EPSC Abstracts
Vol. 6, EPSC-DPS2011-1438, 2011
EPSC-DPS Joint Meeting 2011

Thermal Emission Spectroscopy of M-type Asteroids: How Many are Metallic?

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Abstract

The M-type asteroid taxon was originally inferred to represent metallic objects, presumably the cores of differentiated asteroids. Evidence has mounted that at least some fraction of the members of this class has silicate rather than metallic surfaces, reopening the question of their natures. We have measured thermal emission spectra of 27 M-type asteroids in order to constrain thermal properties as well as silicate mineralogy. We correlate the results from this work with published radar albedos, and reflectance spectra from the visible and near-infrared (0.4 to 4.0 μm), and estimated densities to identify those objects most likely to have a high metal content.

1. Introduction

The Masteroid taxon as originally designated [1, 2] comprised asteroids of moderate albedo that lacked mineral absorption features in the visible and near-IR (0.3–1.1 μm). In the absence of direct spectral evidence of composition, the nature of M asteroids has remained uncertain. In one interpretation [e.g. 3] they are considered to be the asteroid analogues to nickel-iron meteorites, in which case they would be fragments of the cores of one or more parent bodies which must have undergone extensive igneous differentiation before being catastrophically disrupted. Alternatively [4] they have been seen as analogues of the highly reduced enstatite (“E”) chondrites, whose parent bodies could not have been differentiated or indeed melted at all.

Radar observations provide the most compelling direct evidence for the metallic compositions of at least some M asteroids. Very high radar albedos [5, 6] have been observed for various M asteroids, including 16 Psyche, 216 Kleopatra, and several near-Earth objects, consistent with high metal concentrations. The existence of nickel-iron meteorites also implies that their parent bodies must be somewhere among the small bodies of the Solar System. Laboratory studies of iron meteorites [7] suggest that at least 70 distinct metallic parent bodies are represented in the meteorite collection.

Radar observations of at least one other M asteroid [21 Lutetia; 8] suggest that its composition is nonmetallic. Data from the Rosetta flyby of Lutetia also indicate a silicate body [e.g., 9]. A nonmetallic nature for 21 Lutetia and various other M asteroids is also supported by observations of 3-μm absorptions which are characteristic of hydrated silicate minerals. These were first detected in the spectra of the M asteroids 55 Pandora and 92 Undina by Jones *et al.* [10]. These findings were confirmed by Rivkin *et al.* [11, 12], who surveyed the 3-μm spectra of 27 M asteroids and found hydration features on Pandora, Undina, Lutetia, and seven others. On the basis of these observations, they suggested that the former “M” class should be divided into “M” asteroids, which lack hydration features, and “W” asteroids, which resemble the “M” in the visible and near-infrared but are hydrated. Weak low-Fe pyroxene features near 0.9 μm have also been detected in the spectra of several M-type asteroids [e.g., 13], indicating a non-metallic surface.

2. Observations

The spectra were measured using the Infrared Spectrograph (IRS) on the Spitzer space telescope. IRS covers the spectral range 5.2–38 μm in four low-resolution (R~64-128) modules. Two high resolution (R~600) modules operate from 9.9–37 μm. All objects were observed with the short wavelength (SL; $\lambda < 14.2$ μm) modules. Fifteen of the objects in our program were too bright for the long-wavelength (LL; $\lambda > 14.2$ μm) low-resolution modules, so these were observed with the high-resolution mode (SH, LH). The SH module overlaps with the SL1 module from 9.9 to 14.2 μm, providing confirmation of spectral features detected in this important region on the long wavelength edge of the silicate resonance band near 10 μm.

3. Results

The measured flux spectrum depends on the object's size, composition, and temperature distribution. This last term is in turn dependent on several factors, including distance from the Sun, albedo, surface roughness, and thermal inertia. Spectral features are superposed on the thermal continuum. Therefore, modelling the thermal continuum enables the derivation of thermal properties and the reduction to spectral emissivity for mineralogical analysis.

The simplest realistic approach is the Standard Thermal Model (STM)[14]. Our approach in this presentation uses a slight modification of the STM, called the NEATM [15], the primary difference being the form used for the infrared phase curve. Radius and sub-solar temperature (T_{ss}) are allowed to float to fit the model. In this model, the asteroid's thermophysical properties are summarized in a parameter η, which is related to the T_{ss}: $T_{ss}=[S(1-A)/(\eta\varepsilon\sigma)]^{1/4}$, where S is the insolation, A is the Bond albedo, and ε is the effective emissivity. Higher η values, particularly $\eta > 1$, suggest an unusually high surface thermal conductivity. The results of these fits are illustrated in Figure 1 for 758 Mancunia.

More complicated thermophysical models can also be applied to derive thermal inertia directly. Such models require orbital and physical parameters (rotation period, spin-pole orientation, shape) that are not well known for many of the objects in our programs. We will use these models where appropriate and report thermal inertia along with η in these cases. The veracity of the radiometric technique as we use it here is significantly improved over typical ground based mid-IR photometry by the broad and continuous spectral coverage afforded by Spitzer/IRS; coverage which includes the peak in the thermal emission.

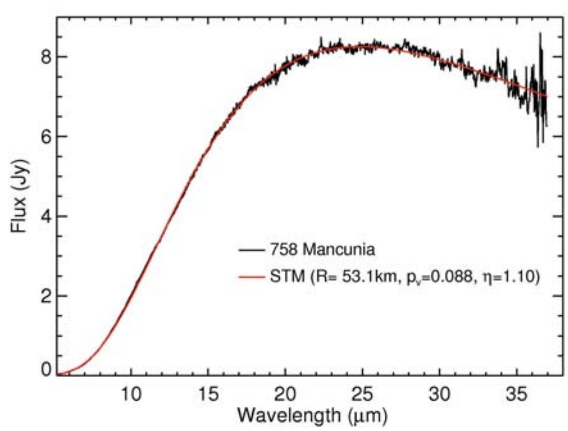

Figure 1: Thermal flux spectrum (black line) and best-fit model (STM; red line) for 758 Mancunia.

4. Discussion

We have completed NEATM modelling of all of our targets. Five of these M-type asteroids have $\eta > 1.3$, suggesting an elevated thermal inertia. Of these five, only one has a published radar albedo, and it is high, suggesting a significant metal content. One other asteroid with a high radar albedo has $\eta < 1$. Three of the five exhibit shallow 0.9 μm absorption features interpreted to be silicate. We will present additional results of thermal modelling of these data, including direct estimates of thermal inertia. Particular attention will be paid to whether thermal properties correlate with physical properties such as radar albedo, near-IR silicate bands, or 3-μm hydration bands. We will also present results of compositional analysis of emissivity spectra, which are derived by dividing the measured thermal flux spectrum by the best fit model thermal continuum. Strong silicate bands near 10 and 20 μm offer a direct means to distinguish between silicate and metallic surfaces.

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