GLOBAL AND LOCAL VARIATIONS IN 1064-NM NORMAL ALBEDO OF BENNU FROM THE OSIRIS-REX LASER ALTIMETER. G. A. Neumann[1], M. K. Barker[1], E. Mazarico[1], M. G. Daly[2], O. S. Barnouin[3], E. R. Jawin[4], D. S. Lauretta[5], [1]NASA GSFC, Greenbelt, MD, USA (Gregory.A.Neumann@nasa.gov); [2]The Centre for Research in Earth and Space Science, York University, Toronto, Ontario, Canada; [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA; [4]National Museum of Natural History, Smithsonian Institution, Washington, DC, USA; [5]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA.

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 active-sensing instrument primarily for determining global shape and preparing for sample acquisition. OLA also records the return intensity of its pulses, from which we derive a normal albedo at 1064-nm wavelength after accounting for the inverse squared dependence of intensity on range. Bennu's polar regions are scarcely illuminated by sunlight and the extremely rough surface poses challenges for imaging as well, but the laser spot returns provide uniform measurements globally of albedo 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 a 10-kHz measurement rate at 600–740 m ranges.

Data: From 1 July to 5 August 2019, 911 scans of ~5.5 minute duration were performed at nearly nadir incidence as Bennu rotated beneath the polar-orbiting spacecraft, providing ~3×10^9 surface heights with roughly 7-cm-diameter footprints. The OLA data from 905 scans during this campaign have usable outgoing and return intensity counts as auxiliary measurements. Altimetric detection was virtually 100% at the low altitude of the mapping campaign whereas the return intensity digital numbers (DN) were highly nonlinear and ranged in excess of 1000, with a mean of 33 and standard deviation (SD) of 37 about the mean. Roughly 30% of DNs are zero, whereas ~5% of higher DN values are 2 SD greater than the mean. The outgoing intensity DNs are also recorded and vary by ~10% but due to calibration uncertainties we assume that the laser energy, nominally 10 μJ, is only varying slowly with time over the 5-week campaign. 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 (at ~7-cm spatial scales) of a rubble-pile asteroid such as Bennu. We exclude ~5% of the spot intensities, particularly those with ranges >730 m or emission angles >30° from the normal to a triaxial ellipsoid shape. Averaging data by median values overcomes other intermittent sources of noise of a few seconds duration that produce anomalously high and low intensities.

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], and then correct for a ~10% linear decline in laser output inferred from the range-corrected intensity over the course of five weeks. The median of the values (typically >100) within each mapping 0.0625° by 0.0625° spatial element, or pixel, yields a robust measure of variations in reflectance in arbitrary units.

Results: The LELT reflectance at 1064 nm is shown in Fig. 1a. The normal albedo varies overall by 12% SD about its mean, which we scale to an average of ~0.04 [5]. Albedo varies substantially with latitude. 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) are independent of latitude. A possible cause of latitudinal change in albedo would be due to global variation in slope (Fig. 1b), with slopes being notably steeper [6] between latitudes of 40–70 degrees N/S. Modification of regolith by local surface failure at such latitudes as well as other regional changes in sub-meter-scale roughness likely result in differential exposure to space weathering [7].

Normal albedo as a function of latitude may also exhibit mineral-grain temperature dependency [8]. Many of the albedo features represent large (> 5 m) boulders (saxum or saxa) on the surface [9–11], for which at least 70 have been identified by names proposed to the IAU Working Group for Planetary System Nomenclature. In particular the larger (> 15 m) saxa and their haloes of derived material are darker than their surrounding terrain. Some of the smaller (< 10 m) saxa also exhibit brighter than average albedo. Several of the brightest features do not appear to correlate with boulders at the OLA scale of resolution (Fig. 2). A histogram of albedo pixel values at the latitude shown here is unimodal and long-tailed, but in the outlined regions (Fig. 2a) the histogram has a higher-reflectance mode (Fig. 2d) that is 2–3x brighter than the nominal average of 0.04.

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. 1b) could result from some degree of shadow hiding (even at nadir incidence), increased porosity and roughness, or space weathering [7]. High albedo deviations at 1064 nm may result from compositional differences involving possibly more mafic or pyroxene-rich rocks [9]. 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 [13] and informs the dynamical evolution of a rubble-pile asteroid.

Acknowledgements: GN and MB were supported by award NNH17ZDA001N through the ORPSP17 Program. The laser altimeter build and Canadian science support was provided by a contract with the Canadian Space Agency. This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. We are grateful to the entire OSIRIS-REx Team for making the encounter with Bennu possible.

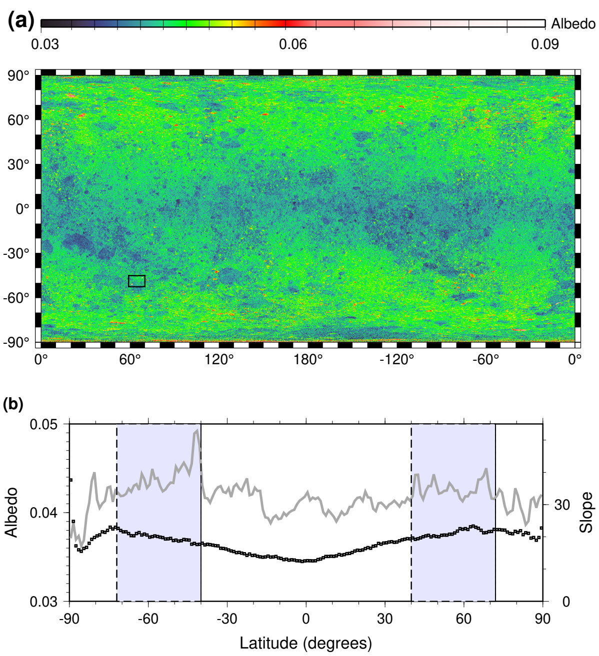

Figure 1. (a) Median-averaged albedo from LELT, in simple cylindrical projection. Outlined region is shown in Fig. 2. **(b)** Average albedo by degrees of latitude (black symbols) and 90th percentile of surface slope (gray curve). Regions of likely slope instability [7] are shaded.

References: [1] Daly M. G. et al. (2017) *SSR*, 212, 899–924. [2] Lucey P. G. et al. (2014) *JGR Planets*, 119, 1665–1679. [3] Neumann G. A. et al. (2013) *Science,* 339, 296–300. [4] Neumann G. A. et al. (2019) *EPSC-DPS Joint Meeting 2019*, Abstract #260. [5] Takir D. et al. (2015) *Icarus* 252, 393-399. [6] Barnouin O. S. et al. (2019) *Nature Geoscience*, 12, 247–252. [7] Barnouin O. S. et al. (2019) *EPSC-DPS Joint Meeting 2019*, 13, #255. [8] Siegler M. et al. (2020) this meeting. [9] DellaGiustina D. N. et al. (in review) *Nat. Astron.* [10] Jawin E. et al. (2020) this meeting. [11] Rossman F. et al. (2020) this meeting. [12] Golish D. R. et al. (in review) *Icarus*. [13] Rizk, B. et al. (2018). OCAMS: The OSIRIS-REx Camera Suite. Space Sci. Rev. 214, 26.

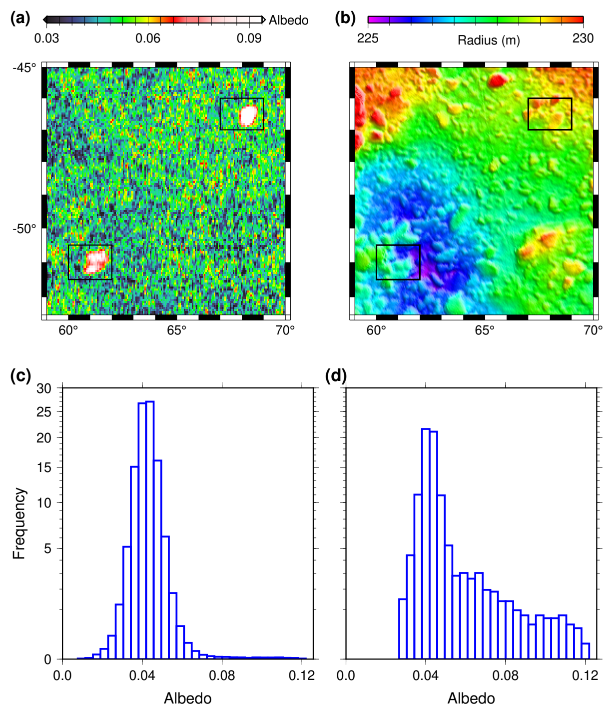

Figure 2. (a) Mercator plot of normal albedo. (b) Color-contoured radius showing regional structure. (c) Histogram of normal albedo between 45°S and 52.5°S latitude, and (d) within the two outlined regions, with quadratic frequency scale for emphasis.