

**THERMAL INERTIA OF ASTEROIDS FROM MULTI-EPOCH OBSERVATIONS BY WISE.** E. M. MacLennan<sup>1,2</sup>, J. P. Emery<sup>2</sup> and D. E. Trilling<sup>2</sup>, <sup>1</sup>Department of Earth & Planetary Sciences and Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37996 (emaclenn@utk.edu), <sup>2</sup>Department of Physics and Astronomy, Northern Arizona University, Flagstaff, AZ 86001.

**Introduction:** The ability of a material to resist changes in temperature is called the thermal inertia. Determination of this quantity can give clues as to the physical properties of the surface of an asteroid, such as composition and the presence of a regolith [1]. Thermal inertia is proportional to the square root of the thermal conductivity, which may take on a large range of values among asteroid surfaces. In general, bare rock surfaces have a higher thermal conductivity and thus correspond to a large thermal inertia while the presence of small grains will decrease the bulk thermal conductivity and lower the thermal inertia. Compositionally speaking, metals have a much higher thermal conductivity than other materials that may exist on asteroid surfaces (e.g. silicates) and may yield relatively higher thermal inertia values.

The presence of asteroid regolith has been hypothesized to be the effect of surface impacts throughout the lifetime of an object [2]. A series of impacts could not only generate regolith particles, but also pulverize existing regolith into smaller particles. Larger asteroids have a higher surface gravity and also longer collisional lifetimes [3], so it is expected that small particle regolith is more abundant on larger-sized bodies due to their longevity and impact frequency.

Thermal inertia has been measured for large solar system bodies, such as the Moon [4] and Mercury [5], and also a few dozen small bodies by [6] using IRAS data. An inverse relationship between diameter and thermal inertia was found by [6] over diameters ranging four orders of magnitude, which supports the theory of regolith generation via impacts. However, the thermal inertia of many asteroid surfaces remains to be determined. The thermal inertia for a large set of asteroids could reveal trends among or between dynamical and compositional groups. Such information will lead to a better understanding of the impact history within in the inner solar system.

**Data:** The Wide-Field Infrared Explorer (WISE) surveyed the entire sky in four different mid-infrared wavelengths (3.4, 4.6, 12, 22 $\mu$ m) in 2010. The moving object selection program, called NEOWISE, detected at least 157,000 solar system objects. This sample consists mostly of main-belt asteroids, but also includes ~ 600 NEAs [7]. This offers a great opportunity to determine the thermal properties of the surfaces of hundreds of objects. For these objects, the 12 and 22 $\mu$ m bands are dominated by thermal emission and can be fit to models describing the surface temperature

distribution. Here, the magnitudes reported for the 12 and 22  $\mu$ m bands in the all-sky single exposure release are used in the thermal model described below. For objects with many observations, the average magnitudes for each band are used and observations in different epochs are treated separately as described below.

**Object Selection:** For a spherical asteroid, the temperature distribution on the surface will depend mostly on the thermal inertia and rotation period. For slow rotators and objects with low thermal inertia, most thermal flux will be emitted from the daylight side, where temperatures are nearly in equilibrium with solar radiation. For fast rotator/high thermal inertia objects, flux will be emitted nearly homogeneously among all longitudes and maximum temperatures at a given latitude will be less than the previous (low thermal inertia) case.

For many objects, the intermediate case holds true, and temperatures are higher on the “afternoon” side and cooler on the “morning” side. This results in an asymmetric emission of flux as the asteroid rotates. If the rotation period and spin pole solution are known the thermal inertia can be determined with flux measurements from one set of observations. Rotation periods are known for many objects; however spin pole solutions have only been determined for a relatively small number of bodies. To determine the thermal inertia of an object for which the spin pole is not known flux measurements must be made at different epochs, ensuring the morning and afternoon sides are observed.

Fortunately, the WISE mission lasted a long enough time to observe a sizable number of objects at two epochs. Here, we obtain results for an asteroid with a known pole solution, with one set observations, and an asteroid with no known pole solution, with two sets of observations.

**Thermophysical Model:** The one-dimensional time-dependent heat diffusion equation was used to calculate surface temperatures on a smooth, spherical model asteroid. Surface temperatures were used to determine the emitted flux over the hemisphere visible to WISE during observations of a particular object. For a given thermal inertia, the best-fit diameter and albedo were determined by minimizing chi-squared value between model and observed flux at 12 and 22 $\mu$ m.

32 Pomona has a known period, spin pole solution and [6] reported a thermal inertia range of 20-120 J m<sup>-2</sup> K<sup>-1</sup> s<sup>-1/2</sup> (units referred later as “SI”). WISE detected 32

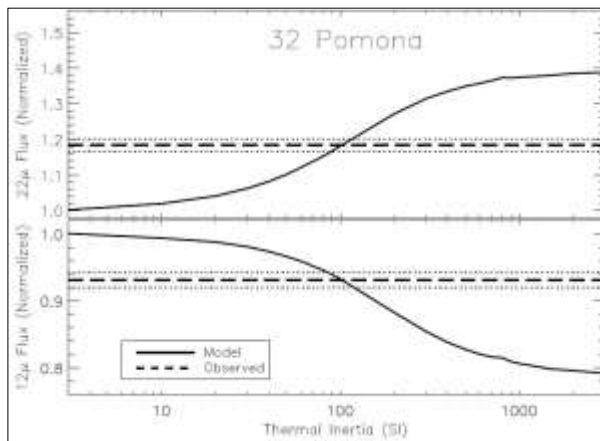


Figure 1 – Best-fit model flux for each thermal inertia value for 32 Pomona. WISE flux is plotted with error range as dashed and dotted lines, respectively.

Pomona in one epoch, which can provide sufficient flux measurements to calculate thermal inertia. The thermophysical model was run, as described above, for the known observing geometries and hemisphere visible to WISE.

The asteroid 270 Anahita has no known spin pole solution, but the rotation period is known and was observed by WISE in two epochs. This provides enough information to deduce the morning and afternoon sides, and calculate the thermal inertia. The thermophysical model was run for the known geometries for each observation circumstances of each epoch. Since the spin pole is not known, zero obliquity is assumed and the model is run assuming the morning and afternoon side is visible, resulting in 4 expected model fluxes.

**Results:** The modeled 12 and 22  $\mu\text{m}$  flux as a function of thermal inertia is plotted along with the WISE flux for each set of observations. To aid comparison between different asteroids, all fluxes in a given band for a given object are divided by the expected flux emitted at the given heliocentric and geocentric distances, zero phase angle, zero obliquity and zero thermal inertia. Bold lines are the expected flux for different thermal inertias after solving for size and albedo, and dashed lines give the measured flux from WISE and range given by dotted lines.

Modeled and WISE observed fluxes for 32 Pomona are plotted in figure 1. Figure 2 has each model plotted, with fluxes from each epoch for asteroid 270 Anahita.

**Discussion:** The thermal inertia range for 32 Pomona computed from these WISE data (80-110 SI) is consistent with the value from [6] which shows that our method, and data, provides useful thermal inertia

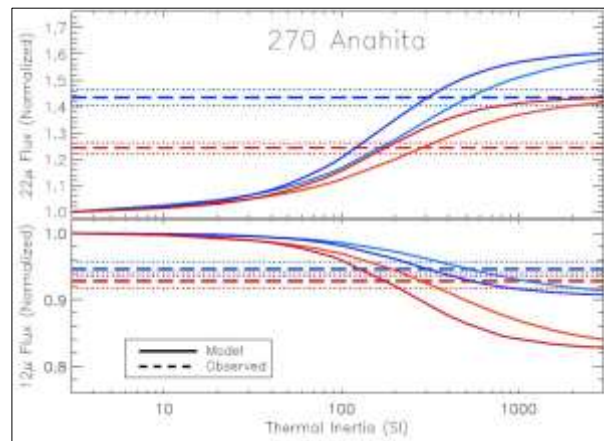


Figure 2 – Best-fit model fluxes for each thermal inertia value and four cases, as described before, for 270 Anahita. Blue and red lines correspond to the first and second epoch, respectively, with darker shades giving the expected afternoon flux and lighter shades corresponding to morning fluxes.

information. The best-fit diameter is 50 km with an albedo of 0.180.

The expected afternoon flux for the first epoch (dark blue curve) and morning flux from the second epoch (light red curve) give the same thermal inertia range for 270 Anahita (220-350 SI). For this range, the minimum chi squared value for the diameter is 60 - 66 km, and albedo is 0.12 - 0.16. Although the exact spin pole cannot be derived here, given the position of 270 Anahita at each sighting by WISE, it can be said that the rotation is prograde with respect to its orbit.

**Future Work:** This method can be used on hundreds of objects in the WISE catalog to compute thermal inertia values for asteroids with and without known spin pole solutions but with known rotation periods. It is also possible to discern between two degenerate spin pole solutions for objects with an asymmetric emission of flux.

**Acknowledgements:** This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration.

**References:** [1] Muller M. (2007) *Ph.D. Thesis*. [2] Housen K. R. and Wilkening L. L. (1982) *Annu. Rev. Earth Planet. Sci.*, 10, 355–376. [3] Bottke, W. F. et al. (2005) *Icarus*, 179, 63. [4] Spencer et al. (1989) *Icarus*, 78, 337-354. [5] Emery et al. (1998) *Icarus*, 136, 104-123. [6] Delbo, M. and Tanga, P. (2009) *Planet. Space Sci.*, 57, 259–265. [7] Mainzer et al. (2011) *ApJ*, 731, 53.