IMPROVED GLOBAL LUNAR TOPOGRAPHIC MODEL BY CHANG'E-1 LASER ALTIMETRY DATA.

Q. Huang[1,2], J. S. Ping[1] , M. A. Wieczorek[2], J. G. Yan[3], X. L. Su[1], [1]Shanghai Astronomical Observatory, Chinese Academy of Science (huangqian@shao.ac.cn), P. R. China, [2]Institut de Physique du Globe de Paris, France, [3] Wuhan University, P. R. China

Introduction: The Chang'E-1 satellite was successfully launched on October 24, 2007 from the Chinese Xichang Satellite Launch Center, and after a one year primary mission and nearly a half year extended mission it impacted the Moon on March 1, 2009. One of the principal scientific instruments on this spacecraft was a laser altimeter (LAM) that was used to measure the distance between the orbiter and the lunar surface. By the end of the Chang'E-1 mission, more than 8 million ranges were obtained, and by combining these with precise orbit and attitude data, a globel model of the Moon's topography has been constructed.

In this paper, about 3 million accepted range measurements from the first "forward-flying" phase of the primary mission have been used to produce China's first global topographic model of the Moon. Our topographic model, a 360th degree and order spherical harmonic expansion of the lunar shape, is designated as Chang'E-1 Lunar Topography Model s01 (CLTM-s01). This model, referenced to a mean radius of 1738 km, has an absolute vertical accuracy of approximately 31 m and a spatial resolution of 0.25^{o} (corresponding to approximately 7.5 km on the surface).

LAM System Specifications: The Chang'E-1 LAM system consisted of two subsystems, one being the Altimeter Optical Head and the other being the Altimeter Circuit Box. The Altimeter Optical Head consisted of a laser transmitting system and an optical receiving system. The laser transmitter contained a Q-switched diode-pumped Nd∶YAG source that produced lasing every second at a wavelength of 1064 nm. The laser had a pulse width that was less than 7 ns, a pulse energy of 150 mJ, and a divergence that was less than 0.5 mrad, giving rise to a spot size on the surface of 120 m for the satellite altitude of 200 km. The optical receiver included a Cassegrain telescope, which had a telescope diameter of 140 mm and a focal length of 538 mm. The total weight of the Laser Altimeter System was 15.5 kg.

The LAM boresight was installed parallel to the *z* axis of the orbiter, with an installation error about 2′. The LAM was designed to work well for pointing angles up to 15^{o} off nadir. Ground based tests showed that the range resolution of the LAM was 0.96 m, and the range error was estimated to be less than ±5 m in aircraft flight tests. The along-track shot spacing was about 1.4 km, and after two months' of measurements, the minimum shot spacing along the equator was about 7.5 km.

A health check of the instrument's electronical performance, thermal control, energy and coaxiality of the laser transceiver was carried out during the in-orbit test phase from November 5 to 20 without laser firing, and the first ranging experiment was successfully carried out on November 27. More than 5 million range data were recorded during the first forward flying phase from 2007/11/20 to 2008/01/26. On January 27, 2008 the attitude of the Chang'E-1 satellite was adjusted into its first "sideways-flying" phase to prepare for the first lunar eclipse that would occur on February 21. The LAM was switched off on February 6 for about 100 days, and was turned back on May 15 during the second forward-flying phase of the mission.

LAM Data Processing: By combining the range data with precise orbit and attitude data we have obtained a global topographic data set and have constructed a global topographic model of the Moon.

We have processed all the recorded ranging data from orbit 0243 to 0878 (between November 27 2007 and January 22 2008). During the first forward-flying phase of the mission, orbital maintainance maneuvers were quite frequent and some orbital arcs had no ground-tracking, so about 7 orbits worth of ranging data were rejected. The first step of the LAM ranging data processing was to identify and remove false returns. In general, a single orbit collected more than 7000 range points, but about 30% of these needed to be discarded. Next, we performed systemic calibrations to correct for systematic errors caused by the oscillator and the optical delay that were characterized during ground tests.

Orbit determination of the Chang'E-1 spacecraft was made possible by closed-loop two-way unified S-band (USB) doppler and ranging data, as well as by VLBI delay and delay rate data collected by four VLBI stations. During the operation periods of LAM, the orbits of Chang'E-1 had a radial accuracy of 30 m (3 σ) and an along-track accuracy of 50 to 100 m (1 σ). Compared to the 100 km altitude orbit of the Japanese SELENE-1 spacecraft, the 200 km altitude orbit of Chang'E-1 was considerably more stably because of the reduced gravitational effects.

Chang'E-1 is a three-axis stabilized satellite using a set of star sensors to measure attitude. By analyzing the measured attitude data, the stability of the Euler angles describing the attitude were all better than 0.008°/s (3 σ), and the vertical error caused by the attitude control was less than 1 m (3 σ). Following the construction of our calibrated topographic profiles, a simple filter was applied in order to remove a few obvious outliers, reducing the number of accepted range measurements by about 1%.

Lunar Topographic Model: All of the LAM laser ranges have been processed, which ultimately yielded about 3.21 million accepted elevation measurements. As one example of the quality of these data, profiles across the Moscoviense impact basin, which is a typical mascon basin [1], are shown in Figure 1. These data clearly demonstrate that LAM can detect precise topographic features, such as the impact basin's multiple ring structure.

Based on the elevation spacing (1.4 km along-track and 7 km across-track), all the elevations were binned and interpolated to form a 0.25°×0.25° grid. From this grid, a spherical harmonic expansion to degree and order 360 was performed, which was named the Chang'E-1 Lunar Topographic Model (CLTM-s01). Figure 2 shows our global topographic map of the Moon from CLTM-s01. Clearly visible are the smooth mare on the nearside hemisphere, the rougher cratered highlands, and the giant farside South Pole-Aitken basin.

Geophysical Characteristics of the Moon: The altimetry data make possible improved estimates of the fundamental parameters of the Moon's shape, which are principally derived from the long-wavelength spherical harmonic coefficients [2, 3]. The mean radius of the Moon given by CLTM-s01 is 1737013 m, and by rotating a flattened ellipsoid to fit the gridded data, the mean equatorial radius, the mean polar radius and the flattening were determined to be 1737646 m, 1735843 m, and 1/963.7526, respectively.

It has long been known that the Moon's geometric center of figure is displaced from its center of mass [3,5], and the degree-1 harmonic coefficients of our topographic model represent the position of this displacement. The center-of-mass/center-of-figure offset is found to be (-1.777, -0.730, 0.237) km in the *x*, *y*, and *z* directions, respectively. As previously found by the Clementine altimeter data [2,4], this displacement does not correspond exactly to the Earth-Moon axis, but is displaced approximately 22° towards the western limb.

Summary: At the time of this writing, several topographic maps are being constructed from orbital laser altimetery data. These include data from the laser altimeter LALT onboard the Japanese lunar explorer KAGUYA (SELENE) [5], the lunar laser ranging instrument (LLRI) onboard the Indian mission Chandrayaan-1, and the Lunar Orbiter Laser Altimeter (LOLA) onboard NASA's Lunar Reconnaissance Orbiter (LRO). By combining the data obtained from all these missions, it will be possible to construct a much higher resolution topographic model of the Moon than could be generated by any single mission.

References: [1] Konopliv A. S. et al. (2001) *Icarus*, *150*, 1-8. [2] Smith D. E. et al. (1997) *J Geophys Res,, 102*, 1591-1611. [3] Sagitov M. U. et al. (1986) London: Academic Press. [4] Zuber M. T. (1994) *Science, 266*, 1839-1843. [5] Araki H. (2009) *Science, 323,* 897-900

Acknowledgment: This study was supported by the National Science Foundation of China (NSFC No. 10973031) by the national high-tech project 2008AA12A210, and by the CAS key direction research Program KJCX2-YW-T13-2.

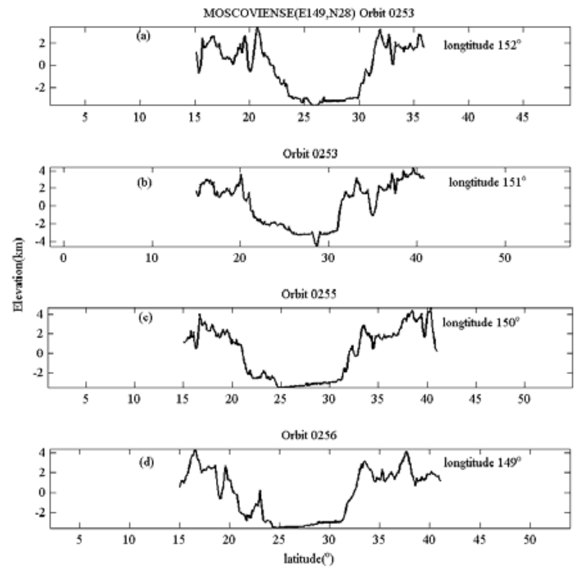

Figure 1. Topographic profiles across the Moscoviense impact basin (149°E, 28°N), illustrating the multiple ring structure of this impact structure. The horizontal axis is lunar latitude, where one degree corresponds to about 30 km. The height is referenced to a sphere with a radius of 1738 km.

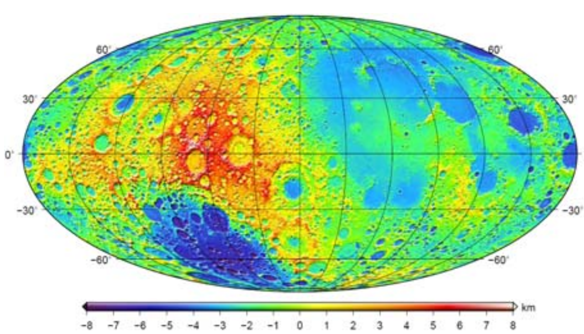

Figure 2. Topography of the Moon from the Chang'E-1 laser altimeter data. The map is shown in a global Mollweide projection with a central meridian of 270° E, where the near side and far side hemispheres are on the right and left, respectively. The longitudinal and latitudinal grid lines are spaced at an interval of 30°.