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Making of the lunar internal structure model

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Abstract

Substantial information about the Moon can be obtained through supervision of physical libration, as well as by way of theoretical modeling of the latter. The beginning of a new millennium has been marked by publication of a number of papers containing reviews of relevant results and problems [1, 2]. Studies of celestial objects' rotation allow understanding of their complex internal structure, especially when other (geophysical) methods are inapplicable.
Obviously, valuable contribution to knowledge of the internal structure of the Moon has been made by Clementine (1994, NASA, USA) and Lunar Prospector (1998–1999, NASA, USA) missions. Nowadays we witness incredible surge in interest to the Moon, its internal and external characteristics.

1. Introduction

New millennium started with a series of the space missions aimed at global research of our unique satellite in Solar system. SMART-1 lunar mission (2003–2006, ESA) opened new technological opportunities in terms of obtaining wide range of data about the Moon. 2007 became the year of triumphal integration in lunar research of various space agencies of Japan, China, and India, to include, first of all, Japanese SELENE (Kaguya) mission, which for the first time in history during its regular operation phase provided high-precision topographical and gravitational mapping of the entire lunar surface, including earlier inaccessible areas of the backside of the Moon and the limb zone. Hopefully, publication of new data received from 14 newest instruments installed on low-orbit satellite Kaguya will essentially enrich our knowledge of the Moon. Chinese satellite ChagE-1 and Indian Chandrayan-1 have demonstrated strong potential of China and India in the field of lunar research and obtained new data on gravitational field, mascons, crust, and geochemical composition of the circumlunar space.

2. Internal structure of the Moon: basic parameters

There are some essential arguments in favor of existence of a small-sized Moon's core made of metallic iron alloyed with a small amount of sulfur and/or oxygen, and availability of hot viscous lower mantle.
Structure of gravitational field of the Moon, determined by the comparison of high-precision trajectory measurements by Lunar Prospector (1998-1999) with the results of laser altimetry obtained by Clementine (1994), as well as with data sets of laser ranging of the Moon (1970-2006), assumes the presence of a metal core.
Interpretation of the polar moment value within the framework of chemical, thermal and density models of lunar crust and mantle informed conclusions about the weight and size of the core.
LLR analysis of dissipation of rotation of the Moon points at two possible sources of dissipation: monthly solid-state inflows and liquid core, rotation of which differs from viscous-elastic mantle [6].
Liquid (melted) core has its unique impact on the Moon's rotation. In particular, there are two force moments due to topographical and phase interaction at the boundary between liquid core and elastic mantle (CMB). Liquid core can rotate independently from solid mantle
Selenoid satellites (SS) open new and most perspective opportunities in the study of gravitational field and the Moon's figure. SSs "Moon 10", "Apollo", "Clementine", "Lunar Prospector" trajectory tracking data processing has allowed for identification of coefficients in decomposition of gravitational field of the Moon of members up to 165th order with a high degree of accuracy. Judging from the given data, the distinctive feature of the Moon's gravitational field is that harmonics of the third and even the fourth order are comparable with harmonics of the second order, except for member J2. Difference from zero of c-coefficients Cnm with odd m and Snm with even m proves asymmetry of gravitational fields on the visible and invisible sides of the Moon. General conclusion: according to recent data of 2009, the true figure of the Moon is much

more complex than a three-axis ellipsoid (Lunar Prospector, 1998, NASA; Kaguya, 2009, JAXA).

3. Gravitational field and dynamic figure of the multilayered Moon

One of the main goals of selenodesy is the study of a dynamic figure of the Moon which determines distribution of the mass within the Moon's body. A dynamic figure is shaped by the inertia ellipsoid set by values of resultant moments of inertia of the Moon A, B, C and their orientation in space.

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4. Deviation of the Moon's figure from hydrostatic equilibrium

The Moon's figure is spheroid, with the semiaxes' difference of about 830 m and with approximately 300 m elongation towards the Earth. It is necessary to note, that the described surface does not coincide with the true lunar surface, and only illustrates non-equilibrium values.

Unlike other celestial bodies, the Moon boasts of relatively large set of measurable values. In particular, to solve the task in question, we should look for average and superficial density, available through celestial-mechanical and geophysical measurements, as well as the value of superficial geometrical and dynamic compression of the lunar body which has been investigated over many decades with the use of both on-Earth and space methods. Also helpful would be estimations of density and intensity of dynamic compression of the hypothesized lunar core which can be obtained, for example, through modeling of such parameters, as normalized moment of inertia or speed of distribution of seismic waves [3].

Two layers should be considered: thick solid mantle and small liquid core, whereas for each of the given structures we assume even distribution of substance of homogeneous density. With regard to the abovementioned approximation, geometrical and dynamic figures match. Thus, in our calculations we can substitute dynamic compressions (ellipticities) for geometrical ones, and vice versa.

The given calculations coordinate with the numerical solution of Clairaut's equation published in [4], being also close to estimations of parameters of geometrical and dynamic compression at the core-mantle boundary received on the basis of LLR data [5], with regard to the dichotomy of visible and far side of the Moon, its Northern and Southern hemispheres.

5. Summary and Conclusions

As a first attempt at solving the problem, the paper presents the survey of internal structure of the Moon, tabulated values of geophysical parameters and geophysical profile of the Moon, including liquid lunar core, analytical solution of Clairaut's equation for the two-layer model of the Moon; mathematical and bifurcational analysis of solution based on physically justified task options; original debugged software in VBA programming language for computer generated simulation for various intervals of radiuses, values of geometrical compression on the Moon's surface, densities, as well as graphic representations of the received data. Description of the geophysical profile of the Moon is based on exact mass, radius and moment of inertia of the Moon.

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