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Prospects in the orbital and rotational dynamics of the Moon with the advent of sub-centimeter lunar laser ranging

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Abstract

Lunar laser ranging (LLR) measurements are crucial for advanced exploration of the laws of fundamental gravitational physics and geophysics as well as for future human and robotic missions to the Moon. The corner-cube reflectors (CCR) currently on the Moon require no power and still work perfectly since their installation during the project Apollo era. Current LLR technology allows us to measure distances to the Moon with a precision approaching 1 mm. As NASA pursues the vision of taking humans back to the Moon, new, more precise laser ranging applications will be demanded, including continuous tracking from more sites on Earth, placing new CCR arrays on the Moon, and possibly installing other devices such as transponders, etc. for multiple scientific and technical purposes. Since this effort involves humans in space, then in all situations the accuracy, fidelity, and robustness of the measurements, their adequate interpretation, and any products based on them, are of utmost importance. Successful achievement of this goal strongly demands further significant improvement of the theoretical model of the orbital and rotational dynamics of the Earth–Moon system. This model should inevitably be based on the theory of general relativity, fully incorporate the relevant geophysical processes, lunar librations, tides, and should rely upon the most recent standards and recommendations of the IAU for data analysis. This paper discusses methods and problems in developing such a mathematical model. The model will take into account all the classical and relativistic effects in the orbital and rotational motion of the Moon and Earth at the sub-centimeter level. The model is supposed to be implemented as a part of the computer code underlying NASA Goddard's orbital analysis and geophysical parameter estimation package GEODYN and the ephemeris package PMOE 2003 of the Purple Mountain Observatory. The new model will allow us to navigate a spacecraft precisely to a location on the Moon. It will also greatly improve our understanding of the structure of the lunar interior and the nature of the physical interaction at the core–mantle interface layer. The new theory and upcoming millimeter LLR will give us the means to perform one of the most precise fundamental tests of general relativity in the solar system.

Keywords: Moon - orbital motion; Moon - nutation and libration; Lunar laser ranging; Fundamental reference frames; General relativity; Gravitation

1. Introduction

After US President George W. Bush announced his "Vision for Space Exploration" in 2004, a plan for new

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