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Preliminary calibration of reflectance data from the OSIRIS-REx Laser Altimeter at Bennu

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Abstract

The OSIRIS-REx Laser Altimeter (OLA) [1] records the return intensity of its pulses, which can be interpreted as a spectral albedo at 1064-nm wavelength. The lidar link equation allows a preliminary calibration of the intensity vs. range, thereby providing a comparison of reflectance with that obtained by the imaging system 1-micron channel at low solar phase angle. Bennu's polar regions are scarcely illuminated by sunlight, but the reflectance at zero phase angle may be obtained globally by using lasers as has been done for other airless bodies, e.g., [2, 3].

1. Introduction

The OLA High Energy Laser Transmitter (HELT) [1] conducted 17 successive observation scans for up to 5 hours duration from 13 February 2019 to 19 April 2019 during the Detailed Survey mission phase. The range to Bennu was ~1.35 km to 4.8 km. Although the outgoing laser intensity measurement was disabled, we have assumed a relatively constant laser output at 0.7 mJ per 100 Hz pulse. Lidar scans from 4 to 16 December 2018 during the Preliminary Survey phase were at distances greater than or equal to OLA's 7-km operational range, and the intensities measured in the returned data were too low to be analyzed.

1.1 Link analysis

The relation between received energy measured at range r and the characteristics of the lidar system, the transmitted energy, and the surface from which the laser pulse is reflected is known as the link equation. For simplicity we consider only transmission through an airless medium with a narrow divergence beam whose footprint on the surface is wholly imaged by the receiver, after passing through a filter that excludes broadband background illumination. The intensity received is therefore proportional to the geometric albedo of the surface and inversely proportional to r^2. The measurements may therefore be fit (after averaging) to a linear model representing the reflectance of Bennu. The normal albedo relative to a Lambert surface measured on any particular facet is insensitive to the orientation relative to the observer [4]. Earth-based photometry and estimates from the Approach phase predicted a very dark and carbonaceous body, whose reflectance (relative to a perfectly Lambertian surface) was in the range of 3 to 4% [5], much lower than that of lunar or other planetary surfaces.

2. Noise averaging

The measurement of normal albedo via laser altimetry is subject to the limitations of 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. As a first look, we median-average the point cloud of returns within 2x2 meter bins after stereographic projection to a Cartesian plane. There are a number of returns whose digital intensity measurements are zero and more so for weaker signals; averaging zero values is appropriate to fit a linear model as shown in Fig. 1, whereas the long-tailed distribution of intensities shown in Fig. 2 warrants a median average. A small number of non-ground returns, generally at ranges lying outside Bennu, are excluded.

3. Results

A northern hemisphere plot of albedo in digital units normalized to 1 km range is shown in Fig. 3. Elevated ridges appear somewhat brighter in reflectance, while a major scarp [5] at 32°N, 125°E, and several large boulders are anomalously dark. There is no discernible latitudinal trend; however, the elevated terrain at the north pole contains many unusually bright and dark observations. This may be a consequence of the oblique geometry and extended range required to reach the poles.

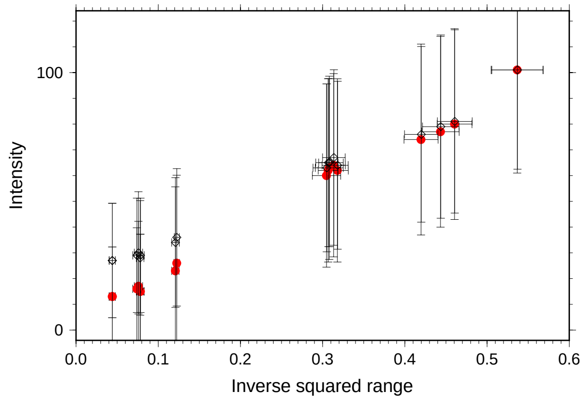

Figure 1: The median averaged intensity count and scale (median absolute deviation) for 17 passes over Bennu vs. range, with (black) and without (red) zero values, during the Preliminary Survey observations. A linear relationship indicates that a model assuming a relatively constant outgoing intensity can be applied and that zero values may be included in averaging.

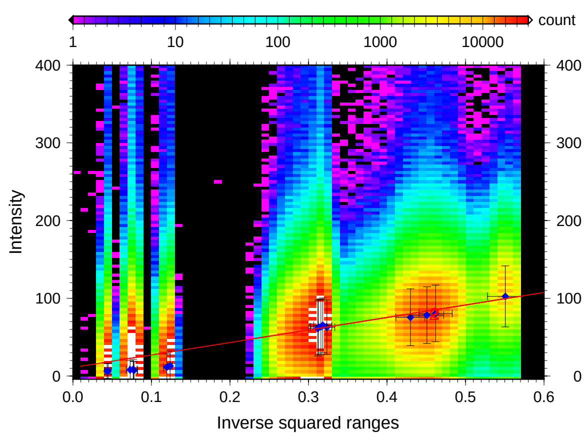

Figure 2: The density of observations vs. range and raw intensity, with a linear fit (red) to all 17 passes in both northern and southern hemispheres. A digital bias of <10 counts at zero intensity is inferred from the linear fit. Error bars show the median absolute deviation of the observations on each day.

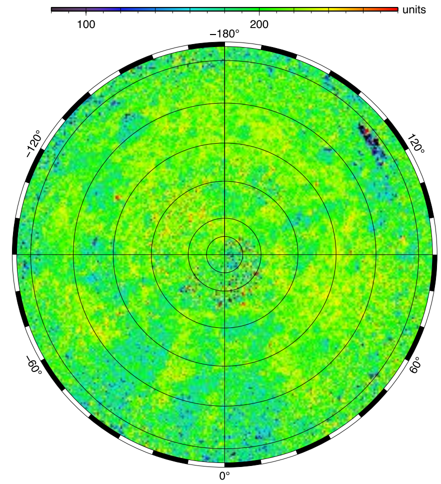

Figure 3: Intensity measurements over the northern hemisphere in stereographic projection to 37°N, with arbitrary scale, from six low-altitude passes.

Summary and Conclusions

OLA conducted 100-Hz laser scans during the Detailed Survey mission phase. The reflectance data will be calibrated with respect to imager observations at low phase. The preliminary data reveal the diverse terrain characteristics of a rubble-pile asteroid [6].

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