The Shape of Near-Earth Asteroid 275677 (2000 RS11)

From Inversion of Arecibo and Goldstone Radar Images

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Introduction

Learning about the physical properties and trajectories of near-Earth asteroids (NEAs) is a part of an ongoing mission to understand the objects around us in the solar system. One method of observing NEAs that has proven increasingly useful over the last couple of decades is the technique of reflecting radio waves off nearby asteroids and analyzing the echoes. Through this technique, called radar astronomy, we can learn about the asteroid's shape, spin state, and trajectory.

We used this method to produce a physical model of near-Earth asteroid 275677 (2000 RS11).

Abstract

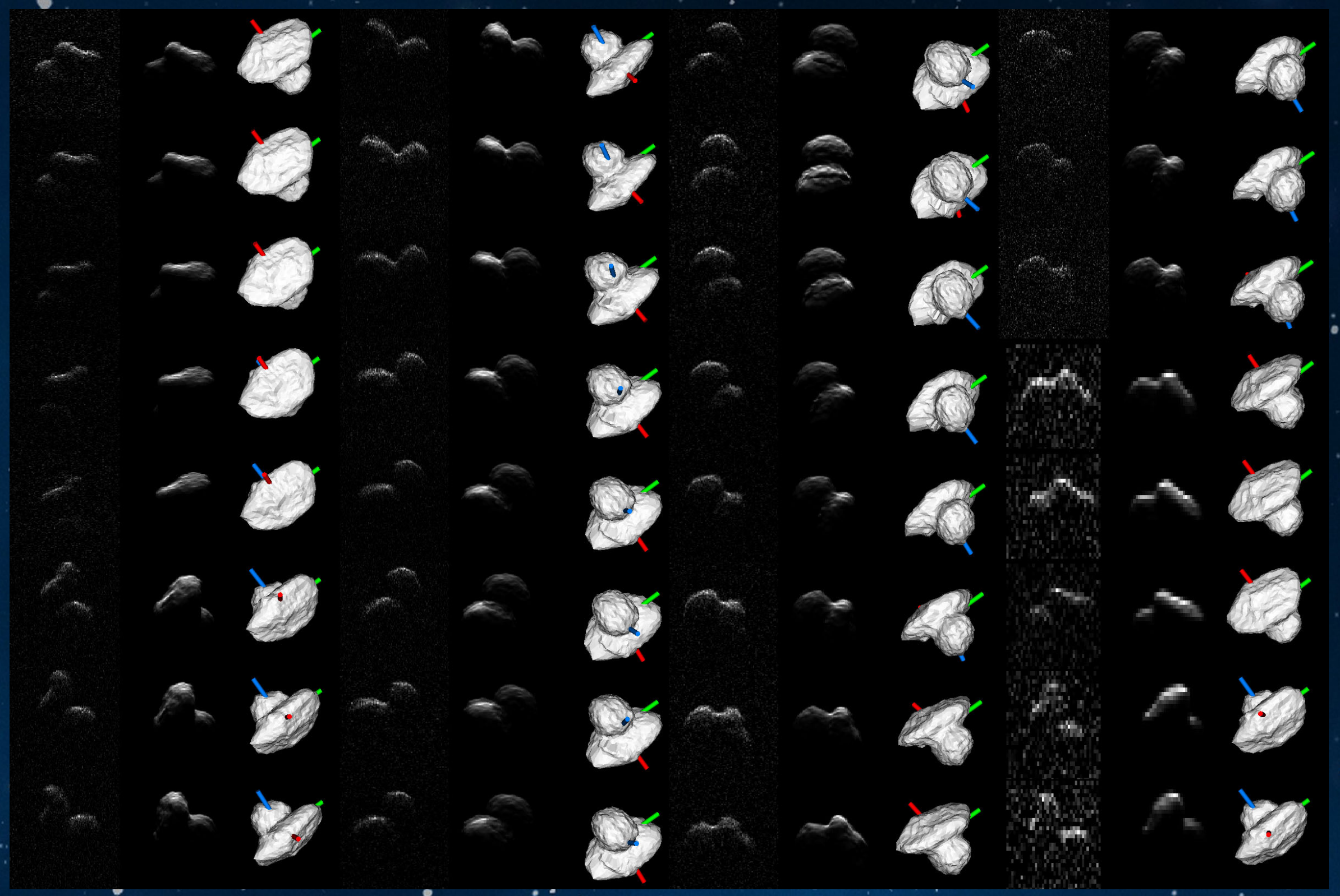
We observed near-Earth asteroid 2000 RS11 with the Arecibo and Goldstone planetary radars during a 0.035 au approach in March 2014. RS11's pole direction is either (λ , β) = (155°, 30°) ± 10° or (335°, -30°) ± 10° in J2000 ecliptic coordinates. These two pole directions correspond to two mirror image models that provide equally good fits to radar data. The pole direction of RS11 is not aligned with the heliocentric orbit normal and instead has an obliquity within 10° of 56° or 124°.

Our best-fit shape models are 1400-vertex polyhedra comprising two lobes in contact. RS11's shape is unusual compared with those of other contact binary NEAs imaged by radar. Its larger lobe is flattened. Additionally, while the neck between the smaller and larger lobes of most contact binaries is located near the larger lobe's longest principal axis (such as in the cases of 25143 Itokawa and 4179 Toutatis), RS11's neck is near its larger lobe's shortest principal axis. RS11 is the first asteroid of this type for which we have a shape model.

Method

To produce our model, we used delay-Doppler images obtained by the Arecibo and Goldstone planetary radars. The finest-resolution images have range resolution of 7.5 m/pixel. We used the SHAPE software package[1] to create a physical model of RS11 and its spin state from these delay-Doppler images.

SHAPE is a constrained-least-squares program that changes one parameter at a time in such a way as to minimize the objective function, the sum of reduced chi-square and optional penalty functions. Penalty functions were used to discourage physically implausible models.



Example SHAPE output for 2000 RS11 model. Each column has Delay-Doppler images of RS11 from Goldstone and Arecibo on the left, corresponding synthetic radar images of the model in the middle, and plane-of-sky projections of the model on the right. Data from March 13th – 17th is included.

Our initial model was a manually-created, simple two-component ellipsoid model, and this model was manipulated in order to determine the possible pole directions of RS11. The sidereal rotation period of RS11 is well constrained from optical lightcurves, P = 4.444 ± 0.001 h[2,3], and knowing this, we were able to conduct a 30°-resolution grid search to narrow down possible pole directions. We found two possible pole directions and corresponding shape models, mirror images of one another, which provide equally good fits to the radar data.

The two possible pole directions are due to a north-south ambiguity inherent in the delay-Doppler images; portions of RS11 in the northern and southern hemisphere plot to the same point in the image. To resolve this ambiguity, we would need either radar or lightcurve observations that viewed RS11 from a drastically different angle. Until that data is taken, both pole directions must be kept as possible.

After possible pole directions were found, those parameters were locked and we began improving the shape model. Ellipsoid models were used until the general shape of RS11 could be determined, at which point we advanced to vertex models to better capture the complexities of the topography.

Additionally, throughout the modeling process, delay corrections were used to align the leading edge of the actual radar echo with the leading edge of the modeled radar echo. Through this process, we corrected the known epheremis of RS11 and improved our knowledge of its trajectory.

Results

Our best-fit shape models are 1400-vertex polyhedra. Properties and principle-axis views of our best-fit model can be seen to the right.

RS11 is far from purely prograde or retrograde rotation, with an obliquity within 10° of 56° or 124°. YORP radiation pressure torques tend to force NEAs into prograde or retrograde rotations, but RS11 has avoided falling into these types of motions. As seen by its possible obliquities, RS11 is almost spinning on its side.

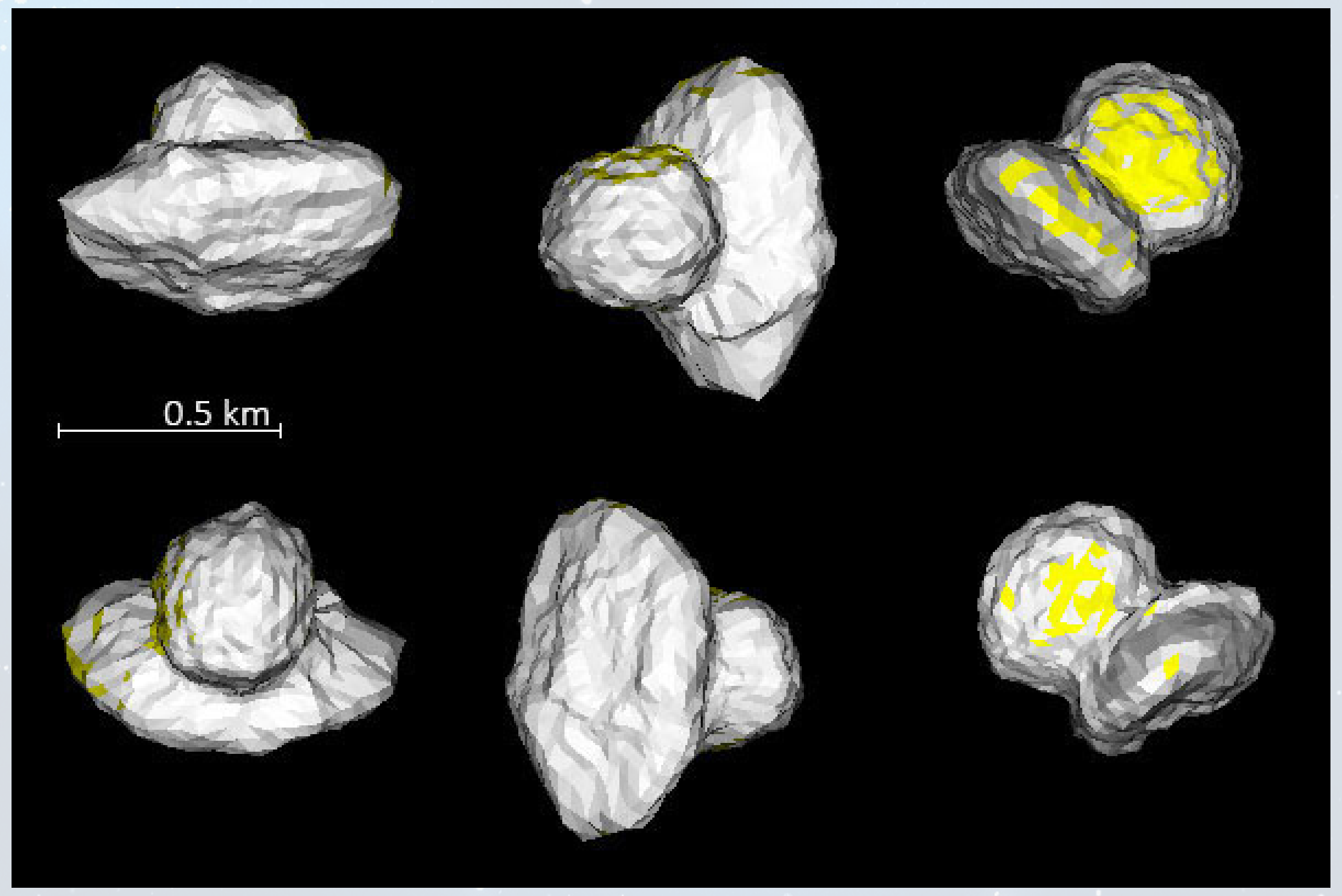
The shape of RS11 is also unusual compared with those of other contact binary NEAs imaged by radar: its larger lobe is quite flattened. Additionally, while the neck between the smaller and larger lobes of most contact binaries is located near the larger lobe's longest principal axis (such as in the cases of 25143 Itokawa and 4179 Toutatis), RS11's neck is near its larger lobe's shortest principal axis.

RS11's unusual shape and obliquity raise questions about the asteroid's origins and history. Spectral data classifying RS11 as a rocky S-class object excludes the possibility of it being an extinct comet.[4]

Example SHAPE output for our model can be seen to the left. Similarities and differences between the actual radar images and the synthetic radar images can be seen. While the synthetic radar images are generally able to reproduce the echoes seen in the actual radar images, some portions of the larger lobe's edge, the Doppler range in the middle columns, and the brightness of some of the echoes do not match the actual images. Some of this is a hysteresis effect from initially modeling the asteroid with ellipsoids, and some of this is due to imperfect scattering laws. Moving farther away from the ellipsoid model and adjusting the scattering laws could improve these imperfections.

Properties of 2000 RS11 Model

Pole direction (J200 ecliptic)	(155°, 30°) or (335°, -30°) ± 10°
Rotation period	4.444 ± 0.001 h2,3
Obliquity	56° or 124° ± 10°
Principal-axis dimesions	(652 ± 67, 591 ± 61, 787 ± 80) m
Volume	0.088 ± 0.027 km^3
Long axis of Lobe 1	786 ± 80 m
Long axis of Lobe 2	417 ± 43 m
Volume ratio between lobes	2.7 ± 10%



Principle-axis views of 2000 RS11 model.
Yellow-shaded regions were either not seen by radar or were seen only at greater than 60° angles of incidence.

Conclusions

Despite imperfections in the model, the general shape and the obliquity of RS11 are well constrained. RS11 is far from prograde or retrograde motion and has an uncommon shape as compared to other contact binary NEAs that have been observed. These unusual properties raise questions about RS11's history.

Future work could involve continuing to improve the model that through continued manipulation of the model and fit parameters with SHAPE. Determining which of the two possible pole directions is accurate is another step to improve our knowledge of RS11, but opportunities to resolve the north-south ambiguity through new observations are years in the future. The next opportunity to record lightcurve observations of RS11 from a drastically different angle with Earth-based equipment will be in 2027.

In addition to improving the model, other future work could involve looking for other asteroids with similar properties to RS11. This could help us better understand the properties of NEAs and determine if RS11 is as uncommon as we believe. Finding other similar asteroids could also potentially shed light on RS11's history and how asteroids like it formed.

[1] Magri et al., Icarus 186, 156–160; 2007. [2] Warner et al., Minor Planet Bulletin 41, 160; 2014. [3] Benishek, Minor Planet Bulletin 41, 257; 2014. [4] Lazzarin et al., Icarus 169, 379; 2004.