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ISO: Asteroid Results and Thermophysical Modeling

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Abstract. Through a recently developed thermophysical model, observations from the Infrared Space Observatory (ISO) were combined with visual photometry, lightcurves, close-up observations and direct measurement. In this way, many applications were possible, ranging from simple diameter and albedo determination of serendipitously seen asteroids to sophisticated studies of mineralogic aspects and regolith properties, like emissivity, roughness or thermal inertia for well-known asteroids. The possibility to combine all sources of information in one single model lead also to a better understanding of thermophysical effects, like beaming or the before/after opposition effect. Thus, the mineralogic signatures can be recognized easier and asteroid data from infrared surveys and individual IR photometry can be interpreted more accurately, even in cases where shape or rotational behaviour are not known. Some well-studied asteroids are now even considered as excellent far-infrared calibrators.

1. ISO and the Thermophysical Model (TPM)

ISO (Kessler et al. 1996) observed between 1995 and 1998 more than 40 asteroids in great detail, including some complete spectra from 2 to 200 micron and large samples of photometric measurements (Müller 2004). The main goals of the about 100 hours of asteroid observing time were: the identification of surface minerals, composition, connection to meteorites and comets, surface alteration processes and the interpretation of taxonomic classes through the identification of mid-infrared features of well-known minerals and meteorites.

In parallel to the ISO mission, Lagerros (1996, 1997, 1998) developed new modelling concepts for the description of asteroids. Müller & Lagerros (1998, 2002) later on combined the modelling efforts with a large variety of thermal observations from ground-based, air-borne and space-based projects to establish a self-standing powerful thermophysical model (TPM). This TPM was the basis for the interpretation of most of the ISO asteroid observations. The key to the successful applications was its capability to combine all available information for one asteroid (e.g., spin vector, shape, size, albedo, H-G values, ...) with the full observational information coming from ISO. In that way, it is now possible to analyse regolith properties, emissivity behaviour, thermal inertia or to improve size and albedo values (e.g., Müller 2002). The TPM facilitates also the interpretation of thermal spectroscopic measurements with respect to mineralogic and meteoritic studies (e.g., Dotto et al. 2002a).

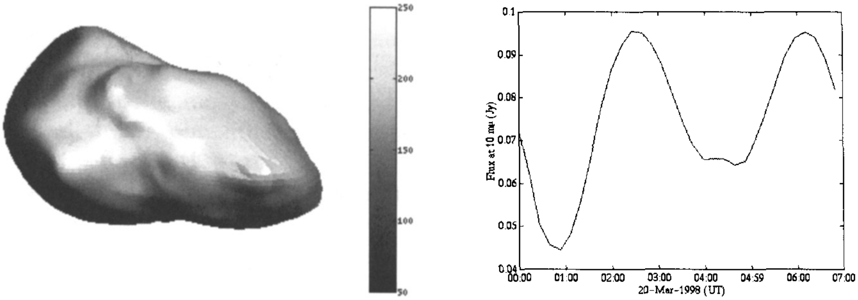

Figure 1. TPM of 951 Gaspra and a predicted thermal lightcurve at 10 μm (Credit: J. Lagerros; Shape model: Thomas et al. 1994).

2. Results and Discussion

Different examples of TPM applications are illustrated in Figs. 1 and 2. The temperature calculation (Fig. 1, left) assumes a default thermal behaviour of a regolith covered surface (Müller et al. 1999). The following TPM predictions are possible: Thermal lightcurves at any given thermal wavelength (Fig. 1, right), disk-integrated spectral energy distributions from 5 μm to the mm-wavelength range for any given time (Fig. 2, left), and multi-epoch/-wavelengths monochromatic or filter band fluxes (Fig. 2, right).

This kind of modelling in comparison with thermal infrared observations provide nice insights into the regolith properties and the emissivity behaviour of the surface material (e.g. Müller & Lagerros 1998; Müller 2002; Müller & Blommaert 2004). The infrared beaming effect, caused by surface roughness/porosity influences, can now be studied and understood (Lagerros 1996, 1998). The before/after opposition effect, caused by rotation in combination with the non-zero thermal inertia, can be calculated and treated in a correct way. The accurate description of the thermal emission for well-known large main-belt asteroids through the TPM even lead to their use as reliable photometric standards in the far-infrared, where good calibrators are scarce (Müller & Lagerros 2002, 2003).

The interpretation of ISO's spectroscopic measurements also benefited from detailed thermal continuum modelling: Dotto et al. (2000; 2002b) and Barucci et al. (2002) investigated silicate features and searched for similarities with meteoritic samples. In all three studies the TPM supported the difficult analysis of low level broad band emission structures on top of the modeled continuum.

A comparison between the Standard Thermal Model (STM; Lebofsky et al. 1986) and the TPM revealed limitations and problems of the STM in analysing multi-epoch and -wavelengths observations. Müller & Blommaert (2004) found wavelengths and phase angle dependent diameter/albedo values with the STM, whilst the TPM produced unique solutions.

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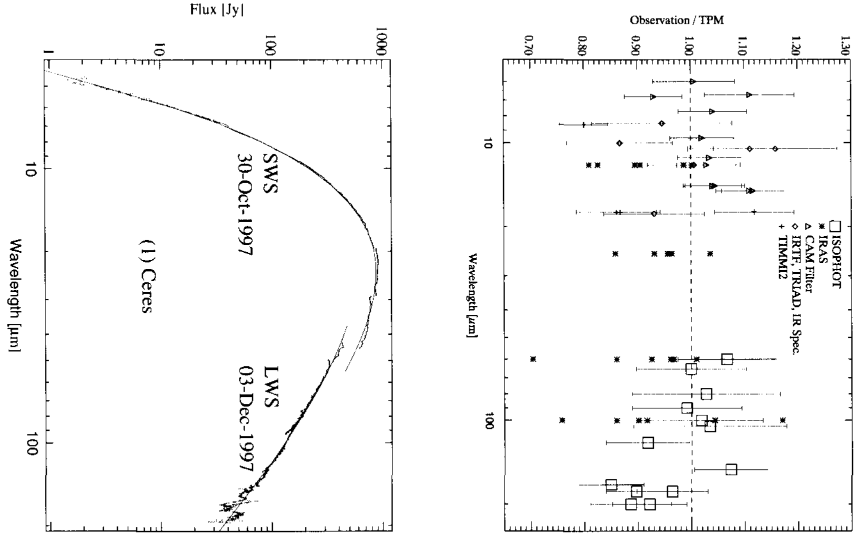

Figure 2. Left: The asteroid 1 Ceres: ISO observations and TPM predictions (solid lines) (Müller 2002). Right: 65 Cybele observation over model ratios for different photometric measurements plotted against the corresponding wavelengths (Müller & Blommaert 2004).

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