COMPARING THE RADAR SHAPE MODEL OF (101955) BENNU WITH \GROUND TRUTH FROM OSIRIS-REX.
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Introduction: Nolan et al. [1] presented a shape model and rotation state of (101955) Bennu using radar and lightcurve observations in 1999 and 2005. The rotation state was updated based on additional HST lightcurves obtained in 2012 [2]. The resulting shape model and radar scattering properties were used in planning the OSIRIS-REx mission in the form of a "Design Reference Asteroid" (DRA) [3]. We compare the "as-built" Bennu with the radar modelling results.

Radar Shape Model: The shape model from [1] (hereafter, "radar shape model") consists of 2692 triangular facets, with a median edge length of 27 m. The radar imaging had 7.5-m (2005) and 15-m (1999) resolution, but to increase SNR the images were binned at 6-degree (~25 m at the equator) rotational resolution. The uncertainty of the overall dimensions of the radar shape model was 10 m in X and Y, but 52 m in Z, because of ambiguities in the radar observations. The radial uncertainty was not reported, but it was likely comparable to the uncertainty in X and Y of 10 m. They saw one "boulder" that they estimated to be 10-20 m in size based on its appearance in the radar images. The shape model reflects this feature because the model resolution was increased to ~5-m edge length in the region of the boulder.

The shape modeling process adjusts the shape of the model to match the data in a chi-squared sense, but also includes a number of "penalties" to enforce "reasonable" shapes. Because the radar data are typically quite noisy, these penalties are required for stability, but it is difficult to a priori decide what is "reasonable". These penalties tend to smooth the model. [4]

Radar Scattering: The radar scattering properties were measured in both disk-integrated and surface-resolved modes, though resolved properties were only obtained in 1999. [1] Interpreted the radar scattering properties to suggest that the surface is smoother than Eros or Itokawa at ~10-cm scales based on a lower radar polarization ratio, and that it has a near-surface bulk density between 0.9 and 1.7 g/cm^3.

Comparison with OSIRIS-REx results: We compare the radar shape model to the OSIRIS-REx images and a stereophotoclinometry (SPC) shape model produced from those images. [5]

The initial images of Bennu in October 2018 looked quite similar to the rendering from the radar shape model (Fig. 1). The dimensions are within 2% of the predicted values, well within 1-sigma. The asteroid appears to be slightly more flattened than the model. The obliquity of the rotation pole is approximately 1-sigma from the prediction, but the actual pole position is approximately 5 (1.5 sigma) degrees away.

The boulder feature in the radar shape model is the largest boulder visible near latitude −45 and longitude 145, which is ~30 m in height and ~50 m across [6]. It has a flat eastward-facing face, which likely is why it was dramatically visible in the radar imaging. Even this boulder was not clearly visible from other viewing directions in the radar imaging. Another boulder at latitude −30 and longitude 0 is slightly shorter, and appears in the shape model as topography but not as a separate object. No smaller boulders were clearly distinguishable from noise in the radar imaging. Miller et al. [7] estimated that 20-m boulders should be visible, but smaller ones might not be. This estimate is apparently still optimistic.

Density: The "surface bulk density" is consistent with the prediction from the radar measurements. Many of the largest boulders appear to have a very low thermal inertia, $\lesssim$ 300 SI units [8], suggesting that even the dense materials on Bennu are relatively low density. This suggests that the macroporosity of Bennu's interior may not be extremely low.

Roughness: We have not specifically measured the roughness at 10-cm scales, but the overall picture of Bennu as a smooth surface based on the radar polarization is not borne out. Bennu is covered with meter-scale or larger rocks, so that the radar scattering is likely dominated by the texture of the rocks rather than the grain size of pebbles. Nolan et al. [1] provided a surface-resolved map of the polarization ratio. We will compare this map to possible features on Bennu, including roughness derived from shape and from thermal properties [9].

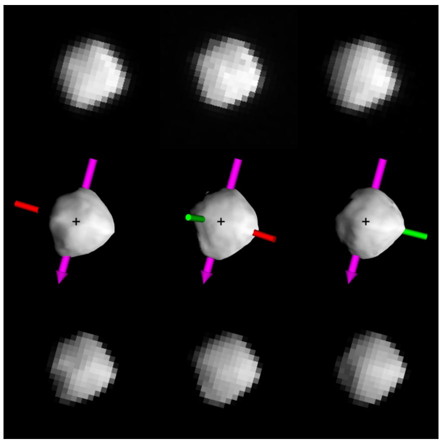

Figure 1. The top row contains three images of Bennu obtained by the PolyCam camera on October 23, 2018, each taken about two hours apart. The images were taken from a distance of 3,000 km from the asteroid and represent Bennu at 13 pixels in the camera's field of view. The middle row shows renderings of Bennu as predicted by [1]. The shape model representations are rendered as if they were observed by the spacecraft at the same time, distance, and lighting conditions as the images. The bottom row pixelates the shape model renderings to be similar to the observed images to make comparison easier. The images show overall agreement between the observations and the radar model predictions, including some of the large-scale features on the asteroid.

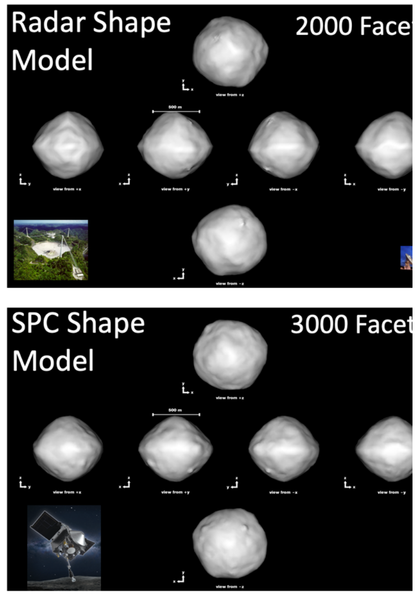

Figure 2. Comparison of the radar-derived and Bennu encounter shape models.

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