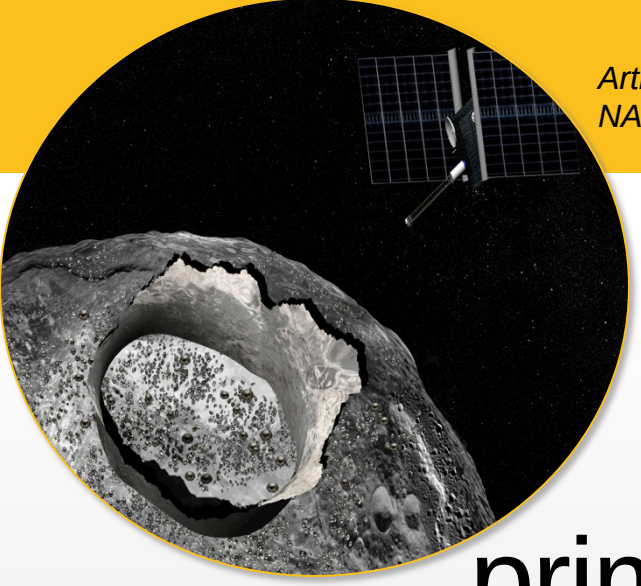


Artist's concept of mission to (16) Psyche
NASA/JPL-Caltech

M-Type asteroids: primitive, metallic, or both?

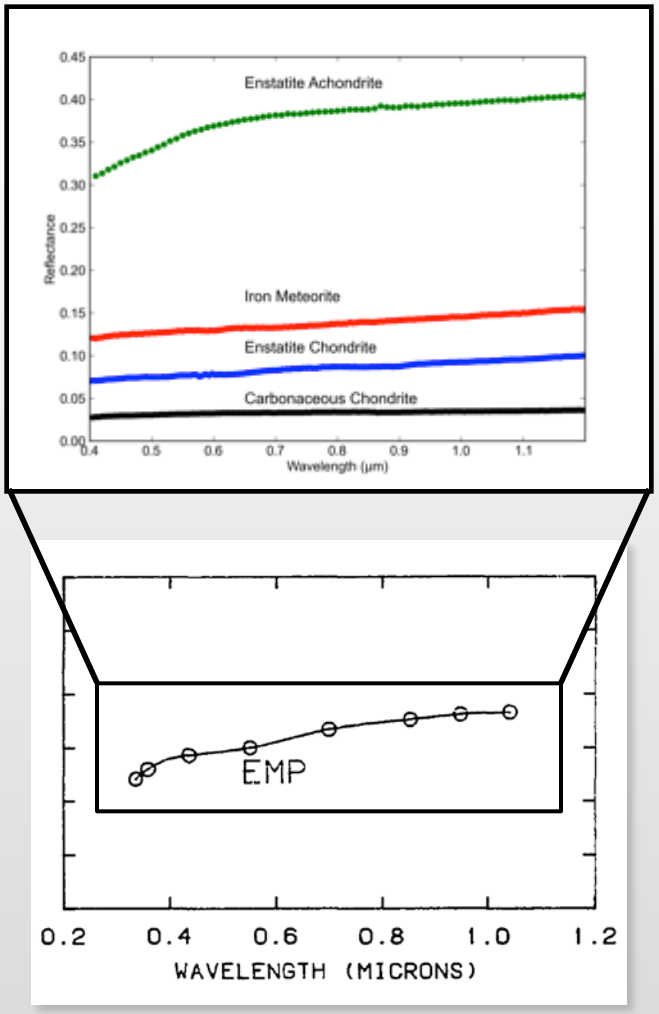
Zoe A. Landsman[1]

Collaborators: J. Emery[2], H. Campins[1]

[1] University of Central Florida, Orlando, FL, USA [2] University of Tennessee, Knoxville, TN, USA

15th Meeting of the NASA Small Bodies Assessment Group
JHU APL, Laurel, MD | June 28-30, 2016

Background

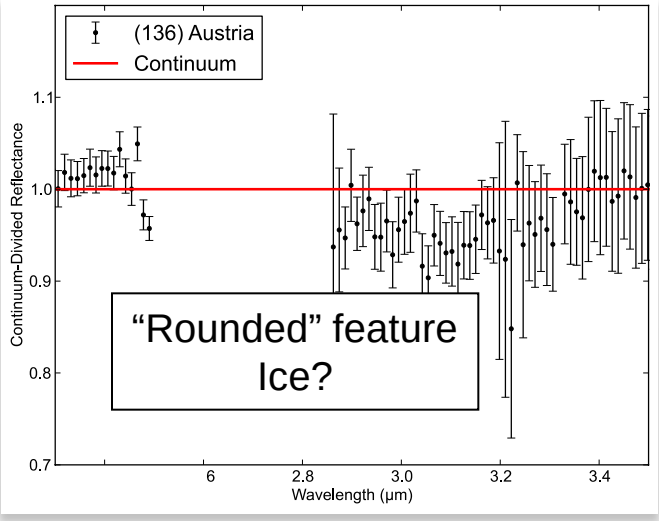


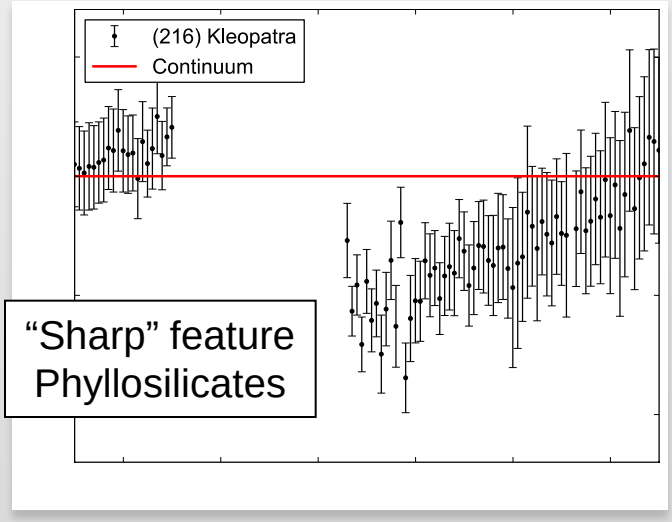
Bottom figure: Tholen 1984

- The M-Type Asteroids
  - M-types are the moderate-albedo group of the spectrally degenerate X taxon
  - Many have a **3-μm hydration feature** (e.g., Rivkin et al. 2000, Landsman et al. 2015)
  - Most have weak **silicate features** at 0.9 μm ±1.9 μm (e.g., Fornasier et al. 2010, Hardersen et al. 2011)
  - Many have **elevated radar albedos**, suggesting high surface density (e.g., Neeley et al. 2014, Shepard et al. 2015)

Previous Work (Landsman et al. 2015)

- Studied 6 M-types in the 2 – 4 μm region using the IRTF
  - (69) Hesperia, (136) Austria, (216) Kleopatra, (261) Prymno, (337) Devosa, (418) Alemannia
- Evidence for a 3-μm hydration feature on all 6, with band depths from ~4 – 8%
- Diversity in the shape of feature among the asteroids



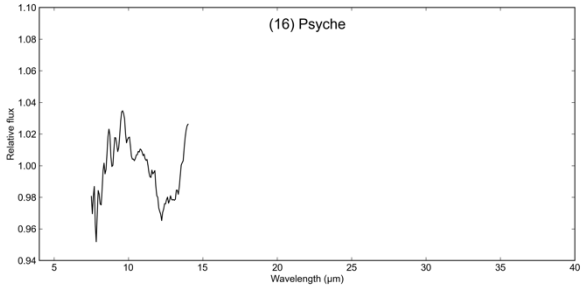


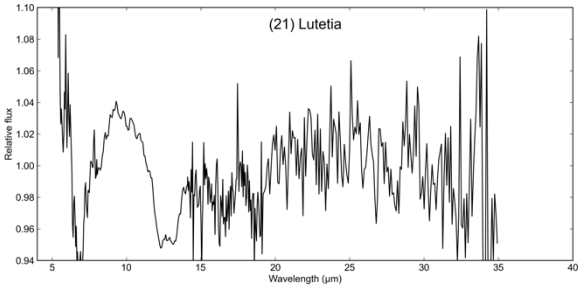
M-types in the Mid-Infrared

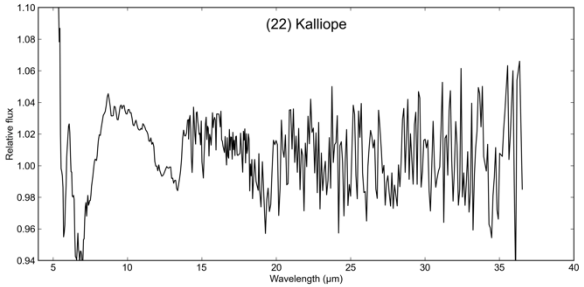

Spitzer Space Telescope

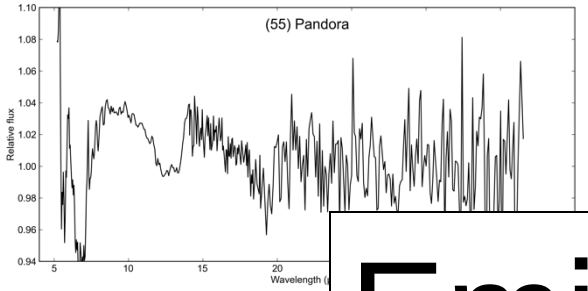
- Thermal modeling allows insight into surface properties of asteroids
  - Albedo, thermal inertia, surface roughness, etc.
- Emissivity spectra contain information about mineralogy and grain size
- This project:
  - Perform thermophysical modeling on 5 – 40 μm Spitzer InfraRed Spectrograph (IRS) spectra of M-type spectra
  - Also look at emissivity spectra
  - Focus on asteroids well-characterized at other wavelengths

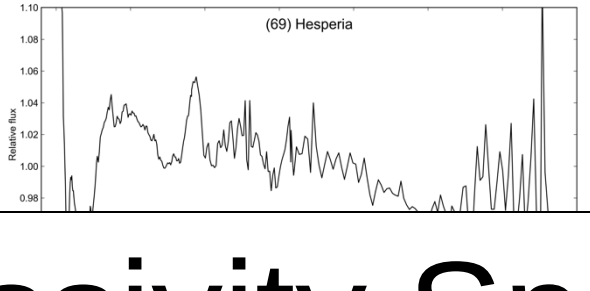
Emissivity Spectra

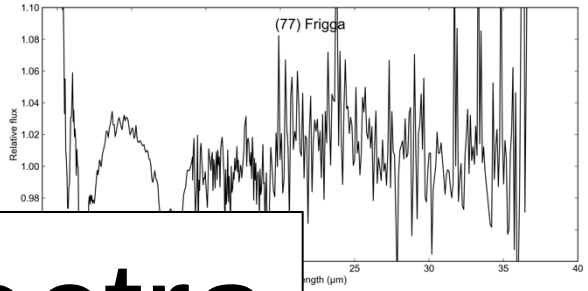


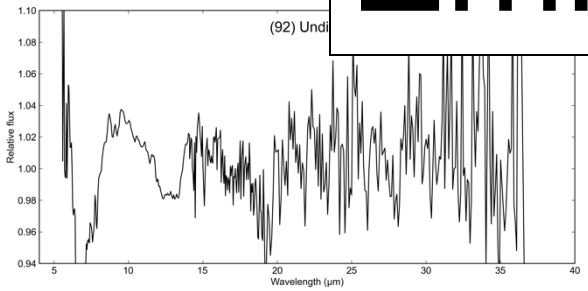


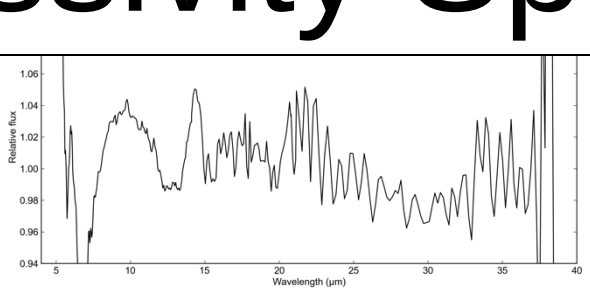


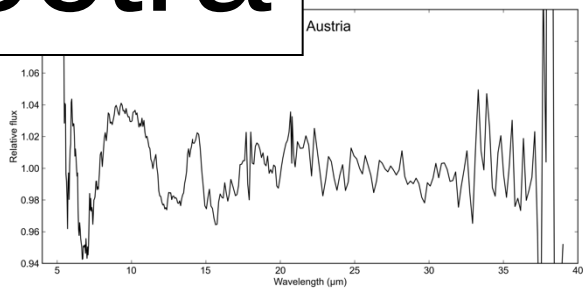


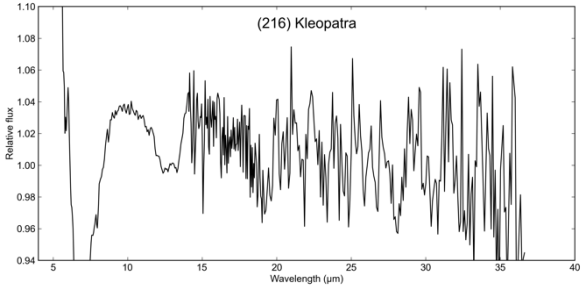


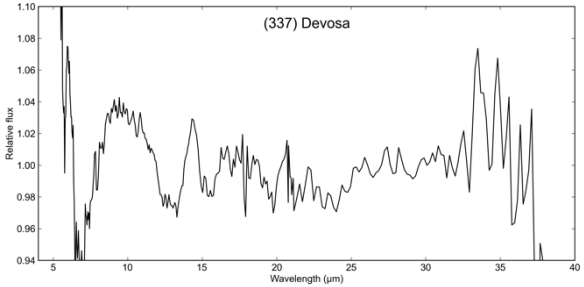


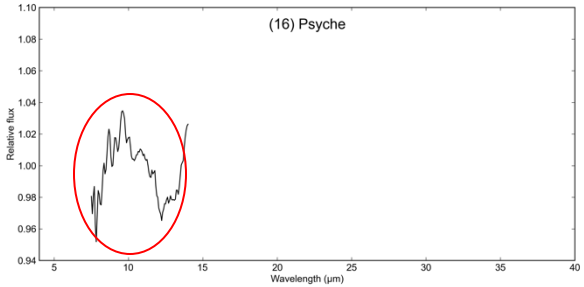


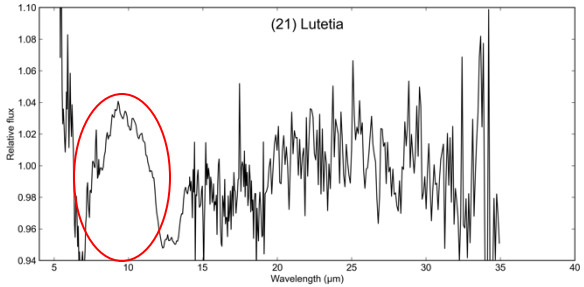


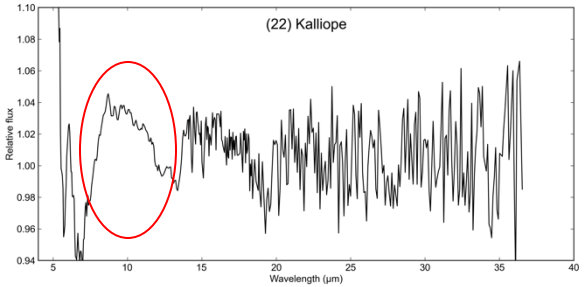


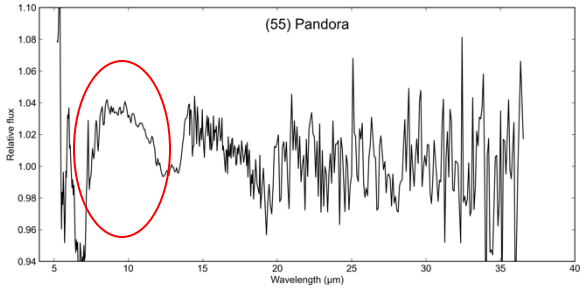


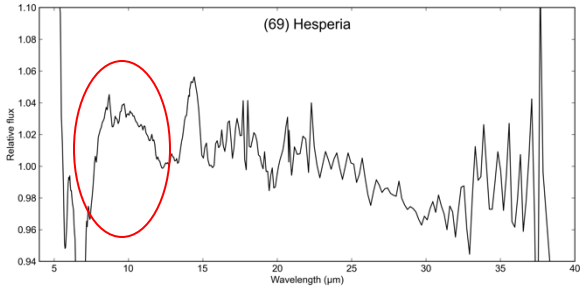


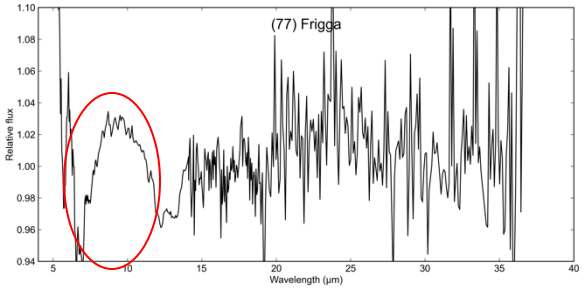

(16) Psyche
Relative flux
Wavelength (μm)

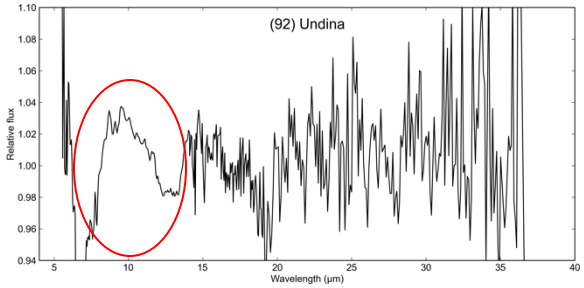

(21) Lutetia
Relative flux
Wavelength (μm)

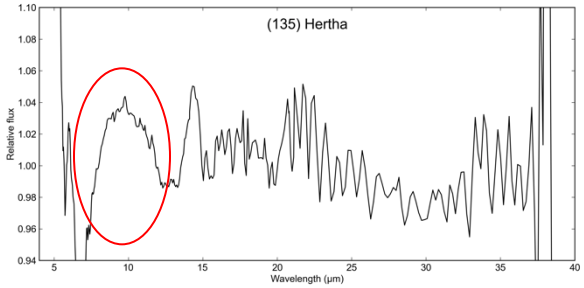

(22) Kalliope
Relative flux
Wavelength (μm)

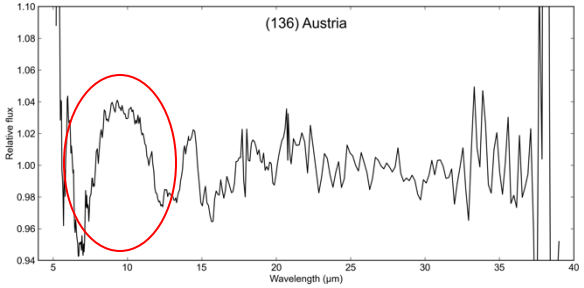

(55) Pandora
Relative flux
Wavelength (μm)

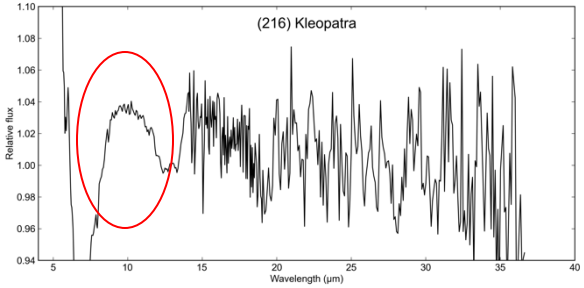

(69) Hesperia
Relative flux
Wavelength (μm)

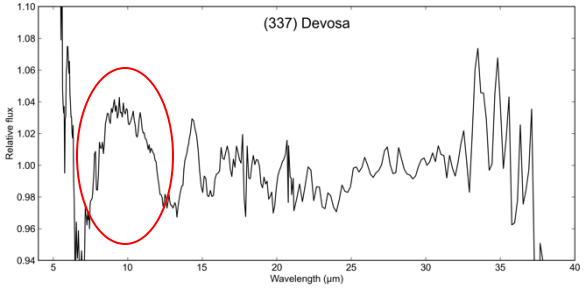

(77) Frigga
Relative flux
Wavelength (μm)


(92) Undina
Relative flux
Wavelength (μm)


(135) Hertha
Relative flux
Wavelength (μm)


(136) Austria
Relative flux
Wavelength (μm)


(216) Kleopatra
Relative flux
Wavelength (μm)


(337) Devosa
Relative flux
Wavelength (μm)

Preliminary TPM Results

Asteroid	Our TPM		Previous TPM work		
	R (km)	Γ (SI units)	R (km)	Γ (SI units)	Ref.
(16) Psyche	140 ± 40	80 ± 80	122. ± 12	125 ± 40	1
(21) Lutetia	65 ± 5	10 ± 10	48. ± 0.5	5 ± 5	2
(77) Frigga	45 ± 5	<10			
(135) Hertha	75 ± 5	<10			
(136) Austria	18 ± 2	<100			
(216) Kleopatra	145 ± 5	<10			

[1] Matter et al. (2013), [2] O'Rourke et al. (2012)

Conclusions and Future Work

- We are using Spitzer spectra (5 – 40 μm) to better constrain the composition of M-type asteroids
- Initial emissivity spectra show signatures of silicates on the entire sample so far
- Initial thermal inertias are typical for main-belt asteroids
- Still a work in progress – we're running more complex models and improving precision of derived quantities

Sincere thanks to NASA and the SBAG Steering Committee for Early Career Travel Support!

Backup Slides

Thermal Inertia vs. Diameter for various asteroid classes
Fig. 9 from Delbo et al. in Asteroids IV

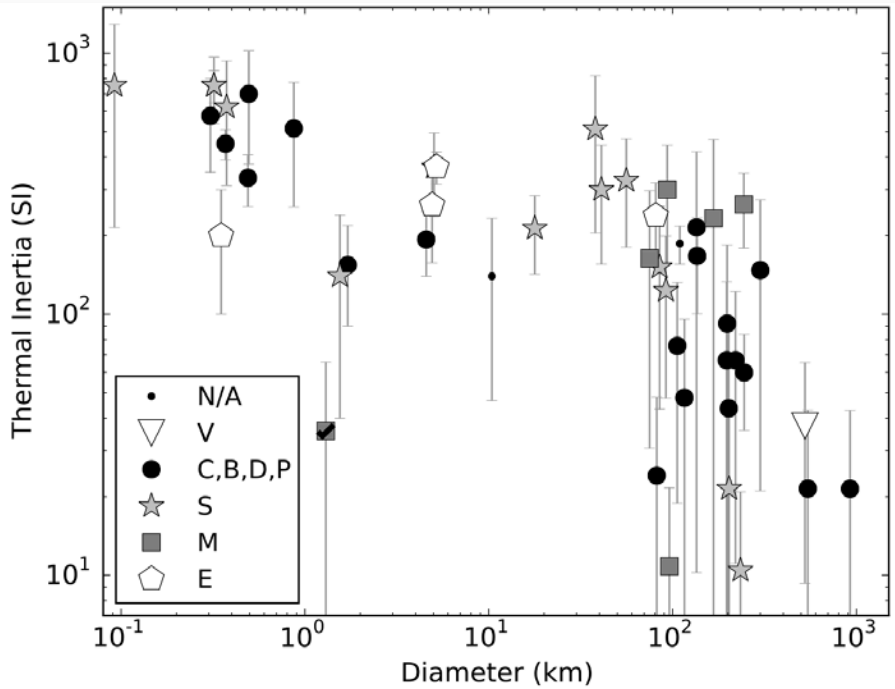
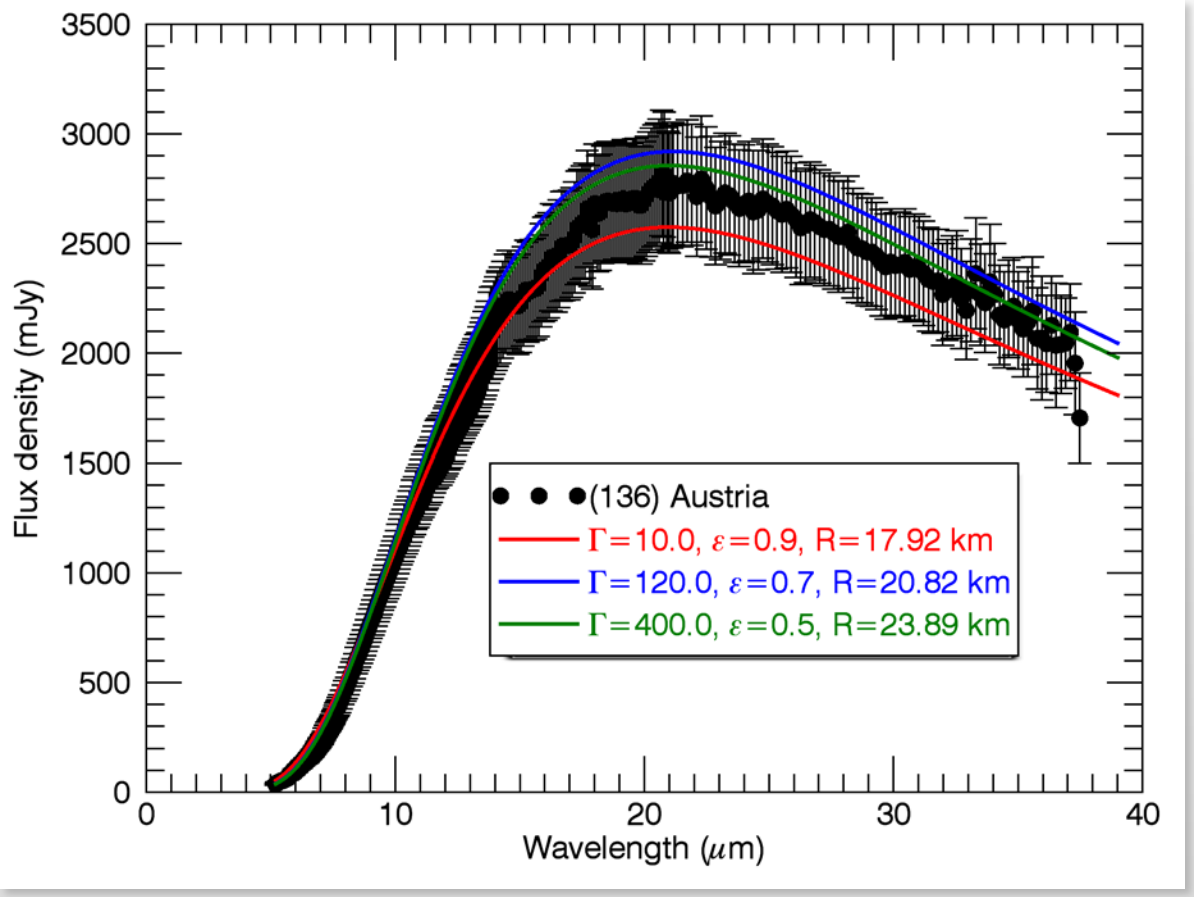
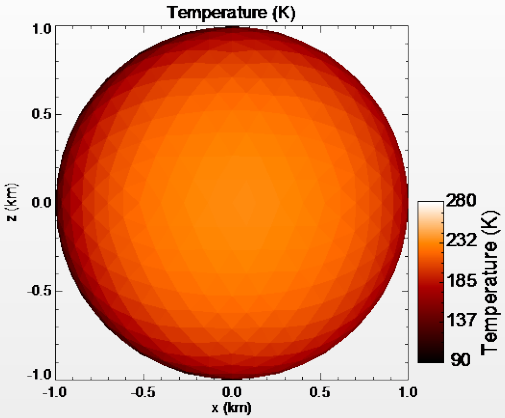


Fig. 9.— Γ values vs. D from Tab. 2 for different taxonomic types (see key). Top plot: original measurements, bottom plot: Γ corrected to 1 au heliocentric distance for temperature dependent thermal inertia assuming Eq. 13 and the heliocentric distance at the time of thermal infrared observations reported in Tab. 2. Trojans, Centaurs and trans-Neptunian objects are not displayed.

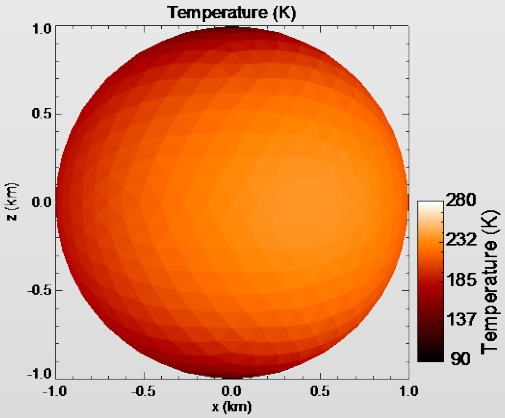
Spitzer IRS spectrum of M-type **(136) Austria**, well fit by thermophysical models with ε=0.9 (red), 0.7 (blue), or 0.5 (green



Γ = **10** J m^{-2} K^{-1} s$^{-½}$
ε = **0.9**



Γ = **100** J m^{-2} K^{-1} s$^{-½}$
ε = **0.5**



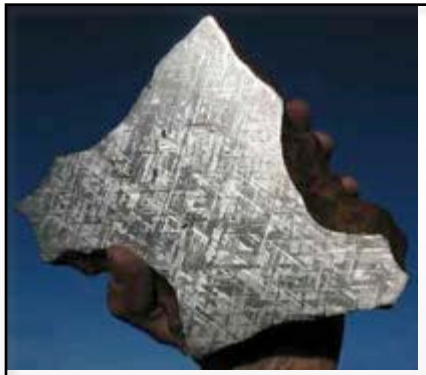
Preliminary TPM Results

Asteroid	ε=0.9		ε=0.7		ε=0.5	
	R (km)	Γ (SI units)	R (km)	Γ (SI units)	R (km)	Γ (SI units)
(16) Psyche	122 - 188	**0 - 160**	127 - 200	10 - 3940	154 - 179	>110
(21) Lutetia	65 - 66	**0 - 20**	60 - 70	11 - 100	64 - 75	80 – 630
(22) Kalliope	-	-	136 - 143	0 - 20	127 - 143	>20
(55) Pandora	-	-	-	-	81 - 98	0 - 2560
(69) Hesperia	-	-	117 - 125	Unconstrained	-	-
(77) Frigga	45 - 45	**<10**	44 - 49	<105	48 - 58	80 - 2650
(135) Hertha	76 - 77	**<10**	74 - 81	<20	-	-
(136) Austria	18 - 20	**<100**	19 - 23	40 - 230	22 - 26	180 - 3320
(216) Kleopatra	134 - 144	**<10**	114 - 126	110 - 115	10 - 185	>560
(337) Devosa					44 - 46	>410

Thermophysical Model

- See Emery et al. 2006, Emery et al. 2014 for details
- Surface roughness implemented as spherical section craters of half-opening γ and fractional crater coverage *f*
  - See also Emery et al. 1998
- Solve heat diffusion equation using the Crank-Nicholson finite-difference method
- Use Brent's method (Brent 1973) for χ^2 minimization

Potential M-type Asteroid Analogs



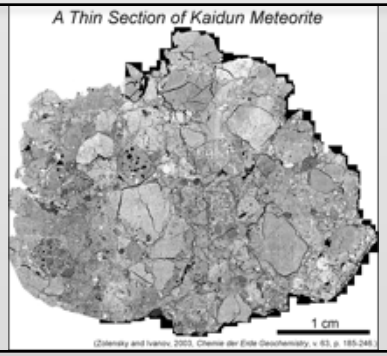
Iron meteorites

Stony-irons

CB chondrites

- Moderate to high inferred metal content
- Weak or non-existent silicate bands
- Examples (Neeley et al. 2014):
  - 16 Psyche
  - 216 Kleopatra

Enstatite chondrite



CR/CH chondrites

- Low inferred metal content
- Weak or non-existent silicate bands
- Examples (Neeley et al. 2014):
  - 21 Lutetia
  - 135 Hertha

Radar Studies

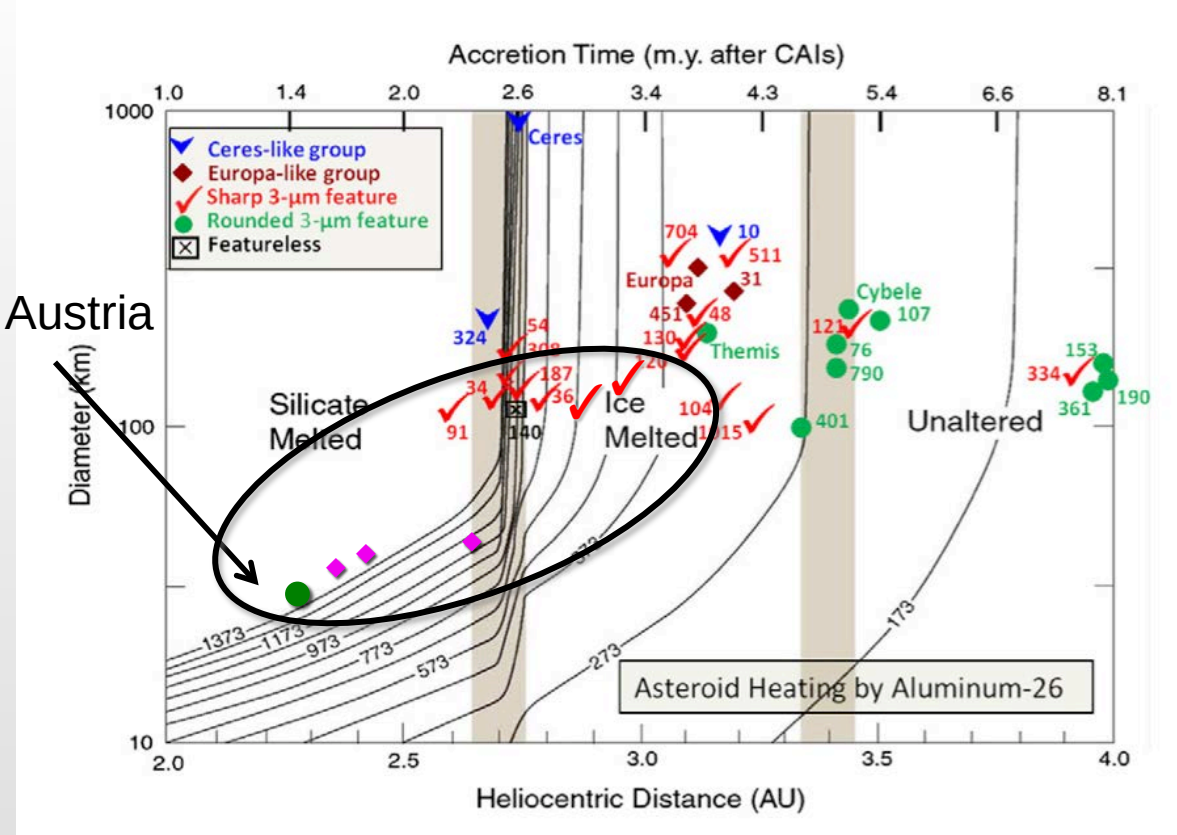
Tholen Class	Radar Albedo (σ_{OC}) ^	Range	N
C	0.127 ± 0.050	0.179	26
G	0.084 ± 0.042	0.109	5
F	0.093 ± 0.055	0.148	6
PD	0.090 ± 0.049	0.161	9
S	0.140 ± 0.044	0.184	27
M (Magri et al. 2007)	**0.255 ± 0.170**	**0.527**	**7**
M (Neeley et al. 2014)	**0.30 ± 0.07**	**0.430**	**18**
All	0.131 ± 0.076	0.561	84

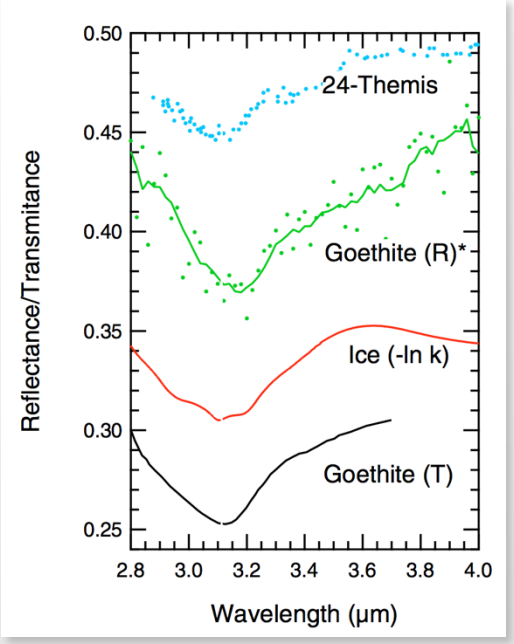
Shepard et al. 2010: Laboratory studies show radar albedo is primarily a function of surface bulk density.

~1/3 of M-types have radar albedos > 0.4, consistent with ρ_{bulk} = 3.8 g/cm^3 (corresponds to iron-nickel with porosity of 50%)

Distribution of 3-micron feature shapes (Takir & Emery, 2012)

136 Austria





Spectra of ice, goethite, and goethite + basalt

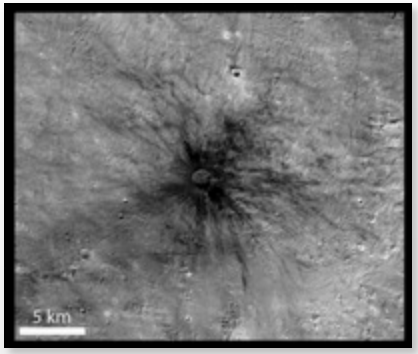
Beck et al. 2011 A&A 526:A85

Grimm & McSween (1993) heliocentric zones with 3-µm feature shapes

Takir & Emery 2012, Icarus 219:641-654

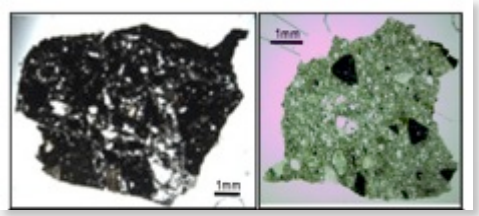
Schörghofer 2008: Buried ice can survive ~10^9 years on dusty surfaces

Origin of Hydration on M-types



Dark material on Vesta

- Exogenic
  - Delivered by impacts of CM-like material?



  - Solar wind interactions?

CR chondrite Renazzo

- Endogenic
  - CR2 Chondrites? Cloutis et al. 2011:
    - Moderate reflectance
    - Weak silicate bands
    - Red slopes
    - Phyllosilicates present, but no 0.7-μm feature

2 – 4 μm Results: Hydration on 6/6