Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PPS03-01 Room:424 Time:April 29 09:00-09:15

About drift, oscillations and steps of the center of mass of the Moon

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We have previously predicted and studied a step (abrupt) shift of the center of mass of the Earth in 1997 - 1998 years relatively to the mantle (Zotov, Barkin, Lubushin, 2009). In accordance with the basic provisions of the geodynamic model of excitation of planets and satellites shells (Barkin, 2002) we expected and we expect similar displacements of the centers of mass for other bodies in the solar system (for Mercury, Moon, Sun, Titan, Mars, etc.). Moreover, according to our hypothesis these abrupt geodynamic phenomena for solar system bodies are synchronous (Barkin, 2000) and, in particular, it should appear in 1997-1998. On the Earth, the similar jumps in 1997-1998 were observed in almost all planetary processes (Barkin, 2009). In the case of the Moon similar jump of center of mass obtains a confirmation in the data of laser observations and accounts for a specified period of time 1997-1998.

The jump (step) in the center of mass of the Moon in 1997 on data of laser ranging of reflectors on the lunar surface. On the basis of current laser measurements of distances to reflectors mounted on the Moon the preliminary estimates of the parameters of drift, oscillations and jump of the center of mass of the Moon were obtained. Their dynamic interpretation on the base of a geodynamic model of forced relative oscillations of the shells of planets and satellites has been done (Barkin, 2002). In the paper of G.A. Krasinskii (2003) from the analysis of lunar laser range measurements (or rather their residual differences compared with the theoretical celestial-mechanical design values of ranges) an abrupt (step) changes (in 1997 - 1998) in the coordinates of reflectors on the very substantial distances of about 15 -25 cm in selenographic coordinate system of the epoch have been discovered. Since jumps of coordinates for all four observed reflectors were quite close, it is natural to assume that the jump occurred in the position of the center of mass of the Moon by about 25-35 cm relatively to the lunar crust (in direction toward the Earth). Extremely important here is the fact that the jumps occurred in 1997-1998, as it was predicted by the theory of the unified geodynamic synchronous rhythms in variations of the activity of natural processes on the bodies of the solar system (Barkin, 2000). For the mean values of displacements of reflectors the following values were obtained (in meters): -0.15 +/- 0.04 m (offset along x coordnate - from the Earth), 0.23 +/- 0.07 m (offset on y - east), - 0.23 +/- 0.07 m (offset along z - to the north). Thus in 1997, the center of mass of the Moon abruptly shifted to a geographical point on the lunar surface with coordinates 40.0o N, 32.1o W approximately on distance in 0.36 +/- 0.11 m. According to the Krasinskii work (2003) we have identified trends in the changes of distances to reflectors and their abrupt changes before 1997 and after 1998, with rates of about 0.036 ns / year (before the jump) and at a rate of 0.128 ns / year (after the jump). If we consider only the drift relatively to the axis x, then estimates the drift velocities decrease: 0.98 cm / year - until 1997 and 1.47 cm / year - since 1998. It is expected to perform a spectral analysis of the residual differences of distances in order to identify their cyclic variations (with lunar months periods and with multiple periods).

Keywords: center of mass of the Moon, jumps and trends of center of mass of the Moon, LLR data

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Interpretation of unexplained secular changes of the lunar orbit

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Unexplained secular effects in the orbital motion of the Moon are consequences of the observed phenomenon of remove of the center of mass of the Moon relatively to its mantle and crust toward the back-side. An explanation of anomalous part of secular variation in the longitude of the Moon and in the eccentricity of the lunar orbit has been obtained.

Unexplained secular variation of the eccentricity of the lunar orbit. In the works of James Williams and his colleagues showed that the observed rate of secular change of the eccentricity of the orbit of the Moon in 2.3x10 (-11) 1/year can not be explained within the framework of the classical model of the tides. Earth tides give only a fraction of the value specified in 1.3x10 (-11) 1/year and lunar tides result even effect with the opposite sign and give part of the acceleration in -0.6x10 (-11) 1/year. Remains unexplained an anomalous part of the secular change in the eccentricity (1.6 +/- 0.4) x10 (-11) 1/year. This value corresponds to abnormal changes in the distances to the perigee and apogee at 6 mm / year. "Abnormal speed distances to the perigee and apogee of the lunar orbit is up to 6 mm / year and its cause is unknown" (Williams J.,2006).

Tidal acceleration and evolution of the Moon's orbit. Laser ranging method proved to be very sensitive to the tidal acceleration of the Moon. Tides on the Earth dominate in the transfer of angular momentum, and energy in the orbital motion, in particular in the removal of the Moon from the Earth. Tidal effects on the Moon are separable from the effects of Earth tides in laser range measurements to the Moon (Chapront et al., 2002; Williams et al., 2009). Full tidal acceleration in the mean orbital longitude (due to the tides of the Earth and the Moon) is estimated at -25.85" 1/cy2, corresponding to the removal of the Moon from the Earth at a speed of 3.81 cm / year (Williams et al., 2009). The rate of secular variation of the eccentricity of the lunar orbit e = (9 +/- 3) x10 (-12) 1/year also detected on the basis of long laser observations over a period of 38.7 years (March 16, 1970 - November 22, 2008) (Williams, Boggs, 2009). The basis of dynamical studies makes a precision lunar ephemeris DE421, taking into account all of Newtonian and Einsteinian effects. The authors believe that the study of the evolution of the lunar orbit is an important and surprisingly difficult task. Lunar laser ranging provides the numerical values for the two sources of dissipation on the Earth and the Moon.

Possible secular drift of the center of mass of the Moon relative to its crust and mantle toward the back side and an explanation of the anomalies of the orbital motion. In this report we give some first estimations of the possible rate of the secular drift of the Moon center of mass with respect to its crust and mantle in the 10 - 15 mm / year toward the back-side of the satellite. This secular drift of the center of mass of the Moon should be considered by the studying of the orbital motion of the Moon on laser-based observations. Namely, to add to the value obtained by laser observations. The result will be an estimate of the secular increasing of semi-major axis is the center of mass of the Moon. It should be expected that this will obtain the interpretation and explanation of the unexplained part of the secular acceleration of the Moon orbit and the anomalous part of the secular variation of the eccentricity of the lunar orbit, identified according to the perennial laser observations of the Moon. An anomalous part of the orbital acceleration (unexplained) of the Moon is 0.7" / cy2, and the anomalous part of the secular variation of the eccentricity is characterized by rate in 1.23x10 (-11) 1/year (Williams et al., 2011). Found offset - drift of the center of mass of the Moon (12 - 15 mm / year) is explained by the mechanism of excitation and the relative displacements of the shells of the Moon (solid core, liquid core, mantle) (Barkin, 2002).

Keywords: anomalous secular variation of the eccentricity of the lunar, tidal and non-tidal acceleration of the Moon, the center of mass of the Moon drift

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Deep interior structure of the Moon inferred from Apollo seismic data and the latest selenodetic data

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Internal structure and composition of the Moon provide important clue and constraints on theories for how the Moon formed and evolved. The Apollo seismic network has contributed to the internal structure modeling. Efforts have been made to detect the lunar core from the noisy Apollo data (e.g., [1], [2]), but there is scant information about the structure below the deepest moonquakes at about 1000 km depth. On the other hand, there have been geodetic studies to infer the deep structure of the Moon. For example, LLR (Lunar Laser Ranging) data analyses detected a displacement of the lunar pole of rotation, indicating that dissipation is acting on the rotation arising from a fluid core [3]. Bayesian inversion using geodetic data weakly suggests a fluid core and partial melt in the lower mantle region [4]. Further improvements in determining the second-degree gravity coefficients and the Love numbers will help us to better constrain the lunar internal structure.

Recent analyses of GRAIL data have achieved the improved k_2 accuracy; JPL solution is 0.02405 ± 0.00018 [5], and GSFC solution is 0.02427 ± 0.00026 [6]. The two solutions are consistent with each other within their error bounds, and the accuracy of k_2 is now about 1 %. By introducing the improved gravity coefficients and k_2 from GRAIL mission, the updated LLR data analysis has also resulted in a better h_2 determination. Such accurately-determined Love numbers will contribute to constrain the structure of the lunar deep interior, such as the radius of the possible liquid core. It is difficult, however, to tightly constrain the internal structure from the geodetic data only because there are trade-offs among the structures of crust, mantle, and core. The combination of the Apollo seismic data and the geodetic data therefore afford the key to better determination of the lunar interior structure. We included geodetic data of the mass, the mean moment of inertia, the Love numbers h_2 and k_2, and 262 P and S travel time data in the analysis.

Markov Chain Monte Carlo (MCMC) method is used to infer the model parameters. When we used a five-layer model consisting of crust, upper-mantle, mid-mantle, lower-mantle, and core, the core radius is estimated to be 483 ± 22 km, and the core density values tend to be sampled around the assumed lower limit of 3600 kg/m^3. However, the inferred core radius is significantly larger than the magnetic constraint from SELENE data [7] which predicts the upper bound of the core radius to be 400 km. This discrepancy might be attributed to a possible low velocity layer above the core-mantle boundary which was not included in the five-layer model. We will discuss the results when such a low velocity layer is taken into account.

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[6] Taken from the PDS label of GRAIL Derived Data Products
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Keywords: Moon, internal structure, gravity field, tidal Love number, GRAIL

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Observations of lunar rotation on the Moon: possibility and problems.

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The lunar rotation is one of the essential and basic target of selenodetic observations for investigation of the interior of the Moon as well as those of gravity fields, and high accuracy of the observations have a potential to detect signals related to the structure of lunar deep interior including the core. We have developed a small telescope like a PZT (Photographic Zenith Tube) for observations of Lunar rotation with the target accuracy of 1 milli-seconds of arc (1 mas)[1]. Theoretical investigation shows that observations by the telescope in the polar area of the Moon will open great possibilities for determining the libration in inclination ρ and node Iσ with the accuracy much better than before, although the determination of the libration in longitude will not be very well. It also showed that the determination error in the libration angles will not exceed $\sqrt{2}\varepsilon$, where ε is the positioning error of stars and is regarded as 1 milli-seconds of arc [2].

There are several technical problems to be solved in the development of the telescope. Effect of large temperature change is one of the most serious problem for such a precise observation, and we can loosen thermal condition by about ten times by introducing a diffraction lens compared with the case not introducing it. It is possible, on the other hand, that the vibrations of the mercury surface caused by the ground vibrations lead to fluctuations of star positions on CCD as large as 1 second of arc judging from laboratory experiments. The amplitude of the fluctuations depend on the amplitude of the ground vibrations and the depth of mercury pool. We can reduce the effect of the vibrations by making the mercury pool shallow down to the minimum depth. In the case of the mercury pool of 64mm diameter, the depth of 0.5mm is the best according to our experience [3]. It is important to keep the proper period of the mercury pool away from the period of ground vibrations in order to avoid the resonance. It is also effective to lengthen the integration time, and it can improve the reliability of the mean value of the center of a star image by statistical procedure.

We have already made a bread board model (BBM) and we will observe the deflection of the vertical on the ground by using the BBM for the time being in order to evaluate the characteristics of the total system of the telescope.

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Keywords: rotation, moon, telescope, PZT, librations

PPS03-05 Room:424 Time:April 29 10:00-10:15

THE EARTH ORIENTATION PARAMETERS AND THE VARIATION OF THE SECOND ZONAL HARMONIC OF THE GEOPOTENTIAL

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The study of the time variations of the geopotential as a result of the rotary-oscillatory processes of the Earth motion is of a significant natural-sciences and practical interest. Oscillations of the Earth′ s inertia tensor components depend on many factors, among them the mechanical and physical parameters of the planet, the motions of tide-forming bodies, and the observed large-scale phenomena in nature. Time-dependent variations of these and other factors (regular and irregular oscillations, stochastic fluctuations, secular variations) affect the Earth rotary-oscillatory processes and the rotational parameters of the planet. The dynamic processes of the Earth orientation parameters (EOP) in turn have an effect on its figure and lead to the fluctuations of the gravitation field. Observed variations of the EOP, the variations of the Earth′ s gravitational field and oscillations in the large-scale geophysical events appear to be in a considerable correlation.

An amplitude-frequency analysis of the rotary-oscillatory Earth motion under the action of gravitational-tidal perturbing torques from the Sun and the Moon is carried out using the classical mechanics' methods. The simulation results of the oscillatory process in the motion of the Earth pole and the variations of the second zonal harmonic of the geopotential are studied. Based on the dynamic Euler-Liouville equations expressions for amplitude and phase of the Earth pole oscillations are obtained. A comparison of the spectral power densities of the time series between the Earth pole coordinates and the variations of the gepotential is carried out. A functional dependence of the aforementioned component of the geopotential from the amplitude and phase of the Earth′ s pole oscillatory process is shown.

Keywords: the rotary-oscillatory processes, secular variations, stochastic fluctuations, geopotential

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The free and forced librations of the Moon with liquid shell and solid core

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In report we present our results of the study of lunar physical libration of the Moon on the base of its two and three layers models. On the base of analytical solution for two layers model (the Moon with liquid core) and empirical theory of the Moon′ s rotation (Rambaux, Williams, 2011), we have identified period, amplitude, and the initial phase of the forth mode of free libration of the Moon, caused by liquid ellipsoidal core. Preliminary results of studies of three-layers model of physical librations of the Moon have been obtained on the base of some simplified approach for the problem of rotation of the Moon with liquid and rigid cores. The plans for future studies of the Moon rotation are discussed.

The modern view of internal structure of the Moon planet takes into account a complex two- or three-layer model. In our work the analytical theory of lunar physical libration based on its two-layer model consisting of a non- spherical solid mantle and of the ellipsoidal liquid core has been developed. The Moon moves on high-accurate perturbed orbit in the gravitational field of the Earth and other celestial bodies. On the base of two layers model of the Moon we have fulfilled systematic studies of the Moon physical librations. And in first we have presented a solution of the problem in components of vector of angular velocity of the Moon. An analytical presentation of LOD of the Moon with high accuracy in form of trigonometric series has here the progressive value. In first we have determined the fourth mode of free libration of the Moon caused by the influence of the liquid core oscillations of pole axis of rotation of the Moon (its mantle), with a long period in 205.7 yr, with an amplitude of 0″ 0395 and the initial phase of -134 º (for the initial epoch 2000.0). This oscillation reflects the so-called phenomenon of free oscillation of the liquid core. The estimates for the dynamic (meridional) oblatenesses of the ellipsoidal liquid core of the Moon: 0.000442 and 0.000283 have been obtained. These fundamental parameters of geodynamics of the Moon could be determined only on the base of data of observations. Earlier the attempts to determine the period of free core nutation undertaken. Our results were obtained by comparing of the developed analytical theory of lunar physical libration with empirical theory libration of the Moon, constructed on the basis of laser observations in last about 40 years (Rambaux, Williams, 2011).

Preliminary results of studies of three-layers model of physical librations of the Moon have been obtained on the base of some simplified approach for the problem of rotation of the Moon with liquid and rigid cores. We have analyzed the Cassini′ s motion of the decoupled solid core and its librations in longitude to compare with the Moon motions. On the base of Getino, Ferrandiz et al. approach we give estimations of the periods of free librations of this system. We have constructed differential equations of rotational motion of three layers Moon from positions of the Hamiltonian formalism with application of Andoyer′ s and Poincare′ s variables. Now we construct analytical theory of rotation of the Moon system consisting from the non-spherical mantle, ellipsoidal liquid core and solid core.

Keywords: Moon rotation, free libration, liquid core, solid core

PPS03-P02 Room:Poster Time:April 29 18:15-19:30

Viscosity structure dependence of large-scale polar wander rate of the Earth: A potential impact of a low-viscosity zone

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In this study, we make an attempt to quantitatively evaluate an effect of presence of a low-viscosity layer inside the mantle of the Earth on the timescale of its polar wander. In particular, we perform model calculation of the viscoelastic Love number which characterizes the mechanical response of the interior of the Earth, and then investigate how the timescales and strengths of some relaxation modes in the Love number depend on the viscosity structure. I compare the structure dependence of these relaxation modes with that of the polar wander speed. For the sake of convenience of this numerical calculation, we simplify the multilayered structure of the Earth and assume its incompressibility to compute the relaxation modes.

In this calculation, we apply the quasi-fluid approximation which makes it possible to integrate the polar motion equation as a non-linear one. Its reason is because the linear approximation is not allowed for the large-scale polar wander as dealt with in here. Following the applicable condition of the quasi-fluid approximation, we consider load history which timescale is slower than the characteristic one of the viscoelastic deformation of the asthenosphere.

As a result of the calculation mentioned above, we find that the timescale of the polar wander depends almost only on the longest relaxation mode. It is a remarkable point here that, in fact, the ratio of the strength of this relaxation mode governing the polar wander to the total viscoelastic Love number is not so large. In other words, this fact means that the other modes which amplitudes of tidal deformation are more dominant have almost no effect with respect to the timescale of the polar wander. Apparently, this might seem to be a peculiar result.

The reason for this dependence is because the timescale only of the above-mentioned longest mode is much longer by a few orders of magnitude compared to those of the other modes. A mode with a longer time constant of viscous relaxation has an effect which stabilizes rotation axis in a longer term even if its strength is smaller. Oppositely, a mode with a shorter time constant contributes less to the long-term rotational stability because of its faster relaxation even if its strength is larger.

In the light of this result, we can tell that the structure dependence of the true polar wander rate also basically reflects just that of the relaxation time of this longest mode. Actually, even assuming the internal structure without the low-viscosity layer inside the mantle, we still find the influence of this mode to be prominent. Once we take the existence of the low-viscosity layer into account, lower its viscosity is, shorter the timescale of the longest mode is. It can be less than forty percent at shortest. However, if this viscosity becomes lower than a certain value, the timescale of this mode is asymptotic to a constant value. Such a trend results from that this layer behaves as a fluid rather than a viscoelastic body in a sufficiently long timescale due to its too low viscosity.

Here we conclude from the calculation result shown above that the presence of the low-viscosity layer inside the Earth generally shortens the timescale of the large-scale polar wander, and also that this impact mainly stems from the variation in the timescale of the longest relaxation mode. Indeed, the preexisting works have already discussed the dependence of the timescale of the large-scale polar wander on the internal structure of the Earth as well. However, they have not examined the impact of the low-viscosity layer therein, considering a more simplified viscosity structure. Also, they have not clearly stated that the major controlling factor on the true polar wander speed. On the contrary, this work estimates the timescale of the polar wander with explicitly including the impact of this layer, and shows the non-negligible effect of the heterogeneous viscosity structure on the large-scale polar wander.

Keywords: true polar wander, the Earth, mantle, low-viscosity layer, relaxation mode, time constant

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Effects of global geodynamics in a series of astrometry observations of latitude at Poltava

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Diverse geodynamic phenomena observed in the modern era, received a convincing explanation in the framework of the northern drift of Earth's core. Model proposed and developed by Yuri Barkin relative to the set of ancient geodynamic processes: the secular drift of the Earth's pole, non-tidal acceleration of the Earth's rotation, secular change of gravity, the evolution of the earth's figure, plate tectonics, the formation of specific geological structures, etc.

The North drift of the core generates mass redistribution of the Earth and leads to changes in the gravitational field. Since astrometry instruments have as a reference axis direction of the local plumb line, then this process should be displayed in the slow position changes no polar zenith Observatory. It is shown that for locations in the northern hemisphere, the north drift of the core causes the displacement of local plumb in a southerly direction. Is the picture of long-term changes in the direction of gravity (NST) in the meridian of Poltava for the period 1962 - 2013 based on long-term observations of latitude prismatic astrolabe taking into account: 1) high-precision catalogs (HIPPARCOS, ARIHIP, Tycho-2), 2) improved model of the pole C01 IERS; 3) the theory of the precession-nutation IAU2000; 4) plate tectonics (NUVEL1A-NNR). The resulting long-period changes in NST can be represented as the sum of three components: a linear trend with velocity ˜-0.0003 ″ /yr, the nonlinear part of the trend, consisting of two branches (descending - in 1962 to 1996. And rising - in 1998 and 2010.), which can be regarded as a fragment of a wave with period T˜50 years and amplitude A˜0.02 ″ ; quasi cyclic part with 11 - year period, close to the main period of index of solar activity period and amplitude $<$0.01 ″ .

The linear part of the translational displacement means the plumb line to the south of Poltava, which is consistent with the above Barkin ′ s model. The observed velocity of motion of zenith corresponds to moving the center of mass of the Earth in a northerly direction at the velocity in 1.4 cm/yr. Found that the nonlinear part of the trend and the 11-year cyclicity in the shifts of plummet quite clearly reproduce the form of low-frequency polar latitude variations at Poltava derived from model C01 (EOP IERS). Actually observed amplitude of long-period oscillations of latitude caused by pole motion, in 2 times higher than the calculated amplitude. The non-linear part of the trend is the projection on the Poltava meridian of the Markowitz wave.

It is shown that both low-frequency cycles are negatively correlated with the corresponding components of the index of solar activity. The most probable mechanism of solar activity influence on the motion of the pole is the North Atlantic Oscillation. An increase in the amplitude of low-frequency polar displacements of Poltava zenith in astrometric observations requires a special study. One from possible explanations - the influence of the features of the geological structure in the vicinity of Poltava, which is located in the center of the so-called rift Poltava site.

Keywords: plate tectonics, secular change of gravity, Markowitz wave

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Minerals detection on Mars from Mars Reconnaissance Orbiter (MRO) CRISM data

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Martian mineral detection and mapping can provide important information and constraints on Martian aqueous history, which can be used to assess the potential habitability of Mars. Degrees of addressing the key question for Martian aqueous alteration are dictated by the depth and extent of grasping the Martian hydrous mineral. Therefore, it is important to know detailed minerals and chemical induction of the existence of water on the Martian surface at past or present. In-situ observations of the Martian rovers, such as Spirit, Opportunity and Curiosity have provided the mineralogical analysis of Martian surface, but restricting in a limited areas. Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) aboard the Mars Reconnaissance Orbiter (MRO) with enhanced spectral resolution can provide more information at spatial and time scale. In this paper, CRISM near-infrared spectral data are used to identify mineral classes and distribution at Martian Gale region, including kaolinite, chlorites, smectite, jarosite, northupite and salts. The detection of northupite that is indicative of evaporation in Gale region suggests that the Gale region has experienced the climate change from moist condition with mineral dissolution to dryer climate with water evaporation.

Keywords: Martian minerals, Mars Reconnaissance Orbiter, CRISM