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Creation of a Global Selenocentric Coordinate Reference Frame

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Abstract—A number of questions about the Moon remain to be answered, including fundamental questions related to the internal structure and origin of the Moon. Studies of the spin–orbital dynamics of the Moon and of selenodesy are required for the practical solution of a number of problems related to navigation on the Moon and in circumlunar space, with the aim of providing coordinate and time support for planned lunar space projects. This paper analyzes existing dynamic selenographic reference grids, considers methods for their development and creation, and describes the modern projects related to navigational support for lunar missions. This paper is based on a presentation made at the conference "Modern Astrometry 2017," dedicated to the memory of K.V. Kuimov (Sternberg Astronomical Institute, Moscow State University, October 23–25, 2017).

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1. INTRODUCTION

Increased attention has been paid recently to the problems related to selenographic coordinate and time systems and the rotational dynamics of the Moon, by scientists working in both astrometry and planetary physics. Various large-scale space and ground-based projects have been implemented over the past few decades: NASA's Clementine (1994) [1] and Lunar Prospector (1998–1999) [2] missions, the Lunar Laser Ranging experiment (1969–2018) [3], the European SMART-1 satellite (2003–2006) [4], the Japanese KAGUYA project (2007–2009) [5], the Chinese missions Chang'e 1 (2007–2009), Chang'e 2 (2010), and Chang'e 3 (2013) [6], the Indian Chandrayaan-1 (2008–2009) and Chandrayaan-2 (2017) satellites [7], and the American LRO/LCROSS (2009–2010) [8], LRO (2009–2014) [9], and GRAIL (2012) [10] missions. The scientific programs of lunar space missions have included studies of higher-order harmonics in theories of physical libration of the Moon, analyses of the lunar gravitational field using inter-satellite tracking, the construction of selenographic altitude–coordinate models, and the determination of parameters of the internal structure of the Moon, such as the Love elasticity, dissipation at the boundary of the viscoelastic mantle and the lunar core, and the parameters of the lunar core itself. Manned exploration of the Moon and the extension of the GLONASS space-based navigational system to a lunar orbit are planned for the fairly near future. The implementation of these projects requires precise selenographic coordinate and time support aimed at determining computational data for the solution of problems in navigation and the implementation of highly accurate spacecraft landing on the physical surface of the Moon. The key component of this coordinate and time support is the construction of a selenocentric dynamical reference coordinate system, whose axes coincide with the lunar axes of inertia and whose origin coincides with the center of mass of the Moon. The development of the theory of physical libration of the Moon is very closely tied to the establishment of a selenocentric dynamical reference coordinate frame.

Currently available selenographic reference frames, i.e., reference frames providing a direct tie to physical objects on the lunar surface, do not have sufficiently high precision for a number of reasons. All existing models of selenographic reference systems have been constructed on the basis of the space data that are essentially oriented around specific coordinate systems designed for specific satellites, which depend directly on the dynamical parameters of the satellite orbit and consequently are not sufficiently precisely tied to a lunar dynamical coordinate reference frame. Thus, satellite data obtained from high-precision laser altimetry of the lunar surface are tied neither to a terrestrial nor to a lunar coordinate system. Therefore, on the one hand, altitude measurements of the lunar surface obtained via satellite altimetry describe the lunar relief well, but cannot serve to create a selenographic reference grid. On the other

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