THERMAL MODELING OF THREE NON-SPHERICAL NEAR-EARTH ASTEROIDS. Sean E. Marshall[1], Ellen S. Howell[2], Christopher Magri[3], Ronald J. Vervack, Jr.[4], Yanga R. Fernandez[5], Donald B. Campbell[6], Michael C. Nolan[2], Patrick A. Taylor[2], Joseph T. Pollock[7], Michael D. Hicks[8], [1]Cornell University (seanm@astro.cornell.edu), [2]Arecibo Observatory, National Astronomy and Ionosphere Center, [3]University of Maine at Farmington, [4]Johns Hopkins University / Applied Physics Laboratory, [5]University of Central Florida, [6]Cornell University, [7]Appalachian State University, [8]Jet Propulsion Laboratory / California Institute of Technology.

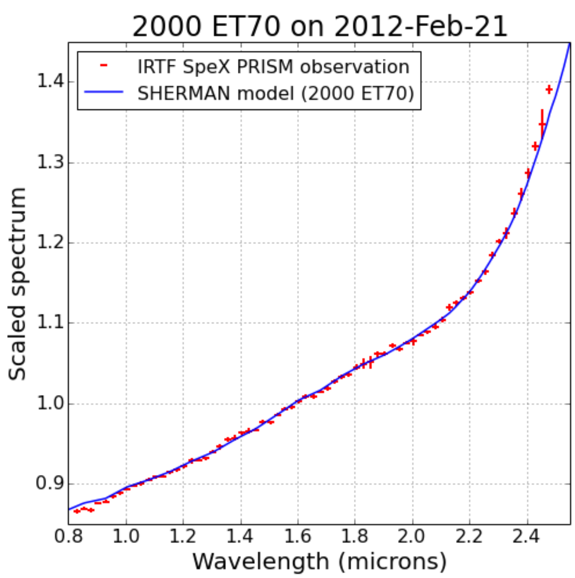
Infrared observations of an asteroid provide constraints on its size, albedo, thermal inertia, and other physical properties [1, 2]. However, these properties are often estimated using thermal models that assume a spherical shape. Detailed shape information is only available for a small fraction of known asteroids, so making simplifying assumptions about the shape is often unavoidable. Still, it is important to quantify the errors that can arise from applying spherical thermal models to non-spherical asteroids.

We have developed thermal models of three near-Earth asteroids for which detailed shape models (derived from radar and lightcurve observations) have been published: (4769) Castalia [3, 4], (8567) 1996 HW1 [5], and (162421) 2000 ET70 [6]. All three have substantial concavities: Castalia and 1996 HW1 are elongated contact binaries, and 2000 ET70 is a spheroidal object with large ridges that resemble fingers in a clenched fist.

Essentially, we are using asteroids with well-determined shapes to investigate: What happens if one assumes an asteroid is spherical when it isn't? How much does the asteroid's shape affect thermal modeling results?

We observed these asteroids using the SpeX instrument [7] of the NASA InfraRed Telescope Facility (IRTF). Each asteroid was observed at multiple phase angles, as part of our campaign to obtain both radar observations and infrared spectroscopy of near-Earth asteroids. Using our shape-based thermophysical modeling program, SHERMAN, we show the range of variations in the asteroids' infrared spectra due to changes in rotation phase and viewing geometry. We also compare the thermal properties derived using the asteroids' true shapes to the thermal properties and sizes that would be derived from applying spherical thermal models to the same observations.

For example: 1996 HW1 is elongated, and as it rotates its projected area changes considerably – particularly when it is observed at low phase angle and the subsolar latitude is near its equator. For the viewing geometry of October 1, 2008 (phase angle 24°), the observed flux density of HW1 at 4.0 microns varied by a factor of about 2.9 as the asteroid rotates. This variation leads to corresponding variations in the



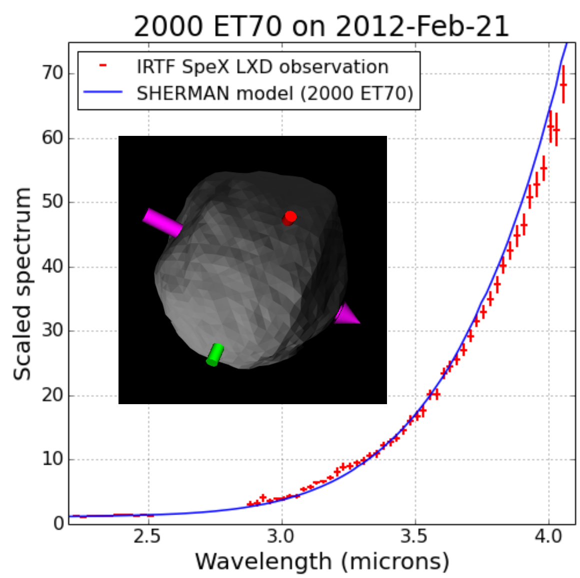


Figure 1: IR observations of 2000 ET70 from February 21, 2012 (phase angle 41°), and the spectrum of a good model (Hapke single-scattering albedo 0.032, thermal inertia 600 in SI units, no craters). The inset in the second plot shows a plane-of-sky view of the model, with the brightness of each facet proportional to its thermal flux.

effective diameter that would be derived from thermal models that assume a spherical shape [8]. This factor of 2.9 in flux density translates to a factor of about 1.7 in the derived effective diameter. Depending on the rotation phase at which HW1 had been seen, the derived diameter could vary from 1.4 km to 2.4 km (see Figure 2). HW1's actual volumetric mean diameter is 2.0 km.

In contrast, during the times of our infrared observations of 2000 ET70, the ridges and concavities near its north pole (the most non-spherical parts of the asteroid) were barely illuminated, so they had very little effect on the observed spectra, so ET70's infrared spectra on those nights are nearly indistinguishable from those of a sphere with the same thermal properties. In other words, ET70 was observed at times when it looked much like a sphere.

For this analysis, we allow each asteroid's albedo, thermal inertia, and surface roughness to vary. Surface roughness is parameterized as a fraction of the surface covered by hemispherical craters, which gives similar results to more complex representations of surface roughness [9].

Laboratory measurements of meteorites have shown that their thermal properties can vary strongly with temperature [10, 11]. However, thermal models typically assume that the asteroid's thermal properties are independent of temperature. Here, we are also examining cases where the thermal properties are temperature-dependent.

References: [1] J. S. V. Lagerros. (1996) *Astron. Astrophys., 310,* 1011–1020. [2] A. W. Harris and J. S. V. Lagerros. (2002) In *Asteroids III,* 205–218. [3] R. S. Hudson and S. J. Ostro. (1994) *Science, 263,* 940–943. [4] R. S. Hudson et al. (1997) *Icarus, 130,* 165–176. [5] C. Magri et al. (2011) *Icarus, 214,* 210–227. [6] S. P. Naidu et al. (2013) *Icarus, 226,* 323–335. [7] J. T. Rayner et al. (2003) *PASP, 115,* 362. [8] S. Marshall et al. (2014) In *AAS/Division for Planetary Sciences Abstracts, 46,* #509.06. [9] J. S. V. Lagerros. (1998) *Astron. Astrophys., 332,* 1123–1132. [10] C. P. Opeil et al. (2010) *Icarus, 208,* 449–454. [11] G. J. Consolmagno et al. (2013) *Planetary and Space Science, 87,* 146–156.

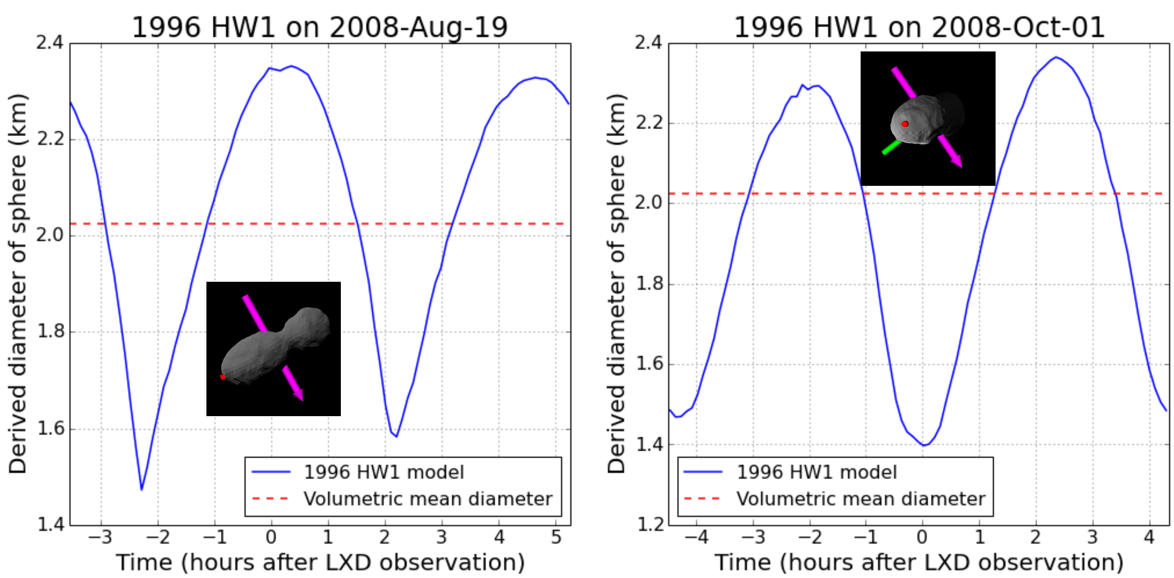


Figure 2: As 1996 HW1 rotates, its flux varies (as seen by an observer on Earth), mainly due to its projected area changing. On the night of August 19, 2008 (phase angle 30°), HW1's flux density at 4.0 microns varied by a factor of about 2.6 (or about 50% above the mean to 30% below the mean), mainly because of the asteroid's projected area changing. This means that the derived diameter, if assuming a spherical shape with identical thermal properties, would vary by a factor of about 1.6 (or about -25% to +15% from its actual volumetric mean diameter). As in Figure 1, the insets show plane-of-sky views of the model's thermal emission at the times of the observations. On the night of October 1 (phase angle 24°), HW1's flux density varied by a factor of about 2.9 (±50% from the mean), so the resulting derived diameter varies by a factor of about 1.7 (-30% to +15% from the mean). During all nights of our IRTF observations, the sub-observer latitude was near HW1's equator, so its projected area varied considerably over the course of a rotation. If we had been looking near its pole (but still at low phase), the variations in its projected area and flux would have been much smaller, so the derived diameters would not vary as much.