Geophysical Research Abstracts
Vol. 12, EGU2010-12534, 2010
EGU General Assembly 2010

Development of analytical theory of the physical libration for a two-layer Moon

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Investigation is being carried out in the frame of Russian-Japanese grant and directed onto providing of the future observations in the frame of the ILOM-project which is planned onto the end of the second decade. The analytical theory presents both scientific interest in its own right and can be useful as a base for the lunar annual in a future, as a clue to lunar interiors and to processes inside the lunar body. A comparison of the libration's analytical theory with new observations will allow to refine the parameters of lunar interiors: an existence or absence of a core, its size, composition and state of aggregation, Love numbers, qualitative parameter Q, etc. Contrary to the usual application of numerical libration models for analyses of observations, the analytical model is able to predict the new harmonics, early unknown and not observed (owing to the insufficient accuracy of observations) in libration's series of observations.

As part of the investigation the following results were achieved.

Development of the analytical theory of the Lunar Physical Libration (LPhL) were performed using the Poisson Series Processor (PSP). The base solution is realized for the "main problem" of the LPhL in view of 4-th harmonic of selenopotential. Data on a dynamical figure of the Moon are incorporated in the theory on the basis of new observations of the Lunar gravitational field, received in a frame of space projects Clementine (1994, NASA), Lunar Prospector (1999, NASA) and the SELENE (2007 – 2009, Japan). On the basis of the constructed theory the following actions were done: 1) analyses of the present dynamical models; 2) modeling of stars trajectories in the field of view of the future optical telescope, which is planned to be placed on one of the Lunar poles in the second stage of the Japanese project SELENE-B - ILOM. Results of modeling have shown opportunities of determination of LPhL-parameters with the desirable accuracy 0.001 arc seconds planned in the ILOM-project. Prognosis recommendations are made for the future experiment.

The model of free rotation of the two-layer Moon is constructed, the periods of the free modes and of the librational motion of a pole are received, effects of influence of a lunar core on behavior of LPhL-harmonics caused by the solid-state rotation of the Moon are deduced. Computer simulating has revealed the sensitivity of the free libration periods to core's ellipticity and to core-mantle boundary dissipation parameters. Geometrical interpretation of the pole motion owing to the free libration is given.

For the first time the theoretical model of tidal potential of the Moon is developed, on the basis of the model the analytical formulae for variations of the Stockes coefficients of the 2-nd order and of the speed of the Lunar rotation is received in dependence on time.

For a two-layer structure of the Moon and the Mercury Cassini's law were stated at the first time: 1. a two-layer Moon *keeps its own stationary* rotation; 2. there is a *splitting* of Cassini nodes and angular momentums of Lunar mantle and core; 3. the same phenomenon will be observed *for any two-layer planet* (Mercury); 4. the differential rotation of a core and mantle is inherent to a planet as result of a generalized Cassini's Laws.

Theoretical and practical methods of construction of the theory of rotation of the Earth have been successfully applied in the development of the theory of rotation of the Moon, in the adaptation of the software PSP to obtain the analytical LPhL-solution by computer with the prospect of the further improvement of the theory for more exact calculation of resonant terms using esheloned series.

A concepts of free and arbitrary libration are considered, analytical and geometrical interpretation of the free pole motion as a result of free libration is given: it is very important for providing ILOM-observations.

Analytical approach allowed receiving numerical values of arbitrary periods for precession, libration in latitude and longitude. For the first time the effect of a liquid core onto the Chandler wobbles and longitude free libration was revealed: liquid core of the Moon leads to decreasing of period of pole (resonant) wobble on 0.095%; period of free precession does not depend from liquid core; period of libration in longitude is decreased on 0.03%. If a liquid core exists in the Moon then systematic increasing of amplitudes of forced librations is prognosticated.

Periods of free core nutation, calculated by different analytical approaches of Barkin Yu. and by Petrova N. with Gusev A. are coincident and are equal to 144 years for a core with ellipticity of $5 \cdot 10^{-4}$.

The research was supported by the Russian-Japanese grant RFFI-JSPS 09-02-92113, (2009-2010)

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