MID-IR SPECTROSCOPY OF M ASTEROIDS WITH THE SPITZER IRS: PRELIMINARY RESULTS. L.F. Lim[1], J.E. Emery[2], T.H. McConnochie[3], [1]*NASA/Goddard Space Flight Center (lucy.f.lim@nasa.gov),*[2]*SETI Institute / NASA Ames,*[3]*Cornell University*.

Introduction: We are conducting a survey of the emission spectra of 27 class M asteroids using the Spitzer Infrared Spectrgraph (IRS; 5.2–38 μm). Although the visible and near-IR spectra of these asteroids are nearly featureless, ten of these asteroids are now known to have hydration features at 3 μm that are absent in the spectra of 15 others [1]. High S/N spectroscopy of these asteroids in the mid-infrared is likely to reveal key thermophysical and compositional information not available in the near-infrared.

The M-asteroid taxon as originally designated [2, 3] comprised asteroids of moderate albedo that lacked mineral absorption features in the visible and near-infrared (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. 4] they have been thought 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 [5] 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.

Previous Evidence for Metallic and Non-Metallic M Asteroids: Radar observations have provided the most compelling direct evidence for the metallic compositions of at least some M asteroids. Very high radar albedos [6, 7] 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 [8] 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; 9]) suggest that its composition is non-metallic. A non-metallic 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.* [1, 11], who surveyed the 3-μm spectra of 27 M asteroids and found hydration features on Pandora, Undina, Lutetia, and seven other M asteroids. 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 in fact hydrated. The non-metallic composition of another hydrated M-asteroid, 22 Kalliope, was supported by the findings of Margot and Brown [12], who discovered Kalliope's satellite and were thus able to determine that Kalliope's density was too low for a metallic composition to be plausible.

Target List: Our observing list includes 25 of the 27 asteroids previously observed at 3 μm by Rivkin *et al.* [1]. Six of these were also observed in the near-infrared by Hardersen *et al.* [13], who detected weak low-iron pyroxene features in five of them, two of which had hydration features at 3 μm. We also include 69 Hesperia, in which pyroxenes were detected [13], and 325 Heidelberga, in which no near-IR silicate features have been detected. A major goal of this survey is to determine whether mid-IR silicate features, which unlike near-IR features should be sensitive to non-iron-bearing minerals, correlate either with the subcategories of M asteroids established by the hydration data [1] or the pyroxene data [13]. Moreover, if any of these M asteroids are asteroid analogues of the enstatite chondrites, which are about 45% enstatite by volume [e.g. 14] and essentially featureless in the near-IR, they should be easily recognizable in the Spitzer IRS data.

Preliminary Thermal Results: Spectra from 77 Frigga, 369 Aeria, 337 Devosa, 857 Glasenappia, 161 Athor, and 22 Kalliope have now been acquired by the IRS. For 77 Frigga, 857 Glasenappia, 161 Athor, and 22 Kalliope, only the SL observations (5.2–13.5 μm) have been reduced to date. (For Glasenappia, the SL2 S/N was rather poor, so only the SL1 observations have been used.) 337 Devosa and 369 Aeria have also been observed in the LL modules (14–38 μm).

Subsolar-point temperatures were derived by fitting the data with the asteroid standard thermal model ["STM"; e.g. 15], allowing the maximum temperature and radius to float. The results of our preliminary STM fitting are summarized in Table 2. In the STM, the asteroid's thermophysical properties are summarized in a parameter η, which is related to the maximum (subsolar-point) temperature: $T_{\max} = (S(1-A)/(\eta\epsilon\sigma))^{0.25}$ where S is the insolation, A is the Bond albedo, and ϵ is the effective emissivity. Most asteroids have negligible thermal inertia and are well described by an STM with η=0.756 $\pm$ 0.014. Higher η values, particularly $\eta > 1$, suggest an unusually high surface thermal conductivity. However, in order to calculate η one must make assumptions about the albedo and emissivity, so that an anomalous η value may indicate merely that an incorrect albedo was assumed.

The Bond albedos used to derive values of η from the subsolar-point temperatures were calculated from the geometric albedos and phase parameters (G) provided by JPL Horizons according to the formula $A = pq$ where q = 0.29 + 0.684*G.

The effective emissivity assumed can also influence the derived beaming parameter. Silicate materials do not differ greatly from each other in effective emissivity, but a solid metal asteroid might have a much lower emissivity. In Table 2 we have quoted η values for emissivities of 0.9 and 1.0 in order to illustrate the effect of a 10% change. The 1.0 value represents a lower limit on η.

From Table 2, we can see that the thermal behavior of

77 Frigga is like that of a "normal" low-thermal-inertia (low-η) asteroid, whereas 337 Devosa, 369 Aeria, and 857 Glasenappia have $\eta > 1$, suggesting that their surface materials have high thermal inertia and are therefore either more conductive or better consolidated than those of the majority of asteroids.

22 Kalliope and 161 Athor have intermediate values of η. 22 Kalliope was previously observed in the mid-IR [16] with a subsolar temperature of 248 $\pm$ 5 K at 2.612 AU. This corresponds to η = 0.98 $\pm$ 8 K at ϵ = 0.9 or η = 0.88 $\pm$ 0.07 at ϵ = 1.0, consistent with the current work.

These results, however, are preliminary. The error bars are expected to improve substantially with further calibration work.

Table 1: Observing Circumstances

Asteroid	Date (UT)	α	R_{Sun} (AU)	IRS Modules
77 Frigga	2005-09-07	18.4°	2.8850	SL1,2
337 Devosa	2005-09-08	21.8°	2.7121	SL1,2; LL1,2
369 Aeria	2005-09-14	23.1°	2.6061	SL1,2; LL1,2
857 Glasenappia	2005-11-19	25.5°	2.3123	SL1
161 Athor	2005-11-19	29.3°	2.0798	SL1,2
22 Kalliope	2005-11-20	20.3°	2.7725	SL1,2

Table 2: Preliminary STM Fitting Results

Asteroid	M/W	T_{max} (K)	η (ϵ=0.9)	η (ϵ=1.0)
77 Frigga	W	250 $\pm$ 3	0.78 $\pm$ 0.04	0.70 $\pm$ 0.04
337 Devosa	M	227 $\pm$ 8	1.28 $\pm$ 0.18	1.16 $\pm$ 0.16
369 Aeria	M	236 $\pm$ 8	1.18 $\pm$ 0.16	1.06 $\pm$ 0.15
161 Athor	M	286 $\pm$ 5	0.87 $\pm$ 0.06	0.78 $\pm$ 0.06
857 Glasenappia	M	244 $\pm$ 5	1.29 $\pm$ 0.11	1.16 $\pm$ 0.10
22 Kalliope	W	243 $\pm$ 6	0.94 $\pm$ 0.10	0.84 $\pm$ 0.09

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