OSIRIS-REx LASER ALTIMETER 1064-nm REFLECTANCE INVESTIGATION AT BENNU.

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Introduction: The Altimetry Working Group (AltWG) of the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) mission will produce near-global reflectance maps of the asteroid Bennu to aid in geological characterization and sampling. The OSIRIS-REx Laser Altimeter (OLA) [1] measures the intensity of the laser returns together with its altimetric measurement. As such, it can provide a photometrically normalized global map of 1064-nm albedo variations of Bennu, independent of the solar illumination geometry. This analysis will corroborate the OCAMS [2] X-filter global mosaic (860-nm wavelength) that the team will multiply by a 1064-nm/860-nm global scale factor determined in the Approach Phase to produce a global 1064-nm reflectance map. These maps quantify the asteroid surface reflectance at the wavelength and zero phase angle needed to predict GN&C LIDAR performance. The OVIRS instrument [3] will further be used to calibrate the absolute reflectance at 1064nm with 8 nm spectral resolution in the Approach and Preliminary Survey mission phases, maintaining its calibration within 5% using internal and external sources.

Bidirectional reflectance at or near the laser wavelength (1064 nm) will be estimated through stereophotoclinometry (SPC) using an assumed phase function [4], except where surfaces lie in shadow. These observations will sample a wide range of phases (angle between incident and emitted rays). OLA complements these with measurements at precisely zero phase, where the opposition effect (shadow hiding and coherent backscatter) provides additional information on surface properties.

OLA will provide information on surface properties important for sample return and characterization. For example, results obtained from the Lunar Orbiter Laser Altimeter (LOLA) have shown the ability to quantify FeO content and Hapke model parameters related to particle size [5]. This technique used both active sensing and a passive "one-pixel camera" method to observe the Moon's surface in sunlight using the background noise on four of the five altimeter detectors.

Active laser sensing provides unique observations within permanently shadowed terrain near the poles of the target asteroid Bennu and depending on the thermal environment, transient occurrences of water ice or other volatile deposits may thus be detected [6].

OLA will obtain the first such lidar radiometric measurements for an asteroid. Planetary missions to Moon, Mars, and Mercury have carried altimeters that produced such measurements, but lidar data obtained from 433 Eros and other small bodies have not yet provided an intensity measurement. The lunar, Mars and Mercury lidars detected water ice and other volatiles but required considerable spatial averaging to overcome substantial noise and limited dynamic range. The 0.1 mrad spot size of the 10 kHz Low Energy Laser Transmitter (LELT) will make possible high resolution (sub-meter-scale) spatial measurements of surface reflectance (Fig. 1) at ranges up to 1 km, while the 0.2 mrad spot size of the 100 Hz High Energy Laser Transmitter (HELT) will provide measurements at greater distances (Fig. 2) and will allow 3x noise reduction through averaging to the ~2 mrad OVIRS spot size..

Observations: During the approach phase (August-November 2018) the MAPCAM photometry will be acquired at distances beyond laser range. The primary goal of the Preliminary Survey phase is to observe the sunlit side of Bennu and both poles. OLA will operate for periods of a few hours after arrival Dec. 3, between Dec. 4–16, 2018. To the extent that OLA HELT intensity data are available at ranges of ~7 km, we will compare measurements with relative reflectance from SPC products using OCAMS imagers. For link calculations, the 75-cm SPC shape model will suffice. During the Orbit B mission phase, a ~24-hr period circular orbit near the solar terminator will provide very high-resolution coverage from OLA LELT.

The proposed investigation within AltWG will perform the following tasks:

Task 1. Calibrate Laser Altimeter Reflectance Measurements. The intensity measurement was not a requirement for altimetry but was developed to refine the ranging precision under the widely varying operating distances of the mission. Creating a time-ordered dataset of calibrated 1064-nm reflectance for an appropriate subset of the OSIRIS-REx Preliminary Survey and Detailed Survey data will entail calibrations for zero level, scale, linearity, and possibly drift and vignetting at some ranges. The calibration will leverage observations from OVIRS during the MAPCAM Distant portions of Preliminary Survey as well as visible observations by Polycam during the approach phase.

Such observations will commence shortly before Arrival within a few km of the surface. During the Preliminary Survey, spectroscopic observations are planned just before the commissioning of the OLA instrument and will inform its calibration.

Task 2. Photometric Assessment of Surface Properties. Analysis of the photometric phase function of Bennu at all illuminated latitudes is a responsibility of the Spectral Analysis Working Group, to which this investigation will contribute its calibrated normal albedo at a wavelength in the MapCam X-filter image band as a preliminary assessment of phase function. The low obliquity of Bennu also raises the possibility of persistently-shadowed regions near the poles, in which temperature and space weathering will differ markedly. We will contribute to the understanding of latitudinal variations in surface properties such as single-scattering albedo, porosity and grain size.

Task 3. Analysis of spacecraft radio tracking data. High-precision orbit reconstruction, gravity field recovery, and altimetric analysis for tidal recovery as described by pre-launch simulation work for OSIRIS-REx [7] will utilize sophisticated solar radiation models. We have developed modeling tools for the illumination conditions as a function of time, now being optimized for graphics coprocessors. We will use the global normal albedo map as an input to a numerical model to compute reflected solar radiation pressure on the spacecraft for navigation purposes. We will also combine this information with a global shape model and the differential radiation pressure on Bennu to provide an assessment of the YORP effect [8] on rotational dynamics and support the radio science objectives. YORP spin-up, impact and/or tidal-derived seismic processes are important to interpret the samples returned to Earth accurately.

Products: We plan to generate a 0.07-m reflectance model during the Orbital B mission phase, when OLA will use its 10-kHz scanning capability to sample Bennu at very close range. We will produce Preliminary Survey models at a coarser resolution as the data quality permits.

References: [1] Daly M. G. et al. (2017) *Space Sci. Rev.,* 212, 899–924. [2] Rizk B. et al. (2017) arXiv preprint arXiv:1704.04531. [3] Reuter D. C. et al. (2017) arXiv preprint arXiv:1703.10574. [4] Gaskell, R. W. et al., 2008, *Meteoritics & Planet. Sci.*, 43(6), 1049–1061. [5] Barker, M. K. et al. (2016) *Icarus*, *273*, 96–113. [6] Paige, D. A. et al. (2013) *Science*, *339*, 300–303. [7] Getzandanner K. et al. (2016) *39th Annual AAS Guidance & Control Conference, AAS 16-103.* [8] Rubincam D. (2000) *Icarus, 148,* 2–11.

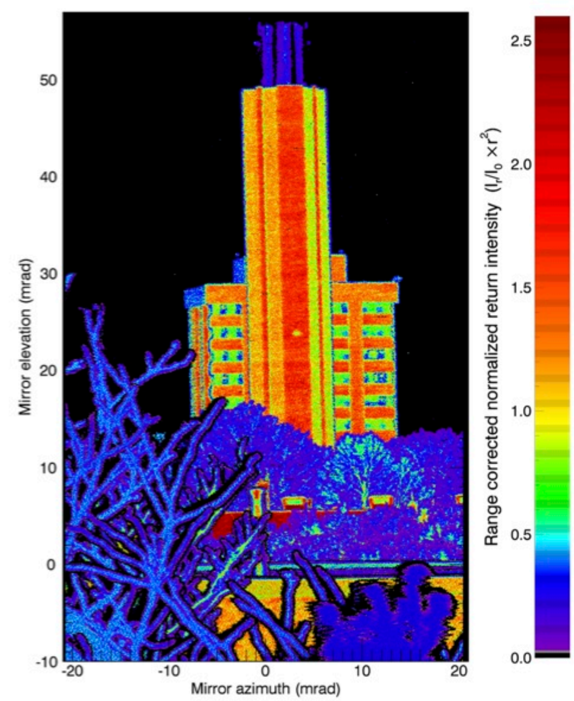

Figure 1. Range-corrected normalized return intensity test data [1] up to a distance of 1200 m from a LELT raster scan.

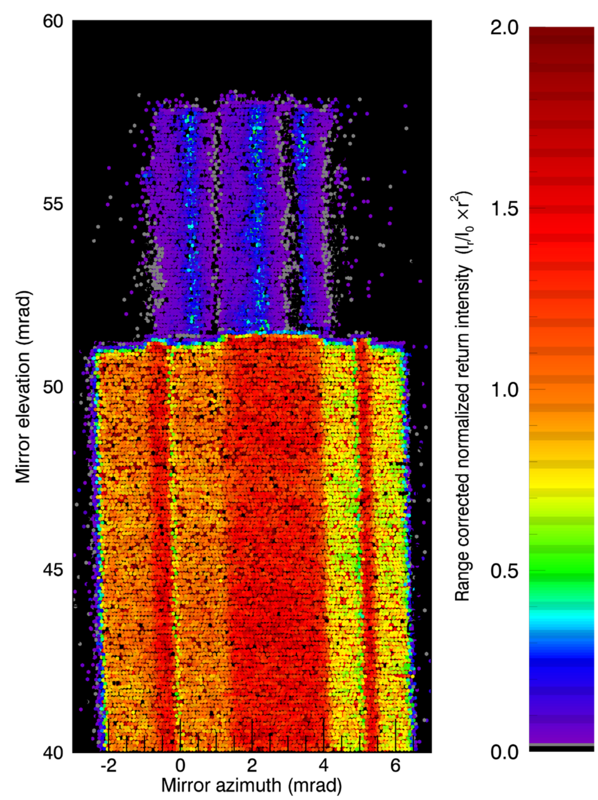

Figure 2. Intensity image from the OLA HELT raster scan of the York University smoke stack at 900 m.