RADAR AND OPTICAL OBSERVATIONS OF EQUAL-MASS BINARY NEAR-EARTH ASTEROIDS (190166) 2005 UP156 AND 2017 YE5.

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Introduction: To date, only four equal-mass binary asteroids have been discovered among the near-Earth population: (69230) Hermes, 1994 CJ1, (190166) 2005 UP156, and 2017 YE5, all of which have been characterized with radar and optical lightcurves. Equal-mass binaries are relatively rare, making up less than 1% of radar-observed near-Earth objects larger than 200 meters in diameter, compared to ~15% for binaries with more disparate sizes and ~15% for bilobate (peanut-shaped) asteroids. Here, we report on modeling of the most recently observed systems: 2005 UP156 and 2017 YE5.

Observations: Radar and optical lightcurve observations of binary asteroids are very complementary. Optical observations precisely constrain the spin states of the components and the mutual-orbital period, while radar observations precisely constrain the sizes, shapes, and scale of the mutual orbit. Whenever possible, radar and optical observations are combined to better understand the physical and dynamical characteristics of multiple-asteroid systems.

(190166) 2005 UP156. The binary nature of near-Earth asteroid 2005 UP156 was shown by distinctive mutual events in its optical lightcurves [1] from 2017 May 4 through June 12. The observed lightcurve period of 40.542 +/- 0.008 h agrees with the period determined in 2014 [2], though no mutual events were noted at that time. An out-of-eclipse lightcurve amplitude of 0.5 mag suggests the components have significant elongations. Radar observations with the Arecibo planetary radar system (Figure 1) on 15 dates from 2017 June 2 to July 10, when 2005 UP156 was 0.13 to 0.19 au from Earth, unambiguously revealed the nearly equal-size components of the binary system.

2017 YE5. Radar observations with the Goldstone, Arecibo, and Green Bank radio telescopes between 2018 June 21 and 26 showed that 2017 YE5 is also two asteroids of similar size in mutual orbit about each other. The first three days of images from Goldstone (Figure 2) were tantalizing, clearly showing two lobes, but the lobes never definitively separated in the horizontal (Doppler) dimension. Combining Arecibo and Green Bank allowed for sufficient frequency resolution to separate the components (Figure 3). The relatively close approach to Earth, only 0.04 au (16 lunar distances), helped make the radar images of 2017 YE5 the best yet of a nearly equal-mass binary system with echo power nearly two orders of magnitude greater than for the more-distant 2005 UP156 encounter. With resolution as fine as 7.5 meters per pixel, these radar images show ten times finer detail than radar images of any other equal-mass binary system.

Figure 1. Arecibo range-Doppler images of 2005 UP156 with 75-m resolution clearly show the two nearly equal-size components with elongated shapes and their long axes pointed toward each other.

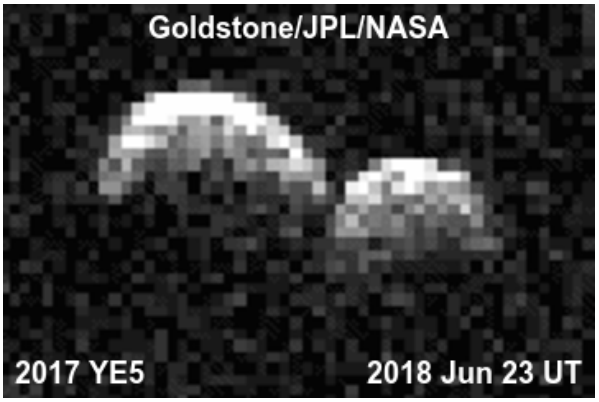

Figure 2. Goldstone range-Doppler image of 2017 YE5 with 37.5-m resolution shows two lobes, but it is not clear if the lobes are in contact or separated.

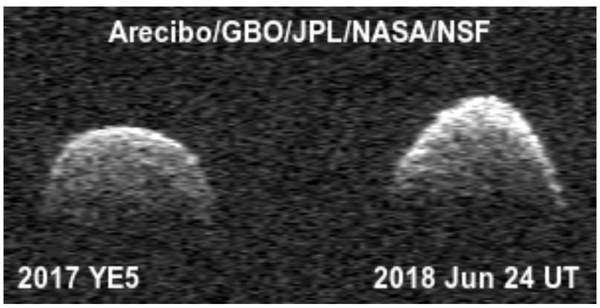

Figure 3. Arecibo-Green Bank range-Doppler image of 2017 YE5 with 7.5-meter resolution clearly shows the separation between the two nearly equal-size components with somewhat different shapes.

Results: Modeling of the shapes, spin states, and mutual orbits of these systems is underway and a progress report will be presented.

(190166) 2005 UP156. Preliminary size estimates from radar images are 900 meters in the longest dimension for both components. Images at different orientations confirm their elongated shapes, as expected from the out-of-eclipse lightcurve variations, with the long axes aligned, i.e., face-locked synchronous rotation, and an orbital period commensurate with the optical lightcurve period. The elongations of the shapes suggest equatorial axis ratios of about 1.5 to 1 for both components making these objects possibly the most elongated near-Earth asteroids known to have a satellite. Based on these ellipsoidal shapes, the absolute magnitude of 17.2 implies a bright optical albedo of roughly 30%. The maximum observed separation between the components of 2.4 km is a lower limit on the semimajor axis of the system, though the projection effect should be minimal given the eclipsing nature of the contemporaneous lightcurves; the true semimajor axis is likely about 2.7 km. Combined with the size and shape estimates, the implied density of the system is 1.6 g/cm^3.

2017 YE5. Both components in the 2017 YE5 system are approximately 900 m in diameter, implying a very dark optical albedo of less than 3% for an absolute magnitude of 19.2. The radar images suggest the components have somewhat different shapes and possibly also different radar-scattering properties. Variation in the radar images from day to day suggests the system was initially viewed very nearly along the mutual-orbit axis and spin axes of the components. The mutual orbit has a semimajor axis of about 1.8 km (four component radii) and a period of roughly 24 hours, corresponding to a low density of less than 1 g/cm^3 and implying significant macroporosity. Analysis of optical lightcurves, including possible mutual events, collected between 2018 June 24 and August 4 is ongoing and suggests there may be an additional period in the system due to non-principal-axis rotation or precession. Analysis of the radar images suggests the spin axes of the components may also be misaligned by a few degrees. The possibility of non-principal-axis rotation and axial misalignment in this system is intriguing and warrants careful analysis.

Conclusions: For both 2005 UP156 and 2017 YE5, the longest dimensions of the components appear to be 900 meters; however, the similarities end there. The components of 2005 UP156 appear significantly elongated compared to the more spherical components of 2017 YE5. The mutual orbit of 2005 UP156 is much wider at more than 6 component radii compared to only 4 radii for 2017 YE5, in addition to a much longer mutual-orbit period. Despite small-number statistics, there appears to be significant variation in the properties of nearly equal-mass binary near-Earth asteroids.

References: [1] Warner, B. D. and A. W. Harris (2017) *CBET* 4394. [2] Warner, B. D. (2015) *Minor Planet Bulletin, 40*, 41-53.

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