LUNAR TOPOGRAPHY MODEL DETERMINED BY INTEGRATING LASER ALTIMETRY FROM MULTIPLE ORBITERS. C.K. Shum[1], Hok Sum Fok[1], Yuchan Yi[1], Chunli Dai[1], Kun Shang[1], Lei Wang[1], Hiroshi Araki[2], Koji Matsumoto[2], Sho Sasaki[2], H. Bâki Iz[3], Xiaoli Ding[3], Jinsong Ping[4]. [1]Division of Geodetic Science, School of Earth Sciences, Ohio State University, Columbus, Ohio, USA (ckshum@osu.edu), [2]National Astronomical Observatory of Japan, Mizusawa, Japan, [3]Dept of Land Surveying and Geo-Informatics, Hong Kong Polytechnical University, Chian, [4]Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai, China.

Introduction: Size and shape are fundamental quantities to provide insights into interiors and origins of planetary bodies. The 1994 U.S. Clementine mission's laser altimetry determined topography improved our understanding of the lunar internal structure and thermal history [1]. The lunar topography, when combined with gravity, seismic, geochemical or magnetic data, quantifies crustal thickness, tides, isostasy, subsurface density anomalies, mantle, core, geology, geomorphology, crustal dichotomy and impact crater locations/features leading to lunar origin studies [2][3]. 13 years after Clementine mission, several contemporary lunar orbiter missions equipped with laser altimetry measuring lunar topography have been launched. These missions include China's Chang'E (CE-1) and Japan's SELenological and ENgineering Explorer (SELENE) in 2007, followed by India's Chandrayaan-1 in 2008, and U.S.'s Lunar Reconnaissance Orbiter (LRO) in 2009. They have different mean orbital altitudes (50 km, 100 km, and 200 km for LRO, SELENE and CE-1, respectively), distinct instrument precision (10 cm, 1 m, and 5 m, respectively) or sampling (1 Hz data from SELENE and CE-1, 140 Hz data from LRO's multi-beam laser), and different radio-tracking systems (DSN, USB, VLBI, lunar orbiting relay-satellite tracking). LRO's Lunar Orbiter Laser Altimeter (LOLA) has a multi (5)-beam laser with the lowest mean orbital altitude (~50 km) and with the highest precision (<10 cm) [4].

These laser altimetry measurements with distinct orbital coverage provide an unprecedented opportunity to improve the accuracy and resolution of the lunar topography. The improved topography or shape of the Moon, lunar gravity field, and rotation/libration allow one to address open lunar science questions, including quantifying the causes of global scale-asymmetry, impact basin sizes/location/features, interior composition, crustal thickness, lunar isostacy, moho depth, and constraints on lunar tidal parameters. LRO's multi-beam laser altimetry (LOLA) represents the most accurate lunar laser altimeter instrument in terms of ranging and pointing precision and has the lowest orbital altitude (~50 km) todate, affording more sensitivity for its data to improve the resolution of gravity field modeling and more accurate geolocation for topography modeling, in particular over the lunar near-side. Here we combine laser altimetry from CE-1, SELENE and LRO for orbit adjustments using a technique of *differenced altimetry* measurements in favor of the traditional altimeter crossovers

Methodology: Each of the respective laser altimetry data are calibrated against the lunar laser ranging retroreflectors (LLRR) amd the radio-tracked Apollo Lunar Surface Experiments Package (ALSEP) reference sites for absolute calibration of the laser altimeter measurement [5]. A bias correction of +150 m has been added to the interpolated radii of Chang'E-1 topography [5. The *differenced altimeter* technique, as opposed to crossovers, is used for generate each altimetry types with respect to a reference topography for orbit and bias adjustments. The three adjusted topographic heights are then integrated using iterative and surface fitting algorithms for an improved topography model with $1/16^0$ resolution. .

Results: Figure 1 shows the comparison of lunar topography models (top, ULCN0205; bottom, combined lunar laser altimetry from this study). Red stars denote locations of the LLRR sites, and black rectangles show the two nearside and farside regions, Oceanus Procellarum and Dririchlet-Jackson basins, for regional topographic spectrum analysis studies. Fig. 2 shows the recent advances in lunar topography modeling shown in lunar (CE-1, SELENE, LRO, and combined), compared with Mars (MOLA), Venus (Magellan) and Earth (ETOPO5) in terms of topographic power spectra (horizontal scale $\lambda/2=2\pi R_p/2l$, R_p is the planetary radius, and l is spherical harmonic degree). Fig. 2 shows that the combined lunar model has a discernable highter power than the individual altimetry derived model extended to l=2880 (1.89 km at lunar equater). Fig. 3 and Fig. 4 shows the respective regional spectra of the lunar topography models for the Oceanus Procellarum (nearside) and the Dririchlet-Jackson Basin (farside) regions, indicating that the combined topography model has higher resolution.

References: [1] Zuber, M.T., Smith, D.E., Lemoine, F.G., Neumann, G.A. (1994). *Science*, 266 (5192), 1839–1843. [2] Wieczorek, M.A., (2007). *Treatise on Geophysics*, 10, 165–206. [3] Garrick-Bethell, I., Nimmo, F., Wieczzorek, M.A. (2010). *Science,* 330, 949-951, 10.1126/science.1193424. [4] Smith, D. E. et al. (2010). *GRL*, 37, L18204, doi:10.1029/2010GL043751. [5] Fok, H., Shum, C., Yi, Y., Araki, H., Ping, J., Williams, J., Fotopoulos, G., Noda, H., Goossens, G., Huang, Q., Ishihara, Y., Matsumoto, K., Oberst, J., Sasaki, S. (2011). *EPS,* 63(1), 15–23.

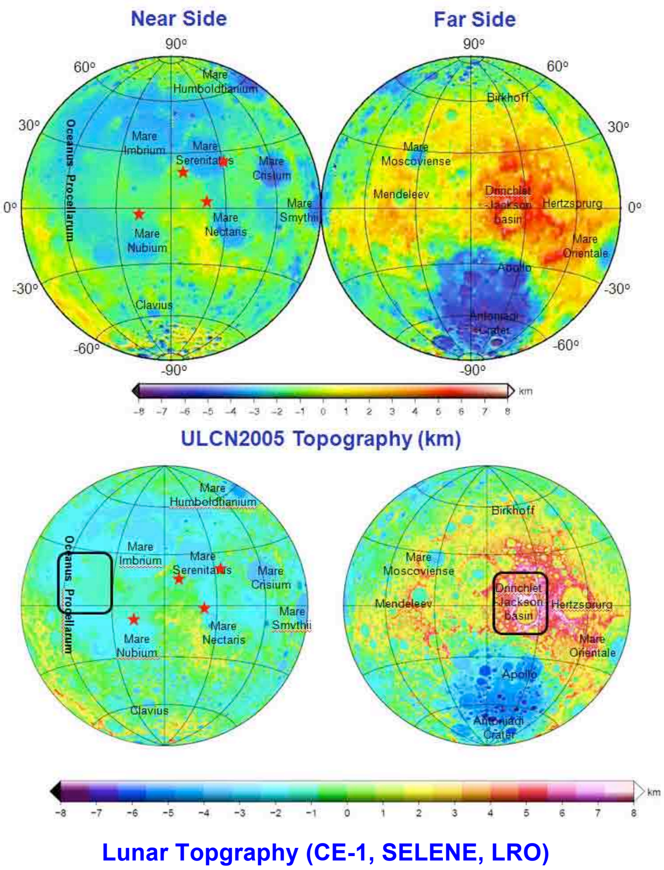

Figure 1. Comparison of lunar topography models (top, ULCN0205; bottom, combined lunar laser altimetry). Red stars denote locations of the Lunar Laser Ranging (LLR) sites, and black rectangles shows the two nearside and farside regions, Oceanus Procellarum and Dririchlet-Jackson basins, for regional studies.

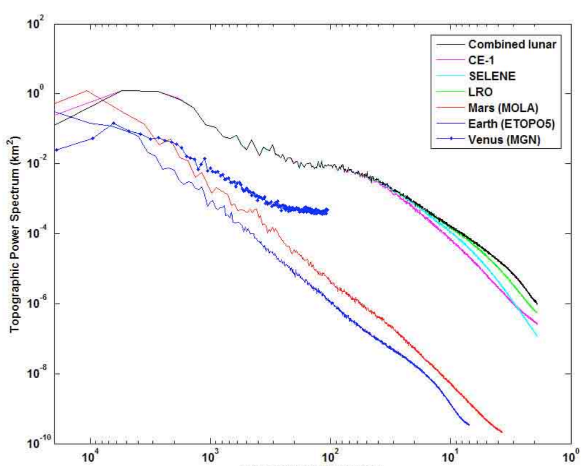

Figure 2. Lunar (CE-1, SELENE, LRO, and combined), Mars (MOLA), Venus (Magellan) and Earth (ETOPO5) topographic model power spectra (horizontal scale $\lambda/2=2\pi R_p/2l$, R_p is the planetary radius, and l is spherical harmonic degree). It is shown here the feasibility to obtain improved or higher resolution lunar topography modeling via combining data from orbiting laser altimeters, with the lunar topographic power spectra extended to l=2880 (1.89 km at lunar equator).

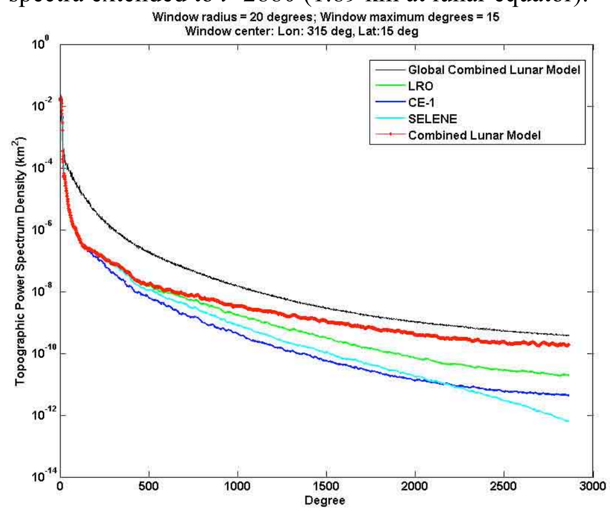

Figure 3. Localized power spectra over the Oceanus Procellarum region (lunar nearside) for the lunar models centering at (15^0 N, 315^0E) with radius 20^0. Estimated localized spectra used Selpian tapering method (L=15).

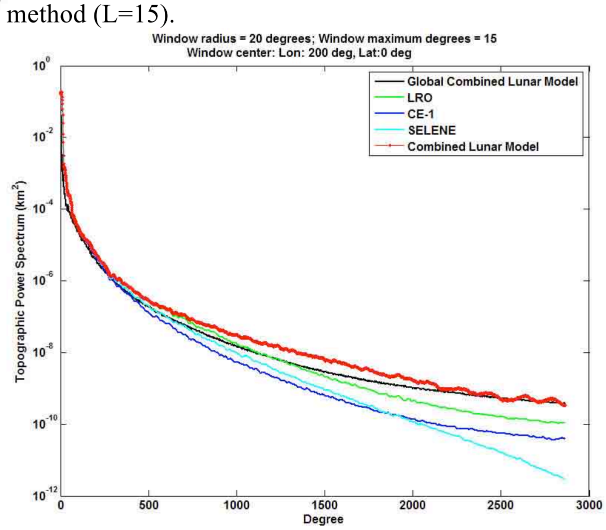

Figure 4. Localized power spectra over the Dirichlet-Jackson Basin region (lunar farside) for thelunar topography models, centering at (0^0 N, 200^0E) with radius of 20^0. Estimated localized spectra used Selpian tapering method (L=15).