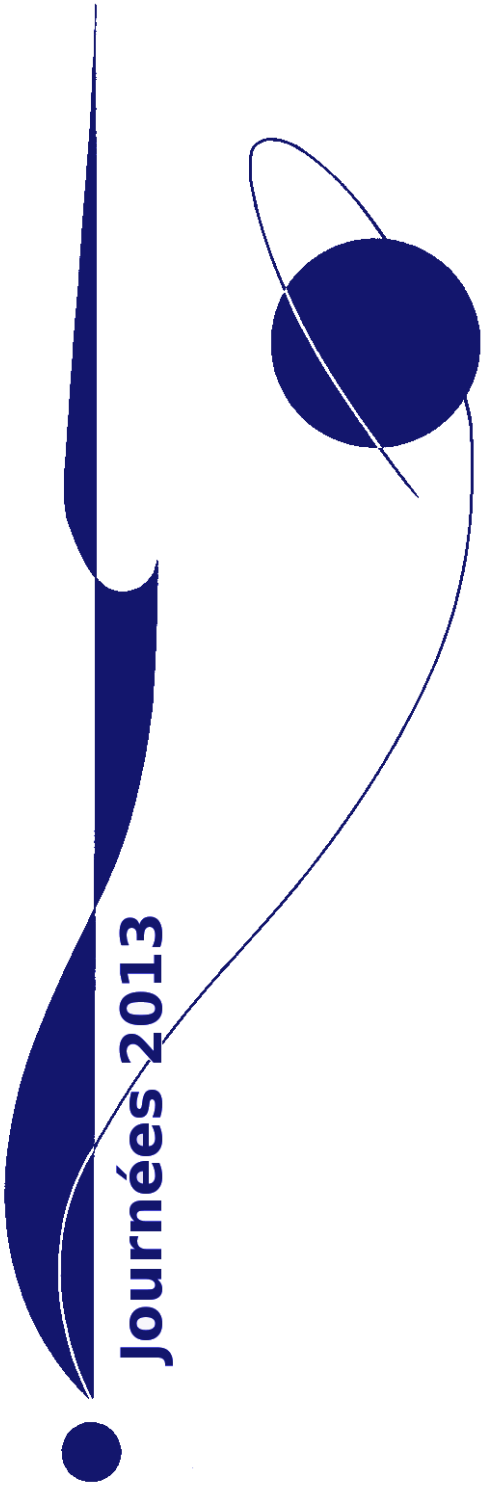
JOURNÉES 2013

« Systèmes de référence spatio-temporels »



Scientific developments from highly accurate space-time reference systems

BOOK OF ABSTRACTS

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JOURNÉES 2013

« Systèmes de référence spatio-temporels »

Scientific developments from highly accurate space-time reference systems

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Session 2 : The Next ICRF - Progress and developments

Proposed Roadmap for the ICRF-3

Jacobs C., ICRF-3 Working group

Jet Propulsion Laboratory, California Institute of Technology, USA

ICRF-3 seeks to improve upon the highly successful ICRF-2. Our goals are to improve the precision, spatial and frequency coverage relative to the ICRF-2 by 2018. This date is driven by the desire to create radio frames that are ready for comparison with the Gaia optical frame. Several specific actions are underway. A collaboration has started to improve at S/X-band precision of the 2000+ VCS sources which are typically 5 times less precise than the rest of the ICRF-2. S/X-band southern precision improvements are planned from observations with southern antennas such as the AuScope and HartRAO, S. Africa. We seek to improve radio frequency coverage with X/Ka and K-band work. An X/Ka frame of 600+ sources now has full sky coverage from the addition of a 2nd southern station in Argentina which should strengthen the southern hemisphere in general. A K-band collaboration has formed with similar coverage and southern precision goals. On the analysis front, special attention will be given to combination techniques both of VLBI catalogs and of multiple data types. Consistency of the CRF with the TRF and EOP is another area of concern. Finally, work is underway to identify and pinpoint sources bright enough in both radio and optical to allow for a robust frame tie between VLBI and Gaia optical frames.

Gaia status and early mission

Mignard F.

Observatoire de la Côte d'Azur, Nice, France

Gaia is due for launch before the end of 2013 from Kourou. The scientific mission will start about 10 week after, when the commissioning is completed. Gaia will survey the entire sky and repeatedly observe the brightest one billion objects, down to 20-th magnitude, during its 5-year lifetime, pinpointing positions and parallaxes to 10-μas for stars brighter than 12-th magnitude, 25-μas for at 15-th magnitude, and 300-μas at magnitude 20. In this talk I will report on the mission status few weeks before launch and will describe the early mission phases up to the first science observations that will start about 2 months after launch. Then I will present the current scenarios for the early science output expected from the mission, including the science alert mode and the first intermediate release scheduled less than two years after launch. A first astrometric position catalogue will be published then involving already a realisation of the optical frame in the visible with QSOs.

Extending the K-band Celestial Frame with Emphasis on the Southern Hemisphere.

Bertarini A.[(1)], Horiuchi S.[(2)], Jacobs C.[(3)], Jung T.[(4)], Lovell J.[(5)], McCallum J.[(5)], Ojha R.[(6)], Quick J.[(7)], Sohn B.W.[(4)], de Witt A.[(7)]

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We present a new collaboration to observe the southern hemisphere sources at 22 GHz (K-band). The aim of this project is to densify the ICRF at that frequency for use as calibrators for astronomy. Relative to the standard S/X observing bands, at K-band sources are expected to exhibit more compact source morphology and reduced core

shift. This reduction of astrophysical systematics should be advantageous in tying the VLBI radio frame to the Gaia optical frame. We have developed a collaboration amongst the telescopes of KVN, HartRAO, Tidbinbilla, and Hobart. Initial fringe demonstrations are planned for August 2013 between KVN's Tamna station and HartRAO. This baseline will extend K-band CRF coverage down to about – 45 deg declination. The second phase of our plan is to observe between S. Africa (HartRAO) and Australia (Hobart, Tidbibilla) in order to extend coverage to the south polar cap and thus gain full sky coverage for the K-band CRF.

Impact of seasonal station displacement models on radio source positions

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(1) *TU Vienna, Austria;* (2) *Pulkovo Observatory, Russia*

The International Terrestrial Reference Frame considers the position at a reference epoch plus a linear velocity term for station coordinates. However, the actual station movement also includes several tidal and non-tidal correction (e.g., solid Earth tides, ocean and atmosphere loading) recommended by the IERS Conventions as well as unmodelled non-linear displacements. In this study we focus on the impact of the neglected seasonal station motions on the celestial reference frame. The increasing accuracy of Very Long Baseline Interferometry (VLBI) observations and the growing time span of available data allow the determination of seasonal signals in station positions which still remain unmodelled in the conventional analysis approach. For that purpose, we create empirical harmonic models for selected stations within a global solution of all suitable VLBI sessions which are then entered a priori. Furthermore, we introduce average yearly models created by stacking yearly time series of station positions. The celestial reference frames estimated simultaneously with terrestrial reference frames and Earth orientation parameters are compared to each other.

On systematic and random errors of radio source position catalogs

Malkin Z.

Pulkovo Observatory, Russia

Radio source position catalogs derived from the astrometric VLBI observations are computed in several IVS Analysis Centers making use of different software and analysis strategies. For this reason, the published catalogs have significant systematic and random differences. Investigation and understanding these differences is very important for improvement of the VLBI-derived ICRS realizations, in particular, ICRF3. In this presentation a comparison of the recent radio source position catalogs will be performed, and their systematic and stochastic errors will be discussed.

Analysis of time series of the EOP and the ICRF source coordinates

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Sternberg State Astronomical Institute, Russia

Time series of the EOP and coordinates of the ICRF radio sources were calculated and analyzed. Original ICRF2 catalog and corrected one (velocities of the sources were added) were used for generation of the time series. We compare the EOP values, analyze the sources velocity field and give recommendations for choice of the defining sources.

Source positions from VLBI combined solution

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The IVS Combination Center at BKG is primarily responsible for combined Earth Orientation Parameter (EOP) products and the generation of a terrestrial reference frame based on VLBI observations (VTRF). The procedure is based on the combination of normal equations provided by six IVS Analysis Centers (AC). Since more and more ACs also provide source positions in the normal equations - beside EOPs and station

coordinates - an estimation of these parameters is possible and should be investigated. In the past, the International Celestial Reference Frame (ICRF) was not generated as a combined solution from several individual solutions, but was based on a single solution provided by one AC. The presentation will give an overview on the combination strategy and the possibilities for combined source position determination. This includes comparisons with existing catalogues, quality estimation and possibilities of rigorous combination of EOP, TRF and CRF in one combination process.

Development of a VLBI Intra-Technique Combination Strategy for CRF Determination

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The existing realizations of the International Celestial Reference System (ICRS), the ICRF1 and ICRF2, are based on solutions estimated by a single VLBI group. In contrast, the International Reference Frame (ITRF) is based on a multi-technique combination with contributions from different geodetic space techniques. These individual technique-specific solutions are again generated in an intra-technique combination of different analysis centers. To overcome the shortcomings of the past ICRF, one of the main goals for the upcoming realizations of the ICRS and ITRS should be an entirely consistent and simultaneous computation of both frames. This involves inter- as well as intra-technique combinations. In several studies it has already been shown that the use of the intra-technique combination in the context of TRF and EOP estimations improves the stability and robustness of the results in comparison to single solutions. This improvement should also be exploited for the ICRF determination. In this work we focus on the consistency within the VLBI intra-technique combination. On the basis of individual solutions and in consideration of different combination methods, a VLBI intra-combined CRF is estimated. Based on comparisons between these combined and individual CRFs the results of different combination strategies are presented and discussed. This includes an overview of the improvements in terms of stability and robustness of a combined CRF.

The Gaia Initial Quasar Catalog

Andrei A.H.[(1,2)], Anton S.[(3,4)], Taris F.[(5)], Bourda G.[(6)], Souchay J.[(5)], Bouquillon S.[(5)], Barache C.[(5)], Pereira Osorio J.J.[(3)], Charlot P.[(6)], Vieira Martins R.[(1)], Lambert S.[(5)], Camargo J.I.[(1)], da Silva Neto D.N.[(7)], Assafin M.[(2)], Le Campion J.-F.[(6)]

(1) *ON/MCTI, Brazil* ; (2*) OV/UFRJ, Brazil* ; (3) *CICGE, Porto, Portugal*; (4) *SIM, Lisboa, Portugal*; (5) *OP/SYRTE, France*; (6) *LAB, OB, France*; (7) *UEZO/RJ, Brazil*

We present the latest, updated, and fully corrected version of the Gaia Initial QSO Catalog (GIQC), produced by the CU3 GWP-S-335-13000. It contains 1 248 372 objects, of which 191 802 are considered and marked as Defining ones, because of their observational history and existence of spectroscopic redshift. Also objects with strong, pointlike radio emission are included in this category. For the whole GIQC the average density is 30.3 sources per sq.deg., practically all sources have an indication of magnitude and of morphological indexes, and 90% of the sources have an indication of redshift and of variability indexes. Besides equatorial position, magnitude, and redshift, the GIQC includes as well morphological, variability, and classification indexes, plus a one-letter comment on the source main feature.

The update of Large Quasar Astrometric Catalog

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(1) *SYRTE/OP, France;* (2) *ON/MCTI, Brazil*; (3*) OV/UFRJ, Brazil*

We present the characteristics of the Large Quasar Astrometric Catalog which gathers more than 180 000 objects in its second update (LQAC-2), insisting on its advantages: improved accuracy of the equatorial coordinates of the sources, extensive photometry, calculation of the absolute magnitudes, morphology indexes. We show some statistical complementary studies carried out from the LQAC-2.

Optical data of ERS made at 60 cm ASV and 2 m Rozhen telescopes useful for the link of ICRF-future Gaia CRF

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At the end of this year will start the European space astrometry mission Gaia (ESA). One of the tasks is to construct a celestial reference frame as a dense optical QSOs-based one. The plan is to observe about 500 000 ERS - extragalactic radio sources. It will be important to align the Gaia and VLBI frames; this requires QSOs that are bright at optical wavelength (QSOs with a compact radio/optical core and without complex structures). Because of this, it is necessary to monitor some QSOs in optical domain, and to check their data (especially, positions stability and structures). The 60 cm ASV (Astronomical Station Vidojevica, Serbia) and 2 m Rozhen (Bulgaria) optical telescopes are used to observe QSOs that are useful for the mentioned ICRF-GCRF link. Some results (obtained with these two telescopes) are presented, here.

Session 1 : Theoretical aspects of reference systems

The ITRF and its scientific applications

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(1) *IGN, LAREG, Paris, France ;* (2*) SYRTE, Observatoire de Paris, France*

The ability to assign accurate time-dependent coordinates to points on the Earth's surface is fundamental for many Earth observation applications. Point positions, to be meaningful and fully exploitable, have to be determined in a well-defined Terrestrial Reference Frame. All current global and regional reference frames rely on the availability of the International Terrestrial Reference Frame (ITRF), which is the most accurate realization of the International Terrestrial Reference System (ITRS). We present here the last release of the ITRF, entitled ITRF2008, which assigns positions and velocities for more than a thousand of geodetic stations distributed over the Earth's surface in a geocentric frame. The positions and velocities are determined with a precision of about a few millimeters and 1 mm/yr, respectively. The presentation will focus on geophysical applications that benefited of the precision and stability of ITRF, with a specific emphasis on the last release, namely ITRF2008. Sea level rise estimation, global plate tectonics, co/post-seismic deformations studies or the interpretation of displacements induced by postglacial rebound or recent ice melting all require an accurate reference frame. Conversely, the knowledge of the expected displacements from geophysical theories and external measurements allows to provide constraints on the ITRF datum error budget. Finally, future challenges towards the refinement of ITRF will be discussed. A particular emphasis will be given to the increased necessity today of geophysical considerations in reference frame determinations.

Relativistic astrometry: status and prospects

Soffel M., Klioner S., Zschocke S.

Lohrmann Observatory, Germany

Astrometric space missions like GAIA have stimulated a rapid advance in the field of relativistic astrometry. Present investigations in that field aim at accuracies significantly less than a microarcsecond. The talk reviews the present status of relativistic astrometry. As far as the problem of light propagation is concerned we face two problems: the form of the BCRS metric and solutions to the light-ray equation (null geodesic equation). Much work has been done in the linear - (post-Minkowskian; linear in G) and more recently in the post-linear approximation to post-post Newtonian order. Open problems will be mentioned at the end of the talk.

Optical coordinate system for a local observer in a weak gravitational field

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National Taras Shevchenko University of Kyiv, Astronomical Observatory, Ukraine

We develop the method to construct the reference system of a local observer within the linear approximation on space-time curvature. Transformation to optical or Fermi coordinates is based on the solutions of the isotropic or space-like geodesic equation and parallel transport equation. The main advantage of the optical coordinates lies in their direct link with observable positions of distant objects on the celestial sphere. We also applied this method to construct the optical and Fermi coordinates for the case of accelerated and rotating observer in gravitational field induced by moving bodies of the Solar system. The transformation formulae from initial coordinates to new ones were obtained and the metric tensors in optical and Fermi frames were found in the cubic approximation on the observer's velocity.

Latest advances in an astrometric model based on the Time Transfer Functions formalism

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(1) *SYRTE, Observatoire de Paris, France ;* (2) *INAF, Astrophysical Observatory of Torino, University of Torino, Italy*

One of the main goals of modern astronomy is the realization of reference frames based on a large number of precise observations of celestial objects. This task requires highly technological capabilities but also an accurate theoretical description of light propagation taking into account General Relativity. At this regard, the standard procedure is to find a solution to null-geodesic equations. Another approach based on the Time Transfer Functions (TTF) has been developed, giving direct access to some important information without computing the whole trajectory of light. We will present here our last advances in extending the TTF formalism to a dynamical metric more adapted to describe the Solar System dynamics. Also, the physical interpretation of high precision measurements is a delicate task ; we need reliable models where no previous well-attested experimental results is available. Concerning relativistic astrometry in the Gaia context, nowadays two main models exist, GREM and RAMOD, both based on a geodesic approach. Here, we propose a procedure to cross-check their results with those of the TTF approach, both analytically and on the data analysis of simulated Gaia observations.

Plans for VLBI observations of close approaches of Jupiter to compact extragalactic radio sources in 2014-2016

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Very Long Baseline Interferometry is capable of measuring the gravitational delay caused by the Sun and planet gravitational field. The post-Newtonian parameter gamma is now estimated with accuracy of 0.0002 using a global set of VLBI data since 1979. Unfortunately, observations very close to the Solar limb are not possible due to strong turbulence of the Solar corona. Instead of that, close approaches of big planets to the reference quasars could be also used for testing of the general relativity theory with VLBI. Jupiter is the most promising among the big planets due to its large mass and relatively fast motion across the celestial sphere. Six close approaches of Jupiter with quasars in 2014-2016 were calculated using the DE405/LE405 ephemerides, including one occultation in 2016. We have formed tables of visibility for all six events from VLBI radio telescopes participating in regular IVS programs. Expected magnitudes of the relativistic effects measured during these events are discussed in this paper.

Enhanced term of order G^3/c^6 in the light travel time

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It is generally believed that the knowledge of the light travel time up to the post-post-Newtonian level (terms in G^2/c^4) is sufficient for modelling the most precise experiments which are currently proposed to test general relativity in a foreseeable future (LATOR, ASTROD, SAGAS , ODYSSEY,…). However, we have recently shown that an enhanced term of order G^3/c^6 appearing for light rays almost grazing the solar surface is larger than some first-order contributions like the gravitomagnetic effect due to the rotation of the Sun. In this talk, we give a brief account of the method we have developed and we discuss the numerical significance of the enhanced third-order term for the determination of the post-Newtonian parameter gamma at a level of accuracy of 10^{-8}.

Binary black holes in nuclei of extragalactic radio sources

Roland J.

IAP, France

Modelisation of the ejection of components of extragalactic radiosources that are observed by VLBI (denoted here VLBI components), indicates that the trajectories and the kinematics of the ejected components can be explained if the nuclei of extragalactic radio sources contain a binary black hole system. In that case, the two black holes can eject VLBI components, and we will observe two families of trajectories. Another important consequence of a binary black hole system is that the VLBI core is associated with one black hole, and if a VLBI component is ejected by the second black hole, one expects to be able to detect the offset of the origin of the VLBI component ejected by the black hole that is not associated with the VLBI core. The ejection of VLBI components is perturbed by the precession of the accretion disk, the motion of the black holes around the center of gravity of the binary black hole system and the motion of the binary black hole system in the galaxy. We will present recent results of the modelisation of ejection of VLBI components.

Aberration in proper motions for stars in our Galaxy

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Accelerations of both the solar system barycenter (SSB) and stars in the Milky Way cause a systematic observational effect on the stellar proper motions, which was first studied by J. Kovalevsky (2003). This paper intends to extend that work and aims to estimate the magnitude and significance of the aberration in proper motions of stars, especially in the region near the Galactic center. We adopt two models for the Galactic rotation curve to evaluate the aberrational effect on the Galactic plane. Based on the theoretical developments, we show that the effect of aberration in proper motions depends on the galactocentric distance of stars; it is dominated by the acceleration of stars in the central region of the Galaxy. Then we investigate the applicability of the theoretical expressions concerning the aberrational proper motions. If the orbital period of stars is only a fraction of the light time from the star to the SSB, the expression proposed by Kovalevsky is not appropriate. With a more suitable formulation, we found that the aberration has no effect on the determination of the stellar orbits on the celestial sphere. The aberrational effect under consideration is small but not negligible with high-accurate astrometry in the future, particularly in constructing the Gaia celestial reference system realized by Galactic stars.

Session 3 : Atomic and pulsar-based timescales - Progress and developments

Multi-GNSS time and frequency transfer

Defraigne P.

Royal Observatory of Belgium, Belgium

Measurements from Global Navigation Satellite Systems (GNSS) are used since the eighties to perform precise and accurate Time and Frequency Transfer (TFT). Only the GPS constellation was used during the last 25 years, with some experiments based on GLONASS measurements. The GLONASS constellation is presently completed, the first four GALILEO satellites are already operational, and the BEIDOU system also provides signals that can be additionally used for time transfer. Increasing the number of satellites, and hence the number of observations, will reduce the noise level of the solution. However, such a combination requires the knowledge of some inter-system biases in the receivers and the existence of satellite clock products which can be expressed with respect to a common reference. This paper will propose recent advances in these combinations, focusing on GPS, GLONASS and GALILEO.

A pulsar-based time scale from the International Pulsar Timing Array

Hobbs G.

CSIRO Astronomy and Space Science Sydney, Australia

I will present some recent work from the International Pulsar Timing Array related to developing a pulsar-based time scale. I will compare the pulsar-based time scale with terrestrial time scales. I will also provide updates from an IAU working group relating to pulsar time scales.

Atomic time scales

Petit G.

BIPM, France

I review the atomic time scales generated by the BIPM, International Atomic Time TAI and the realization of Terrestrial Time TT(BIPM). TAI gets its stability from some 400 atomic clocks worldwide that generate the free atomic scale EAL and its accuracy from some ten primary frequency standards (PFS) which frequency measurements are used to steer the EAL frequency. Because TAI is computed in "real-time" (every month) and has operational constraints, it is not optimal and the BIPM computes in deferred time TT(BIPM), which is based on a weighted average of the evaluations of TAI frequency by the Primary Frequency Standards. The performances of TAI and TT(BIPM) are compared and they are presently in the low 10^{-16} in relative frequency stability and accuracy. It is shown that TT(BIPM) should be used as a reference whenever a posteriori analysis is possible as e.g. in pulsar analysis. Since the beginning of regular millisecond pulsar observations in the 1980s, primary standards and atomic time have gained one order of magnitude in accuracy every ~12 years, and this trend should continue for another order of magnitude

Time and frequency comparisons with optical fiber links

Pottie P.-E.[(1)], Lopez O.[(2)], Kanj A.[(1)], Rovera D.[(1)], Aschkar J.[(1)], Chardonnet Ch.[(2)], Amy-Klein A.[(2)], Santarelli G.[(3)]

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For the last 5 years, ultra-stable optical fiber links have been successfully developed in order to enable precise and accurate frequency transfer between the best modern atomic clocks whose accuracy are below 10^{-15}. Optical fiber links exhibit fractional frequency stability in the range of 10^{-18} after only 3 h of measurement and frequency accuracy of a few 10^{-19}, with a range of a few 100-km up to 1800 km. Recently, time

transfer through optical fiber link was demonstrated, simultaneously with frequency transfer, by the LPL-SYRTE group and 2 other groups in Europe. Time deviation of the time transfer is as low as a few 10th of ps, and its accuracy range between 75 and 250 ps. These results overcome the capabilities of satellite-based comparisons and could play a key role for geodesy, high-resolution radio-astronomy, and modern particle physics.

Some astrometric discussions on the pulsar parameters by timing

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Shanghai Astronomical Observatory, CAS

Besides the pulsar timing measurement error, the largest remaining sources of potential errors also include the interstellar scattering, solar system ephemeris errors, atomic clock instability and gravitational waves. The latter three items are the systematic errors for pulsar timing. We will discuss how the errors in the ephemeris effect the pulsar parameters. If we regularly observe scores of Millisecond pulsar with high timing accuracy, the space-time reference system can be formed based on pulsars, which will play an important role in the deep space exploration. In addition, we obtain the position parameters of MSP J1939+2134 based on the Chinese VLBI Network. And we plan to carry on the pulsar timing observations with Shanghai 65m radio antenna by the end of this year. It will be the potential work to link the ICRF and dynamical planetary reference frames at mas-level with MSP, both by VLBI and timing.

Session 4a : Earth Rotation - Theory

The goal of the IAU/IAG Joint Working Group on the Theory of Earth rotation

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The Earth rotation is considered as one of the three pillars of modern Geodesy. Some months ago, the International Association of Geodesy (IAG) and the International Astronomical Union (IAU) initiated a process to set up a joint WG on Theory of the Earth Rotation, to promote the development of improved theories of the Earth rotation which reach the accuracy required to meet the needs of the near future as recommended by, e.g. GGOS, the Global Geodetic Observing System of the IAG. That WG was approved by both institutions in April, and it is chaired by the two authors. Its structure comprises three Sub-WGs addressing Precession/Nutation, Polar Motion and UT1 and Numerical Solutions and Validation, respectively. Those SWG should work in parallel, for the sake of efficiency, but keeping consistency as an overall issue. This presentation intends to offer a view of the range and scope of the WG, and to report about its initial activities and plans.

Next step in Earth interior modeling for nutation.

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Accurate reference systems are important for many geophysical applications and satellite observations. It is therefore necessary to know the Earth rotation and orientation with high precision. Interactions between the solid Earth and its fluid layers (liquid core, atmosphere, ocean) induce variations in the Earth's speed of rotation. In addition, because the Earth is not a perfect sphere, but rather an ellipsoid flattened at its poles, the combined gravitational forces acting upon it produce changes in the orientation of its spin axis. Precession describes the long-term trend in the orientation of the Earth, while nutation refers to shorter-term periodic variations. The nutations of the Earth are the prime focus of the present talk. Models are used to predict the real-time Earth rotation and orientation, based on the past observations and the consideration of geophysical processes. Amongst these, the coupling mechanisms at the internal boundaries have been shown to be important for rotation. We address the coupling mechanisms at the core boundaries such as the topographic, electromagnetic and viscous couplings, and the improvement of their computation and observation. The study uses and compares numerical and semi-analytical approaches, with the objective of improving the nutation model and the rotation, as well as to better understand the interior of the Earth.

On the changes of IAU 2000 nutation theory stemming from IAU 2006 precession theory

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The adoption of IAU 2006 precession theory [1] introduced some small changes in IAU 2000A nutation theory, relevant at the microarcsecond level. These adjustments were derived in [2] and are currently considered in the international standards (e.g., [3] and [4]). We re-examine the issue, working out the induced modifications due to a change in the value of the obliquity of the ecliptic and to the secular variation of the Earth dynamical flattening. In particular, within the framework of the Hamiltonian theory of the rotation of the Earth we derive analytical expressions of those changes for the motion of the figure axis. These expressions and their corresponding numerical contributions will be compared with those obtained in [2]. [1] Capitaine, N., Wallace, P. T., & Chapront, J. 2003, A&A, 412, 567. [2] Capitaine, N., Wallace, P. T., & Chapront, J. 2005, A&A, 432, 355. [3] IERS Conventions (2010). Gérard Petit and Brian Luzum

(eds.), IERS Technical Note 36, 2010. [4] The Explanatory Supplement to the Astronomical Almanac, 3rd edition, Sean E. Urban and P. Kenneth Seidelmann (eds.). University Science Books, 2013.

Rotational-oscillatory motion of the deformable Earth in the short time intervals

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Diurnal oscillations of the Earth orientation parameters (EOP) represent the ongoing dynamical processes leading to the significant changes both in EOP and in geophysical events. Based on the celestial mechanics' methods, namely the spatial version of the problem of the Earth-Moon system in the gravitational field of the Sun, a mathematical model of the rotational-oscillatory motion of the elastic Earth is developed (Markov Yu.G. et al, Astronomical Journal, 90, 15: 432-440). It is shown that the perturbing component of the gravitational-tidal forces normal to the lunar orbit's plane is responsible for some short-term perturbations in the Moon's motion. With the aid of the numerical-analytical approach a comparison between the constructed model and the high-frequency International Earth Rotation and Reference System Service (IERS) measurements and VLBI observations is made. As it follows from the proper analysis of the numerical simulation results for the average daily Earth's pole motion the accuracy estimation of the model forecast is in the range of 1-2 cm.

A generalized theory of the figure of the Earth: application to the moment of inertia and global dynamical flattening

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Shanghai Astron. Obs., China

Following the Darwin - de Sitter second-order theory, which is considered as standard theory of equilibrium figures of the Earth, we developed here a new integrated formula to obtain the equilibrium figures to third-order accuracy. In this formula, both the direct and indirect contribution of the anti-symmetric crust layer are included; as a result, all the non-zero order and odd degree terms are included in the spherical harmonic expression of the equilibrium figures. The moment of inertia (A, B, C) and global dynamic flattening (H) are important quantities in research of rotating Earth. Accurate precession observation gives H_obs=0.0032737=1/305.5, while its value from rotating symmetric PREM model and above standard theory of equilibrium figures, H_PREM, is about 1.1% less than H_obs. Using our new potential theory and replacing the homogenous outermost crust and oceanic layers in PREM with various real surface layers data, we recalculate the geometrical flattening profile of the Earth interior and finally get the moment of inertia and global dynamical flattening (H) of the Earth. It is shown that the match between the above calculated values and their observed ones are much improved comparing with those based on traditional theory of equilibrium figures of the earth. Comparison with other results is made, and some further discussion is also presented.

Construction of the new high-precision Earth rotation series at a long time intervals

Pashkevich V.V.

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This research is the continuation of our studies of the rigid Earth rotation at a long time intervals (Pashkevich V.V. and Eroshkin G.I., 2005). The main purpose of this investigation is the construction of the new high-precision Rigid Earth Rotation Series (RERS), dynamically adequate to the JPL DE406/LE406 and DE422/LE422 ephemeris over 2000 and 6000 years. The dynamics of the rotational motion of the rigid Earth is studied numerically with the quadruple precision of the calculations over 2000 and 6000 years. The orbital motions of the disturbing celestial bodies are defined by the DE406/LE406 and DE422/LE422 ephemeris, respectively. The results of the numerical

solutions of the problem are compared with the different semi-analytical solutions of the rigid Earth rotation with respect to the fixed ecliptic of epoch J2000. The investigation of these discrepancies is carried out by the least squares and spectral analysis methods for the relativistic (Kinematical) case, in which the geodetic perturbations (the most essential relativistic perturbations) in the Earth rotation are taken into account. As a result, the rigid Earth rotation series RERS2012 and RERS2013 are constructed, which are dynamically adequate to the DE406/LE406 and DE422/LE422 ephemeris, respectively. The discrepancies between the new numerical solutions and the semi-analytical solutions of RERS do not surpass 4 micro arc seconds over 2000 year time interval and 1 mas over 6000 year time interval. Thus, the result of the comparison demonstrates a good consistency of RERS series with the DE/LE ephemeris.

Free core nutation - Possible causes of changes of its phase and amplitude.

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The displacements between the observed position of the Earth's spin axis in space and its position predicted by the adopted models of precession and nutation, the Celestial Pole Offsets (CPO), are regularly measured by Very Long-Baseline Interferometry (VLBI) since 1980. These offsets contain a mixture of several effects: the unpredictable free term, Free Core Nutation (FCN) that is due to the presence of the outer fluid core of the Earth, forced motions excited by the motions in the atmosphere, oceans, and other geophysical phenomena, and also imperfections of the adopted precession-nutation model. The atmospheric and oceanic excitations are available with a sufficient time resolution (6 hours) since 1989, as determined by atmospheric and oceanographic services. The numerical integration of Brzeziński's broadband Liouville equations, using atmospheric and oceanic excitations, yields CPO that are mostly consistent with VLBI-based observed values. However, there are several moments when changes of the phase and amplitude of FCN occur. We attempt to explain these discrepancies at the epochs of known huge seismic and geomagnetic events that occurred since 1989 up to present.

Study of the prograde and retrograde excitation at the Chandler frequency

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Observed motion of the Earth's rotation axis consists of uniform circular motions at positive and negative frequencies. Whereas many studies are devoted to the clarification of the excitation sources of the counterclockwise resonant Chandler wobble at +0.843 cycles per year, only a few works are devoted to the ellipticity of this wobble. Actually new generalized Liouville equations of Bizouard, accounting for Earth's triaxiality and asymmetry of the ocean pole tide, show that retrograde and prograde excitations are coupled. In this work, using specially designed narrow-band Panteleev filter and inversion, we reconstruct geodetic excitation in the prograde and retrograde Chandler frequency bands. Then we compare it with geophysical excitation, obtained from more or less extended (~50 years) time series of the angular momentum for oceans (OAM) and atmosphere (AAM). We study the oceanic and atmospheric excitation not only globally, but also regionally, using longitude-latitude maps of the angular momentum distribution for ocean and atmosphere, separating mass and motion terms.

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Session 4b : Earth Rotation - Modelling and observations

The IERS Retreat: How to improve Earth Rotation products?

Thaller D.

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The IERS held a two-day retreat in May 2013 in Paris. The outcome of the discussions at the retreat are presented with respect to Earth Rotation studies. Special focus is given on the plans to improve the Earth rotation products of the IERS.

Comparison of geodetic and modeled excitation functions by Allan variance

Bizouard C.

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Allan variance analysis allows to quantify and qualify the stability or the noise of a physical process at a given time scale. Whereas this statistical tool is widely used for quantifying the stability of the atomic clock, it can be applied to any time series. This is especially interesting for analysing the Earth rotation excitation functions: in complement of the standard numerical methods (spectra, least-square adjustment, correlation and explained variance), it brings complementary information on the information contained by observed excitation and that one derived from geophysical models. This permits to draw conclusions on the nature of the geophysical forcing of the Earth rotation in function of the considered time scale.

Analysis of atmosphere-excited intraseasonal polar motion via the torque approach

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Alongside the analysis of matter and motion terms of fluid angular momentum, geophysically-induced perturbations of Earth rotation can be investigated by means of interaction torques arising at the boundary layers of the solid Earth. We present an update and extension of previous studies dealing with this torque approach for the purpose of explaining atmosphere-excited intraseasonal polar motion. Specifically, two novel, four-year records of equatorial atmospheric torques are computed from two state-of-the-art meteorological reanalysis systems and analyzed for their interagreement. The coherence noted in terms of torque constituents clearly exceeds the match achievable for the more routinely applied motion portion of atmospheric angular momentum (AAM). This finding encourages the usage of Earth-atmosphere interaction torques as excitation measures together with standard estimates of oceanic and hydrological angular momentum within a newly proposed excitation formalism, which builds on the conversion of torque terms to their AAM counterparts. When validated against polar motion observations at intraseasonal periodicities, the torque-based excitation functions yield marginally better statistical results than the conventional AAM functions. At selected frequency bands, we additionally exploit the potential of the torque approach to highlight the specific locations and processes that lead to a change in the angular momentum of the solid Earth.

Estimation of the Chandler wobble parameters by the use of the Kalman deconvolution filter

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The parameters of the Chandler wobble (CW), the frequency F (or, equivalently, the period T=1/F) and the quality factor Q, are important for studying global dynamics of

the Earth because they define the equation describing geophysical excitation of polar motion and are closely related to various geophysical parameters. Our purpose here is to estimate the CW parameters based on the stochastic models of polar motion and geophysical excitation data. We apply the Kalman deconvolution filter developed by Brzezinski (1992, Manuscripta Geodaetica 17: 3-20). This filter can be used to analyze either the polar motion data alone, or simultaneously the polar motion and the excitation data, in order to estimate the unknown residual excitation. By imposing the minimum variance constraint upon the estimated excitation we can find the best value of the resonant parameters F and Q. We will show here some results based on different available sets of polar motion and geophysical excitation data. The estimated CW parameters will be compared to each other as well as to the results based on the alternative algorithms.

Natural and systematic polar motion jumps

Chapanov Y.(1), Vondrak J.(2), Ron C.(2), Pachalieva R.(1)

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The small jumps of the polar motion are determined by a useful method, which consists of the following steps: a removal of linear trend from the original data, followed by the integration of the resulting time series. The new integrated time series consists of oscillations with the amplitudes smaller than in the original data and of the parts with visible piecewise significant linear or parabolic trends. The parts with linear trends of integrated data correspond to the constant mean behavior of the original data, the sudden changes of the linear trends occur at the epochs of the jumps in the original data. The parts of integrated data with significant parabolic trends point out to the linear variations of the original data. The second step of the method is the creation of the table containing all the epochs of data jumps. The next step consists in calculating the mean values or trends in the original data parts, corresponding to the table of jump epochs, and the last step is the calculation of jump values between neighboring data parts. This method is applied to determine the natural and systematic polar motion jumps existing in polar coordinates from the IERS solutions C01 and C04. Only a few of the determined polar motion jumps can be interpreted as systematic biases due to observational errors. The major part of the detected polar motion jumps occurs almost regularly near the epochs of minimum amplitude (due to the beat of seasonal and Chandler wobbles), so the natural origin of these jumps is supposed.

Observation of a 531-day-period polar motion

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Previous studies show that the polar motion contains two dominant components, namely the annual wobble (AW) with a 12-month period and the Chandler wobble (CW) with a 14-month period. Some scholars consider that the frequency of the CW varies with its amplitude; some scholars consider that CW has double or multiple frequencies; some scholars consider that the frequency of CW is invariant. In the beginning of 1980s, a 530-day-period wobble in polar motion was marginally detected using 16-year-length time series (1962-1978) of International Polar Motion Service (IPMS) data. Since then, in our knowledge, no further literatures addressed this wobble period from any kind of observations. In this study, we apply the ensemble empirical mode decomposition (EEMD) method to analyses of two kinds of observations. First, applying EEMD to two polar motion time series, the EOP C04-05 series with one-day sampling interval spanning 1962 to 2012 and the POLE2010 series with one-month sampling interval spanning 1900 to 2011, we observed a 531-day-period (about 0.6868 cpy) wobble and a 530-day-period (0.6891 cpy) wobble, respectively. The estimated frequencies and especially the amplitudes of this wobble from the two series are different from each other, which is considered due to the relative poor quality of the POLE2010 series during 1900-1961. Taking away the poor quality data sets, we obtain the 531-day-period wobble from both time series. Our results show that the

frequency modulation of the CW may greatly suppress the 531-day-period wobble so that it cannot be observed in conventional direct power spectra of the polar motion series. Second, applying EEMD to two superconducting gravimeter records with a length of about 15 years and one-day sampling interval, we also observed the 531-day-period wobble. We consider that this not-well-known 531-day-period signal might be caused by the fluctuations of global atmospheric and oceanic angular momentums. *This study is supported by NSFC (grant No. 41174011), National 973 Project China (grant No. 2013CB733305) and NSFC (grant No. 41210006, 41128003, 41021061, 40974015)*.

Nutation determination by means of GNSS - Comparison with VLBI

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Space geodetic techniques cannot be used for a direct determination of the celestial pole offsets, due to deficiencies in the modeling of the satellite orbits. However, as shown by Rothacher et al. (1999), GPS can be used to estimate the time derivatives of nutation quantities, similarly to what is done on a regular basis for UT1-UTC rates (or LOD) estimation. We have investigated the potential of GNSS observations for nutation estimation with the high precision currently achieved by this technique. The computations have been carried out by means of a new software, which has been developed in Matlab in the framework of Yao's PhD (2013), based on the GPS observations analysis strategy of CNES-GRGS GINS software but with a few specific characteristics. The reference system for orbit computations is different from that generally used in order to minimize the influence of the a priori values of precession-nutation and UT1-UTC. The method is based on the determination of the time derivatives of the GCRS CIP coordinates (X, Y) with high temporal resolution. The observations used are 3 years of GPS measurements from 1 January 2009, obtained from a dense and globally distributed reference station network. The Xdot and Ydot time series so obtained are then analyzed in order to determine the corrections to the amplitudes of the short periodic terms of the IAU 2000 nutation model. The methodology, time series and results of this analysis are compared with those of Very Long Baseline Interferometry (VLBI) on extragalactic radio sources.

The Earth's nutation: VLBI vs. IAU 2000A

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The nutation as observed by the VLBI is compared to the model IAU 2000A. The differences can be modeled by the free forced motion associated with the free core nutation, and a number of tidal terms including purely lunisolar terms (e.g., 18.6-yr) and some planetary terms. We discuss the consequences for the Earth's nutation and geophysical models.

Gravimetric excitation function of polar motion from the GRACE RL05 solution

Nastula J.

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Impact of land hydrosphere on polar motion excitation is still not as well known as the impact of the angular momentum of the atmosphere and ocean. Satellite mission Gravity Recovery and Climate Experiment (GRACE) from 2002 provides additional information about mass distribution of the land hydrosphere. However, despite the use of similar computational procedures, the differences between GRACE data series made available by the various centers of computations are still considerable. In the paper we compare three series of gravimetric excitation functions of polar motion determined from RL05 GRACE solution from the Center for Space Research (CSR), the Jet Propulsion Laboratory (JPL) and the GeoForschungsZentrum (GFZ). These data are used to calculate the equivalent water thickness (EWT), and subsequently, to determine the polar motion excitation function. Gravimetric signal is compared also

with the geodetic residuals computed by subtracting atmospheric and oceanic signals from geodetic excitation functions of polar motion. Gravimetric excitation functions obtained on the basis of JPL data differ significantly from the geodetic residuals while the series obtained from CSR and GFZ are more compatible.

Researches on predictions of Earth orientation parameters

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Earth orientation parameters (EOP) are essential for transformation between the celestial and terrestrial coordinate systems, which has important applications in the Earth sciences, astronomy and navigation system. In this report, we firstly describe the principles and analyze the characteristics of several commonly used EOP prediction methods. Based on this discussion, we found that it is essential to select appropriate method and length of base prediction sequence at different prediction span, e.g., autoregressive (AR) model has a higher accuracy in short-term forecasting, while the artificial neural network (ANN) model has advantage in the long term forecasting. Secondly, we employ for the first time a combination of AR model and Kalman filter (AR+Kalman) in short-term EOP prediction. Comparing with the single AR model, the combination of AR model and Kalman filter shows a significant improvement in short-term EOP prediction. At last, we will present the recent work during the period of our participation in the Earth Orientation Parameters Combination of Prediction Pilot Project (EOPC PPP). The EOPC PPP was initiated by the International Earth Rotation and Reference Systems Service (IERS) and Jet Propulsion Laboratory (JPL) in the summer of 2010, with the goal to develop a strategy for combining predictions.

The "Simeiz-Katsiveli" co-location site of space geodesy techniques:current state and future activity

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Main Astronomical Observatory NAS of Ukraine, Ukraine

The activity of the "Simeiz-Katsiveli" co-location site of space geodesy techniques (VLBI, SLR and GNSS) in 2010-2012 is discussed. Special attention on local tie surveys is paid. Future plan for this site is proposed.

Session 5 : Solar System Dynamics - Theory, modelling and numerical standards

New results from NASA's lunar gravity mapping mission GRAIL

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(1) *Institut de Physique du Globe de Paris, France ;* (2) *Department of Earth, Atmospheric and Planetary Sciences, MIT, USA*

The Gravity Recovery and Interior Laboratory (GRAIL) mission, NASA's 11th Discovery mission, has successfully mapped the Moon's gravity field to unprecedented accuracy. The scientific objective of the GRAIL mission were to determine the structure of lunar highland crust and maria, addressing impact, magmatic, tectonic and volatile processes that have shaped the near surface. GRAIL is the lunar analog of the successful GRACE twin-spacecraft terrestrial gravity recovery mission that has been mapping Earth's gravity field since its launch in 2007. During the three month primary mission, and from a mean altitude of about 50 km, a global gravity field to spherical harmonic degree 660 was obtained. During the subsequent three month extended mission, the average altitude was lowered to about 25 km, allowing for the construction of gravity models that exceed spherical harmonic degree 900. In addition to the static gravity field, GRAIL has also determined the degree-2 and 3 Love numbers, and is searching for time variable signals related to inner core precession. In this presentation, a review of the most recent results from the GRAIL mission will be given, including the structure of large impact basins, subsurface magmatism, the density and porosity of the lunar crust, and constraints on interior structure.

Rotation/libration of solar system bodies

Rambaux N.

UPMC - Observatoire de Paris - IMCCE, France

Planetary exploration has revealed the great richness and diversity of the terrestrial planets and natural satellites. Until recently, planets were known only as point masses and for the past fifty years their rotation motion was one of the key measurements achieved from ground-based telescopes. Nowadays, the measurement resolution afforded by space telescopes and spacecraft allows the detection of small variations in the rotational motion that bear the signature of internal properties. The investigation of the interior of planets and satellites is instrumental to understanding planetary processes operating on a global scale. Here, we will present the knowledge of the rotation and librations (for bodies in spin-orbit resonance) of some solar system bodies that has been measured recently.

Tests of gravitation at Solar System scale beyond PPN formalism

Hees A.[(1)], Folkner W.[(1)], Park R.[(1)], Jacobson R.[(1)], Lamine B.[(2)], Le Poncin-Lafitte C.[(3)], Wolf P.[(3)]

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In this presentation, the current tests of gravitation available at Solar System scale will briefly be recalled. These tests rely mainly on two frameworks: the PPN framework and the search for a fifth force. Some motivations to look for deviations from General Relativity in other frameworks than the two extensively considered so far will be given. A recent analysis of Cassini data in an extended framework will be presented. Furthermore, possibilities to constrain Standard Model Extension using Solar System data will be developed.

Numerical ephemerides of planets (EPM) and natural satellites of IAA RAS and their uses for scientific research

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The dynamical model of EPM ephemerides (planet part) of IAA RAS includes mutual perturbations from planets, the Sun, the Moon, 301 large asteroids and 30 TNO, from massive two-dimensional asteroid and TNO rings, the lunar physical libration and the solar oblateness. The last EPM ephemerides were fitted to 680 000 observations (1913-2011). Their orientation has been realized by including into the solution the 213 ICRF-based VLBI measurements of spacecraft. The EPM uncertainty is controlled by comparison with the DE424 ephemeris. EPM ephemerides are the basis for the Russian Astronomical and Nautical Astronomical Yearbooks; they are planned to be used in the GLONASS and LUNA-RESOURCE programs, and for determination of physical parameters (asteroids masses, planet rotation, topography), the GM_Sun and its secular variation, the PPN parameters, the upper limit on the dark matter mass in the solar system. Moreover, numerical ephemerides of the 22 main planet satellites were constructed taking into account mutual perturbations of satellites, perturbations from planets and the Sun, and figures of planets those also provide the basis for improving positions of the outer planets. Currently EPM are developed with cross-platform software comprising a high-precision integrator. Files containing polynomial approximation for EPM ephemerides (EPM2004, EPM2008, EPM2011) along with TT-TDB, and ephemerides of Ceres, Pallas, Vesta, Eris, Haumea, Makemake, Sedna, are available from ftp://quasar.ipa.nw.ru/incoming/EPM/. Files are provided in IAA's binary and ASCII formats, SPK and PCK formats.

INPOP13

Fienga A.[(1)], Verma, A.K.[(2)] , Laskar[(3)], J., Manche, H.[(3)], Gastineau, G.[(3)]

(1) *GéoAzur - Observatoire de Côte d'Azur, France* ; (2) *Lucknow University, India*; (3) *IMCCE, Observatoire de Paris, France*

We will present here the new INPOP version, INPOP13. A specific focus will be made over the Messenger 1.5 years of radio science data analysed by our group and used for the construction of INPOP13. Tests of GR will also b presented and discussed.

Approximation of orbital elements of telluric planets by compact analytical series

Kudryavtsev S.

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We take the latest long-term numerical ephemeris of the major planets DE-424 (Folkner 2011, JPL IOM 343R-11-003) and approximate the orbital elements of telluric planets by trigonometric series. Amplitudes of the series' terms are the 2nd- or 3rd-degree polynomials of time, and arguments are the 4th-degree time polynomials. The resulting series are precise and compact; in particular the maximum deviation of the planetary mean longitude calculated by the analytical series from that given by DE-424 over 3,000 B.C. - 3,000 A.D. (the total time interval covered by the numerical ephemeris) is: - for Mercury: 0.0016 arcsec (the series includes 765 terms); - for Venus: 0.020 arcsec (612 terms); - for the Earth-Moon barycenter: 0.019 arcsec (580 terms); - for Mars: 0.056 arcsec (806 terms).

EPM-ERA 2013 - New Version of Lunar ephemeris Developed in IAA RAS

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EPM-ERA 2013 is the newest version of the lunar ephemeris developed in IAA RAS after 2011. New ephemeris version was constructed based on the following additions: increased number of LLR measurements; improvement of lunar reflectors geometry by

adding recently rediscovered lunar reflector Lunokhod 1; re-weighting of the most accurate LLR observations; adjustment of both LLR measurements reduction and mathematical model of orbital and rotational motion of the Moon; improvement of the accuracy of numerical integration by use of 80 bits floating point operations instead of 64 bits ones. EPM-ERA 2013 was compared with American DE403, DE405, DE421, DE423 and French INPOP10b lunar ephemerides. Comparison showed that EPM-ERA 2013 is still slightly worse than all of these ephemerides except DE403 one. The necessity of further improvements of the dynamical model of EPM-ERA is pointed out. The fact that all modern lunar ephemerides evidently cannot adequately describe most accurate LLR observations makes this task especially actual for authors. Several practical applications were considered also to estimate the impact of the usage of different lunar ephemerides on the accuracy of the orbit determination of such objects as GNSS satellites and Near-Earth asteroids.

Solar System dynamics with the Gaia mission and beyond

Hestroffer D., Berthier J., Carry B., David P., Thuillot W., Arlot J-E., Bancelin D., Colas F., Devillepoix H., Fouchard M., Ivantsov A., Lainey V., Rambaux N., Robert V.

IMCCE/Paris Observatory, France

The Gaia mission will be launched end 2013 by the European Space Agency (ESA). Solar System science is also well covered by the mission and has been included since the early stages of its concept and development. We develop aspects on the astrometry and dynamics of Solar System Objects (SSO), in particular asteroids, comets and satellites as well as ground-based support. We also develop the future of SSO astrometry that will be achieved indirectly, after mission completion, from the Gaia astrometric catalogue.

Abstracts for the poster presentations

(sorted by session and alphabetic order)

Session 1: Theoretical aspects of reference systems

1.1 *On the definition of a reference frame and the associated space in a general spacetime*

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A reference frame is essentially a three-dimensional congruence of observers equipped with clocks and meters. This is a fundamental notion not only for astronomy but for physics in general. The same is true for the notion of the associated space, in which the observers of the congruence are by definition at rest (even though their mutual distances may depend on time). However, for a curved spacetime, as considered in relativistic theories of gravitation, the theoretical concept of a reference frame is not fully clear, and the notion of the associated space is hardly considered. In a recent work, we proposed a formal definition of a general reference frame in a general spacetime, as being an equivalence class of charts (coordinate systems). This formal definition corresponds with the physical notion of a reference frame, recalled above; moreover it is easy to use in modelling. Our definition allowed us to associate rigorously with each reference frame F, a unique "space" -- a three-dimensional differentiable manifold M -- which is the set of the world lines bound to F. However, this definition of a reference frame and its associated space manifold applies to a parametrizable domain U of the spacetime manifold V. Since V itself as a whole is in general not parametrizable, no global reference frame exists in general. Accordingly the space manifolds do not look "maximal". We define also global concepts of a reference fluid and its associated space manifold, and show their strong link with the formerly defined local notions.

1.2 *The Time Transfer Function as a tool to compute Range, Doppler and astrometric observables*

Hees A.[(1)], Bertone C.[(2)], Le Poncin-Lafitte C.[(2)]

(1) *Jet Propulsion Laboratory, USA;* (2) *SYRTE, Observatoire de Paris, France*

In this poster, we will show how the Time Transfer Function can be used in the relativistic modelling of range, Doppler and astrometric observables. We will present a method to compute these observables up to 2 Post-Minkowskian order directly from the space-time metric without explicitly solving the null geodesic. The resulting expressions involve integrals of some functions defined by the metric over a straight line between the emitter and the observer of the electromagnetic signal. Some illustrations will be given within the context of future space mission.

1.3 *Noise characteristics in DORIS position time series derived from IGN-JPL, INASAN and CNES-CLS analysis centres*

Khelifa S.

Centre of Space Techniques, Algeria

Using wavelet transform and Allan variance, we have analyzed three different DORIS solutions of station coordinates, in order to compare the spectral characteristics of their residual noise, which allows to evaluate the positioning stability of stations. The data used are the STation Coordinate Differences (STCD) files of weekly position time series of 9 high latitude stations, provided by the three IDS analysis centres: IGN-JPL (solution ign11wd01), INASAN (solution ina10wd01) and CNES-CLS (solution lca11wd02). The temporal correlations between the three solutions in each component (North, East and Vertical) reveal a high correlation in the horizontal components (North

and East). In the North component, the correlation average is about 0.88, 0.81 and 0.79 between, respectively, IGN-INA, IGN-LCA and INA-LCA solutions, and in the East component it is about 0.84, 0.82 and 0.76, respectively. The correlations in the Vertical component are moderate with an average of 0.64, 0.57 and 0.58 for, respectively, IGN-INA, IGN-LCA and INA-LCA solutions. After having removed the trends, annual and semi-annual signals from the analysed time series, the Allan variance analysis shows that the three solutions are dominated by a white noise. The wavelet transform analysis, using the VisuShrink method with soft thresholding, reveals that the noise level is the smallest in the LCA solution compared to IGN and INA solutions. Indeed, the standard deviation of the noise in the three components is in the range of 5-11, 5-12 and 4-9 mm for, respectively, IGN, INA, and LCA solutions.

1.4 *Corrections to the IERS amplitudes of variations of the geopotential coefficients due to frequency dependence of Love numbers*

Kudryavtsev S.

Sternberg Astronomical Institute of Moscow State University, Russia

A new algorithm is proposed for calculating variations of the geopotential coefficients due to the frequency dependent part of Love numbers. Unlike the approach presently suggested by the IERS Conventions (2010), the new algorithm uses the representation of the Earth tide-generating potential in the standard HW95 format and takes into account the phase of tidal waves. Corrections of up to 2×10^{-12} to the amplitudes of the corresponding variations of the geopotential coefficients published by the IERS Conventions (2010) are suggested.

1.5 *On the Galactic aberration constant*

Malkin Z.

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Galactic aberration (GA) is a small effect in proper motion of about 5 μas/yr already noticeable in VLBI and other highly-accurate astrometric observations. However, accounting for this effect during data processing faces difficulty caused by uncertainty in the GA constant, A, equal to $R_0*(Omega_0)^2/c$, where R_0 is the Galactocentric distance of the Sun, Omega_0 is the angular velocity of circular rotation of the Sun around the Galactic center, c is speed of light. In this work, we used several tens of determination of R_0 and Omega_0 made during last 10 years to derive the most probable value of the GA constant. We used several statistical methods to obtain reliable estimates of R_0 and Omega_0 and their realistic errors. In result, we have obtained the value of A = (4.9 +- 0.4) μas/yr as the current best estimate of the GA constant. For practical applications we suggest an approximation A = 5 μas/yr. Using this value of the GA constant allows us to eliminate at least 90% of the GA effect. Remaining uncertainty in proper motion of about 0.5 μas/yr is negligible nowadays. Thus the proposed value of the GA constant can be safely used in practice during coming years.

1.6 *OMIM, an interdisplinary group at SYRTE*

Nicolaidis E., Débarbat S., Malpangotto M., Eisensdaedt J., Blay M., Toulemonde M., Dimarcq N., Delva P., Lautier J., Meynadier F., Bizouard C.

SYRTE, Observatoire de Paris, France

Activities of SYRTE cover both time and space metrology, and the realisation and maintenance of the underlying time and space reference frames. A deep understanding of those matters cannot ignore the historical developments of the observational techniques and concepts from Antiquity to nowadays. Moreover ancient observations, involving various techniques and epochs, are quite often reprocessed, because of the extension or modification of their compilations or for benefiting of the progress of the computer capabilities. These historical aspects constitute another skill of SYRTE. For a better integration of our various researches and their achievements, and having a

epistemological overview on them, we set up in 2013 an internal interdisciplinary group, assembling time and astro-geodesy competence centers with the historians. This is OMIM: "Observations, Mesures, Incertitude, Modèles" (i.e. Observations, Measurements, Uncertainties and Models). Present poster offers a synthesis of three meetings of the OMIM group, and is aimed at illustrating the evolution in measuring/conceptualising space and time from the Greeks to our days.

1.7 *Astrometric Support for the Lunar-based Ultraviolet Telescope*

Qi Z., Yu Y., Tang Z., Zhao M.

Shanghai Astronomical Observatory, Chinese Academy of Sciences, China

The Lunar-based Ultraviolet Telescope (LUT) is an astronomical instrument for the Chinese Chang'e-III mission, which will be launched around Oct. 2013. LUT will be the first sky survey telescope landed on the Moon, and will chart an ultraviolet map of the Milky Way, on top of that, it will also do long-term light variation monitoring for some celestial objects. The Lunar module on which LUT is mounted is unmanned. The accurate values of position and the attitudes for LUT on the Moon is unable to be known from the Shuttle measurement and control system, which makes the pointing and tracking for the wanted celestial objects impossible. The great efforts devoted to calibrate the basic info (attitudes, CCD constants etc.) of LUT for the accurate pointing and tracking of celestial objects via a new astrometric process and associated method is presented. Some ground verification has been done and the results from those tests show the reliability and feasibility of the new astrometric process, which will give a powerful support for LUT and other similar equipments.

Session 2 : The Next ICRF - Progress and developments

2.1 *The SDSS quasars as a testbench for the Gaia fundamental reference frame grid-points*

Coelho B.[(1)], Andrei A.[(1,2)], Antón S.[(3,4)]

(1) *OV/UFRJ, Brazil*; (2) *ON/MCTI, Brazil* ; (3) *CICGE, Porto, Portugal*; (4) *SIM, Lisboa, Portugal*

The ESA mission Gaia will furnish a complete census of the Milky Way, delivering astrometry, dynamics, and astrophysics information for 1 billion stars. Operating in all-sky repeated survey mode, Gaia will also provide solar system objects and exo-planets observations and discoveries, plus fundamental physics experiments and measurements of extra-galactic objects. Among the later there will be about 500 000 quasars that will be used to build the reference frame upon which the several independent observations will be combined and interpreted. Not all the quasars are equally suited to fulfill this role of fundamental, fiducial grid-points. Brightness, morphology, and variability define the astrometric error budget for each object. The quasars spectroscopically certified from the SDSS catalog offer an optimum sample to discuss the future, still largely unknown Gaia quasar population. We present a new method, based on the Gaia quasar database, to derive absolute magnitudes, either in the Gaia and SDSS filters domains, as well as all over the extended optical window. We also discuss how well absolute magnitudes, colors, redshift, plus the morphological type, can trace characteristics of the host galaxy.

2.2 *Experimental plan for improving the K-band Celestial Frame*

de Witt A.[(1)], Horiuchi S.[(2)], Jacobs C.[(3)], Jung T.[(4)], Lovell J.[(5)], McCallum J.[(5)], Ojha R.[(6)], Quick J.[(7)], Sohn B.W.[(4)], Bertarini A.[(7)]

(1*) NRF/HartRAO, South Africa;* (2) *Tidbinbilla/CSIRO, Australia*; (3) *JPL/NASA, USA*; (4) *KASI, Korea*; (5) *UTAS, Tasmania*; (6) *GSFC/NASA*; (7) *IGG & MPIfR, Germany*

The aim of this poster is to complement our oral presentation on the K-band (22 GHz) Celestial Frame with detailed technical information about the telescopes that we propose to use for our initial studies. Phase I of our plan calls for an initial fringe demonstrations in August 2013 between KVN's Tamna station and HartRAO. This baseline will extend K-band CRF coverage down to about – 45 deg declination. We discuss the available overlapping frequency coverage, planned data rates and the resulting sensitivity. Phase II of our plan is to observe between South Africa (HartRAO) and Australia (Hobart,Tidbinbilla) in order to extend coverage to the south polar cap and this gain full sky coverage for the K-band CRF. We discuss the potential baselines, their mutual spatial and frequency coverages and the implications for K-band CRF work.

2.3 *VLBI representations of the celestial reference system*

Lambert S.[(1)], Arias E. F.[(2)], Souchay J.[(1)]

(1) *SYRTE, Observatoire de Paris, France;* (2) *BIPM, France*

We discuss the quality of the most recent VLBI radio source catalogs submitted by various analysis groups at the IVS data center in terms of error distribution, global systematics against the ICRF2, and internal noise.

2.4 *An accurate and stable mixed method to obtain coefficients in VSH developments of residuals from ICRF2- Catalog differences*

Marco F.J., Martinez M.J., Lopez J.A.

Universidad Jaume I, Spain

In our paper (Marco et al., A&A. 2004. 418) it was obtained a development in VSH, providing a high value for the meridian component of the deformation in the variations in declination. The development was made only up to the first order in vectorial harmonics, but the used procedure is adaptable for the calculation of higher orders.

One of the advantages of this method is that it uses a mixed adjustment over the whole sphere, by assigning virtual values on equi-spaced points. The problem of minimization may then be carried out as a continuous problem (in contrast to the usual discrete formulation) and allows the orthogonality functional of the VSH to be preserved in the normal algebraic equations, whose coefficients and independent terms are computed using integrals. These integrals may be calculated numerically as accurately as necessary. On the other hand, it is interesting to note, that the order of the development in vectorial of surface harmonics should not be chosen "a priori" (the method is applied equally in both cases) because the algebraic orthogonality preserves the coefficients already calculated as the order increases. This fact implies the nonlinearity of our method. So, the order will be increased to cover, as far as possible, the power (or energy) of the adjustment function. An also remarkable result consists in the not insignificant value obtained for eps_z+d_{1,0} for the Hipparcos-FK5 residuals. These values should be taken into account when carrying out an adequate embedding between visible and not visible wavelengths systems

2.5 *About homogeneity in combined catalogs*

Marco F.J., Martinez M.J., Lopez J.A.

Universidad Jaume I, Spain

The combination of catalogs in the ICRF system, is a necessary task that must be made carefully. This implies a suitable assignment of weights, in order to get the final residuals behave as a pure Gaussian and not as a "gaussian mixture". This is necessary to obtain a combined homogeneous catalogue. Summing up, our aim is to obtain an improved and homogeneous catalogue. To this goal we propose, in the first place, to take all the defining sources of the ICRF2 catalog, which are common to all of the catalogs that are to be combined. Then, we obtain through an adjustment over the whole sphere, the rotation plus deformation corrections for each one of them. Then, only the rotations are considered and all the catalogs are brought at the same "interim system" without deformations. In fact, deformations are contained in the remaining residuals. The statistical properties, which remain preserved, are used to deduce an improved and homogeneous catalog, which implies, as we have previously stated, a particular choice of the weights for each catalog. This problem has its counterpart in the sense that it is possible to study if a combined catalog is or is not homogeneous in the sense that we propose. We provide a technique to decide if the final residuals ("noise") of the combined catalog behave as a normal random variable (homogeneity) or as a gaussian mixture (not homogeneity). The procedure can be also successfully used to provide an objective criterion that allows us to change the status of some candidate sources into reference sources

2.6 *Problems caused by biased data in models of catalog adjustment*

Martinez M.J., Marco F.J., Lopez J.A.

Universidad Politecnica de Valencia, Spain

Most of the adjustment models (with the exception of those regarding with vectorial or surface spherical harmonics) presuppose that the data are unbiased (because the mathematical expectations of the adjustment model are null). This is a basical mistake that has repercussions in the obtained results. If the errors are random, after carrying out an unbiased adjustment over biased data, we will continue having a biased noise. This fact turns out to be, to many effects, highly inconvenient and potentially a source of instabilities. Particularly interesting is to explain what happens (and later to search why) with different constant bias, both in right ascension and in declination. In a certain way, we can consider this poster to be a particular and usual example of the problems presented in our poster "An accurate and stable mixed method to obtain coefficients in VSH developments of residuals from ICRF2- Catalog differences" presented in this same meeting.

2.7 *Effects of the datum configuration of radio sources on the EOP determined by VLBI*

Raposo-Pulido V.[1,2], Heinkelmann R.[2], Nilsson T.[2], Karbon M.[2], Schuh H.[2], Gómez-Gónzalez J.[1]

(1) *IGN, Madrid, Spain*; (2) *GFZ, Germany; (3)* TU Vienna, Austria

The Earth Orientation Parameters (EOP) provide the orientation of the International Terrestrial Reference System (ITRS) to the Geocentric Celestial Reference System (GCRS) as a function of time. How many and which radio sources are taken into account for the datum definition has a significant effect on the EOP determined by Very Long Baseline Interferometry (VLBI). When estimating a Celestial Reference Frame (CRF), usually radio sources with a long history of observations and with stable positions are included in the datum definition used to define the orientation of the frame. In principle, we wish to increase the number of observed radio sources to reach a homogeneous distribution covering the whole sky. However, if too many sources with not very stable positions are included in the datum definition, the errors of the estimated source coordinates will degrade the accuracy of the celestial datum. As a compromise, an optimal number of defining sources needs to be found. For the second realization of the International Celestial Reference Frame (ICRF2) some radio sources were included just to improve the geometrical distribution of the defining sources. Some of them were only observed in a few VLBI sessions by a small number of observations. In this case, the radio source positions could not be estimated with enough redundancy. In this work we determine a CRF together with EOP using different options for the celestial datum definition. The approaches are compared for quantifying their impact on the accuracy of the EOP.

Session 3: Atomic and pulsar-based timescales – Progress and developments

3.1 *The new UTC(OP) based on the LNE-SYRTE atomic fountains*

Chupin B., Abgrall M., Bize S., Guéna J., Laurent Ph., Rosenbusch P., Rovera G.D., Uhrich P.

LNE-SYRTE, Observatoire de Paris, France

The generation of UTC(OP) by steering a H-maser signal to the average of all SYRTE commercial clocks has been tested for a few years. After running this alternate time scale in parallel with the official UTC(OP) which is based on one single commercial Cs clock, we concluded that the gain was not justifying the complexity of the system. Instead, we have developed a very simple new algorithm for the steering of a H-maser signal to the SYRTE atomic fountain ensemble (comprising 3 Cs primary frequency standard and one Rb fountain). Preliminary tests of the new algorithm started in December 2011. Besides, for these tests we have been using a new 100 MHz micro phase stepper developed by a small company in collaboration with SYRTE. The results being very promising, in October 2012 we implemented the new algorithm to generate the official realization of UTC(OP). However, because there was no redundancy for the 100 MHz micro phase stepper at the switching date, we started with the old equipment working on 5 MHz signal, by changing only the master clock and the steering software. We plan to switch to the new 100 MHz micro phase stepper in the near future, in the framework of a major revision of the signal distribution at SYRTE, which will participate to the ground segment of the Atomic Clock Ensemble in Space (ACES) mission. At SYRTE all fountains share the same cryogenic oscillator, which is phase locked to a H-maser. This way, all the fountains measure the frequency of the same H-maser.

3.2 *ACES Micro-wave Link data analysis - status update*

Meynadier F., Delva V, Le Poncin Lafitte C., Guerlin C., Laurent P., Wolf V.

SYRTE, Observatoire de Paris / UPMC, France

The Atomic Clocks Ensemble in Space (ACES-PHARAO) mission is due to be launched in 2016. As the hardware preparation goes on, our team within the SYRTE laboratory focuses on the MicroWave Link (MWL) data analysis software. The MWL and this software will allow to perform time transfers between the International Space Station (ISS), where ACES will be located, and multiple ground stations which will be disseminated among various time and frequency laboratories across the world. The phase stability of this long range link is specified to reach 0.3 ps after 300 s integration time, with long term stability better than 7 ps over 10 days. This link will play a key role in the success of the ACES/PHARAO experiment. We present here the current status of the data processing software, which has reached several milestones in the last few months. We also present some key features of the simulation software that we developed in parallel.

3.3 *Prediction the Atomic Clock Bias for COMPASS Satellites*

Y. Song, X. Hu, Y. Huang

Shanghai Astronomical Observatory China

The COMPAS system is a project established by China to develop an independent global satellite navigation system. The system is based on the previously deployed BD-1 navigation demonstration system. There are 5 satellites in Geostationary Orbit (GEO), 5 in Inclined Geodsynchronous Orbit (IGSO) and 4 in Medium Earth Orbit (MEO) in operation now. In order to assess the performance of spaceborne atomic clocks, using several different methods to predict the clock bias. The results shows forecasting 12 hours, I3 and G6 are the worst, the bias reaches 8 ns and 12 ns, respectively. Others are basically maintained within 3 ns. For comparison, all of GPS clocks bias prediction performances are analyzed, results show that the GPS clock bias prediction is still better than BD's atomic clocks.

Session 4b - Earth Rotation - Modelling and observations

4.1 *Anomalies of astronomical time-latitude residuals at YAO before Wenchuan Earthquake*

Hui H.[(1)], Vondrak J.[(2)], Youjin S.[(1)]

(1) *Yunnan Observatory, Academia Sinica, Kunming, China*; (2) *Astronomical Institute, Academy of Sciences of Czech Republic*

Accurate optical astrometric observations of the local variations of the vertical contain rich geophysical information. These may be used not only in the astronomical research, but also can provide important information for the earthquake forewarning. In the paper we analyze astronomical time-latitude residuals observed in Yunnan Astronomical Observatory in 2008-2009, and find that significant anomalies appeared before the earthquake of magnitude 8.0 that occurred in Wenchuan on May 12, 2008. The results obtained make us believe that the observed anomalies of time-latitude variations may provide an important warning sign before strong earthquakes and thus deserves further research.

4.2 *Prediction of EOPs using the artificial neural network: Revisiting the method*

Lopes P., Barache C., Richard J.Y., Bizouard C., Gambis D.

SYRTE, Observatoire de Paris, France

The monitoring of the Earth Orientation Parameters (EOP) variations is the main task of the Earth orientation Center of the IERS. In addition, for various applications linked in particular to navigation, precise orbit determination or leap seconds announcements, short and long term predictions are required. The method which is currently applied for predictions is based on deterministic processes, Least Square fitting, autoregressive filtering. We present in the poster an alternative method, the artificial neural network Artificial neural networks (NN) which has already been successfully applied for pattern recognition. It has been tested as well by various authors for EOP predictions but with so far no real improvement compared to the current methods. New formalisms recently developed allow reconsidering the use of neural networks for EOP predictions. Series of simulations were performed for both short and long term predictions. Statistics and comparisons with the current methods are presented.

4.3 *On detection of the free inner core nutation from VLBI data*

Malkin Z.

Pulkovo Observatory, Russia

Free inner core nutation (FICN,) is one of the four free rotational modes of the Earth considered in the theory of the Earth's rotation. According to Mathews et al. (2002) the FICN period is between 930 and 1140 days. Detecting of this signal in the observational data is a very important scientific task allowing us to substantially improve our knowledge about the Earth's interior and rotation. Due to small expected amplitude of the FICN oscillation its detection can be successful only from the most accurate nutation series obtained from the VLBI observations. Several attempts to find the FICN signal in these series made during last years failed. In this poster, we present some results of our further steps in this direction, unfortunately not successful either. We investigated several VLBI nutation series by means of spectral and wavelet analysis. It has been shown that there are several periodic signals with close amplitude around the expected FICN period without any prevailing one that could be associated with the FICN. So, it seems to be necessary to improve the theoretical estimates of the FICN period to make its search in the observational data more promising.

4.4 *Analysis of EWT maps from GRACE mission and land hydrology data.*

Nagalski T.

Space Research Centre of the Polish Academy of Sciences, Poland

Using the gravity field from the Gravity Recovery and Climate Experiment (GRACE) gravimetric mission we can assess the Equivalent Water Thickness (EWT). Nevertheless the maps of EWT delivered from unfiltered data, present characteristic stripes. To cut out the perturbation and to enhance the signal to noise ratio we need to use a filter to the raw data. Then we investigate the impact of the smoothing of the Stokes coefficients on the resulting EWT distribution and the gravimetric polar motion excitation function amplitudes. To do these analysis we used the Stokes coefficients made accessible and filtered by the ICGEM (imported from three research centers GFZ, JPL and CSR) with the aid of an anisotropic method of smoothing of the geopotential coefficients from GRACE with three degrees of smoothing DDK3, DDK2 and DDK1 (Kusche 2007). Additionally we obtained the Stokes coefficients from the land hydrosphere geophysical models. To do this we computed the EWT maps from the geophysical models. The resulting coefficients were subjected to filtration in the same way as the GRACE data. Next the EWT maps from the filtered coefficients were computed. By comparing the original and the filtered geophysical EWT maps we got a scaling factor for the DDK filters.

4.5 *Amplitude-frequency analysis of the Earth orientation parameters and the variation of the second zonal harmonic of the geopotential*

Perepelkin V., Bondarenko V.V., Markov Yu.G.

Moscow Aviation Institute, Russia

Modeling temporal variations of the geopotential caused by the oscillatory-rotational processes of the Earth's motion is of a significant interest for some satellite navigation applications and geophysics problems. Observed variations of the Earth orientation parameters (EOP), the variations of the Earth's gravitational field and oscillations in the large-scale geophysical events appear to be in a considerable correlation. Based on the celestial mechanics' methods namely the spatial version of the problem of the Earth-Moon system in the gravitational field of the Sun a mathematical model of the rotational-oscillatory motion of the elastic Earth is developed. A comparison between the real and theoretically obtained Earth's pole motion trajectory as well as between real and derived variations of the length of the day demonstrate the adequacy of the derived model to the International Earth Rotation and Reference System Service (IERS) observations data. Based on the amplitude-frequency analysis of the oscillation processes in the motion of the Earth's pole and on the observations' data of the SLR a modeling of the second zonal harmonic of the geopotential has been carried out. Its functional dependence on the amplitude and phase of the Earth's pole oscillatory process is shown by the means of periodic functions of time.

4.6 *CONT11 - High-Frequency Earth Rotations Variations from VLBI Observations*

Skurikhina E., Ipatov A., Smolentsev S., Kurdubov S., Gayazov I., Diyakov A., Schpilevsky V.

IAA RAS, Russia

Results of data processing of CONT11 15 day campaign of continuous VLBI sessions with a network of eleven globally distributed stations in September 2011 with participation of two stations of Russian QUASAR network stations, Badary and Zelenchukskaya, are presented. Preliminary analysis results on EOP precision, baseline length precision are discussed. The observed intraday variations EOP are compared with a tidal model and with results of previous CONT campaigns. Troposphere parameters are compared with ones obtained with GPS technique.

Session 5: Solar System Dynamics - Theory, modelling and numerical standards

5.1 *Local test of General Relativity with Solar System objects.*

Hestroffer D., David P., Saillenfest M.

IMCCE/Paris Observatory, France

The Gaia mission to be launched by ESA in 2013 will observe, in addition to stars, a large number of solar system objects (SSO). Gaia will provide during its 5 years mission high precision astrometry in an absolute reference frame of about 300 000 asteroids, including many Near-Earth Objects. The very precise orbits will enable to determine simultaneously the solar J2 and the PPN parameter beta and other parameters for testing the GR. Improvement from combining Gaia and radar data are also expected.

5.2 *Progress Report: The IAU Commission 4 Working Group on Standardizing Access to Ephemerides and File Format Specification*

Hilton J.[(1)], Acton C.[(2)], Arlot J.-E.[(3)], Bell S.[(4)], Capitaine N.[(5)], Fienga A.[(6)], Folkner, W.[(2)], Gastineau M.[(3)] , Pavlov D.[(7)], Pitjeva E.V.[(7)] , Skripnichenko V.I.[(7)], and Wallace P.T.[(8)]

(1) *USNO, USA*, (2) *JPL, USA*, (3) *OP/IMCCE, Fance*, (4) *HMNAO, UK*, (5) *OP/SYRTE, France*, (6) *UTINAM, France*, (7) IAA, Russia, (8) *RAL Space, UK*

The IAU Commission 4 Working Group on Standardizing Access to Ephemerides and File Format Specification is nearing completion of its work. The working group has formalized the use of text PCK files to store additional data such as the values of parameters used in construction of the ephemerides. This was the final unresolved specification. The working group's report is nearing completion. The bulk of the report consists of a detailed summary of the file formats and probably not of interest to most readers. Likely, the full report will be made available through IAU Commission 4 - Ephemerides and a summary version will be published in a journal. This poster provides a general outline of the file formats and their expected uses.

5.3 *SOFA: Authoritative Tools and Standard Models*

Hohenkerk C.

HM Nautical Almanac Office, United Kingdom

The International Astronomical Union's Standards of Fundamental Astronomy (SOFA) service has the task of establishing and maintaining an accessible and authoritative set of algorithms and procedures that implement standard models used in fundamental astronomy. This poster highlights the current tools, in particular "Earth Attitude" and "Times Scales and Calendars," and previews the upcoming set of "Astrometry Tools".

5.4 *On Solution of the secular system in the analytical Moon's theory*

Ivanova T.

Institute of Applied Astronomy, RAS, Russia

This paper is the final step to construct the analytical theory of the orbital Moon's motion with taking into account the planetary perturbations in the form of the general planetary theory (GPT). Trigonometric theory of the secular perturbations in the motion of the major planets is used to obtain a trigonometric solution of the secular system for the Moon's motion. This solution has been built up to the tenth degree terms with respect to the eccentricities and inclinations of all the bodies. The right-hand members of the secular system for the Moon were obtained earlier in the purely analytical form but the trigonometric solution of the secular system has the semi-analytical form. It includes two basic sets of inequalities due to the secular evolution of the lunar perigee and node as well as of that of the major planets. All the analytical calculations are performed by the echeloned Poisson series processor EPSP.

5.5 *On future opportunities to observe gravitational scattering of main belt asteroids into NEO source regions*

Ivantsov A., Eggl S., Hestroffer D., Thuillot W.

IMCCE / Observatoire de Paris, France

Orbital resonance crossings are believed to be responsible for the delivery of main belt asteroids to the inner Solar System. Several possibilities have been suggested to transport asteroids and their fragments into mean motion and secular resonances including non-gravitational forces and gravitational scattering (Menichella et al. 1996, Bottke et al. 2002, Greenstreet et al. 2012, Carruba et al. 2013 and references therein). We investigate close encounters that occur between asteroids in the main belt over the next century in order to identify observable injections of asteroids into those resonances that are considered to be source regions for Near Earth Objects (NEOs).

5.6 *Comparisons of Ephemerides*

Nelmes S., Hohenkerk C.

HM Nautical Almanac Office, United Kingdom

The objectives of IAU Division A Commission 4 - Ephemerides include -Promote improvements to the usability and accuracy of astronomical ephemerides, and provide information comparing computational methods, models, and results to ensure the accuracy of data provided. and -Promote the development of explanatory material that fosters better understanding of the use and bases of ephemerides and related data. As part of this remit work has been carried out to produce a new webpage that provides a tool for comparing three ephemerides, in particular EPM2011/m, DE430/LE430 and INPOP10e. These ephemerides are from expert groups around the world; Russia's Institute for Applied Astronomy, USA's Jet Propulsion Laboratory and France's IMCCE and Paris Observatory. In this poster we describe some of the aspects of this webpage and the comparisons being carried out.

5.7 *Neptune's ring arcs : VLT/NACO near-infrared observations*

Souami D.[(1)], Sicardy B.[(2)], Renner S.[(3)], Carry B.[(2)], Dumas C.[(2)]

Observatoire de Paris, UPMC, France: (1) *SYRTE; (2) LESIA; (3) IMCCE*

Neptune's incomplete rings (arcs) have been stable since their discovery in 1984, as these structures should be destroyed in a few months through differential keplerian motion. They are close to but not within a 42:43 corotation inclination resonance forced by Galatea, thought to be responsible for the azimuthal confinement of the arc system. We present NACO adaptative optics observations of Neptune's ring arcs at 2.2 μm (K band), taken with the VLT telescope in August 2007. These data have been calibrated and aligned using the JPL satellite ephemerides of the satellites Proteus and Triton, available through Horizons on-line ephemeris system (http://ssd.jpl.nasa.gov/?horizons). We give improved mean motion values for the arcs and Galatea, thus confirming the mismatch between the arcs' position and the location of the 42:43 corotation inclination resonance.

5.8 *On the spatial distribution of Main Belt Asteroids*

Souami D.[(1)], Lemaitre A.[(2)], Souchay J.[(1)]

(1) *SYRTE, Observatoire de Paris, UPMC, France*; (2) *University Namur, Belgium*

We investigate the distribution (inclination, longitude of the ascending node) of main belt asteroids in space with respect to the ecliptic-equinox J2000. We identify/confirm a sinusoidal behaviour of this distribution, which disappears when the inclination is given with respect to Jupiter's orbital plane, or the invariable plane. We show that this behaviour can be explained by secular effects due mainly to Jupiter. Furthermore, we identify three different orbital behaviours that explain the density distribution in this space.

5.9 *Recent activities of the FP7-ESPaCE consortium*

Thuillot W.[(1)], Lainey V.[(1)], Arlot J.-E.[(1)], Dehant V.[(2)], Oberst J.[(3)], Gurvits, L.[(4)], Hussmann H.[(3)], Marty J.C.[(5)], Rosenblatt P.[(2)], Vermeersen B.[(6)]

(1) *IMCCE-Paris Observatory, France; (2) ORB, Belgium; (3) DLR, Germany; (4) JIVE, The Netherland; (5) CNES, France: (6) TUD, The Netherland*

The consortium ESPaCE (European Satellite Partnership for Computing Ephemerides) is composed of seven European institutes: IMCCE-Paris Observatory, Royal Observatory of Belgium, Technical University of Berlin, Joint Institute for VLBI in Europe, University of Technology of Delft, and the space agencies CNES in France and DLR in Germany. The objective of this FP7 European project is to provide new accurate ephemerides of natural satellites and spacecraft. For this goal many astrometric data issued from ground-based observations as well as from space observations have been analyzed and reduced. On the other hand new technologies applied to the positioning of spacecraft are also studied. The ESPaCE project addresses also data related to gravity and shape modeling, control point network and rotational parameters of natural satellites. The accuracy improvement of these ephemerides makes them a powerful tool for the analysis of space missions or the preparation of future missions, or for the determination of some physical parameters. This poster gives a description of the ESPaCE program and describes the results already obtained.