Near Earth Asteroid Thermal Modeling [NEATM] and Thermophysical Modeling of 10 low albedo NEAs using Infrared Spectrograph (IRS) on NASA's Spitzer Space Telescope

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Introduction: Near-Earth Asteroids (NEAs- 0.983AU<q<1.3AU) are fragments of remnant primordial bodies dating since the formation of Solar System. Information about the albedo and size distribution of the NEAs is an essential prerequisite for exploring their physical nature, thermal properties, mineralogy, taxonomy and for developing reliable NEA population models [1]. In support of the ExploreNEOs campaign of the Warm Spitzer program, the current project is a study of a sample of NEAs using the Infrared Spectrograph (IRS) on NASA's Spitzer Space Telescope [Programs 88 and 91- Extinct Comets and Low- albedo Asteroids]. The 5.2-38 μm thermal emission spectra[R~60- 130] are fitted with models of the thermal continuum employing the Near Earth Asteroid Thermal Model [NEATM] (Harris 1998) and a thermophysical model. The sample of asteroids which are a part of this study are 1602 Geographos, 1580 Betulia, 433 Eros, 2212 Hephaistos, 1685 Toro, 1917 Cuyo, 1566 Icarus, 3200 Phaethon, 7092 Cadmus and 1866 Sisyphus. This study will give in-depth understanding of the applicability of the NEATM for NEAs observed at higher phase angles, having larger thermal inertia than main-belt asteroids, and/or displaying varied geometries.

Background: Gathering information about the physical characteristics of the near-Earth asteroid (NEA) population is important for a number of scientific and technical reasons, including accurate assessment of the impact hazard and considerations of mitigation techniques [1]. Observations in the thermal infrared enable albedos and diameters to be derived. Albedos are particularly important for resolving ambiguities in the determination of taxonomic types from reflection spectra and the optimization of survey strategies [2]. The current rate of discovery of NEAs is far outstripping progress in their physical characterization. Over 1500 NEAs have been discovered to date, but <50 have reliably determined albedos and diameters. On discovery the only physical information available for a NEA is its visible brightness.

Assuming an instantaneous equilibrium between insolation and thermal emission for each point on the surface of the body, and by combining the physical relationships governing the two processes, it is possible to determine both the diameter and albedo of the object.
This is the principle on which most of the thermal models are designed [3][4].

Similar such work has been performed by Harris (1998), Delbò (2003), Delbò (2004), Wolters (2008), wherein most datasets were observations of a broadband N magnitude, or at only one or two wavelengths [5]. The current project extends previous efforts by analysis of complete 5.2 – 38 μm spectra, which, for NEAs, covers the peak in thermal emission. These data enable more accurate and detailed modeling of the surface temperature distributions.

Observations: Spitzer observed the ten asteroids in this study between June 2004 and April 2006. Thermal spectra from 5.2 to 38 μm were measured with the Infrared Spectrograph (IRS), which collects data in four different modules:
Low-resolution, short-wavelength - 5.2 - 14 microns,
Low-resolution, long-wavelength - 14 - 38 microns,
High-resolution, short-wavelength - 10 - 19.5 microns,
High-resolution, long-wavelength - 19 - 37 microns.
The spectra analyzed here use only the low-spectral resolution modules ($R=\lambda/\Delta\lambda\sim64$ to 128). The data were reduced using SPICE (The Spitzer IRS Custom Extraction) – a JAVA-based tool that allows the user to interactively extract Spitzer Infrared Spectrograph (IRS) spectra.

	H Magnitude	Phase Angle	Distance Sun AU	Distance Spitzer AU
Eros	11.16	50.6	1.31	0.96
Phaethon	14.51	63.2	1.13	0.50
Toro	14.23	61.2	1.14	0.38
Cadmus	15.40	44.0	1.37	0.62
Sisyphus	13.00	37.6	1.65	1.36
Betulia	14.52	31.2	1.92	1.76
Geographos	15.60	54.6	1.25	0.77
Hephaistos	13.87	20.7	2.85	2.49
Cuyo	13.90	34.0	1.80	1.61
Icarus	16.90	56.14	1.21	0.53

Much of the data reduction and calibration is carried out by pipeline processing. We performed background subtraction on the flat-fielded, flux calibrated spectral images, extracted the 1-D spectra, and scaled the modules relative to each other using regions of overlap. The extraction was performed using SPICE (The Spitzer IRS Custom Extraction) – a JAVA-based tool provided by the Spitzer Science Center. We have "cleaned" the masked pixels in a set of data by using IRSCLEAN.

Thermal Modeling: The NEATM employed for the current work assumes a spherical shape of the object. It calculates the sub-solar temperature (Tss). The temperature is then assumed to vary as $\cos^{1/4}$(solar zenith angle) on the dayside and is set to zero on the night side The flux is integrated over visible portion of the sunlit hemisphere and the beaming parameter η varies to fit fluxes (temperatures) to data [3][4].

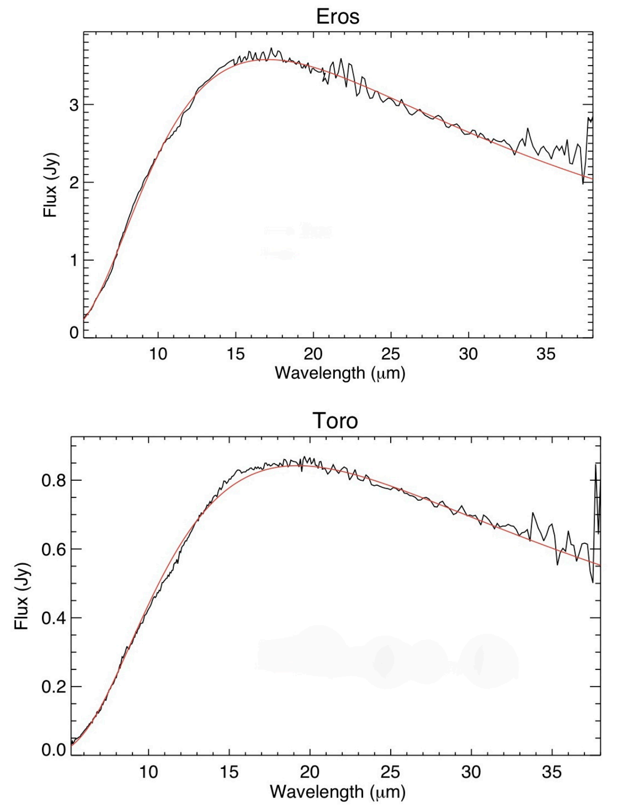

Figure 1. *Near-Earth asteroid Thermal Model (NEATM) fits to spectra of (433) Eros and (1685) Toro.*

Results and Discussions: Figure 1 shows model (NEATM) fits to the Spitzer data of two asteroids 433 Eros and 1685 Toro. As the figure shows, the models are very good fits to the data.

The beaming parameter η can be considered as a measure of departure of the asteroid temperature distribution from what would be expected for a spherical, smooth, zero-thermal inertia body. It is a strong function of the thermal inertia, but its value also depends on a number of other parameters such as surface roughness, rotation period, shape of the body as well as non-zero thermal infrared emission from the dark side.

Figure 2 is a graph showing the relationship between phase angle α and fitted beaming parameters η. The bold, italicized labels mark results from our new analysis of the Spitzer data. The others are from previous work [2][4][5]. The line shows a linear fit [5]

$$\eta = (0.013 \pm 0.004)\ \alpha + (0.91 \pm 0.17)$$

wherein our updated trend shows consistency.

In the case of a body with low thermal inertia and significant surface roughness, for low phase angles, the beaming parameter will be a smaller value due to increased emission in the sunward direction. For higher phase angles, the 'missing' thermal flux sent in the sunward direction must be balanced by a higher value of the beaming parameter, for energy to be conserved. For high-quality data like the spectra from Spitzer, η can be derived from the data along with size and albedo. However, in many applications of the technique of radiometry, only one or two broadband fluxes are available. In those cases, accurate estimates of size and albedo depend critically on using an appropriate value for η. On the basis of an assumption that, the thermal inertia is roughly constant within the NEA population for a given size, it might be possible for its value to be inferred from the distribution of the measured η-values versus α [5][6].

This provides us with further motivation to study the various parameters and their inter-relationships by employing the thermophysical model (TPM).

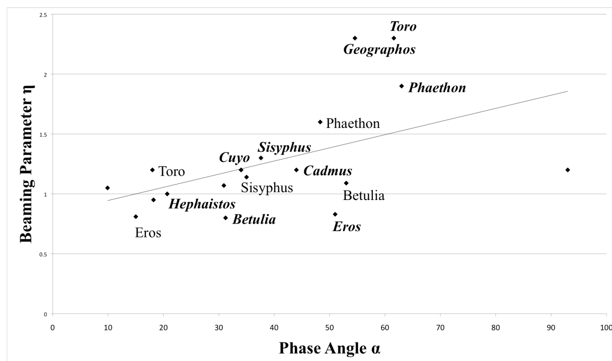

Figure 2.*The relationship between phase angle α and fitted beaming parameters η.*

Thermophysical Modeling: We will further use a Thermophysical model [7] that determines diurnal temperatures in spherical-section depressions and includes the effects of subsurface heat flow and direct and scattered sunlight. The variation of η with roughness and thermal inertia will be an interesting study .We will be interested in optimization of the model to achieve accurate sizes and albedos [8].

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References: [1] Bottke, W.F., Jedicke, R., Morbidelli, A., Petit, J.M., Gladman, B., 2000. Science 288, 2190–2194. [2] Delbó, M., 2004. Doctoral thesis, Freie Universität Berlin. [3] Delbó, M., Harris, A.W., 2002. Meteorit. Planet. Sci. 37, 1929–1936. [4] Harris, A.W., 1998, Icarus 131, 291– 301. [5] Wolters, S.D. et al, 2008, Icarus 193, 535-552. [6] Delbó, M., dell'Oro, A., Harris, A.W., Mottola, S., Mueller, M., 2007. Icarus 190, 236–249. [7] Spencer, J.R., Lebofsky, L.A., Sykes, M.V., 1989. [8] Spencer, J.R., 1990, Icarus 83, 27–38.