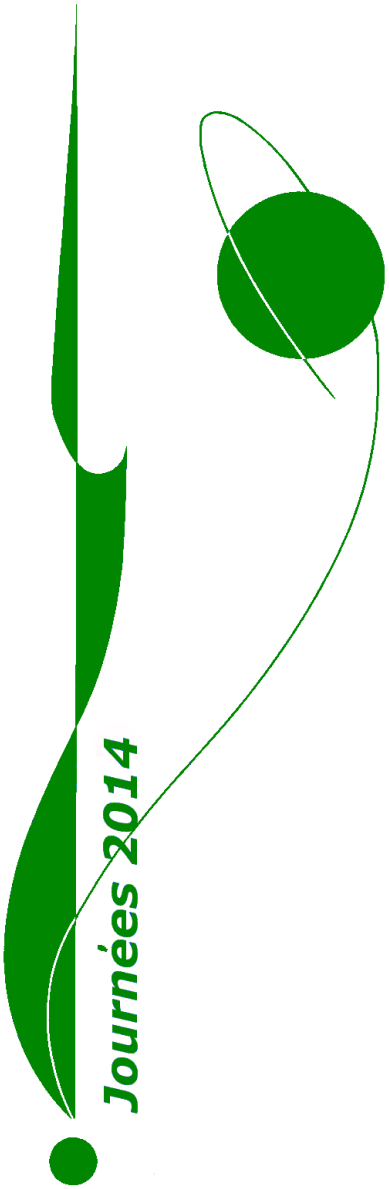
JOURNÉES 2014

SYSTÈMES DE RÉFÉRENCE SPATIO-TEMPORELS

Recent developments and prospects
in ground-based and space astrometry



BOOK OF ABSTRACTS

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JOURNÉES 2014

«Systèmes de référence spatio-temporels»

Recent developments and prospects
in ground-based and space astrometry

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Session 1: Celestial reference system and frame

Abstracts for the oral session

The ICRF-3: Status, plans, and progress on the next generation celestial reference frame

[(1)]Malkin Z., [(2)]Jacobs S., and IAU ICRF3 Working Group
(1) Pulkovo Observatory RAS and St. Petersburg State University, Russia; (2) Jet Propulsion Laboratory, Caltech, 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 VLBA Calibrator Survey' 2000+ 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 640 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.

The stability of the ICRS axes

Lambert S.
SYRTE, Observatoire de Paris, France

The ICRS axes are defined by the coordinates of distant radio sources observed by the VLBI. The stability of the axes is primarily depending on the apparent variations of sources' coordinates which are due to intrinsic phenomenon like, e.g., jets and flux variations, or to global effects like the galactic aberration. The mismodeling of the Earth's nutation and precession also affects the position of the celestial pole as defined by the TRF-to-CRF coordinate transformation. In this talk, I will review the various points above and comment the accuracy of the current quasar catalogs and nutation series.

On the systematics in apparent proper motions of radio sources observed by VLBI

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(1) GFZ Potsdam, Germany; (2) SYRTE, Observatoire de Paris, France

Since about twenty years, several authors have investigated the systematics in the apparent proper motions of radio source positions. In some cases, the theoretical work

developed (Pyne et al., 1996) could not be assessed due to the few number of VLBI observations. In other cases, the effects attributed to apparent proper motion could not be related successfully because of there were not significant evidences from a statistical point of view (MacMillan, 2005). In this work we provide preliminary results about the estimation of the coefficients of spherical harmonics, based on a Three-step procedure: (i) Radio source time series from VLBI analysis (VieVS software), (ii) Apparent proper motions fitted to their coordinate time series, (iii) Spherical harmonics fitted to the proper motion field. The early stage of this work has been to compare step by step the computations and estimation process between the CALC and VieVs software. To do that, the results were analyzed and compared with the previous study done by Titov and Lambert in 2013. With the improvement of the VLBI system and the increase of number of VLBI observations, we aim to provide useful information regarding the current situation of the radio sources observed with VLBI.

Morphology of QSO host galaxies – a look at the SED

[(1,2,3)]Andrei A., [(2)]Coelho B., [(4,5)]Antyn S.

(1) Observatyrio Nacional/MCTI, Brasil; (2) Observatyrio do Valongo/UFRJ, Brasil; (3) SYRTE/Observatoire de Paris, France; (4) CICGE, Faculdade de Cικncias da Universidade do Porto, Portugal; (5) SIM/Faculdade de Cικncias da Universidade de Lisboa, Portugal

We develop a program to study the host galaxies of QSOs present in the SDSS up to its 8th release. The main observational data thus comprises a large retrieved data bank of images in the ugriz colors for the 105,783 objects spectroscopically found as QSOs, within frames containing tens of comparison stars and several field galaxies. Complementary, images of nearly 200 bright quasars that will be used to link the future GCRF to the ICRF were taken using 2m class telescopes, over the entire sky. The first scope of this program is to select QSOs for which the isophotes of the host galaxy are not pronounced so that the centroid determination is not affected over those fundamental grid-points of the GCRF. Ancillary we prepare templates upon which the Gaia observations of the ensemble QSO plus host galaxy can be interpreted. This program in itself aims to discuss the characteristics of the host galaxy on basis of this large, statistically complete sample of images. Since the target images come from relatively short exposures, our approach is to access disturbances of the target PSF relatively to the nearby stars, as well as the photometric ratio between the central and the peripherical portions, and the interpretation of best morphological fit. We present the first results for absolute magnitude of QSOs combining the SDSS colors and the SED library from Gaia. Finally we discuss the findings of the signature of the presence of host galaxies at redshifts larger than one in terms of the population of young stars in the host galaxy, fostered up by the presence of the central QSO.

Some preliminary photometric results of QSOs useful for the link between future Gaia CRF and ICRF

[(1)]Damljanovic G., [(2)]Taris F., [(3)]Boeva S.
(1) Belgrade Astronomical Observatory, Serbia; (2) SYRTE, Observatoire de Paris, France; (3) Institute of Astronomy with NAO, BAS, Bulgaria

Gaia was launched in December 2013 as cornerstone mission of ESA. Its main goal is to map the entire Galaxy (over one billion stars) and more than 500000 quasars (QSOs); all objects with apparent V band magnitudes in the range 5.6<V<20. During its 5-year lifetime it will produce a unique time-domain space survey. It will be made a dense optical QSO-based Gaia CRF, and the link between future Gaia CRF and International CRF with the highest accuracy will be of importance. About 90% of the ICRF sources are not suitable for the link (they are not bright enough in optical domain, they have significant extended radio emission, etc.), but there are other (candidate) sources (weak extragalactic radio sources - ERS with bright optical counterparts) which we need to investigate. Some candidate sources were imaging by VLBI. And some sources were detected as useful ones on VLBI scales. The astrophysical processes could produce displacements of the optical photocenter of these objects, and because of it the variations of their light curves are important information to establish the link of reference systems. Our observations of 47 objects were carried out more than one year in the B, V and R bands using new telescope D(cm)/F(cm) = 60/600 at the Astronomical Station Vidojevica – ASV of Astronomical Observatory in Belgrade (Serbia), and TJO (Telescopi Juan Oro) 0.8 m telescope in Observatori Astronomic del Montsec (Spain). Some photometric results are presented as a part of astrophotometric and astrophysical investigations of ERS in the framework of the reference systems.

First results of S/X and X/Ka-band catalogue combinations with full covariance information

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The currently existing realizations of the International Celestial Reference System (ICRS), the ICRF1 and ICRF2, are based on solutions estimated by a single VLBI group. All sessions used were dual frequency S/X-band (2.3/8.4 GHz) VLBI sessions. In addition to an improved precision one of the main goals for the upcoming realization of the ICRF3 is an enhanced frequency coverage compared to the ICRF2. By including solutions with full variance-covariance information based on X/Ka-band (8.4/32GHz) observations in the rigorous VLBI intra-technique combination, an improved frequency coverage can be realized. In this paper, we present a method to mix the combination on the level of datum free NEQ and on the solution level with full covariance information. We show preliminary results of a combined S/X- and X/Ka-band catalogue and discuss the prerequisites and the limitations of this approach. Furthermore, we show the benefits for the upcoming ICRF3.

Comparison of astrometric catalogues UCAC4, XPM, PPMXL

Tsvetkov A., Vityazev V.
St. Petersburg State University, Russia

The fast procedure to represent the systematic differences of proper motions of stars in UCAC4, XPM and PPMXL catalogues by means of vector spherical harmonics in galactic

coordinate system is suggested. The representation of the differences UCAC4-PPMXL, XPM-UCAC4 and XPM-PPMXL by vector spherical harmonics is made in the 10 to 16 J mag range. It was found that the absolute proper motion XPM catalogue has the least systematic deviation from the ICRS proper motion catalogue UCAC4 in the 12–16 J mag range. The magnitude equation in the differences was found. The influence of systematic differences of proper motions on the determination of kinematical parameters is discussed.

Some common problems in geodesy and astrometry after establishing ICRF

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(1) CNIIGAiK, Russia; (2) Pulkovo Observatory RAS, Russia

Revolution in astrometry on the border of XX – XXI centuries was a result of technical progress in equipment and methods of observations. Since that time radio system ICRF was established as the main reference frame for astrometry and sciences connected to it, e. g. geodesy and gravimetry. During previous years stars were used as reference points and unity of the sciences based on observations, was achieved by means using the plumb lines as terrestrial reference at observatories. The expansion of this terrestrial frame to vertical lines in many places has been one of the purposes of geodetic measurements. We consider this very useful empirical unity of three branches of the one indivisible science should be preserved. Up to now some parameters geodesists get or use in common with astronomy, therefore we consider a comparison of different views will be helpful. We suppose Journees "System de Reference Spatio-Temporale" is the most important place for discussion of fundamental problems of modern astronomy.

The Galactic coordinate system based on multi-wavelength catalogues

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The Galactic coordinate system (GalCS) is important for studying structure, kinematics and dynamics of our Galaxy. The current GalCS, transformed from the FK4 system at B1950.0 to the FK5 system at J2000.0, was adopted by the Hipparcos Team. Since it is not connected directly to the International Celestial Reference System (ICRS), establishing a new GalCS based on recent observations is essential. We have carried out a series of work to find the Galactic plane and directions of three axes of the GalCS using data from four all-sky surveys 2MASS, SPECFIND, AKARI, and WISE. The wavelengths for these observations are no shorter than the near infrared wave, therefore the effect of extinction is not significant. By analyzing different methods employed in calculating three GalCs parameters, used for computing the transformation matrix from the equatorial system to the new GalCS, we have determined a most proper way to find an optimal GalCS, which means that the x-axis pointing to the observed Galactic center, and the x-y plane coincide with the best determined Galactic plane. After calculating the GalCS parameters in eight wavelengths, we synthesized these parameters with various wavelengths and the resulting parameters for defining the new GalCS in the ICRS are summarized as: α^p = 192.777 deg, δ^p = 26.9298 deg, for the equatorial coordinates of the north Galactic pole and θ = 122.95017 deg for the position angle of the Galactic center.

Abstracts for the poster session

Core sources set selection

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Ranking method for sources sets in order to select the list of sources that better define the orientation parameters of rigid rotation transformation from one system to another suggested in earliest works is applied. The transformation parameters formal errors were selected as characteristic of sources set. For all catalogues IVS WG2 was selected special order in the sources list and obtained transformation parameters accuracy as function of the number of sources. For all catalogues that function has a minimum between 300 and 400 sources, adding the sources after the minimum leads to increasing formal errors of orientation parameters. After that we selected the common sources which placed before minimum of functions and obtained the "optimal set". Source position time series were obtained and analysed for the optimal set of sources. It was shown that some of the core sources have unstable positions and need to be excluded from optimal set. Nevertheless time series shows that mainly optimal source set consists from stable sources.

Binary black hole systems and the ICRF

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(1) SYRTE, Observatoire de Paris, France; (2) Institut Astrophysique de Paris, France

Last two decades of VLBI observations bring strong evidences that quasars host black hole systems. Studies of VLBA maps at 15GHz of some well-observed radiosources suggest binary black hole (BBH) systems of apparent radius of few hundreds of microarcseconds, i.e., several times larger than the current accuracy of the ICRF source positions. In this study, we compare the results of fitting BBH system parameters to VLBI data against geodetic VLBI results. We also address the possible consequences of BBH systems for high precision astrometry in the current geodetic VLBI program as well as for higher frequency observations and the future link to Gaia.

On the transition to the radio system coordinates ICRF

Lipovka A., Lipovka N.
Sonora State University, Mexico

ICRF Radio Catalogue was recommended by IAU in 2009 as a main reference coordinate system, to which all results of observations in optical wavelength range should be agreed. In this paper we show that the binding of the optical and radio sky must be proved and confirmed by the coincidence of several objects in radio and optic in the investigated field, within the first lobe of the radio interferometer. Paradox of mismatching (non-coincidence) of most part of radio objects with the optical ones should be resolved by using the correct method of the identification of the radio sources with the optical ones.

Further study of correlation information impact on the mutual orientation between celestial reference frames

Lopez Y.
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In this study, we continue our investigation of impact correlation information on determination of the mutual orientation between celestial reference frames realized by radio source position catalogues. As in a previous study we compared orientation parameters of modern catalogues obtained by applying three methods of accounting for: position errors only, RA/DE correlations reported in radio source position catalogues in the IERS format and full correlation matrix. Our analysis has shown that applying full correlation matrices leads to substantial change in the orientation parameters between the compared catalogues. It is also possible that accounting for a full correlation matrix will be essential not only at definition of mutual orientation, but also at decomposition of coordinates differences by orthogonal functions. An attempt to investigate this effect on representation of mutual orientation by spherical function has also been undertaken.

On the selection of the common VLBI/Gaia sources

Malkin Z.
Pulkovo Observatory RAS and St. Petersburg State University, Russia

IAU-approved International Celestial Reference Frame (ICRF) is based on the source position catalog obtained from VLBI observations. It is expected that by the end of this decade, the new highly accurate Gaia Celestial Reference Frame (GCRF) will be available. Comparison and merging of these frames is one of the actual tasks of modern astrometry. The accuracy of the ICRF-GCRF link would benefit of larger number of extragalactic objects, primarily quasars, which have precise VLBI-derived position and are bright enough to be reliably observed with Gaia. An extended list of optically bright radio sources suitable for the alignment of GCRF to ICRF is discussed in this presentation.
Optical monitoring of QSOs in the framework of the Gaia space mission

Using positional observations of numbered minor planets for determination of star catalog errors

Medvedev Y., Kuznetsov V.
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The systematic errors of star catalogs have been defined by the O-C ("observed-calculated" residuals) for the asteroid positional observations. Improvement of asteroid orbits was carried out by differential method which was conducted in two steps. At the first step the orbital elements of Ceres, Pallas and Vesta were improved, taking into account the perturbations from the major planets, the Moon, Pluto using DE405 and their mutual perturbations. Then we calculated ephemerides of these three planets. To calculate the orbital elements of other numbered asteroids we used obtained ephemerides and all available positional observations. The mean value of O-C was calculated for each of 10212 equal areas on the celestial sphere and interpreted as a star catalog systematic bias for the corresponding area. Error of this value depends on number of O-C and number of planets which observations were used for calculation in this area. We calculated the systematic errors of USNO A2.0 and UCAC-2 and 3. The estimations of variation of systematic errors for the USNO A2.0 catalog have been defined also. Our calculation

shows considerable variation of systematic errors of USNO A2.0, especially in declination. This allows us to conclude, that values of systematic errors for this catalog are changed not only from area to area, but also with time. It means that the observations based on this catalog must be corrected not only depending on various areas, but various epochs as well.

Optical monitoring of QSOs in the framework of the Gaia space mission

[(1)]Taris F., [(2)]Damljanovic G., [(3,4,1)]Andrei A.
(1) SYRTE/Observatoire de Paris, France; (2) Astronomical Observatory, Serbia; (3) Observatyrio Nacional/MCTI, Brasil; (4) Observatyrio do Valongo/UFRJ, Brasil

The Gaia astrometric mission of the European Space Agency has been launched the 19th December 2013. It will provide an astrometric catalogue of 500.000 extragalactic sources that could be the basis of a new optical reference frame after the Hipparcos satellite one. On the other hand, the current International Celestial Reference Frame (ICRF) is based on the observations of extragalactic sources at radio wavelength. The astrometric coordinates of sources in these two reference systems will have roughly the same uncertainty. It is then mandatory to observe a set of common targets at both optical and radio wavelength to link the ICRF with what could be called the GCRF (Gaia Celestial Reference Frame). This poster presents the set of optical telescopes used to observe the targets chosen for the link of the two reference systems. More precisely we will focus on results obtained with the TJO, Telescopi Juan Oro, from Observatori Astronomic del Montsec in Spain. It also presents some results obtained with the Lomb-Scargle method applied to optical magnitude monitoring of extragalactic sources suitable for the GCRF-ICRF link. A morphological index is defined and applied to the 5000 images obtained during a first observation campaign.

Kinematics derived from Northern and Southern Galactic hemispheres of huge ICRS optical catalogues

Vityazev V., Tsvetkov A.
St. Petersburg State University, Russia

We present parameters of the stellar velocity field derived from proper motions of the new massive astrometric catalogues UCAC4, XPM, PPMXL. Our main goal is to see whether the parameters of the Ogorodnikov-Milne model are the same in northern and southern Galactic hemispheres. To avoid significant correlations in standard LS solution over a hemisphere we constructed the set of vector spherical harmonics which are orthonormal on a declination zone of the sphere. It was shown that several Ogorodnikov-Milne parameters change the sign when passing from one hemisphere to another. The attempts to explain these changes are made.

Session 2: Relativity and time scales

Abstracts for the oral session

The Time Transfer Function as a tool to compute range, Doppler and astrometric observables

(1)Hees A., (2)Bertone S., (2)Le Poncin-Lafitte C., (2)Teyssandier P.
(1) Rhodes University, South Africa; (2) SYRTE, Observatoire de Paris

In this talk, we will show how the Time Transfer Function (TTF) can be used in order to model the relativistic range, Doppler and astrometric observables. Therefore, the computation of light propagation can be replaced by the determination of the TTF. Then, we will review how the TTF can be determined as a post-Minkowskian expansion. The resulting formulas are quite simple and some analytical results will be presented in the cases of a gravitational field generated by a static point mass, a moving point mass, an axisymetric body and a moving axisymmetric body. We will also show how this formalism can be used to numerically determine the light propagation very efficiently at first and second post-Minkowskian order. Finally, some examples focusing on on-going and future space missions like Gaia, Juno and BepiColombo will be discussed.

Relativistic aspects of Gaia mission

Klioner S.
Lohrmann Observatory, Dresden University of Technology, Germany

The second ESA space astrometry mission Gaia launched on 19 December 2013 is expected to obtain astrometric, photometric and spectroscopic information for a total of a billion of celestial objects including stars, quasars, asteroids etc. The accuracy of Gaia will reach 10 microarcseconds for the stars optimal for Gaia observations. Such an accuracy requires adequate and thorough relativistic modelling of all parts of data processing chain. Relativistic aspects of the mission will be summarized. An overview of Gaia status will also be given.

On the definition and use of the ecliptic in modern astronomy

(1)Capitaine N., (2)Soffel M.
(1) SYRTE, Observatoire de Paris, France; (2) Lohrmann Observatory, Dresden University of Technology, Germany

The ecliptic was a fundamental reference plane for astronomy from antiquity to the realization of the FK5 reference system. The situation has changed considerably with the adoption of the International Celestial Reference system (ICRS) by the IAU in 1998 and the IAU resolutions on reference systems that were adopted between 2000 and 2009.They correspond to major improvements in concepts and realizations of astronomical reference systems, in the observational data used and the accuracy of the models for the motions of the solar system objects and Earth's rotation. First, the ICRS has the property of being independent of epoch, ecliptic or equator. Second, the IAU resolutions that followed specified the systems of space-time coordinates for the solar system and the Earth within the framework of General Relativity; they provided clear procedures for the transformation

between the barycentric and geocentric coordinates (i.e. BCRS and GCRS coordinates), but did not provide any definition of a GCRS ecliptic. These resolutions also provided the definition of the pole of the nominal rotation axis (the Celestial intermediate pole), and of new origins on the equator (the Celestial and Terrestrial intermediate origins), which do not require the use of an ecliptic. Therefore, the ecliptic has lost its importance. We will review the consequences of these changes and improvements in the definition and use of the ecliptic; then we will discuss whether the concept of an ecliptic is still needed for some specific use in modern astronomy.

Relativistic precession model of the Earth for long time interval

[(1)]Tang K., [(2)]Soffel M., [(1)]Tao J.-H., [(1)]Tang Z.-H.
(1) Shanghai Astronomical Observatory, China; (2) Lohrmann Observatory, Dresden University of Technology, Germany

A model of long-term precession was obtained by Vondrak et al., (2010) to provide an extension of IAU 2006 model of precession to scales of several thousand centuries. Now we develop their work to deal with long-term precession in a relativistic framework. The motion of the solar system is calculated in the BCRS by numerical integration with a symplectic integrator. Special Newtonian corrections accounting for tidal dissipation are included in the force model. The part of Earth's rotation is obtained in the GCRS by integrating the post-Newtonian equations of motion published by Klioner et al., (2003). All the main relativistic effects are included following Klioner et al., (2010) especially we considered several relativistic reference systems with corresponding time scales, scaled constants and parameters. Approximate expressions for the Earth's precession over several million years around J2000.0 are provided. The results are consistent with other long-term precession theories.

Work for IAU C52 (RIFA)

Soffel M.
Lohrmann Observatory, Dresden University of Technology, Germany

A report will be given on ongoing work to formulate a consistent relativistic VLBI theory and an exhaustive documentation. The gravitational time delay was reformulated by using the Time Transfer Method.

Gravitational redshift experiment with the space radio telescope RadioAstron

Litvinov D., Bartel N., Biriukov A., Kauts V., Kulagin V., Rudenko V.
Sternberg Astronomical Institute, Lomonosov Moscow State University, Russia

The space radio telescope RadioAstron has an ultra-stable hydrogen maser frequency standard on board, which offers a unique opportunity for testing the gravitational redshift effect. The accuracy of the anticipated experiment, taking into account the hydrogen maser's stability and accuracy, can reach a value of $\sim 10^{-6}$, which is 100 times better than the result of the GP-A mission. However, the lack of a specially designed on-board communications subsystem degrades this value by several orders of magnitude. We discuss the possibilities for overcoming this issue and present some results of the developed techniques.

The deflection of light induced by the Sun gravity field and measured with geodetic VLBI

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(1) Geoscience Australia, Australia; (2) Institute of Applied Astronomy RAS, Russia

The Sun's gravitational field deflects positions of close objects in accordance with the formulae of general relativity. The optical astrometry used to test the prediction only with the stars close to the Sun and only during total Solar eclipses. The geodetic VLBI technique is capable to measure the deflection of the light from distant radio sources anytime and around the whole sky. We show that the effect of light deflection is equivalent to the gravitational delay calculated for reduction of VLBI data. All reference radio sources display an annual circular motion with the magnitude proportional to their ecliptic latitude. In particular, the radio sources near the ecliptic pole draw an annual circle with magnitude of 4 mas. This effect could be easily measured with the current precision of the geodetic VLBI data.

Time and frequency transfer with a microwave link in the ACES/PHARAO mission

Le Poncin-Lafitte C., Delva P., Meynadier F., Guerlin C., Wolf P., Laurent P.
SYRTE, Observatoire de Paris, France

The Atomic Clocks Ensemble in Space (ACES/PHARAO mission), which will be installed on board the International Space Station, uses a dedicated two-way Micro-Wave Link (MWL) in order to compare the timescale generated on board with those provided by many ground stations disseminated on the Earth. Phase accuracy and stability of this long range link will have a key role in the success of the ACES/PHARAO experiment. SYRTE laboratory is heavily involved in the design and development of the data processing software: from theoretical modelling and numerical simulations to the development of a software prototype. Our team is working on a wide range of problems that need to be solved in order to achieve high accuracy in (almost) real time. In this article we present some key aspects of the measurement, as well as current status of the software's development.

Abstracts for the poster session

Parametric invariance of the relativistic pulsar time scales

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Pulsar time scales which are described usually in the barycentric reference system cannot be extended to other coordinate systems in the 4D space. Our approach is based on an approximation of topocentric and barycentric timing intervals obtained in numerical form by the planetary ephemeris, in the form of analytic functions, expressed in terms of the parameters of the pulsar rotation. By matching the numerical values of the observable intervals and approximating functions, we obtain two invariant equations whose solutions are the observable rotation parameters of the pulsar in the topocentric and barycentric coordinate systems. The rotation period and derivatives correspond to the epoch observation in the scales of the local coordinate time. On matching the epochs the numerical values of the rotation period and derivatives in the coordinate systems are

identically equal. This confirms the metric equivalence observable and approximate intervals concerning their coordinate transformations, taking into account the relativistic motion of spatial reference systems to represent the observable intervals in numerical form. The uncertainty of the intervals approximated by the rotation parameters of pulsar is limited within nanosecond range during several years of observations, which is comparable with inconsistency of the instrumental atomic time scales and planetary ephemeris.

Gravitational effects from a series of IVS R&D VLBI-sessions with observations close to the Sun

Heinkelmann R., Soja B., Schuh H.
GFZ Potsdam, Germany

In 2011 and 2012 a series of twelve IVS R&D (research and development) sessions has been carried out including successful observations with Sun elongation angles as small as about 4 degree. Based on the analysis of these sessions we assess the capability of VLBI to determine Sun-related parameters by evaluating extended models of higher order gravitational effects. We investigate (i) the influence of the non-stationary gravitational field caused by the Sun's velocity, (ii) the determination of a second zonal harmonic coefficient and of the Sun's radius via the Sun's gravitational quadrupole field, and (iii) the Sun's angular momentum via the gravitational delay induced by the Sun's rotation. We will also comment on the usefulness of observations under small Sun elongation angles for the derivation of the parameterized post-Newtonian parameter gamma.

Session 3: Solar and extrasolar systems dynamics

Abstracts for the oral session

Development of orbital elements of the Moon and planets to compact analytical series
Kudryavtsev S.
Sternberg Astronomical Institute, Lomonosov Moscow State University, Russia

We discuss various approaches presently used for representation of planetary/lunar ephemerides by analytical series. The emphasis on methods of frequency analysis of numerical ephemerides is done. A historical background on the topic and comparison of the development series with modern analytical motion theories and numerical ephemerides of the Moon and planets are presented.

Resonances in the Solar and exoplanetary systems
Shevchenko I.
Pulkovo Observatory RAS, Russia

Dynamical problems on the orbital resonances, including mean motion resonances (both two-body and three-body ones) and secular resonances, are considered in application to the dynamics of the Solar and exoplanetary systems. The analyzed systems include multiplanetary (those with two or more than two planets) systems and planetary systems of double stars. Theoretical methods and criteria for revealing stability or instability of various planetary configurations are described.

Investigation of asteroids in Pulkovo Observatory
Devyatkin A., Gorshanov D., L'vov V., Tsekmeister S., Petrova S., Martyusheva A., Slesarenko V., Naumov K., Sokova I., Sokov E., Zinoviev S., Karashevich S., Lyashenko A., Rusov S., Kouprianov V., Bashakova E.
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Laboratory of Observational Astrometry and Sector of Ephemerid Supplying of Pulkovo Observatory make complex investigations of asteroids belonging to various groups. Astrometric and photometric observations are made with ZA-320M and MTM-500M telescopes situated in Pulkovo and at Northern Caucasus correspondingly. The results of light-curves observations allow determination of spin parameters of asteroids and estimation of their form. Observations with wideband filters allow determination of colour indices and estimation of taxonomy classes of asteroids. Orbit enhancement of asteroids is executed with use of the results of positional measurements. The modelling of orbital evolution of asteroids is made including taking in account non-gravitational effects: light pressure and Yarkovsky's effect. NEAs as well as binary asteroids have important place in our investigations. Quasi-satellites of Venus, Earth and Mars are new direction of our researches. The example of the asteroids is 2012 DA14. It had approach to Earth in early 2013 and a lot of observations of the asteroid were made with MTM-500M telescope around this event.

The binary asteroid 22 Kalliope: Linus orbit determination on the basis of speckle interferometric observations

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The present work describes the determination of the orbital elements of the Linus satellite of 22 Kalliope binary asteroid. The orbital element determination is based on the observed data collected with the use of speckle interferometry on the 6-m BTA telescope operated by SAO RAS. 9 clear positions of Linus orbiting around the main component 22 Kalliope have been obtained during the period from December 10, 2011 to December 16, 2011. Using the observed data of 1.5 period of Linus revolution around the main component 22 Kalliope we have been able to plot an almost instantaneous orbit of Linus at the mean epoch of observation. In order to measure the orbital elements we have applied the direct geometric method that allowed us to calculate the elements with the precision of 5 mas. Achieved precision of calculations will make it possible to study variations of the Linus orbital elements influenced by different perturbations over the course of time. All of the obtained estimations of six classical orbital elements, such as the semi-major axis of the Linus orbit a = 1109 ± 6 km, eccentricity e = 0.016 ± 0.004, inclination i = 101 ± 1 degrees to the ecliptic plane and others, are presented in this work.

Evolution of ephemerides EPM of IAA RAS

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The evolution of numerical EPM ephemerides of the IAA RAS from available EPM2004, EPM2008, EPM2011, to the new version EPM2014 is presented briefly. The comparison progress of ephemerides includes: program software from ERA-7 to ERA-8 (see the presentation by D. Pavlov and V. Skripnichenko); the growing database of different types of observations from classical optical to radio technical of spacecraft from 1913 to 2014, enlarged by three times up to 100000 measurements; improved dynamical model from mutual perturbations of all planets, the Sun, the Moon, 301 largest asteroids to additional perturbations from of 30 largest trans-neptunian objects (TNO) and perturbations from remaining smaller asteroids and TNO modeled by the two-dimensional asteroid ring and the one-dimensional TNO ring; about 280 adjusted parameters. Improvement of accuracy for the planet orbital elements (see the presentation by A. Girdiuk about Pluto), and ephemeris accuracy for all planets obtained by comparison with the last DE432 version are shown.

Improvement of the Pluto orbit using additional new data

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Observational series of the Pluto dwarf planet has started since 1914. At this moment observations have covered only a third of the Pluto orbit, therefore, the Pluto orbital elements are defined with insufficient accuracy. Growing in the number of observations leads to improvement of the accuracy of the orbit determination. The database of the Pluto's observations was expanded with help of about 350 observations during 1930–1996 obtained at Pulkovo Observatory, and about 5500 observations (1995–2013) including occultation data by Brazilian colleagues obtained at European Southern Observatory and

Pico dos Dias Observatory. The process of constructing the Pluto's orbit consists of numerical integration of the equations of planet motion, calculation of the partial derivatives and residuals of Pluto observations, and evaluation of the corrections to the Pluto's orbital elements by the least squares method. A new cross-platform software ERA-8 has been developed in IAA RAS for implementation of all mathematical procedures. Several ephemerides (EPM2011, EPM2014, DE430) are used for comparison of the errors of orbital elements and differences in the equatorial coordinates and distance. These calculated differences are presented graphically. Main result of the work is significant improvement of the Pluto's orbit using additional observations.

Phobos mass estimations from MEX and Viking1 data: influence of different noise sources and estimation strategies

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The mass of Phobos (GM more precisely) estimated by different authors based on diverse data-sets and methods, varies by more than 1-sigma error. The most complete lists of GM values are presented in the works of R. Jacobson (2010) and M. Paetzold et al. (2014) and include the estimations in the interval $[5.39–8.5]\times10^5$ [m^3/s^2]. Furthermore, even the comparison of the estimations coming from the same estimation procedure applied to the consecutive flybys of the same spacecraft shows big variations in GMs. The indicated behavior is very pronounced in the GM estimations stemming from the Viking1 flybys in February 1977 (as well as from MEX flybys, though in a smaller amplitude) and in this work we made an attempt to figure out its roots. The errors of Phobos GM estimations depend on the precision of the model (e.g. accuracy of Phobos a priori ephemeris and its a priori GM value) as well as on the radio-tracking measurements quality (noise, coverage, flyby distance). In the present work we are testing the impact of mentioned above error sources by means of simulations. We also consider the effect of the uncertainties in a priori Phobos positions on the GM estimations from real observations. Apparently, the strategy (i.e. splitting real observations in data-arcs, whether they stem from the close approaches of Phobos by spacecraft (s/c) or from analysis of the s/c orbit evolution around Mars) of the estimations has an impact on the Phobos GM.

Expansion of the Hamiltonian of the planetary system into the Poisson series in all elements

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Work is related to the problem of planetary system Hamiltonian expansion into the Poisson series. Hamiltonian is written in Jacobi coordinate system, which is useful for research of planetary systems dynamic evolution. We used second system of Poincare elements. It allows simplifying an angular part of series. In this case only one angular element – mean longitude, is defined. Computer algebra system "Piranha" is used for expansion of the Hamiltonian. "Piranha" is new specialized system, used for analytical calculation in celestial mechanics. Use of celestial mechanics special functions, such as Legendre polynomials, allows reducing of number expansion terms, necessary working memory and disc space. We present algorithm of four planetary system Hamiltonian expansion into the Poisson series for all orbital elements. The Hamiltonian was received to the second (third) degree of small parameter.

Some orbital peculiarities of observed comets

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Orbital elements of all observed comets were investigated that allows us to reveal some interesting peculiarities. Very old comets (until 1760) and small sungrazers were excluded from the statistical analysis (eccentricity e = 1 was adopted for all these comets with poor observational history). It should be noted the comparable amount of short-period comets (almost all with e<0.9), long-period comets (0.9<e<1), comets with parabolic orbits (e=1) and hyperbolic ones (e>1). This fact corresponds to the recent simulation results on the comet origin and orbital evolution. Spatial distribution of the perihelia coordinates reveals the expected strong concentration of the short-period comets to the ecliptic plane. Otherwise, all other groups of comets (long-period with 0.9<e<1, parabolic e=1, hyperbolic e>1) show very similar perihelia distribution but strongly different from the short-period comets and concentrated to the galactic plane.

Long-time dynamical evolution of highly elliptical satellites orbits

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We consider dynamical evolution of objects near Molniya-type orbits. Initial conditions correspond to highly elliptical satellite orbits with eccentricities 0.60–0.65 and a critical inclination 63.4 degrees. Semi-major axis values are varied near resonant value 26560 km in an interval 500 km. Variations were analyzed for positional orbital elements, an ascending node longitude and an argument of pericenter. Initial conditions determined when orbital elements variations are minimal. These regions can be used as orbits for safe stationing passive satellites which finish work on Molniya-type orbits. The study of dynamical evolution on long time intervals was performed on the basis of the results of numerical simulation. We used "A Numerical Model of the Motion of Artificial Earth's Satellites", developed by the Research Institute of Applied Mathematics and Mechanics of the Tomsk State University. The model of disturbing forces taken into account the main perturbing factors: the gravitational field of the Earth, the attraction of the Moon and the Sun, the tides in the Earth's body, the solar radiation pressure, taking into account the shadow of the Earth, the Poynting-Robertson effect, and the atmospheric drag. Time interval was up to 240 yr. Area-to-mass ratio varied from small values corresponding to satellites to big ones corresponding to space debris.

Planned LLR station in Russia and its impact on the lunar ephemeris accuracy

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There are some plans to construct the new LLR station in Siberia region of Russia. To check the urgency of the project it should be shown in particular that the accuracy of the lunar ephemeris will visibly increase. The only way to prove that fact now is the numerical simulation. This numerical simulation was made in suggestion that planned LLR station was operated together with the existing ones during some time interval in the past. Several observation plans were considered for simulated LLR station including different time tables and the distributions of observed lunar reflectors. The accuracy of the following

parameters was estimated depending on the conditions above: initial Moon position and velocity, initial Euler angles and their derivatives, reflectors positions, parameters of gravitational potential of the Moon and so on. Results of numerical simulation are presented depending on the observation plans. It was shown that the accuracy of the lunar ephemeris visibly increased.

Abstracts for the poster session

Local test of General Relativity with Solar System objects

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The Gaia mission from ESA that has been launched in December 2013 will revolutionaries future astrometry of celestial objects (as well as past one, from e.g. digitalization and re-reduction of ancient plates [1]). From the long-term (5 years nominal) and high precision data collected on Solar System Objects, Gaia will also huge step in science of SSOs [2]. Since positions of about 300,000 asteroids will be given to sub-milliarcsecond precision, local tests of General Relativity can be performed [3] independently of other existing tests. The very accurate orbits that will be retrieved – in particular for the Near-Earth Objects, and possibly complemented by other high precision data such as radar -- will enable to determine simultaneously the solar J2 and the PPN parameter beta, together with other parameters and linking of a dynamical reference frame. [1] Arlot J-E. The astrometry of the natural planetary satellites applied to their dynamics before and after Gaia. PSS 73, 66 [2] Mignard F. et al. 2007. The Gaia Mission: Expected Applications to Asteroid Science. EM&P. 101, 97 [3] Hestroffer et al. 2010. Gaia and the asteroids: Local test of GR. Proc. IAUS 261, 325

Taking the opportunity of the Gaia reference star catalogue for observing the Solar system in the past

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The Gaia astrometric catalogue of reference star will provide proper motions of stars with an accuracy better than 10 mas over one century. So, we may reduce all astrometric observations of Solar System objects made since the end of the XIXth century with an accuracy better than the present accuracy of the best reference star catalogues such as the UCAC2 or UCAC4. This should solve or considerably reduce the problems of biases in ephemerides because of zonal errors in the catalogues. We performed tests on photographic plates and, thanks to the use of sub-micrometric scanners, we succeeded to improve the reduction of plates made in the 1960's for planetary satellites. Even with an accuracy less than the expected one of the future Gaia catalogue, we show a systematic shift of the ephemerides during the last decades.

Statistical inversion method for binary asteroids' orbit determination

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We focus on the study of binary asteroids, which are common in the Solar system from its inner to its outer regions. These objects provide fundamental physical parameters such as mass and density, and hence clues on the early Solar System, or other processes that are affecting asteroid over time. The present method of orbit computation for resolved binaries is based on Markov Chain Monte-Carlo statistical inversion technique. Particularly, we use the Metropolis-Hasting algorithm with Thiele-Innes equation for sampling the orbital elements and system mass through the sampling of observations. The method requires a minimum of four observations, made at the same tangent plane; it is of particular interest for orbit determination over short arcs or with sparse data. The observations are sampled within their observational errors with an assumed distribution. The sampling yields the whole region of possible orbits, including the one that is most probable. Acknowledgements: work is supported by Labex ESEP (ANR N 2011-LABX-030)

Diagrams of stability of circumbinary planetary systems

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The stability diagrams in the "pericentric distance – eccentricity" plane of initial data are built and analysed for Kepler-38, Kepler-47, and PH1. This completes a survey of stability of the known up to now circumbinary planetary systems, initiated in (Popova and Shevchenko, 2013), where the analysis was performed for Kepler-16, 34, and 35. In the diagrams, the planets appear to be "embedded" in the fractal chaos border; however, I make an attempt to measure the "distance" to the chaos border in a physically consistent way. The obtained distances are compared to those given by the widely used numerical-experimental criterion by Holman and Wiegert (1999), who employed smooth polynomial approximations to describe the border. I identify the resonance cells, hosting the planets.

Measures of the Earth obliquity during 1701 winter solstice at the Clementine meridian line in Rome

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The great meridian line in the Basilica of Santa Maria degli Angeli in Rome was built in 1701/1702 with the scope to measure the Obliquity of the Earth's orbit in the following eight centuries, upon the will of pope Clement XI. During the winter solstice of 1701 the first measurements of the obliquity have been realized by Francesco Bianchini, the astronomer who designed the meridian line, upgrading the similar instrument realized by Giandomenico Cassini in San Petronio, Bononia. The accuracy of the data observed by Francesco Bianchini is discussed and compared with up-to-date ephemerides. The modern situation of this historical instrument is also presented.

Bodies with higher spin-multipole moments

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We have constructed various models for bodies with higher spin-multipole moments. Especially the model of a rigidly rotating oblate spheroid is of interest. These higher moments are computed for the Sun and the planets; conclusions for corresponding Lense-Thirring effects are given.

Method of determining the orbits of the small bodies in the Solar system based on an exhaustive search of orbital planes

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We have developed a new method for determination of small bodies' orbits in the Solar system using their positional observations. In this method the exhaustive search for heliocentric orbital planes of a small body is used. For each plane we obtain the geocentric distances of a small body at times of observations. The orbital elements are determined by the Gauss method using the first and last observations. The obtained sets of elements are used to calculate the rms between the observed and calculated positions. Further, we consider the plane, which gives the least rms, to be the most probable one. Afterwards, the elements, associated with this plane, are improved using the differential method.

Session 4: Earth's rotation and geodynamics

Abstracts for the oral session

Do we need various assumptions to get a good FCN? – A new multiple layer spectral method

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Free core nutation (FCN) is a rotational modes of the earth with fluid core. All traditional theoretical methods produce FCN period near 460 days with PREM, while the precise observations (VLBI + SG tides) say it should be near 430 days. In order to fill this big gap, astronomers and geophysicists give various assumptions, e.g., increasing core-mantle-boundary (CMB) flattening by about 5%, a strong coupling between nutation and geomagnetic field near CMB, viscous coupling, or topographical coupling etc. Do we really need these unproved assumptions? Or is it only the problem of these traditional theoretical methods themselves? Earth models (e.g. PREM) provide accurate and robust profiles of physical parameters, like density and Lame parameters, but their radial derivatives, which are also used in all traditional methods to calculate normal modes (e.g. FCN), nutation and tides of non-rigid earth theoretically, are not so trustable as the parameters themselves. Moreover, the truncation of the expansion series of displacement vector and stress tensor in traditional methods is also of question. A new multiple layer spectral method is proposed and applied to the computation of normal modes, to avoid these problems. This new method can solve not only one order ellipsoid but also irregular asymmetric 3D earth model. Our primary result of the FCN period is 435 sidereal days.

The global S1 tide and Earth's nutation

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Diurnal S1 atmospheric oscillations induced by the cyclic heating of air masses through solar radiation exert small contributions to Earth's prograde annual nutation at a level of 0.1 mas (milliarcseconds). This study reviews the thermal excitation mechanisms and global distribution of the S1 tide, highlighting characteristics of its seasonal modulation as well as local-scale features that are of major relevance for an accurate prediction of celestial Earth rotation variations. We retrieve numerical values of in- and out-of-phase nutation corrections for S1 and its side lobes from three, previously unavailable global atmospheric reanalyses and indicate how model advances, e.g. in terms of temporal and spatial resolution, lead to different estimates with respect to now dated predecessor reanalyses. Motion term forcing of nutation exhibits a clear stability across all probed datasets, whereas the agreement among the mass term excitation seems to be impaired by an unfavorable dependency on local tidal oscillations. Diurnal oceanic angular momentum changes – forced by the S1 air pressure variations at the water surface – act as an additional driving agent of the prograde annual nutation, and we investigate to which extent oceanic excitation terms from various sources can be superposed to the deduced atmospheric estimates. The combined influence of the principal diurnal tide on Earth's nutation, related to both atmosphere and ocean dynamics, is found to yield a rough

agreement with its observational evidence from geodetic VLBI (Very Long Baseline Interferometry) measurements.

Refinements on precession, nutation, and wobble of the Earth
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Most of the essential elements of the theory of nutation of the no rigid Earth have been presented in the IAU adopted model MHB2000. However in the meantime, the observation number and the observed nutation amplitudes have been redetermined with a better precision. A number of relatively small effects have to be taken into account before one can expect to have a theoretical framework that can yield numerical results that match the observational data on nutation and precession to approximately the same level of accuracy as the precision of the observations themselves. The adopted model already accounts for the geomagnetic field passing through the mantle and the fluid core regions and beyond, and showed that the electromagnetic torque generated by this field when the core and the mantle are in relative motion can affect some nutation amplitudes (both in phase and out of phase) to the extent of a few hundred microarcsecond, playing thus a significant role. The presentation revisits the last adopted model in order to incorporate potential additional effects at an observable level like the existence of a non-hydrostatic core-mantle boundary topography, the viscosity of the liquid core, the existence of a stratification in the core, of boundary layers at both sides of the core-mantel boundary etc.

Possible improvements in the IAU 2006 precession based on recent progresses
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This work aims at studying possible improvements in the IAU 2006 expressions for the precession of the ecliptic and the precession of the equator based on more recent developments in Solar system dynamics and more recent determinations of the Earth's gravitational field by satellite observations. The integration of the equations for the precession of the equator are made in a similar method as that used for obtaining the IAU 2006 model and the solutions are compared with the most recent series of VLBI celestial pole offsets.

Towards new nutation theory
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Time series of the Earth orientation parameters (EOP) were calculated. The ARIADNA software was used to obtain solutions: at first for the catalog ICRF-2. Corrections to sources' positions and apparent velocities of sources were used to obtain the second solution of the EOP. Time series of the nutation angles for both solutions are analyzed. Corrections for the precession constants and main nutation term are estimated.

Moon influence on equatorial atmospheric angular momentum and consequences for nutation

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Equatorial oscillation of the atmospheric angular momentum is investigated in a non-rotating frame in relation with the lunar tide. Between 2 day and 30 days, the corresponding equatorial component or Celestial Atmospheric Angular Momentum (CEAM) is mostly composed of prograde circular motions. Main components are an harmonic at 13.66 days O_1 diurnal tide in the terrestrial frame) presenting side-lobe at 13.63 days, and a weekly broad band variation. The 13.6 day terms are clearly linked with tidal influence of the Moon on the atmosphere; the powerful episodic fluctuations between 5 and 8 days possibly reflect an atmospheric normal mode excited by the tidal waves $2Q_1$ (6.86 days) and σ_1 (7.095 days). Moreover, between 2 day and 30 days, the CEAM present two specific features by contrast to seasonal band dominated by solar thermal effect: i) pressure term and wind term are almost proportional; ii) north and south hemispheres contribute equally and synchronously two the wind term. This can be explained by the tidal origin of these variations, provided that the atmospheric torque on the solid Earth mostly results from the equatorial bulge in the considered frequency band. Finally possible effect on Earth nutation is discussed.

Estimation of nutation rate from combination of ring laser and VLBI data

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Ring laser gyroscopes are instruments measuring inertial rotations locally and in real-time without the need for an external reference system. They are sensitive to variations in the instantaneous rotation vector, therefore they are considered as a potential complement to space geodetic techniques for studying Earth rotation. To date many experiments have been conducted in order to investigate possible advantages of combining ring laser observations and data from space techniques, especially from Very Long Baseline Interferometry (VLBI). The majority of those experiments concerned polar motion and UT1 variations at diurnal and subdiurnal frequencies. In this work we examine the usability of ring laser observations for estimation of nutation rates. We investigate possibilities of computing those parameters from only one ring laser within a combination solution with VLBI and GNSS data.

On application of the complex demodulation procedure for monitoring Earth rotation: comparison with the standard approach using the long periodic EOP components estimated from VLBI data analysis by the VieVS CD software

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In the recent works (Boehm et al., J. Geodynamics, 62 (2012) 56–68; Brzezinski and Boehm, Proc. Journees 2011, 132–135) we demonstrated the application of the complex

demodulation (CD) technique for VLBI estimation of the Earth orientation parameters (EOP). This technique enables simultaneous determination of the long period components of polar motion (x,y), universal time dUT1 (=UT1-UTC) and nutation (celestial pole offsets dX,dY) as well as the high frequency (diurnal, semidiurnal, ...) components of polar motion and dUT1. In this work we discuss advantages of this approach over the conventional procedures applied for the EOP estimation. We also show results of an analysis of the long periodic time series x, y, dUT1, dX, dY derived by the complex demodulation algorithm implemented in the Vienna VLBI Software (VieVS CD). Results are compared to those based on the EOP series based on the standard VieVS run as well as to the combined EOP solutions provided by the IVS and the IERS.

Effects of the tidal mass redistribution on the Earth rotation

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The effects of the tidal mass redistributions on the Earth precession and nutations are revisited, using the Hamiltonian approach and different hypothesis on the elastic response of the Earth. New non-negligible secular and periodic contributions have been found.

New high-precision earth and moon rotation series at long time intervals

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Dynamics of the rotational motion of the Earth and Moon is investigated numerically at a long time intervals. In our previous studies (Pashkevich, 2013), (Pashkevich and Eroshkin, 2011) the high-precision Rigid Earth Rotation Series (designated RERS2013) and Moon Rotation Series (designated MRS2011) were constructed. RERS2013 are dynamically adequate to the JPL DE422/LE422 (Folkner, 2011) ephemeris over 2000 and 6000 years and include about 4113 periodical terms (without attempt to estimate new sub-diurnal and diurnal periodical terms). MRS2011 are dynamically adequate to the JPL DE406/LE406 (Standish, 1998) ephemeris over 418, 2000 and 6000 years and include about 1520 periodical terms. The main aims of present research are improvement of the Rigid Earth Rotation Series RERS2013 and Moon Rotation Series MRS2011, and as a result of the construction of the new high-precision Rigid Earth Rotation Series RERS2014 dynamically adequate to the JPL DE422/LE422 ephemeris over 2000 years and Moon Rotation Series MRS2014 dynamically adequate to the JPL DE422/LE422 ephemeris over 6000 years. The elaboration of RERS2013 is carried out by means recalculation of sub-diurnal and diurnal periodical terms. Improve the accuracy of the series MRS2011 is obtained by using the JPL DE422/LE422 ephemeris.

Numerical-analytical modeling of the Earth's pole oscillations

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For the purpose of more accurate forecasting the oscillatory process of the Earth pole in time periods with significant anomalies (irregular deviations) a numerical-analytical approach is presented for the combined modeling of the interdependent dynamical processes – the oscillatory-rotational motion of the Earth and the time dependant

coefficients of the geopotential. The oscillations of the inertia tensor components of the Earth depend on various factors such as mechanical and physical parameters of the planet, the motions of the tide-generating bodies and observed large scale natural events. Time variations of these and some other factors affect the Earth orientation parameters. The generalization of the previously researched mathematical model of Chandler and annual oscillations of the Earth pole is being held with the use of celestial mechanics methods and the mathematical description of the Earth gravitational field's temporal variations. The latter makes possible to improve the forecast precision of the Earth pole trajectory. Also the more precise model is to have small number of parameters and to agree with the previously developed one (to have the same structural features and to have a correspondence between the averaged dynamical parameters and the parameters of the basic model).

Comparison of polar motion excitation functions computed from different sets of gravimetric coefficients

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Since its launch in February, the Gravity Recovery and Climate Experiment (GRACE) has been source of data of temporal changes in Earth's gravity field. These gravity fields can be used to determine the changing mass field of the Earth caused by redistribution of the geophysical fluids, and from that excitations of polar motion. The so-called Level 2 gravity field product are available, in the form of changes in the coefficients: Cnm Snm. Since 2002 until the present time there are still attempts to better process these data. In this study we estimate gravimetric excitation of polar motion using a recent series of C21, S21 coefficients. In our calculations we use several series developed by different centers. Firstly, we compare these gravimetric functions with each other. Then we examine the compatibility of these functions with hydrological signals in observed geodetic excitation function. We focus on seasonal and subseasonal time scales. The main purpose is to explore which from these several solutions are closed to observation.

Geomagnetic excitation of nutation

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We tested the hypothesis of Malkin, who recently proposed that the observed changes of FCN phase and amplitude occur near the epochs of geomagnetic jerks. We found that if the numerical integration of Brzezinski broad-band Liouville equations of atmospheric/oceanic excitations is re-initialized close to the epochs of geomagnetic jerks, the agreement between the integrated and observed celestial pole offsets is improved. This approach however assumes that the influence of geomagnetic jerks has a stepwise change in the position of celestial pole, which is physically not acceptable. Therefore we introduce a simple continuous excitation function that hypothetically describes the influence of geomagnetic jerks, and leads to rapid but continuous changes of pole position. The results of numerical integration of atmospheric/oceanic excitations plus this newly introduced excitation are then compared with the observed celestial pole offsets, and prove that the agreement is improved significantly.

The Chandler wobble of the poles and its amplitude modulation
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It is shown that the period of the Chandler wobble of the poles (CWP) is a combined oscillation caused by three periodic processes experienced by the Earth: (a) lunisolar tides, (b) the precession of the orbit of the Earth's monthly revolution around the barycenter of the Earth-Moon system, and (c) the motion of the perigee of this orbit. The addition of the 1.20-year Chandler wobble to sidereal, anomalistic, and synodic lunar yearly forcing gives rise slow periodic variations in the CWP amplitude with periods of 32 to 51 years.

Prediction of the Chandler wobble
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Instability of the Chandler wobble reduces predictability of the long term polar motion (>6 months). We design the narrow-band filters to extract Chandler wobble and study its complex envelope based on Gabor window-transform. Amplitude and phase modulation of the Chandler wobble are unveiled in this way, 40 and 80-year modulations are found and modeled. Regularities of the envelope permit to predict the Chandler wobble. Using Euler-Liouville equation we derive the relation between Chandler wobble envelope and underlying excitation envelope. We confirm 20-year modulation in the Chandler excitation. Possible link with climate cycles is discussed.

Operative EOP activities in VNIIFTRI
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VNIIFTRI as the Russian Main Metrological Center of Time, Frequencies and Earth Rotation Service carried out the rapid EOP processing based on GNSS, VLBI and SLR observations for many years. VNIIFTRI takes participation in GNSS and SLR observations of IGS and ILRS too. The EOP activities at VNIIFTRI can be grouped in four basic topics: 1) Processing GNSS, SLR and VLBI observation data for EOP evaluation; 2) Combination of EOP series for evaluation of reference EOP values; 3) Combination of GLONASS satellites orbit/clock; 4) Providing GNSS and SLR observations at five metrological sites acting under the auspices of VNIIFTRI. The processing of GNSS, SLR and VLBI observations is currently executed with the help of modern application program packages such as BERNESE GPS software, OCCAM software and VieVs software that were properly adapted to the rapid service mode. Combining daily EOP are calculated in Russian Main Metrological Center by means the combination of the eight independent individual EOP series provided by four Russian analysis centers. The orbit/clock combination is carried out by means of the software which has been recently developed in VNIIFTRI. GNSS observations on the five metrological sites are carried out permanently and hourly files are formed. The results of observations are collected in Russian Main

Metrological Center in hourly mode. SLR observations are carried out at Mendeleevo and Irkutsk.

Application of the wavelet semblance filtering to determine the geocenter motion stochastic model

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The origin of the International Terrestrial Reference Frame (ITRF) is considered as the center of figure (CF) while the center of the whole Earth including atmosphere, oceans and continental water is recognized as the center of mass of the Earth (CM). CM is instantaneous due to mass redistributions in the fluid layers and its variations with respect to the CF are usually defined as geocenter motions. The geocenter coordinates time series, used in analyses, are determined from observations of space geodetic techniques such as Satellite Laser Ranging (SLR), Global Navigation Satellite System (GNSS) and Doppler Orbitography and Radiopositionig Integrated on Satellite (DORIS). These data were listed in pairs SLR-DORIS, SLR-GNSS, GNSS-DORIS and filtered using wavelet based semblance filtering which allows computing a common signal in two time series. The common signals in the pairs of the geocenter time series were then used to compute weighted common model of the geocenter motion assuming that weights for particular techniques as inversely proportional to the variances of the corresponding geocenter coordinates. To find geophysical interpretation of the geocenter motion model the first degree gravity coefficients determined from ocean and atmospheric models and GRACE coefficients of degrees 2 and higher were examined. The wavelet semblance functions between such first degree gravity coefficients and the geocenter motion model show agreement in the phase and amplitude of the annual oscillation in all projections of this motions onto XY, YZ and ZX planes of the ITRF.

Deformation of the South-Eastern Baltic Shield from GNSS observations

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The Pulkovo observatory is situated in a unique geological setting. Within only 300 kilometers from Northern Karelian Isthmus to a few kilometers south from the observatory the Archean, Paleo and Neo Proterozoic, Cambrian, Ordovician, Devonian, and Carboniferous rocks are sequentially surfacing. Thus this 300 kilometers in distance correspond to 3 billion years in geologic time. The city of St. Petersburg marks a transition zone from the Baltic Shield to the East European Platform, and the observatory is built on the Baltic Klint that in turn marks a transition from Ediacaran to Devonian. Such a rich geological constitution of the region summons a need for geodynamical studies. The authors have recently gathered the GNSS observations available in the region from 1993 until present, including those made by the authors, with permanent and high quality field GNSS stations. These measurements were processed with the GIPSY software using the PPP strategy. The resulting coordinates were then adjusted for atmospheric and hydrological loading corrections, and station velocities were omputed. The station

velocities were then used for estimation of the regional deformation field. The resulting deformation field shows a weak meridional compression and possibly a slow clockwise rotation of the Baltic shield with respect to the East European platform.

Abstracts for the poster session

GLONASS orbit/clock combination in VNIIFTRI

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An algorithm and a program for GLONASS satellites orbit/clock combination based on daily precise orbits submitted by several Analytic Centers were developed. The calculation results of combine GLONASS satellites orbits and clock corrections as well as the coordinate differences for GNSS antennas positions in VNIIFTRI (Mendeleevo, Moscow reg.) and the North-Eastern branch of VNIIFTRI (Irkutsk) based on orbit/clock solutions of different Centers are provided. Some theoretical estimates for combine orbit positions RMS were derived. It was shown that under condition that RMSs of satellite orbits provided by the Analytic Centers during a long time interval are commensurable the RMS of combine orbit positions is no greater than RMS of other satellite positions estimated by any of the Analytic Centers.

On the minimization properties of the Tisserand systems

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Tisserand systems are a useful concept to model the rotation of deformable sets of particles. They can be characterized by the condition (definition 1) that the rotational angular momentum of the set of particles can be expressed formally as if it were rigid, introducing in this way the angular velocity of the Tisserand system which determines its rotational evolution. Other possible characterization (definition 2) is achieving by imposing that the deformation kinetic energy of the set must reach a minimum, what also allows obtaining an expression for the angular velocity vector. Usually the equivalence of both of them is established by showing, partially, that definition 2 leads to definition 1 (e. g., Moritz and Mueller 1986). In this note, we prove that equivalence in the contrary sense, that is to say, that definition 1 implies definition 2. In addition, we revisit other properties of those constructions such the dependence of the Tisserand system on an initial orientation. Moritz, H., Mueller, I.: Earth Rotation. Frederic Ungar, New York (1986)

Study of the pole tide triggering of seismicity

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The pole tide (PT) of the Earth is generated by the centrifugal effect of polar motion on the chandler and annual frequencies (0.84 – 1.0 cpy). These frequencies, their beat frequency (0.16 cpy) and doubled frequency of chandler wobble (1.66 cpy) were revealed in seismic intensity spectrum. The failure time for the weak earthquakes with magnitudes $3 < Mw < 5$ averages 1–10 years for various regions that is in a good agreement with the periodicity of

stress oscillations excited by PT. The global CMT (Centroid-Moment-Tensor) catalogue (1976–2014) were used for search of the pole tide influence on the intensity of seismic process. For 32.2 thousand seismic events from CMT were calculated normal and shear stresses excited by PT using strike, dip and rake angles of the earthquake fault plane from this catalogue. The phases of the PT stresses for each earthquake were assessed and then they were used for statistical estimation of pole tide influence on seismicity. The PT stress oscillations excite the week (Mw < 5.5) earthquakes of reverse fault type on 5% significance level by χ^2 and Schuster's statistical tests. The shear and normal PT stresses for these types of earthquakes have the same phase. It is probably this fact that explains triggering of seismicity by weak enough PT stress variations (less 1 kPa).

Estimating the period and Q of the Chandler Wobble from observations and models of its excitation

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Any irregularly shaped solid body rotating about some axis that is not aligned with its figure axis will freely wobble as it rotates. For the Earth, this free wobble is known as the Chandler wobble in honor of S.C. Chandler, Jr. who first observed it in 1891. Unlike the forced wobbles of the Earth, such as the annual wobble, whose periods are the same as the periods of the forcing mechanisms, the period of the free Chandler wobble is a function of the internal structure and rheology of the Earth, and its decay time constant, or quality factor Q, is a function of the dissipation mechanism(s), like mantle anelasticity, that are acting to dampen it. Improved estimates of the period and Q of the Chandler wobble can therefore be used to improve our understanding of these properties of the Earth. Here, estimates of the period and Q of the Chandler wobble are obtained by finding those values that minimize the power within the Chandler band of the difference between observed and modeled polar motion excitation spanning 1962–2010. Atmosphere, ocean, and hydrology models are used to model the excitation caused by both mass and motion variations within these global geophysical fluids. Direct observations of the excitation caused by mass variations as determined from GRACE time varying gravitational field measurements are also used. The resulting estimates of the period and Q of the Chandler wobble will be presented along with a discussion of the robustness of the estimates.

The consistency of the current conventional celestial and terrestrial reference frames and the conventional EOP series

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Earth orientation is defined as the transformation between the Geocentric Celestial Reference System (GCRS) and the International Terrestrial Reference System (ITRS). In terms of orientation the GCRS is realized by the International Celestial Reference Frame 2: ICRF2, while the ITRS is realized through the International Terrestrial Reference Frame 2008, ITRF2008. The current conventional Earth Orientation Parameters (EOP), the IERS 08 C04, are based on the reference frame ITRF2008. Together with ITRF2008 they were calculated in a monolithic fit. ITRF2008, however, contains only data until 2008. Since then the IERS 08 C04 series were updated on a regular basis including data that were unavailable during the creation of ITRF2008. The ICRF2 was determined from a VLBI-only

solution based on the VLBI Terrestrial Reference Frame (VTRF2008) that corresponds to the terrestrial frame provided by the VLBI part of ITRF2008. ICRF2 includes data until 2009. As a consequence the conventional celestial and terrestrial reference frames and the conventional EOP are not fully consistent. In our report we assess the inconsistencies among the conventional reference frames and EOP empirically by analyzing a large and geometrically stable set of geodetic and astrometric VLBI sessions collected and provided by the IVS (International VLBI Service for Geodesy and Astrometry). We compare the EOP determined using the same VLBI data and fixing different TRFs. One complication for the assessment comes through the fixation on TRF coordinates. The coordinate model of current TRFs is the regularized position and velocity that is not free of geophysical signals. If coordinates are fixed on catalogue values, those unmodeled signals propagate into other parameter groups including the EOP. Another complication for the assessment of inconsistencies among frames and EOP time series is the different temporal resolution. The frames are determined as global parameters, while the EOP are determined as local parameters, i.e. on a single session basis. Therefore, we also determine and compare global rotations among the frames.

Application of Titius-Bode law in earthquake study

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In the ITRF frame, station motion is described by the piecewise linear model. However, the actual station motion is more complicated and includes other effects such as seasonal and irregular position variations as well as jumps and exponential relaxation after large earthquakes. So, the studies on the earthquake time distribution and prediction is of large importance for the assessment of the ITRF stability. This article introduces application of the commensurability revealed by Titius-Bode Law in earthquake prediction study. The results show that most of the world's major earthquake occurred at their commensurable points of time axis. The EQ 7.0 occurred in Lushan of China on 2013-04-20 and the EQ 8.2 occurred in Iquique of northern Chile on 2014-04-01 both occurred at their commensurable points of time axis. This provides an important scientific basis for the prediction of major earthquakes, which will occur in the area in future.

Optimizing interpolation procedures for polar motion coordinates

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Many various individual and combined time series of the pole coordinates are available for users to solve their specific tasks. These time series may be evenly spaced or given on irregularly spaced epochs, contain raw or smoothed data, etc. For different data, different interpolation procedures should be recommended for different purposes. Results of a comparative analysis of several interpolation methods applied to various polar motion time series are presented.

Long periodical regularities of polar motion in the Pulkovo latitude variations

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The work studies the main components of Polar motion, obtained from variations in the Pulkovo latitude. We employed the different methods of the analysis of the no stationary time series – Singular Spectral Analysis, and Fourier and Hilbert transforms. It was shown that time changes in the amplitude and phase of Chandler polar motion can be studied based on the long term observation time series of the latitude at a single observatory, even if these observation records have gaps.

GRACE mission and land hydrology data – analysis of EWT maps

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Employing Stokes coefficients from the gravity field expansion from the Gravity Recovery and Climate Experiment (GRACE) mission we can assess the Equivalent Water Thickness (EWT). The maps of EWT delivered from unfiltered data, face characteristic North-South stripes. To improve the signal to noise ratio we have to use a filter to the raw data. We investigate the influence of the filtering of the Stokes coefficients on the resulting Equivalent Water Thickness (EWT) distribution. To do these analysis we used the Stokes coefficients delivered and filtered by the ICGEM (imported from three research centers GFZ, JPL and CSR) with an anisotropic method of smoothing of the geopotential coefficients from GRACE with three degrees of smoothing DDK3, DDK2 and DDK1 (Kusche 2007). We got the Stokes coefficients from the land hydrosphere geophysical models. The resulting coefficients were filtered in the same way as the GRACE data. Next obtained the EWT maps from the filtered coefficients. By comparing the original and the filtered geophysical EWT maps we got a scaling factor for the DDK filters.

Irregular effects in the oscillatory process of the Earth's pole and temporal variations of the geopotential

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The observed irregular effects in the oscillatory process of the Earth pole are of significant variability. They may be caused by the hydrosphere oscillations as well as the perturbations associated with the process of excitation and maintenance of the main oscillations components. Previously while carrying out the modeling of the Earth orientation parameters (EOP) in short time intervals (interyear periods) the tidal coefficients correlation procedure, which took into account high-frequency unstable fluctuations with small amplitudes, was considered alongside with the regular model components. Such a short-period variations caused by geophysical processes (the oscillations of the Earth inertia tensor) don't make a significant influence on the quasiperiodical Earth motion and can be presented in the model as the additional components – residiums, and thus to be considered in the proper time scales. According to the modeling results and the processing of the high-frequency series of the IERS observations in the oscillation process of the Earth pole "irregular effects" can be defined, that are associated with intrayear variation of the main oscillation components and corresponding modulations and also with the existence of multiple and combined harmonics. That sort of effects that are registered by IERS, are significantly different than the ones in earlier researches. They are presented as "anomalous" fluctuations of the

Earth pole coordinates, which have a negative impact on the interpolation and prognosis of the mathematical model in first approximation.

Bretagnon fundamental arguments in the nutation theory

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Fundamental arguments of the IAU2000 nutation theory implicitly include the argument of the Earth perihelion. This implies that most of the Solar nutational harmonics appear in pairs consisting of harmonics very close to each other in frequency. This is due to a very slow precession of the Earth perihelion. Since the amplitudes of the nutational constituents are presently estimated by a least squares fit of the largest rigid Earth nutations to the observed celestial pole offsets there is no chance to resolve those pairs with a few decades of data. In this contribution an attempt is made to make a least squares fit for the largest nutations based on fundamental arguments proposed by Bretagnon that do not include the argument of the Earth perihelion. This way all largest nutations are easily resolved from available observations. The parameters of the transfer function are estimated as well.

Astro-geodetic techniques combination at the normal equation level for global space reference determination

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Combination of space geodetic techniques (VLBI, SLR/LLR, GNSS, DORIS) at the normal equation level aims to improve precision, resolution and consistency of products (EOP, TRF, CRF) by combining GNSS, SLR/LLR, VLBI, DORIS techniques at the level of observations. The next realization of ITRF, ITRF2013 is expected for the end of 2014. According to the call of participation, the results obtained by multi technique combinations at the level of normal equations will not contribute to ITRF2013 but will be compared and evaluated in a second step. GRGS is organized to participate to this project. We will provide at least 10 years of combined weekly normal equations. Preliminary results over the year 2009 are presented and discussed.

High-frequency earth rotation variations from VLBI observations CONT14

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Results of data processing of CONT14 IVS 15 day campaign of continuous VLBI sessions with a network of 17 globally distributed stations in May 2014 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 mode and the results of previos CONT observations (CONT02, CONT05, CONT08, CONT11). Troposphere parameters are compared with ones obtained with GPS technique.

The probabilistic approach to the description of the Chandler wobble

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It is shown that the atmospheric component of polar motion can be treated as the anisotropic Markov process with discrete time, and the torque exerted by the atmosphere on the solid Earth, as the white noise. The intensity and characteristic correlation time of the process are estimated. The efficiency of the atmospheric mechanism in the excitation of the Chandler wobble is estimated in the context of the probabilistic model. It is shown, that one can interprets the oceanic perturbation as a stationary anisotropic random process characterized by the correlation time less than 100 day. The share of Chandler Wobble, enforced by this perturbation is appreciated. The atmospheric and oceanic deposits in the Chandler Wobble initiation are compared. The probabilistic approach to the description of the Chandler wobble is expanded to the case of anisotropic random load. The polar motion is treated as a two-dimensional Markov process, i.e. the solution of the Liouville equation with discrete time. It is shown that with a sufficiently large time step, the polar motion can be considered as an isotropic process irrespective of the particular ratio between the eigenvalues of the diffusion matrix. Thus, it is demonstrated that the observed variations in amplitude can be explained in the context of the probabilistic approach without hypothesizing the isotropy of the random load.

Triaxial Earth's rotation: Chandler wobble, free core nutation and diurnal polar motion

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In this study, we formulate two-layered triaxial Earth rotation theory, focusing on the influence of the triaxiality on the Chandler wobble (CW), free core nutation (FCN) and diurnal polar motion. We estimate the normal modes CW and FCN frequencies, and results show that though the influence of two-layer triaxiality on the CW and FCN frequencies are very small, there appear some new natures. The response of the Earth\'s polar motion to the excitation consists of two parts. One is in response to the same frequency excitation and the other is in response to the opposite frequency excitation. For an Earth model with triaxial mantle and core, both these two parts have four resonant frequencies rather than two that are suggested by rotational symmetric Earth model. However, due to the small strength of these new resonances, the effects of these resonances are only of importance when the excitation frequencies are very near to these resonance frequencies. In addition, compared to the biaxial case, the influences of the triaxiality on the prograde and retrograde diurnal polar motions excited by ocean tide component K1 are estimated as -1.4 microarcsec and -0.95 microarcsec respectively, which should be taken into account in theory. This study is supported by National 973 Project China (grant No. 2013CB733305), NSFC (grant Nos. 41174011, 41210006, 41128003, 41021061, 40974015).

Improvement of the software BERNESE for calculation of the earth rotation parameters according to the data of satellite laser ranging (LAGEOS 1, LAGEOS 2) in the Main Metrological Centre of the State Time and Frequency Service

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Preparatory works for resuming operational calculations of the Earth rotation parameters based on the results of satellite laser ranging data processing (LAGEOS 1, LAGEOS 2) are to be completed in the Main Metrology Centre Of The State Time And Frequency Service (VNIIFTRI) in 2014. For this purpose BERNESE 5.2 software (Switzerland) was chosen as a base software which has been used for many years in the Main Metrological Centre of the State Time and Frequency Service to process phase observations of GLONASS and GPS satellites. Although in the BERNESE 5.2 software announced presentation the possibility of the SLR data processing is declared, it has not been fully implemented. In particular there is no such an essential element as corrective action (as input or resulting parameters) in the local time scale ("time bias"), etc. Therefore, additional program blocks have been developed and integrated into the BERNESE5.2 software environment. The program blocks are written in Perl and Matlab program languages and can be used both for Windows and Linux, 32-bit and 64-bit platforms.

Sub-Session: IAU/IAG Joint Working Group on Theory of Earth Rotation

Report on the activities of the IAU/IAG Joint Working Group on Theory of Earth Rotation

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(1) University of Alicante, Spain; (2) Jet Propulsion Laboratory, Caltech, USA

The purpose of this talk is reporting on the progress of the activities of the IAU/IAG Joint Working Group on Theory of Earth Rotation, focusing on the topics that are common to its three Sub Working Groups.

Report on activities of the Sub-Working Group 2 "Polar motion and UT1" of the IAU/IAG Joint Working Group on Theory of Earth Rotation

Brzezinski A.
Space Research Center PAS, Poland

This is the mid-term report of the Sub-WG2. The main objectives are (1) to summarize the status of the current theories of Earth rotation n focusing on variations with long and diurnal periods, and on modeling of geophysical excitations; (2) to give a list of selected recent publications contributing to the progress in the field; (3) to point out some unsolved problems which should be discussed by the Sub-WG2.

Report on activities of the Sub-Working Group 3 "Numerical Solutions and Validation" of the IAU/IAG Joint Working Group on Theory of Earth Rotation

Heinkelmann R.
GFZ Potsdam, Germany

This is the mid-term report of the Sub-WG3. The main objectives are (1) to summarize the status of the current numerical solutions and validations of Earth rotation, and (2) to give a list of selected recent publications contributing to the progress in the field; (3) to point out some unsolved problems which should be discussed by the SubWG3.

Session 5: Astronomical almanacs and software

Abstracts for the oral session

Future of almanac services
Bell S., Nelmes S., Prema P.
HM Nautical Almanac Office, UK

This talk will explore the means for delivering almanac data currently under consideration by HM Nautical Almanac Office in the near to medium future. While there will be a need to continue printed almanacs, almanac data must be available in a variety of forms ranging from paper almanacs to traditional web services through to applications for mobile devices and phones. The supply of data using applications may call for a different philosophy in supplying ephemeris data, one that differentiates between an application that calls on a web server for its data and one that has built-in ephemerides. These ephemerides need to be of a reasonably high precision while maintaining a modest machine footprint. These services also need to provide a wide range of applications ranging from traditional sunrise/set data though to more specialised services such as celestial navigation. The work necessary to meet these goals involves efficient programming, intuitive user interfaces, compact and efficient ephemerides and a suitable range of tools to meet the user's needs.

Rework of the ERA software system: ERA-8
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The software system that has been powering many products of the IAA during decades has undergone a major rework. ERA stands for "Ephemeris Research in Astronomy" and has capabilities for: processing tables of observations of different kinds (optical, radar ranging, laser ranging), fitting parameters to observations using the LSM, integrating equations of motion of the Solar system bodies. ERA comprises a domain-specific language called SLON, tailored for astronomical tasks. SLON provides a convenient syntax for reductions of observations, choosing of IAU standards to use, applying rules for filtering observations or selecting parameters for fitting. Also, ERA includes a GUI table editor and graph plotter. ERA-8 has a number of improvements over previous ERA versions: such as: integration of the Solar system and TT-TDB with arbitrary number of asteroids; option to use different ephemeris (including DE and INPOP); integrator with 80-bit floating point. The code of ERA-8 has been completely rewritten from Pascal to C (for numerical computations) and Racket (for running SLON programs and managing data). ERA-8 is portable across Windows and Linux, 32-bit and 64-bit. The format of tables in ERA-8 is based on SQLite. The main format for ephemeris in ERA-8 is SPK, now generally accepted among main producers of ephemeris. In general, ERA-8 provides more precise computations, more flexible logic, and more user-friendly interface than past versions. ERA-8 will be freely downloadable to users. EPM2014 ephemeris and the Astronomial Yearbook 2016 are produced using ERA-8.

The software "IDA" for investigation of asteroid dynamics and its use for study of some asteroid motion

Galushina T., Bykova L., Letner O., Baturin A.
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This work is devoted to description of the application suite "IDA" that is designed for investigation of dynamics and probability orbital evolution of asteroids. "IDA" allows to predict asteroid motion, to reveal close encounters, possible collisions and orbital resonance with planets, to estimate impact probability, to demonstrate asteroid and planets motion on a computer screen and to solve some additional problems. The features of the suite are multifunctionality, high efficiency and a convenient interface. The application suite "IDA" consists of following subsystems: subsystem "Assol" which allows to study orbital evolution of the nominal orbit and to demonstrate the asteroid and planets motion on a computer screen; subsystem "Observations" which intended to asteroid orbit fitting to positional observations and construction of initial probability domain with non-linear methods; subsystem "Distribution" which developed for the visualization of distribution of observations along an asteroid orbit; subsystem "Clones ensemble" which allows to construct an initial probability domain with the linear method; subsystem "Evolution" which designed for the study of the orbital evolution of an ensemble of asteroid clones; subsystem "Megno" which intended to estimate of predictability time of asteroid motion by means of average MEGNO parameter. The results of the motion investigation of the asteroid 2012 MF7 are given to demonstrate use of the application suite. This object has nonzero collision probability with the Earth in 2046.

Application of software package "Numerical model of motion artificial earth satellite" for study the earth artificial satellite dynamics by measurements

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Numerical simulation of the motion of artificial satellites (AES) is a highly expensive computing process, since it is necessary to take into account very complex model forces acting on the satellite. Particularly, this task is time-consuming in the case when the study included a large number of objects. Application of parallel computing allows increasing the performance of the modeling process and increasing its accuracy by extending the word length to 128 bits. Moreover, the expansion of word length does not lead to a significant increase in time-consuming. Represented software package allows parallel computing environment to solve various problems of orbital dynamics. In particular, the system allows, using observations, determine the parameters of force models, to improve and build a satellite orbit ephemeris in the form of domains of possible motions at specified intervals. In addition, the software package allows to investigate the orbital evolution of a large set of objects; to identify dynamic randomness in the motion of objects using index MEGNO; to track near misses and to simulate the process of collision debris objects in Earth orbit; to study further evolution and interaction of debris replacing objects exposed defragmentation by an array of objects. Numerous examples of the application of software package are presented in the paper.

Abstracts for the poster session

Astrometry and numerical methods for the solar heliometer

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Started its regular, daily operational phase in 2011, the results so far obtained show that the Heliometer from Observatorio Nacional fulfilled its planed performance of single measurement to the level of few tens of mas, freely pivoting around the heliolatitudes without systematic deviations or error enhancement. Such fruition led to evaluate high order terms that are commonly neglected in other solar astrometric observations. Before and foremost is the constancy of the basic heliometric angle, against which the measurements are made. This is monitored by the timing of the solar transit over the CCD with the instrument halted. Next the usual terms of observational origin are studied, namely dependence to meteorological and pointing conditions. These are shown of no effect, due to the cares used in the making and use of the instrument. The second order terms for diurnal aberration and parallax are then discussed. The effects are found negligible on themselves, and also on the building up of spurious yearly trends. On the contrary, for the accounting of the Earth's ellipticity of the orbit the standard astrometric procedures had to be upgraded to make room for the full description of daily variations, instead of the usual approximation to the mean observational day. Finally, a thorough model for the second order atmospheric refraction has had to be developed to match the systematics left on the observations by using the geometrical second order description. We present and discuss these astrometric additions that are seldom required on ground base astronomic programs.

SINCom – the new program package for combined processing of space geodetic observations

Brattseva O., Gayazov I., Kurdubov S., Suvorkin V.
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The software SINCom realizing the combination of standardized SINEX-files is introduced. The program package is meant to work in the following two modes: a combined solution within one observational technique on the appointed time interval and an inter-technique combination of daily SINEX-files. The realization of stations velocities estimation is recounted. The mathematical model, algorithms and the special task-forming language are presented. The main features of developed software and the arising problems are discussed. The problem-oriented aspects and the requirements for the content of incoming SINEX-files are viewed. The extensive plans of the SIN-Com use to obtaining TRF combined solution are considered. The first experimental results of single-technique combination for VLBI, GPS and SLR observations are presented.

SOFA & Astrometry

Hohenkerk C.
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The International Astronomical Union's (IAU) Standards of Fundamental Astronomy's (SOFA) software library has in the last year introduced a tranche of thirty-two new routines dealing with the subject area "astrometry". This poster provides a guide to enable users to get to grips easily with the various routines for the transformations between ICRS, ICRS astrometric, GCRS, Celestial Intermediate and observed positions of stars, together with their underlying routines for proper motion, parallax, aberration, light deflection and refraction. A summary of the current status of SOFA is also included.

Russian astronomical ephemeris editions and software

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Institute of Applied Astronomy has published "The Astronomical Yearbook" (AY), "The Nautical Astronomical Yearbook" (NAY), "The Nautical Astronomical Almanac" biennial (NAA-2). Last considerable reforms of ephemerides were carried out stage by stage according to resolutions of General Assemblies IAU of 2000–2006. According to the recommendations of the conference CTNS-2007 ("Coordinate, Time, and Navigational Support", IAA RAS, SPb, 2007) the EPM domestic theory of movement of the Solar system bodies is used in Russian astronomical ephemeris editions and software since 2009. In addition reform of computing base and technology of preparation ephemeris data for printing is carried out. All calculations are work out on the basis of the multifunctional software system AEWinERA. Preparation of the ephemeris data carried out by means of software BookA and Izdatel. Along with printing the astronomical software are elaborated. "The Personal Astronomical Yearbook" (PersAY) allows the user to solve tasks of calculation of ephemerides for any moment in various time scales, and for any position of the observer on a terrestrial surface. The PersAY covers the basic types of ephemerides resulted in AY and rightfully can be considered as its electronic version. System of the removed access the "Scturman" is developed also intended to solve some the navigating tasks described in NAA-2. The solutions is entirely accordant to the accuracy of these editions and with detailed reports of the solutions.

Decomposition of galaxy images and galaxy rotation curves

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We present two new Python packages to perform structural and kinematical decompositions of galaxies based on their imaging and rotation curves. The DECA (DEComposition Analysis) code is designed to investigate images of galaxies in an automatic regime (using the simple 'bulge+disc' model) as well as in manual mode for more detailed images and/or for multicomponent structures. DECA can be applied for description of edge-on disc warps, disc truncations, and bulge ellipse shape. The great advantage of DECA is a new developed technique to analyze spiral structure of galaxies (e.g. estimating pitch angle and arm width) if spiral pattern can be well detected in the image. The GRCF (Galaxy Rotation Curve Fitting) package allows to perform the decomposition of the rotation curve of a disc galaxy onto three components: a bulge, a

disc, and a dark halo. The set of possible models includes spherical and oblate Sersic bulges, infinitely thin and thick exponential discs, isothermal dark halo, and the Navarro-Frenk-White dark halo profile with taking into account the adiabatic contraction. The package contains several different fitting techniques including bounded gradient descent routine, maximal and minimal disc approximation. Big advantage of this package is the presence of the graphical interface which makes the decomposition process more transparent and controllable by user. Both packages have been tested on the sample of artificial galaxies. Output galaxy models are in a good agreement with the input ones. The codes are now free available to the astronomical community.

Almanac Services for Celestial Navigation

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Celestial navigation remains a vitally important back up to Global Navigation Satellite Systems and relies on the use of almanac services. HM Nautical Almanac Office provides a number of these services. Our printed book, The Nautical Almanac, printed yearly is continuously being improved, making use of the latest ideas and ephemerides to provide the user with the data that they require. This book is now also available as an electronic publication. We also produce NavPac, a software package that assists the user in calculating their position at sea as well as providing additional navigational and astronomical tools. A new version of NavPac will be released in 2015 that will both improve the user experience and, as with the printed book, make use of the most up-to-date ephemerides and incorporate relevant IAU resolutions. Looking ahead, the development of applications for mobile devices to assist the user with celestial navigation is also being considered. This poster describes how HMNAO continues to combine the latest improvements and theories of astrometry with the creation of books and software that meet the needs of our users in the field of celestial navigation.

EROS – automated software system for ephemeris calculation and estimation of probability domain

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This work is devoted to the description of the software EROS (Ephemeris Research and Observation Services), which is being developed both by the astronomy department of Ural Federal University and Tomsk State University. This software provides the ephemeris support for the positional observations. The most interesting feature of the software is an automatization of all the processes preparation for observations – from the determination of the night duration to the ephemeris calculation and forming of a program observation schedule. The accuracy of ephemeris calculation mostly depends on initial data precision that defined from errors of observations which used to determination of orbital elements. In the case if object has a small number of observations which spread at short arc of orbit there is a real necessity to calculate not only at nominal orbit but probability domain both. In this paper under review ephemeris we will be understand a field on the celestial sphere which calculated based on the probability domain. Our software EROS has a relevant functional for estimation of review ephemeris. This work contains description of software system and results of the program using.

GNSS processing in Institute of Applied Astronomy RAS

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The previous GPS processing software GRAPE was replaced by the new software package. It processes GPS and GLONASS zero-difference ionosphere-free combinations of phase and pseudorange observations and uses the segmented least squares method for the solution of the equations. The processing strategy is mostly consistent with the latest methodology and the physical models of those that are recommended by IGS and IERS. This software is used in GNSS EOP Service of Institute of Applied Astronomy RAS for daily estimation of Xp, Yp, Xp_rate, Yp_rate and LOD and provides other products such as satellites ephemerides, troposphere delays, satellites and receivers clock biases.

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