Surface composition of icy asteroids and the special case of Ceres

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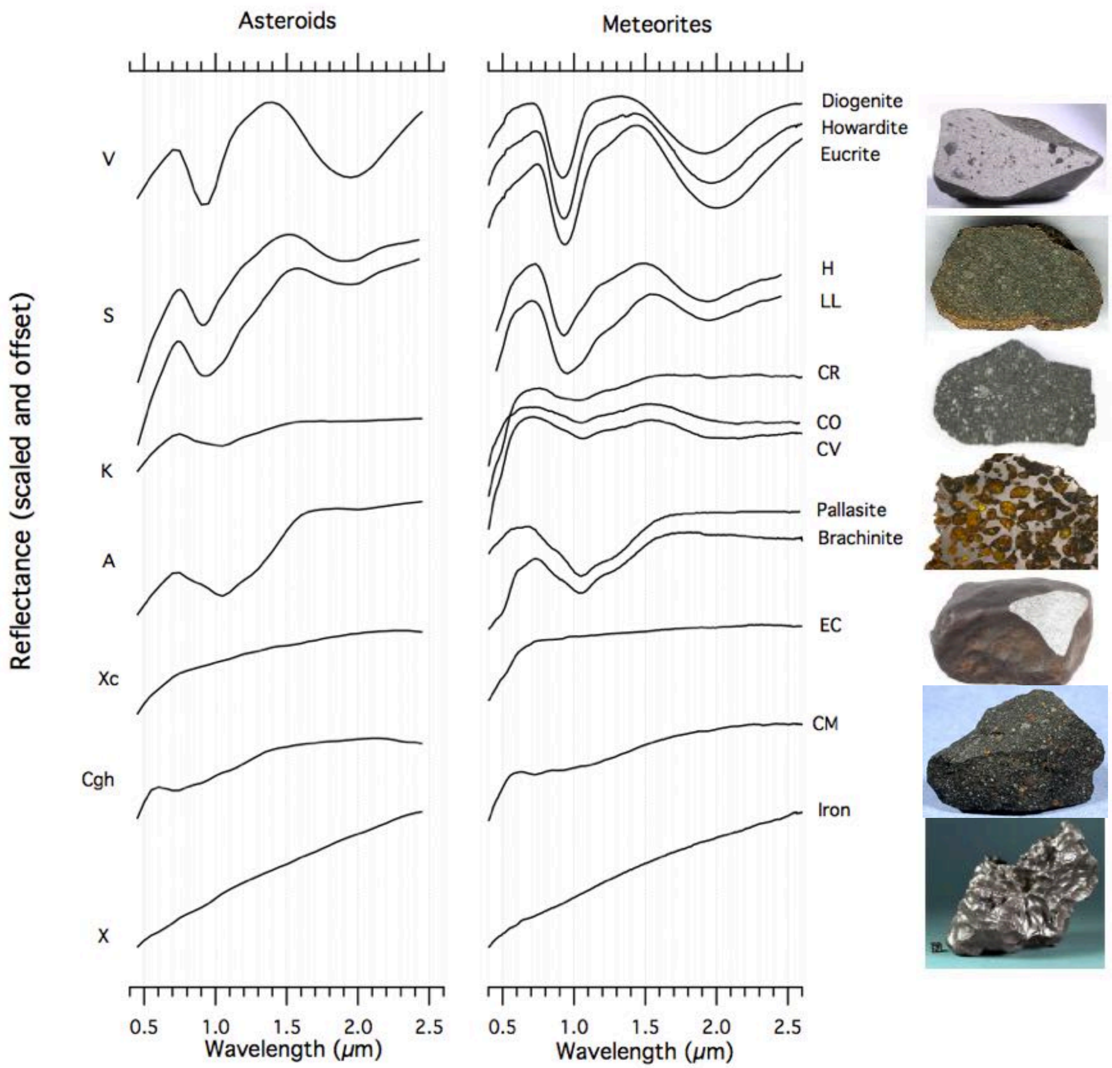
Examples of asteroids with meteoritic analogues



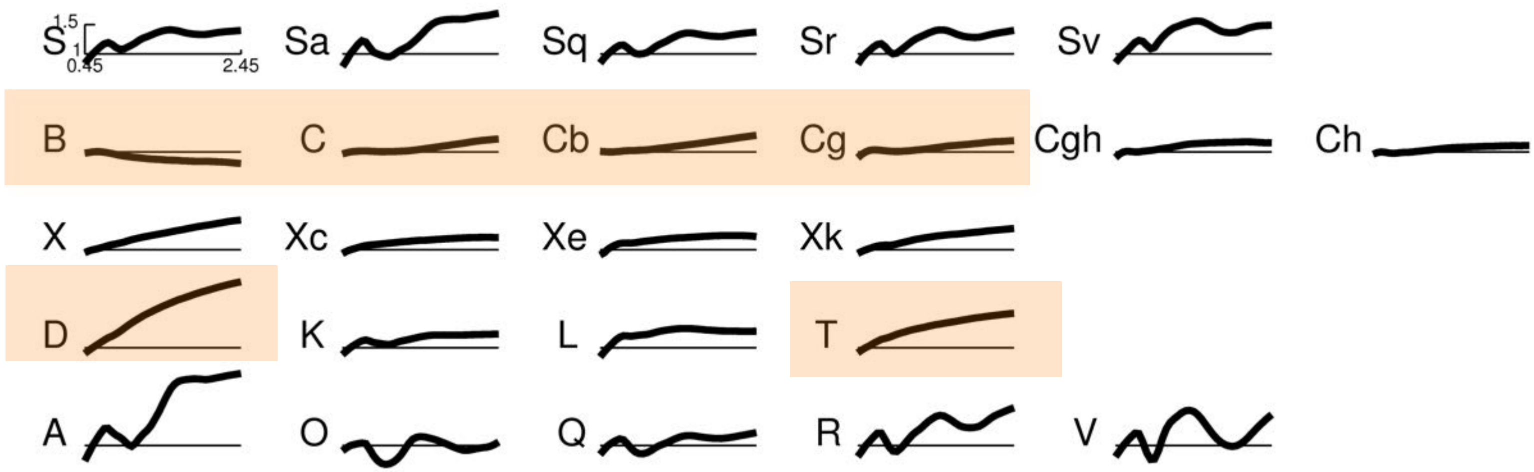
Vernazza & Beck 2016

Falls	Mass in the asteroid belt
6.2%	9.6%
80.0%	8.4%
1.9%	1.0%
1.1%	0.4%
2.5%	0.1%
1.5%	7.0%
4.6%	3.3%
Total ~98%	Total ~30%

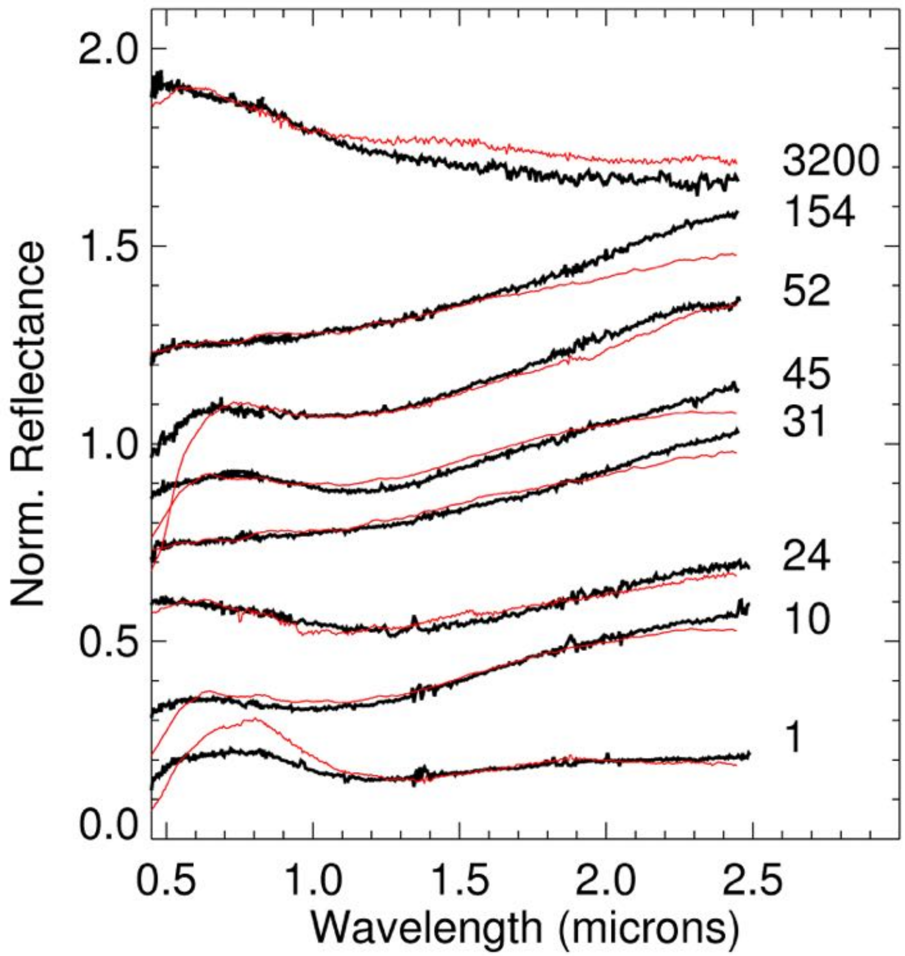
~2/3 of the mass of the asteroid belt seems absent from our meteorite collections

6 asteroid types, representing ~2/3 of the main belt mass (DeMeo & Carry 2013), are presently unconnected to meteorites.

Asteroid spectral properties (DeMeo et al. 2009)



Metamorphosed CI/CM chondrites as analogues of most B, C, Cb, Cg types? (1)



Metamorphosed CI/CM chondrites as analogues of most B, C, Cb, Cg types? (2)

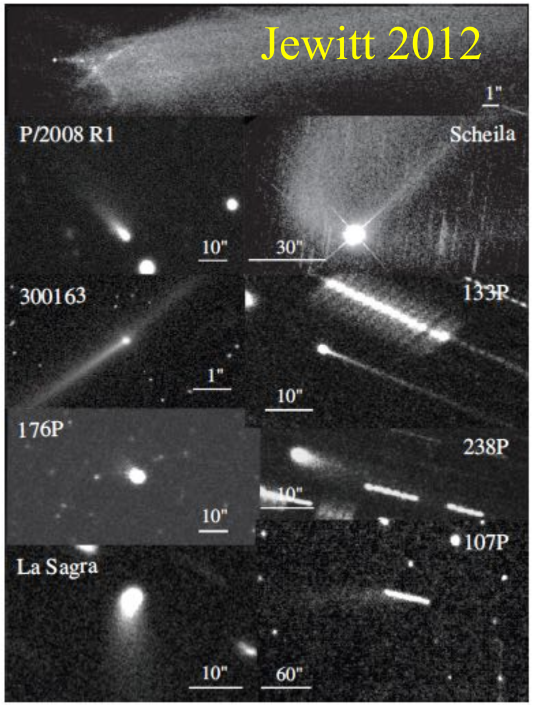
This is very unlikely because:

a)Metamorphosed CI/CM chondrites represent 0.2% of the falls whereas B, C, Cb and Cg type represent ~50% of the mass of the belt
b)Metamorphosed CI/CM chondrites possess a significantly higher density (2.5-3 g/cm^3) than those asteroid types (0.8-1.5 g/cm^3)
c)Metamorphosed CI/CM chondrites possess different spectral properties in the mid-infrared with respect to those asteroid types

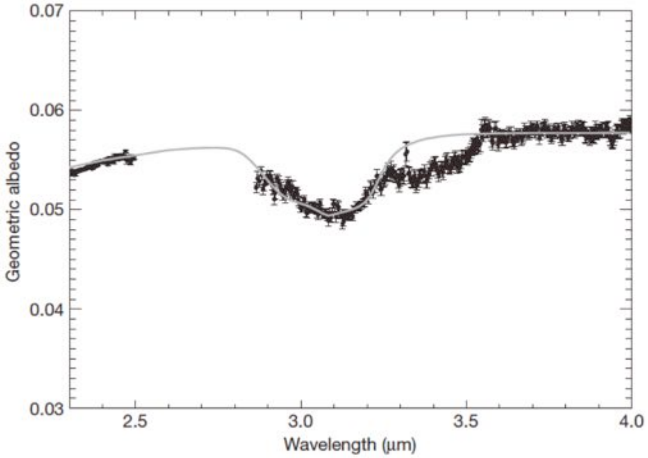
Why are most B, C, Cb, Cg, P and D types unsampled by our meteorite collections?

The lack of samples for these objects within our collections may stem from the fact that they are volatile-rich as implied by their low density (0.8-2 g/cm^3) and their comet-like activity in some cases.

Main belt comets

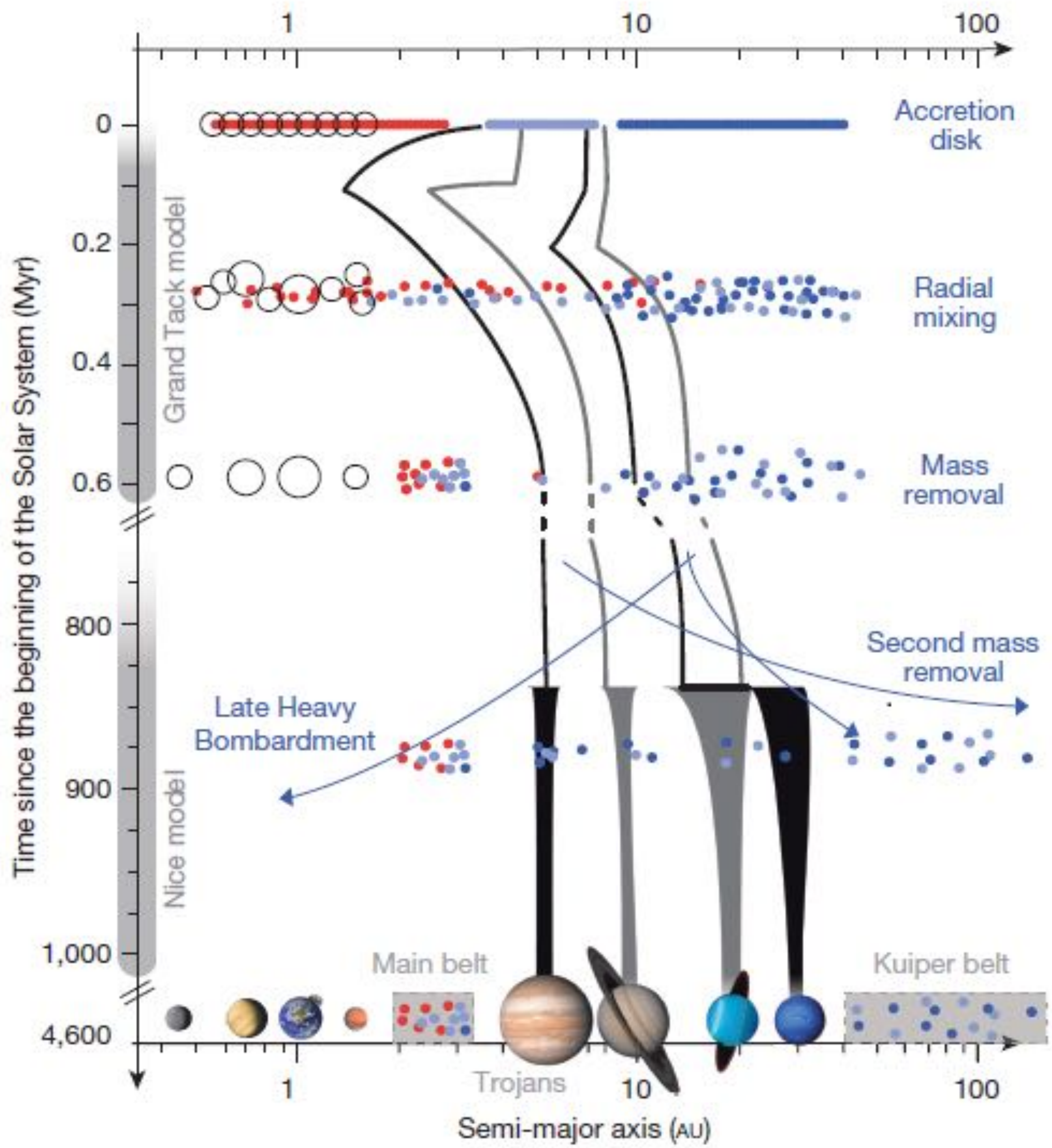


Ceres (Kuppers et al. 2014)



Water ice at the surface of Themis (Campins et al. 2010)

The asteroid belt as a condensed version of the early solar system as the result of giant planet migrations?



Grand Tack model
Walsh+ 2011

Nice model
Morbidelli+ 2005
Tsiganis+ 2005
Gomes+ 2005

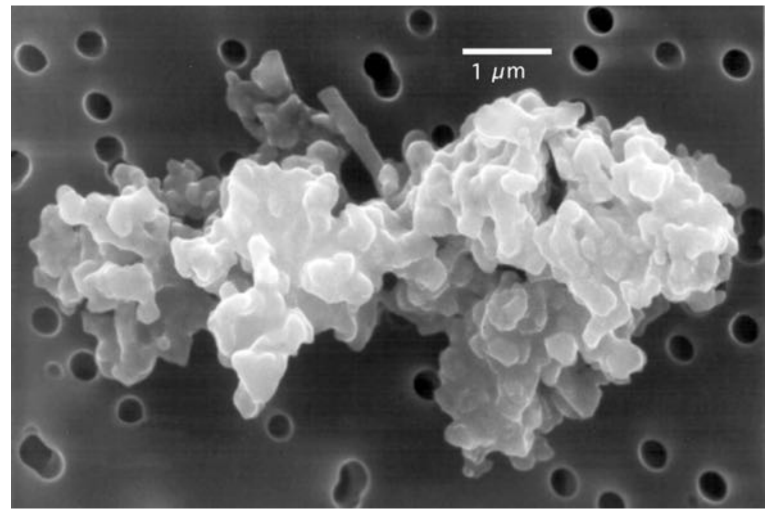
DeMeo & Carry 2014

Because a large fraction of main belt asteroids appears unsampled by our meteorite collections, it seems logical, as a next step, to test a link between these asteroids and the other significant source of extraterrestrial materials, namely ***interplanetary dust particles (IDPs)****.*

Interplanetary dust particles (IDPs): the MAIN class of extraterrestrial materials

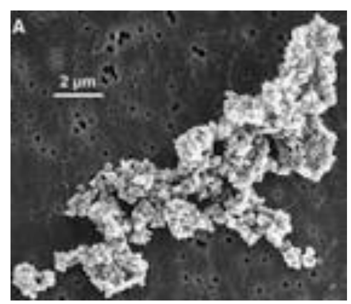
Fluffy aggregates of:

- silicates (amorphous and crystalline)
- Sulfides
- Iron-nickel
- Carbonaceous matrix



3 classes:

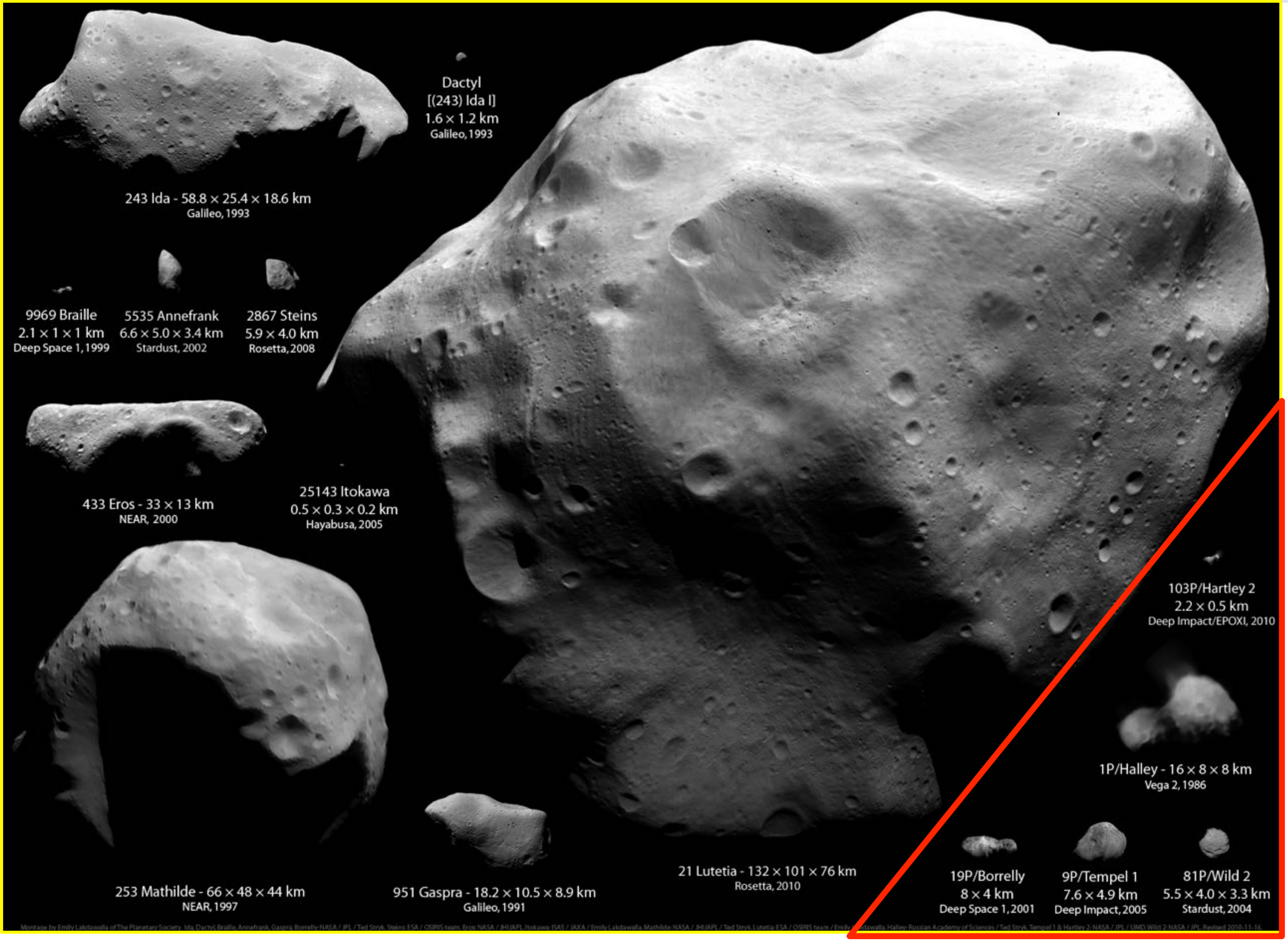
- Pyroxene-rich
- Olivine-rich
- Phyllosilicate-rich



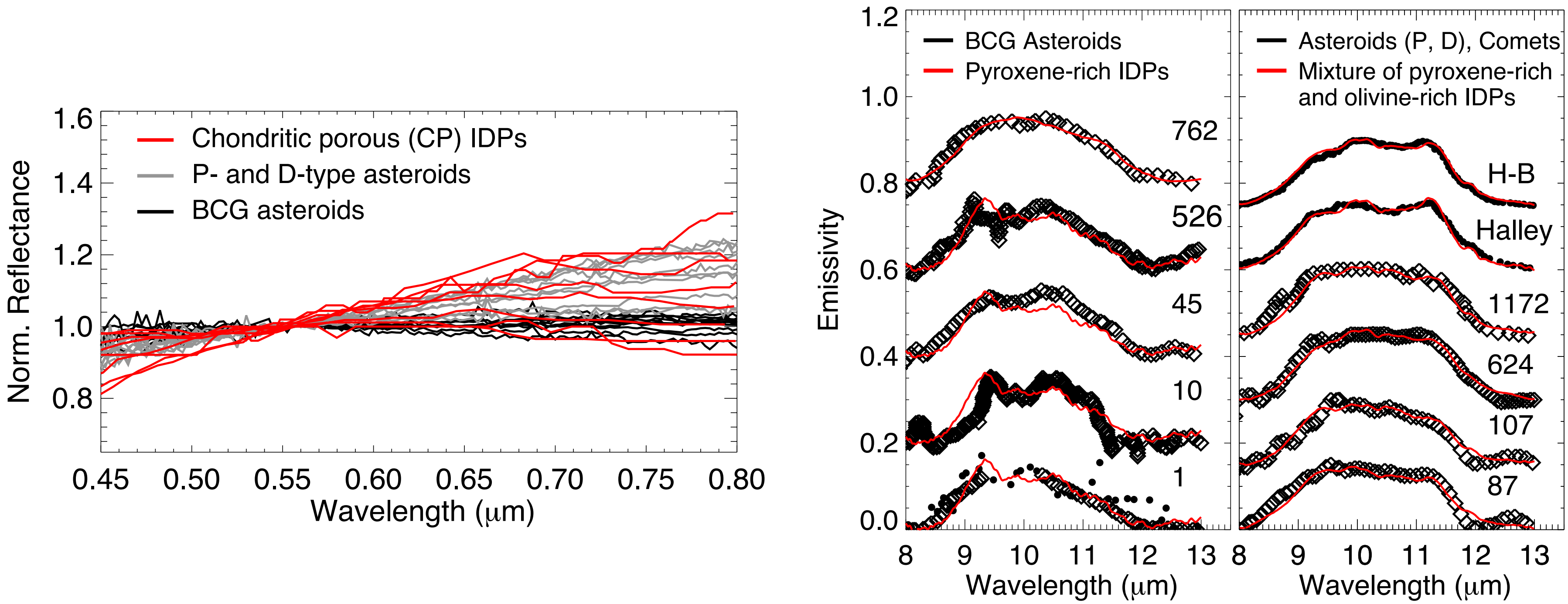
IDPs differ from meteorites in being:

- Smaller (< 2 mm)
- More plentiful (~40,000 tons/year accreted by the Earth)
- Different in texture and composition

Parent bodies of IDPs: asteroids? comets?

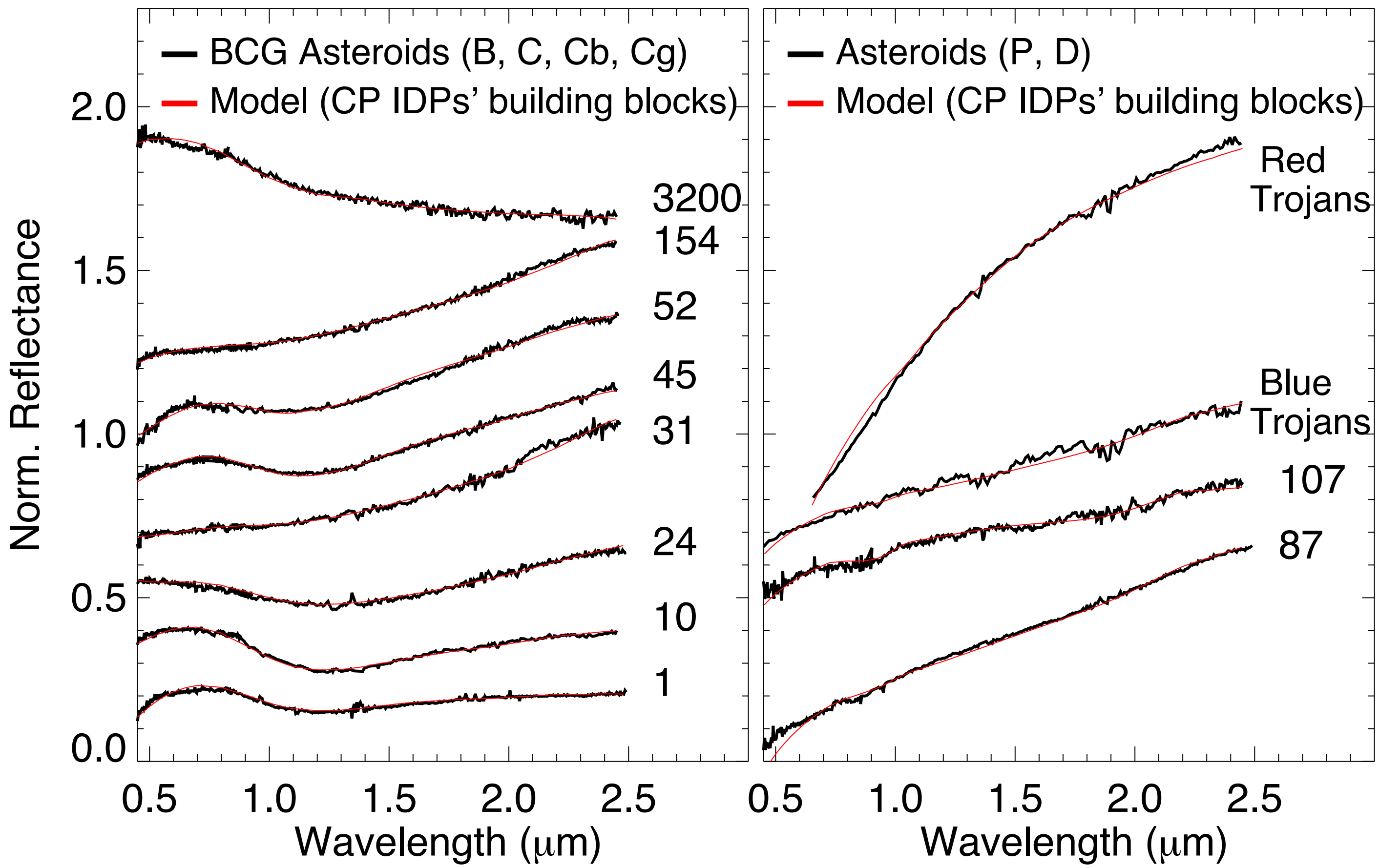


IDPs as analogues of B, C, Cb, Cg, P and D types



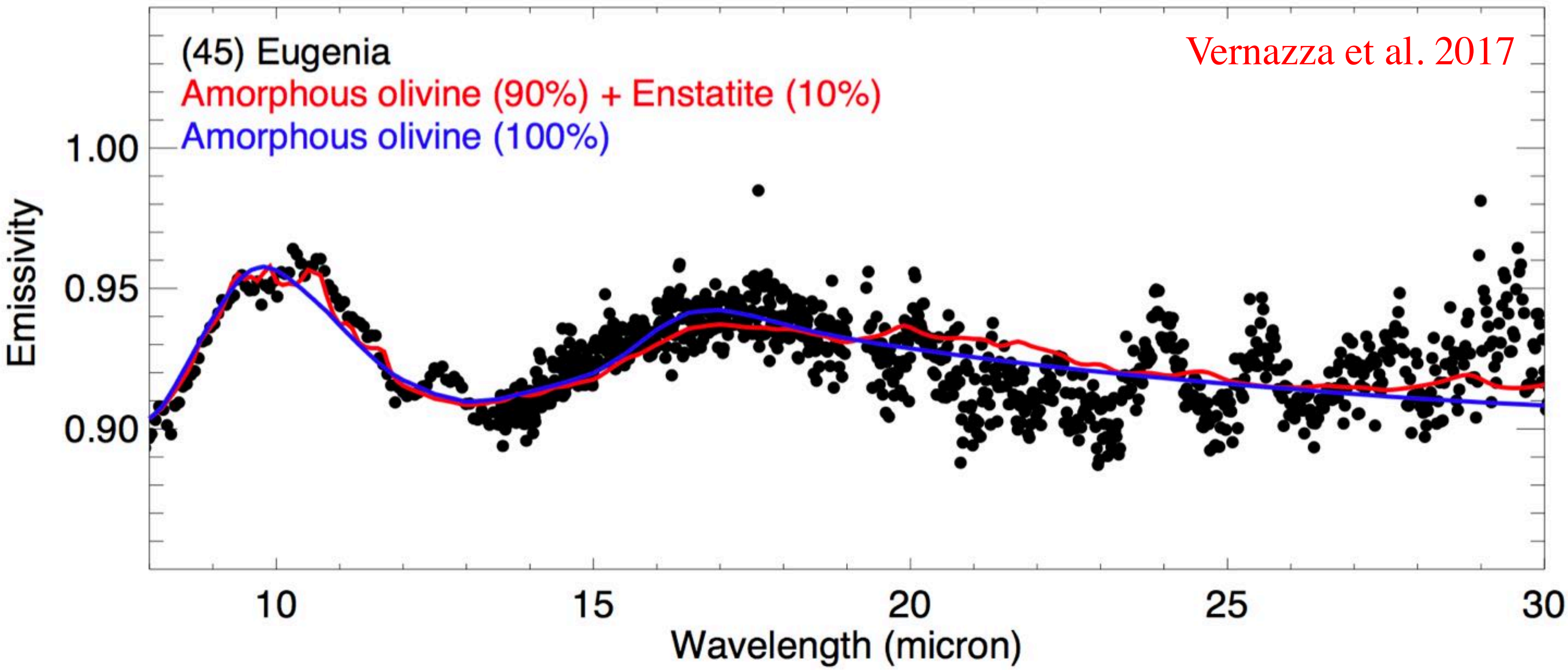
Vernazza et al. 2015

IDP-like surface composition for B, C, Cb, Cg, P and D types



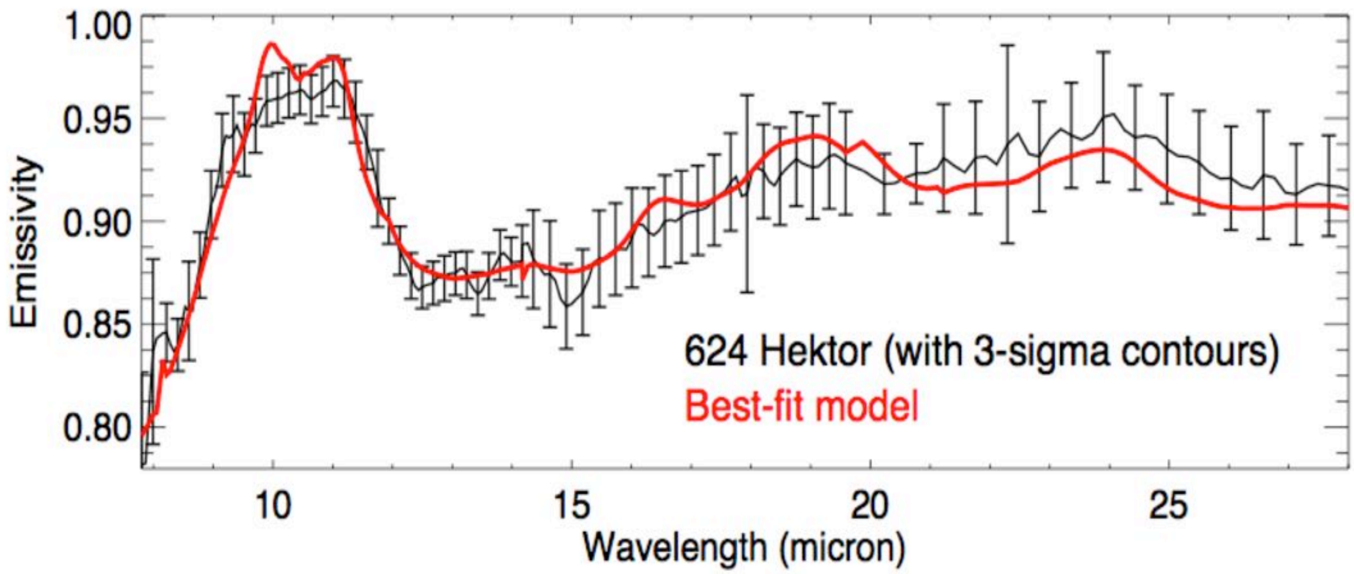
Vernazza et al. 2015

C-types: Surface composition dominated by crystalline pyroxene and amorphous silicates



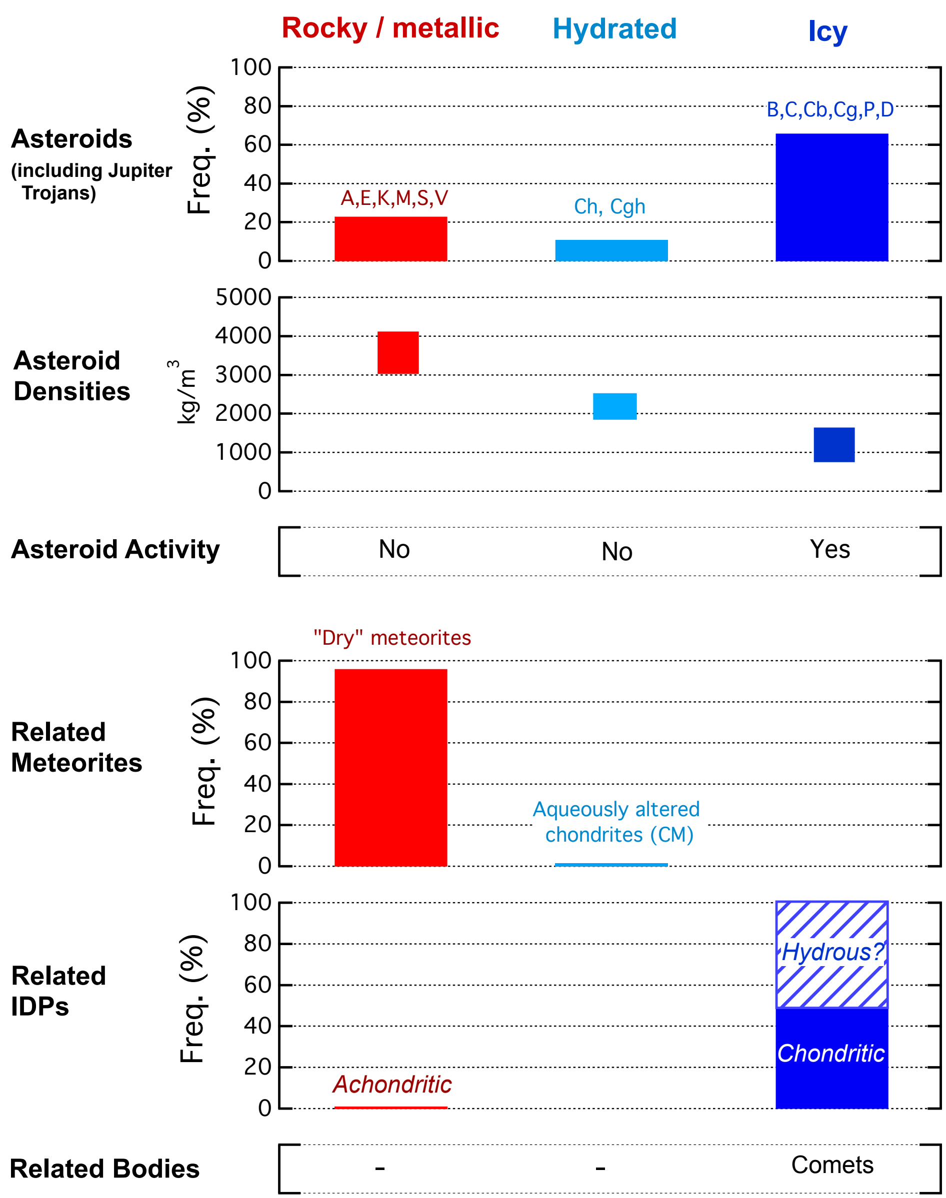
Jupiter Trojans (D-types): Surface composition dominated by crystalline olivine and amorphous silicates

Vernazza et al. 2012



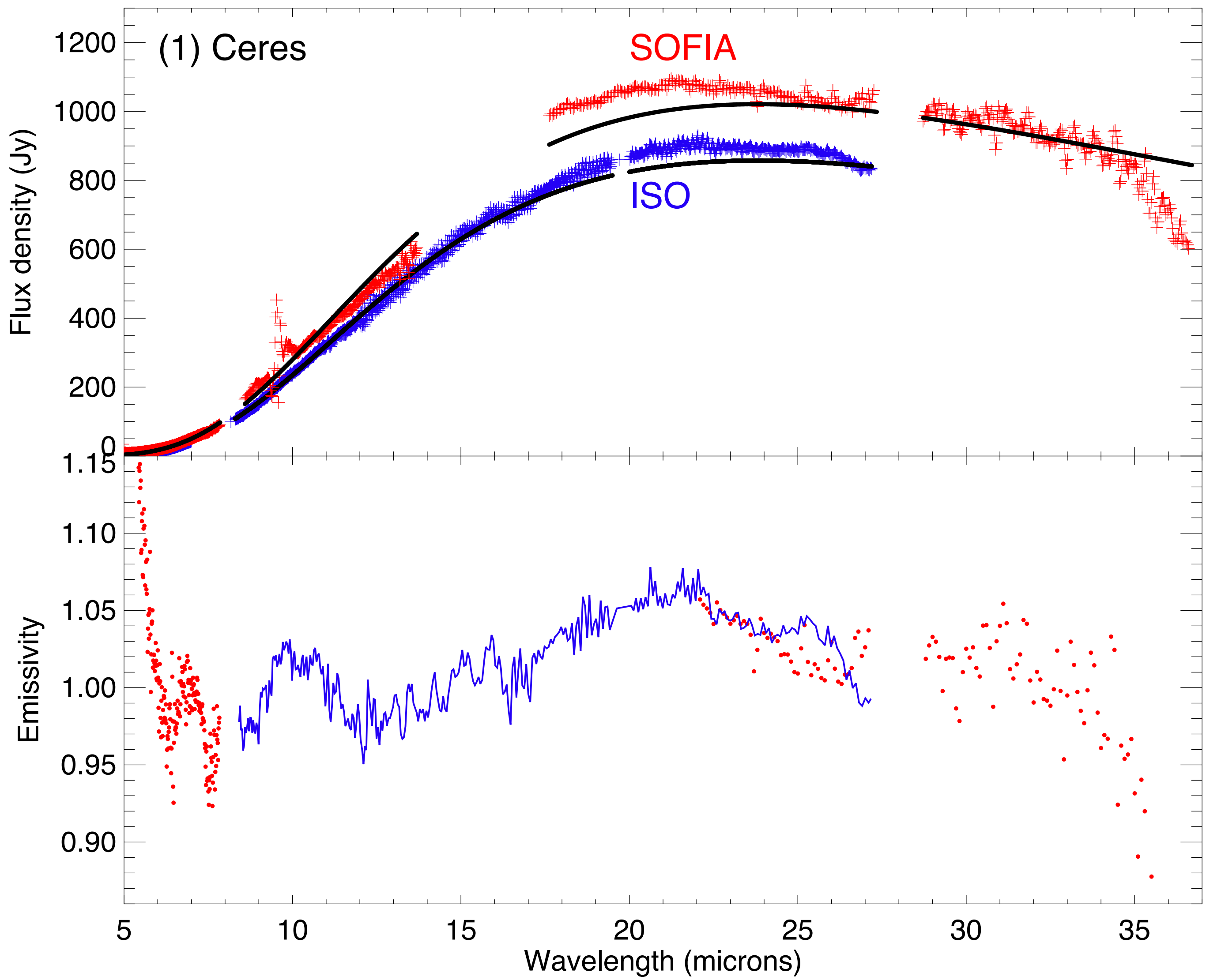
Mineral species	Abundance (in mass)	Abundance of the silicates (in mass)
Silica (SiO_2)	0.00	-
Crystalline olivine	0.68	22.74
Crystalline pyroxene	0.05	1.67
Amorphous olivine [(MgFe) SiO_4, Mg_2SiO_4]	2.19	73.25
Amorphous pyroxene [$MgSiO_3$, (MgFe)Si_2O_6]	0.07	2.34
Amorphous carbon	97.01	-

Summary figure

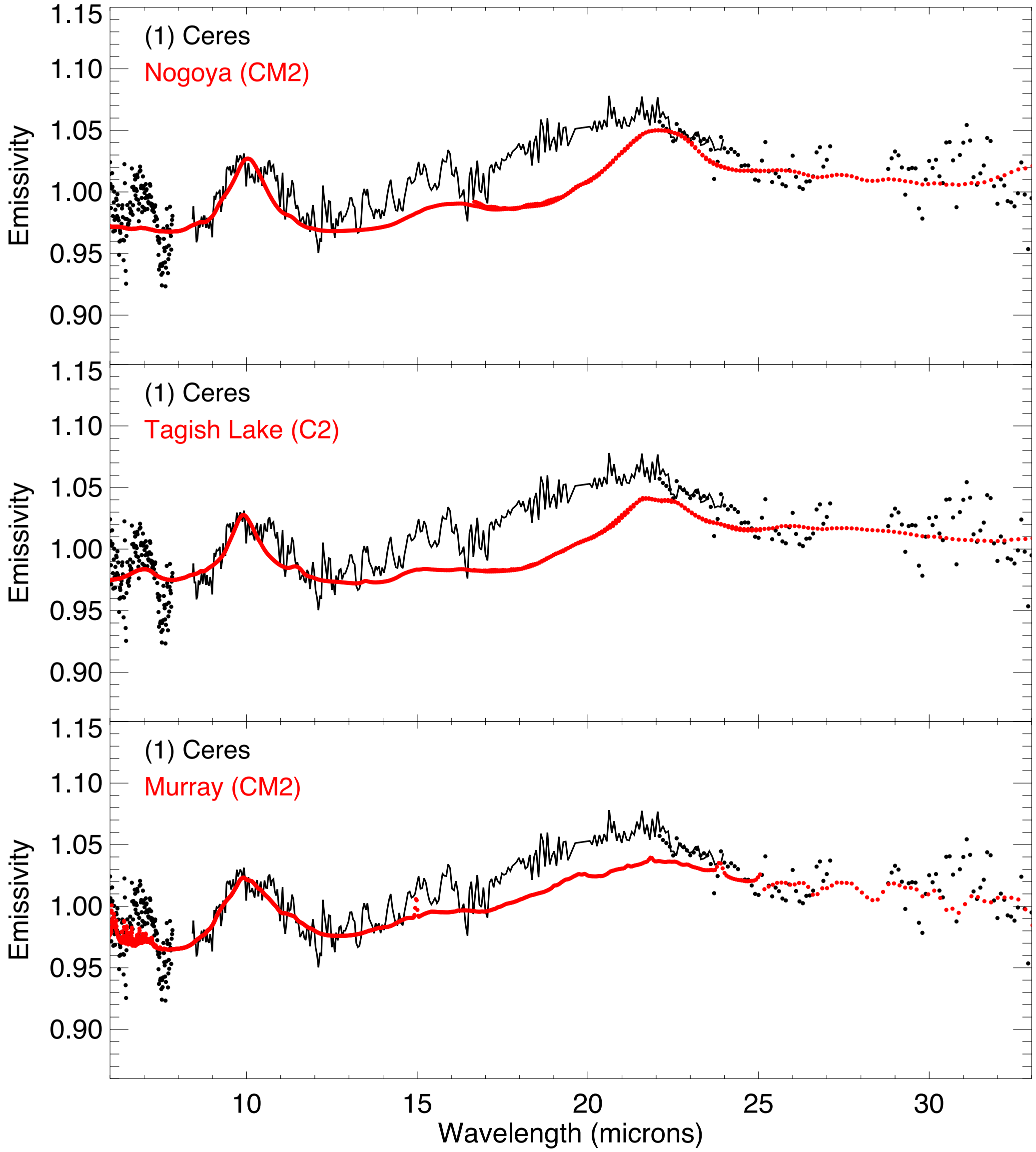


Vernazza et al. 2015

The case of Ceres

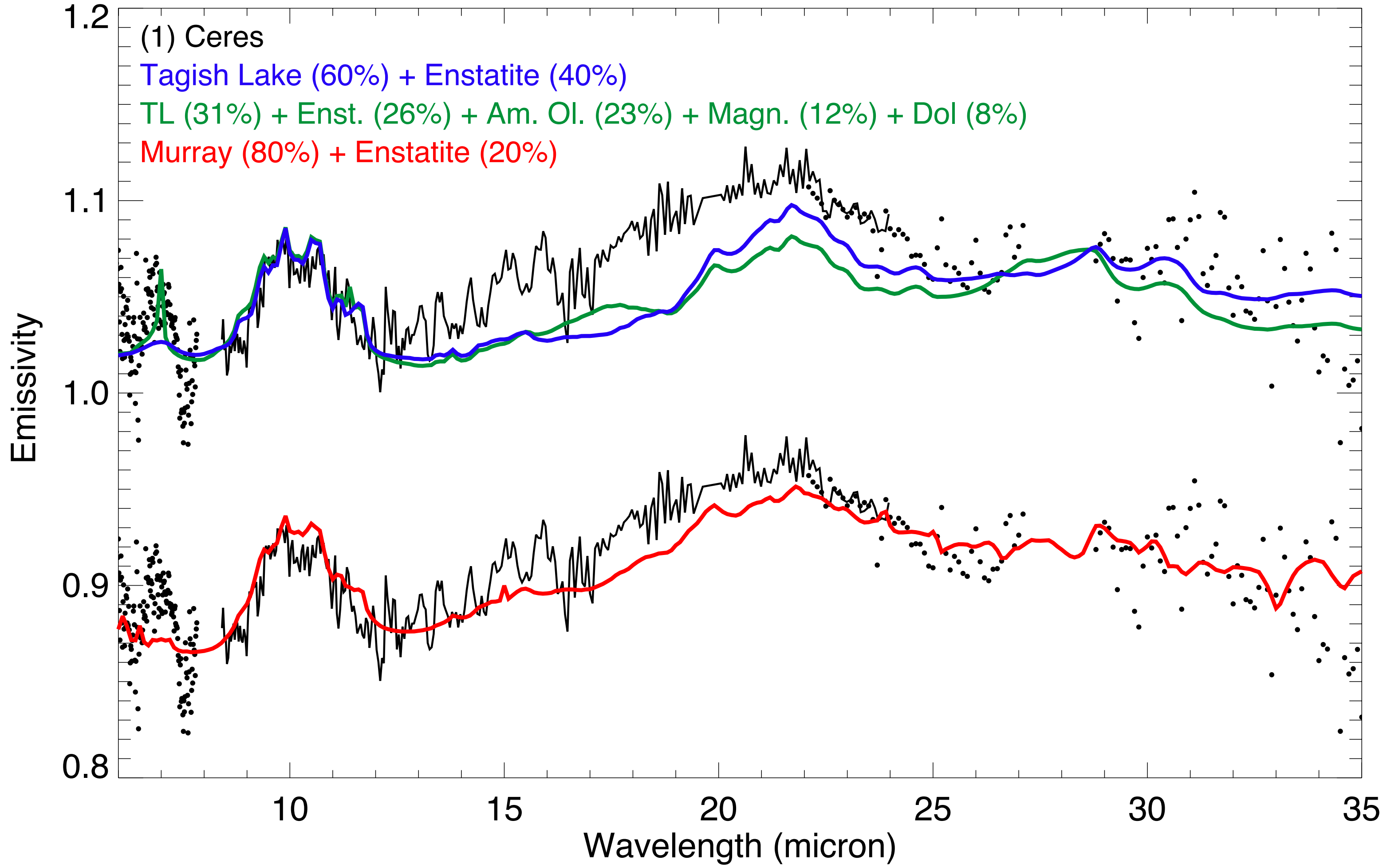


Comparison between Ceres and hydrated CC meteorites: Something is missing!



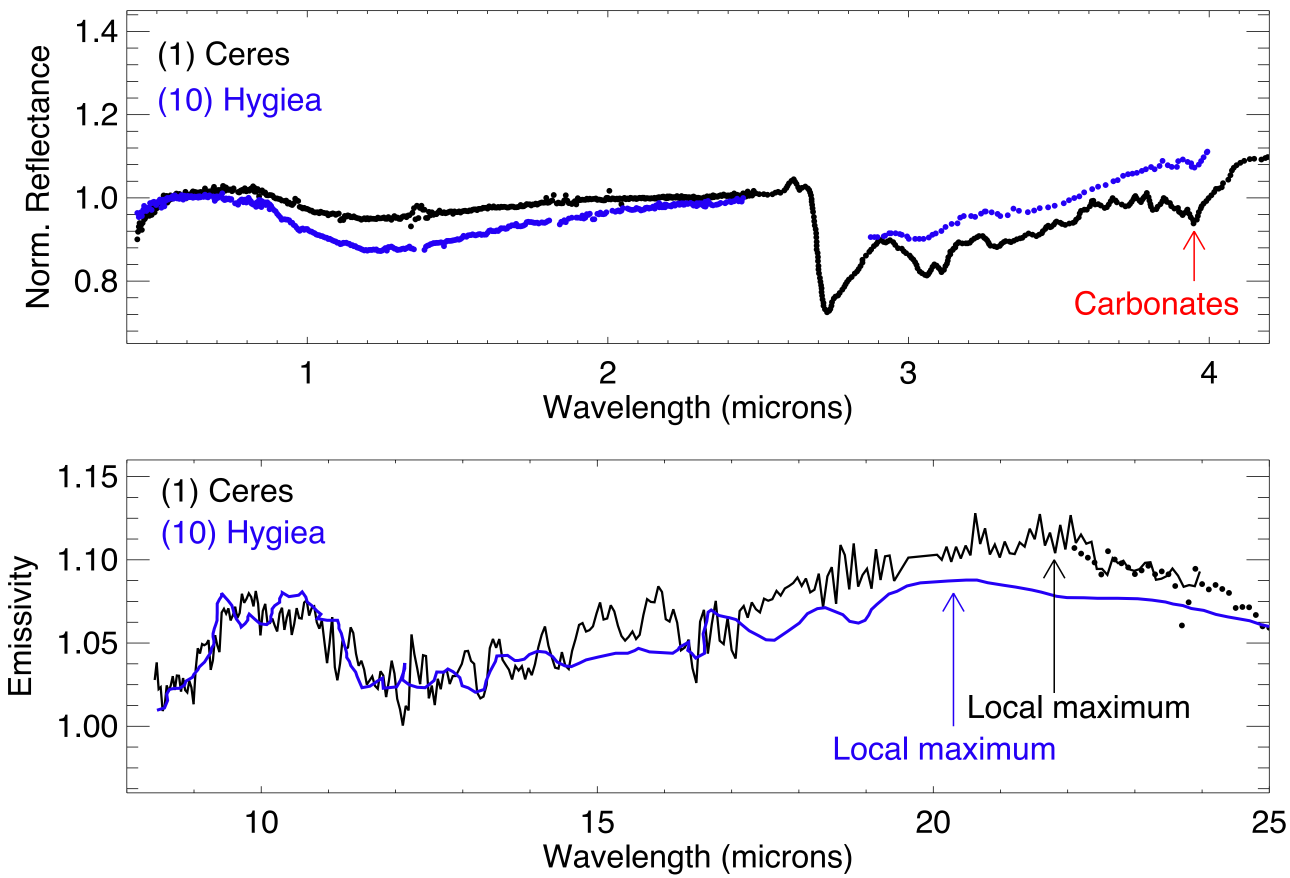
Vernazza et al. 2017

Ceres: Surface composition dominated by **crystalline pyroxene**, hydrous silicates and carbonates

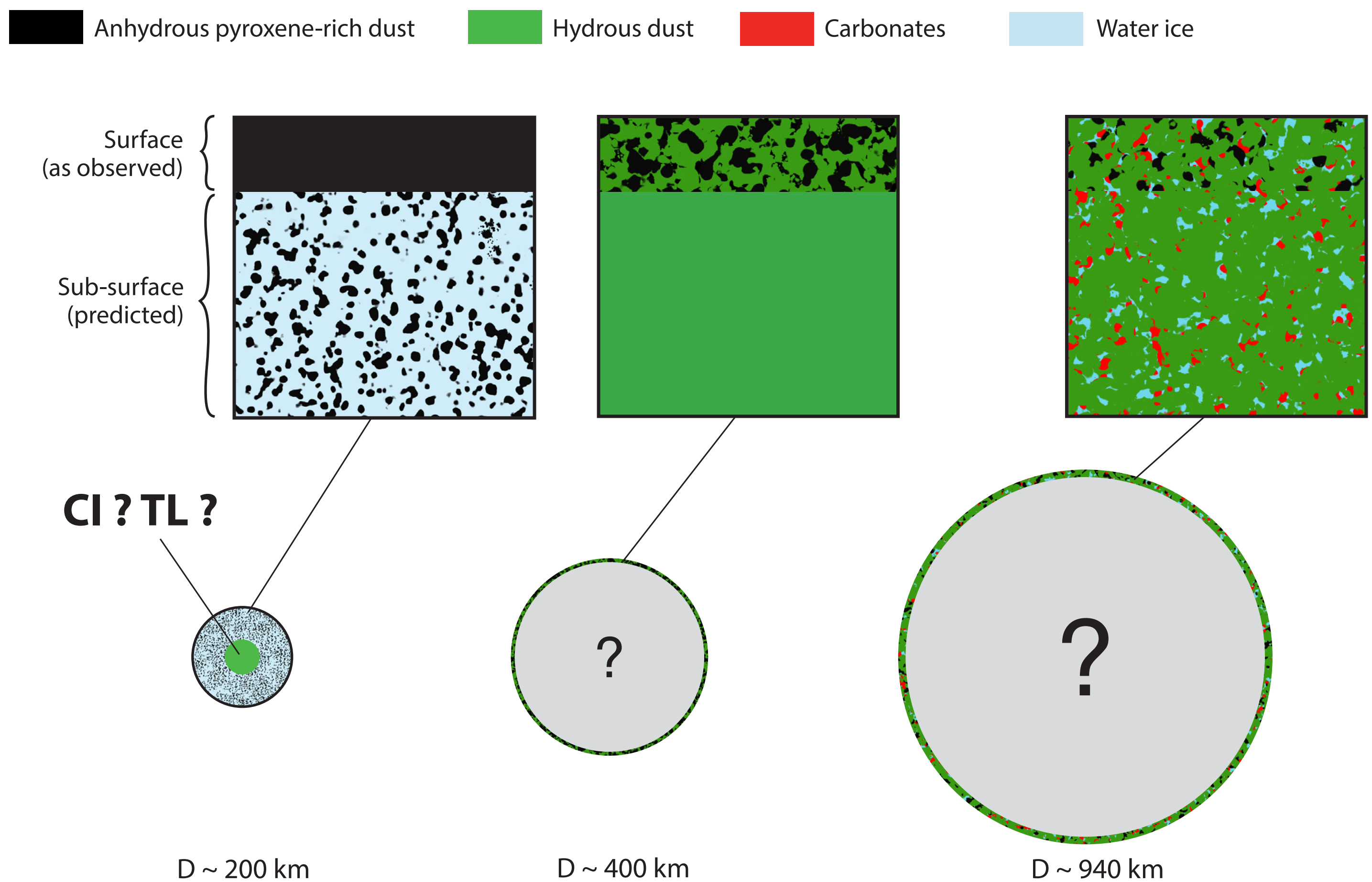


Vernazza et al. 2017

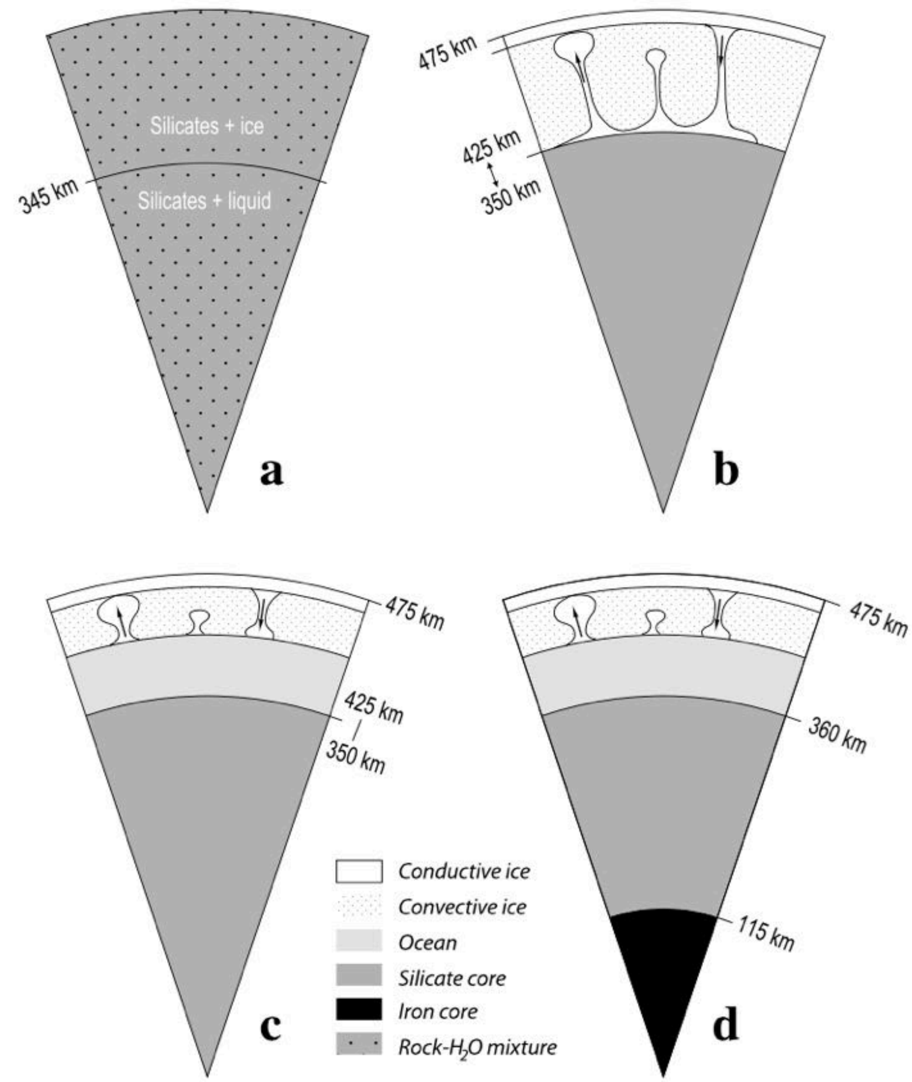
Ceres and Hygiea: similarities and differences



Enstatite at the surface of Ceres: Endogenous or exogenous? Result of thermal evolution or impact contamination?



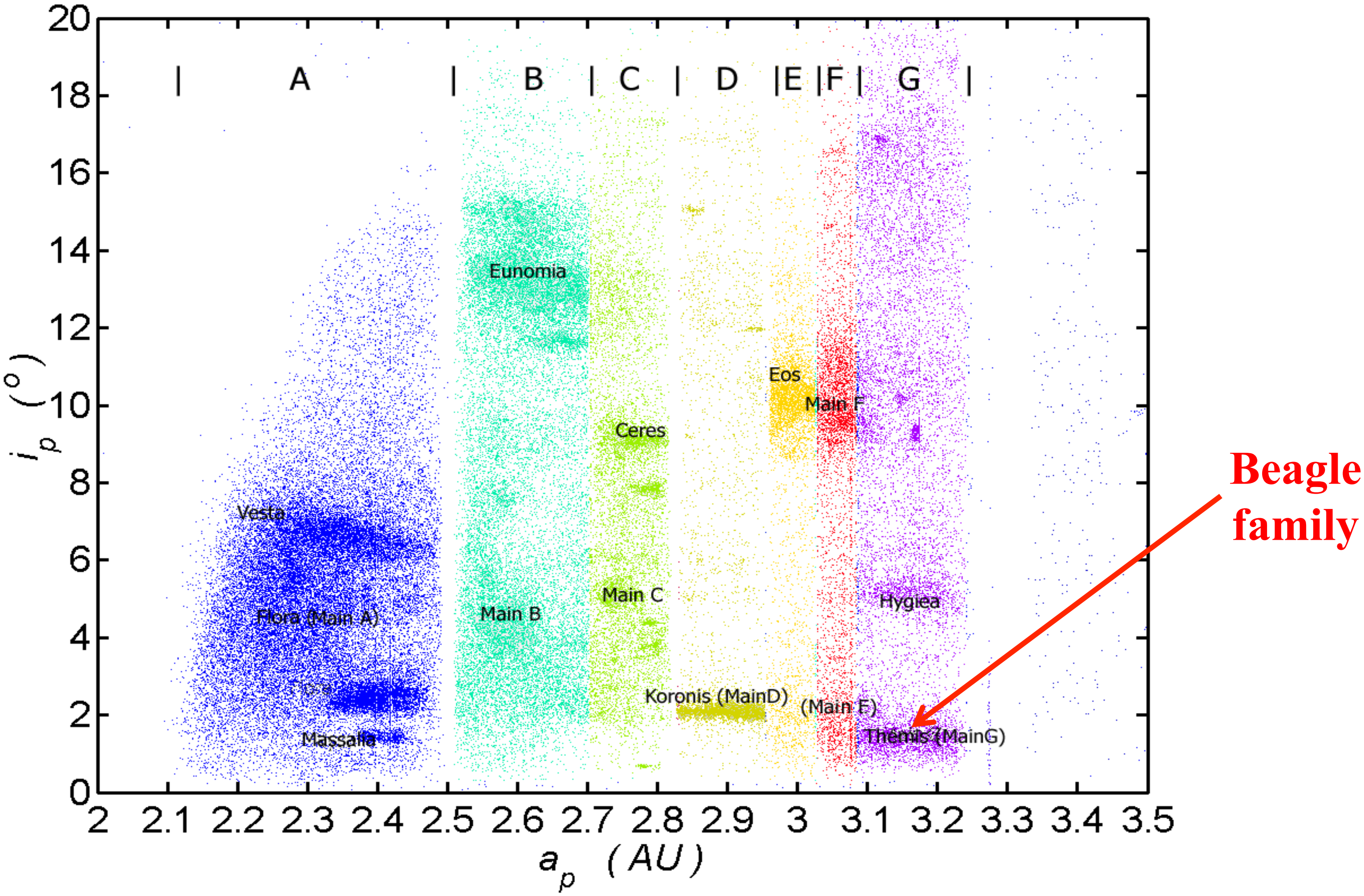
Enstatite as an endogenous component: Results of thermal evolution models



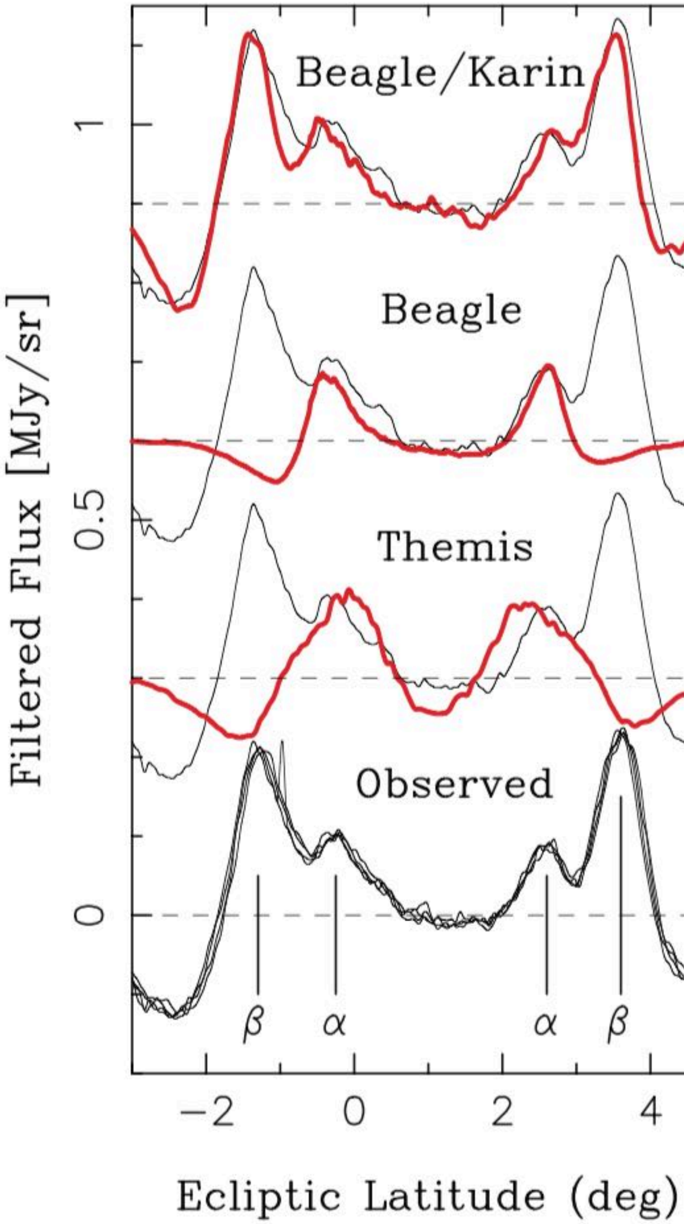
McCord and Sotin 2005

Enstatite as an exogenous component: The case of the Beagle family

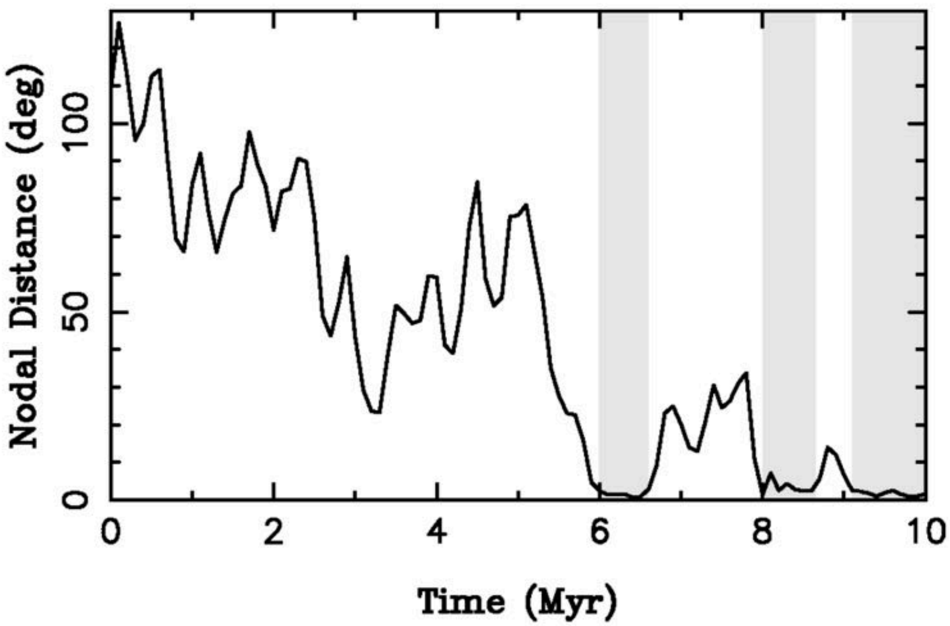
The Beagle family belongs to the Themis family. Marsset et al. (2016) showed that the latter has a composition similar to pyroxene-rich IDPs.



Enstatite as an exogenous component:
The case of the Beagle family



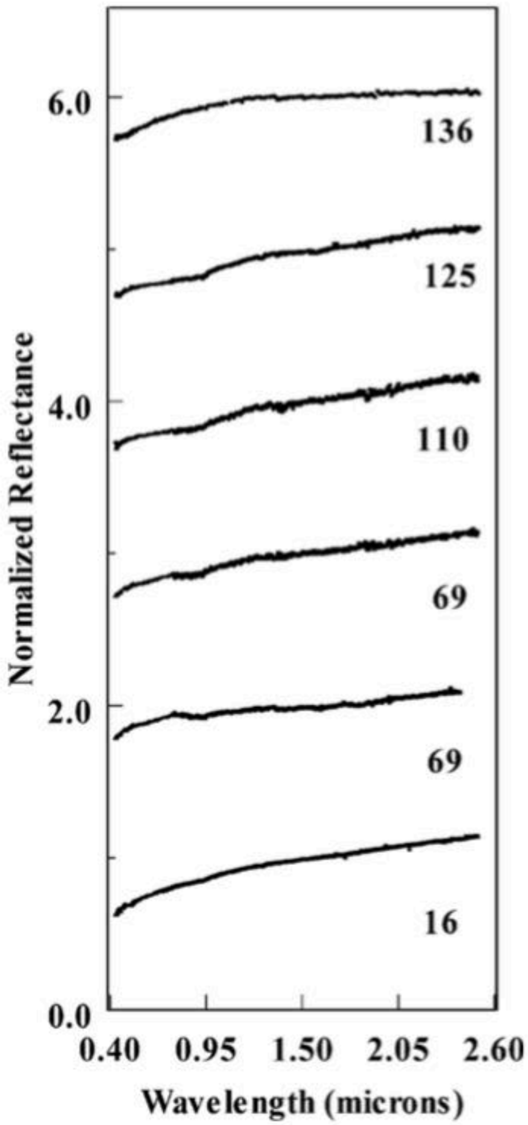
3 possible ages for the Beagle family



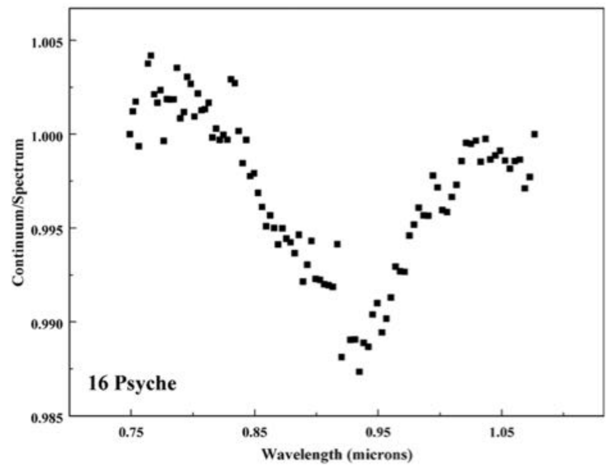
Nesvorny et al. 2008

Other cases of contamination? The case of M-types

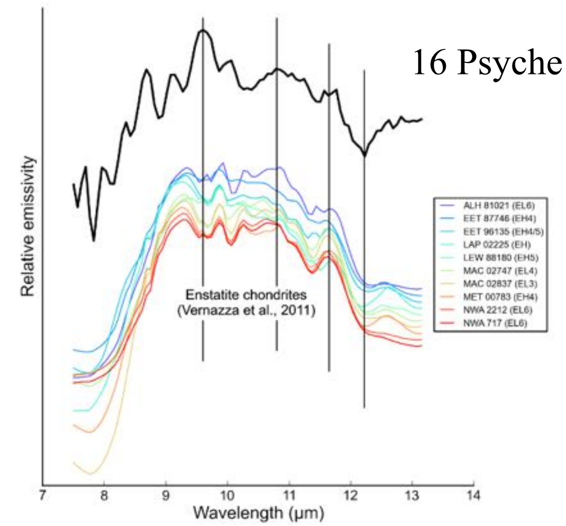
Hardersen et al. 2005



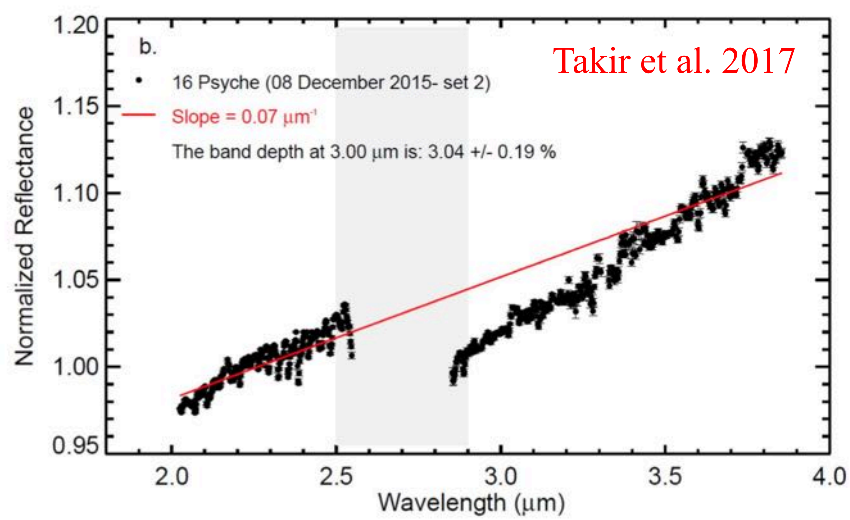
Hardersen et al. 2005



Landsman et al. 2017



Takir et al. 2017



Conclusions / Open questions

1. The majority (~2/3 of the mass) of main belt asteroids appear unsampled by our meteorite collections. Instead, IDPs appear as plausible analogs for these objects.

2. Ceres' surface = complex mixture of a) enstatite, b) ammoniated phyllosilicates, c) carbonates and d) water ice

3. What was the initial composition of Ceres? Is it connected to C-types or rather to P/D-types? Could Orcus and Ceres be twins?

4. Contamination of asteroid surfaces by IDPs: a reality? a common process?