Observations of asteroids in the thermal infrared

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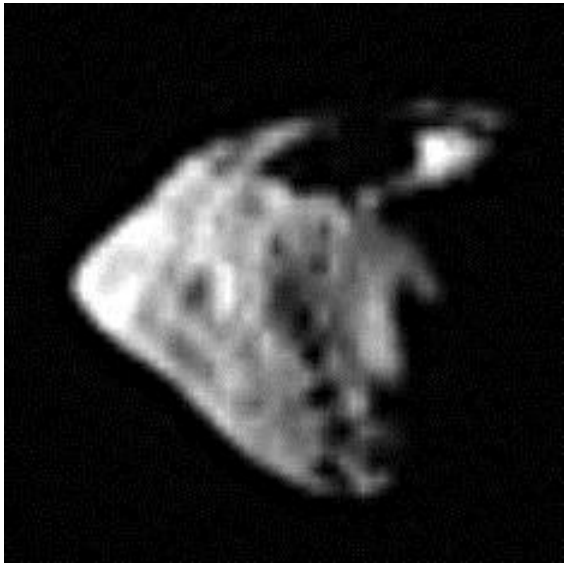
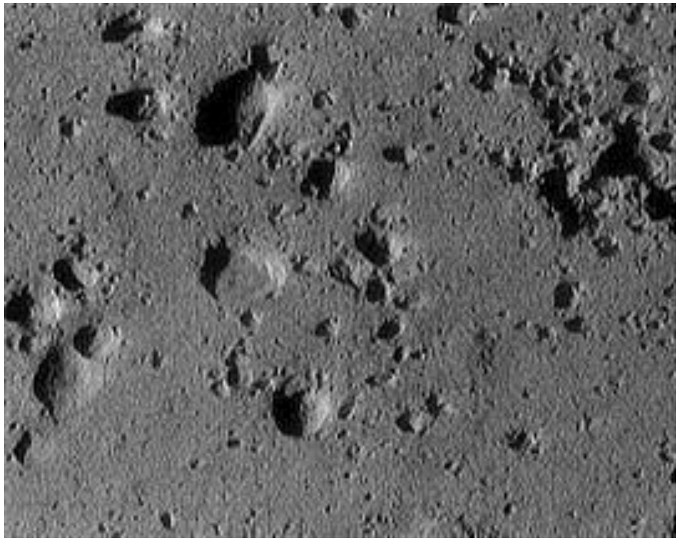


Steins seen by Rosetta



Eros seen by NEAR-Shoemaker

It appears that the average particle size may be larger than that of lunar soil, but that the larger grains are mixed and partially coated with very fine dust (smaller than 10 micron).

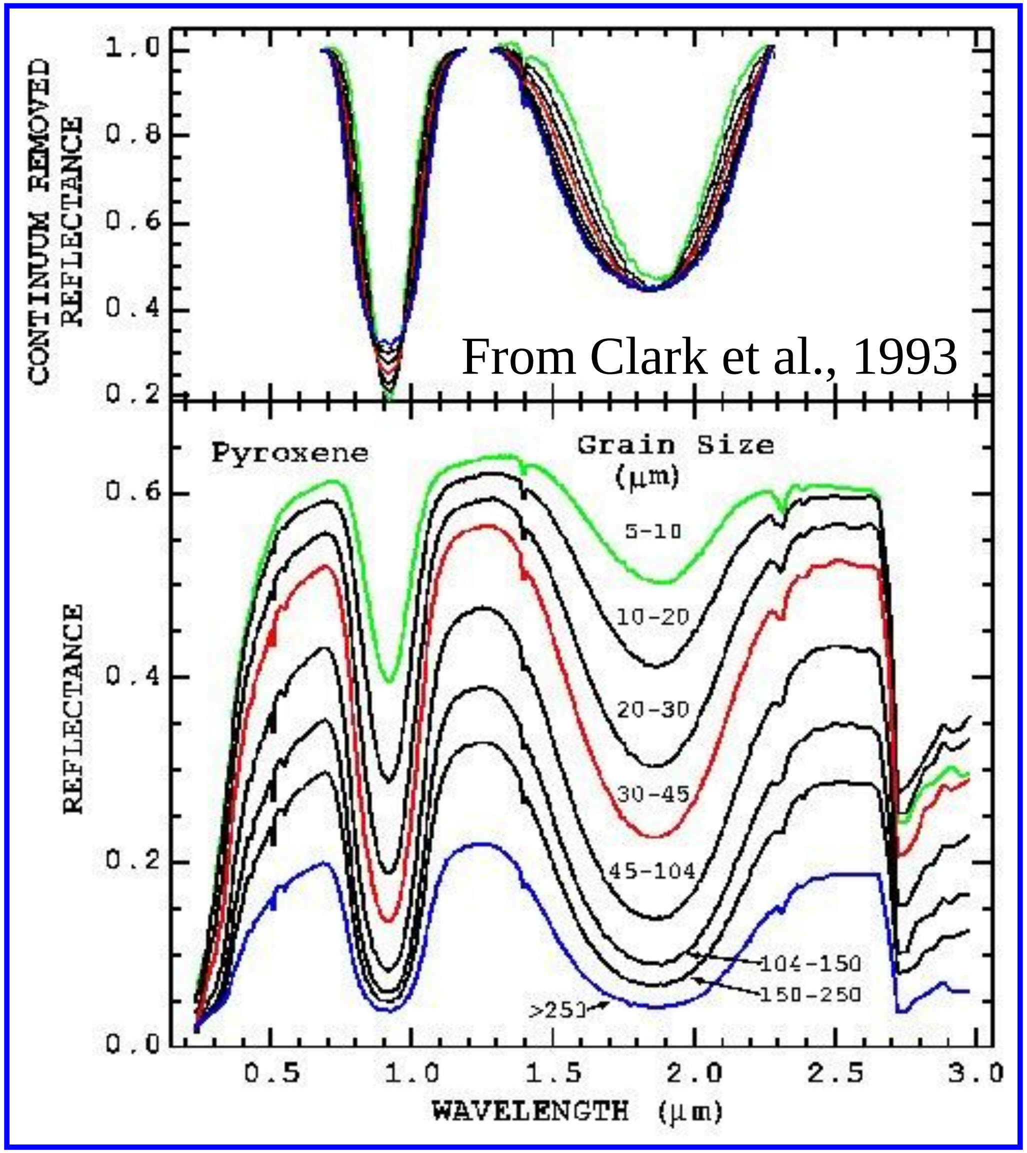
Lutetia seen by Rosetta

Physical Effects: Grain size

Particle size and contrast:

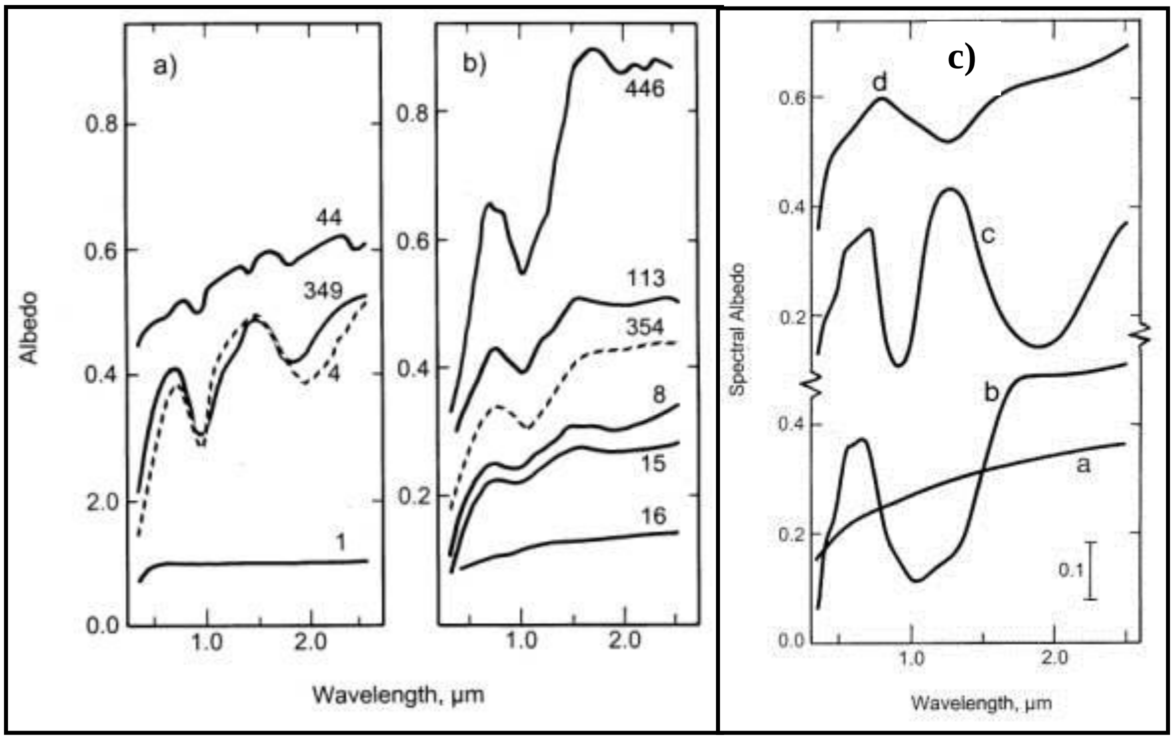
Absorption band contrast varies with particle size but does not affect the position of absorption features

Grain size needs
to be considered!



From Clark et al., 1993

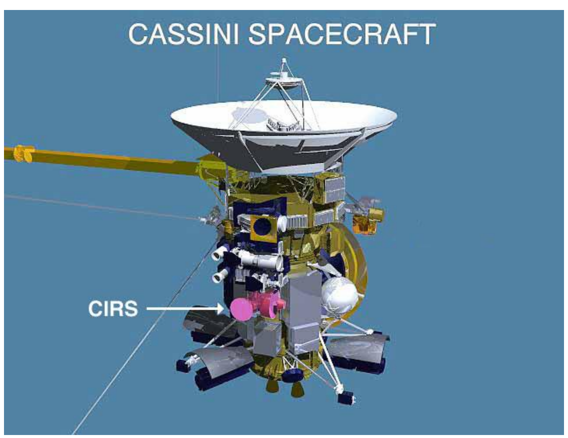
Asteroid spectra: surface composition

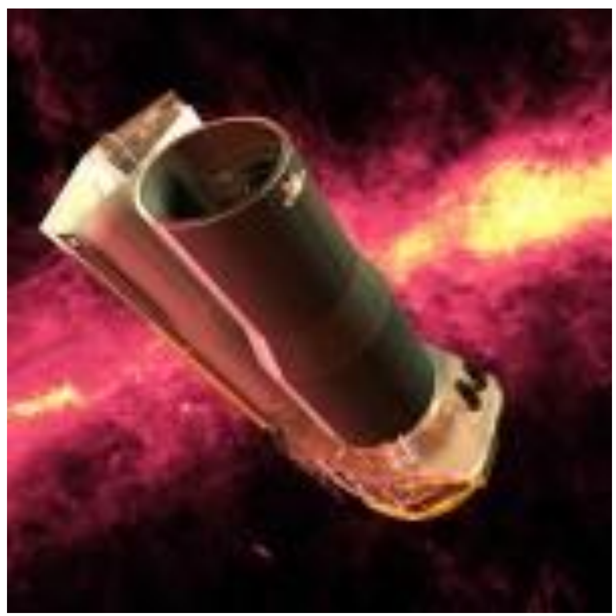


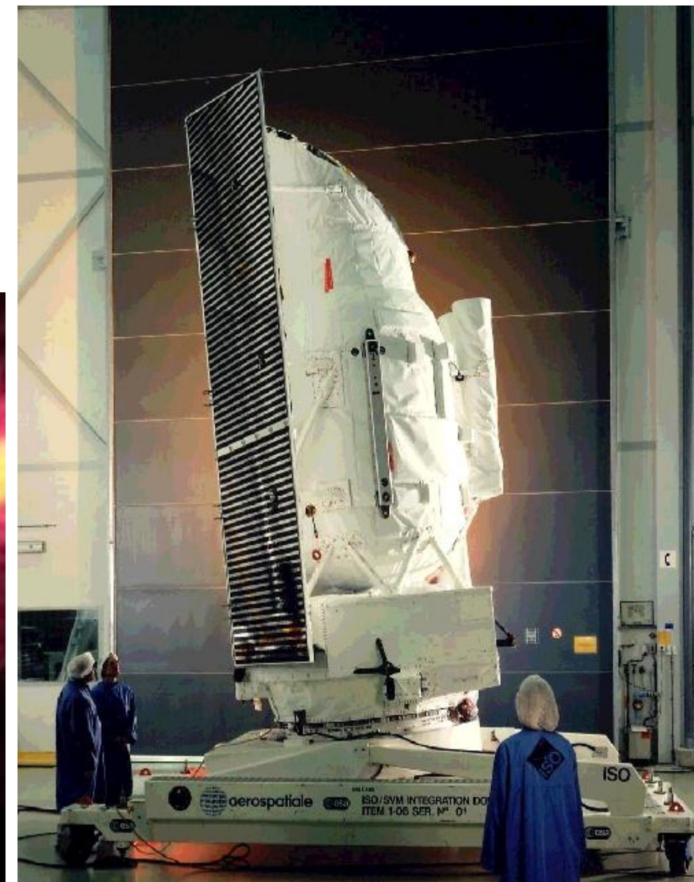
Left [a) e b)] spectra of asteroids compared with [c)] spectra of known minerals: a-iron-nichel, b-olivine, c-pyroxene, d-anorthite.

The lesson learned from
ISO, SPITZER, and CIRS-Cassini

- ➢ Spectroscopic data (surface composition and morphology)
- ➢ Thermal models
- ➢ Laboratory experiments



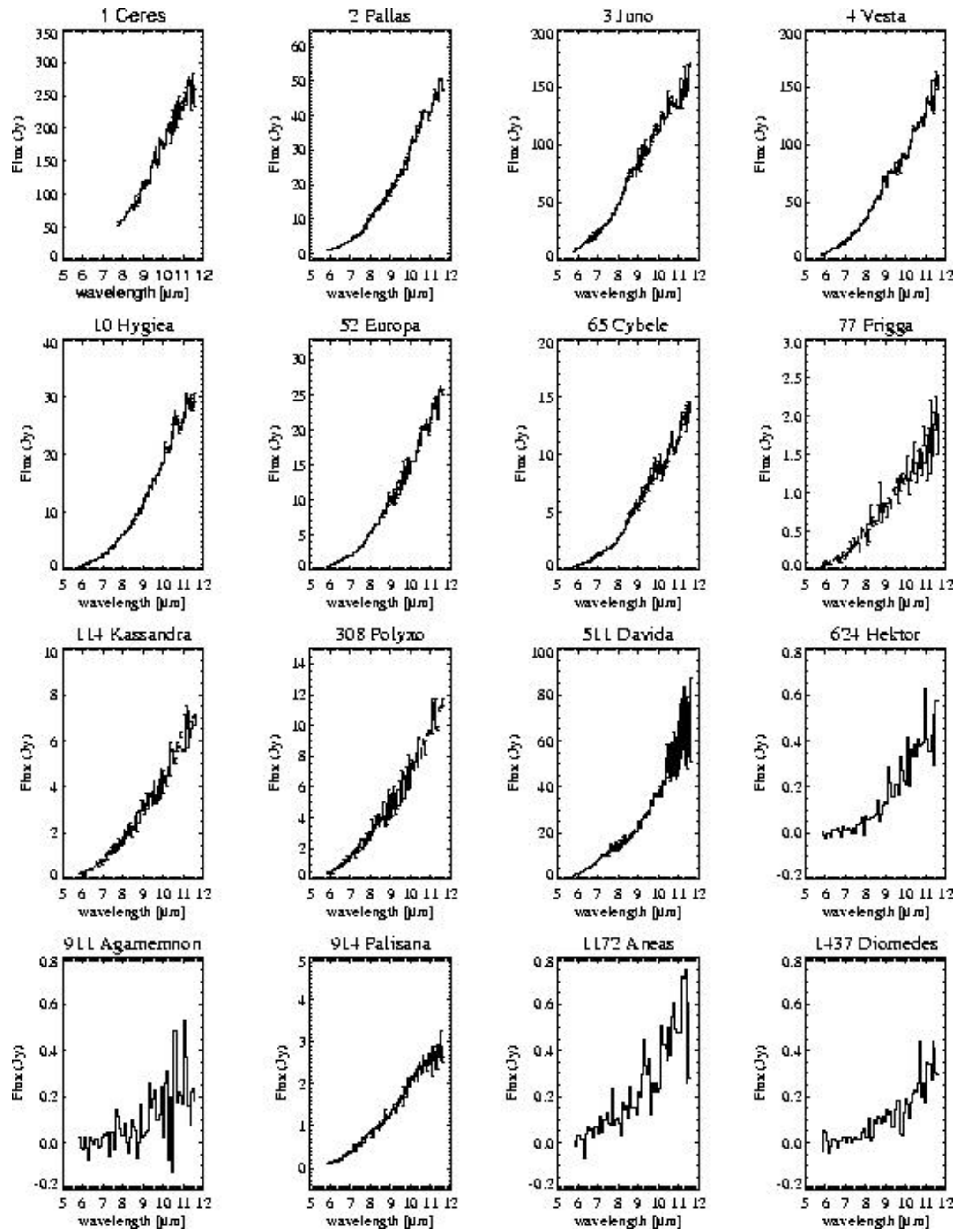




Main Belt Asteroids seen by ISO

A sketch of 16 ISO spectra between 5.8 and 11.6 micron

The thermal continuum of these spectra was modeled using the Standard Thermal Model (Lebofsky and Spencer, 1989), or more evolved thermophysical models (e.g. Lagerros, 1996, 1997, 1998).



(Dotto et al., 2000, 2002, 2004; Barucci et al. 2002)

The Standard Thermal Model (Lebofsky and Spencer 1989)

The STM assumes a non-rotating spherical asteroid, in istantaneous equilibrium with solar insolation, observed at 0^o solar phase angle. In this ideal situation the sub-solar temperature is given as:

$$T_{SS} = [\ (1-A)S\ /\ \varepsilon\eta\sigma\ ]^{1/4} \quad \text{and} \quad T(\Omega) = T_{SS} \cos^{1/4}(\Omega)$$

where Ω is the zenith angle, A is the bolometric Bond albedo, S is the solar flux at the distance of the asteroids, η is infrared beaming, ε is the wavelength-independent emissivity, and σ the Stefan-Boltzmann constant.

The ThermoPhysical Model (Lagerros 1996, 1997, 1998)

The TPM calculates the surface temperature from the energy balance between absorbed solar radiation, the thermal emission, and heat conduction into the surface material.
The object is described as rotating ellipsoid, and its spin vector, shape, and albedo are used as input parameters. The disk integrated model flux at the wavelength λ is computed as:

$$F_\lambda = (1/\pi\Delta^2)\int_S \varepsilon_d B_\lambda(\gamma T)\ \mu\ dS$$

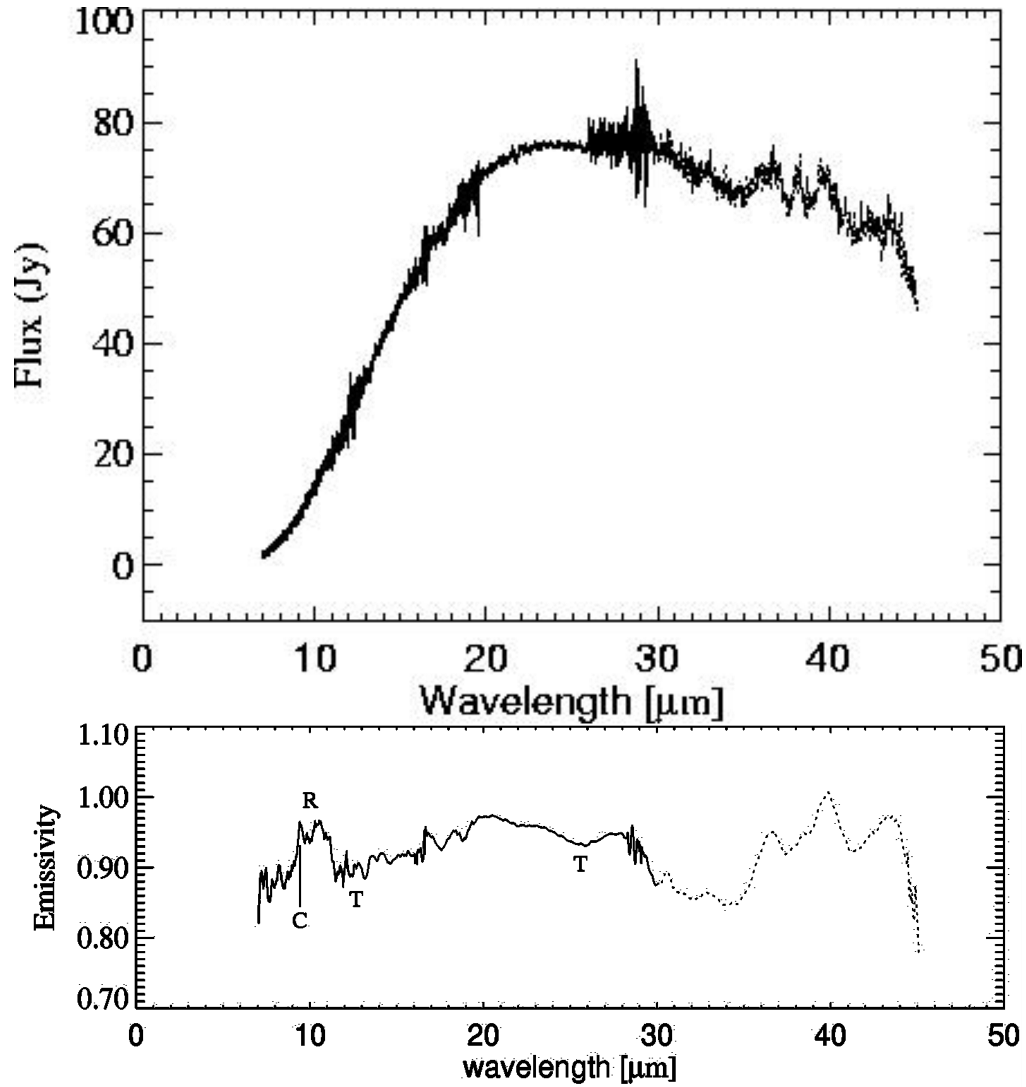
where Δ is the distance from the observer, B_λ the Planck function, and the direction cosine μ projects the surface element dS towards the observer, γ is the beaming function and ε_d the wavelength- and direction-dependent emissivity.

ISO-SWS spectrum of 10 Hygiea: surface composition

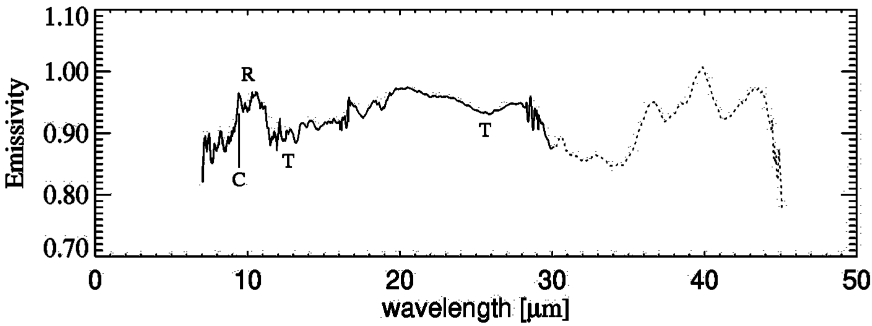
C-type asteroid.

The thermal continuum has been modeled using the ThermoPhysical Model.

The emissivity has been obtained deviding the observed spectrum for the TPM expected flux.



(Barucci, Dotto et al. 2002)



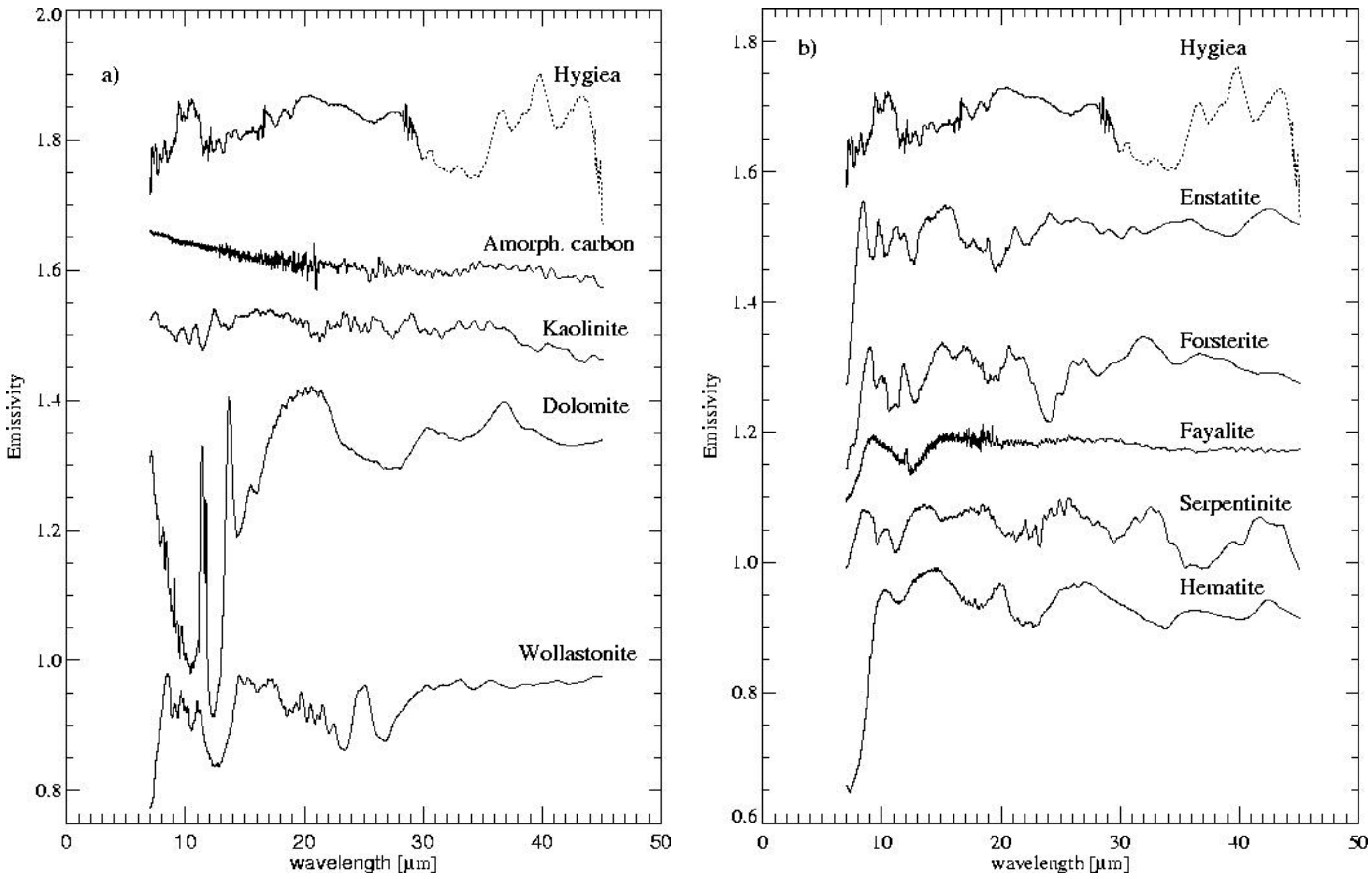
Diagnostic features in thermal infrared

Reststhralen features: due to the vibrational modes of molecular complexes. Usually occurs like a plateau between 9 and 12 micron

Christiansen peak: is directly related to the mineralogy and the grain size. It is associated with the principal molecular vibration band and for silicates occurs just short of the Si-O stretching vibration bands between 7.5 and 9.5 micron.
In the spectral range between 5.8 and 11.6 micron the Christiansen peak is the most diagnostic feature, which marks the boundary between the wavelength region dominated by volume scattering and the wavelength region dominated by surface scattering and reststrahlen bands.

Transparency features: in the spectral region where the absorption coefficient decreases, grains become more transparent. If the grain size is small, volume scattering occurs and transparency features are observable due to a loss of photons crossing many grains.

10 Hygiea and laboratory spectra of minerals

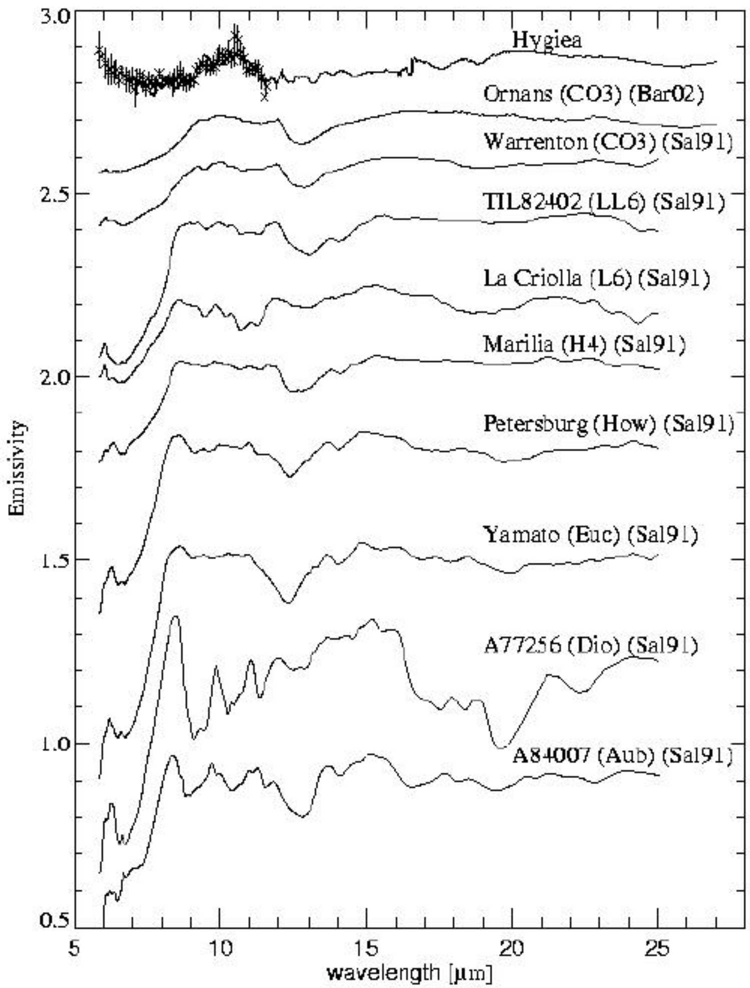


(Barucci, Dotto et al. 2002)

Many attempts were made to combine (by intimate or geographical mixing models) different components.

None of the analysed spectra matched the Hygiea spectrum.

10 Hygiea and laboratory spectra of meteorites



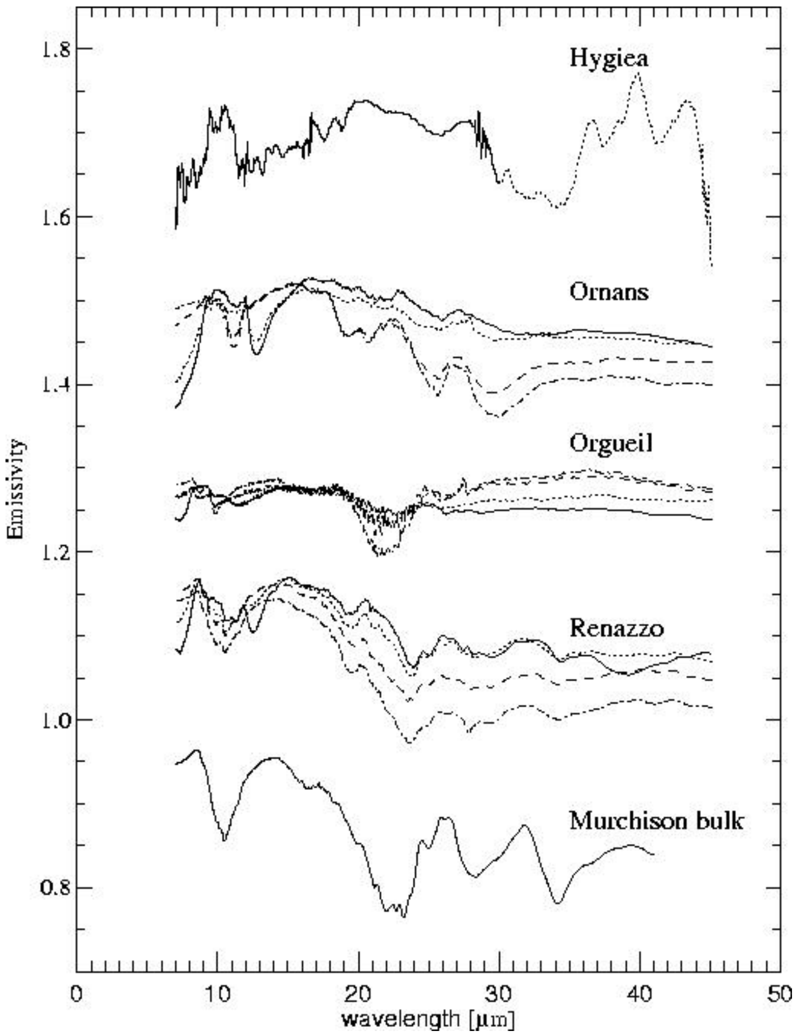
(Barucci, Dotto et al. 2002)

We compared our ISO spectrum of Hygiea to all the spectra of meteorite particulates available in literature.

The most consistent analogy is with the spectra on carbonaceous chondrites Ornans and Warrenton.

This confirm previous works in which C-type asteroids were associated to this kind of meteorites.

10 Hygiea and laboratory spectra of carbonaceous condrite meteorites



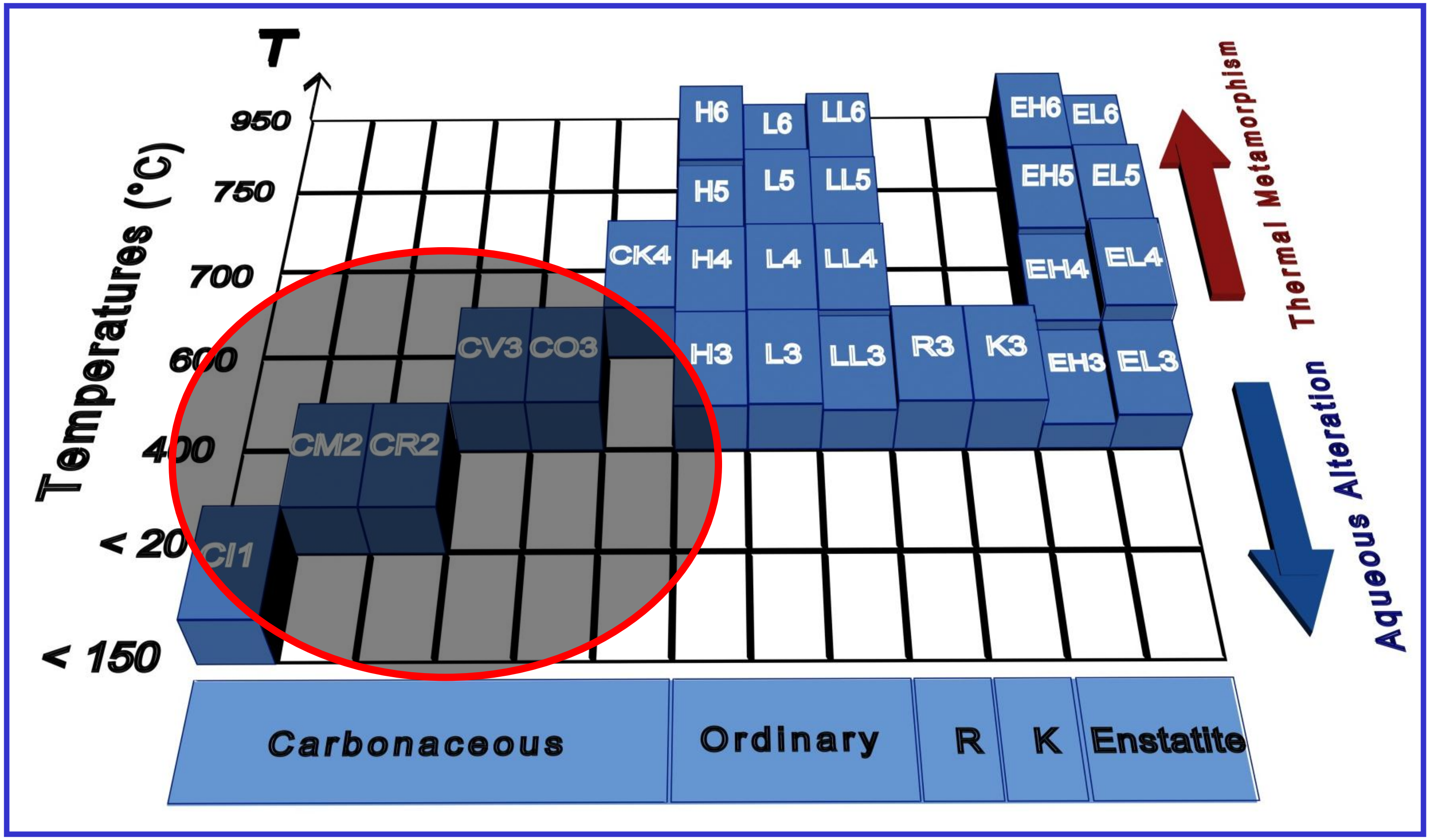
(Barucci, Dotto et al. 2002)

New laboratory experiments were performed at the Capodimonte Observatory, to obtain infrared spectra on four different carbonaceous chondrites (CO, CI, CR and CM) up to 45 micron. Several size ranges were selected, from a few microns up to 100-200 micron.

Ornans and Renazzo: grain dimension 0-20 micron (continuous lines), 20-50 micron (dotted lines), 50-100 micron (dashed lines) and >100 micron (dashed-dotted lines).
Orgueil: 0-50 micron (continuous lines), 50-100 micron (dotted lines), 100-200 micron (dashed lines) and >200 micron (dashed-dotted lines).
Murchison: bulk sample.

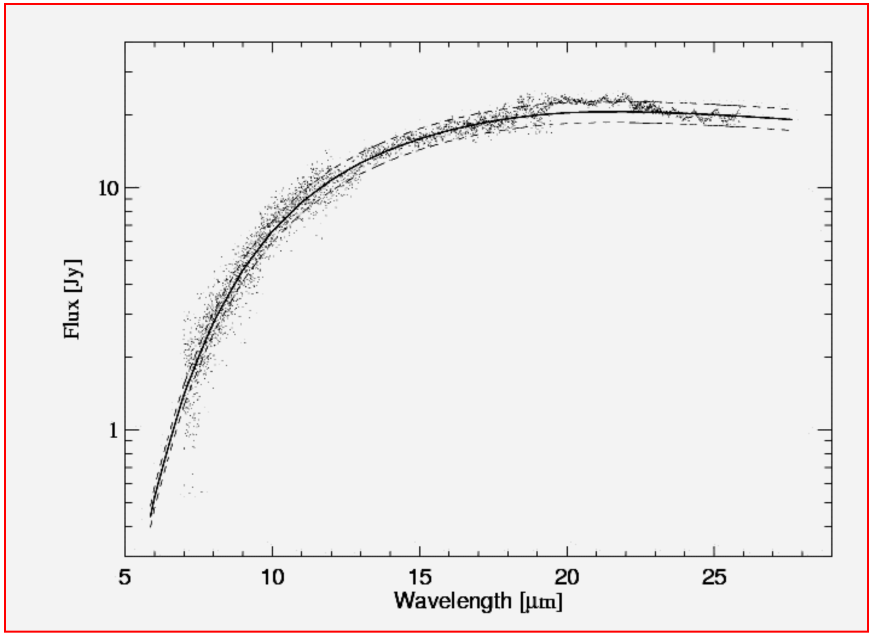
Ornans represents the greatest similarity with the spectral behavior of Hygiea.
The analogy is supported by the comparison of the Christiansen peak (about 9.3 micron), the reststrahlen features around 10-11 micron, and by the transparency features at about 13 micron and 26 micron

This match supports the view that Hygiea is a primitive object that has undergone slight thermal alteration and some aqueous alteration.
Hygiea is one of the biggest asteroids of the main belt and thus may have supported some initial stage of methamorfism.



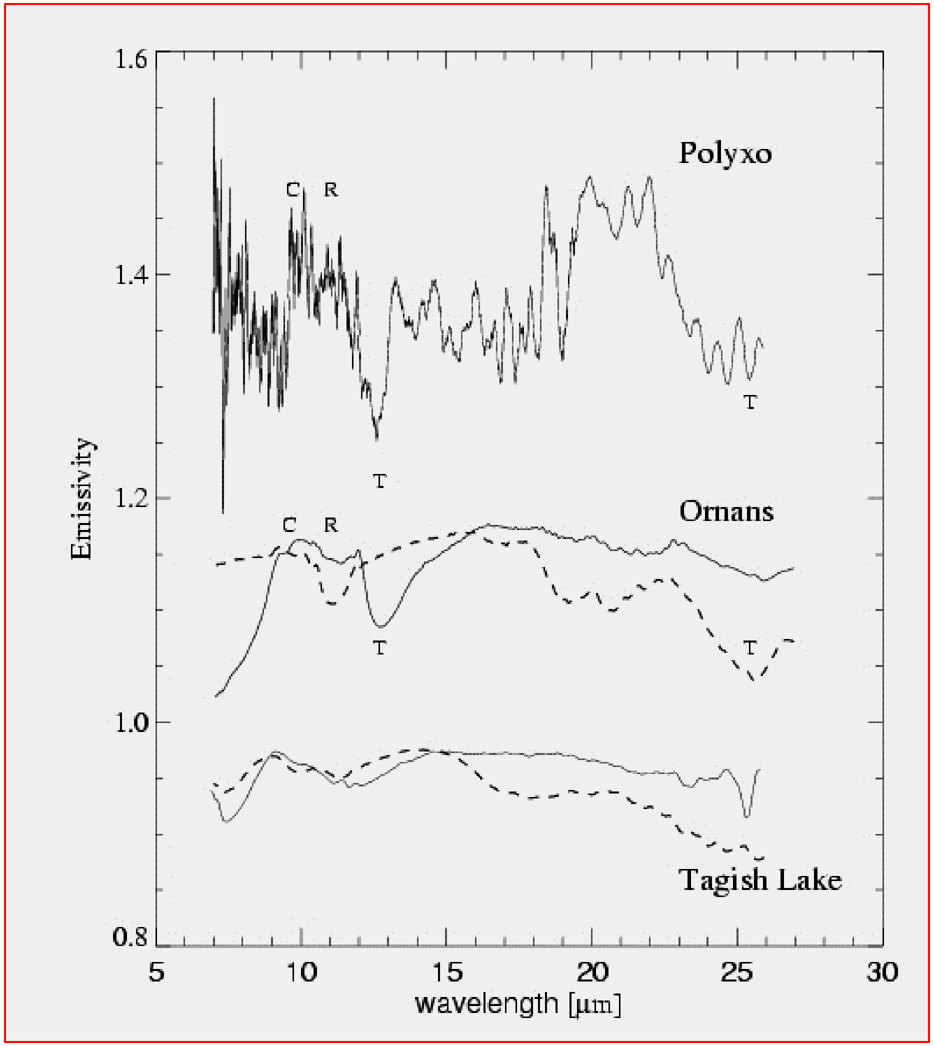
Chondritic meteorites: temperatures and evolution

ISO-SWS spectrum of 308 Polyxo



(Dotto, Barucci et al. 2004)

Polyxo is not the parent body of the Tagish Lake meteorite, as suggested on the basis of visible and near-infrared spectroscopic data.



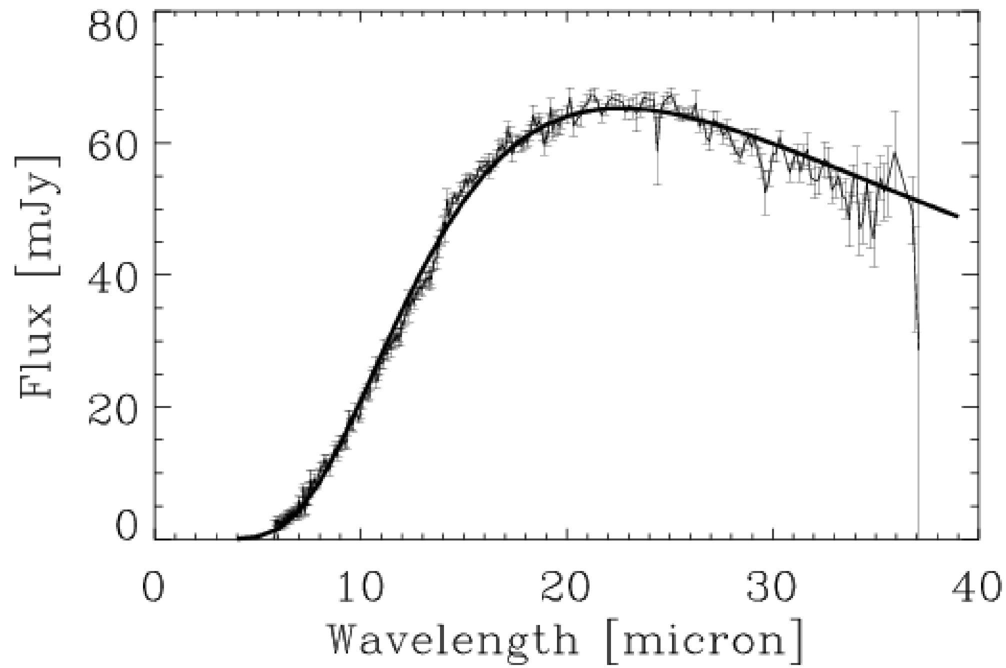
grain dimensions: 0-20 micron (continuous lines), >100 micron (dashed lines).

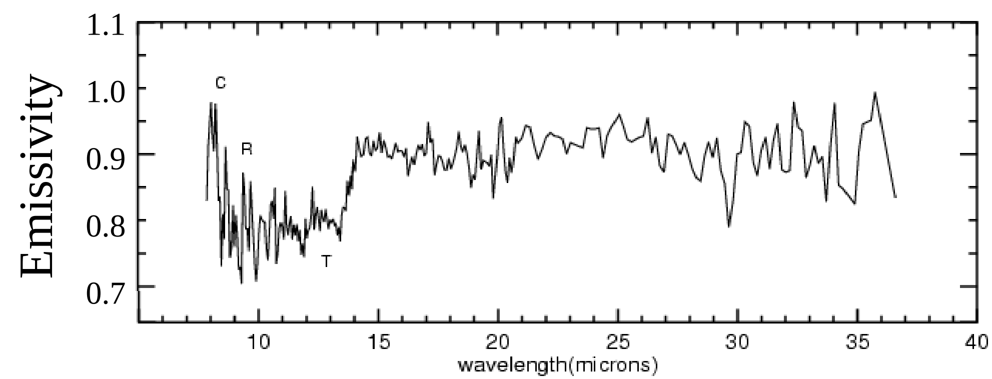
Steins seen by Spitzer

The thermal continuum has been modelled using the thermophysical model by Groussin et al. (2004).

Albedo and dimensions were computed:
p_R(H-G) = 0.40±0.07
5.73±0.52×4.95±0.45×4.58±0.41 km

The emissivity was obtained by deviding the observed spectrum for the expected flux.



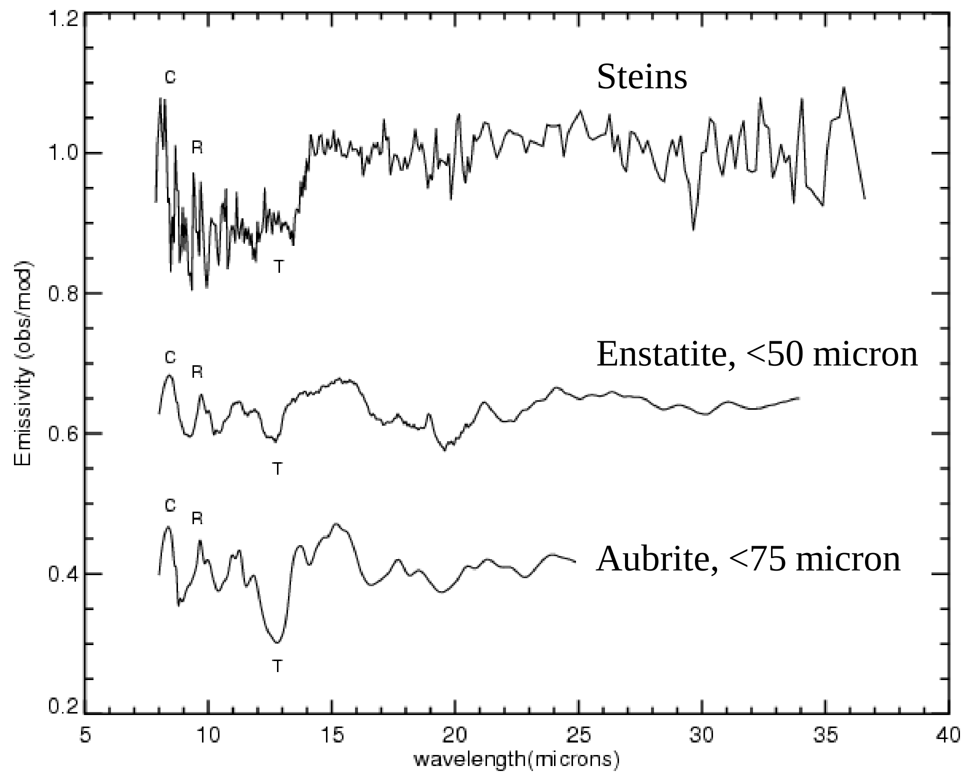


(Barucci, Fornasier, Dotto et al. 2008)

Steins seen by Spitzer

The emissivity spectrum of Steins is similar to that one of the enstatite achondrites (aubrites).

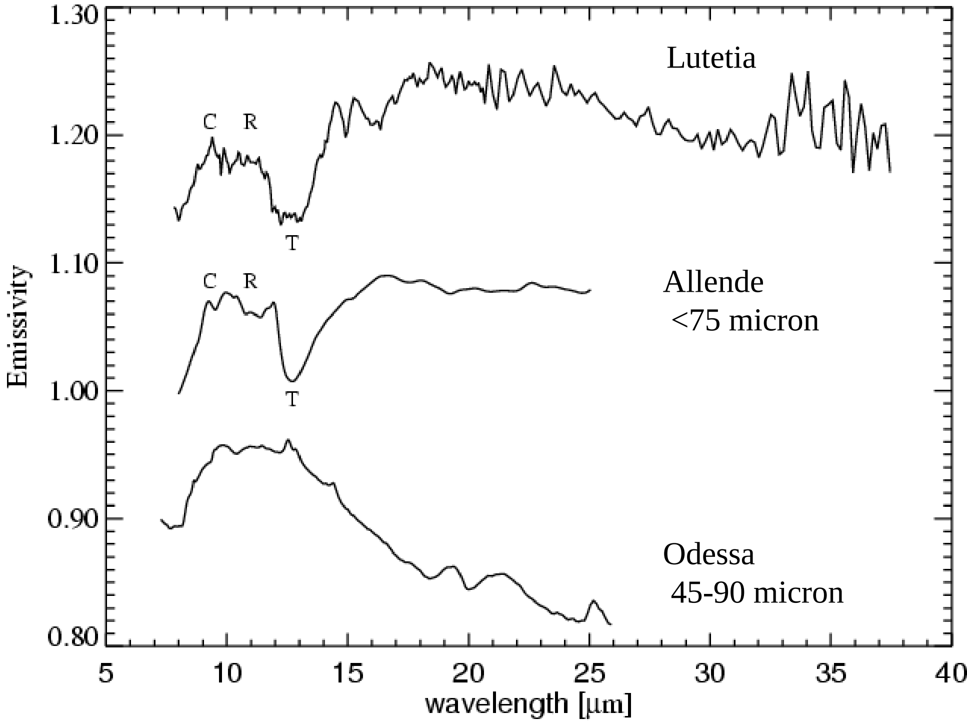
Confirmed the E-type classification.



(Barucci, Fornasier, Dotto et al. 2008)

Lutetia seen by Spitzer

(Barucci, Fornasier, Dotto et al. 2008)

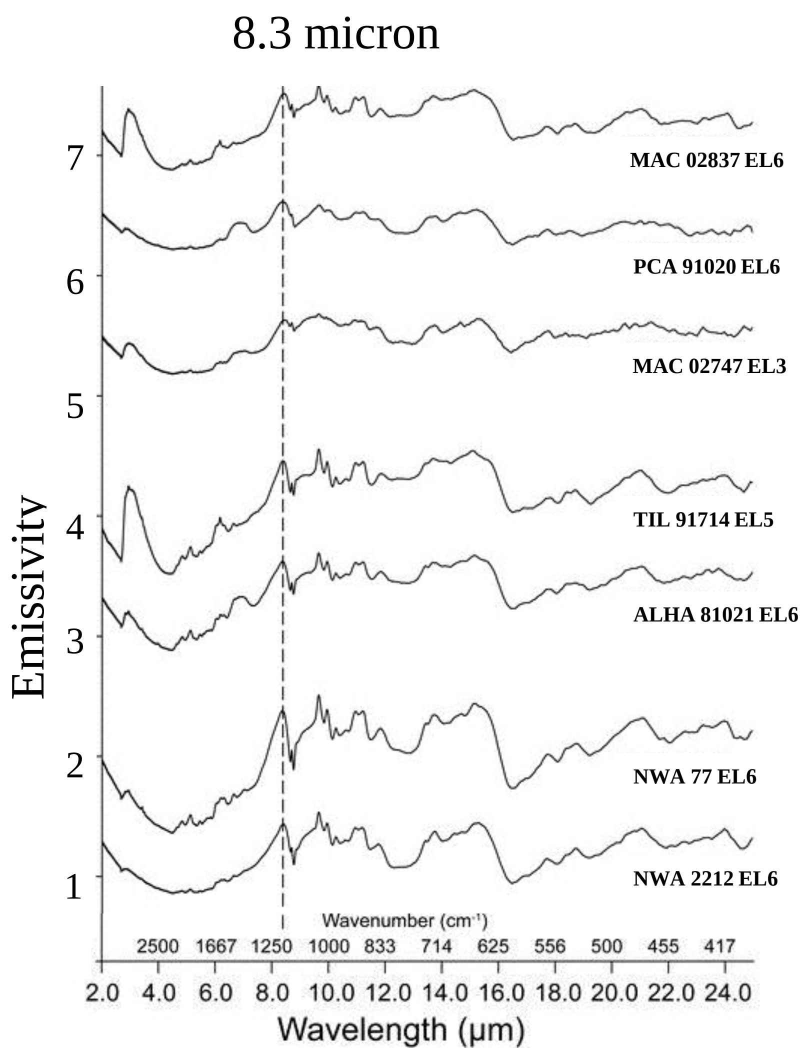


The Lutetia emissivity spectrum seems to be similar to that one of carbonaceous chondrites (CO-CV types).

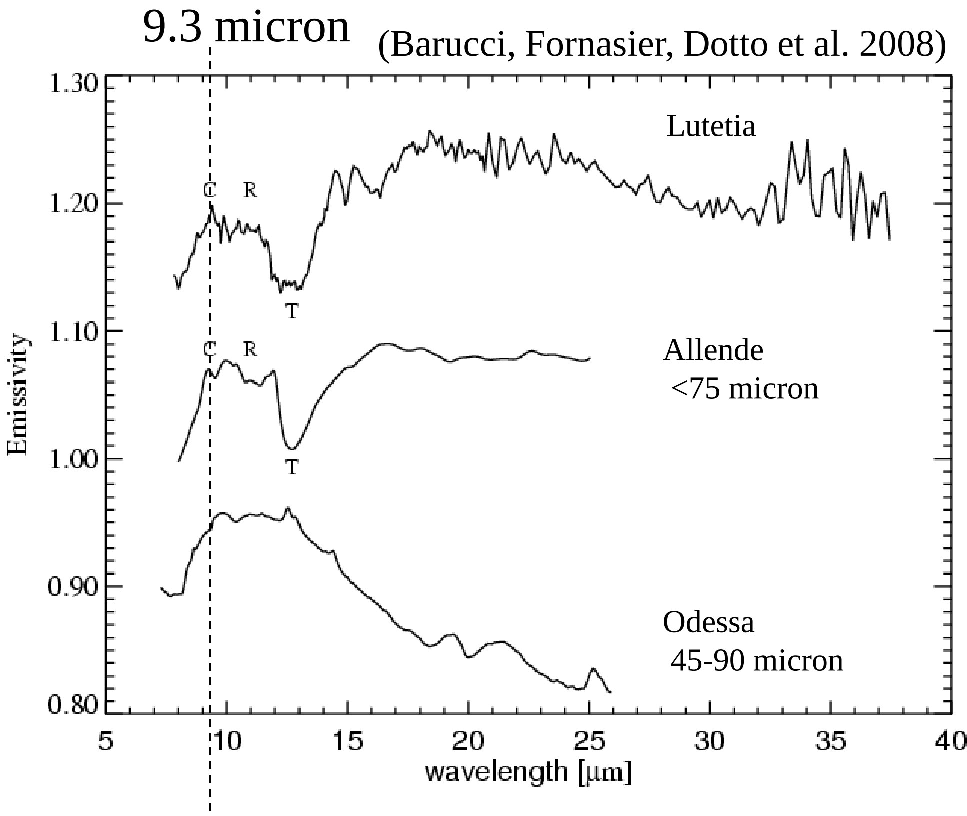
Albedo: p_R(H-G) = 0.19±0.02

No similarities with the metallic meteorite Odessa.

Lutetia seen by Spitzer



Emissivity spectra of enstatite chondrites (from Izawa et al. 2010)



No similarities with the metallic meteorite Odessa.

The similarity with enstatite chondrites suggested on the basis of V+NIR data, seems to be not confirmed.

The CIRS spectrum of Saturn's satellite Phoebe

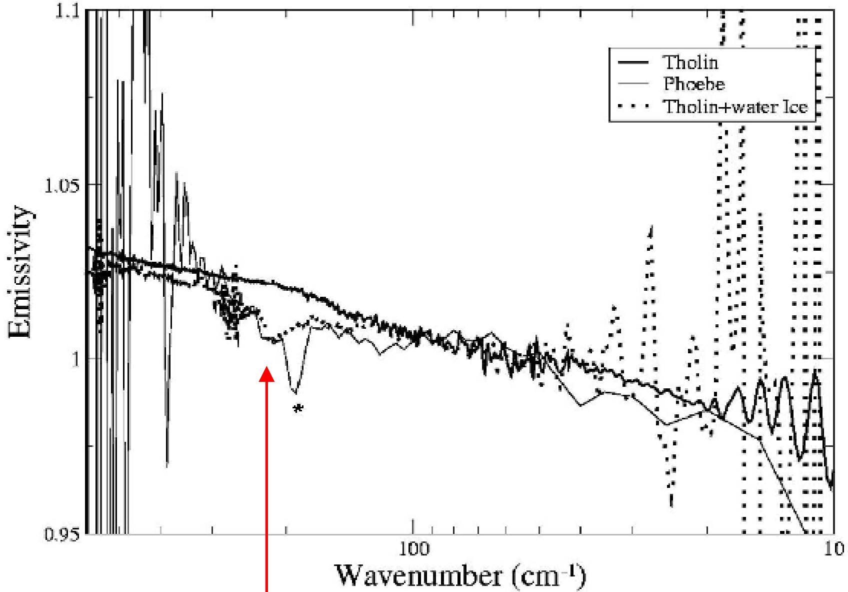
It is evident that slab and powder tholin have a different reflectance.
The emissivity of Phoebe is reproduced by flat slab tholin covered by a thin layer of water ice.

The physical conditions present on Phoebe could be seen as a surface made of compact bulk material covered by a fraction of tholin regolith and water ice.

If the fraction of grains that is responsible for the bands observed in NIR has sizes of 100s micron, the same fraction of grains will not be sufficient to be seen in the FIR, where the emission of smooth compact tholin dominates.

A considerable amount of compact smooth millimeter-size carbonaceous compounds are present on the Phoebe satellite covered with water ice and tholin regolith.

(Brucato et al. 2010)



Water ice embedded at molecular level in the tholin or coating the surface as thin layer.

This suggests a surface highly processed by small object impacts and a peculiar nature of Phoebe with respect to other Saturn satellite. It could be a primitive Kuiper belt object captured by Saturn that contains an high amount of HCN-like polymers active in prebiotic chemistry.

Discussion and conclusions

✓ Thermal infrared spectra can give us fundamental information not only on albedo, diameter, thermal structure and thermal inertia, but also on the surface composition and regolith of asteroids and the other atmosphereless small bodies of the Solar System.

✓ The surfaces of these bodies are composed of mixtures of minerals, whose absorption features are combined following non-linear paths.

✓ The interpretation of thermal infrared spectra needs of laboratory experiments to compare the observed spectral behaviors with the emissivities of mineral and meteorite particulates.

✓ Thermal infrared information is complementary with data obtained in visible and near-infrared spectral ranges: a multiwavelength approach is the only way to contrain the surface composition/properties of small bodies of the Solar System.