EARLY RESOLVED PHOTOMETRY OF ASTEROID BENNU. D. R Golish[1], B. E. Clark[2], J.-Y. Li[3], X.-D. Zou[3], D. N. DellaGiustina[1], C. Hergenrother[1], K. J. Becker[1], C. Drouet d'Aubigny[1], C. A. Bennett[1], B. Rizk[1], D. S. Lauretta[1], and the OSIRIS-REx Team, [1]Lunar and Planetary Laboratory, University of Arizona (1415 N. 6th Ave., Tucson, AZ 85705, dgolish@orex.lpl.arizona.edu), [2]Department of Physics and Astronomy, Ithaca College (953 Danby Road, Ithaca, NY 14850), [3]Planetary Science Institute (1700 E Ft. Lowell Rd, Tucson, AZ).

Introduction: OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer) is a NASA mission to study and return a sample of asteroid (101955) Bennu [1]. The OSIRIS-REx spacecraft arrived at Bennu on December 3, 2018; during the weeks preceding and following arrival, OSIRIS-REx imaged the asteroid with two of the three instruments in the OSIRIS-REx Camera Suite (OCAMS) [2], PolyCam and MapCam. The data included images specifically designed for photometric modeling. Though the formal photometric modeling data will not be collected until late spring of 2019, this initial data provides an early look into Bennu's photometric character.

Image Data: Data collected during the Approach (pre-arrival) and Preliminary Survey (post-arrival) phases of the mission spanned from when Bennu was still a point source to high-resolution images (< 0.33 m/pixel) of the surface. The highest-resolution images are acquired by PolyCam, but utilize only a panchromatic filter (500-800 nm). The MapCam images, while not as high resolution, are acquired with a matching panchromatic filter, as well as four narrow-band color filters, roughly corresponding to a subset of the Eight Color Asteroid Survey (ECAS) filters [3], though the OCAMS b′ filter is slightly red-shifted from its ECAS counterpart. The OCAMS filters have effective wavelengths of 473, 550, 698, and 847 nm for the b′, v, w, and x bands. We base our initial photometric modeling of Bennu on these color data. In order to avoid point-source effects, we limit our data to those when Bennu was resolved (> 5 pixels). Each of the MapCam photometric images sets were taken at an arbitrary (and variable between image sets) point in Bennu's rotation. As a result, we do not have full surface coverage at every phase angle. Therefore, for this initial data, we analyze Bennu as a global average. Figure 1 shows a sample of some of the highest-resolution, mid-phase images acquired on December 12, 13, and 14.
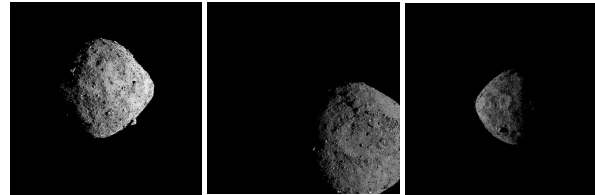

Figure 1. MapCam images taken during the Preliminary Survey phase.

Photometric Coverage: The phase angles covered by this data set span from ~0.7° to ~90° in all five filters, as illustrated in Figure 2. Because the images are of the whole disk of Bennu, and must be treated as hemispherical averages of the portion facing the camera, we do not attempt to analyze the emission or incidence angle coverage. Hemispherical averages are expressed in terms of reflectance (I/F), such that the value at 0° phase is approximately equivalent to the geometric albedo of the surface in that filter.
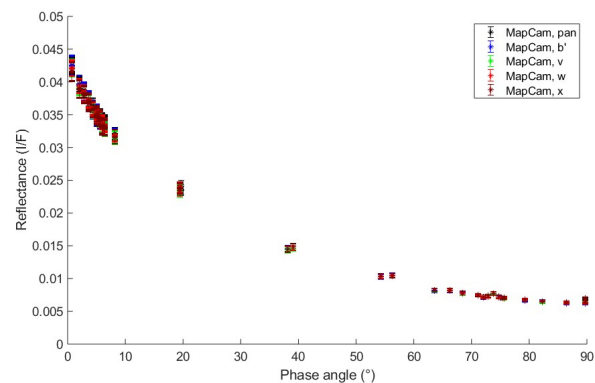

Figure 2. Images of Bennu acquired by MapCam in all five filters cover phase angles from ~0.7° to ~90°.

Initial Photometric Model: When we acquire the dedicated photometric dataset later in the mission, we will apply it to a suite of models [4]. However, for this initial analysis, photometric modeling is performed using a Lommel-Seeliger disk function (Eq. 1) and an exponential-polynomial phase function (Eq. 2). Photometric modeling is performed in terms of reflectance. These forms fit the data well in all colors.

$$d(i,e) = \frac{\cos(i)}{\cos(i) + \cos(e)} \qquad (1)$$

$$f(\alpha) = e^{\beta * \alpha + \gamma * \alpha^2 + \delta * \alpha^3} \qquad (2)$$

We fit the photometric image data to this model and plot them for each filter in Figure 3. The colors generally trend together and peak at Bennu's geometric albedo of 0.0435 ± 0.0015. However, slight differences in the colors are potentially revealing. In particular, Bennu seems to demonstrate a distinct increase in the x filter at high phase, indicative of phase reddening. Due to Bennu's low albedo and presumed single scattering nature, we would not expect strong phase reddening. However, a recent photometric analysis of Ceres [5] has suggested that micron-size grains might enhance phase reddening in single scattering material. As such, continued photometric analysis might act as an indicator of such a population.
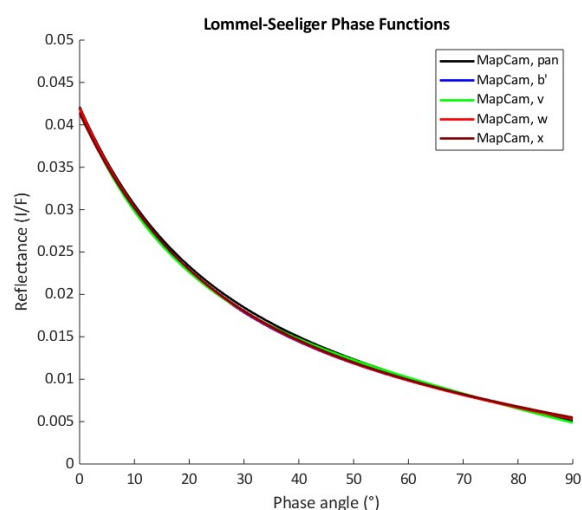

Figure 3. Initial photometric modeling of Bennu is performed with a Lommel-Seeliger disk function and exponential-polynomial phase function.

References: [1] Lauretta, D. S. et al. (2017) *Space Science Reviews*, 212, 925–984. [2] Rizk, B. et al. (2018) *Space Science Reviews,* 214, 26. [3] Zellner, B. et al. (1985), *Icarus*, 61(3), 355-416. [4] Golish, D. et al. (2019), *Earth and Space Science*, in review. [5] Li, J.-Y. et al. (2019), *Icarus*, accepted
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