1064-NM REFLECTANCE AT (101955) BENNU: LOW-ALTITUDE RESULTS FROM THE OSIRIS-REX LASER ALTIMETER.

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Introduction: The Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission to the dark and primitive asteroid Bennu carries a laser altimeter (OLA) [1], an actively sensing instrument uniquely suited to deriving global shape and preparing for sample return. OLA also records the return intensity of its pulses, from which we derive a spectral albedo at 1064-nm wavelength using the inverse squared dependence of intensity on range. Bennu's polar regions are scarcely illuminated by sunlight, but the laser spot returns provide the albedo globally at zero phase angle, as has been done for other airless bodies, e.g., [2, 3]. We now report on the results from the Low Energy Laser Transmitter (LELT) campaign during the Orbital B mission phase, with 10-kHz ranges at 600–740 m distance.

Data: From 1 July to 5 August 2019, 897 scans of ~5.5 minute duration were performed at nearly nadir incidence as Bennu rotated beneath the polar-orbiting spacecraft, providing global coverage with $>3\times10^9$ altimetric ranges and return intensities. The level 2 data stream during this campaign has accurate geolocation, more than sufficient for comparison of albedo with other datasets at sub-meter resolution and includes the outgoing and return intensities as auxiliary measurements. Altimetric detection was virtually 100% at the low altitude of the mapping campaign, but the return intensity digital numbers (DN) varied over a wide range, with a mean of 33 and standard deviation (SD) of 37 about the mean. Roughly 30% of DNs are zero, whereas ~5% of DNs are more than 2 SD greater than the mean. The outgoing intensity recorded DNs vary by ~10% but due to calibration uncertainties we will assume the laser energy, nominally 10 μJ, to be constant. Return intensity measurement precision is limited by the relatively small number of photons collected from a brief laser pulse, the excess noise factor of the detector photodiode, the integrator digital readout, and the heterogeneity of the surface albedo of a rubble-pile asteroid such as Bennu.

Methods: The range to surface r varies by ~25% due to topographic and orbital variation, so we first correct for signal dependence on r^2 as previously noted for the High Energy Laser Transmitter (HELT) data [4]. Single measurements have a non-Gaussian distribution and too high a variance, as noted above, to be informative. We average the hundreds to thousands of values within a single ~1 m^2 spatial element, or pixel, to obtain physically meaningful variations in reflectance. The broad and long-tailed distribution of values suggests that the median rather than the average of values within a single pixel is appropriate, which is implemented by including the zero values as representing one of the tails of the measurement distribution. Roughly 15 seconds out of each minute of scanning are also contaminated by noise from heater circuitry, and so only the remaining ¾ of the data are used here. The LELT intensities lack an absolute calibration so we scale the reflectances to an average normal albedo [5] of ~0.04.

Results: The LELT reflectance at 1064 nm is shown in Fig. 1. The albedo map correlates with many of the large individual boulders on the surface and displays regional variations related to the asteroid geology.

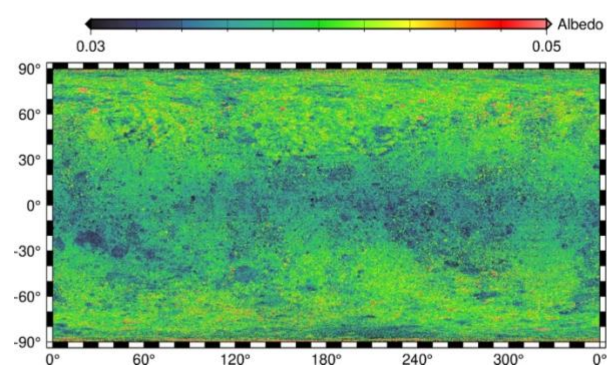

Figure 1. Median-averaged albedo from LELT, ~1 m pixels, in simple cylindrical projection.

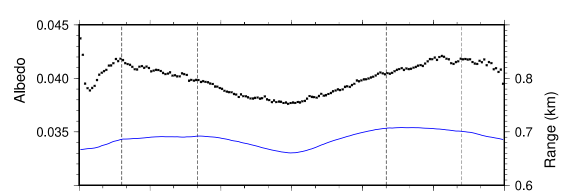

Figure 2. Average albedo by degrees of latitude (black) and average range to surface (blue curve). Regions of slope instability are denoted by pairs of dotted lines.

The latitudinal variation does not appear to be an artifact produced by range variation, outgoing intensity variation, or noise level since all of these (except range) appear to be independent of latitude. Range from the near-circular orbit increases away from the equator because of the equatorial bulge, but the relative brightening at higher latitudes is more pronounced than the range variation. Possible causes of global changes in albedo would be variation in slope stability, localized regional surface failure and thereby exposure to space weathering, and modification of regolith [6] noted within the outlined region.

Since the intensity measurement does not depend on solar illumination or photometric corrections, the polar regions are of particular interest (Fig. 3). Small bright areas correspond to isolated elevated features, while more diffuse dark patches also correspond, in some cases, to prominent boulder-like features. A dark albedo region at the north pole in Fig. 3 corresponds to a likely boulder pair surrounded by prominent blocks in the hill-shaded relief map of shape (Fig. 4). The highest point in Fig. 4 lies on the boulder at 86.25°N, 103°E which sits on a ridge extending southward towards 120°E, the bulk of which is somewhat darker than average.

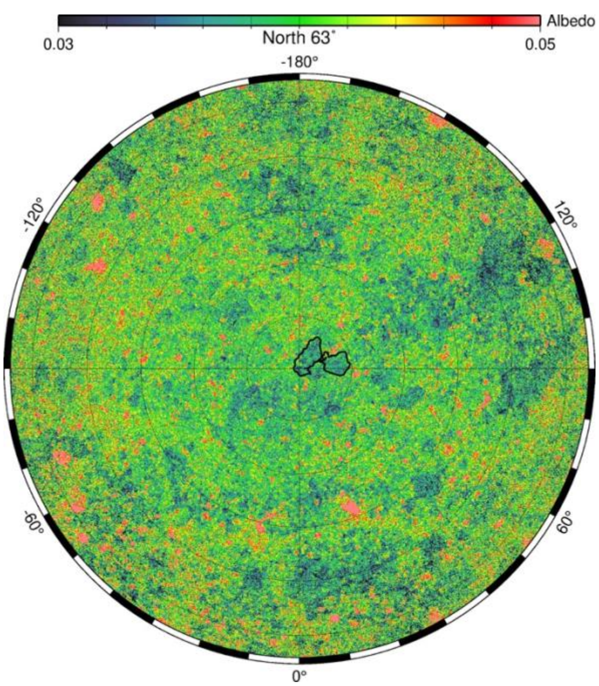

Figure 3. Median normalized intensity, ~24 cm pixel bins, in stereographic projection from 63°N to 90°N. The mapped area is approximately 240 m in diameter. Contours outline two possibly related boulders discussed in text and shown in the next figure.

Discussion: The intensity measurements suggest a variety of lithologies for boulders, both darker and brighter than the background (~0.04 average). The darkening of albedo, especially towards the north pole (Fig. 2) could result from shadow hiding (unlikely at nadir incidence), increased porosity and roughness, or space weathering [7]. Albedo variations at 1064 nm may also result from compositional differences involving possibly more mafic or pyroxene-rich rocks [8]. The use of a laser altimeter to independently assess surface characteristics in poorly illuminated polar areas with uniform coverage complements the OSIRIS-REx spectral imaging suite and informs the dynamical evolution of a rubble-pile asteroid.

References: [1] Daly M. G. et al. (2017) *SSR*, 212, 899–924. [2] Lucey P. G. et al. (2014) *JGR Planets*, 119, 1665-1679, 2014. [3] Neumann G. A. et al. (2013) *Science,* 339, 296–300. [4] Neumann G. A. et al. (2019) EPSC-DPS2019 Abstract #260. [5] Clark B. E. et al. (2011) *Icarus* 216(2), 462–475. [6] Barnouin O.S. et al. (2019), *this meeting*. [7] Clark B. E. et al., *this meeting.* [8] Kaplan H.H. et al., *this meeting*.

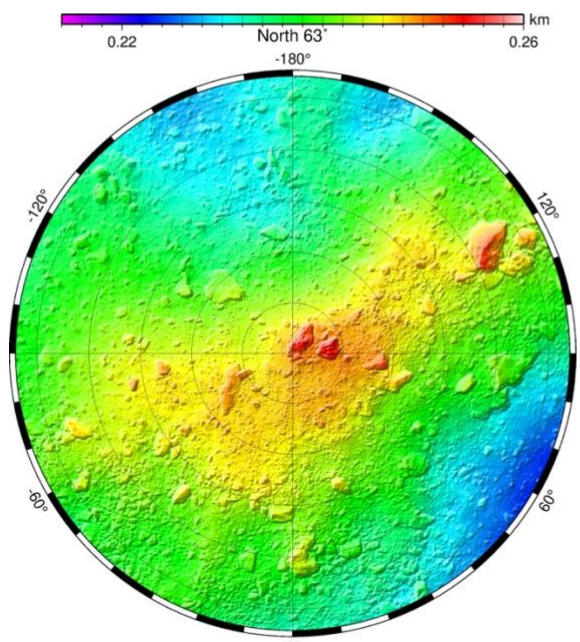

Figure 4. Shape (radius), corresponding to Fig. 3.

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