

**THE ORBIT SOLUTION OF NEAR-EARTH BINARY 164121 (2003 YT1) COMBINING LBT DIRECT IMAGING AND ARECIBO RADAR OBSERVATIONS.** Ellen S. Howell<sup>1</sup>, A. R. Conrad<sup>2</sup>, C. Magri<sup>3</sup>, R. J. Vervack, Jr.<sup>4</sup>, J. L. Crowell<sup>5</sup>, S. Ertel<sup>6</sup>, C. Veillet<sup>2</sup>, J. Stone<sup>6</sup>, J. Leisenring<sup>6</sup>, M. C. Nolan<sup>1</sup>, P. A. Taylor<sup>7</sup>, A. Virkki<sup>8</sup>, L. F. Zambrano-Marin<sup>8</sup>, <sup>1</sup>Lunar and Planetary Laboratory, University of Arizona, AZ 85721 ehowell@LPL.arizona.edu, <sup>2</sup>LBTO, University of Arizona, AZ, <sup>3</sup>University of Maine at Farmington, Farmington, ME, <sup>4</sup>Applied Physics Laboratory, JHU, MD, <sup>5</sup>Spawar, San Diego, CA, <sup>6</sup>Steward Observatory, University of Arizona, AZ., <sup>7</sup>Lunar and Planetary Institute, Universities Space Research Assoc., Houston, TX, <sup>8</sup>U. Central Florida, Orlando, FL/Arecibo Observatory.

**Introduction:** We observed the binary near-Earth asteroid 164121 (2003 YT1) (hereafter YT1) in October of 2016 using both direct imaging and radar. Previously, in May 2004, YT1 was shown to be a binary system from Arecibo Observatory radar images [1]. Additional radar observations of YT1 were obtained in 2016 using the Arecibo planetary radar system. The orbit was not well determined in 2004, but an eccentricity of at least 0.1 was required to fit the observations. The satellite has an apparent rotation period of about 6 hours, much faster than the orbital period of about 36.8 hours. The primary rotates in 2.343 hours, and has large-scale features visible in the radar images [2]. A shape model is in progress using the radar data combined with lightcurves.

Spectral observations made at the IRTF confirm previous measurements [3] that YT1 is a V-type asteroid. The radar shows the high polarization ratio typical of V-types ( $0.54 \pm 0.03$ ). The combined spectrum including visible photometry [4] is shown in Figure 1. Thermal observations were also obtained and are being analyzed to determine the thermal properties of this binary asteroid system.

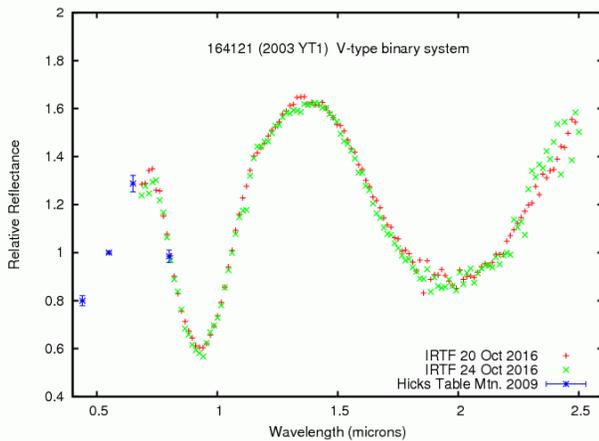


Figure 1 Combined visible and near-infrared spectra of YT1 showing the deep 0.9 and 2 micron absorption bands of pyroxene characteristic of V-type asteroids.

**LBT Observations:** Using the Large Binocular Telescope interferometer (LBTI) in adaptive optics (AO) assisted classical imaging mode on October 31, 2016, we obtained K-band images of YT1 and detected its satellite. The observations span 4.7 hours. We utilized angular differential imaging (ADI), commonly used for exoplanet detections [5]. The apparent motion of the satellite is shown in Figure 2 below over a time span of 1.901 hours, from A to B. For clarity, the center region is masked out with a radius about 90mas, or 1.5 times the resolution.

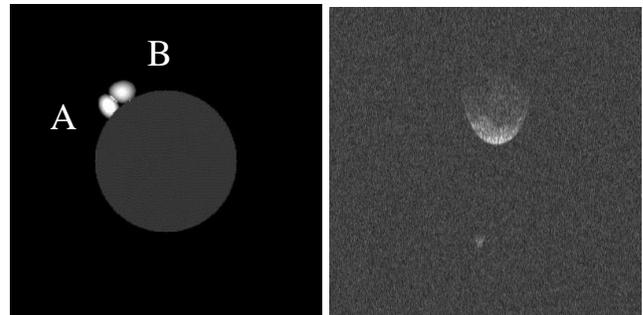


Figure 2. The left panel is a combined LBT angular difference image showing the satellite motion over 1.9 hours in a clockwise direction (from A to B). For clarity, the residual speckles from the primary asteroid have been masked out with a 90mas circle. The right panel is a radar image from Oct 30 showing the primary in the upper center and satellite below, slightly left of center.

The radar image shows distance from the observer in the vertical direction, increasing from bottom to top. The horizontal axis is Doppler shift due to the rotation of the bodies. The satellite is in front of the primary and moving back towards it.

This is the second ground-based AO imaging detection of a near-Earth asteroid satellite [6], and the first attempt to combine optical and radar image data to determine the satellite orbit. The orbit solution

using these complementary data sets will be presented.

**Acknowledgments:** Partial support provided by NASA NNX12AF24G and NASA NNA14AB02A.

**References:** [1] Nolan, M. C., Howell, E. S., and Miranda, G. (2004) *BAAS* 36 1132. [2] Nolan, M. C., Howell, E. S. and Hine, A. A., (2004) 2003YT\_1, IAUC 8336. [3] Abell, P. A, Gaffey, M. J. and Hardersen, P. S. (2004) *BAAS* 36 28.09, [4] Hicks, M. Somers, J., Barajas, T. Foster, J. McAuley, A., Shitanishi, J. (2009) *Astron. Telegram* 2289. [5] Marois, C., Macintosh, B., Konopacky, Q., Barman, T., and Zuckerman, B. (2011) *BAAS* 43, 301.01, [6] Merline, W. J., and 9 co-authors, (2008) IAUC 8977.