Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-01 会場:102B 時間:5 月 25 日 09:00-09:30

Mercury's moment of inertia from spin and gravity data
Mercury's moment of inertia from spin and gravity data

Jean-Luc Margot[1*]
MARGOT, Jean-Luc[1*]

[1]University of California, Los Angeles
[1]University of California, Los Angeles

Rotation studies coupled with gravity measurements provide powerful probes of planetary interiors (e.g., Munk and MacDonald 1960, Peale 1976, Lambeck 1980, Wahr 1988, Dickey et al 1994). Peale (1976) has shown that measurements of Mercury's obliquity and amplitude of longitude librations, together with a knowledge of the second-degree coefficients of the gravity field, can illuminate the size and state of the core.

Over the past ten years we have used the Goldstone Solar System Radar (GSSR) in conjunction with the Green Bank Telescope (GBT) to characterize the spin state and interior of Mercury. We implemented a technique (Holin et al, 1988, 1992) that provides instantaneous spin rate measurements with 10 ppm fractional precision and spin axis orientation at the arcsecond level. On the basis of measurements at 21 distinct epochs between 2002 and 2006, we found observational evidence that Mercury closely follows a Cassini state and that it exhibits forced librations in longitude, as predicted by theory. The amplitude of the librations indicates that the mantle of Mercury is decoupled from a molten outer core (Margot et al 2007). A long-period (˜12 year) libration signature may be present in the data.

Analysis of the radio science signal from the MESSENGER spacecraft (Solomon et al, 2001) has provided measurements of the low-degree gravitational harmonics with a precision of better than 1% (Smith et al, 2012). The combination of spin and gravity data permits a determination of the polar moment of inertia of the entire planet and that of the outer librating shell. The moments can be used with interior models (Hauck et al, 2004, 2007) to arrive at an estimate of the core size. The core size error budget indicates that the precision of the ground-based estimates of obliquity and librations will ultimately dictate the quality of the core size determination, as well as the attendant inferences regarding the interior structure, thermal evolution, and magnetic field generation of the planet.

Spin measurements obtained since 2006 are being used to (1) refine the determination of the obliquity and of the libration amplitude; (2) confirm the presence or absence of a long-period libration component; (3) quantify deviations of the pole from the strict Cassini state. Departures from the expected spin orientation can provide information about core properties and dynamics. Such an offset in the spin orientation of the Moon has been used to quantify dissipation in the lunar interior, with both dissipation due to solid-body tides and dissipation at a liquid core/solid body boundary playing a role (Yoder 1981, Williams et al 2001).

PPS04-01 会場:102B 時間:5 月 25 日 09:00-09:30

キーワード: Mercury, interior, gravity, spin
Keywords: Mercury, interior, gravity, spin

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-02 会場:102B 時間:5 月 25 日 09:30-09:45

Some preliminary estimates of the possibility of determining the Lunar physical libration in the project ILOM

Some preliminary estimates of the possibility of determining the Lunar physical libration in the project ILOM

Natalia Petrova[1], Tagir Abdulmyanov[2], Hideo Hanada[3*]
Natalia Petrova[1], Tagir Abdulmyanov[2], HANADA, Hideo[3*]

[1]Kazan Federal University,Russia, [2]Kazan State Power Engineering University, Russia, [3]RISE Project, National Astronomical Observatory, Japan
[1]Kazan Federal University,Russia, [2]Kazan State Power Engineering University, Russia, [3]RISE Project, National Astronomical Observatory, Japan

A brief description of targets and problems of the future Japanese project ILOM (In situ Lunar Orientation Measurement), which is planned to be realized as one of kinds of observations of lunar rotation at the second stage of SELENE-2 mission, is given in the report. One of the important elements of the project is placing of a small optical telescope on the lunar surface with the purpose to detect the lunar physical libration with high accuracy 0.001 arc sec. Computer simulation of the future observation is being done with the purpose of their optimization: effective placement of measuring system on the lunar surface and formation of scheduling of observations for monitoring the physical libration of the Moon. The results of the first stage of the simulation are presented in the paper. At this stage the tracks for the selected stars are constructed and analyzed, their sensitivity to the internal characteristics of the lunar body, in the first place, to the selenopotential coefficients, is tested.

Analyses of simulated stellar tracks observable from the lunar surface (in a polar zone) revealed a difference from daily parallels of stars in comparison with ground based observations. During one ”lunar day” equal to 27.3 terrestrial days, a star moves along a spiral. In dependence on the longitude of the star, these spi-rals can be untwisted or twisted. In the latter case a star can describe a loop in the sky of the Moon during the observation period. The reason of such unusual astrometry phenomenon is combination of the slow rotation of the Moon as compared with the Earth and the fast precession motion of the lunar pole (in comparison with precession motion of a terrestrial pole).

Due to physical libration the shifts of all tracks will be observed towards direction opposite the Earth. The tracks are sensitive to gravity model of the Moon and are different even for the most accurate modern gravity field models LP150Q and SGM100h.

In the current report we present formulation of the inverse problem of the lunar libration and the application of gradient method for solution of this problem. It is shown that longitudinal libration can not be revealed from observations of polar stars. It is shown, that measuring inaccuracy E in selenographic coordinates x and y causes the inaccuracy in libration angles less than sqrt(2)∗E. Residuals in comparing libration angles of inclination (rho) and node (I∗sigma) calculated for two kinds of lunar body model (deformable and rigid Moon) are analyzed. FFT applied on the residuals spectra reveals several periodical components which are sensitive to the Love number k2 Identification of the components with origin harmonics in analytical series of libration is carried out, what can be useful for the future spectral analyses.

References:

Hanada H et al. Science China Vol.54, (2011)

Petrova, N., Hanada, H., Planetary and Space Science (2011), doi:10.1016/j.pss.2011.10.002.

キーワード: Lunar physical libration, simulation, ILOM
Keywords: Lunar physical libration, simulation, ILOM

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-03 会場:102B 時間:5 月 25 日 09:45-10:15

SELENE-2/VLBI ミッションによる月内部構造制約
VLBI mission proposed for SELENE-2 and its contribution to constrain the lunar internal structure

松本 晃治 [1*], 菊池 冬彦 [1], ホーセンス　サンダー [2], 鎌田 俊一 [4], 岩田 隆浩 [3], 花田 英夫 [1], 石原 吉明 [1], 山田 竜平 [1], 佐々木 晶 [1]
MATSUMOTO, Koji[1*], KIKUCHI, Fuyuhiko[1], Sander GOOSSENS[2], KAMATA, Shunichi[4], IWATA, Takahiro[3], HANADA, Hideo[1], ISHIHARA, Yoshiaki[1], YAMADA, Ryuhei[1], SASAKI, Sho[1]

[1] 国立天文台, [2]NASA ゴダード宇宙飛行センター, [3] 宇宙航空研究開発機構, [4] 東京大学
[1]National Astronomical Observatory of Japan, [2]NASA Goddard Space Flight Center, [3]JAXA, [4]University of Tokyo

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 (such as mass, moments of inertia, tidal Love numbers k2 and h2, and quality factor Q) also suggests a fluid core and partial melt in the lower mantle region [4]. Further improvements in determining the second-degree gravity coefficients (which will lead to better estimates of moments of inertia) and the Love number k2 will help us to better constrain the lunar internal structure.

Differential VLBI (Very Long Baseline Interferometry) technique, which was used in the Japanese lunar exploration mission SELENE (Sept. 2007 - June 2009), is expected to contribute to better determining the second-degree potential Love number k2 and low-degree gravity coefficients. In SELENE, the VLBI radio sources (called VRAD) were on board the two sub-satellites, Rstar and Vstar. The differential VLBI data, when both the radio sources were within the beam-width of the ground antennas, were of particular importance because they are highly accurate with atmospheric and ionospheric disturbances almost cancelled out by the simultaneous observation. Such tracking data, i.e. ”same-beam differential VLBI data” were useful for precision orbit determination [5] and also used to develop an improved lunar gravity field model SGM100i [6].

SELENE will be followed by the future lunar mission SELENE-2 which will carry both a lander and an orbiter. We propose to put the VRAD-type radio sources on these spacecraft in order to accurately estimate k2 and the low-degree gravity coefficients. By using the same-beam VLBI tracking technique, these parameters will be retrieved through precision orbit determination of the orbiter with respect to the lander which serves as a reference. The VLBI mission with the radio sources is currently one of the mission candidates for SELENE-2.

We have conducted a preliminary simulation study on the anticipated k2 accuracy. With the assumed mission duration of about 3 months (84 days) and the arc length of 14 days, the k2 accuracy is estimated to be better than 1 %, where the uncertainty is evaluated as 10 times the formal error considering the errors in the non-conservative force modeling and in the lander position.

Through forward model calculation, we will show that the k2 error as small as 1 % is sensitive enough to the change in the liquid core radius of about +/-40 km. We will also show that the k2 accuracy has sensitivity to possible partial melt layer and contribute to narrow the range of the plausible internal structure models. Although k2 by itself can not distinguish the effect of core size from that of partial melt layer, it is expected that the combination with other geophysical data such as seismic data as well as geochemical data will establish a realistic lunar interior model.

References

[1] Weber et al. (2011), Science, 331, 309-312, doi:10.1126/science.1199375
[2] Garcia eta l. (2011), PEPI, doi:10.1016/j.pepi.2011.06.015
[3] Williams et al. (2001), JGR, 106, E11, 27,933-27,968
[4] Khan and Mosegaard (2005), GRL, 32, L22203, doi:10.1029/2005GL023985
[5] Goossens et al. (2011), J. Geod.,85, 487-504, doi:10.1007/s00190-011-0446-2
[6] Goossens et al. (2011), J. Geod., 85, 205-228, doi:10.1007/s00190-010-0430-2

キーワード: 月, 重力場, 潮汐ラブ数, 内部構造, VLBI, SELENE-2
Keywords: Moon, gravity field, tidal Love number, internal structure, VLBI, SELENE-2

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-04 会場:102B 時間:5 月 25 日 10:45-11:15

Comparison of changes in Earth rotation with temperature changes in the recent century
Comparison of changes in Earth rotation with temperature changes in the recent century

Leonid Zotov[1*], Nikolay Sidorenkov[2], YongHong Zhou[3]
ZOTOV, Leonid[1*], Nikolay Sidorenkov[2], YongHong Zhou[3]

[1]Sternberg Astronomical Institute of Moscow State University, Russia, [2]Hydro-Meteorological center of Russia, Moscow, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, China
[1]Sternberg Astronomical Institute of Moscow State University, Russia, [2]Hydro-Meteorological center of Russia, Moscow, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, China

Chandler wobble is the resonant motion of the Earth pole, which was discovered more than a century ago. It is supposed that atmospheric and oceanic processes supply energy for it. To reveal the sources of the Chandler excitation and their spatiotemporal behavior, we study atmospheric angular momentum (AAM) geographical maps since 1948 yr, by applying multichannel singular spectrum analysis (MSSA, [1]) and Panteleev filtering in the Chandler frequency band.

We also try to find explanations for similarities between the curves of Earth rotation changes and global mean temperature anomalies. The latter, besides the global worming ”hockey stick”, shows about 20-year period variability. In [2] presence of a 18.6-year amplitude modulation in the Chandler excitation was revealed. In [3] it was shown that the Moon tide could play an important role in the weather variability and atmospheric circulation.

This joint study is an attempt, to draw attention to these interesting facts and to obtain pro and contra of the hypothesis of the existence of a common factor, that influences both Earth rotation changes and climate variability.

[1] http://lnfm1.sai.msu.ru/˜tempus/science/MSSA/index.htm

[2] Sidorenkov N.S., The interaction between Earth’s rotation and geophysical processes. WILEY-VCH Verlag GmbH and Co. KGaA, Weinheim, 2009, 305 pp.

[3] L. Zotov, Dynamical modeling and excitation reconstruction as fundamental of Earth rotation prediction , Artificial Satellites, Warsaw, Vol. 45, N. 2 , 2010, p. 95-106.

The first author is supported by the Chinese Academy of Sciences Fellowship for Young International Scientists grant.

キーワード: Earth rotation, atmospheric circulation, climate change
Keywords: Earth rotation, atmospheric circulation, climate change

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-05 会場:102B 時間:5 月 25 日 11:15-11:30

The mechanism and regularities of heat planets and satellites due to the excitation of their shells by external celestia

The mechanism and regularities of heat planets and satellites due to the excitation of their shells by external celestia

Yury Barkin[1*]
BARKIN, Yury[1*]

[1]Sternberg Astronomical Institute
[1]Sternberg Astronomical Institute

Mechanism, providing a high endogenous activity of the Earth and other celestial bodies, was proposed by the author in 1996-2002 (Barkin, 2002). Its essence lies in the fact that the external celestial bodies are not only deform the Earth's mantle layers and excite the system itself, its shells, primarily the core and mantle. The gravitational attraction of non-spherical shells of the earth by external celestial bodies, occupying, generally speaking, the eccentric positions relative to each other, inevitably causes a small relative displacements of the shells and their relative rotations (swinging) and as a consequence deformations, additional to the classical tidal deformations, and new dissipation processes.

In this paper we study the deformations, changes of the elastic energy, of the energy of dissipation in a viscous-elastic mantle as a result of the polar drift and oscillations of the core, both globally across the planet, and in relation to the northern and southern hemisphere. The basis of study is a solution of problem of elasticity theory of deformation of the mantle at the polar displacements and oscillations of the core under certain boundary and initial conditions (Barkin, Shatina, 2005). It is assumed that the core and mantle separated by a thin viscous-elastic layer, similar to the corresponding layers of zone D", whereby it becomes possible the small oscillations of the core and its secular drift, which have been confirmed with modern data on space geodesy about the displacements and oscillations of the mass center of the Earth. That is, the core-mantle system is considered as not rotating. In the unperturbed state the mantle is characterized by concentric density distribution. The excess (superfluous) mass of the core by its displacements and due to its gravitational attraction causes the deformation of all layers of the mantle. Deformations of the planet are described by the linear model of a viscous - elastic Kelvin-Voigt body. As the basic parameters the appropriate parameters of elasticity and viscosity of the Earth and their average values in accordance with the classical model of the Earth (PREM) have been taken (Dziewonski, Anderson, 1981). For these deformations the elastic energy of the planet and energy of dissipation is determined and estimated.

The northern hemisphere plays dominant role, and (at the northern drift of the core) obtains the elastic energy and thermal energy by about 30% more than in the southern hemisphere. Thus, the geomodel explains the observed in present the natural phenomena: activation of volcanic and seismic activity in the northern hemisphere, more active increased warming and catastrophic events in the northern hemisphere compared to the southern hemisphere and oth. On the basis of this model an explanation of fundamental geodynamic phenomena of tidal acceleration of Earth's axial rotation, the secular drift of the Earth's pole in the present epoch, the global rise in sea level and contrast of secular changes in mean sea level in northern and southern hemispheres has been given.

An explanation of the phenomenon of dichotomy of geological structures and geophysical phenomena and natural processes on Mercury, the Moon, Mars, Vesta, Titan, Enceladus, Pluto, Charon and other bodies of the solar system has been given. Similar phenomena of inversion, contrast, asymmetry, cycling, curling of hemispheres and polar regions, ordering, synchronization, etc. will be opened in the near future for celestial bodies in others exo-planetary systems and for pulsars (Barkin, 2007-2011).

The work was supported by the Russian Japanese and Russian Chinese grants of RFBR N 11-02-91160 and RFBR N 11-02-92113 and Russian grant RFBR N 11-05-01134.

キーワード: endogenous energy, heat flow, shell dynamics, planets, satellites
Keywords: endogenous energy, heat flow, shell dynamics, planets, satellites

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-06 会場:102B 時間:5 月 25 日 11:30-11:45

月潮汐応答の内部構造依存性：月マントル最下部の部分溶融層への測地学的示唆
Dependence of the tidal response on the internal structure of the Moon: Geodetic implication to the partial melt layer

原田 雄司 [1*], ホーセンス サンダー [2], 松本 晃治 [3], エン 建国 [4], 平 勁松 [5], 野田 寛大 [3]
HARADA, Yuji[1*], Sander Goossens[2], Koji Matsumoto[3], Jianguo Yan[4], Jinsong Ping[5], Hirotomo Noda[3]

[1] 中国科学院上海天文台, [2] 米国航空宇宙局ゴダード宇宙飛行センター, [3] 自然科学研究機構国立天文台, [4] 武漢大学測絵遥感信息工程国家重点実験室, [5] 中国科学院国家天文台
[1]SHAO, CAS, [2]GSFC, NASA, [3]NAOJ, NINS, [4]LIESMARS, Wuhan Univ., [5]NAOC, CAS

一般に，天体の潮汐変形や物理秤動に伴なう内部のエネルギー散逸は，内部構造，取り分け粘性構造に依存する．天体内部の粘性分布は内部の物理的状態，特に熱的状態を強く反映するから，潮汐エネルギー散逸は熱史の観点において重要な現象の一つである．中でも月やガリレオ衛星のような，熱進化と軌道進化が相互作用する天体においては尚更である．ここで潮汐散逸の大きさは，主にクオリティファクタ（Q）及びラブ数（k_2）によって表現される．これらの値も必然的に粘性構造に依存し，従って熱的状態やその歴史を知る手掛かりを与える．

月の潮汐散逸の粘性依存性は或る先行研究によって既に調べられているが，そのパラメタスタディには残念ながら幾つかの問題点が含まれている．一点目は，月内部を均質球と仮定している事である．しかし現実の月内部は分化している事が月震の観測から明らかとなっている．よって均質球ではなく地震学的に得られた速度構造を前提とするべきである．二点目は，Q だけしか計算されていない事である．しかし実際に測地観測から得られるのは Q と k_2 の両方である．よって両方の値が計算されるべきである．三点目は，そもそも計算結果と対応する観測量が当時は存在しなかった事である．しかし現在では，月レーザ測距による回転計測から Q が求まっており，周回機の精密軌道決定による重力場計測から k_2 も求まっている．よってパラメタスタディの結果と，現時点での Q や k_2 の計測結果が照合されるべきである．

これらの問題を解決すれば，月の内部構造に対して新たな制約を課す事が出来るであろう．即ち，Q と k_2 の双方を矛盾無く説明し得るのはどのような粘性構造であるのか，という考察が可能となる．更に，そのような考察を踏まえて，次世代の月探査計画において調査すべき事は何か，という布石を打つ事も可能となる．

そこで本研究では，現実的な内部構造に基づいて粘弾性潮汐変形のパラメタスタディを行ない，その計算結果を既存の測月学的な観測結果と比較した．具体的には月震の逆解析に基づく密度構造と弾性構造を踏まえ，かつアセノスフェアの粘性をパラメタとして与えて，Q 及び k_2 を算出した．同じく月震に基づく知見によれば，月のマントルの最下部には減衰の大きな領域が存在すると考えられている．この領域の粘性は上部の粘性よりも相対的に低い可能性がある．よって本研究では，簡単化の為に二つの極端な粘性構造を想定した．一つ目は，アセノスフェア全体の粘性を均一と見做し，その値を桁の範囲で変化させた場合である．二つ目は，高減衰領域の粘性の値のみ同じ範囲で変化させた場合である．そして各々のモデル計算に関して，かぐや，嫦娥 1 号，LRO によって得られている観測値と比べる事によって，Q と k_2 を同時に満たす粘性の解が許容されるかどうか検討した．

その結果，内部構造が特定の低粘性領域を含み，かつかぐや又は嫦娥 1 号に基づく値を参照した場合のみ，回転と重力の両方の測地観測を満足する粘性の解が存在する，という事が分かった．この場合，観測された Q に対応する粘性の範囲は一つしか存在しない．そしてこの範囲に対応する k_2 の理論値は，観測値と概ね調和的であった．尚，LRO の観測値と一致しなかった理由は，LRO の観測値が他の二つの観測値よりもやや大きな値を示すからである．一方，低粘性領域を含まない場合，観測された Q に対応する粘性の範囲は大きく二つ存在する．しかしながら，どちらの範囲に対応する k_2 の値も，何れの周回機の観測値とも調和しなかった．

結論として，月内部の地震波の減衰領域は恐らく低粘性領域に相当すると考えられる．そして従来から指摘されていたように，この高減衰領域では部分溶融が起きているであろう．何故なら測地観測の結果から推定される粘性の値は非常に低いからである．特筆すべき点は，少なくとも固体の橄欖岩の粘性としては低過ぎるが，完全な液体としては高過ぎる事である．従ってこの領域は，レオロジー的に臨界状態となる量の液相を含んでいると期待される．この部分溶融層はマントルの熱対流の様式，ひいては熱の輸送効率に大きな影響を与えるであろう．その一方で，この部分溶融層の存在によって潮汐散逸による内部発熱量にも影響するであろう．従って，もし部分溶融層が月の歴史の長期に及んで存続していたならば，月の熱進化や軌道進化を復元する上で考慮されるべき要素の一つである．

又，LRO から得られた k_2 の値は，かぐやや嫦娥 1 号の値と比べて過大評価されていると考えられる．ただこの予想は勿論，将来の探査を踏まえて再検証されるべきである．例えば現在進行中の GRAIL において，より精密な重力場観測が行なわれた暁には，今回の結論の妥当性に関して更に確実な議論が可能となるかもしれない．

キーワード: 月, 潮汐応答, 内部構造, 部分溶融, クオリティファクタ, ラブ数
Keywords: the Moon, tidal response, internal structure, partial melt, quality factor, Love number

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-07 会場:102B 時間:5 月 25 日 11:45-12:00

The expanding Earth confirmed by geodetic observations
The expanding Earth confirmed by geodetic observations

Wen-Bin Shen[1*], Zi-Yu Shen[1], Rong Sun[1]
SHEN, Wen-Bin[1*], Zi-Yu Shen[1], Rong Sun[1]

[1]School of Geodesy and Geomatics/Key Lab of Geospace Env and Geod, Wuhan Univ, Wuhan, China
[1]School of Geodesy and Geomatics/Key Lab of Geospace Env and Geod, Wuhan Univ, Wuhan, China

Whether the Earth is expanding or contracting is an interesting question in geoscience. Some scientists support the viewpoint of the Earth expansion, and some are against this viewpoint. This study focuses on estimating the Earth expansion rate using the space-geodetic data over land, global gravimetric observations, and altimetry data over oceans. Space-geodetic data recorded at stations distributed over land areas were used to estimate the Earth expansion rate, and the results suggest that the Earth is expanding at a rate about 0.24mm/a. Based on the EGM 2008 and the secular variation rates of the second-degree coefficients determined by satellite laser ranging and Earth mean-pole data, the principal inertia moments of the Earth (A, B, C) and in particular their temporal variations were determined, and the results show that the Earth is expanding at a rate ranging from 0.17 mm/a to 0.21 mm/a, which coincides with the space-geodetic evidences. Further, by examining the sea level rise observed by satellite altimetry, taking into account the contributions of the mass migration due to glacier and ice sheet melting, global temperature increase and post-glacier respond effects, we find that the Earth is expanding at a rate around 0.9+/- 0.6 mm/a. A relative large uncertainty (+/- 0.6mm/a) is due to the fact that the sea level rise and the relevant contributions to it cannot be relatively well estimated at present, and further investigations are needed. Finally, a possible expansion mechanism is provided in this investigation. This study is supported by Natural Science Foundation of China (grant No. 41174011; 40974015; 40637034).

キーワード: Earth expansion, space-geodetic data, gravimetric data, sea level rise
Keywords: Earth expansion, space-geodetic data, gravimetric data, sea level rise

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-P01 会場:コンベンションホール 時間:5 月 25 日 13:45-15:15

The theory of the unperturbed and perturbed rotational motion of celestial bodies in the Sadov and Kinoshita variables

The theory of the unperturbed and perturbed rotational motion of celestial bodies in the Sadov and Kinoshita variables

Mikhail Barkin[1*], Yury Barkin[2]
BARKIN, Mikhail[1*], BARKIN, Yury[2]

[1]Moscow Aviation Institute, [2]Sternberg Astronomical Institute, Moscow
[1]Moscow Aviation Institute, [2]Sternberg Astronomical Institute, Moscow

The analytical theory of the unperturbed and perturbed rotational motion of a rigid celestial body (planet or satellite) is developed. As the unperturbed motion it is accepted and developed the free rotational motion of a rigid triaxial body with unequal principal moments of inertia (the case of the Euler-Poinsot). The body has any triaxiality and arbitrary dynamic oblateness. Also another class of celestial bodies ? non-rigid, and weekly deformed, with a variable geometry of the densities. A new theory of the unperturbed rotational motion of celestial bodies, which takes into account own rotational deformation of the body, is constructed and developed (Chandler-Euler motion, Barkin Yu., 1998). In both cases, the unperturbed rotational motion is a motion on the Euler-Poinsot. However, for weekly deformed celestial body this motion is characterized not by its real moments of inertia, and some the changed constant moments of inertia, taking account of its tidal deformations caused by its own rotation.

Hamiltonian formalism is developed and the unperturbed rotational motion of rigid and weekly deformed celestial bodies are described by <<action-angle>> variables in the form introduced in the well-known works of Yu. Sadov (1972), H. Kinoshita (1977) and Yu. Barkin (1992, 1998). The of paramount importance for the study of the perturbed rotational motion of the planet (satellite) in the gravitational field of the perturbing bodies has the construction of expansions of the force function of the Newtonian interaction of the body with the surrounding celestial bodies in ”action-angle” variables. The first attempts to construct such expansions in the theory of rotation of the Earth have been made in the work of H. Kinoshita (1977) for the second harmonic of the force function. In this case the author has made some simplifications and some restrictions on the dynamic oblatenesses of the planet. But it was in the works of Yu Barkin (1992, 1998), these expansions were obtained in an exact representation in the form of Fourier series on multiple variables ”angle” with the coefficients represented by functions of the variables ”action.” This representation of the coefficients is not trivial, and makes extensive use of the apparatus of elliptic functions, theta functions, hyperbolic functions and elliptic integrals of three kinds.

In the papers (Yu. Barkin, 1992, 1998), the expansion of the force function was obtained for the main terms of the second harmonic proportional to the coefficients of the gravitational field of the body C20 (zonal harmonic) and C22 (the main tesseral harmonic). In this paper, a complete expansions in Fourier series of all components of the second harmonic of the gravitational potential, i.e. additional terms proportional to the geopotential coefficients C21, S21 and S22 have been obtained (M. Barkin, 2011). The expansions are presented in a compact form convenient for applications.

Analytical formulas for the first-order perturbations in ”action-angle” variables in this more general formulation of the perturbed rotational motion of the planet (the Earth) under the gravitational attraction of external celestial bodies (Moon, Sun) have been obtained in explicit form. We studied also the changeable Earth’s rotation with variable coefficients of the gravitational potential C20 (t), C22 (t), C21 (t), S21 (t) and S22 (t). Separately the dynamic effects due to the observed secular changes of these coefficients and the observed annual variations obtained by the long-term observations of geodetic satellites (Cheng et al., 1997, 1999) have been studied.

Follow to modern studies and works of astrophysicists (Link et al., 2001) we developed a number of applications of the formulas of our unperturbed rotational motion to study the kinematics and dynamics of isolated pulsars with precession.

キーワード: Kinoshita variables, Sadov variables, unperturbed and perturbed motion, gravitational attraction, celestial bodies, <<action-angle>> variables
Keywords: Kinoshita variables, Sadov variables, unperturbed and perturbed motion, gravitational attraction, celestial bodies, <<action-angle>> variables

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS04-P02 会場:コンベンションホール 時間:5 月 25 日 13:45-15:15

月の溶岩地形データを用いた古セレノイドの復元
Reconstruction of paleoselenoid using surface shapes of mare basalts and flow directions of sinuous rilles

小川 達彦 [1*], 日置 幸介 [1]
OGAWA, Tatsuhiko[1*], HEKI, Kosuke[1]

[1] 北大・院・理学院自然史科学専攻
[1]Dept. Nat. Hist. Sci., Hokkaido Univ.

月はその歴史を通じて公転周期：自転周期＝１：1 の同期自転運動をしてきたと考えられている。しかしながら、現在のセレノイド（月の重力等ポテンシャル面）の２次の係数は多少奇妙である（Garrick-Bethell et al. 2006）。同期自転運動をしている衛星の静水圧平衡形状では、遠心力ポテンシャルと潮汐力ポテンシャルの比は１：３となり、２次の重力場係数の C_{20}（＝－ J_2）と C_{22} の比は１０：３となるはずである。しかし、月探査衛星かぐやによって観測された J_2 ／ C_{22} の比は 9.09 で（Namiki et al. 2009）、J_2 の値が C_{22} に対して大きすぎる。この問題のさらなる研究のため、我々は月の海の表面地形から後期重爆撃期当時のセレノイドの一部を復元し、地球―月力学系の進化の議論を試みる。我々は玄武岩溶岩が月の盆地を埋めた当時のセレノイドの形状を復元するために、日本の月探査衛星かぐやのレーザー高度計（LALT）のデータを使った。また、sinuous rille の流れた方向から現在と過去のセレノイドの違いを議論するために地形カメラ（TC）のデータを用いた。

最初に我々は LALT の地形データ（Araki, et al., 2009）と月の重力モデル（SGM100h, Matsumoto et al., 2010）を比較し、マスコン盆地内の溶岩表面がセレノイドと平行であるか調べた。月の玄武岩溶岩は地球上のどの溶岩よりも粘性が低いので（Murase and R. McBirney, 1970）、溶岩表面から当時のセレノイドの形状を推測できる。我々は３つのマスコン盆地（雨の海、晴れの海、湿りの海）で、海の表面地形がセレノイドと平行な「上に凸」の曲面を示していることを確認した。この局地的バルジに加え、これら３つのマスコン盆地内のセレノイドの形状は月の平均的形状（球体）に対して全体としてわずかな傾きを持つ。湿りの海と晴れの海の勾配は、同期自転衛星の静水圧平衡の特徴的な２次の形状（J_2：C_{22} ＝ 10：3）と調和的な方向を示したが、雨の海はそれと合わない奇妙な勾配の向きを示した。雨の海は南東上がりの勾配を示すはずだが、観測された勾配は南西上がりを示し、赤道バルジの分を補正すると雨の海は原因不明の西上がりの傾きを示していることになる。

この結果を別のデータから確認するべく、我々は TC データから sinuous rille の流れた方向を調べた。sinuous rille は溝もしくは谷で、玄武岩溶岩流の熱浸食によってできたとされる。これらの流れた方向は地球の河川と同様重力ポテンシャルが下がる向きである。しかし中村（2011, pers. Comm.）は、Rimae Plato（雨の海の北側に位置）が、現在のセレノイドに対して上向きに流れたように見えることを見出した。これは現在と過去のセレノイドの傾きが若干異なる可能性を示唆している。雨の海周辺には多くの sinuous rille が存在するが、Rimae Plato 以外にもいくつかの sinuous rille が現在のセレノイドに対して上向きの流れを示す。その中でいくつかの興味深いケースを報告する。たとえば Rima Suess（雨の海の南西に位置する）は現在の重力場に逆らって流れたように見えるが、雨の海の異常な傾動が rille の形成後に起こったものと考えると下向きになる。これは雨の海の傾斜に対するさらなる証拠を示すのかもしれない。他のいくつかの sinuous rille は Rima Suess と同様の流れ方を示すが、すべてが同様でもない。今後は rille の流動方向についてさらに系統的な調査を行い、雨の海の傾動の時期や原因を探る。

キーワード: 月, セレノイド, リル, 玄武岩溶岩, 雨の海
Keywords: Moon, Selenoid, sinuous rille, basaltic lava, Mare Imbrium