MEASUREMENTS OF MOON'S ROTATION BY CO-REGISTRATION OF LASER ALTIMETER PROFILES AND DIGITAL TERRAIN MODELS

Alexander Stark [1] (Alexander.Stark@dlr.de); **Jürgen Oberst** [1,2] , **Frank Scholten** [1], **Philipp Gläser** [2]
[1] German Aerospace Center, Institute of Planetary Research; [2] Institute of Geodesy and Geoinformation Science, Technische Universität Berlin;

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Motivation

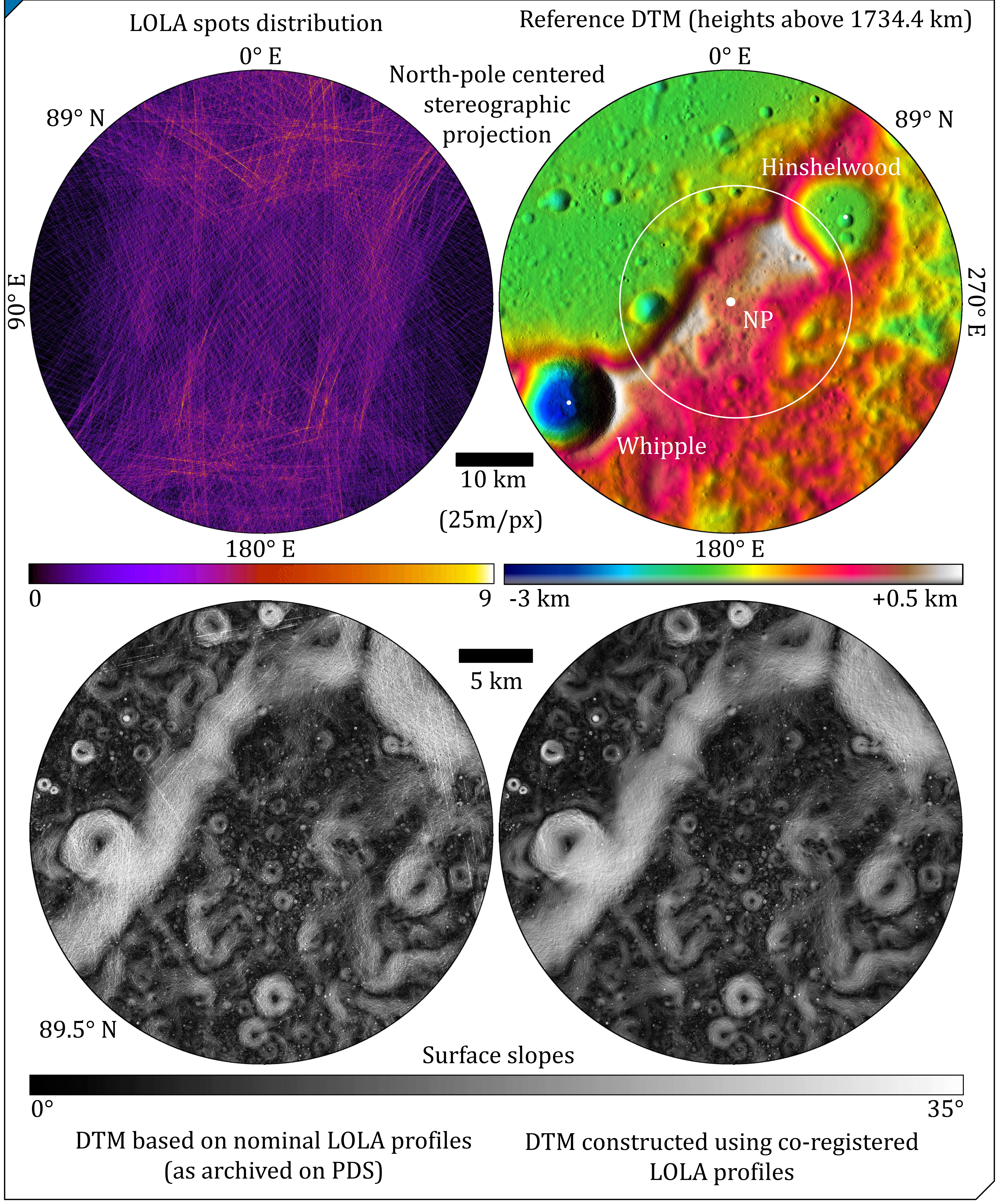
The Moon exhibits a complex rotational state, including precessions, nutations and librations. The "physical librations", known already from early Earth-based optical observations (Bessel, 1839), are forced by changes in the tidal torque acting upon the Moon, associated with the orbit of the Moon about the Earth and the orbit of the Earth-Moon system around the Sun, among other. Furthermore, the analysis of data obtained through terrestrial laser ranging to retroreflectors on the Moon confirmed the existence of free physical librations (Rambaux and Williams, 2011). The amplitudes of forced and free librations are connected to the properties of the Moon's interior. They in turn have strong implications on models for the origin and the evolution of Earth's satellite.

Method

In a recent study (Stark et al., 2015) the co-registration technique was used to measure the libration amplitude of the planet Mercury. The application of this same technique may offer the possibility to track the rotation of the Moon. In fact, we propose to use data obtained by the Lunar Reconnaissance Orbiter (LRO), which is equipped with a camera system, the LRO Camera (LROC), and a laser altimeter, the Lunar Orbiter Laser Altimeter (LOLA). Starting in 2009 both instruments acquired a wealth of high-precision data on the topography of the Moon (Robinson et al., 2010; Smith et al., 2017). A previous study (Gläser et al., 2013) demonstrated that laser profiles obtained by LOLA can be co-registered to stereo digital terrain models (DTM) derived from LROC images (Scholten et al., 2012) with a very high vertical and lateral accuracy.

In this work we apply methods for generation of a DTM from LOLA developed by Gläser et al., (2014) to the measurement of the rotational state of the Moon. In a first step a reference DTM is generated using the co-registration technique and later used for rotation state measurement. Unlike the method used by Stark et al., (2015) we construct the reference DTM from laser profiles themselves (see Gläser et al., (2014) for further details) and not from stereo images. The constructed DTM along with LOLA spot distribution is shown below. During the co-registration the positioning of LOLA profiles was improved (see zoomed region below).

LOLA based DTM of the Lunar North pole



Lunar Rotation Measurement

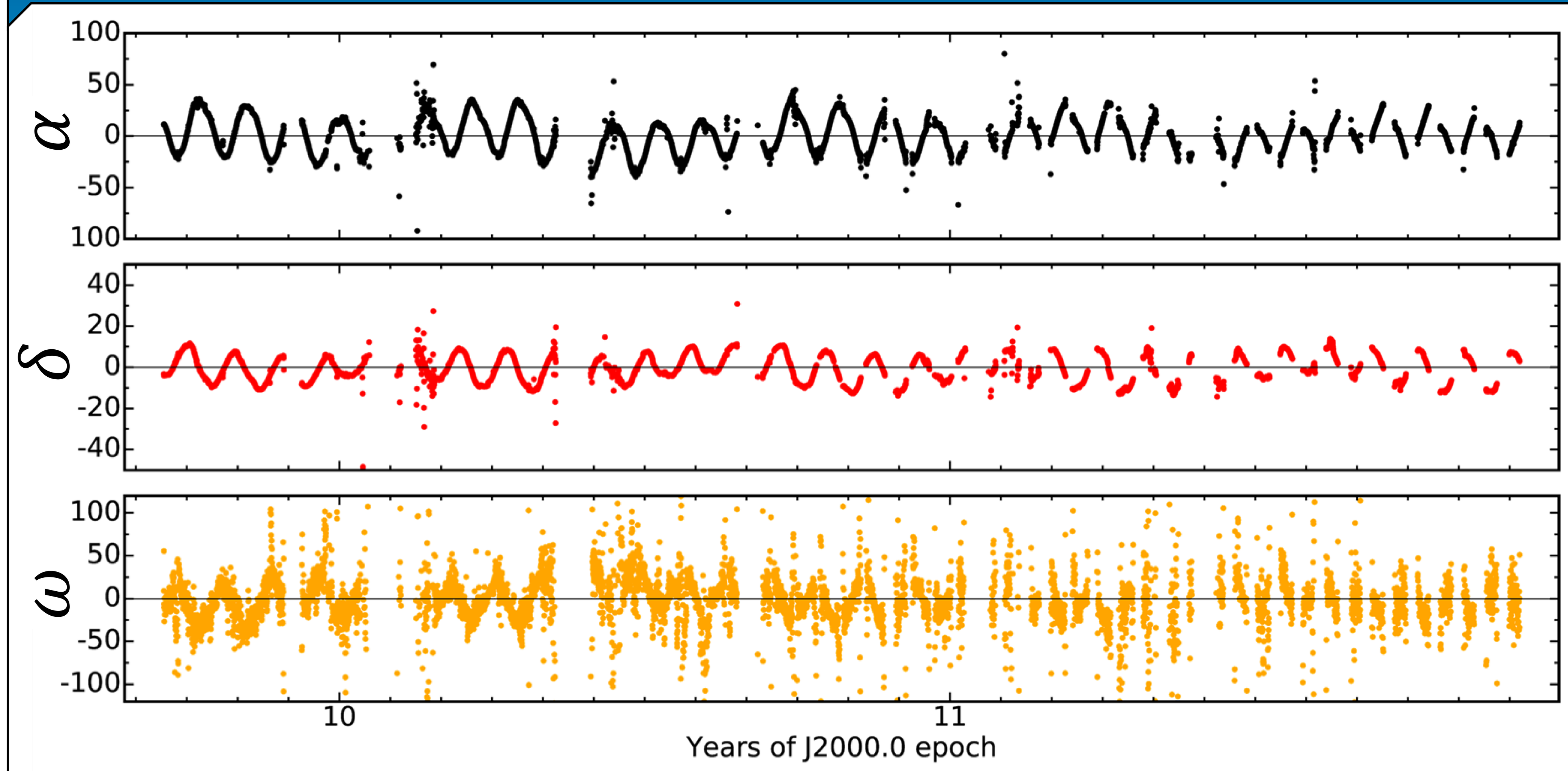


Fig. 1: Corrections to the Euler angles of the lunar reference frame IAU_MOON in arc seconds. Each point correspond to a LOLA profile.

In order to measure the rotation state the LOLA profiles were computed in the inertial frame (ICRF). The transformation from inertial to body-fixed coordinates can be parameterized by Euler angles (α, δ, ω). Using the reference DTM we can measure the Euler angles that are required to rotate each LOLA profile to the position where it fits best to the reference DTM. In particular, we solved for corrections to the closed form of the reference frame (IAU_MOON, Archinal et al., 2011). Note that due to the usage of a polar DTM the rotation angle ω has larger uncertainties than the rotation axis angles (α, δ).

The lunar free libration in longitude has an amplitude of 1.3 arc seconds (corresponding to 10.9 m the equator) and a period of 2.9 years. The wobble mode of the spin axis has amplitudes of 3.3 and 8.2 arc seconds (or 27.8 m and 68.9 m) with periods of 74.6 years (Rambaux and Williams, 2011). Further analysis of the rotation state measurements will be performed to cross check the free libration modes using orbital observations by LRO.

References & Acknowledgments

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