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Dynamically active Moon

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Abstract

The lunar motion has been measured accurately for 39 years with Lunar Laser Ranging [1,2,3]. Today, the time-span of several decades and the accuracy of a few centimeters allow one to identify and characterize some geophysical mechanisms that influence the rotational motion.

Normal modes

The three dimensional rotational motion of the Moon is characterized by the physical librations, the departure from uniform rotational motion. Classically, there are three normal modes of librations for a rigid Moon. One is in longitude, parallel to the equatorial plane of the Moon, with a period of 2.9 years, and a second one in latitude, motion of the axis normal to the lunar equatorial plane, with a period around 81 years. These two modes are related to the synchronous spin-orbit motion of the Moon and the periods are given in the inertial reference frame [4,5]. The third mode of free libration is related to the motion of the axis of figure about the rotation axis. It is analogous to the Earth's Chandler wobble and has a period around 75 years in the lunar reference frame, i.e around 27 days in the inertial reference frame [4]. Each proper mode is characterized by a damping time scale. Based on the tide and core dissipation results given in [1,6], the damping times are 2 10^4 yr for the longitude mode, 1.6 10^5 yr for the 81 yr latitude mode, and 1 10^6 yr for the wobble mode. As a consequence, the observational detection of free librations requires recent excitation mechanisms compared to the damping times.

Determination of the amplitudes of the normal modes

The data accuracy of a few centimeters, over a time-span of several decades, along with a new numerically integrated ephemeris, DE421 [7], encourages new analysis of the lunar physical librations, and especially the detection of three modes of free physical librations (longitude, latitude, and wobble modes). This analysis was performed by using iteratively a frequency analysis [8,9] and a linear least-squares fit of the wide spectrum of DE421 Moons physical librations as suggested by [4]. The new analysis of series [10] identifies and estimates about 130 terms in the angular series for latitude librations and about 70 terms in the longitude angle and polar coordinates. In this determination, non-negligible amplitudes of the three modes of free physical libration have been detected. The determined amplitudes become 1.296" in longitude (after correction of two close forcing terms), 0.032" in latitude and 8.196" by 3.312" for the wobble, with the respective periods of 1056.13 days, 8822.88 days (referred to the moving node), and 27257.27 days. The presence of such terms, despite short damping times of 10^4 to 10^6 yr, suggests the existence of some source of stimulation acting in geologically recent times.

Possible excitation mechanisms

Some possible mechanisms have been explored in the past with various degrees of success. It has been shown that a recent meteoritic impact is an unlikely source of such excitation [11]. Yoder [12] proposed an alternative mechanism, based on turbulent fluid core interaction, to excite the wobble mode. Eckhardt [13] proposed an interesting excitation process to explain the longitude mode. The mechanism is related to a resonance event between the longitude proper mode (of 2.9 years) and close forced frequencies in the past evolution of the Moon. During the evolution of the lunar orbit, the free frequency changes slowly due to the tides and can become equal to a forced period in longitude. Here, we revisit this scenario in more detail.

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