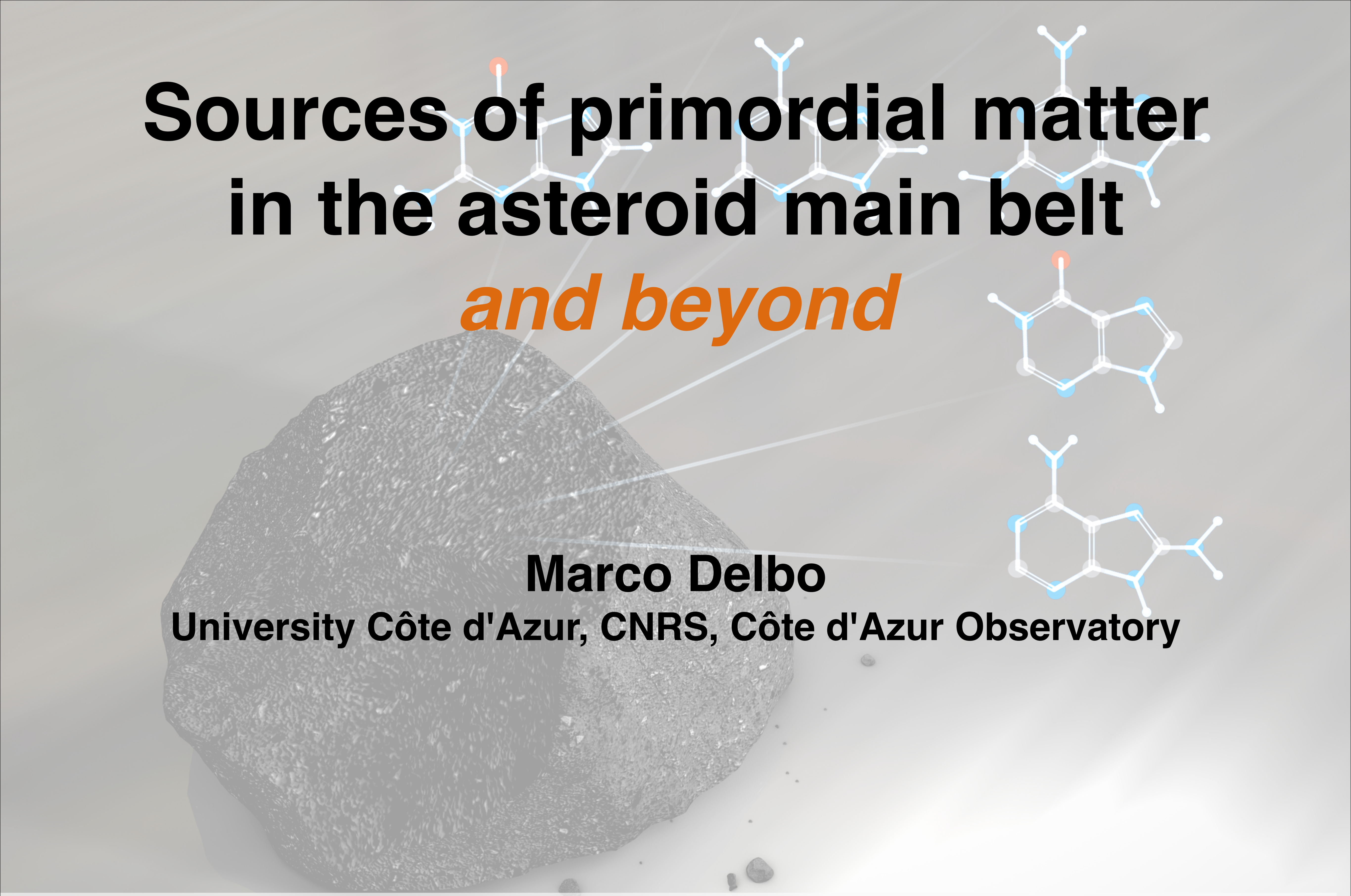


Sources of primordial matter in the asteroid main belt *and beyond*

Marco Delbo

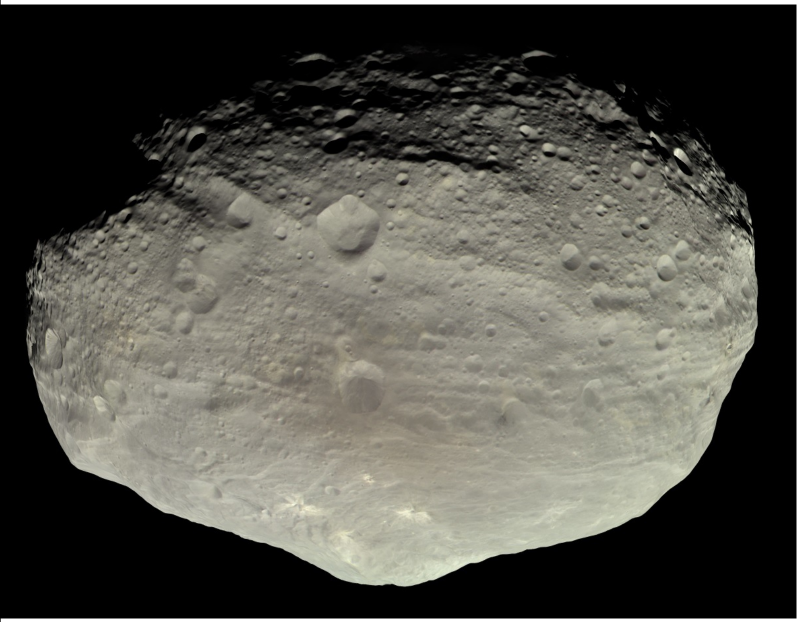
University Côte d'Azur, CNRS, Côte d'Azur Observatory

51st

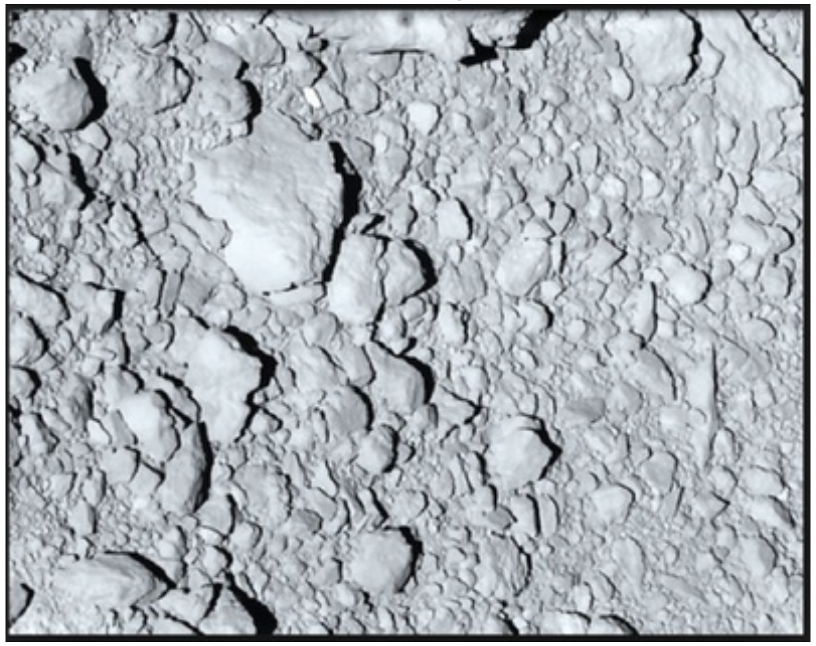
Extreme habitable worlds

The big questions

(4) Vesta from DAWN



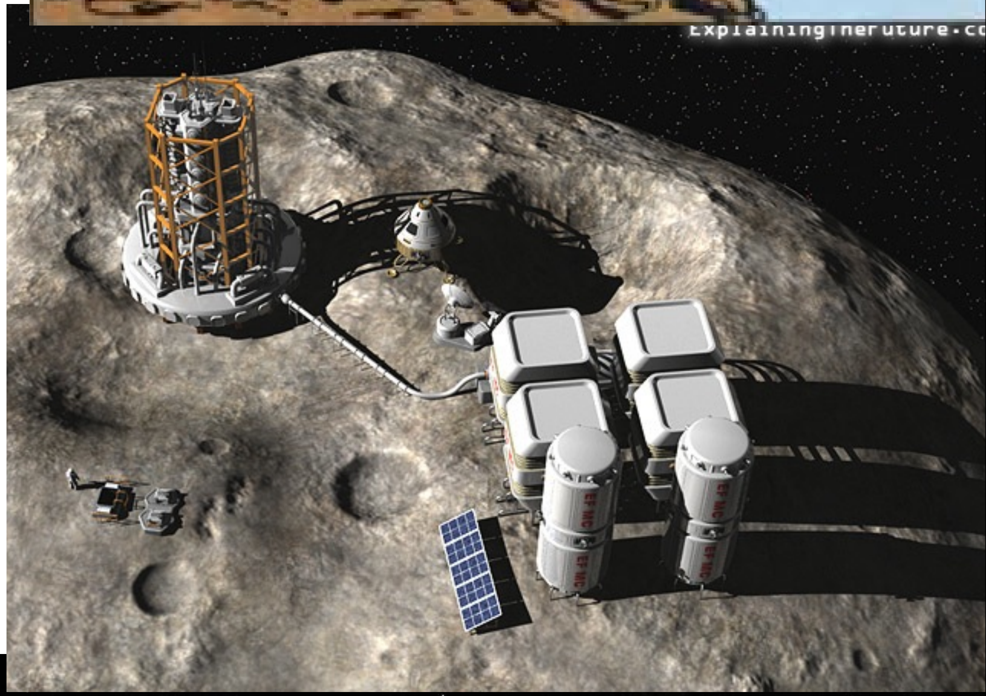
The soil (regolith) of (25143) Itokawa from JAXA's Hayabusa

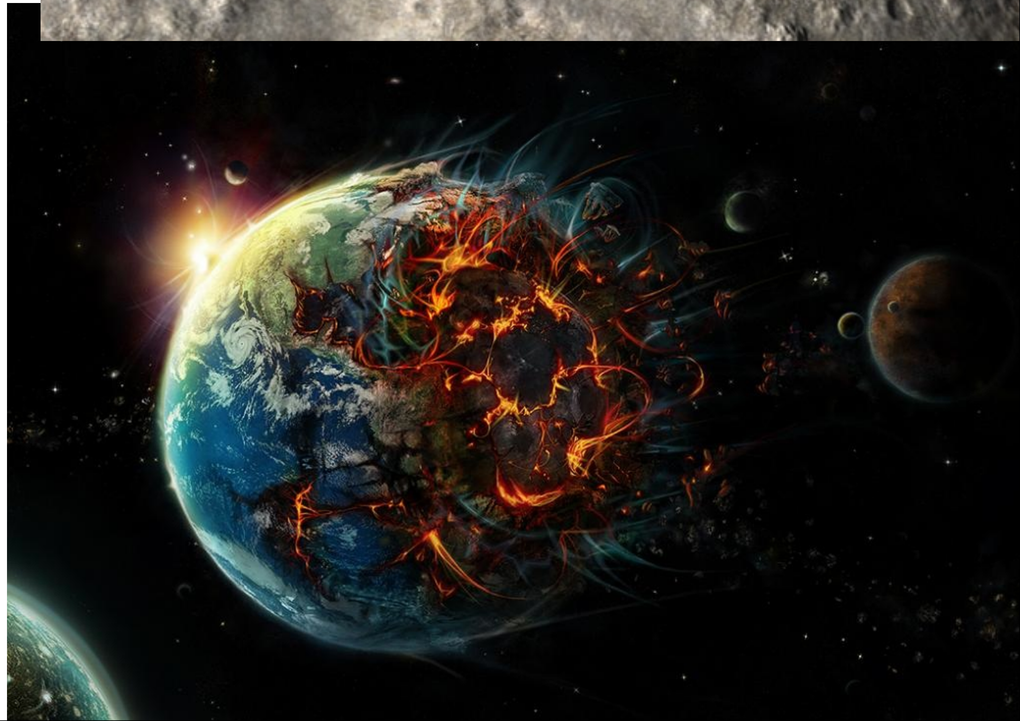


Is any of these small worlds (extremely) habitable ?
Or was it in the past ?
And under which conditions ?

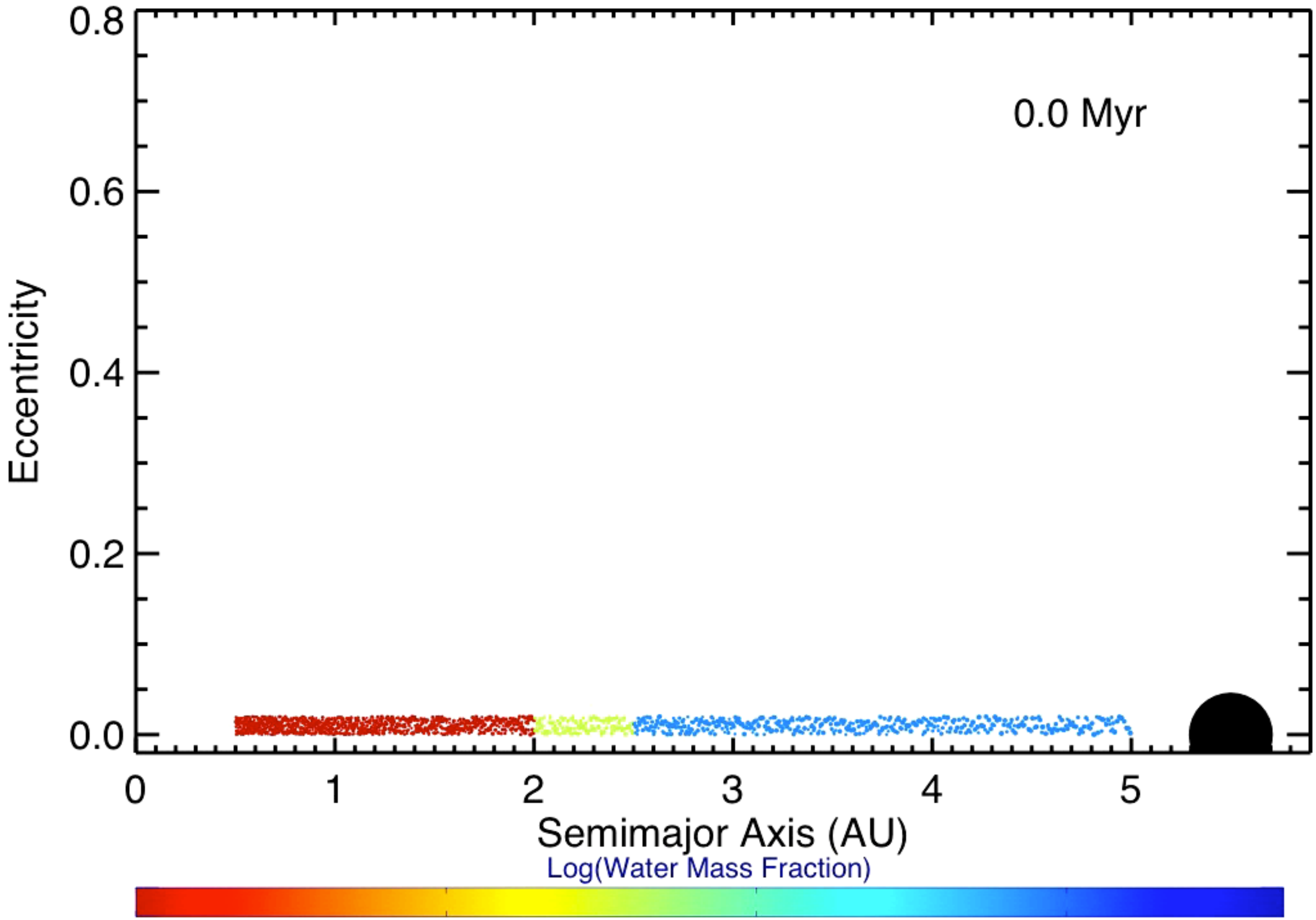
and
Can we make them habitable ?

Or
Did small bodies contribute to make other places habitable?



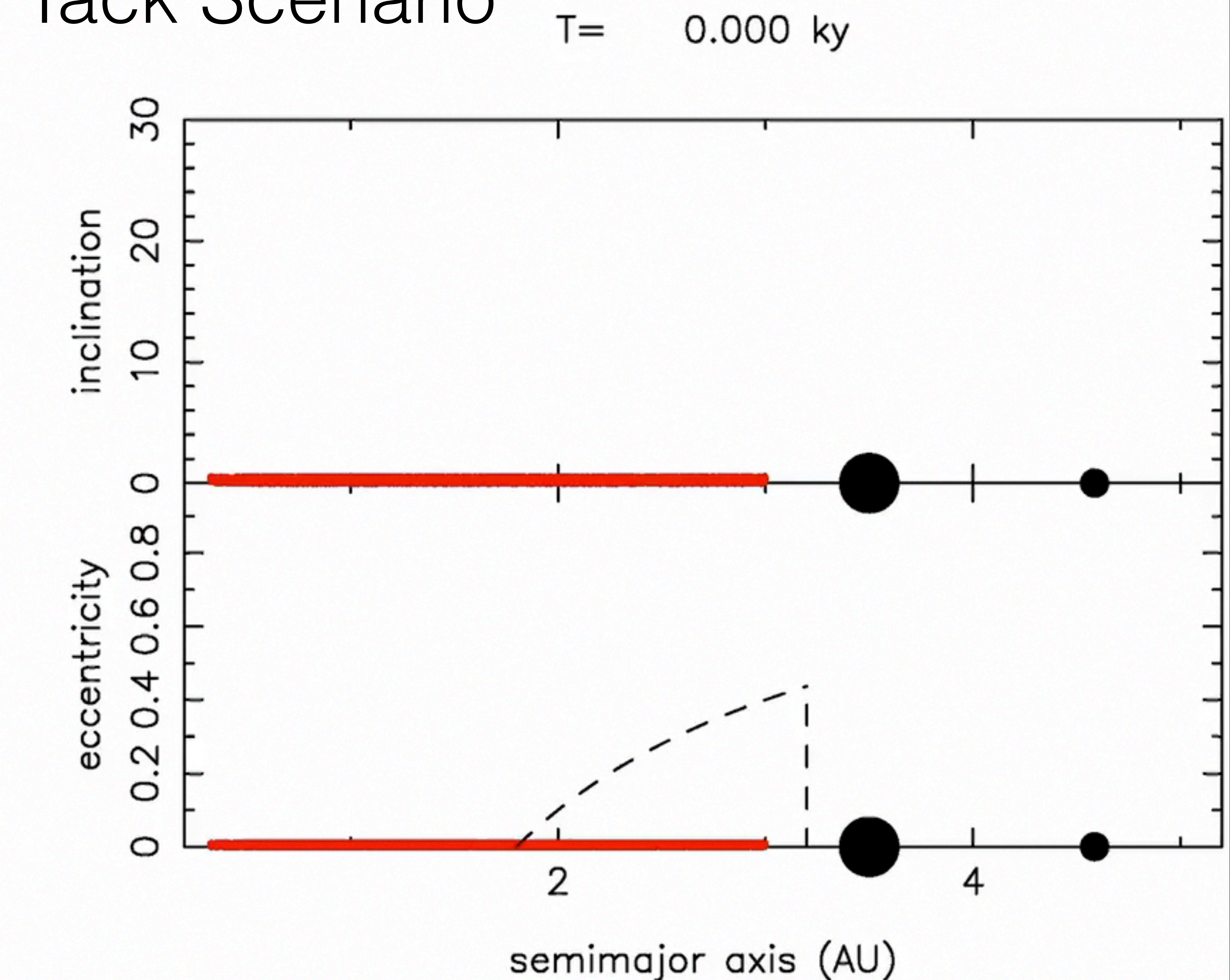


Water and organics delivery to terrestrial planets by planetesimals

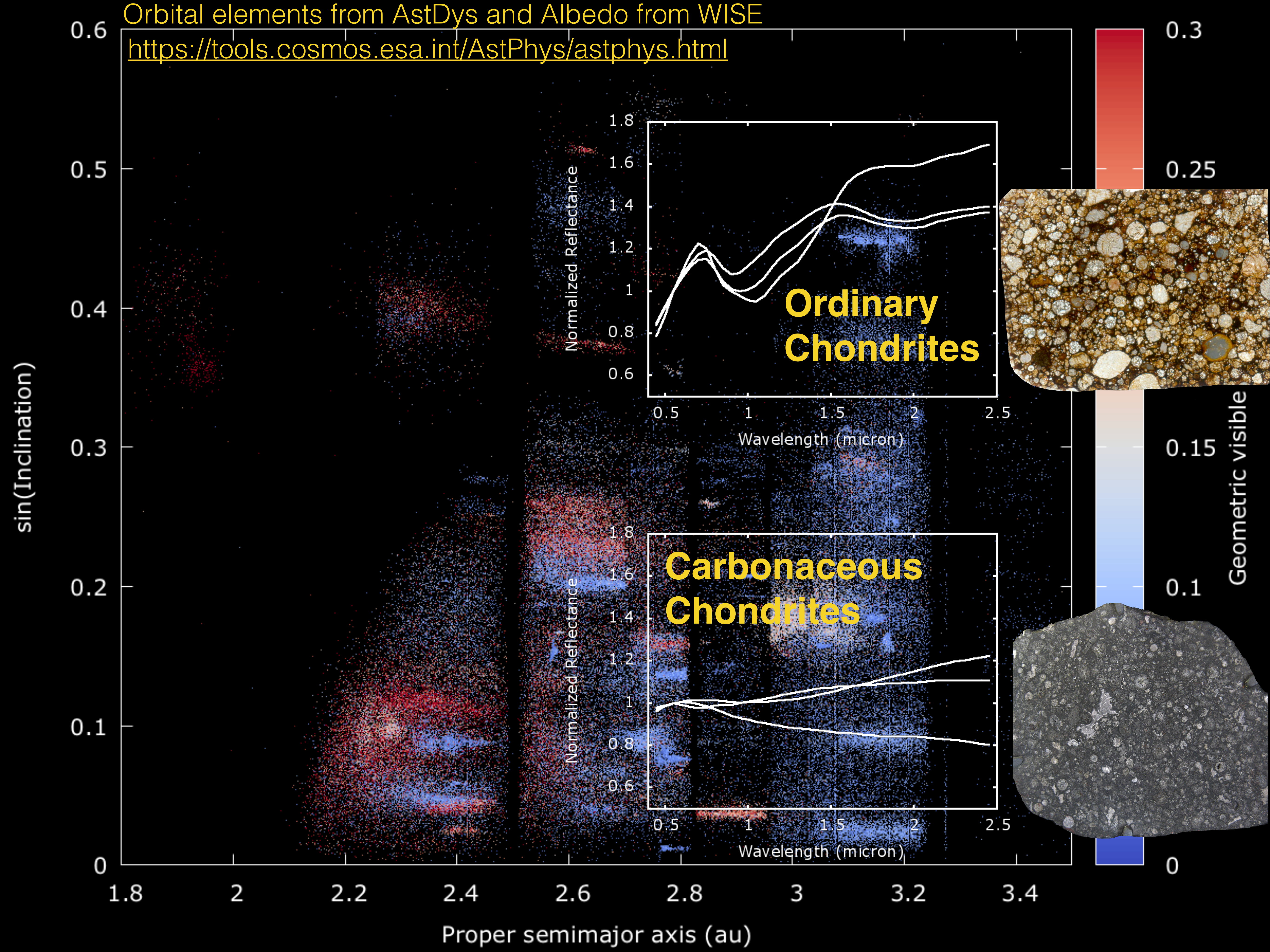


Raymond, Quinn & Lunine (2006)

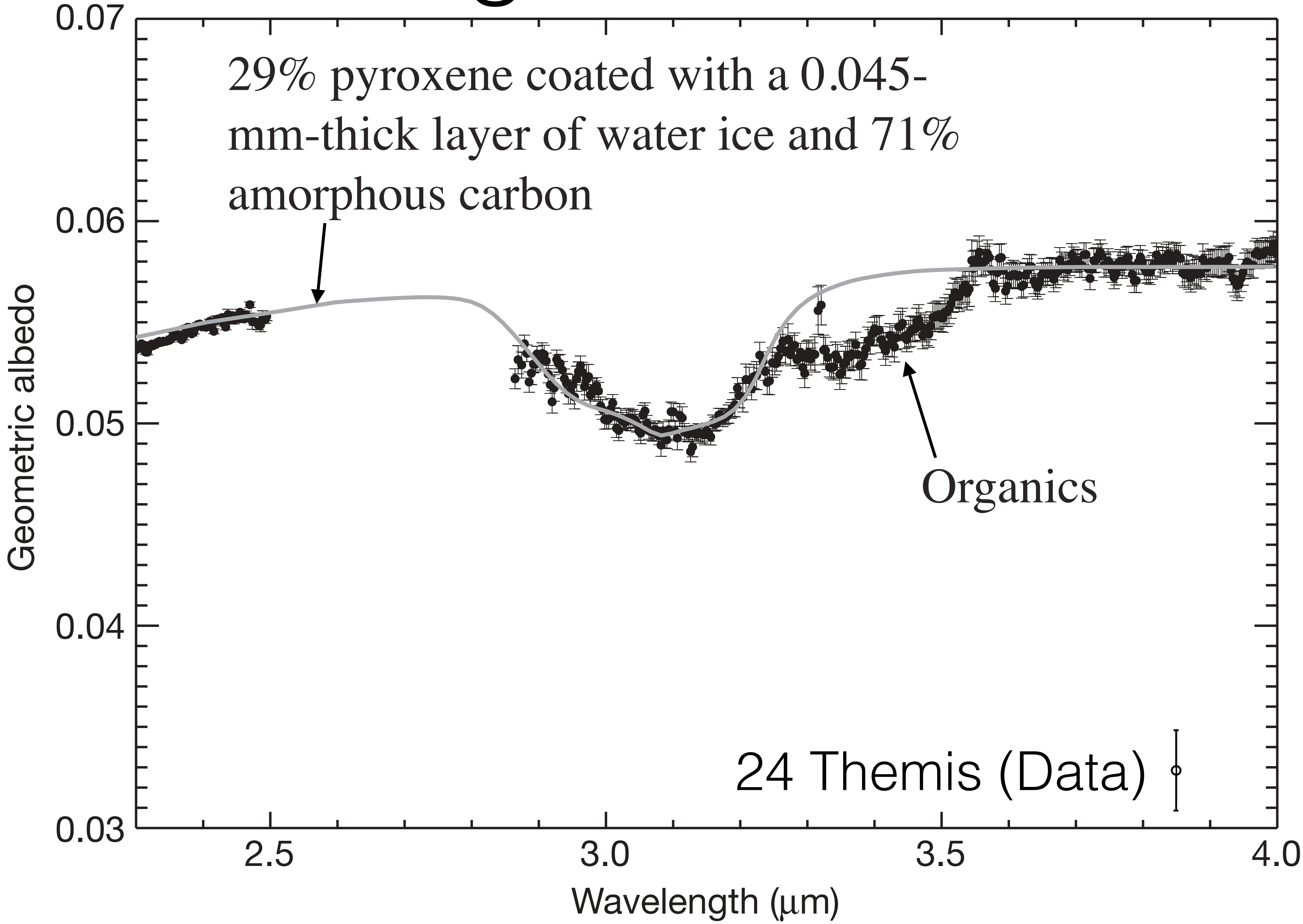
Grand Tack Scenario



Walsh+ 2011. Simulation by S. Raymond

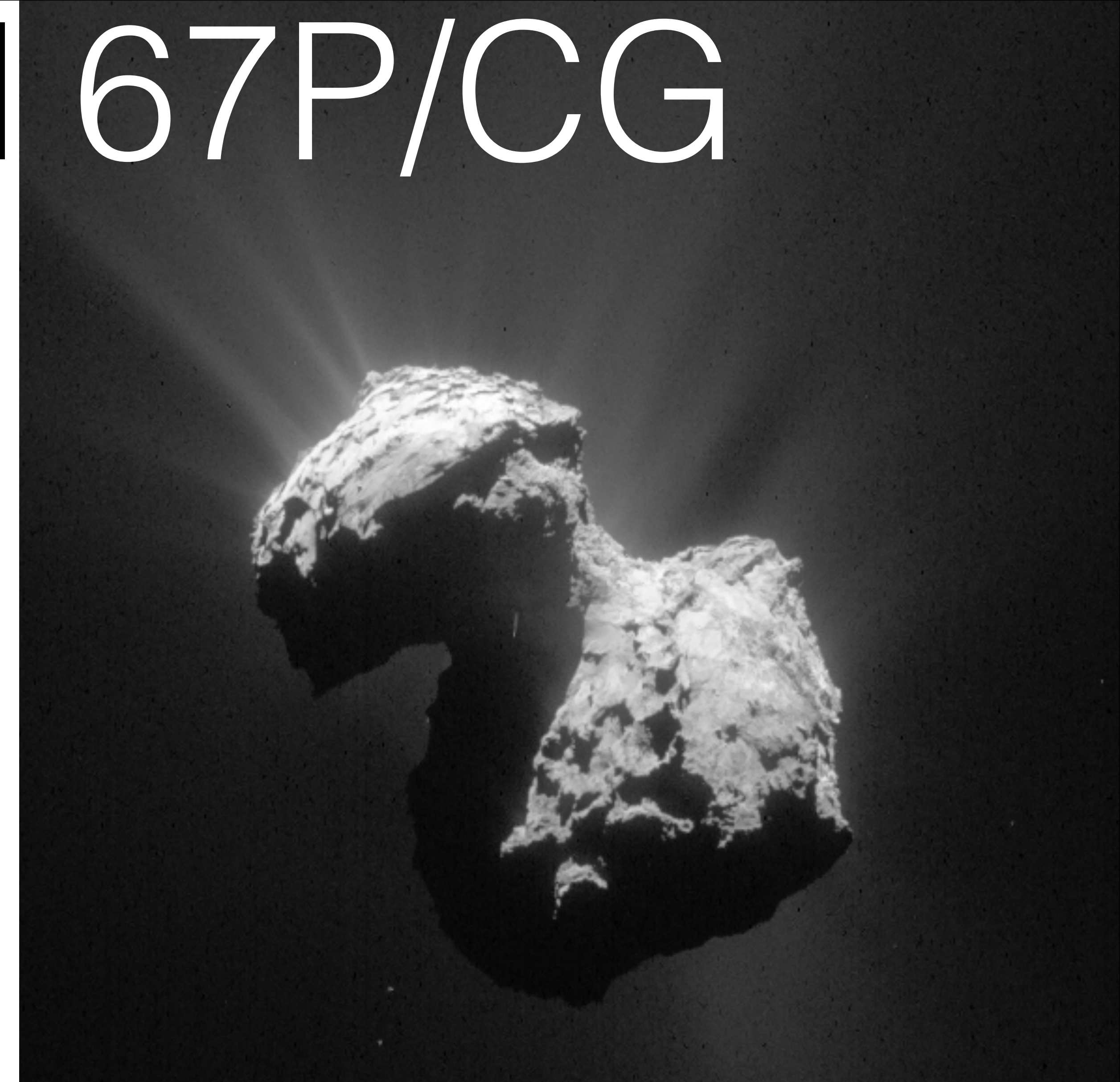

Orbital elements from AstDys and Albedo from WISE
https://tools.cosmos.esa.int/AstPhys/astphys.html
Ordinary Chondrites
Carbonaceous Chondrites
Normalized Reflectance
Wavelength (micron)
sin(Inclination)
Proper semimajor axis (au)
Geometric visible
0.6
0.5
0.4
0.3
0.2
0.1
0
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
0.3
0.25
0.15
0.1
0

Water & organics in asteroids

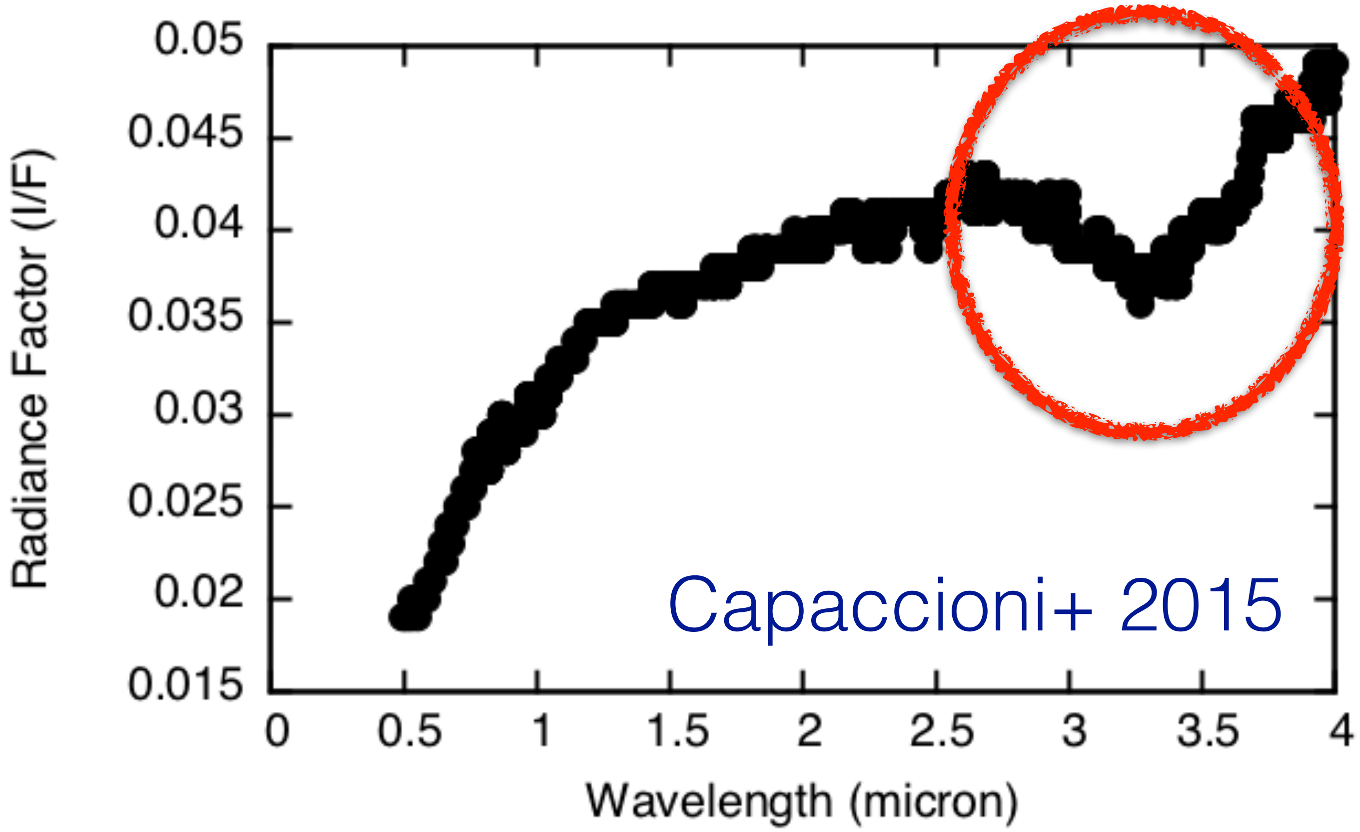


Rivkin & Emery 2010; Campins+ 2010

Comets and 67P/CG

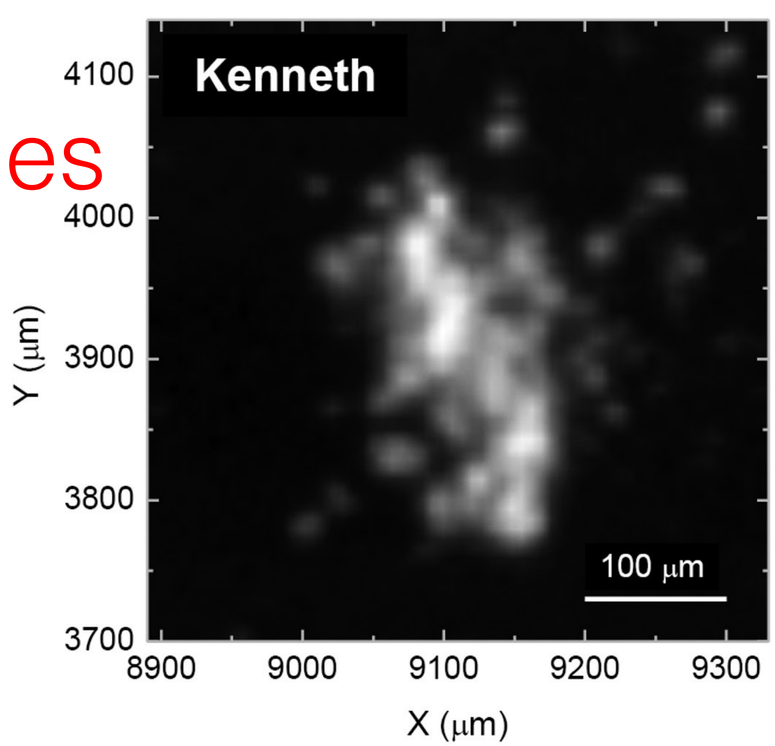


Organics from spectroscopy



Organic macromolecules in the dust (COSIMA)

Fray+ 2016

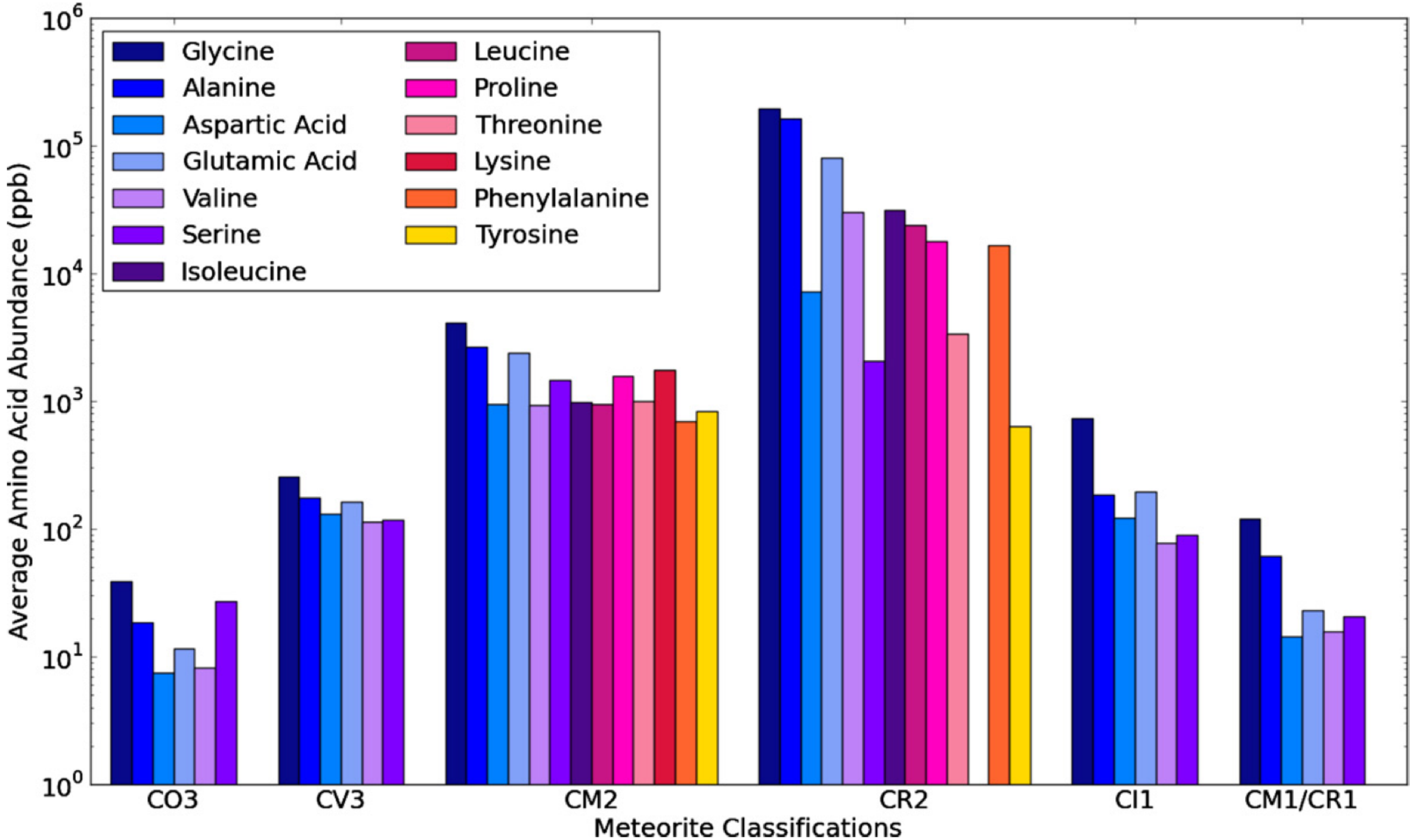


Glycine ($C_2H_5NO_2$) — *Amino Acid* — Methylamine (CH_5N), Ethylamine (C_2H_7N) Altwegg+ 2016

Also found in the dust of **Wild2**: Elsila+ 2009

Phosphorus, never previously detected Altwegg+ 2016

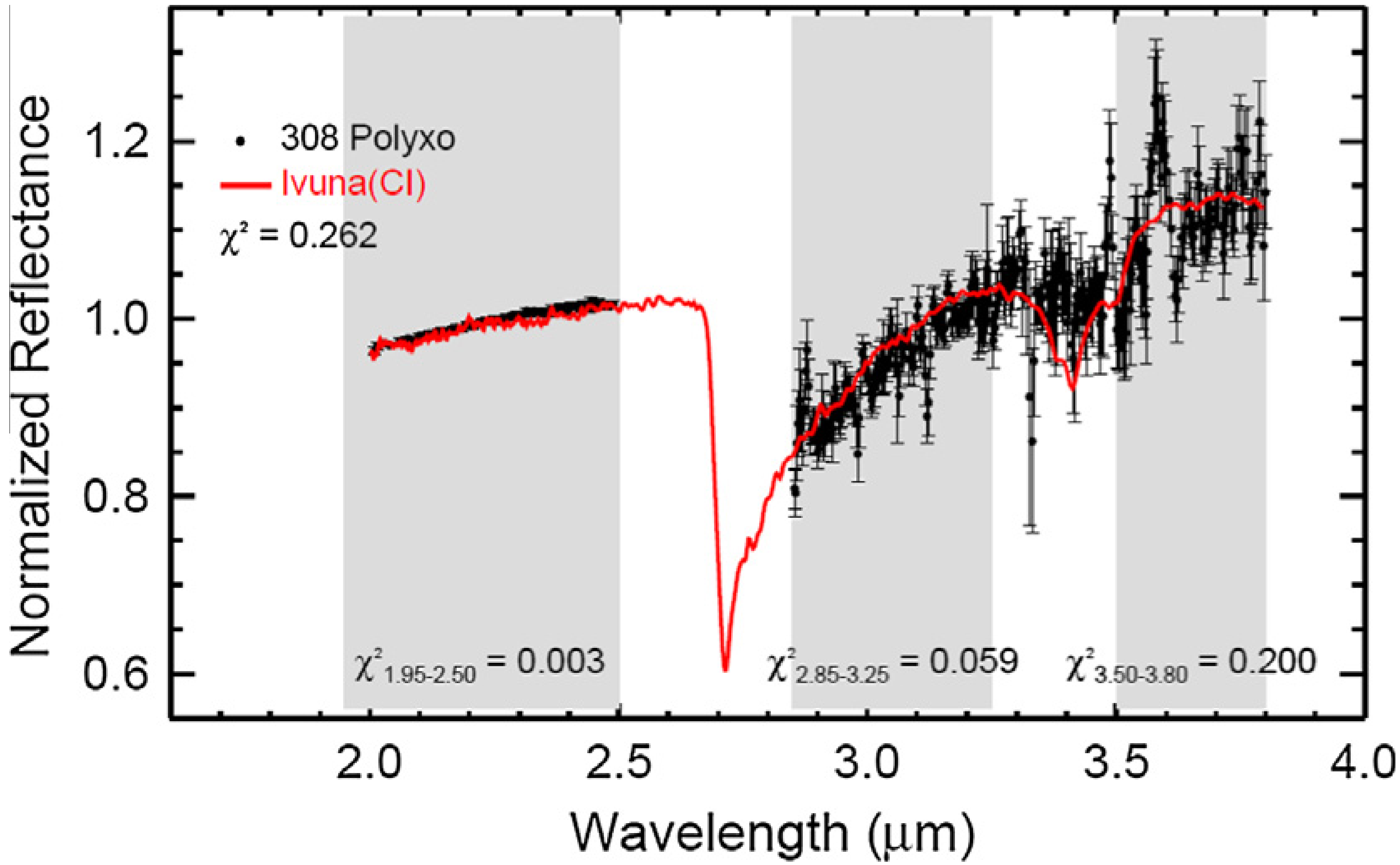
Amino acids in meteorites



CM2 and CR2 type have the highest abundance of amino acids —> abundance of amino acids depends on the degree of aqueous alteration

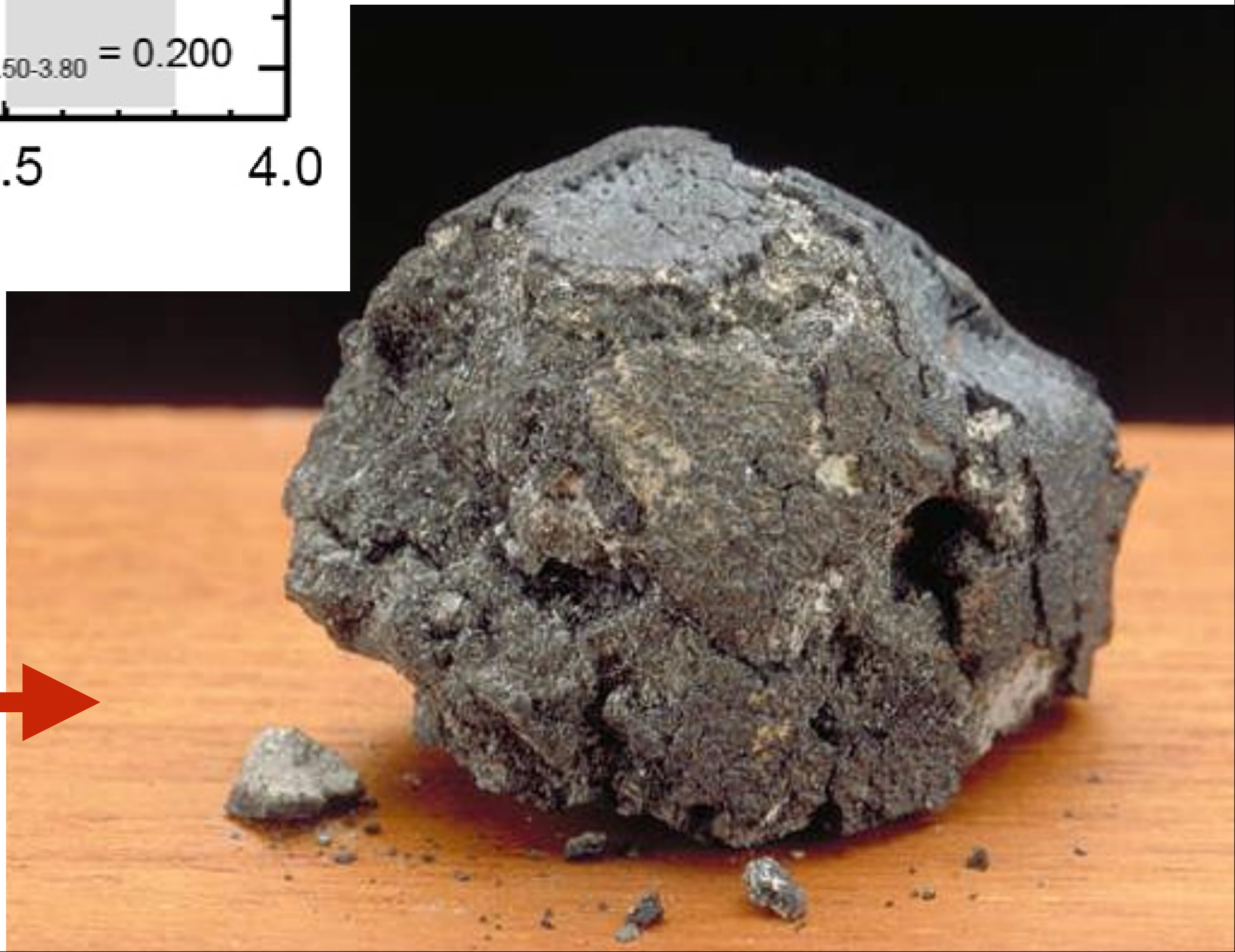
Cobb & Pudritz 2014

Structural water in asteroids



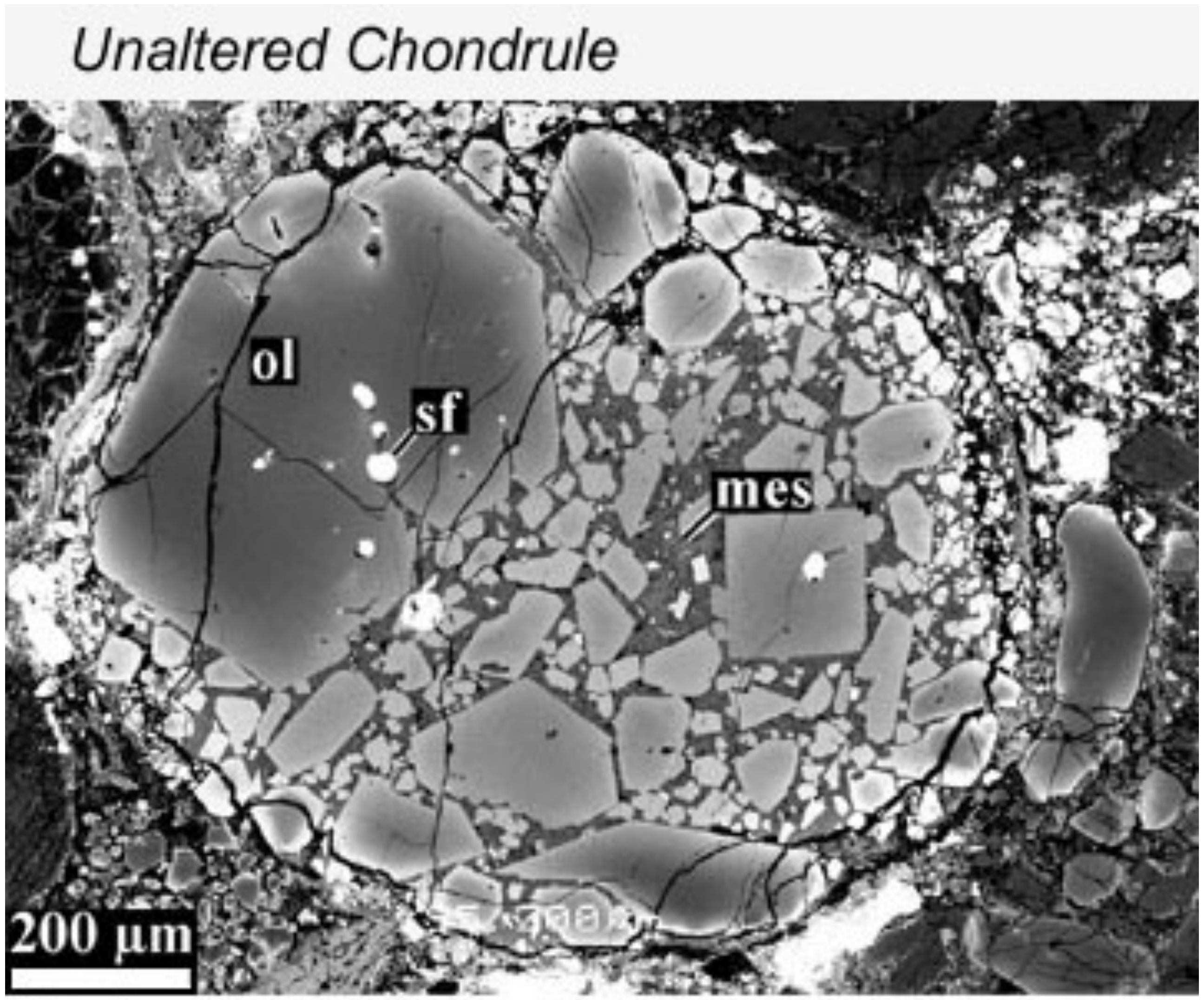
"Sharp" 2.8 μm band is matched with CI and CM carbonaceous chondrites: Takir+ 2015; Rivkin+ 2015

Signature of aqueous alteration is observed in meteorites such as Ivuna

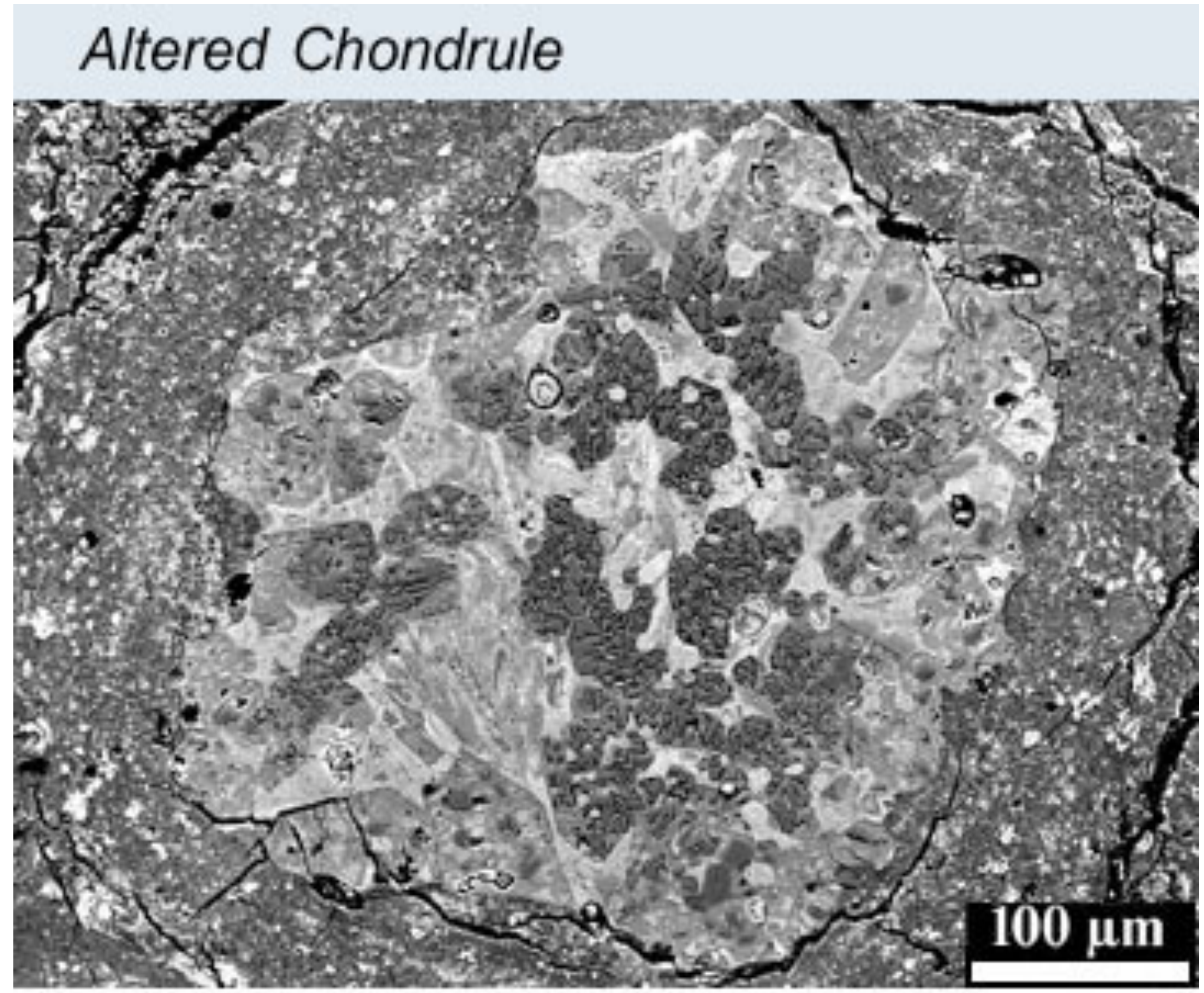


Aqueous Alteration

High temperature phases are replaced by phyllosilicates



(Courtesy of Sasha Krot, University of Hawaii.)

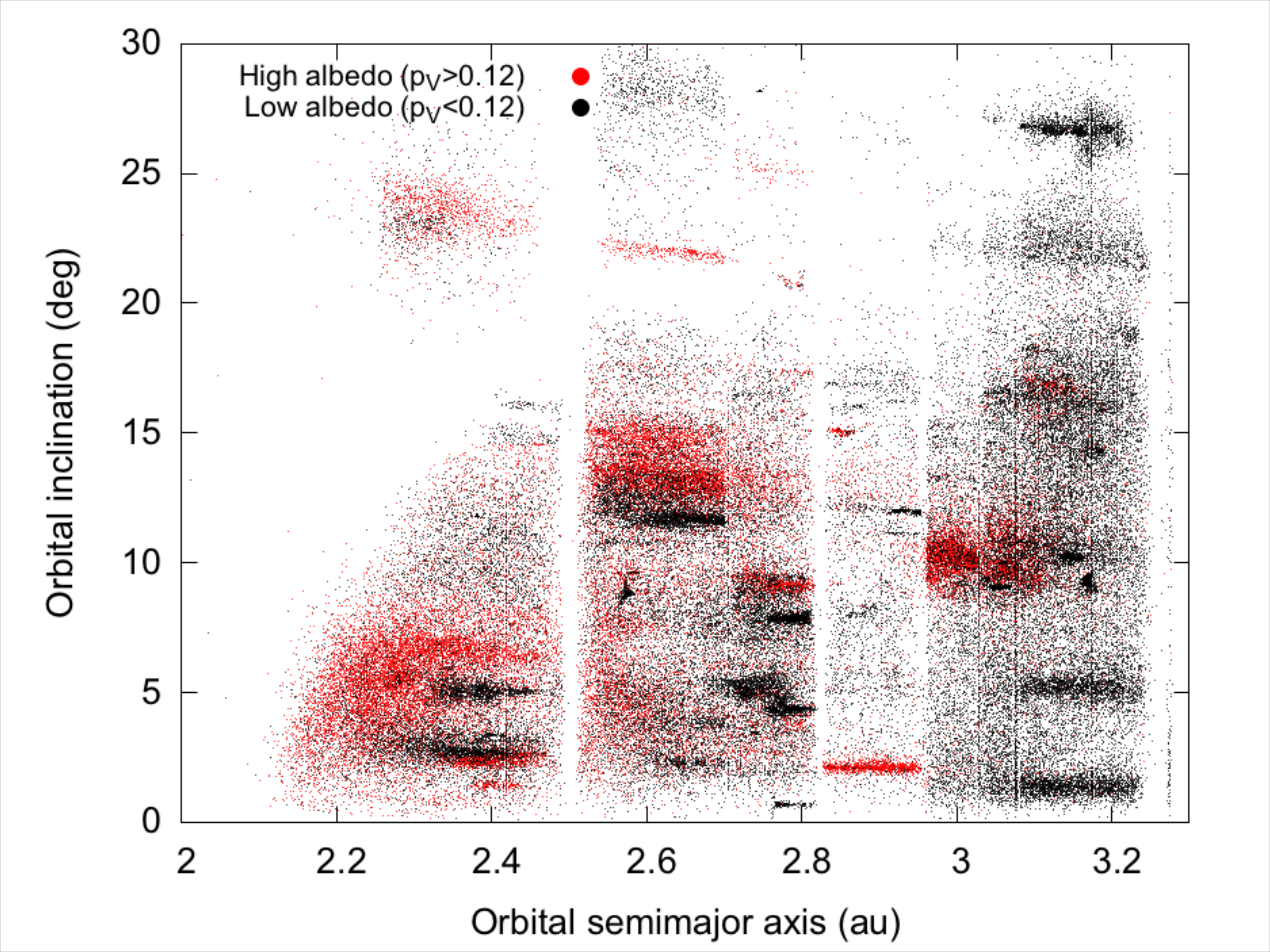


(Courtesy of Adrian Brearley, University of New Mexico.)

This is believed to be a parent body process, that occurred as it is thought that planetesimals were heated (by e.g. ^{26}Al) during accretion.

NASA OSIRIS-REx

see OSIRIS-REx video on youtube



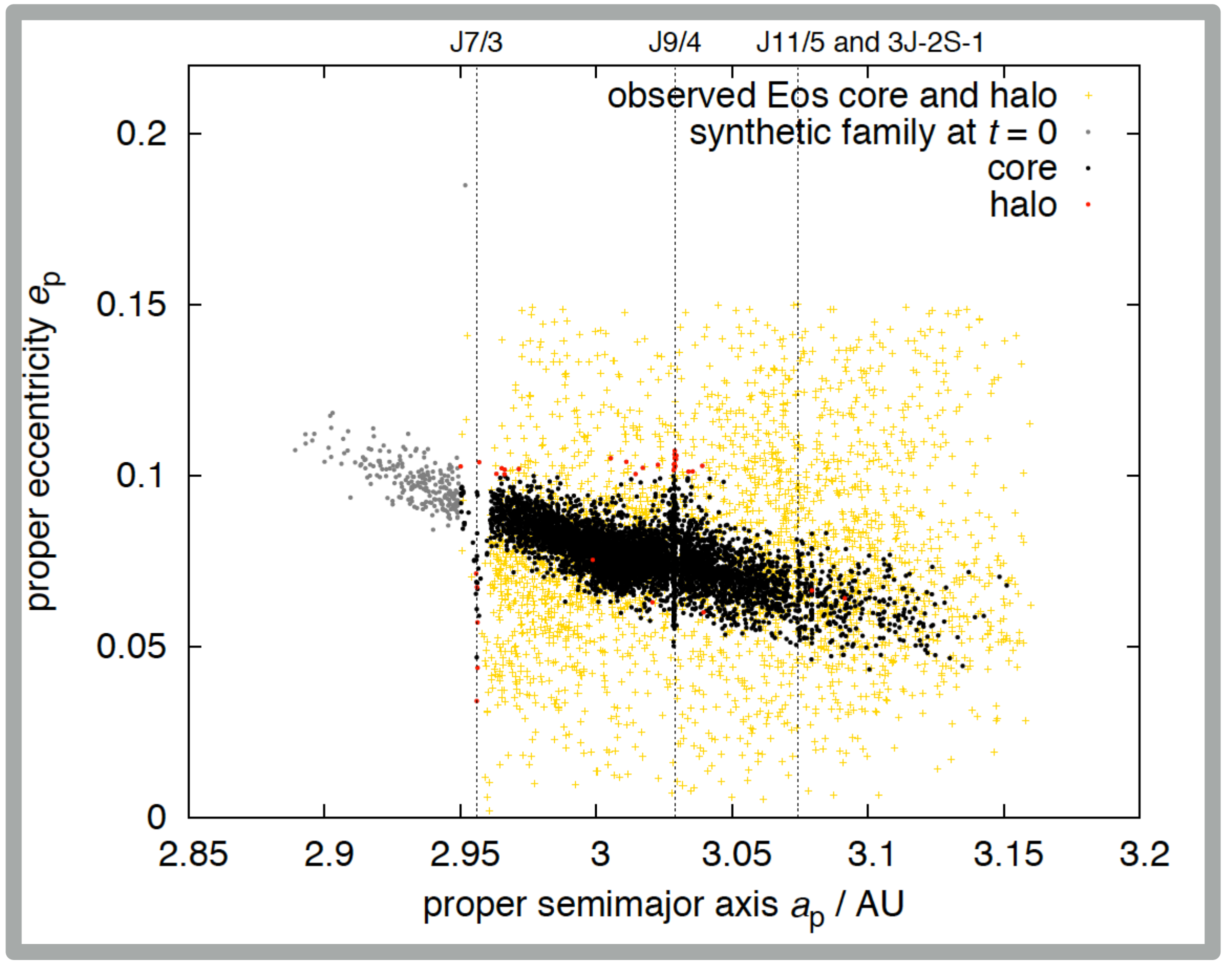
High albedo (p_V>0.12)
Low albedo (p_V<0.12)
Orbital inclination (deg)
Orbital semimajor axis (au)
0
5
10
15
20
25
30
2
2.2
2.4
2.6
2.8
3
3.2

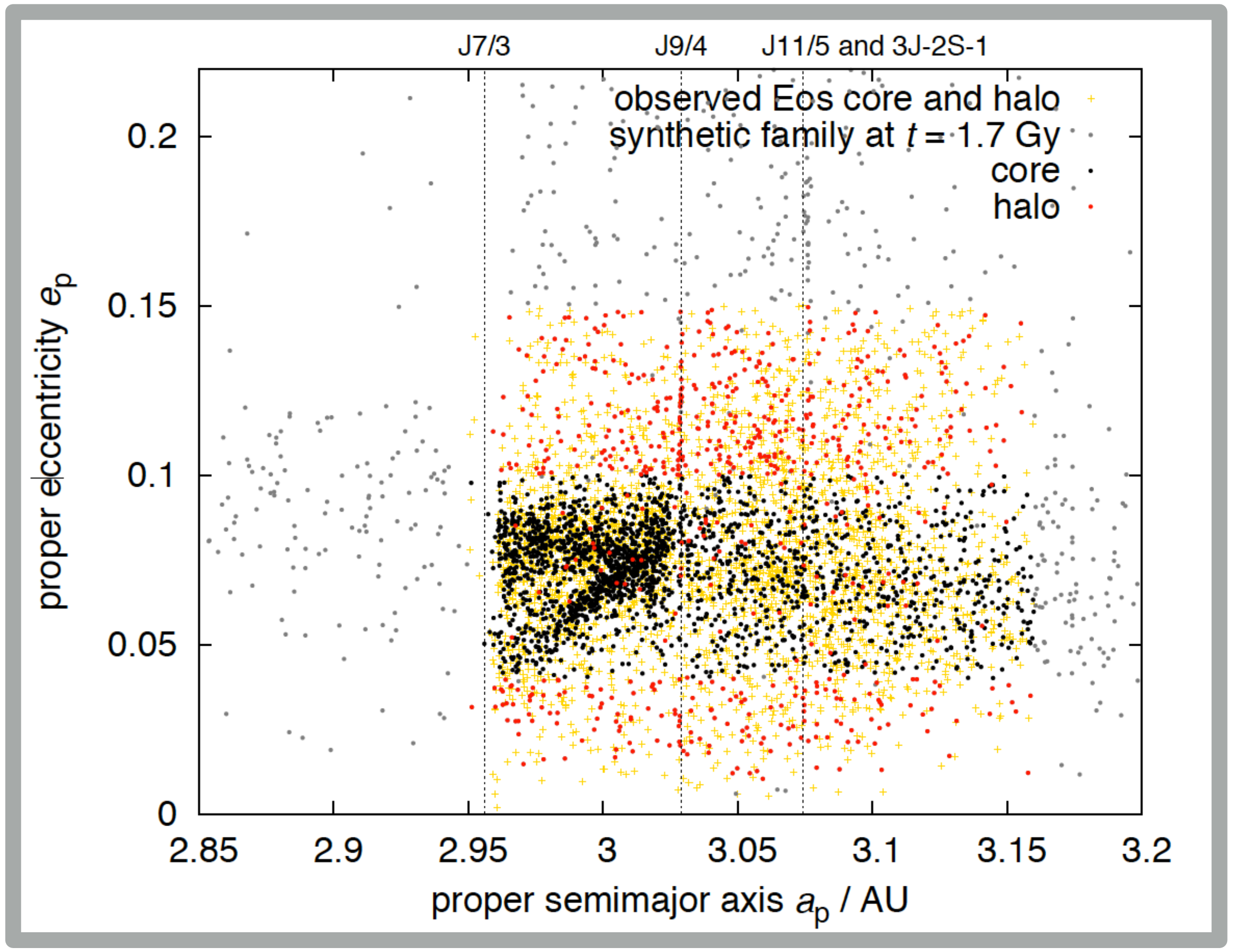
Asteroid family-forming impact

Credits: Patrick Michel

Diffusion of orbital elements

- Family fragments diffuse in (e,i) due to secular and mean motion resonances (MMR).

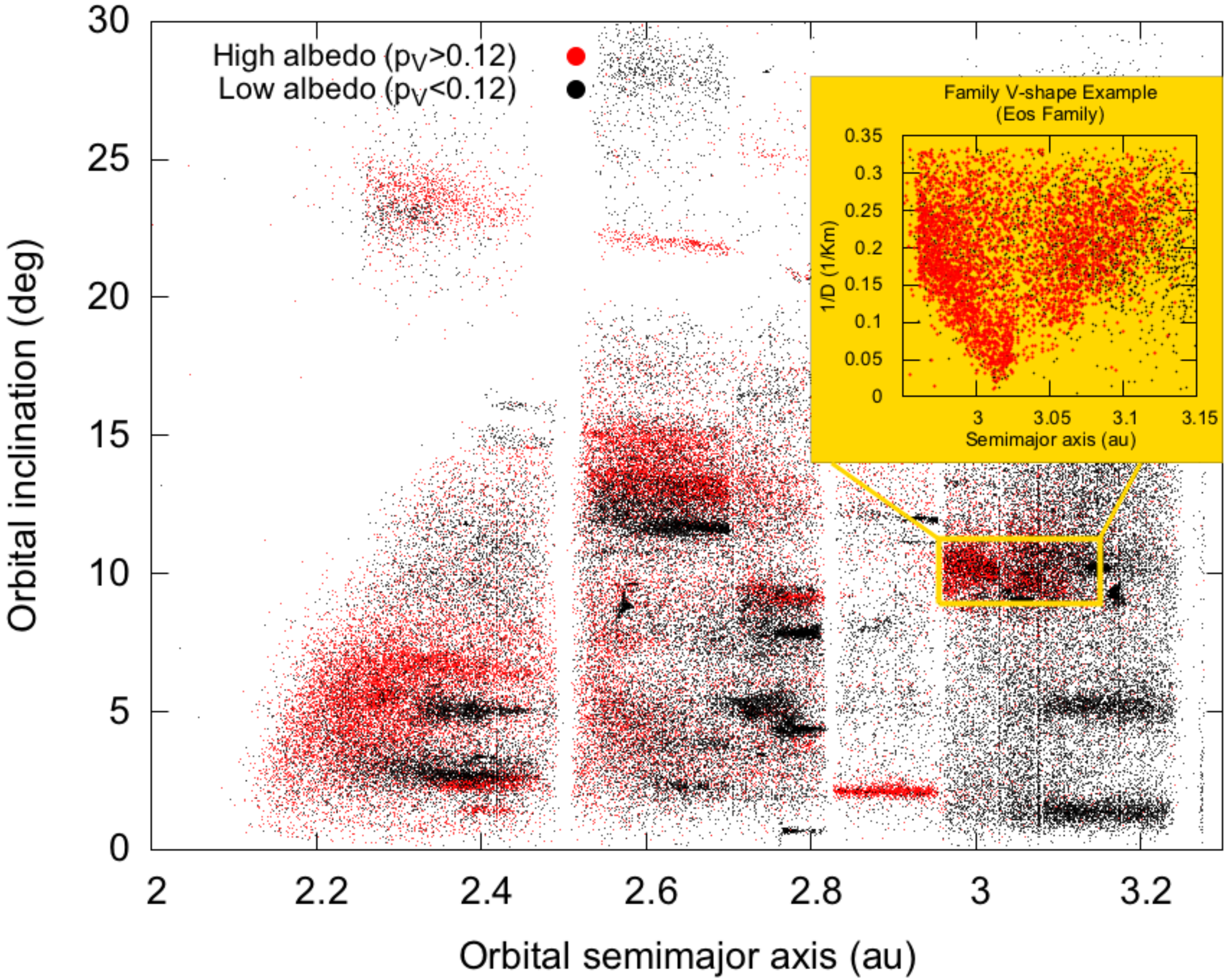




1.7 Gyr

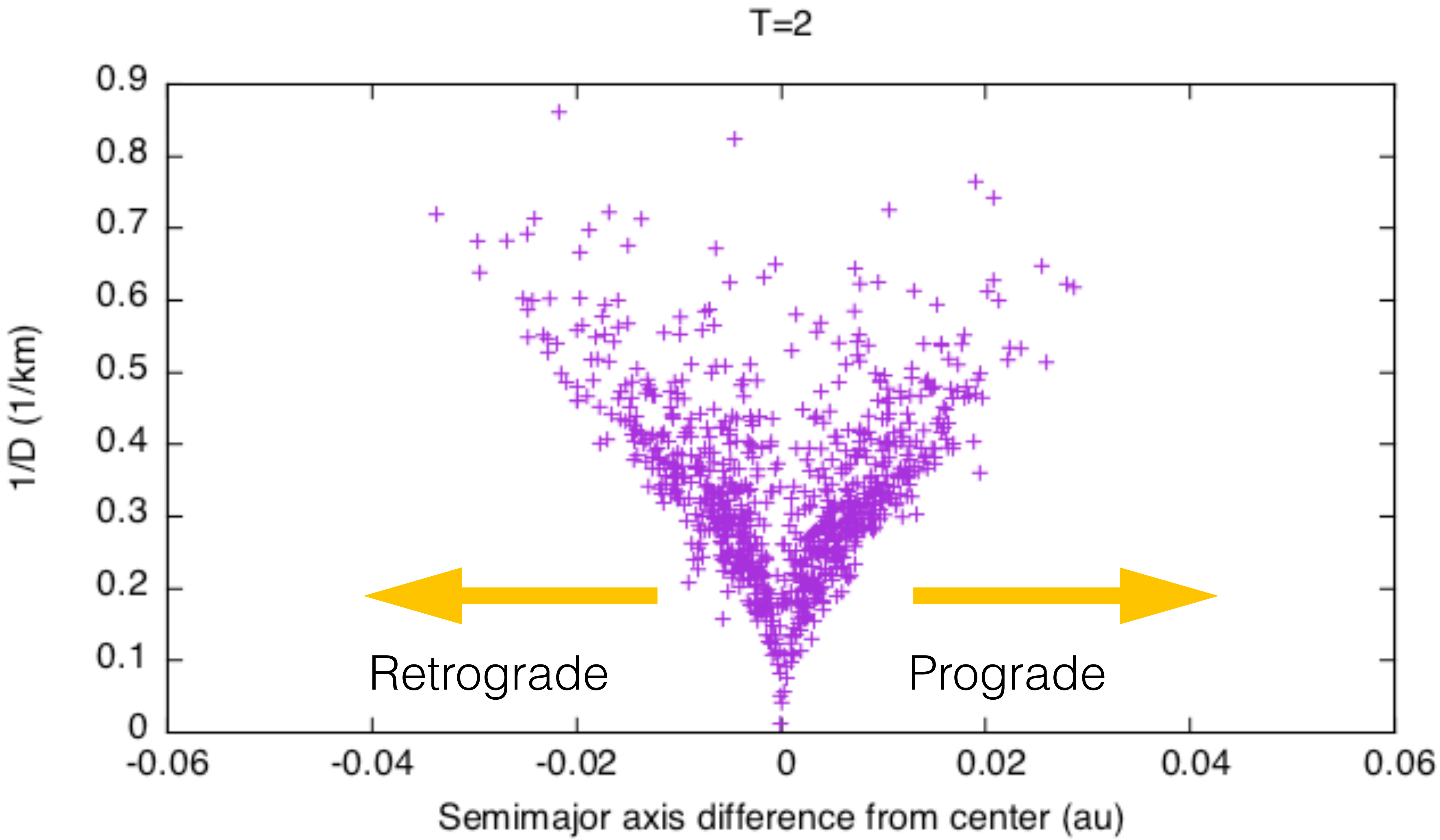
Brož and Morbidelli, 2013

The V-shape of asteroid families



Diameters & Albedos: Masiero+11,12,14; Nugent+15,16; Usui+11; Ryan&Woodward+10; Tedesco+02

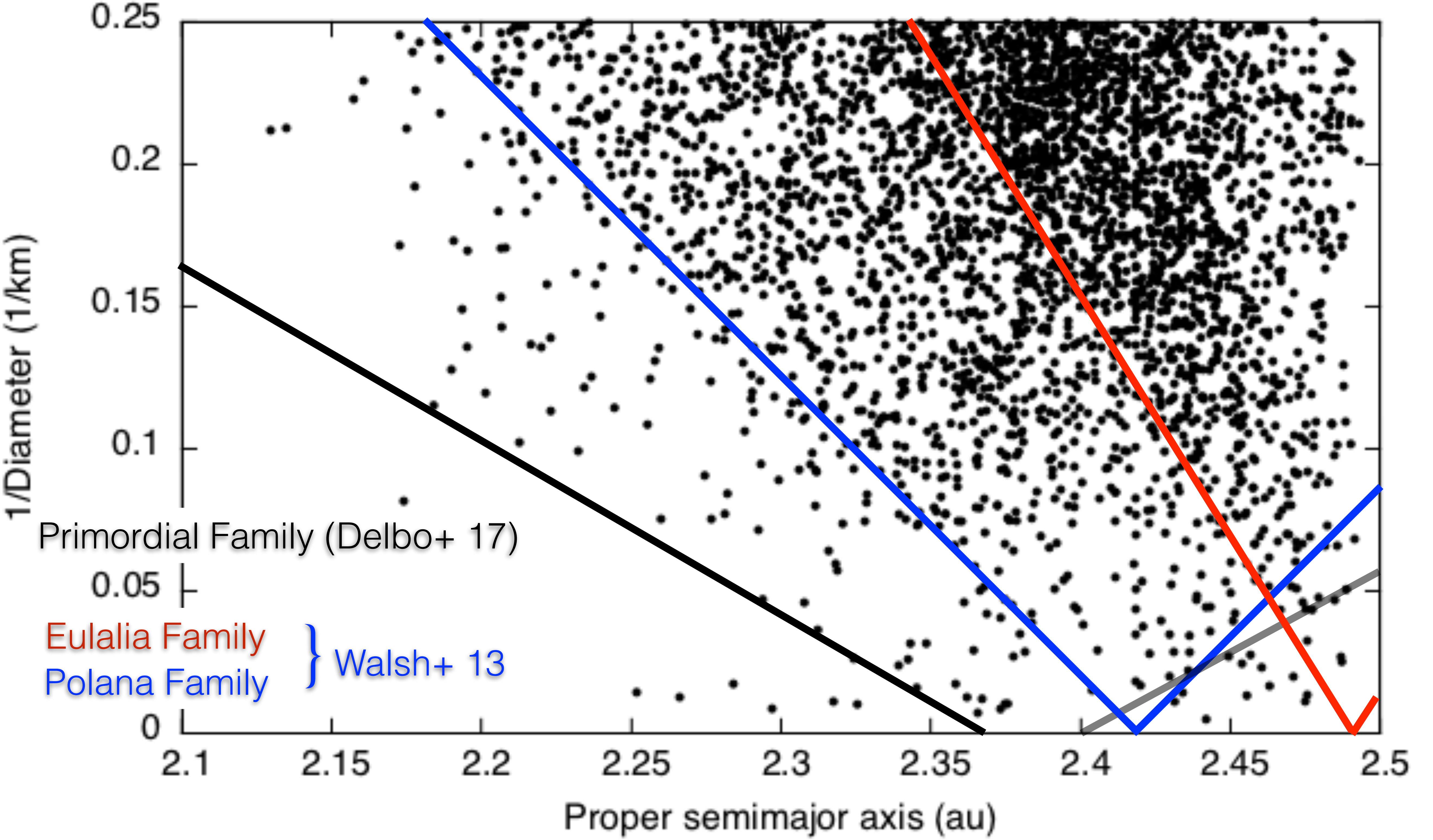
Yarkovsky V-shape



da/dt prop.to 1/D

The entire inner Main Belt makes a V-shape

for the low-albedo asteroids

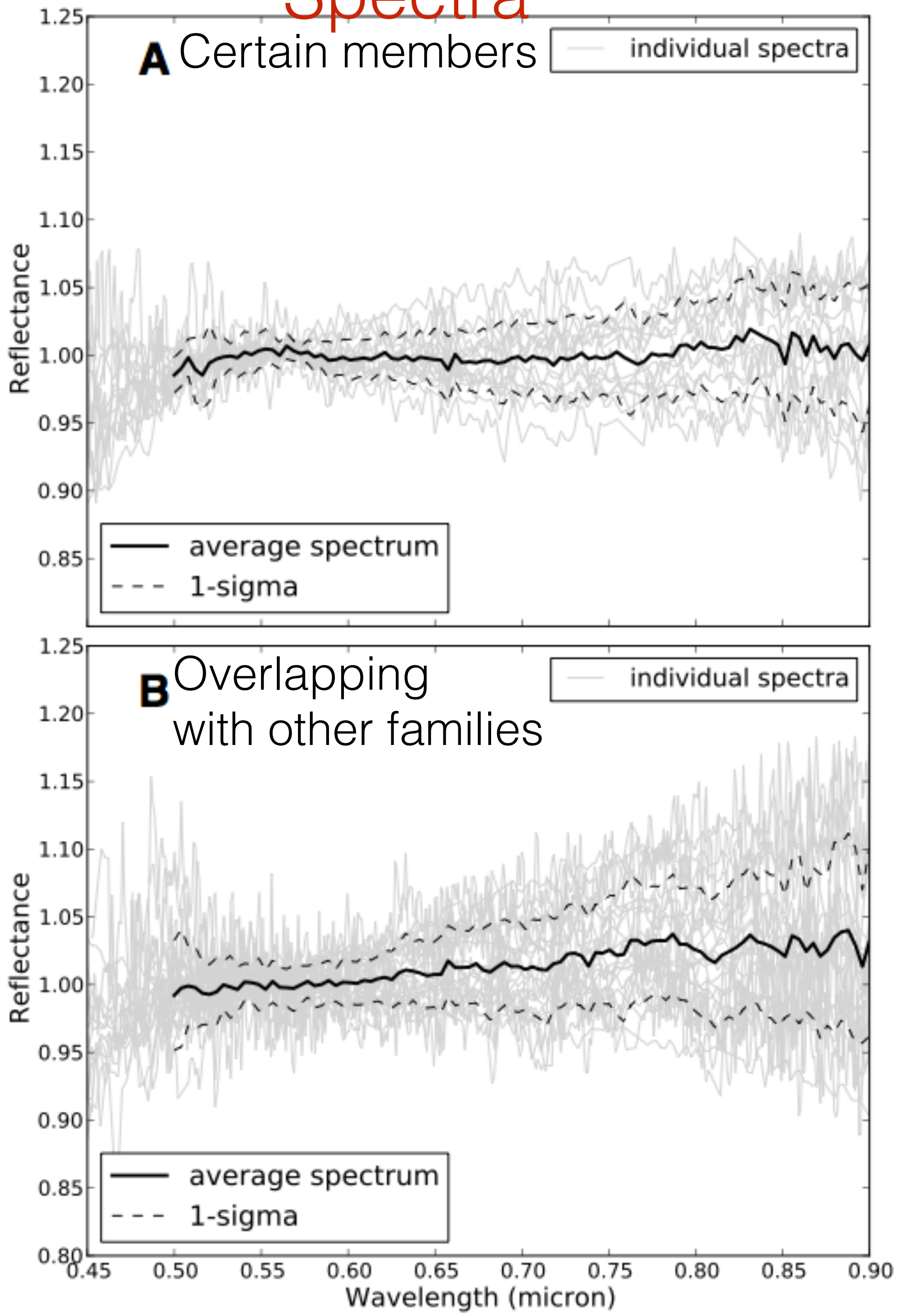


- The V-shape slope of the primordial family is ~ 0.6 $km^{-1}au^{-1}$ corresponding to an age $t = 4.0^{+1.7}_{-1.1}$ Gyr

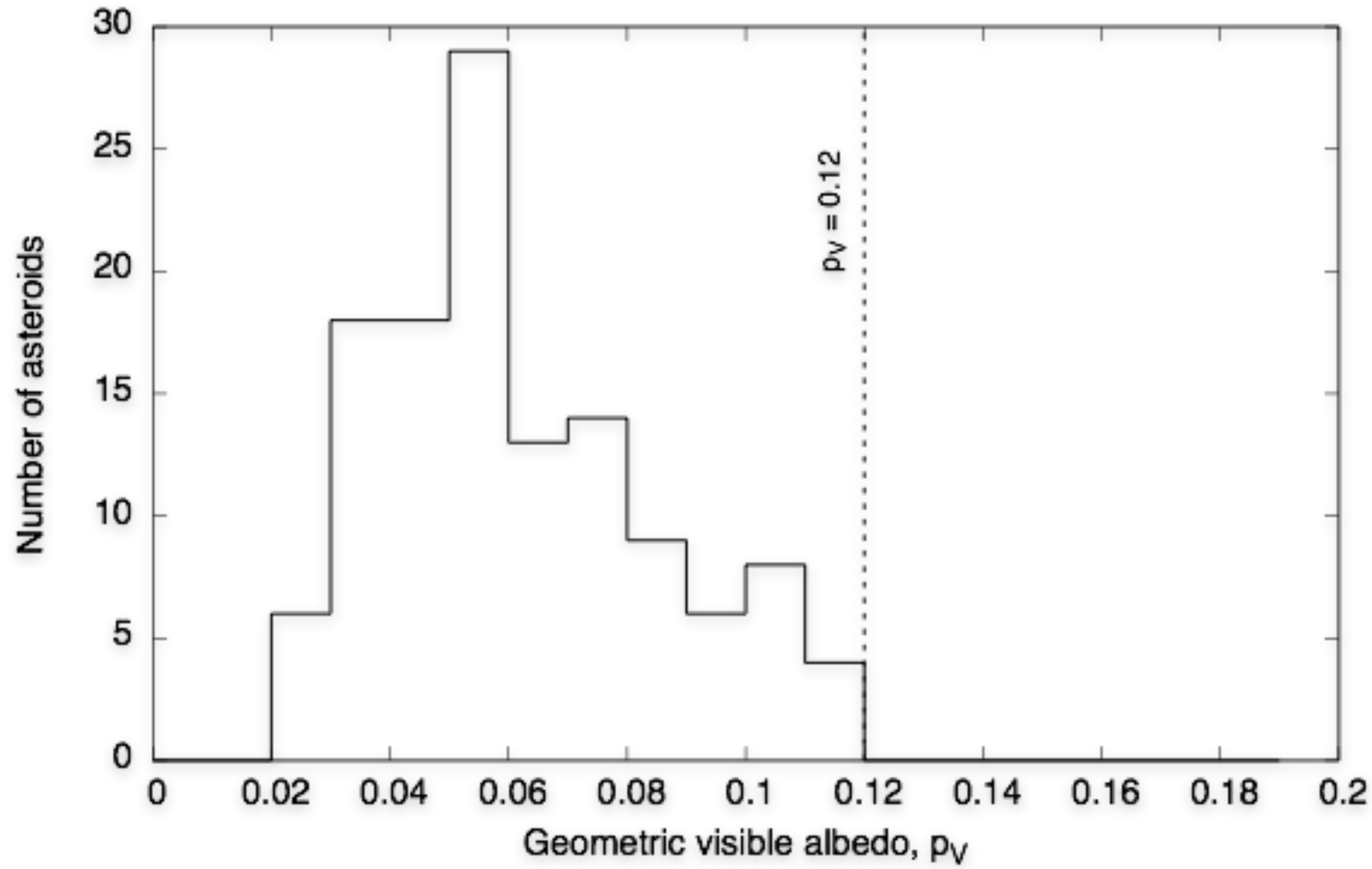
Physical properties

Homogeneity of the physical properties of its members (albedo and spectra are expected to be similar for asteroids sharing origin from a common parent body)

Spectra



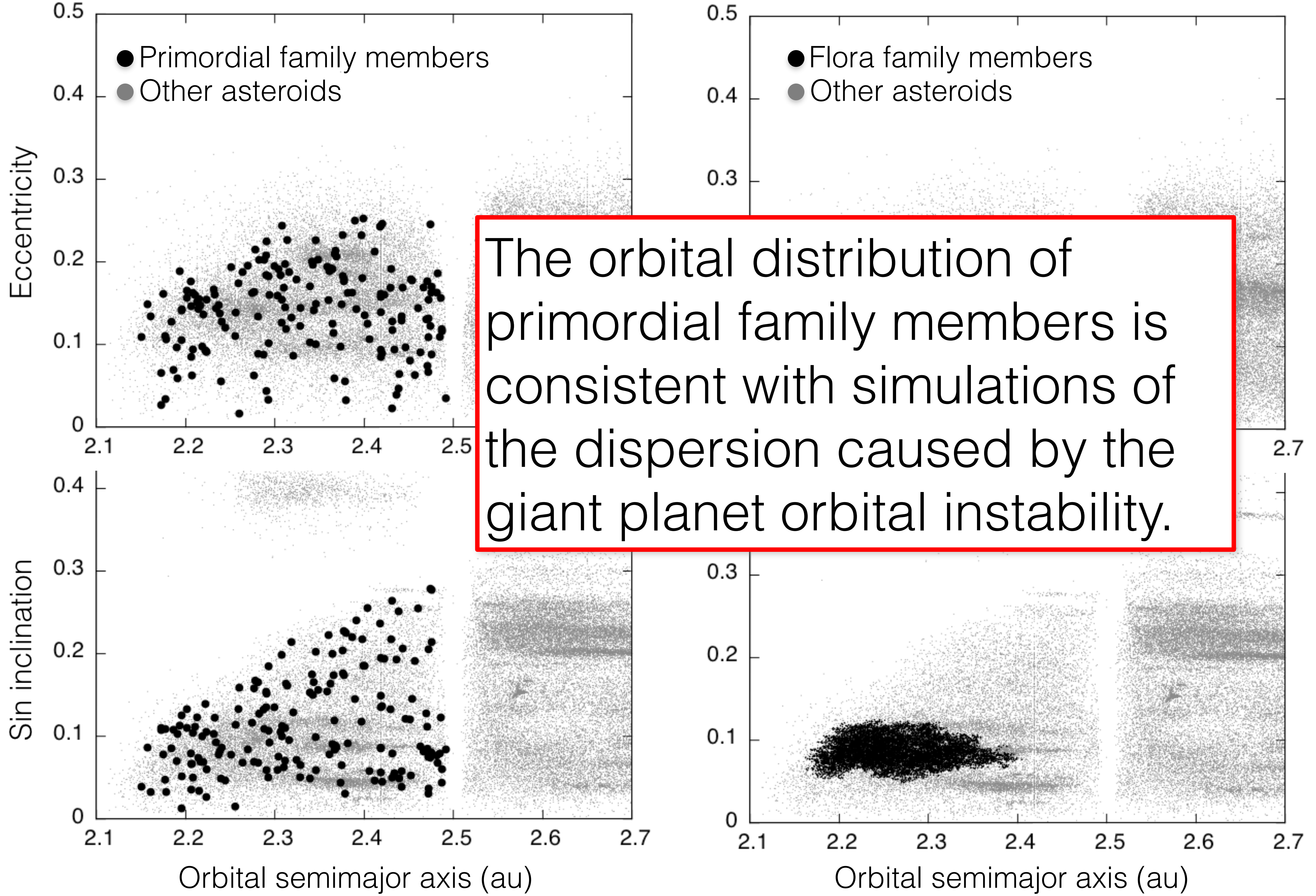
Albedos



- Homogenous albedos and spectra, similar other low-albedo families of the inner Main Belt (Walsh+2013; Pinilla-Alonso+2016; DeLeon+2016; Masiero+2013,2015; Nesvorny +2015;)

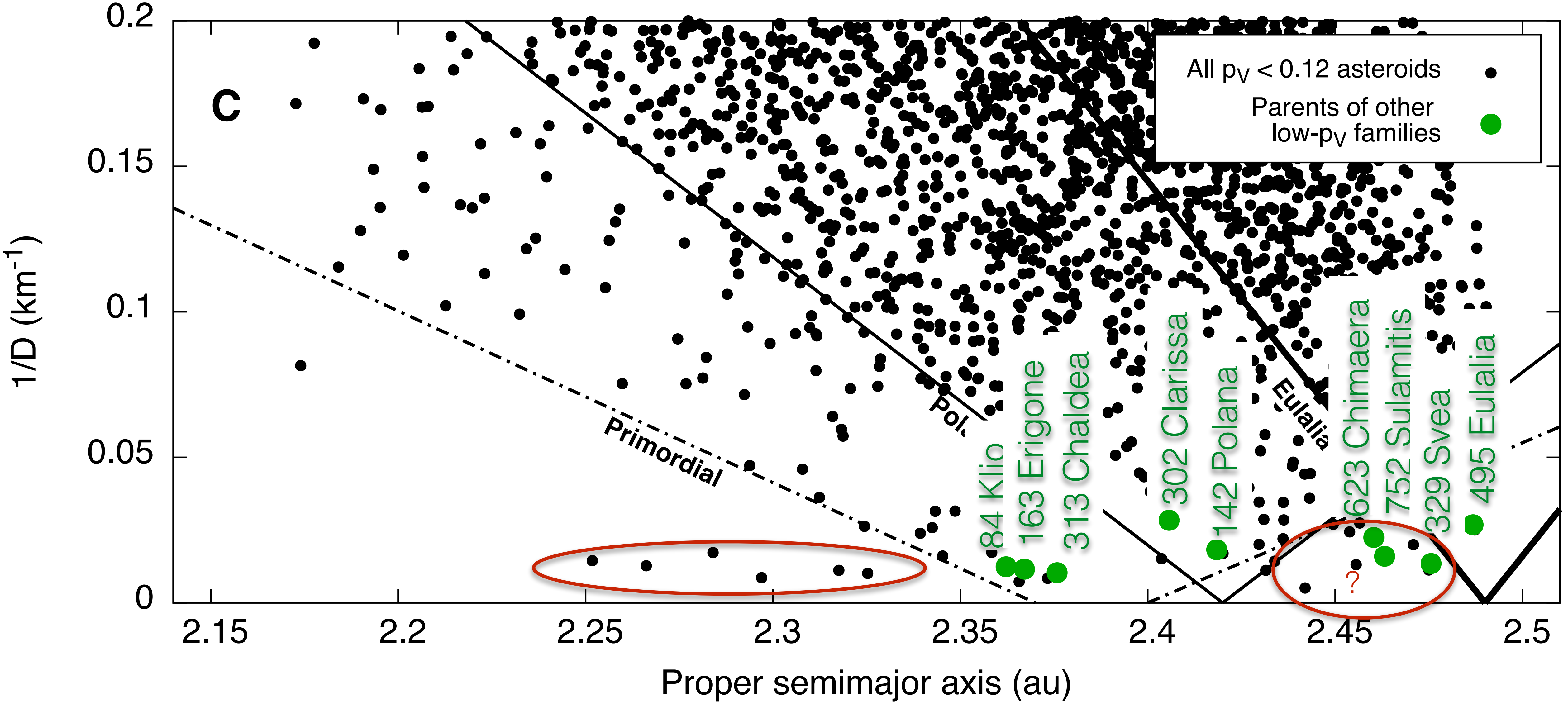
Orbital distribution

Compare the dispersion in orbital elements of our primordial family with the old but less dispersed Flora family.



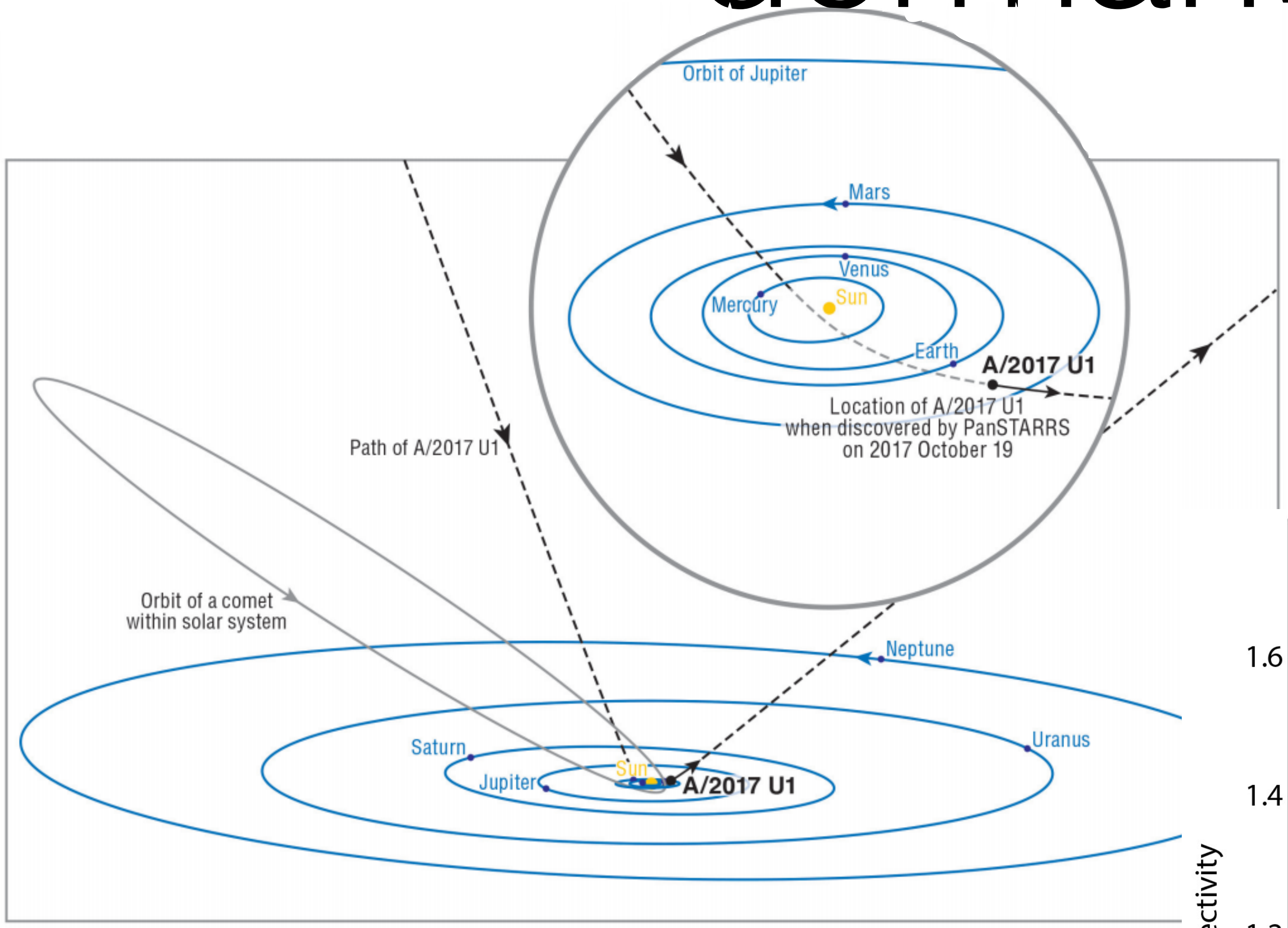
The orbital distribution of primordial family members is consistent with simulations of the dispersion caused by the giant planet orbital instability.

A family tree for the inner Main Belt

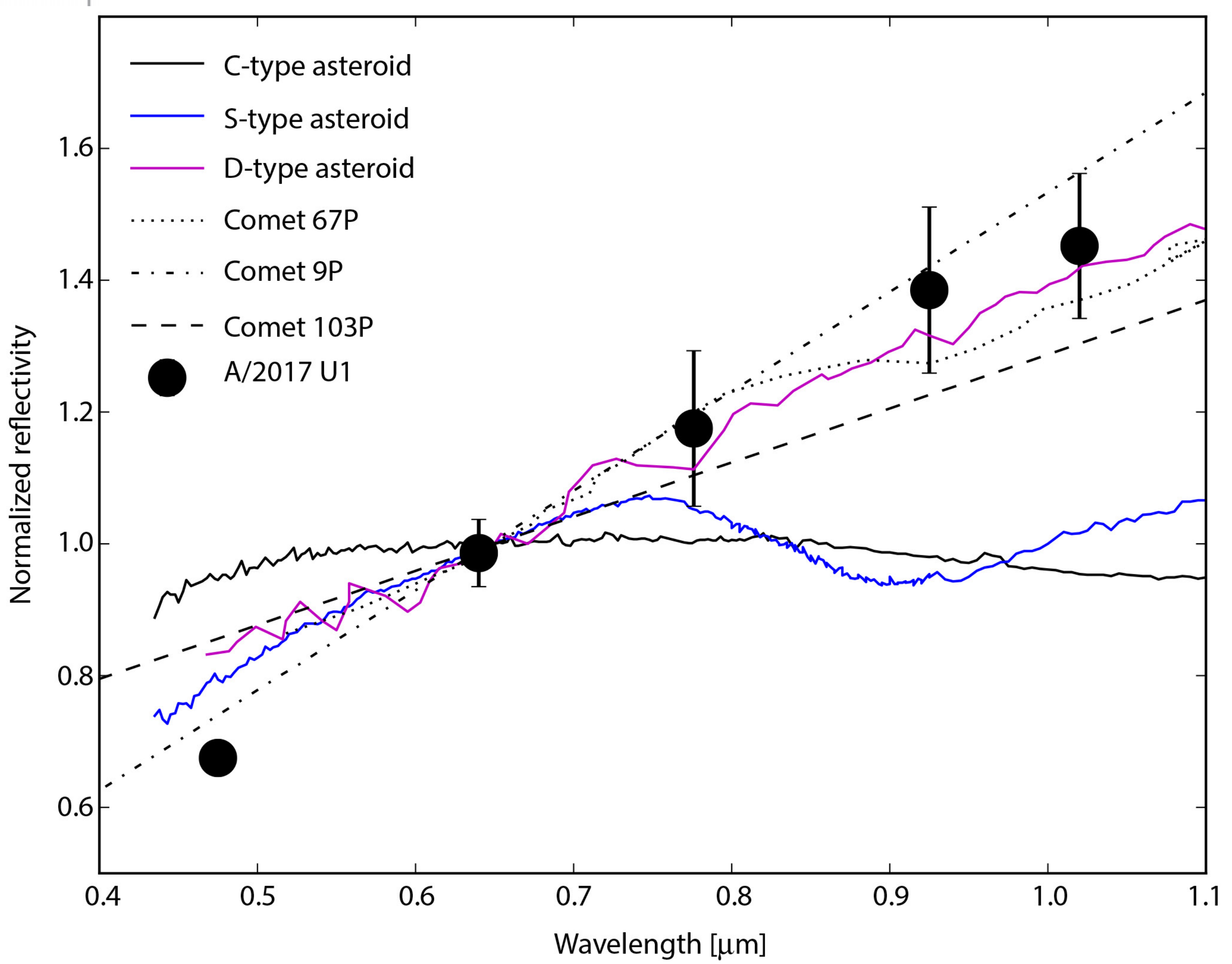


- Some of the parents of known low-albedo families are within the boundary of the primordial family. They could be members of the primordial family that suffered further family forming impacts.
- Two populations of asteroids: those inside V-shapes and those that cannot be inside V-shapes. The former are family members; the latter the original ones.

Interstellar asteroid or dead/ dormant comet **Oumuamua**



Colors alike cometary nuclei, but no activity detected despite q=0.25 au



Trajectory inconsistent with origin from our solar system as eccentricity ~ 1.2

Meech+ 2017

Conclusions

- Asteroid precursors impacted the early Earth
- Carbonaceous asteroids contains water and water-bearing minerals and organics, which were thus delivered to Earth
- Most of low-albedo (carbonaceous) of the inner Main Belt asteroids are genetically related.
  - This could be a general feature of the main belt.
- ESA should send a mission to the primordial asteroids: i.e the planetesimals.