate data. These ground-based observations (made over many decades to determine the EOP series), are useful for the opposite task (i.e. to check the accuracy of coordinates and proper motions of Hipparcos stars). I used the latitude part of ten Photographic Zenith Tubes (PZT) data to construct the PZT catalogue of proper motions in declination and to check these data for 807 common PZT/Hipparcos stars; the results are in good agreement with the Earth Orientation Catalogue (EOC-2) and new Hipparcos ones. The systematic errors in determined proper motions (the proper motion differences with respect to the Hipparcos, EOC-2 and new Hipparcos ones, as a function of coordinates and magnitude) are presented here. After determination of the random and systematic errors for pairs of four catalogues, there is no significant relationship between the differences of their proper motions in declination and magnitudes and color indices of the common 807 stars. The catalogues have got high accuracy of proper motions in declination (small random and systematic errors which are close to each other), but the formal error of PZT catalogue is overestimated by factor near 1.7 (2.0 for EOC-2) if new Hipparcos (or Hipparcos) is taken as a reference. It is the independent checking of proper motions in declination (from mentioned catalogues) by using the PZT catalogue data.

The XPM catalogue as a realisation of the extragalactic reference system in optical and near infrared wavelengths

Yatskiv Ya, Fedorov P., Akhmetov V.

Main Astronomical Observatory NAS of Ukraine, Ukraine

The final version of the XPM catalogue compiled on the basis of 2MASS and USNO 2.0 catalogues is presented. The XPM catalogue contains positions and absolute proper motions of about 300 million objects covering the whole sky in the magnitude range 10m < B < 22m as well as the standard J, H, K, B and R magnitudes. Positions in the XPM are referred to the International Celestial Reference System for the J2000 epoch. The Catalogue contains proper motions over the whole sky without gaps. In the fields, which cover the zone of avoidance or which contain less

than of 25 galaxies the so-called quasi absolute calibration was performed. The proper motion errors are varying from 3 to10 mas/yr depending on a field under consideration. The zero-point of the absolute proper motion frame (the absolute calibration) was derived by using more than 1 million galaxies from 2MASS and USNO-A2.0. The mean formal error of absolute calibration is less than 1 mas/yr. We present also some investigations of the XPM catalogue and some information for possible users of the Catalogue. The XPM Catalogue will be available via CDS in Strasbourg in 2010.

Optical positions of ICRF sources using UCAC3 reference stars

Maigurova N.

RSI Nikolaev Astronomical Observatory, Ukraine

Optical positions for 171 extragalactic radio sources were derived using UCAC3 as a reference catalogue. The extragalactic sources are located in the range of declinations from -30° to +80° degrees. We estimate the accuracy of the optical positions to be about 40 mas for both coordinates. The observations of the optical counterparts of the extragalactic radio sources were performed using 1.5 m Russian-Turkish Telescope (Turkey) and 1m YAO (Kunming, China) during 2000-2003 years. The fields around the extragalactic sources have sizes of 4'x3', 6.5'x6.5' and 8'x8'. We checked UCAC3 catalogue for the completeness and showed that it contains enough reference stars in most of our fields for the astrometric reduction. The mean optical positions were compared with ICRF radio positions. Additionally, the results obtained with UCAC3 as a reference catalogue were compared with the previous ones obtained with UCAC2 and 2MASS catalogues.

Session 4 - Recent developments in theory and observation of Earth rotation and related reference systems

Diurnal excitation of Earth rotation estimated from recent geophysical models (invited)

Brzezinski A.

Faculty of Geodesy and Cartography / University of Technology, and Space Research Centre, Poland

Nearly diurnal variations in the atmospheric and nontidal oceanic angular momenta (AAM, OAM) contribute at measurable level to all components of Earth rotation. The estimated contributions to nutation have amplitudes over 0.1 milliarcsecond (mas), while in case of polar motion and UT1 the amplitudes are up to 0.04 mas. However, there are still significant discrepancies between the contributions estimated from different geophysical models as well as between those derived from geophysical models and geodetic data. Here we use a new consistent set of 20-year time series of AAM and OAM based on the ERA-Interim reanalysis fields and the corresponding simulation from the ocean model OMCT, to extract the diurnal component and to estimate the influence on Earth rotation. Results are compared to the earlier estimates using the AAM series from the NCEP/NCAR reanalysis model and the OAM series from the barotropic ocean model, derived by Brzezinski, Ponte and Ali (2004, JGR, Vol.109, B11407). The estimated geophysical contributions are also compared to the available results derived from the space geodetic observations of Earth rotation.

Observing and modeling long-period tidal variations in polar motion (invited)

Gross R.

Jet Propulsion Laboratory, USA

By exchanging angular momentum with the solid Earth, tidal variations in oceanic currents and sea level cause the rotation of the solid Earth to change. Observations of Earth rotation variations can therefore be used to evaluate ocean tide models. The long-period rotational predictions of a spherical harmonic ocean tide model that is not constrained by any type of data are compared here to the predictions of other numerical ocean tide models and to Earth rotation observations from which atmospheric and non-tidal oceanic effects have been removed. The spherical harmonic ocean tide model is shown to account reasonably well for the observed variations at the fortnightly tidal period in polar motion excitation. Overall, its long-period polar motion excitation predictions fit the observed tidal signals better than do the predictions of the other numerical ocean tide models studied here. It also compares favorably to the recent empirical ocean tide model of Gross (2009) which was determined by fitting periodic terms at the tidal frequencies to polar motion excitation observations spanning 1980-2006 from which atmospheric and non-tidal oceanic effects were removed. The empirical model of Gross (2009) has been updated here by fitting an additional 3.5 years of observations. The convergence properties of the updated empirical ocean tide model will be examined here as will its agreement with the spherical harmonic ocean tide model.

Examination of ITRF2008 results (invited)

Altamimi Z.

Institut Géographique National, France

Following the procedure already used for the ITRF2005 formation, the ITRF2008 uses as input data time series of station positions and Earth Orientation Parameters (EOPs) provided by the four space geodetic techniques (GPS, VLBI, SLR, DORIS). The integration of these techniques together in the ITRF construction crucially requires co-location sites where two or more techniques are (were) operated and where local ties between the instrument reference points are available. The paper focuses on the main features and results of the ITRF2008, with a particular emphasis on the frame parameters (origin, scale, orientation and their time evolution), as well as the quality assessment of the estimated quantities: station positions and velocities and EOPs. The level of agreement between the four techniques in co-location sites, involving the used local ties will be examined.

Subdiurnal polar motion from GNSS observations

Petrov S., Bashakova, E., Fetisov S., Smirnov S., Trofimov D.

St.Petersburg State University, Russia

The established practice in estimation of the Earth Orientation Parameters (EOP) consists in computing one value, or normal point, per day. However, presently there is a strong need in the EOP time series with a subdiurnal resolution. Recent advances in the technology and coverage of the Global Navigation Satellite Systems (GNSS) is leading to a higher accuracy for the estimated EOP. This allows one to attempt an estimation of Polar motion, Length of day (LOD) and nutation angles more frequently than just once per day. The present paper is devoted to the derivation of an adjusted model for the transformation from celestial to terrestrial reference systems. This transformation is then applied to the GNSS adjustment procedure in order to produce hourly estimates of Polar motion and LOD. The first results of application of the new algorithm to the GNSS observations are presented.

Response of the Earth system to zonal tidal forcing examined by VLBI based dUT1 variations

Boehm S., Schuh H.

Vienna University of Technology, Institute of Geodesy and Geophysics, Austria

The VLBI group at the Institute of Geodesy and Geophysics of Vienna University of Technology is developing the software VieVS (Vienna VLBI software) for the analysis of geodetic VLBI data. VieVS incorporates the most recent models recommended by the IERS Conventions and in contrast to other VLBI software uses a parameterization with piece-wise linear offsets at integer hours. Thus it provides more flexibility for combination or comparison with time series from other space geodetic techniques or of geophysical origin. We employ this new software to re-process all available geodetic VLBI sessions from 1984 till 2010, suitable for the determination of the Earth rotation parameters (ERP), i.e. dUT1 and the polar motion components xp and yp. Zonal tidal signals with periods from 5 to 35 days in the derived dUT1 long-time series are then used to estimate the so-called zonal response coefficient kappa defined by Agnew & Farrell (1978). The frequency dependent zonal response coefficient is an extension to the concept of the Love number k2 which allows for a response of the Earth to tidal forcing, deviating from purely elastic behaviour and thus taking into account effects of ocean tides, a fluid core and mantle anelasticity. A tidally induced change of the rotation rate of the Earth and consequently of dUT1 is proportional to the tide-generating potential through the zonal response coefficient kappa. The values estimated for kappa for different tidal frequencies from VLBI observations of dUT1 are compared to theory and to the results of previous determinations of kappa from observations of space geodetic techniques.

Centennial cycles of the solar activity and Earth rotation

Chapanov Y.[(1)], Vondrák J.[(2),] Ron C.[(2)]

(1): *Central Laboratory for Geodesy - BAS*, Bulgaria; (2): *Astronomical Institute,* Czech Republic

The centennial variations of the Universal Time UT1 and Length of Day LOD are investigated by means of long historical observational series of UT1 and LOD variations, which cover time span more than 3 centuries long. The correlation between the centennial cycles of the Earth rotation, climate and Total Solar Irradiance TSI is determined using the time series of Mean Sea Level MSL variations at Stockholm tide gauge station since 1774 and reconstructed TSI variations since 1610. The model of the solar influences on the centennial and decadal cycles of the Earth rotation is based on a main centennial cycle and harmonics, ending by oscillation with period around 9a. The proper value of the period of the main centennial cycle of this model is determined between 178.8a (Jose cycle) to 220a (de Vries cycle) by looking for the minimal residuals of UT1, LOD, TSI and MSL approximation.

Influence of the inner core geopotential variations on the rotation of the Earth

Escapa A.[(1),] Getino J., Miguel D., Ferrándiz J. M.

(1): *Dep. Applied Mathematics. University of Alicante*, Spain

In this investigation we determine a new contribution to the rotation of a three layer Earth model composed by an axial-symmetric mantle, a fluid core and an axial-symmetric inner core. This contribution emerges as a consequence of the variation of the geopotential induced by the differential rotation of the solid inner core. Within the framework of the Hamiltonian theory of the rotation of the non-rigid Earth, and following the same guidelines as those described in [1] and [2], we derive the analytical formulae that configure the motion of the Earth figure axis. In addition, we examine the dependence of those formulae on the rheological parameters of the model, providing numerical estimations for the amplitudes of the nutational motion. [1] Escapa, A., J. Getino and J. M. Ferrándiz, J. Geophys. Res., 106, 11387, 2001 [2] Escapa, A., Getino, J. and Ferrándiz, J.M., Proceedings of the Journées 2007. Ed. N. Capitane, Observatoire de Paris, 113, 2008.

On Solution of the three-axial Earth's rotation problem

Ivanova T., Brumberg V.

Institute of Applied Astronomy, Russia

In the present paper the equations of the translatory motion of the major planets and the Moon and the equations of the three-axial solid Earth's rotation in Euler parameters are reduced to the secular system describing the evolution of the planetary and lunar orbits (independent of the Earth's rotation) and the evolution of the Earth's rotation (depending on the planetary and lunar evolution). Hence, the theory of the Earth's rotation is presented by means of the series in powers of the evolutionary variables with quasi-periodic coefficients. This form of the Earth's rotation problem is compatible with the general planetary theory [1] involving the separation of the short-period and long-period variables and avoiding the appearance of the non-physical secular terms. In extending the technique of [2] for the axially symmetrical Earth we got a combined secular system for the evolution parameters of the orbits of the eight major planets and the Moon and the rigid-body rotation of the three-axial Earth. The solution of the secular system is obtained in semi-analytical form. All actual calculations were performed with the aid of the Poisson Series Processor [3]. References 1. Brumberg V.A. Analytical Techniques of Celestial Mechanics. //Springer, Heidelberg (1995). 2. Brumberg V.A., Ivanova T.V. Precession/Nutation Solution Consistent with the General Planetary Theory. //Celest. Mech. Dyn. Astron. 97, 189-210 (2007). 3. Ivanova T.V. PSP: A New Poisson Series Processor. // In: S.Ferraz-Mello, B.Morando, J.-E.Arlot (eds.), Dynamics, Ephemerides and Astrometry of the Solar System, Kluwer (1995).

A refined definition of the International Terrestrial Reference System

Boucher C.

Observatoire de Paris/SYRTE/CNRS, France

Recent discussions have shown the need to upgrade and refine the definition of the International Terrestrial Reference System (ITRS). This presentation reviews the various issues, in particular related to the scale and origin. It also looks at the impact on IERS activities (ITRF and conventions), on the need to modify the related IUGG resolution, as well as the ongoing ISO standard related to ITRS.

Influence of station referencing on the quality of EOP time series

Coulot D., Bernard E., Collilieux X.

Institut Géographique National/LAREG, GRGS, France

EOP series (at a daily sampling) are computed together with (weekly) station positions. The definition of the terrestrial frames (TF) underlying these position series affects the accuracy of the estimated EOP series. The goal of this work is to evidence this influence for Satellite Laser Ranging (SLR) network, from two points of view. In the first case study, the station referencing is realized through minimum constraints which align the orientation of the weekly TF with respect to a given Terrestrial Reference Frame (TRF). The weekly station networks over which these

constraints are applied have a significant influence on the stability of the EOP series. To get the best stability, we thus search for weekly core networks with optimization methods. The WRMS of the so-computed EOP series shows a 25 μas improvement compared to the standard approach recommended by the analysis working group of the International Laser Ranging Service (ILRS). In the second approach, the station referencing with respect to a given TRF is realized through the computation of weekly Helmert transformations. The EOP series consistent with the so-obtained station position series are directly computed by adding the estimated rotations. The results provided by an optimization (on the basis of a stochastic algorithm) of this approach will be compared to the results above are directly computed by adding the estimated rotations. The results provided by an optimization (on the basis of a stochastic algorithm) of this approach will be compared to the results above.

Comparison of the hydrological excitation functions HAM of polar motion for the period 1980.0-2009.0

Nastula Y., Pasnicka M., Kolaczek B.

Space Research Centre, Polish Academy of Sciences, Poland

The impact of continental hydrologic signals, from land water, snow and ice on polar motion excitation HAM (hydrological angular momentum) is not so well known as atmospheric and oceanic ones. Hydrological angular momentum have been estimated in several models of global land hydrology, based on the observed distribution of surface water, snow, and soil moisture. We have compared the global and regional hydrological excitations from the period 1980.0 to 2009.0. The results are compared with observed excitations of polar motion GAM and contributions from the atmosphere AAM and ocean OAM excitations. In our consideration we make use of the following global models of hydrology: NCEP/NCAR, CPC, GLDAS, HAM GFZ, NOAA, WGHM CRU and data from the Gravity Recovery and Climate Experiment (GRACE). Phasor diagrams and spectra of the seasonal components of the polar motion excitation function of all HAM excitation functions as well as of two GRACE solution were determined.

Wavelet based comparison of high frequency oscillations in the geodetic and fluid excitation functions of polar motion

Kosek W., Popíski W., Niedzielski T.

Space Research Centre, Polish Academy of Sciences, Poland

It has been already shown that short period oscillations in polar motion with periods less than 100 days are very chaotic and are responsible for increase of short term prediction errors of pole coordinates data. The wavelet technique enables comparison of the corresponding polar motion excitation functions in the high frequency band in many different ways, by looking at the time-frequency coherence functions, frequency dependent time lag functions, as well as polarization functions. The wavelet based semblance filtering enables computation of the common signal in both geodetic and fluid excitation time series. In this paper the fluid excitation functions considered comprise the atmospheric, oceanic and land hydrology excitation functions from ECMWF atmospheric data produced by IERS Associated Product Centre Deutsches GeoForschungsZentrum, Potsdam. The geodetic excitation functions were computed from the combined pole coordinates data.

Comparison of CPO and FCN empirical models

Malkin Z.

Pulkovo Observatory, Russia

In this presentation, several publicly available empiric models of the celestial pole offset (CPO) and free core nutation FCN), included those newly developed by the author, are investigated and compared each other from different points of view, such as representation of the observation data, FCN parameters variation, prediction accuracy. Based on this study, some practical recommendations are proposed for using different CPO and FCN models in data processing and geophysical studies.

Impacts of the 2010 Chile earthquake on Earth rotation

Nilsson T., Boehm J., Schuh H.

Vienna University of Technology, Institute of Geodesy and Geophysics, Austria

On February 27, 2010, an Earthquake of magnitude 8.8 occurred in Chile near the city of Concepción. This Earthquake caused huge displacements in the Earth's crust, e.g. the GPS and VLBI stations in Concepción moved about 3 metres to the West. It can be expected that such a big Earthquake also changed the rotation of the Earth. We use information about the magnitude and geometry of the Earthquake in order to model how large the impact on Earth rotation was. These estimates are compared to the observed Earth rotation variations. Preliminary analyses indicate that the length of day (LOD) has increased by about 0.3 microseconds and the figure axis has moved by about 2.6 milliarcseconds, which is comparable to the measurement accuracies.

Thermal S1-tide in the atmospheric angular momentum and polar motion

Pavloskaya N., Petrov S.

St.Petersburg State University, Russia

In this work the influence of the thermal S1-tide in the atmospheric angular momentum (AAM) on Polar motion was studied. The thermal S1-tide is understood here as a diurnal tide modulated by the visible longitude of the Sun. Different AAM time series were analyzed. Time series of Earth orientation parameters (EOP) with subdiurnal resolution were obtained from reanalysis of the Very Long Base Interferometry (VLBI) observations. Amplitudes and phases of S1-tide in AAM and Polar motion were estimated. Comparison of S1-tide in the atmospheric angular momentum, the ocean tide angular momentum and Polar motion was made. Special attention was paid to the procedure of VLBI observations adjustment in view of estimation of subdiurnal Polar motion. An objective algorithm of the a priori Polar motion variance selection was worked out.

High-resolution atmospheric angular momentum functions from different ECMWF data classes

Schindelegger M., Boehm J., Schuh H., Salstein D.

Vienna University of Technology, Austria

Atmospheric excitation of Earth rotation at daily and sub-daily periods is routinely inferred from six-hourly atmospheric angular momentum (AAM) functions, which are derived from the operational analysis fields of Numerical Weather Models. The so-called delayed cut-off stream, recently introduced by the European Centre for Medium-Range Weather Forecasts (ECMWF), though, produces meteorological data with higher temporal resolution by incorporating short-term forecasts, and thus allows the estimation of hourly and three-hourly AAM functions. In detail, we determine six- and three-hourly AAM functions for the whole year 2008 as well as hourly AAM functions for August 2008. Comparisons of the three series reveal differences in amplitude and phase, but also highlight the counteraction of pressure and wind terms at short time scales, which originates from atmospheric circulation on short time scales. Moreover, the three-hourly AAM record for 2008 represents an opportunity to resolve better the semi-diurnal band of atmosphere-induced variations in polar motion and LOD. A comparison of the estimated atmospheric effects with high-resolution Earth rotation parameters from VLBI and GPS will be provided, too.

Recent Improvements in IERS Rapid Service/Prediction Center Products

Stamatakos N., Luzum B., McCarthy D.D.

US Naval Observatory, USA

The International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC) has made improvements to its products and has also developed a web-based Earth Rotation matrix calculator. The improvements include a correction to the UTAAM implementation in the combination. Also, use of the IGS Ultras for UT1-UTC and a twice daily EOP solution are being investigated on testing computers. The web-based calculator returns the Earth rotation matrix at specified user input times based on the IERS 2003 Conventions models.

Analysis of Chandler wobble excitation, reconstructed from observations of the polar motion of the Earth

Zotov L.

Sternberg Astronomical Institute, Moscow State University, Russia

Excitation functions reconstruction from observations of the polar motion (PM) is an ill-posed problem. Wilson-Jeffreys filter is a standard procedure of reconstruction, but it does not include stabilization of solution. We suggest to use Panteleev corrective smoothing or Tikhonov regularization. Chandler excitation reconstruction is complicated, because of its resonance nature and strong annual component (AC) presents nearby in frequency band. We use 2-D Singular Spectrum Analysis (SSA), least squares adjustment (LSA) and Panteleev smoothing to remove it and release signal from noise. Chandler excitation was reconstructed by three different methods: Panteleev corrective smoothing; Jeffreys-Wilson filter with SSA; regularization with subtraction of AC. Results are in agreement with each other. Amplitude and phase evolution in time was analyzed by Gabor transform. It was found out, that in 1930-th, when amplitude of Chandler component decreases and phase jump appears, the amplitude of excitation increases and phase jump in excitation decreases by ~pi. Amplitude changes of Chandler excitation were compared with atmospheric, oceanic angular momentum changes, southern oscillation index and tides. Modulation of Chandler excitation of ~18 yr period, synchronous with saros tidal effects in the length of the day (LOD) was observed. That brings us to conclusion, that the Lunar-Solar tide energy is transferred to Chandler wobble. The mechanism is to be found. It could involve ocean and atmosphere as mediators.

Session 5 – Pulsars timing, relativity and time transfer

An extension of the IAU framework for reference systems (invited)

Kopeikin S.

University of Missouri, USA

IAU-2000 resolutions on the reference frames set up a solid theoretical foundation for implementing general relativity in computer-based data processing algorithms and unambiguous interpretation of astronomical observations. We discuss possible directions for further development of the IAU resolutions aimed to take into account the decadal progress in observational techniques and computer technologies. We address the following subjects: 1) space-time transformations and the structure of the metric tensor; -2) PPN parameters and gauge invariance of equations of motion; -3) ramified hierarchy of astronomical reference frames.

Developing a pulsar-based time scale (invited)

Hobbs G.

CSIRO Australia Telescope National Facility, Australia

Using data from the Parkes Pulsar Timing Array project I show how a pulsar-based time scale can be developed. The long-term stability of this time scale is compared with the best available terrestrial time scale.

Ensemble pulsar time scale

Rodin A.

Pushchino Radio Astronomy Observatory, Russia

A new approach based on the correlation analysis of the pulsar time series (time of arrivals residuals) is used for construction of the ensemble pulsar time scale. This approach is applied to timing data of a few millisecond pulsars.

IPTA and sensitivity of radio telescopes

Korotkova N., Ilyasov Yu. P., Pshirkov M. S.

Sternberg Astronomical Institute, Moscow State University, Russia

Precise millisecond pulsar timing is being made with the larges radio telescopes all over the world. Pulsar timing arrays (PTA) are formed in Europe, USA, Australia and Russia (EPTA, NANOGrav, PPTA, KPTA, respectively). They are included in the International Pulsar Timing Array (IPTA) with the aim to detect super low frequency gravitational waves. Time-of-arrival errors due to telescope noise has been calculated for IPTA and Kalyazin telescopes (Russia) for observed millisecond pulsars and then compared to current rms of timing residuals, published for EPTA, NanoGrav, PPTA and KPTA. Considerable correlation between the TOA error, rms and peak pulsar flux densities has been shown up, which probably means, that current rms of millisecond pulsars residuals (timing noise) are defined mostly by the telescope sensitivity and pulsar flux density, but not the pulsar itself, for a while. Calculations of simulated models have been made to define the algorithm for obtaining 'ensemble residuals' which would be the best to generate the time scale, based on pulsars. It has been applied to real timing data of 6 millisecond pulsars made at the Pushchino Radio Astronomical Observatory of the Lebedev Institute for 12 years by Kalyazin radio telescope 64-m dish at 0.6 GHz.

High precision pulsar timing: Nancay and the European Pulsar Timing Array

Cognard I.

CNRS LPC2E, France

The Nancay radiotelescope is involved in high precision timing since more 20 years. Since 2004, a coherent dedispersion instrumentation enables numerous routine observations on more than 200 pulsars using half of the time with this 100-meters class radiotelescope. In addition to a FERMI/LAT high energy observations support, a set of ~30 highly stable millisecond pulsars is monitored as our contribution to the European Pulsar Timing Array built to probe any kind of Gravitational Wave background.

Chandler wobble and Free Core Nutations of single pulsar

Gusev A.

Kazan University, Russia

The long-periodic precession phenomenon was detected for few pulsars: PSR B1828–11, PSR B1557-50, PSR 2217+47, PSR 0531+21, PSR B0833–45, PSR B1642–03. We are propose the explanation for all harmonics of Time of Arrival (TOA) pulses variations as precession of a neutron star owing to differential rotation of crust, outer liquid core and inner crystal core of the pulsar PSR B1828–11: 250, 500, 1000 days. Like the Earth, a neutron star (NS) can undergo a free precession (Pines, Shaham, 1974) . We used canonical method for interpretation TOA variations by Chandler Wobble (CW) and Free Core Nutation (FCN) of pulsar. The two - layer model can explain occurrence twin additional fashions in rotation pole motion of a NS: CW and FCN. In the frame of the three-layer model we investigate the free rotation of dynamically-symmetrical PSR by Hamilton methods proposed Getino J. (1999, 2001). Correctly extending theory of core-mantle-crust differential rotation of NS, we investigated dependence CW, ICW, FCN and FICN periods from flatness of liquid outer core, crust and total pulsar. Getino's investigation showed that interaction between rigid mantle, FOC and SIC can be characterized by four modes of periodic variations of rotation pole: CW, retrograde Free Core Nutation (FCN), prograde Free Inner Core Nutation (FICN) and Inner Core Wobble (ICW). We have got the estimates of dynamical flattening of the crust, the outer liquid and the inner solid cores of the pulsar for known periodic variations of the TOA pulse from PSR B1828–11.

About the MacCullagh relations in Relativity

Soffel M., Klioner S., Gerlach E.

Lohrmann Observatory, Dresden Technical University, Germany

The MacCullagh relations in the Newtonian framework relate the components of the mass quadrupole tensor with certain components of the moments of inertia tensor. For the Earth they relate the fields of global geodynamics and the Earth's gravity field. For practical applications the problem of MacCullagh relations in the first post-Newtonian approximation to Einstein's theory of gravity is of interest. To illustrate this point the post-Newtonian mass quadrupole tensor and moment of inertia tensor are explicitly calculated for the model of a uniformely rotating homogeneous oblate spheroid. Violations of the classical MacCullagh relations are found that are proportional to (GM/c^²²²2 a) e^2, where a and e are semi-major axis and eccentricity of the model spheroid. Implications for a post-Newtonian modelling of Earth's rotation are given.

Post-Newtonian mechanics of the Earth-Moon system

Xie Y.[(1),] Kopeikin S.[(2)]

(1): Astronomy Department of Nanjing University, China; (2): *University of Missouri*, USA

We introduce the Jacobi coordinates adopted to the advanced theoretical analysis of the relativistic celestial mechanics of the Earth-Moon system. Theoretical derivation utilizes the relativistic resolutions on the local reference frames adopted by the International Astronomical Union in 2000. The advantage of the local frames is in a more simple mathematical description of

the metric tensor and equations of motion. The set of one global and three local frames is introduced in order to decouple physical effects of gravity from the gauge-dependent effects in the equations of relative motion of the Moon with respect to Earth. We pay particular attention to a unique opportunity to detect the gravitomagnetic tidal field in the orbital motion of the Moon with the advanced LLR technology.

Post-post-Newtonian light propagation without integrating geodesic equations

Teyssandier P.

Observatoire de Paris/SYRTE/CNRS, France

We present a new calculation of the propagation direction of light in a 3-parameter family of static, spherically symmetric space-times within the post-post-Newtonian framework. Based on the use of the time-delay function, our method avoids any integration of the geodesic equations and straightforwardly yields the solution in the generic case where both the emitter and the observer are located at a finite distance. Our formulae involve a coordinate-independent impact parameter of the ray and confirm a recent analysis due to Klioner and Zschocke. Applying these results to the limiting case of a ray emitted at infinity, we obtain an intrinsic expression of the light deflection angle by an elementary calculation. The inverse problem is also briefly discussed.

Test of General Relativity with the Gaia mission

Mouret S.

Lohrmann observatory - Technical University of Dresden, Germany

The Gaia mission due for a launch in late 2012 will observe a very huge number of minor planets (> 250,000) with an unprecedented precision (under the sub-milliarcsecond). Thus, we are given new perspectives in testing General Relativity from the dynamics of asteroids. We will present the possibilities for Gaia to measure the dynamic solar quadrupole J2, the PPN parameters gamma and beta, the variation in time of the gravitational constant dG/dt and the Nordtvedt parameter eta (test of the strong Principle Equivalence) by giving the expected precisions on these parameter estimates from realistic Gaia simulated data.

Testing gravity law in the solar system

Lamine B.[(1)], Courty J.-M.[(1)], Reynaud S.[(1)], Jaekel M.-T.[(1)]

(1): *Laboratoire Kastler Brossel*, France; (2): LPTENS, France

General relativity (GR) is well tested in the solar system but challenged by anomalies at galactic and cosmic scales (dark matter/dark energy) and its unification in the framework of quantum field theories remain open. A few anomalies observed on spacecraft tracking data (Pioneer and flybys anomalies) are a strong motivation for improved and more systematic tests of GR in the solar system. We present metric extensions of general relativity which preserve the equivalence principle but modify the coupling between energy and curvature in a phenomenological framework which generalizes the PPN framework. We also discuss some of the possible observational consequences of this framework.

Abstracts for the poster presentations

Session 1 - The astronomical constants, SI units and future developments in numerical standards

(alphabetic order)

1.1 - *From old weights and measures to the SI as a numerical standard for the world*

Débarbat S., Passeron I.

Observatoire de Paris/SYRTE/CNRS, France

After some unsuccessful attempts by Charlemagne, Picard was, most probably, the first in France to submit a proposal for a new system based on a unit relying length to time through the second-pendulum. Despite other proposals, during the 18th century, one century after PIcard came the Système métrique décimal, which fundamental standard was the Mètre. After almost one more century, by 1960, the SI was decided at the international level and, by 1983, a new realization of the meter was decided, relying length and time !

1.2 - *An effect in satellite motion non-modeled by the current numerical standard*

Kudryavtsev S.

Sternberg Astronomical Institute of Moscow State University, Russia

Here we derive a theoretical effect in satellite motion, in particular non-modeled by the current IERS Conventions (McCarthy & Petit 2004). Numerical tests prove that, e.g., for LAGEOS and ETALON this effect may lead to periodic perturbations in the satellites coordinates of up to 10-20 cm (to be detectable by modern laser measurements). The respective excitations of the satellites eccentricity vector may reach the amplitude of a few tens of mas/year. This value is comparable to anomalous excitations observable in the satellites eccentricity vector (see, e.g., Tapley et al. 1993; Appleby 1998), that are still not completely explained. Research supported in part by the Russian Foundation for Basic Research under grant no.10-02-00234-a. References: Appleby, G.M. (1998): J. Geodesy, 72, 333-342. McCarthy, D.D., Petit,G. (2004): IERS Conventions (2003), IERS Tech. Note 32. Tapley, B.D. et. al. (1993): In: Contributions of Space Geodesy to Geodynamics: Earth Dynamics, AGU, 24, 147-173.

Session 2 - Solar system ephemerides and their comparison

(alphabetic order)

2.1 - *Session 2 Introductory remarks*

G. Kaplan, IAU Commission 4 President

2.2 - *Web Interface for Lunar Laser Ranging observations*

Barache C.[(1)], Bouquillon S.[(1)], Carlucci T.[(1)], Deleflie F.[(2)], Feraudy D., Francou G.[(1)], Manche H.[(2)], Samain E.[(3)], Torre J-M.[(3)]

(1) *Observatoire de Paris, SYRTE/CNRS,* (2) : *IMCCE ;* (3): *OCA ; GRGS,* France

We report the current development of a web Interface for preparing and validating LLR observations. With this service, distant LLR Observers will be able to easily run some Paris Observatory tools dedicated to Lunar motion. It will allow them to compute predictions of Moon retro-reflectors topocentric coordinates and predictions of round-trip times of the laser-pulses. It will also allow them to compare their own LLR Data with Paris Observatory Lunar Ephemeris, in terms of rms, and with a real-time access.

2.3 - *A dynamical study of Phoebe's rotation*

Cottereau L.

Observatoire de Paris/SYRTE/CNRS, France

With a fast non synchronous rotation, Phoebe is a particular satellite in the Saturnian system(most of the satellites are subject a synchronous rotation)and must show a very different rotational evolution. We propose for the first time to determine the combined motion of the precession and nutation of Phoebe considered as a rigid body by numerical and analytical integration. We further compare our results with those obtain by Kinoshita for the Earth (1977), emphasizing their astonishing similarities (obliquity, value of the precession, nutation amplitudes and arguments).Moreover we show that a pure analytical accurate model of the nutation is not easy to construct due to the fact that the orbital motion of Phoebe is far from being keplerian. At last we present the prospect for future studies among which are the effect of the Sun , Titan and the dynamical ellipticity of Saturn on the precession-nutation motion.

2.4 - *New analytical planetary theories VSOP2010*

Francou G[(1)],, Simon J.L.[(2)]

(1) *Observatoire de Paris, SYRTE/CNRS,* (2): *Observatoire de Paris, IMCCE* ; France

The planetary theories VSOP are essentially issued from Bretagnon's research works. The precision of the last version, VSOP2000 (Bretagnon & Moisson) fitted to DE403, was 10 times better than the previous solutions VSOP82 and VSOP87, both fitted to DE200. Subsequently, Bretagnon began to make some improvements: better accuracy for the computation of series, simultaneous determination of the 8 major planets and the 5 big asteroids orbits, lunar perturbations taken into account for the motions of the major planets. We took up again this work introducing various changes and complements : fits to the numerical integrations DE405 (JPL) and INPOP08A (IMCCE) for VSOP2010A and VSOP2010B respectively, introduction of the perturbations coming from 298 asteroids, contribution of TOP theory (Simon), i.e., analytical theory of Pluto, perturbations due to Pluto, better accuracy for the orbits of Jupiter and Saturn. Over the time interval [1890,2000], the discrepancies between theories and numerical integrations are : < 0,04 mas for Mercury, Venus and Earth-Moon barycentre, <0,07 mas for Jupiter, <0,3 mas for Saturn and Neptune, <1,5 mas for Mars and Uranus. The precision is 3 to 10 times better than that of VSOP2000. Over the time interval [-4000,8000], the precision is a few 0.1" for Mercury, Venus and Earth-Moon barycentre and a few arc seconds for the other planets. Here, the gain in precision is 5 times better for the telluric planets and 10 to 50 times better for the major planets in comparison with VSOP2000.

2.5 - *Summary and Status of the Horizons Ephemeris System*

Giorgini J.

Jet Propulsion Laboratory/California Institute of Technology, USA

Since 1996, the Horizons system has provided searchable access to JPL ephemerides for all known solar system bodies, several dozen spacecraft, planetary system barycenters, and some libration points. Responding to 18,400,000 requests from 300,000 unique addresses, the system has recently averaged 420,000 ephemeris requests per month. Horizons is accessed and automated using three interfaces: interactive telnet, web-browser form, and e-mail command-file. Asteroid and comet ephemerides are numerically integrated from JPL's database of initial conditions. This small-body database is updated hourly by a separate process as new measurements and discoveries are reported by the Minor Planet Center and automatically incorporated into new JPL orbit solutions. Ephemerides for other objects are derived by interpolating previously developed solutions whose trajectories have been represented in a file. For asteroids and comets, such files may be dynamically created and transferred to users, effectively recording integrator output. These small-body SPK files may then be interpolated by user software to reproduce the trajectory without duplicating the numerically integrated n-body dynamical model or PPN equations of motion. Other Horizons output is numerical and in the form of plain-text observer, vector, osculating element, or close-approach tables, typically expected be read by other software as input. About one hundred quantities can be requested in various time-scales and coordinate systems. For JPL small-body solutions, this includes statistical uncertainties derived from measurement covariance and state transition matrices. With the exception of some natural satellites, Horizons is consistent with DE405/DE406, the IAU 1976 constants, ITRF93, and IAU2009 rotational models.

2.6 - *A Comparison of the High Accuracy Planetary Ephemerides DE421, EPM2008, and INPOP08 (continued)*

Hilton J, Hohenkerk C. (see the abstract on page 9)

2.7 - *Propagation in time of errors for the mutual inclination of satellites*

Marco F., Martínez M. J., López J. A.

Universitat Jaume I, Spain

The theoretical and the observed values of the mutual inclination between natural satellites may be different due to physical or geometrical causes (or due to both of them). It is clear, for example, that a geometrical variation between the reference systems, for example the application of a infinitesimal rotation around an axis, implies a modification in the elements that determine the orbits. In addition, a bad determination of the mass of the body may imply false values in the integration of the elements. These errors in the initial elements propagate in time, so it may be useful to provide methods to analyse them and also to be able to discriminate the true source of the error, if possible.

2.8 - *Calculation of Lunar Librations in The Astronomical Almanac using JPL Lunar Ephemerides*

Weratschnig J.[(1)] Taylor, D.B.[(1)], Bell S.A.[(1)], Hilton J. [(2)], Sinclair A.T. [(1),]

(1): *HM Nautical Almanac Office,* UK; (2): *US Naval Observatory*, USA

This poster is based on HM Nautical Almanac Office Technical Note 74, which describes the method used for calculating lunar librations used in Section D of The Astronomical Almanac. The Euler angles from the JPL DE403/LE403 ephemerides are used to calculate improved lunar librations, beginning with the 2011 edition. This method supersedes the analytical theory of Eckhardt (1981, 1982) used since 1985. This poster paper and the Technical Note are for the practitioner of astronomical calculations. They provide an algorithm and a numerical example, employing the same computer routines used for the production of The Astronomical Almanac, showing all the relevant stages in the computation of the librations and related quantities.

Session 3 - Progress in astrometric catalogs in optical and radio wavelengths

(alphabetic order)

3.1 - *Gaia Initial Quasar Catalogue – updates: morphology and variability*

Andrei A.H.[(1)], Gontier A.-M.[(2)], Barache C.[(2)], da Silva Neto D.N.[(1)], Taris F.[(2)], Bourda G.[(3)], LeCampion J.F.[(3)], Souchay J.[(2)], Camargo J.I.B.[(1)], Pereira Osório J.J.[(1)] , Assafin M.[(1)], Vieira Martins R.[(1)], Bouquillon S.[(2)], Anton S.[(1)]

(1): *Observatorio Nacional/MCT*, Brasil; (2): *SYRTE, Observatoire de Paris*, (3): *Laboratoire d'Astrophysique de Bordeaux*, France

The present version of the GAIA Initial QSO catalogue (GIQC_III) contains 174,744 sources, divided in 3 categories: defining (full reliability, 123,880 sources), candidate (lacking full confirmation of redshidft or magnitude or pointlikeness, 24,229 sources), and other (pending confirmation of two or more characteristis, 26,235 sources). The GIQC_III now includes morphological indexes, as derived from the study of the target's PSF from DSS R, B, and I plates, in comparison with at least 6 well imaged neighboor stars. A study was also made on the relationship between optical flux long term variability and the centroid's random walk. For that, classes of objects most prone to exhibit such relationship are discussed.

3.2 - *The maoC08a combined catalogue of radio source positions created in the course of preparation for the ICRF2*

Yatskiv Ya., Bolotin S., Lytvyn S.

Main Astronomical Observatory NAS of Ukraine, Ukraine

Starting with 1991 the 12 combined radio source catalogues (RSC) were created at the Main Astronomical Observatory of the NAS of Ukraine (GAO UA acronym was used by the IERS) by using the so-called Kiev arc length method. In the course preparation for realization of the ICRF2 we created the new combined catalogue (designated as maoC08a) on the basis of data provided by the IVS WG. In this paper, the method for combining the individual RSC as well as the results of comparison of the maoC08a catalogue with other catalogues are briefly discussed.

Session 4 - Recent developments in theory and observation of Earth rotation and related reference systems

(alphabetic order)

4.1 - *On correlation between variations in Earth rotation and frequency of earthquakes*

Aleshkina E.

Pulkovo observatory of RAS, Russia

Global geophysical phenomena such as powerful earthquakes make a significant contribution to the Earth rotation fluctuations. Catalogue CPE of powerful earthquakes with magnitudes greater then 7.5 for 450-years period are presented. The system of time-correction (TD-UT) characterized irregularities in Earth rotation for the time span 1700-1950 was obtained from analysis of the transits of Mercury and Venus and lunar observations. Changes in LOD for 250 years period were determined. Comparison of the frequency of earthquakes and secular and long-periodic changes in Earth rotation was carried out.

4.2 - *Relationship between solar activity and the earth rotation; reanalyses*

Abarca Del Rio R.[(1)], Gambis D.[(2)]

(1): *Universidad de Concepcion*, Chili; (2): *SYRTE, Observatoire de Paris*, France

Global atmospheric and surface fields derived from the Twentieth Century Reanalysis Project extends the coverage of the precedent global NCAR/NCEP gridded reanalyses (1948-until now). This reanalysis dataset assimilates the surface observations of synoptic pressure, monthly sea surface temperature and sea ice distribution. It provides an valuable opportunity to investigate the angular atmospheric variability over the 20th century and their effect on earth rotation parameters. We firstly analysed the variability of the axial angular momentum to derive Length of the day variability, mainly focusing on the decadal time scales in order to investigate the putative link with the decadal time scales in solar activity. The regional variability and the modulation of seasonal time scales are taken into account.

4.3 - *The source of the variable Chandler wobble*

Bizouard C., Lambert S., Remus F., Seoane L., Gambis D.

Observatoire de Paris/SYRTE/CNRS, France

We explain the variability of the Chandler wobble (CW) amplitude and phase along 1949-2009 by variations in atmospheric and oceanic excitations, as estimated from the NCEP/NCAR reanalysis project and the ECCO model, respectively. Unlike most of the studies related to this topic, the geophysical effects on polar motion are computed by a time integration of the Euler-Liouville equations. We show that the CW amplitude decreases between 1949 (250 mas) and 1970 (120 mas). Then, it slowly increases until the mid 1990's (200 mas) and finally decreases during the first decade of the 21st century (100 mas). The phase remains stable within 40°. For the total atmospheric and oceanic contribution, the correlation between the observed and modeled amplitudes of the Chandler mode and the explained variance reach about 80% and 60%, respectively. Though atmosphere and oceanic variations exhibit concomitant irregularities, the oceans are still dominant around 1990.

4.4 - *Earth rotation based on the coordinates of the CIP in the GCRS: solution for a rigid Earth*

Capitaine N.[(1)], Folgueira, M.[(2)]

(1): *Observatoire de Paris/SYRTE/CNRS*, France ; (2): *Ínstituto de Astronomía y Geodesia*, Spain

We report on the continuation of the work devoted to the integration of the Earth's rotational motion in terms of the coordinates, X, Y of the celestial intermediate pole (CIP) in the Geocentric celestial reference system (GCRS) for an axially symmetric rigid Earth (Capitaine et al. 2006). Here, we discuss the method of integration in comparison with other methods used for the rigid

Earth. We also analyse the semi-analytical solution for X and Y derived from the integration of these equations based on the external torque as computed from the theories ELP2000 for the Moon and VSOP87 for the Sun and planets. We compare different components of the obtained solution for the motion of the CIP in the GCRS with other solutions derived indirectly from the original SMART97 solutions for the Euler angles or the REN2000 solution for the classical precession and nutation variables.

4.5 - *Variations of the Earth main moments of inertia due to glacial cycles for the last 800Ka*

Chapanov Y.[(1)], Gambis D.[(2)]

(1): *Central Laboratory for Geodesy – BAS*, Bulgaria; (2): *Observatoire de Paris/SYRTE/CNRS*, France

The Earth shape, gravity and rotation are highly affected by climatic variations associated with the glacial cycles in the late Pleistocene. The processes of glaciation, followed by ice melting, are connected with significant changes of the mean sea level. These processes redistribute great amount of water masses between oceans and ice sheets, which lead to changes of the main moments of inertia. The mean sea level data for the last 800Ka are composed by the reconstructed glacial sea level for the last 380Ka, determined by the sediments from the Red sea and sea level variations for the period 380Ka-800Ka before present, based on the temperature changes, determined by deuterium data from Antarctica ice core. The model of main moments of inertia variations is based on mean sea level changes and spatial and temporal variations of the continental ice sheets. The time series of the Earth main moments of inertia variations for the last 800Ka with step 500a are determined.

4.6 - *Combination of GPS and GLONASS in Precise Point Positioning algorithms and its effect on site coordinates determination*

Hefty J., Lubomira Gerhatova, Juraj Burgan

Slovak University of Technology, Slovakia

The Precise Point Positioning (PPP) adjustment using the un-differenced code and phase GPS observations, precise orbits and precise satellite clocks is recently an important alternative to the double differenced approach usually applied for geocentric coordinate determination. We introduce models for separate GPS and GLONASS PPP processing as well as for the combined solution. The procedures are examined by the software package ABSOLUTE developed at the Slovak University of Technology in Bratislava. Obtained site coordinates time series based on GPS and GLOANSSS observations processed at zero difference level are compared with GPS-only series resulting from application of other PPP packages.

4.7 - *Solution and an analysis of the general celestial body rotation problem*

Kudlay O.

Main Astronomical Observatory of NAS, Ukraine

One performed numerical integration of general 3-axis solid body rotation problem to compare with commonly used linear system of Munk & Macdonald. Been calibrated on analytical Euler solution it provided the accuracy better than 1 microsecond of arc for wobble and 1 nanosecond for spin. This enabled to investigate the effect of as ever neglected small terms and find out the new phenomena. Wobble period variation under atmospheric forcing is studed as example of nonlinearity influence and compared with observations.

4.8 - *Determination of nutation offsets by combining VLBI/GPS-produced normal equations*

M. Kudryashova[(1)], S. Lambert[(2)], P. Defraigne[(1)], V. Dehant[(1)], C. Bruyninx[(1)]

(1): *Royal Observatory of Belgium*, Belgium; (2): *Observatoire de Paris/SYRTE/CNRS*, France

Long standing routing operation of individual geodetic space- and ground-based techniques (like, for instance, VLBI, GNSS, LLR, etc.) revealed their strong and weak aspects. More effective use of

these strengths as well as reduction of their weaknesses is possible by incorporating of the information collected by each individual technique into combined products. Such a consistent combination can be performed either by combination at the observational level or at the level of normal equations. We concentrate on the combination of normal equations gathered during VLBI/GPS-data processing. The main goal of this combination is to construct a time series of nutation offsets in the most consistent way. The objective of this presentation is to describe the developed strategy of combination and to present the current status of its implementation and first results. Combination presented here is based on the normal equations stemmed from the processing of VLBI and GPS observations during a continuous VLBI campaign CONT08. Earth orientation parameter determination will, in our procedure, benefit from angle and rate observation for a unique estimation.

4.9 - *Operational and research activity at the Paris Observatory VLBI analysis center*

Lambert S., Gontier A.-M., Barache C.

Observatoire de Paris/SYRTE/CNRS, France

The Paris Observatory IVS analysis center (OPAR) renewed its activities after 2007. It is now fully operational for processing of diurnal and intensive VLBI sessions scheduled by the IVS, with a latency optimized by an automated analysis scheme. A number of other tasks are regularly achieved: quarterly solution providing up-to-date reference frames and Earth orientation parameters, time series of site coordinates, and time series of radio source coordinates. Publication and availability of the products are ensured by the maintenance of one of the primary IVS data center and by a web site. After a large participation to the construction of the ICRF2, future developments include software improvement, new operational products, and new axes of research mainly oriented towards astrometry of quasars.

4.10 - *Physical characteristics of the ICRF2 quasars*

Lambert S., Gontier A.-M.

Observatoire de Paris/SYRTE/CNRS, France

As of 1 January 2010, the fundamental IAU celestial reference frame is the second realization of the ICRF (ICRF2). The ICRF2 catalogue is made of 3 414 radio sources observed at 3.6 cm wavelength. The axes of the system are maintained by 295 sources selected on the basis of their positional stability and compactness. Beyond the Earth-centered point of view, for which radio sources are simply points pinned up on a sphere, how are these sources distributed in the universe? The permanently updated astronomical databases (e.g., NASA, CDS) and the recent LQAC help us in finding some photometric and spectroscopic information on the ICRF2 sources to get a 3-dimensional view of the new frame at cosmological scales.

4.11 - *Using modified Allan variance for time series analysis*

Malkin Z.

Pulkovo Observatory, Russia

Allan variance (AVAR) was first introduced more than 40 years ago as a estimator of the stability of frequency standards, and now it is actively used for investigations of time series in astronomy, geodesy and geodynamics. However, unlike time and frequency measurements, astronomical and geodetic time series consist, as a rule, of data points with associated uncertainties, which are used for data weighting during statistical processing. Moreover, some kinds of time series we deal with in practice are in fact physically connected components of multidimensional vectors, e. g. Cartesian station coordinates with respect to the station position vector. Unfortunately, originally defined AVAR definition does not allow us to process unevenly weighted and multidimensional data. To overcome this deficiency, AVAR modifications are proposed (Malkin, J. of Geodesy, 82, 325, 2008). In this paper, several examples are given of processing of various time series making use the classical and modified AVAR approaches, and a comparison of results is made.

4.12 - *Phase variations of the Chandler wobble from 163-yr polar motion series*

Malkin Z., Miller N.

Pulkovo Observator, Russia

Investigations of the anomalies in the Earth rotation, in particular, the polar motion components, play an important role in our understanding of the processes that drive changes in the Earth's surface, interior, atmosphere, and ocean. This paper is primarily aimed at investigation of the Chandler wobble (CW) at the whole available 164-year interval to search for the major CW amplitude and phase variations. First, the CW signal was extracted from the IERS (International Earth Rotation and Reference Systems Service) pole coordinates time series using two digital filters: the singular spectrum analysis and Fourier transform. The CW amplitude and phase variations were examined by means of the wavelet transform and Hilbert transform. Results of our analysis have shown that, besides the well-known CW phase jump in the 1920s, two other large phase jumps have been found in the 1850s and 2000s. As in the 1920s, these phase jumps occurred contemporarily with a sharp decrease in the CW amplitude.

4.13 - *Method for prediction of DeltaT based on long-periodic terms in the Earth's rate of rotation*

Marceta D., Segan S.

Faculty of Mathematics of Belgrade, Serbia

Both external and internal mechanisms are responsible for variations in the Earth’s rate of rotation. Seasonal and annual fluctuations have been mapped in detail only since the introduction of atomic time. Decadal variations in the length of day (LOD) can be traced over the last four centuries i.e. over the telescopic period, mainly using occultations of stars by the Moon. However, any trend is difficult to detect over such a relatively short period. Regardless of choice of expression used to extrapolate DeltaT in pretelescopic period or to the future, still there is an inherent uncertainty of about +-20s due to indeterminate behavior of decade fluctuations. As we know, for very near future the uncertainty will be much smaller than this because in the next few years mathematical modeling can be used to predict value of DeltaT with more confidence (Kalarus M. at all,2010, in press). By using parabolic long term approximation (Stephenson and Morrison, 1995) of LOD changes in pretelescopic period, we have modified expression for DeltaT by adding some long-periodic terms to gain inner uncertainty less than +-5s for whole period.

4.14 - *Applications of simultaneous ground-based and satellite observations*

Marco F.[(1)], Martinez M.[(2)]

(1): *Universitat Jaume I*, (2): *Universidad Politécnica de Valencia:* Spain

Simultaneous ground-based and satellite observations either of a body in the solar system or an external source, together with mutual observations between satellite and Earth observational site could be used to monitorize different reference systems.

4.15 - *Delta T and tidal acceleration values from three european medieval eclipses*

Martinez M.[(1)],, Marco F.[(2)]

(1): *Universidad Politécnica de Valencia*; (2): *Universitat Jaume I*; Spain

Delta T value is strongly related with occultations and eclipses because it is necessary not only for the calculation of exact times of an eclipse, but also for determining the position of the central line or the zone of visibility. The eclipse of AD1239 June 3 was observed at no less than ten sites in Europe. The one of AD1241 October 6 was reported from two European places and possibly one or two other sites in North Africa, while the one from AD1354 September 17 was observed from two European sites. The conjunct analysis of these astronomical phenomena is useful for determining a range of Delta T in function of the variations for the tidal acceleration of the Moon.

4.16 - *About the configuration of the geoid undulations and their kinematics*

Morcov G.

Technical University of Civil Engineering of Bucharest , Romania

The paper will cover the following: Purpose: - Highlight the continuity of certain positions of the same frequency undulations on the equipotential surface, due to possible differential movements of these undulations in relation to the Earth's rotation Method: Creating the undulations configuration in some sections, at the same scale, resulting in specific figures. Kinematic running (animation) of these figures in order to determine if there is: - a continuity of the same frequency undulations from a section to another - kinematic vectors of the undulations in certain directions Results: By kinematic unfolding of the undulation's configuration is found that: - There is a continuity of the same frequency undulations from a parallel to another - there are kinematic vectors in two directions: a) in east-west direction b) in north-south direction in the Boreal Hemisphere and in south-north direction in the Southern Hemisphere. - There is an advance of the same frequency undulations in equatorial section, in progressively relation with the undulations placed in the parallels sections. Conclusions: Using the undulations animation globally highlights the Coriolis effect, emphasizing possible progressive stages in undulation's translation from west to east and from the equator to the poles. If the apparent path of the undulations in some directions, can be explained as a product of continental drift, there may be clarifications, for the principle of the terrestrial reference frame, no net rotation (NNR) with regard to the Earth's lithosphere.

4.17 - *Nonlinear sea level variations in the equatorial Pacific due to ENSO*

Niedzielski T., Kosek W.

Space Research Centre, Polish Academy of Sciences, Poland

Gridded sea level anomaly time series from TOPEX/Poseidon and Jason-1 satellite altimetry have been processed in order to detect nonlinearity of sea level change. Basic statistics, such as standard deviation, skewness and kurtosis, along with testing hypothesis served well the purpose of statistical evaluation. The data span has been fixed to be 10.01.1993-14.07.2003. The data obtained by both satellites have been merged by applying the offset between two time series, separately for each location grid. In order to infer nonlinear features of sea level variation, four specific terms (linear trend, annual oscillation, semiannual component and alias-type 62-days oscillation) have been removed from merged time series at every grid. It has been shown that the particularly meaningful departures from the normal distribution of sea level change are present within the equatorial zone in the Pacific and Indian Oceans. This finding has been associated with the asymmetry between strengths of El Niño and La Niña episodes. The interpretation of the results has been based on the geophysics of Kelvin and Rossby ocean waves which drive the ocean part of the ocean-atmosphere coupling in the El Niño/Southern Oscillation (ENSO). It has been argued that the local nonlinear heating occurring only during strong ENSO episodes can be responsible for the local nonlinear sea level change during such considerable ENSO events.

4.18 - *Earth rotation parameters determined over CONT08 VLBI campaign by the GRGS from the combination of space geodetic techniques*

Richard J.Y., Gambis D., Bizouard C.

Observatoire de Paris/SYRTE/CNRS, France

An IERS Working Group on Combination at the Observation Level (COL) was created in the course of 2009. Its main objective is to review the interest in combining techniques at the observation level for EOP and reference frames and to bring together groups capable to do such combinations. The first action taken by COL was to select a benchmark period to make inter comparisons between the different groups involved. The continuous VLBI campaign CONT08 period extending from 10 to 30th August 2008 was a good opportunity for such analyses We present the first analyses performed in the frame of the GRGS before results be compared in the future to those obtained by the other institutes taking part of the project.

4.19 - *Comparison of the various atmospheric and oceanic angular momentum series*

Ron C., Vondrák J., Stefka V.

Astronomical Institute AS CR, Czech Republic

Two approaches are used for studying the impact of the atmospheric and oceanic excitations on the motion of Earth's spin axis in space. One way consists in the integration of the Brzezinski broad band Liouville equation and second way in the spectral analysis of both the geodesic and geophysical excitation functions. We applied both approaches to the latest series of the atmospheric (NCEP/NCAR, ERA40) and oceanic (ECCO, OMCT) angular momentum excitation functions. The comparison of the methods and series is discussed.

4.20 - *The recent results of non-rigorous combination method of results of space geodetic techniques*

Stefka V.

Astronomical Institute AS CR, Czech Republic

The non-rigorous method is based on combining station position vectors in the celestial reference frame using the transformation from ITRF to GCRS, which is function of known and solved parameters. The new terrestrial reference frame (ITRF 2008) was recently published with revised collocation ties, which play key role in combination of different techniques because they give necessary information about spatial relation between geodetic instruments located on particular collocation site. By using the revised ties, some discontinuities in coordinate series at particular stations were corrected so that they could then be used in the combination to compute EOPs and station coordinate vectors. All results were compared with the ones published by ITRF 2008. Additionally, computed EOPs were compared with C04 2005 (IAU2000A).

4.21 - *The interpretation of the high frequency signals in the G-ring laser gyroscope*

Tian W.[(1)], Brzezinski, A.[(2)], Soffel, M.H.[(1)], Gebauer, A.[(3)], Schreiber K.U.[(3)], Kluegel Th.[(4)]

(1): *TU Dresden, Lohrmann-Observatory*, Germany; (2): *Space Research Centre, Polish Academy of Sciences*, Poland; (3): *Technische Universitaet Muenchen, Munich,* Germany; *Geodätisches* (4): *Observatorium Wettzell*, Germany

As a promising geodetic instrument, G-ring laser gyroscope in Wettzell has been improved over last several years. Its current sensitivity is around 10^{-9} which makes it possible to detect the variations of the instantaneous rotation pole directly and precisely. In this paper, concerning its long stability, we only consider the high-frequency (diurnal and semi-diurnal) signals existing in the raw data. There are two main sources contributing the diurnal and semi-diurnal signals in ring laser gyroscope. one is the orientation variations of the platform which are reduced by the tilt meters nearby, another one is the variations of Earth rotation (Retrograde diurnal polar motion) modeled by Brzezinski (1986) using the transfer function of Wahr which is consistent with the nutation model IAU 1980. After these reductions have been done, there are still some diurnal and semi-diurnal signals remaining in the reduced data. So in this paper our aim focuses on interpreting these unknown high-frequency signals by extending our Earth rotation models according to the IERS convention 2003.

4.22 - *Modelling of the Earth orientation and high precision astrometric observation techniques*

Yao K., Capitaine, N.

Observatoire de Paris/SYRTE/CNRS, France

After a short description of the characteristics of each technique contributing to observations of Earth's rotation, we investigate their potentiality to determine the various components of precession-nutation.

Session 5 – Pulsars timing, relativity and time transfer

(alphabetic order)

5.1 - *2PN light propagation and measurement in the solar system*

Deng X.-M., Huang T.-Y.

*Purple Mountain Observatory,*China

The second post-Newtonian (2PN) framework for light propagation is developed with two additional parameters varsigma and eta besides the two parameterized post-Newtonian (PPN) parameters gamma and beta. For a precision level of a few microacrsecond for space astrometry missions in the near future, we consider the effects of monopole and quadrupole moments of the gravitating bodies in the Solar System and their gravitomagnetic fields on light propagation. Besides, the expression for the influence of the second zonal harmonic coefficient on light propagation is presented. After the light trajectory is obtained, the light time equation is given. Started from the definition of a measurable quantity, a gauge-invariant angle between the directions of two incoming photons for a differential measurement in astrometric observation is discussed and its formula is derived in detail.

5.2 - *Perturbation of a Planetary Orbit by the Lambda-Term ("Dark Energy") in Einstein Equations*

Dumin Y.

IZMIRAN, Russian Academy of Sciences, Russia

The problem of cosmological influences at small (e.g. interplanetary) scales is discussed for many decades, starting from the early 1930's, but still remains unsolved definitively by now [W.B.Bonnor. Gen. Rel. Grav., v.32, p.1005 (2000)]. It became especially topical in the context of the "dark-energy"-dominated cosmology, because the commonly-used arguments against the local Hubble expansion (such as Einstein-Straus theorem [Rev. Mod. Phys., v.17, p.120 (1945)]) are no longer applicable when the most contribution to the energy density of the Universe comes from the perfectly-uniform dark energy (Lambda term). Moreover, there are some empirical evidences in favor of the local cosmological influences. For example, assumption of the local Hubble expansion in the dynamics of the Earth-Moon system enabled us to resolve a long-standing discrepancy in the rates of secular increase of the lunar semi-major axis measured by the lunar laser ranging, on the one hand, and derived from the astrometric observations of the Earth's rotation deceleration, on the other hand [Yu.V.Dumin. Adv. Space Res., v.31, p.2461 (2003); Proc. 11th Marcel Grossmann Meeting on Gen. Rel., p.1752 (2008)]. The aim of the present report is to provide a rigorous mathematical treatment of the planetary motion against the cosmological background, which is based on the Kottler metric reduced to the Robertson-Walker cosmological coordinates, as outlined in our earlier work [Yu.V.Dumin. Phys. Rev. Lett., v.98, p.059001 (2007)]. As follows from our numerical computation, under certain circumstances (depending on the ratio between the radius of the orbit, Schwarzschild, and de Sitter radii) the perturbed orbit becomes a spiral. This points out the potential importance of the Hubble effect for the local planetary dynamics.

5.3 - *Millisecond pulsars and planetary ephemerides: frame ties and other considerations*

Fienga A.[(1)],, Desvignes G.[(2)],, Cognard I.[(2)],, Theureau G.[(3)]

(1) : *IMCCE - observatoire de Besancon*; (2) : *CNRS LPC2E* ; (3) :O*bservatoire de Paris/GEPI ;* France

We have used pulsar timing (obtained at NRT) and pulsar VLBI observations to link reference frames: planetary ephemerides to each others (DE200,DE405,INPOP08 and DE421) and to ICRF. The obtained rotation matrices will be presented here.

5.4 - *Development of the TWSTFT Carrier–Phase technique at LNE-SYRTE*

Kanj A., Achkar, J.

Observatoire de Paris/SYRTE/CNRS, France

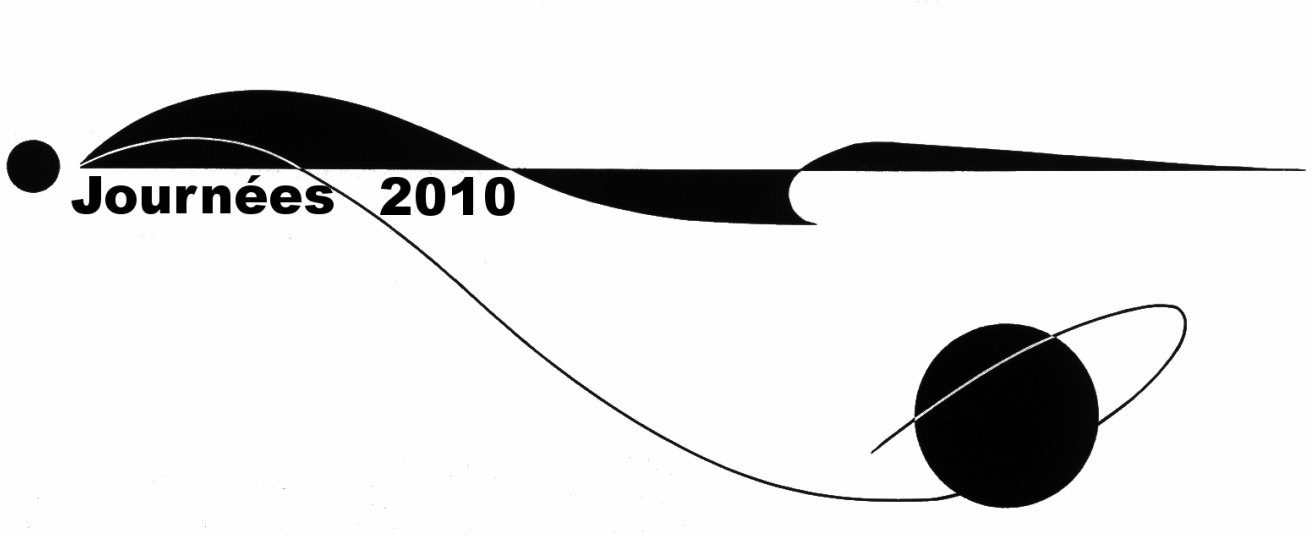
The Two-Way Satellite Time and Frequency Transfer (TWSTFT) method [ITU-R TF.1153-3 recommendation, 2010] permits to compare two remote atomic clocks by using a microwave link through a geostationary satellite. The best performance reachable today is achieved on the Ku band link with a frequency stability of 8.10-16 at one day [Zhang et al., PTTI meeting, 2009]. Our aim is to improve this value and to obtain a high performance comparison system of remote primary frequency standards with uncertainties in order of sub-nanoseconds. In this case, the TWSTFT carrier-phase is the most appropriate method to improve the short-term stability of the two-way links. The work proposed here is limited to the development of the TWSTFT carrier-phase method. The main idea is to calculate the offset between the frequencies of the two clocks located each one in a different station. The Doppler's effect is taken into consideration regarding the spread of the signal between each station and the satellite and vice versa. We establish the equation system of the TWSTFT carrier-phase technique composed by four nonlinear equations with four unknowns: the first Doppler coefficients, the satellite's local oscillator frequency and the frequency offset of the distant clocks. This system cannot be solved directly [Fonville et al., PPTTI meeting, 2004]. As a first approach, we use the Newton-Raphson method to transform the nonlinear system to a linear one. Then, the singular value decomposition technique is used to solve the resulting linear system. Scientific and technical details will be presented at the conference.

5.5 - *Light time calculations for deep space navigation*

Le Poncin-Lafitte C., Bertone S.

Observatoire de Paris/SYRTE/CNRS, France

With the recent discovery of several astrometric anomalies derived from tracking of spacecrafts, such as Pioneer 10/11 and Earth Flyby, we propose to reconsider the relativistic formulation of Deep Space Navigation. We show in particular that some traditional approximations can lead to neglect tiny terms that may produce instability in the orbit determination of probe during Earth flyby.


Journées 2010