Science of Small Bodies

(based on remote sensing, spacecraft missions, samples)

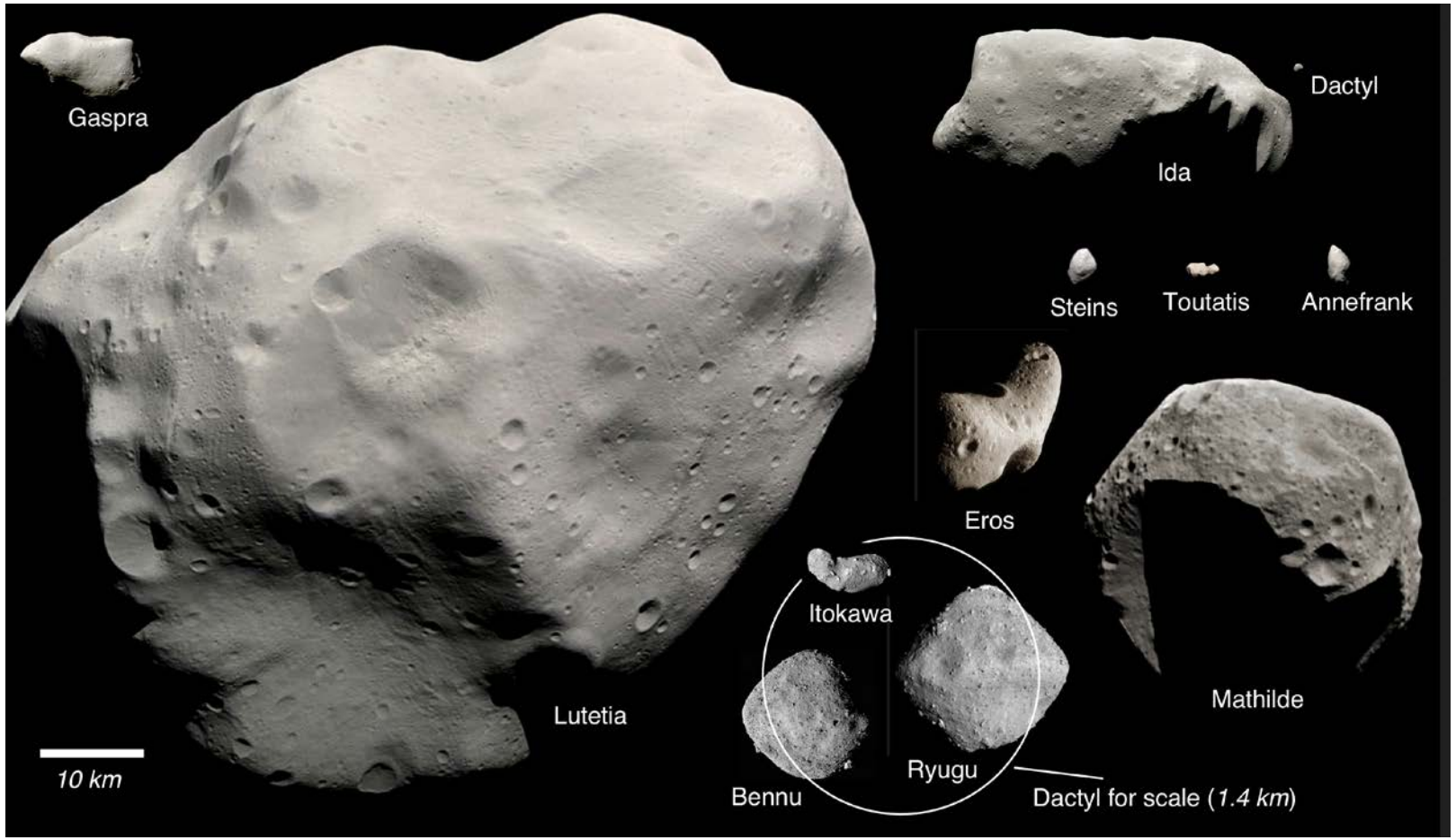
How unique are small bodies, and can we risk contaminating some of them by spacecraft missions?

Hap McSween

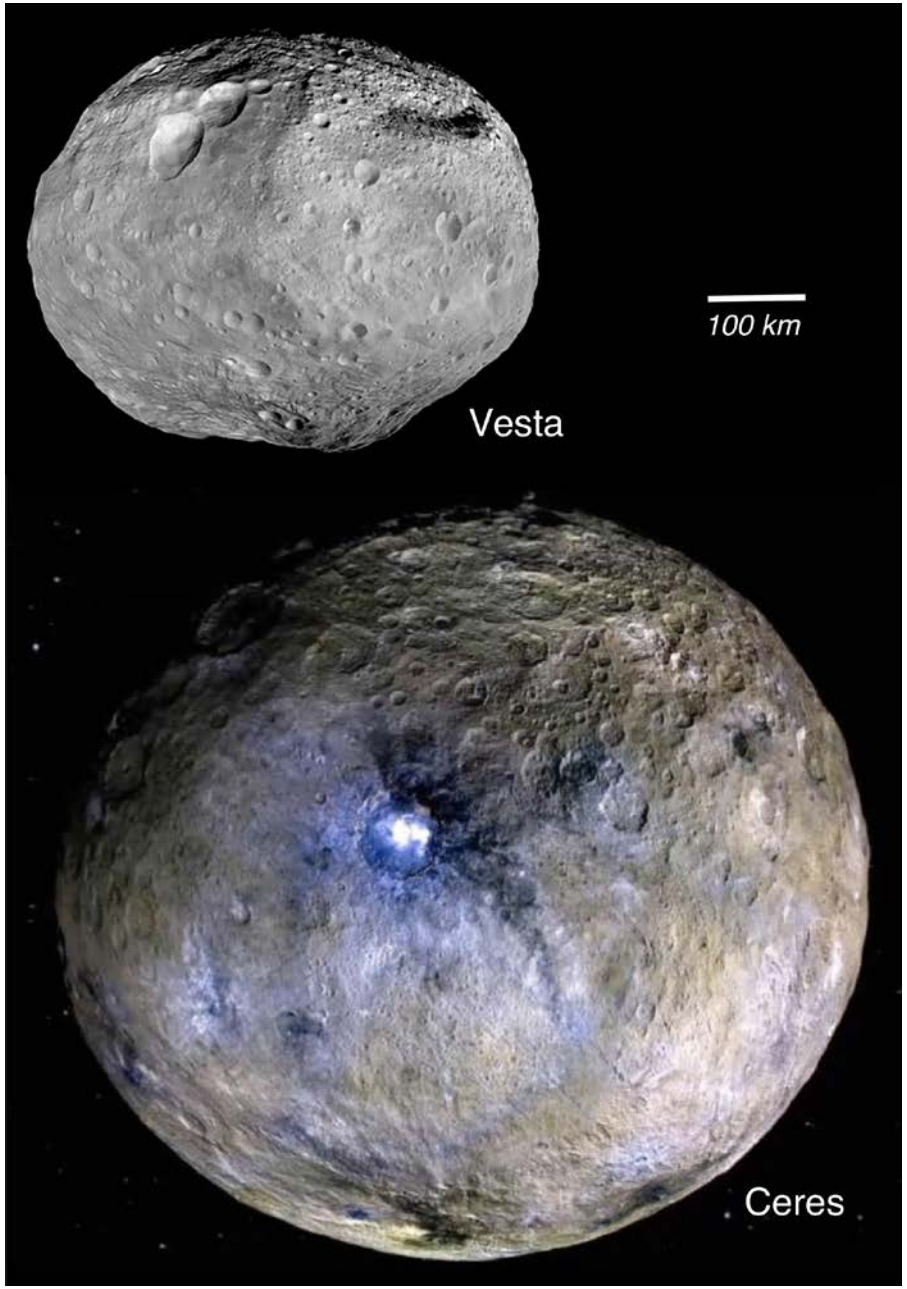
University of Tennessee

Presentation to Committee on Planetary Protection
December 1, 2021

Asteroids (and one dwarf planet) visited by spacecraft

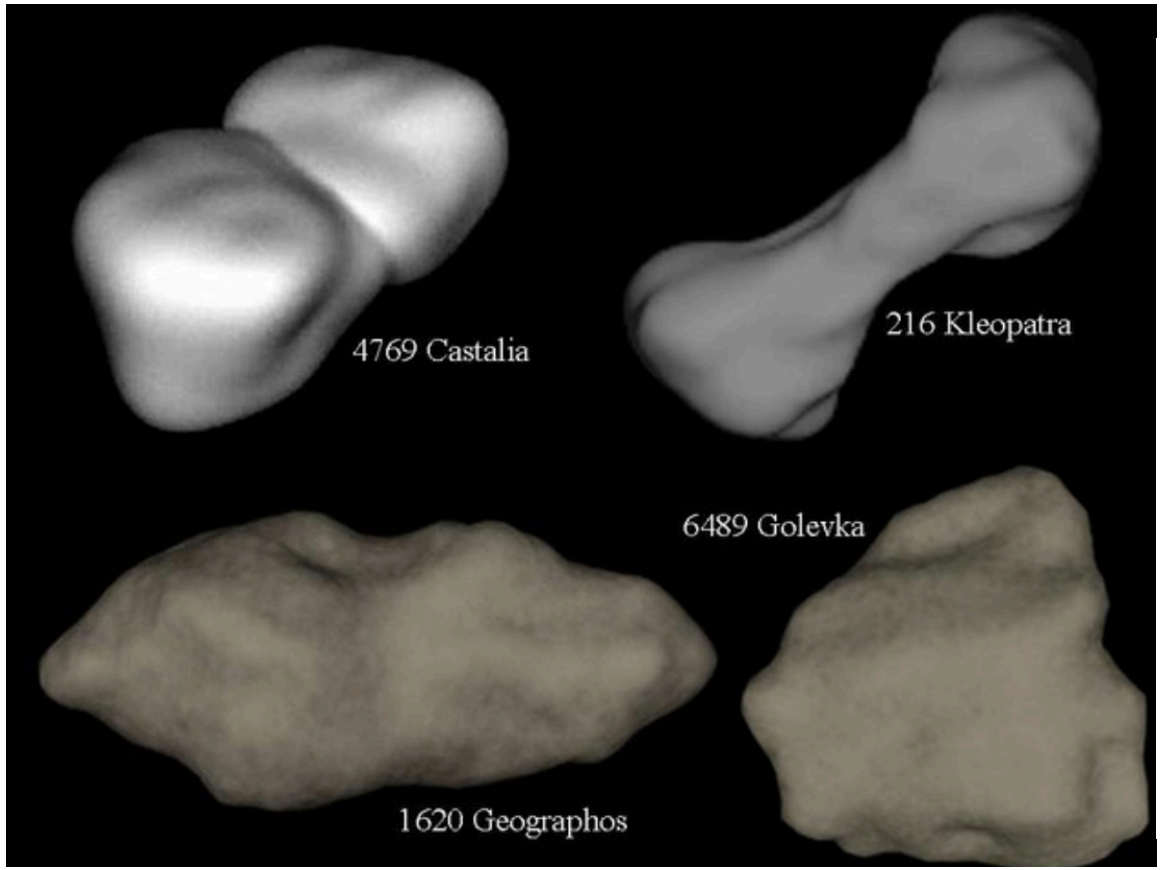


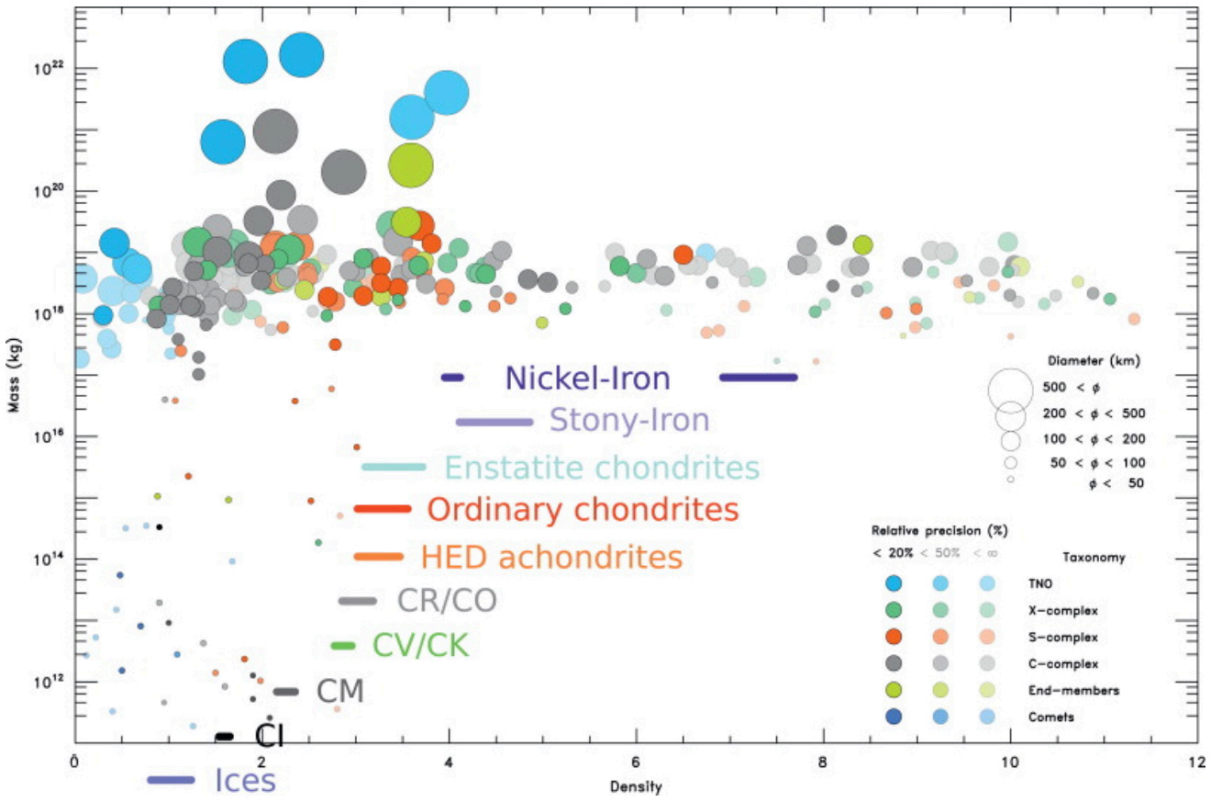
Small bodies in the Main Asteroid Belt or near-Earth space - fragments



The two most massive bodies - intact

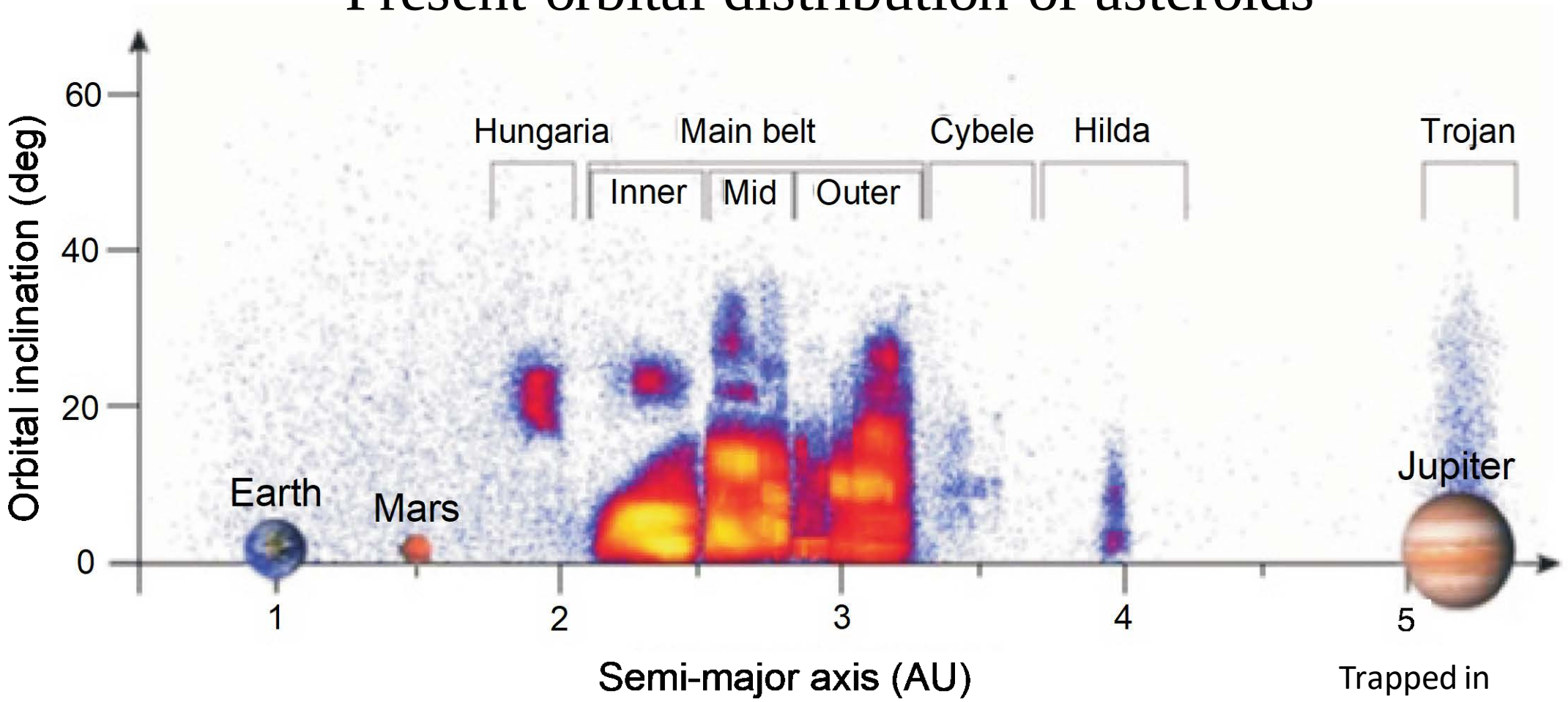
Shape models for asteroids constructed from radar observations and bulk densities from mass/volume estimates





Most small bodies are angular fragments with variable macroporosities - collisional rubble

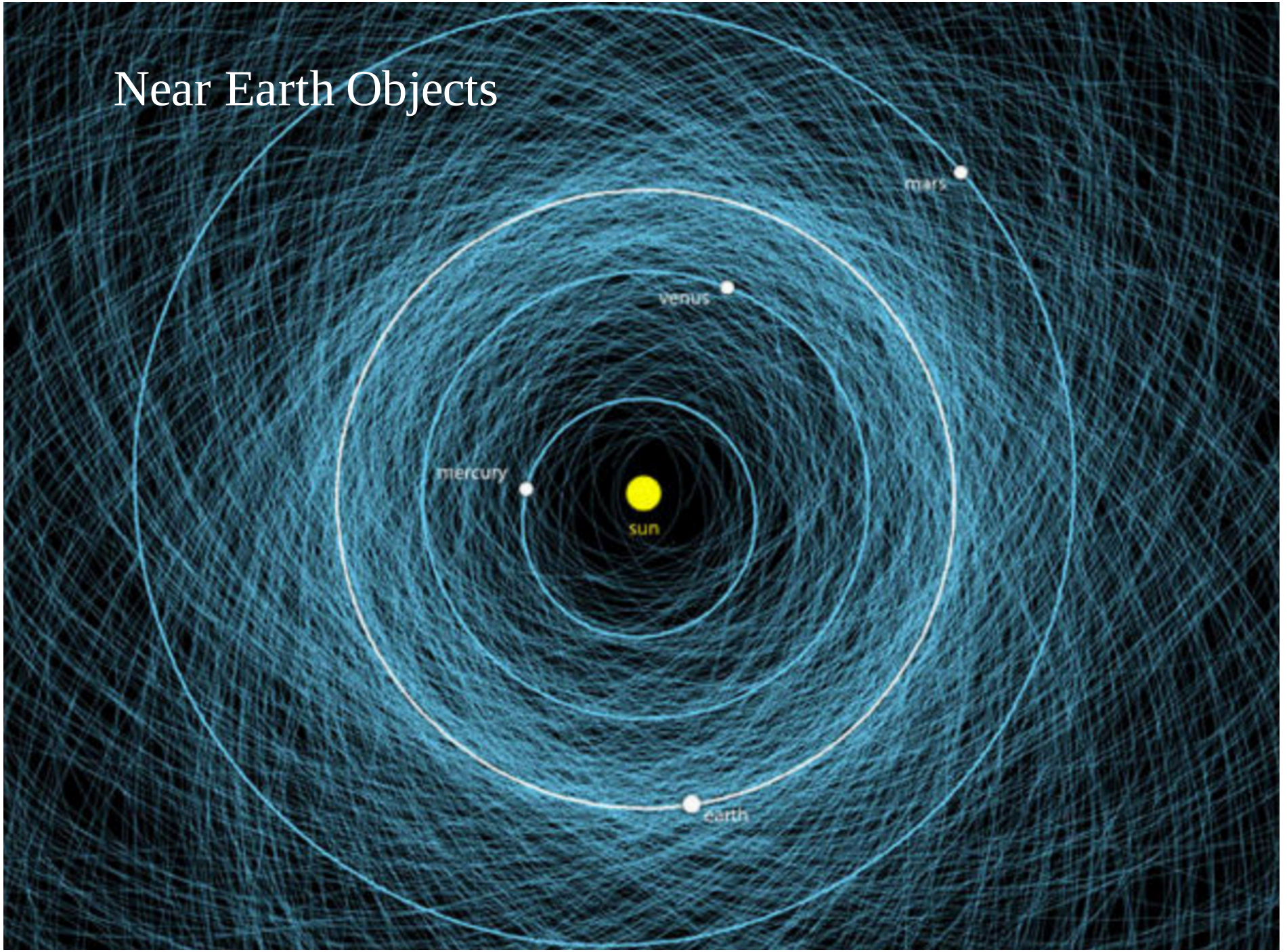
Present orbital distribution of asteroids



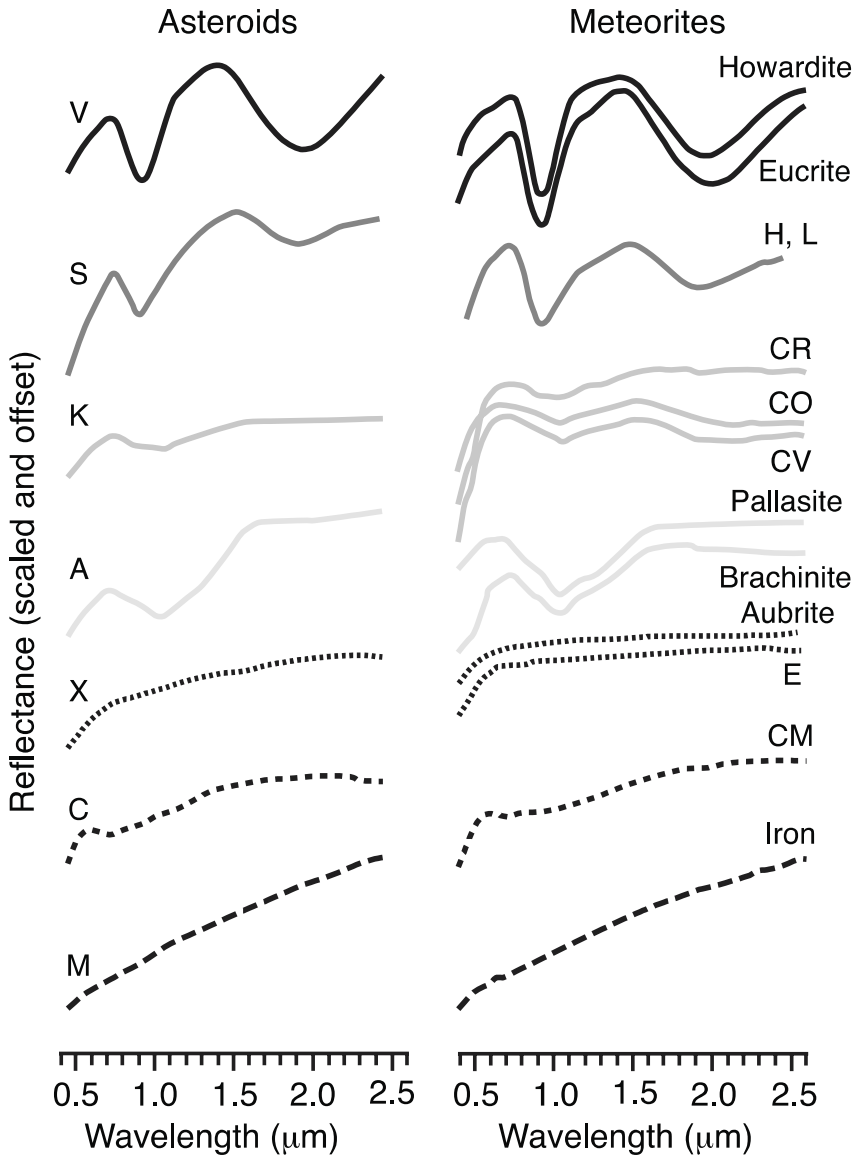
Controlled mostly by orbital resonances with Jupiter, which serve as escape hatches for asteroids/meteorites

Trapped in Lagrangian points

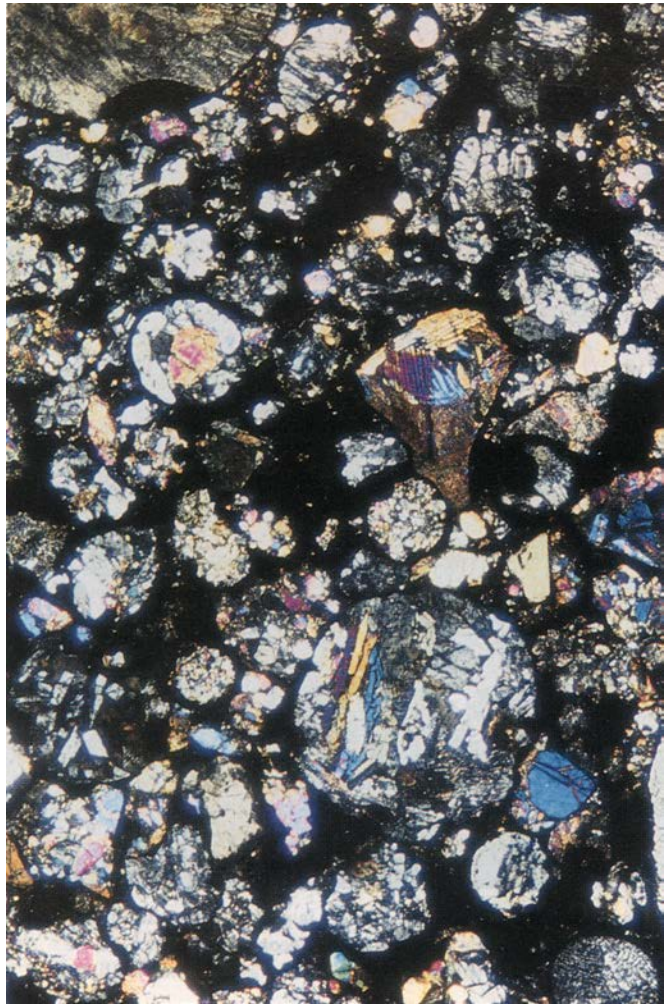
Near Earth Objects



Asteroid spectral classification, and relation to meteorites



But only one specific meteorite parent body identified

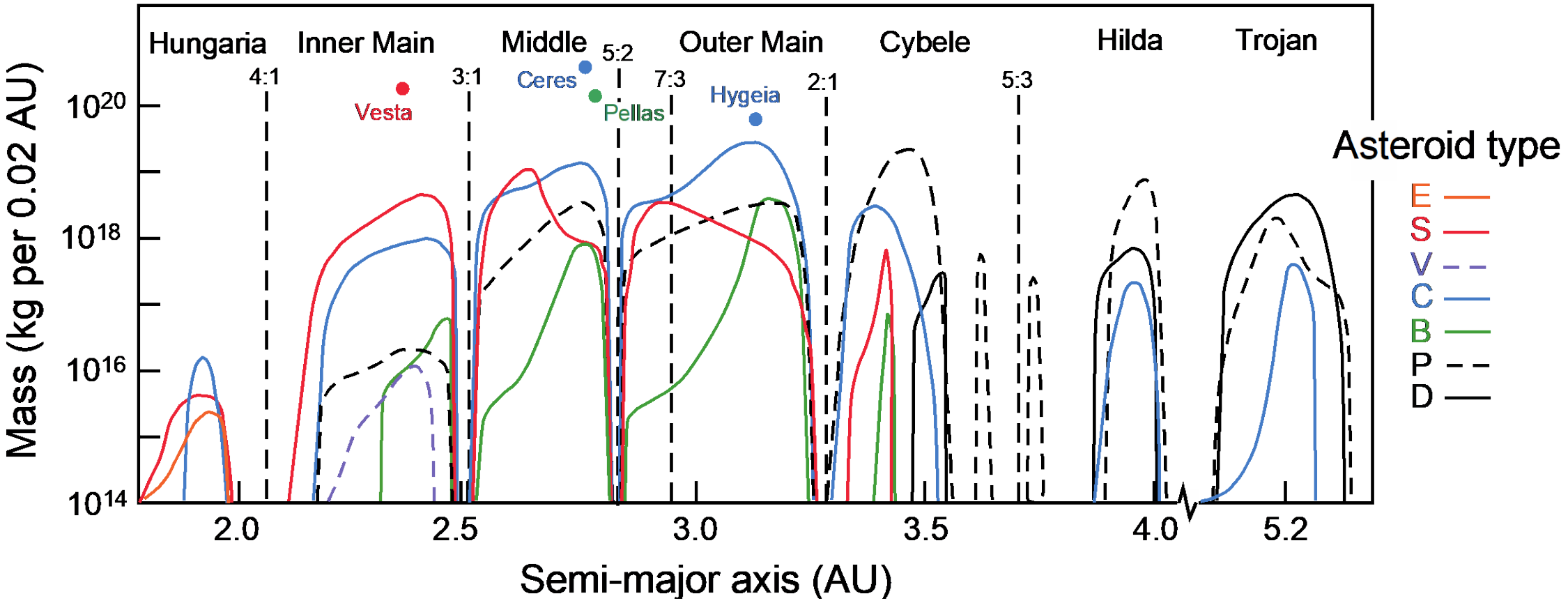


ordinary chondrite

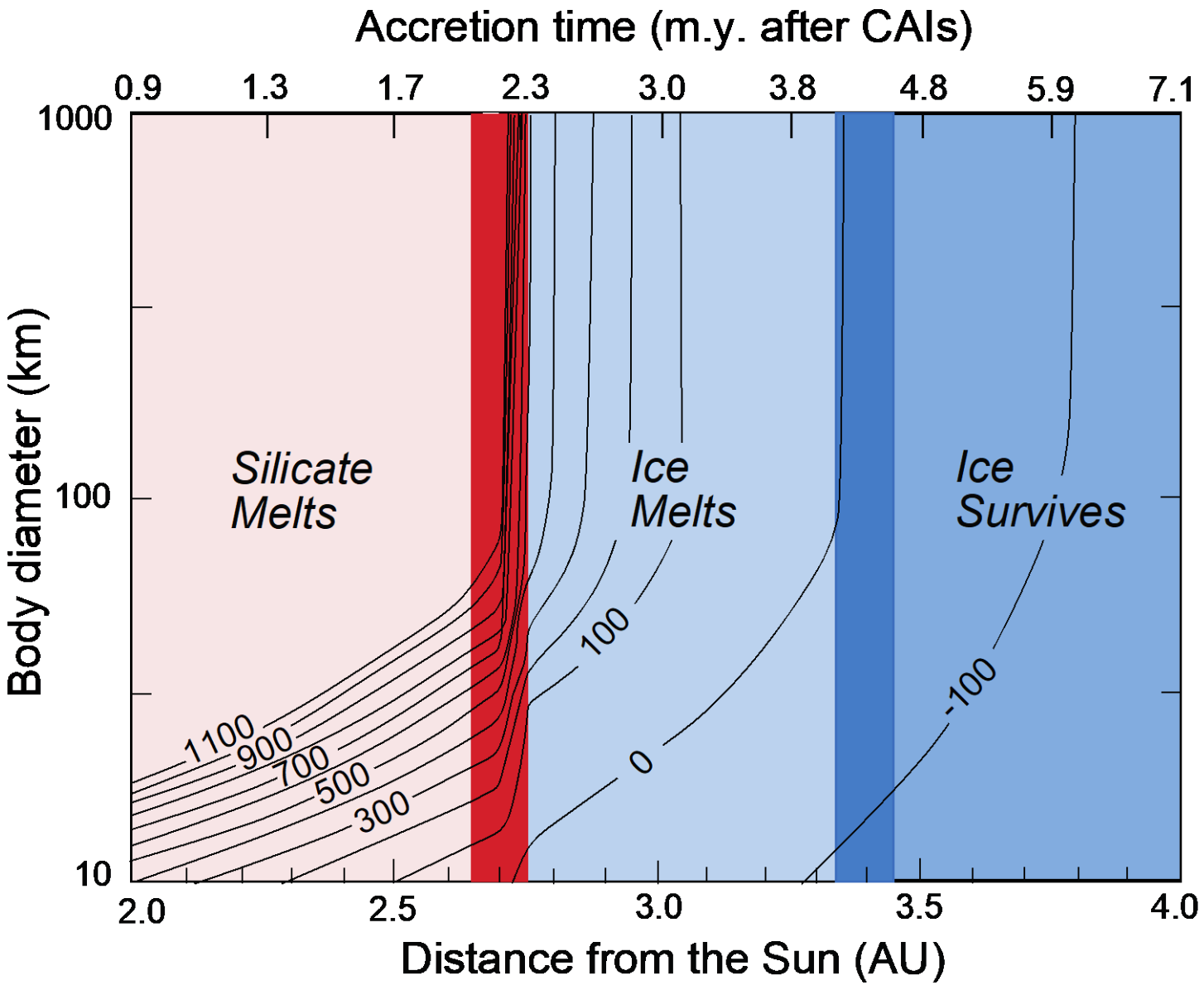
achondrite

Orbital distribution of asteroid spectral classes

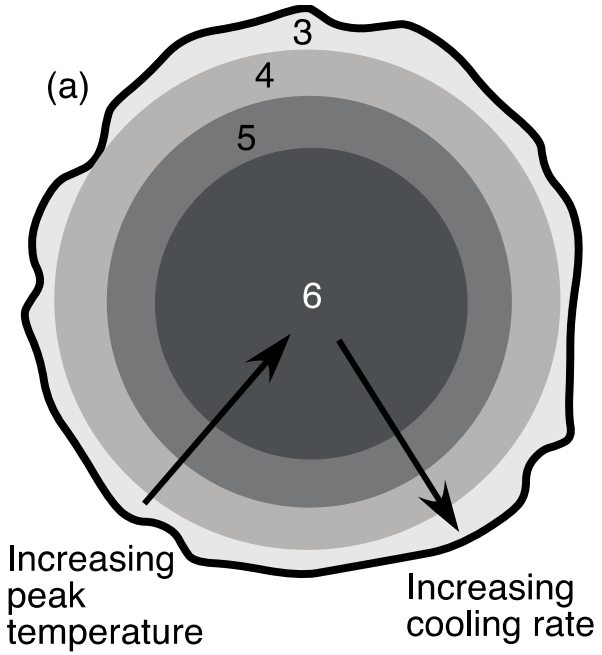
Lots of overlap, but melted and metamorphosed asteroids tend to be concentrated in the inner belt, aqueously altered bodies in the middle, and bodies in which ice never melted in the outer belt



Thermal model based on ^{26}Al decay

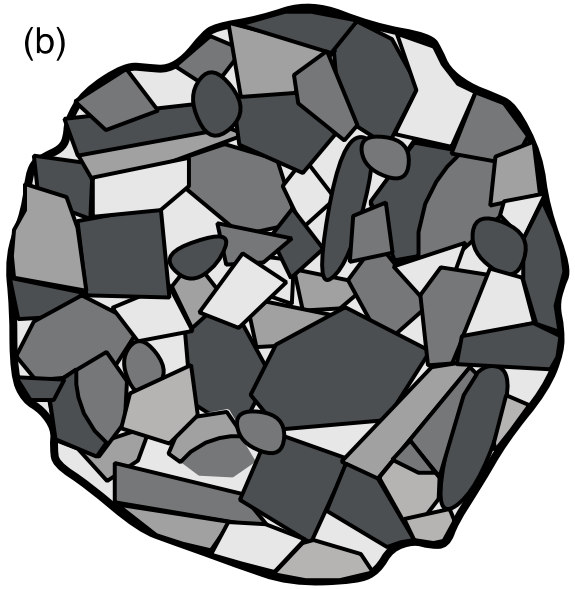


Asteroid structural models



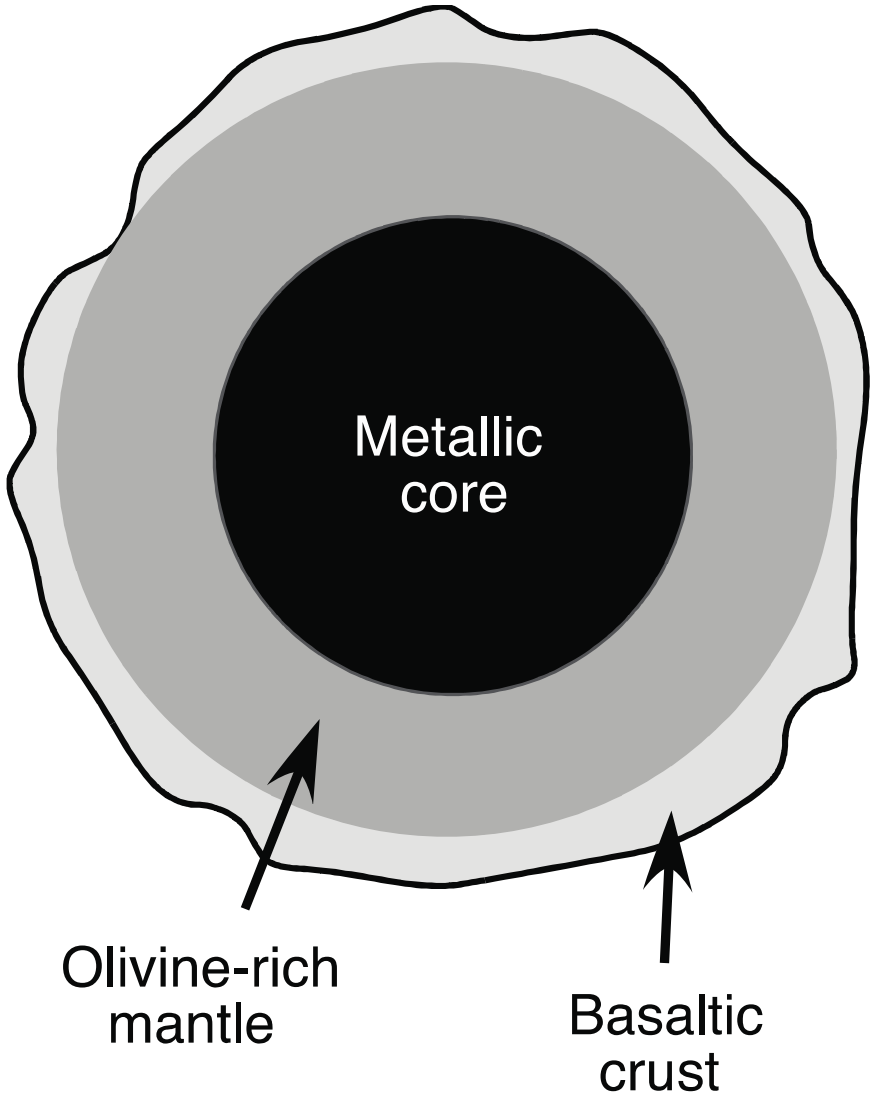
Onion shell (metamorphosed chondrite)

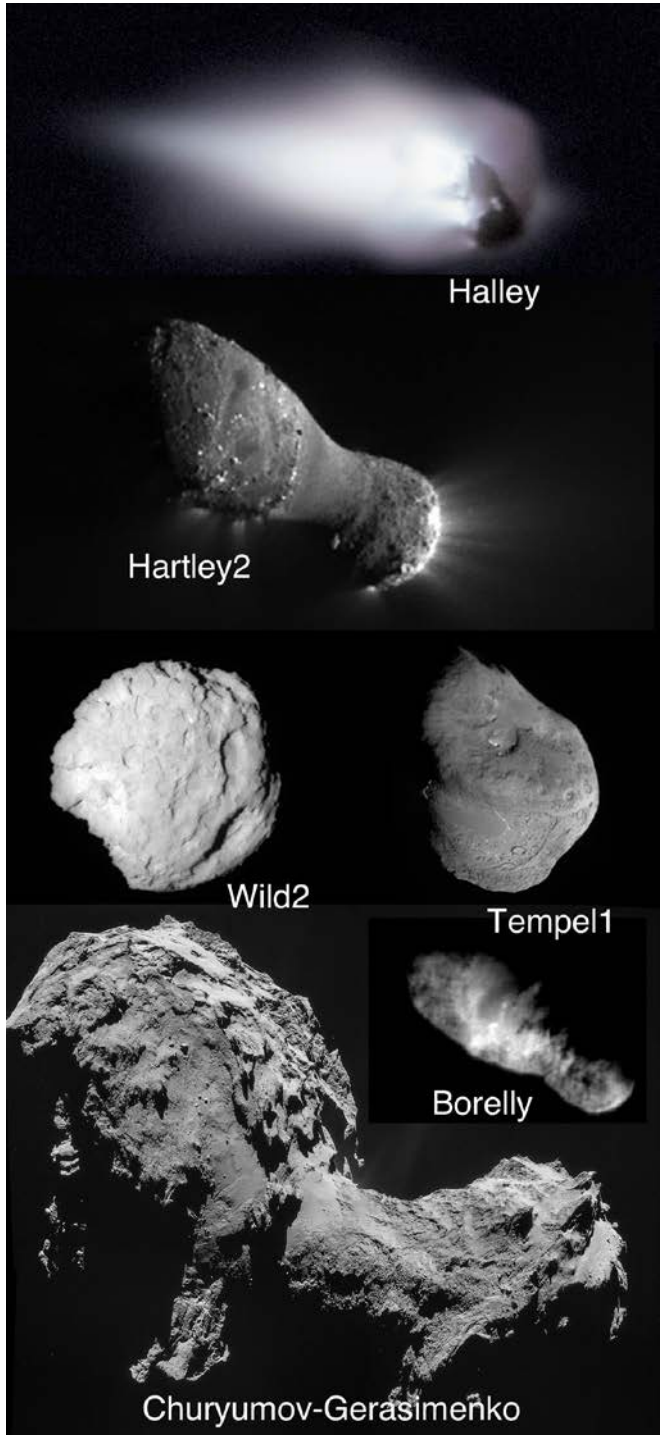
Aqueously altered?



Rubble pile (disrupted and re-accreted)

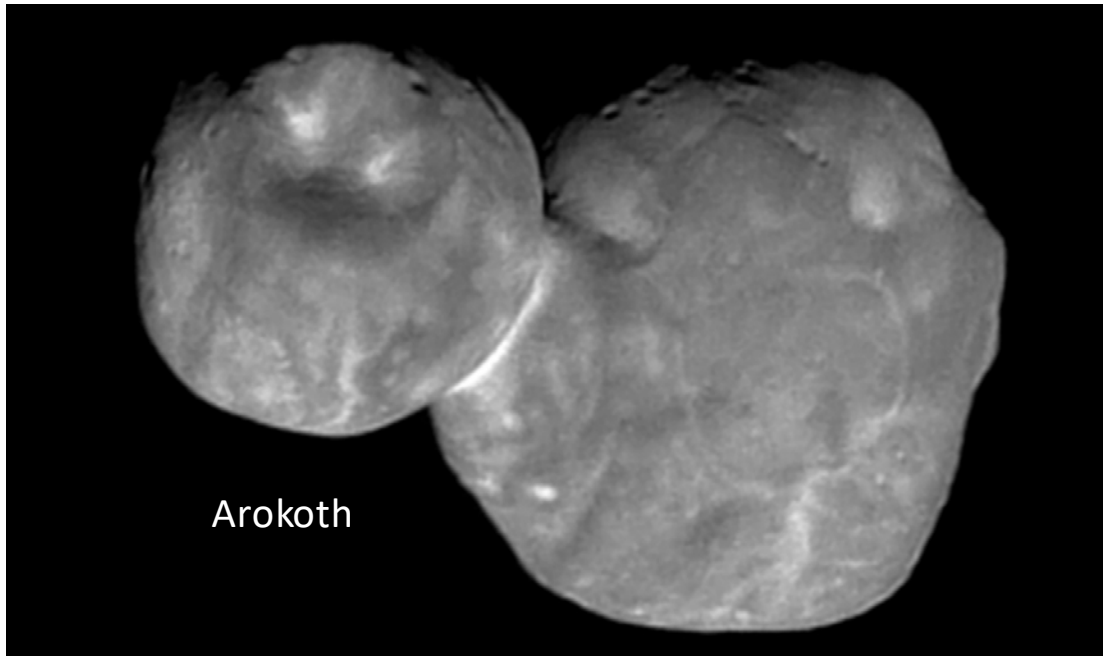
Differentiated (achondrite and iron)





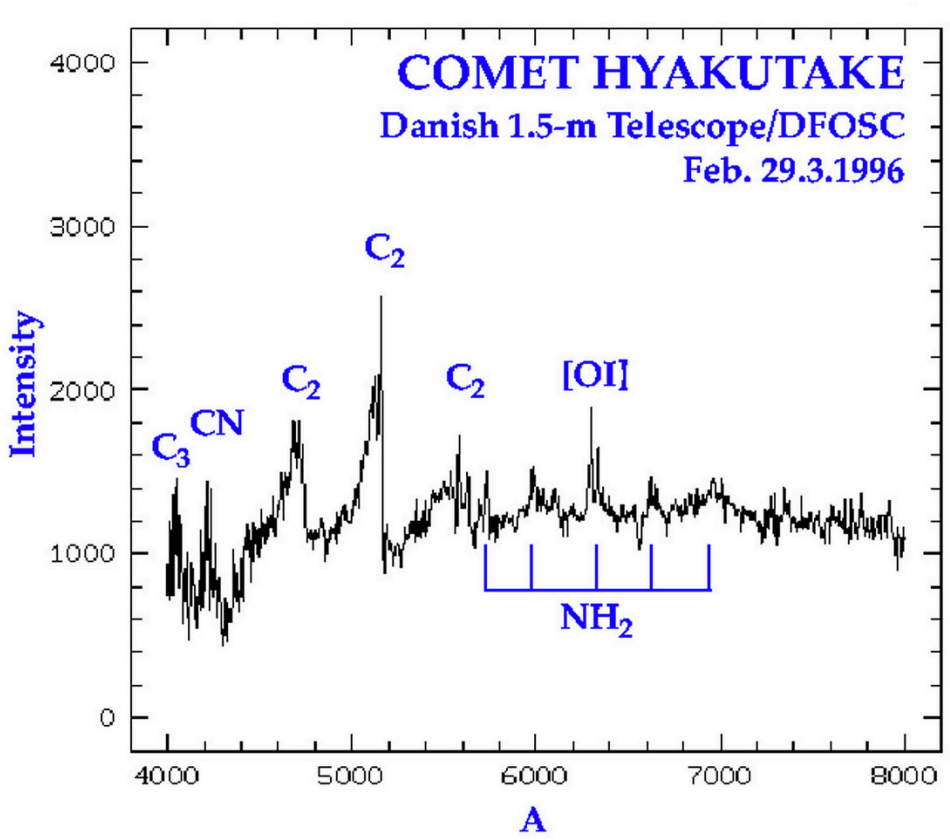
Comet nuclei (and a Kuiper Belt Object) visited by spacecraft – fragments or not?

(not to scale)

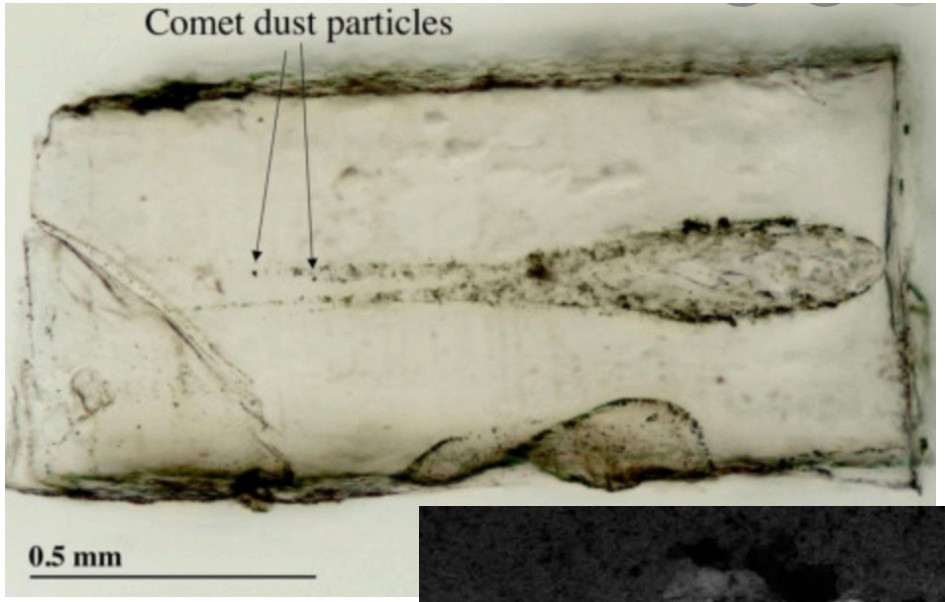


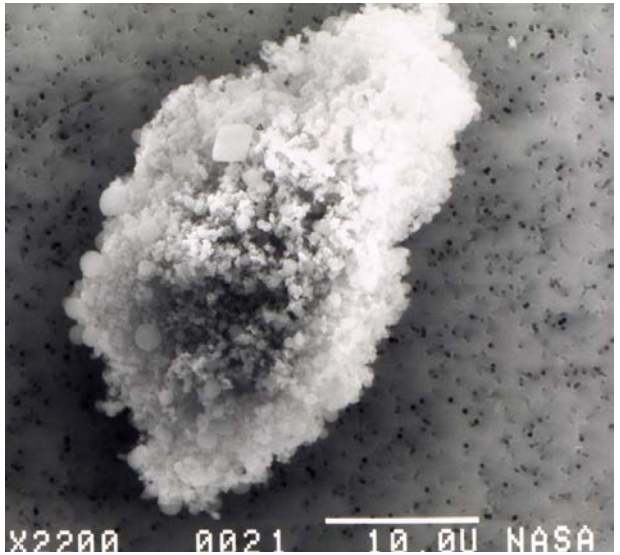
KBO, perhaps a comet in-waiting?

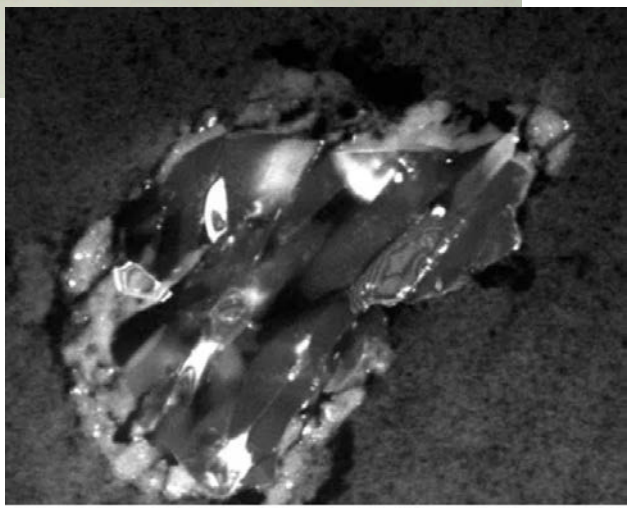
Spectra and samples of comets



Chondritic porous interplanetary dust particles (IDPs) are thought to be comet particles

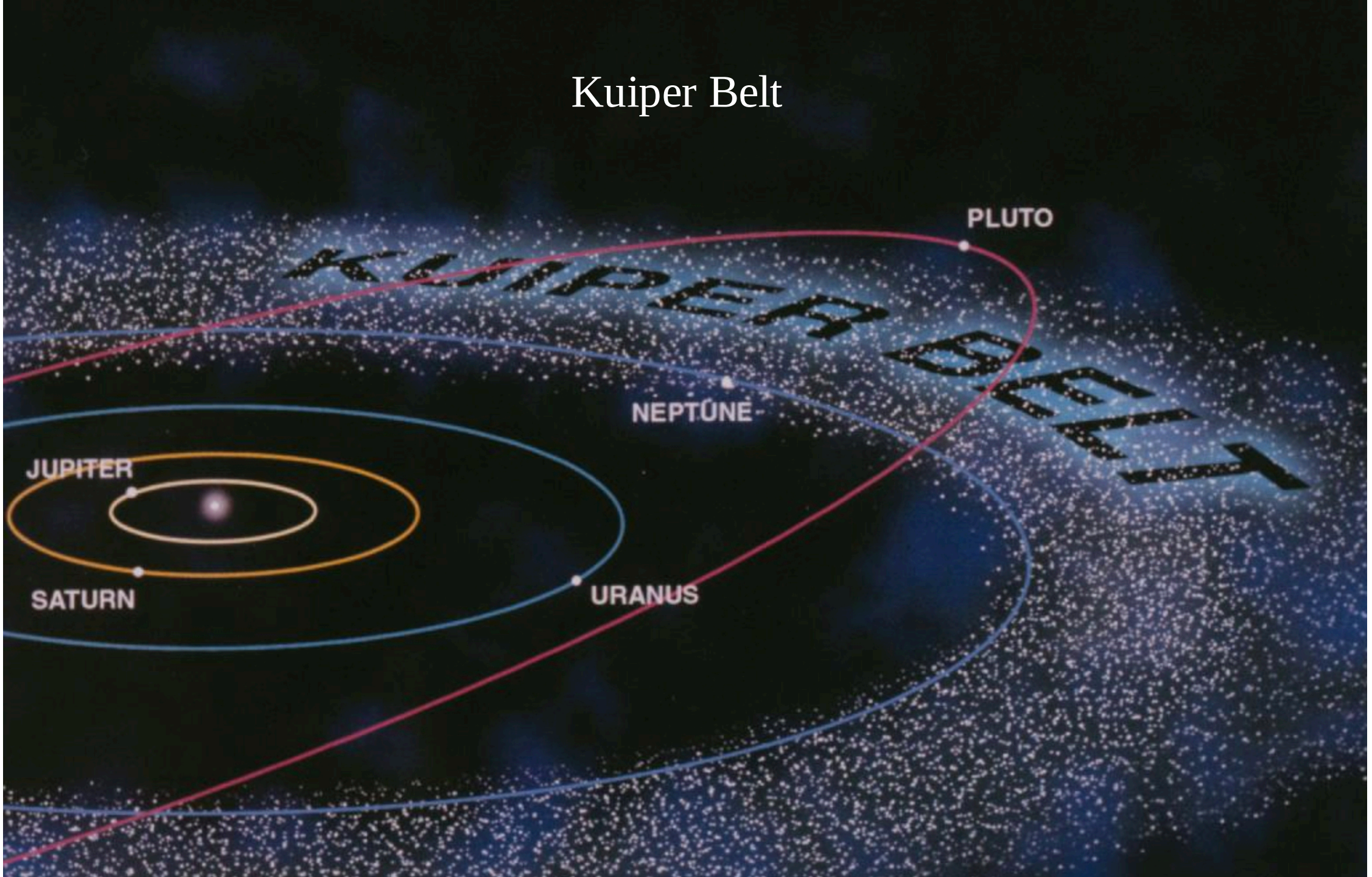




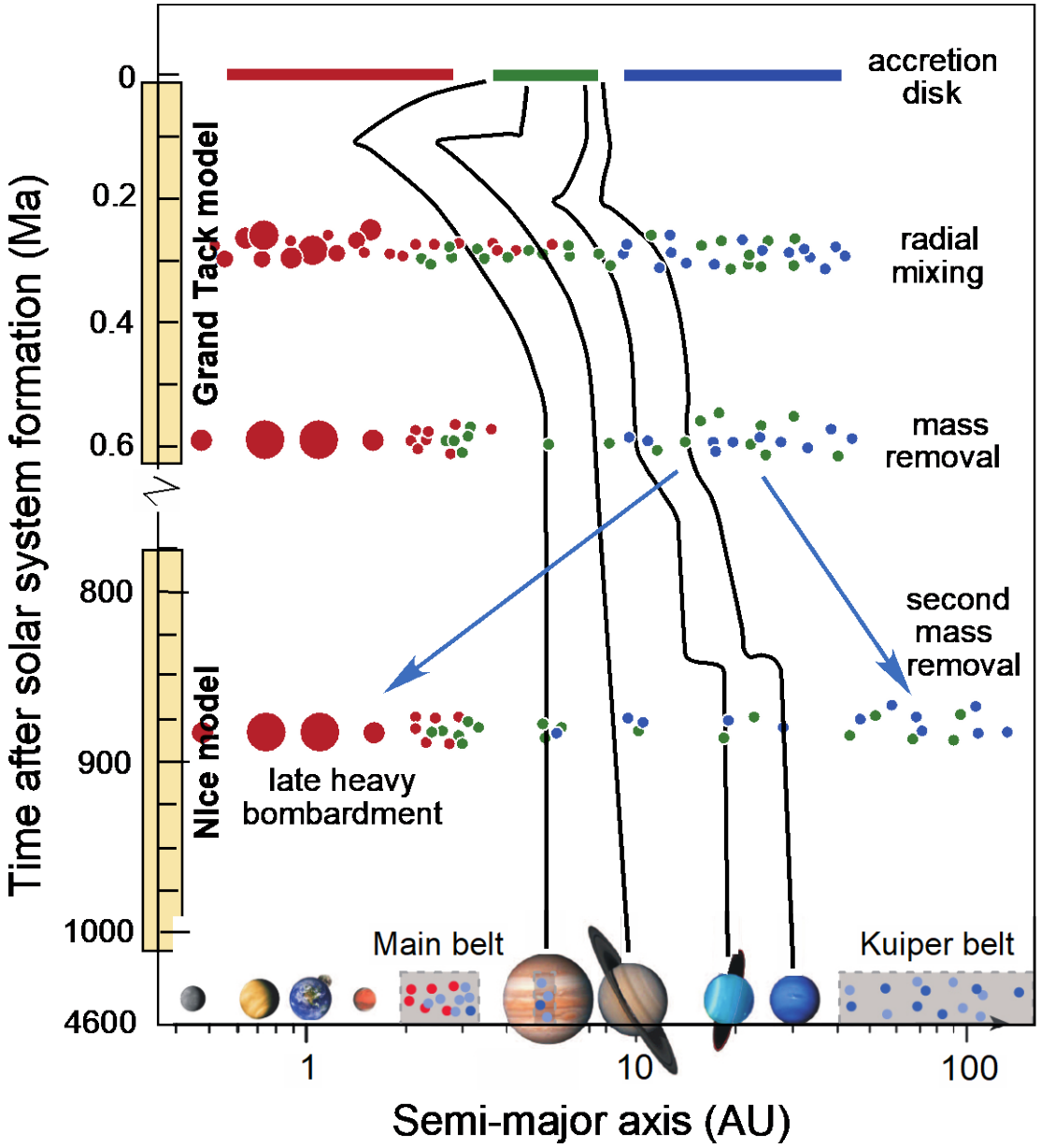


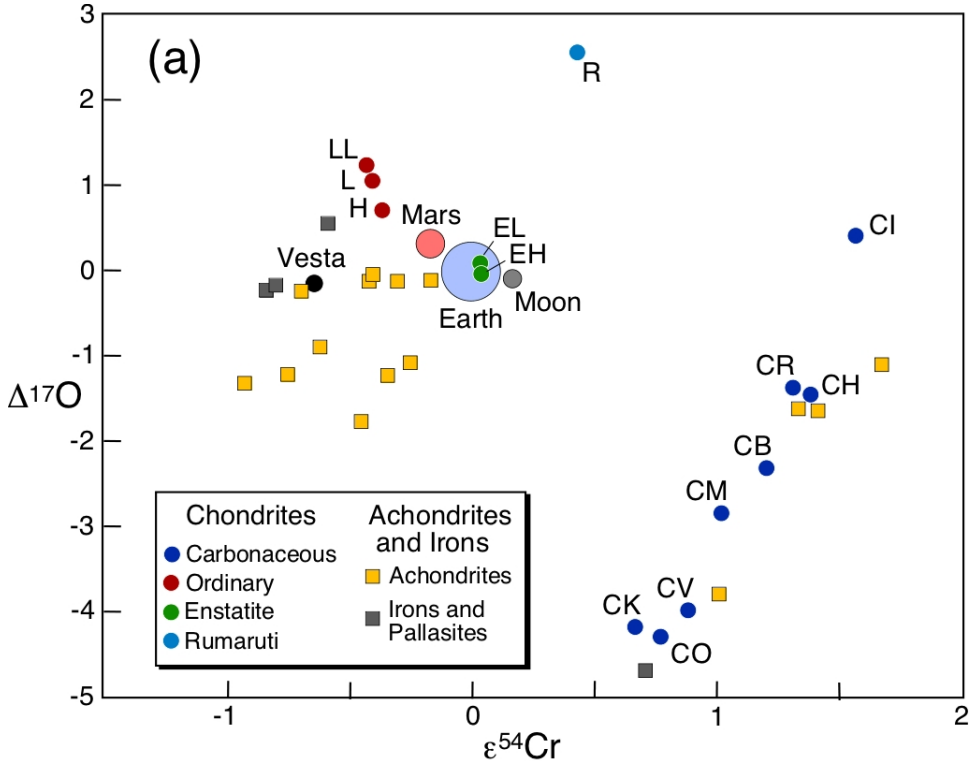
Stardust spacecraft returned comet samples

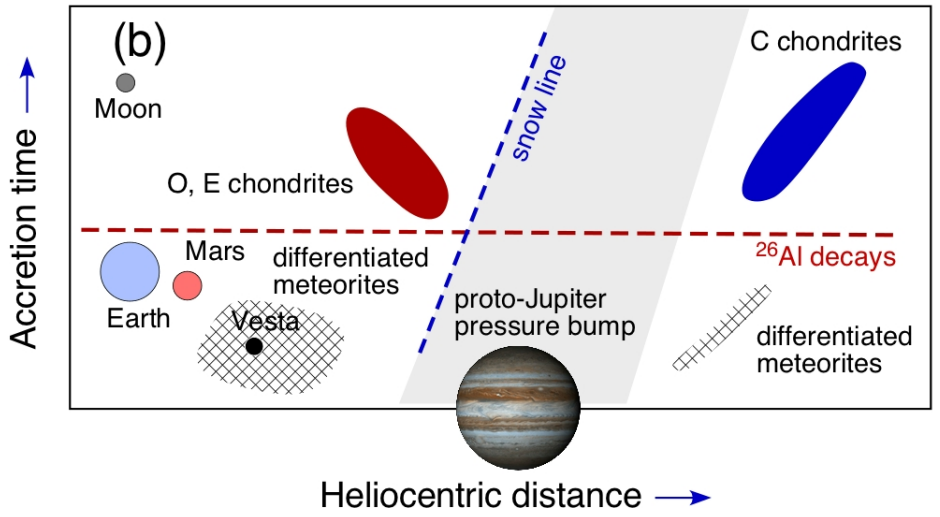
Kuiper Belt



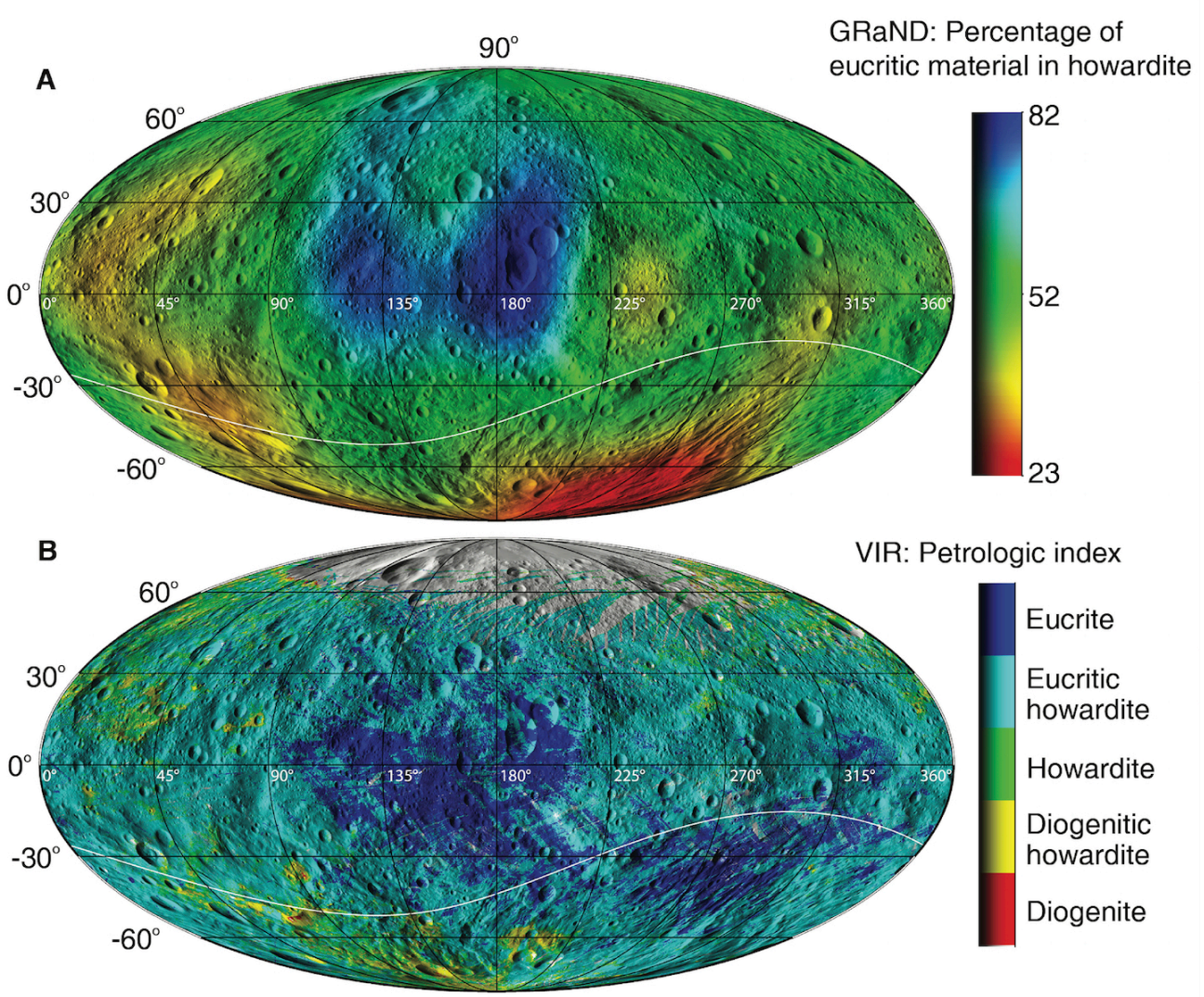
Migrations in the early solar system



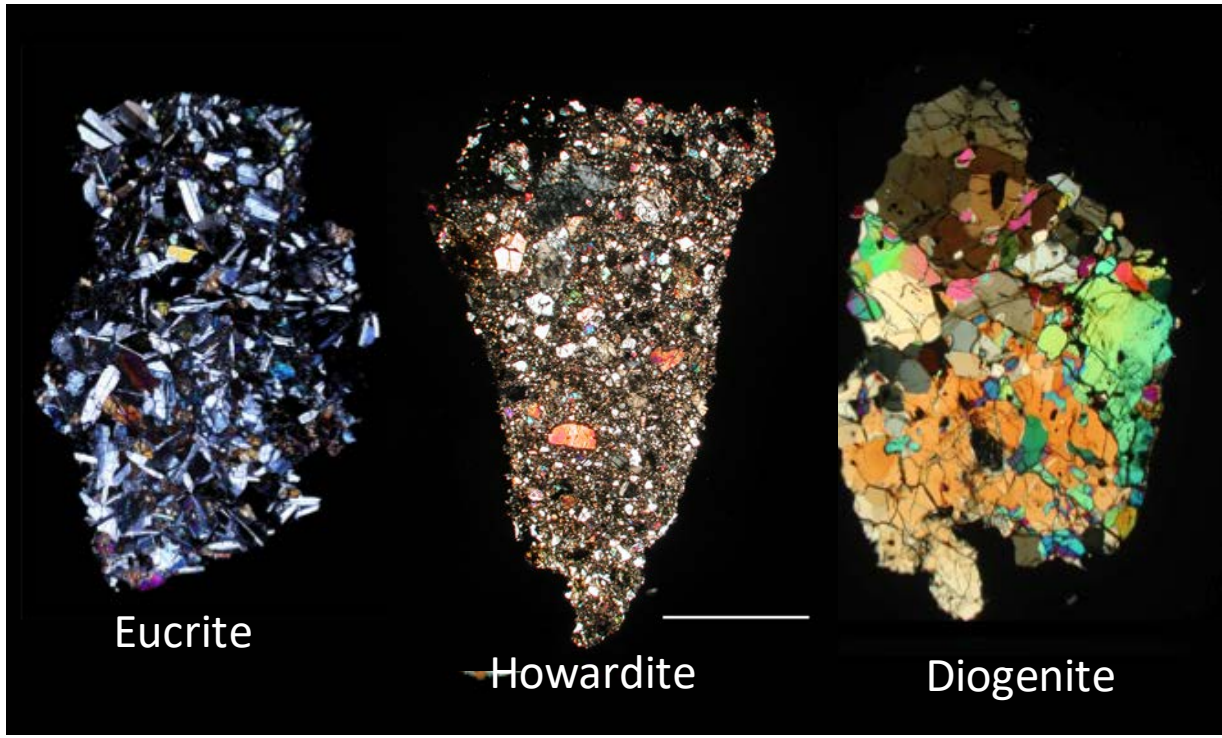




An example of a unique ‘small’ body: asteroid Vesta

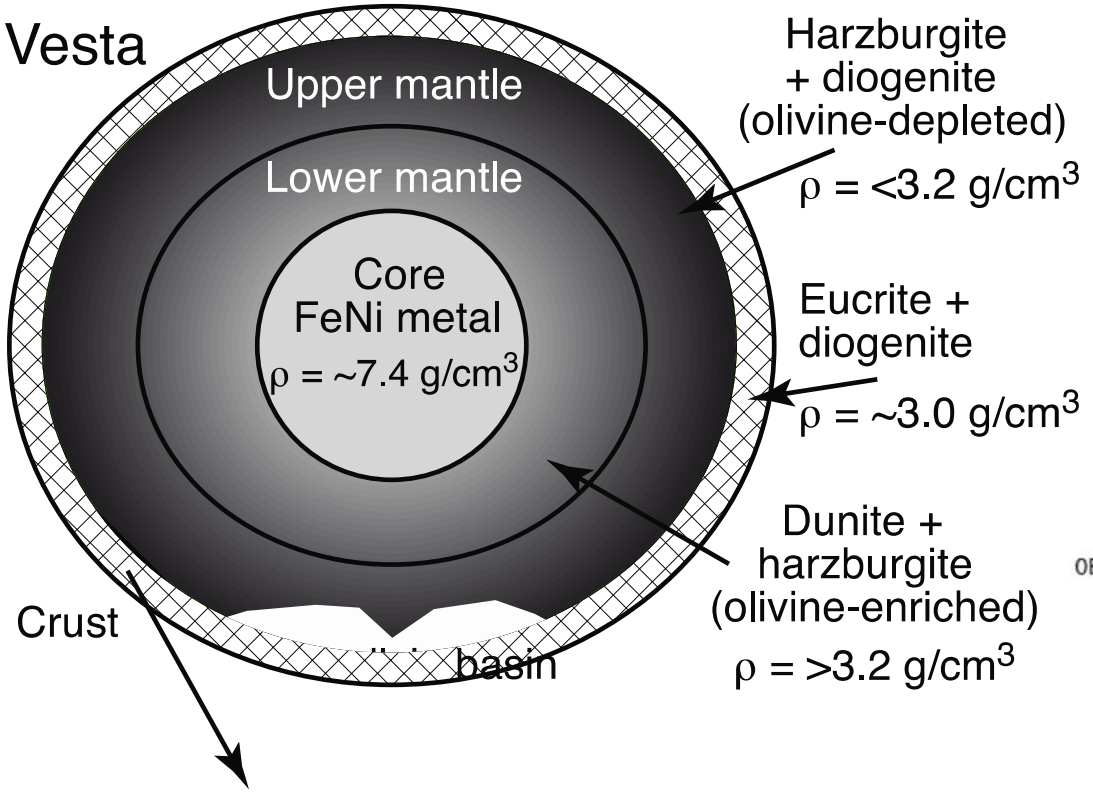


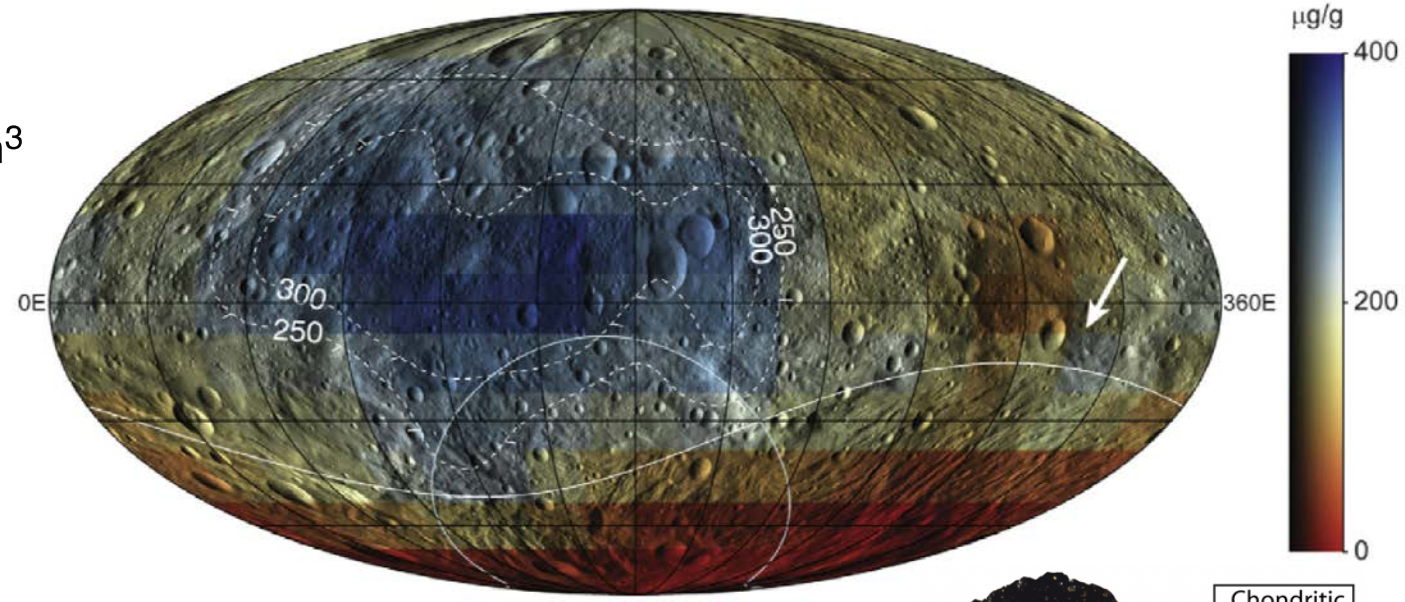
The only body tied specifically to meteorites



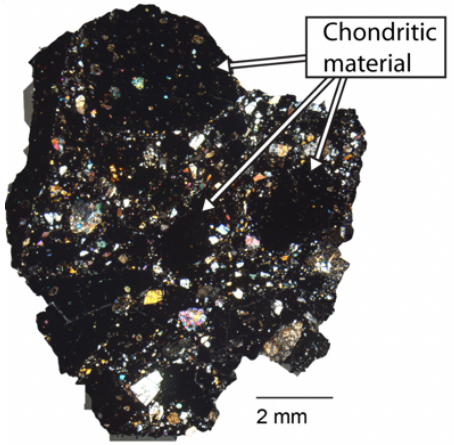
Vesta meteorites

Vesta: completely differentiated, igneous rocks and iron core



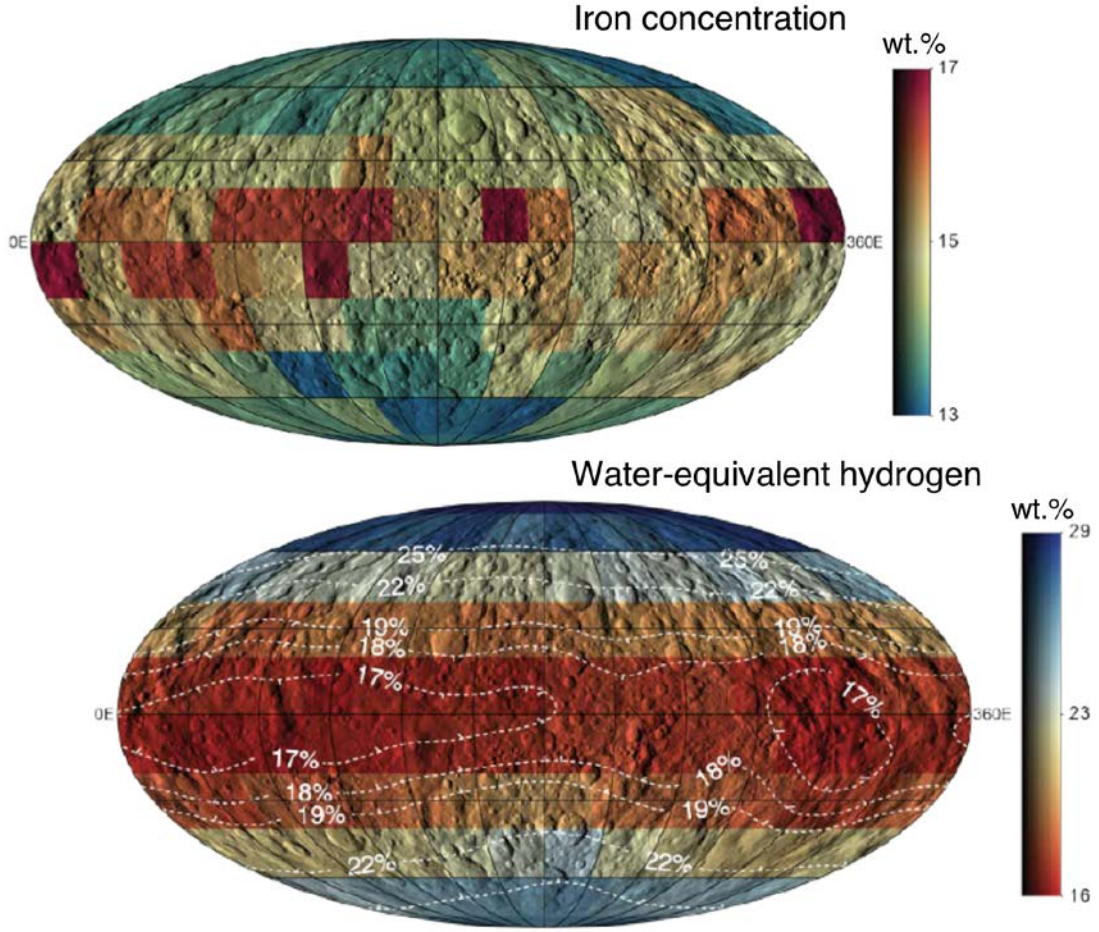


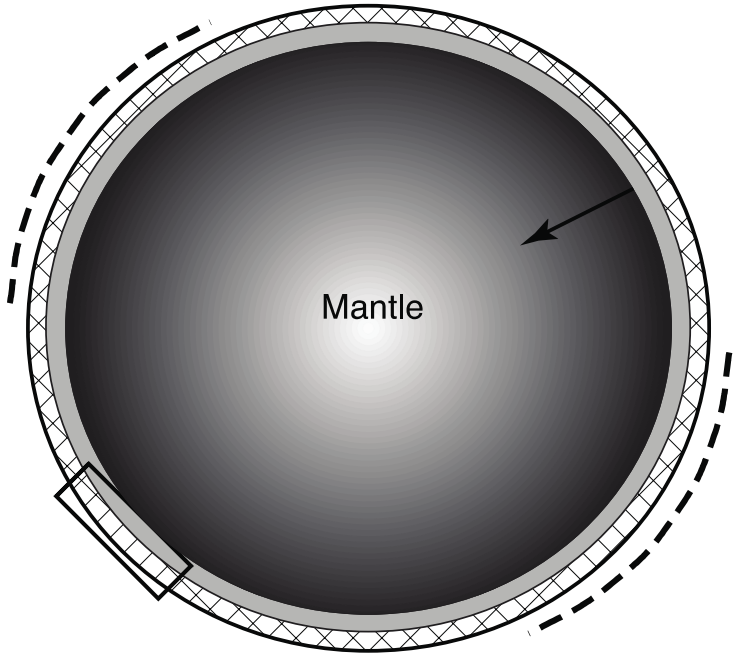
Hydrogen map, interpreted as H_2O

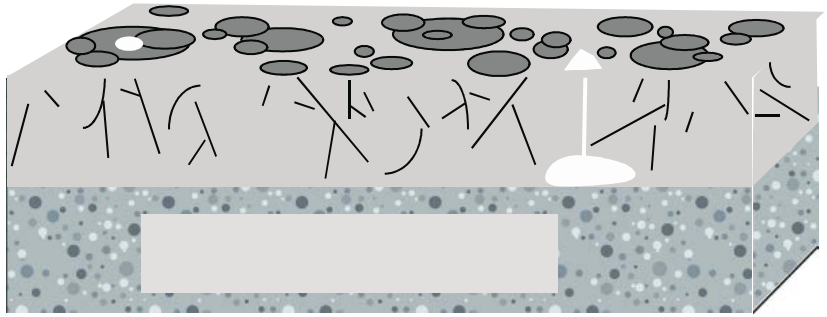


Vesta has been contaminated by a carbonaceous chondrite impactor

Another unique body: Ceres, pervasively altered by fluids, partially differentiated

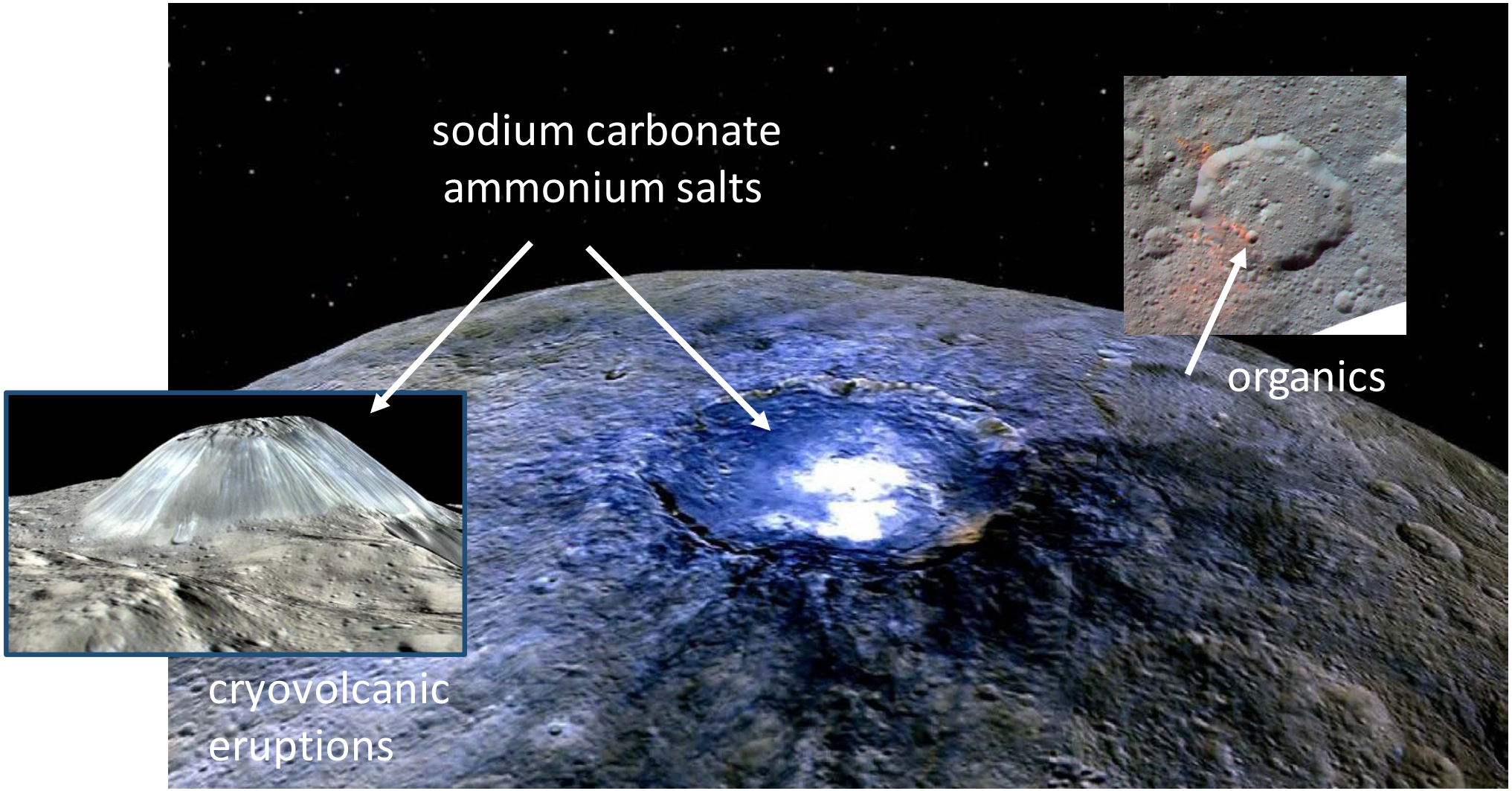






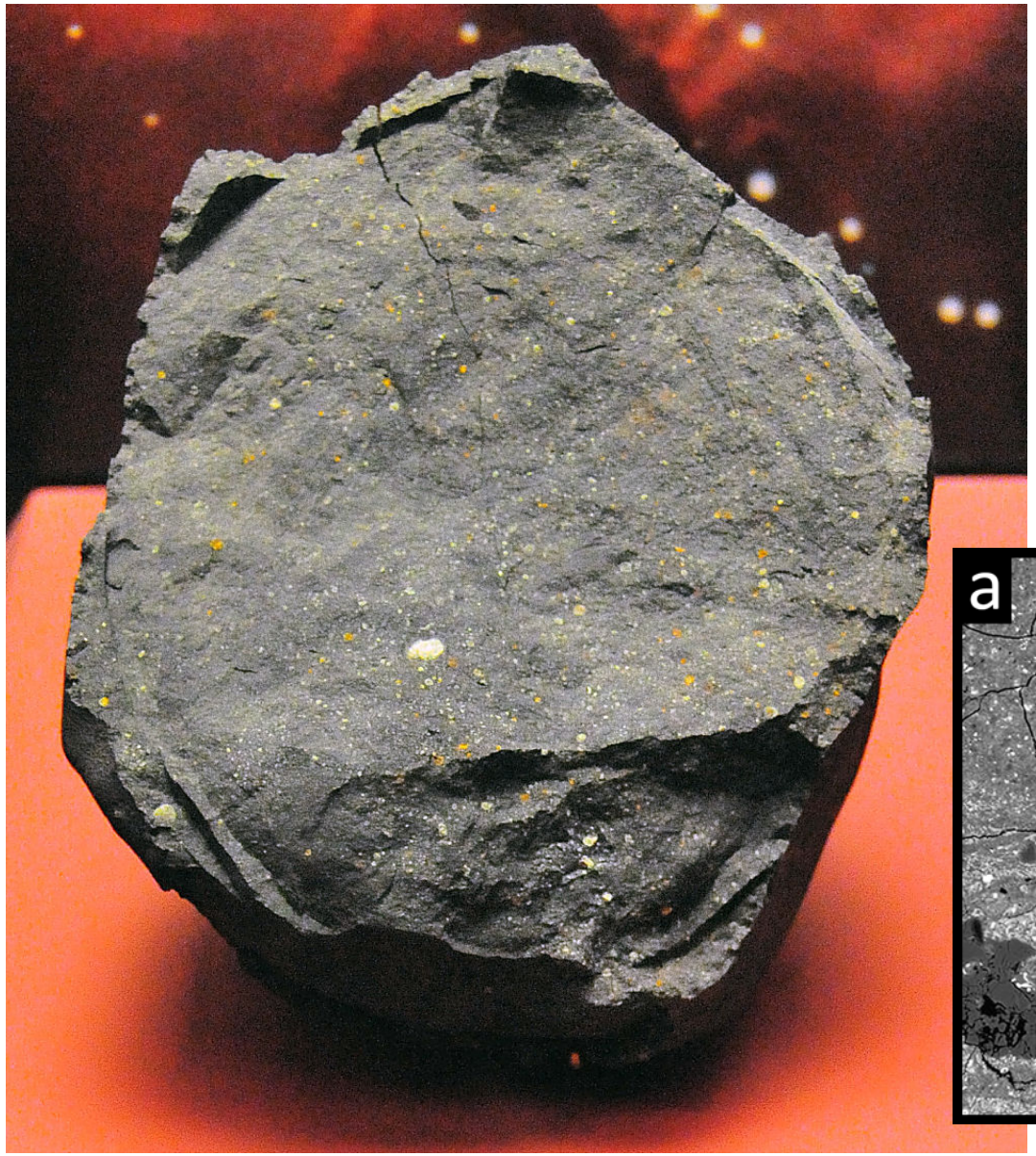
uddy upper mantle
grading into denser mantle rock
(ρ= 2.4-2.9 g/cm^3)

Ceres has erupting liquid brines and organics persisting today



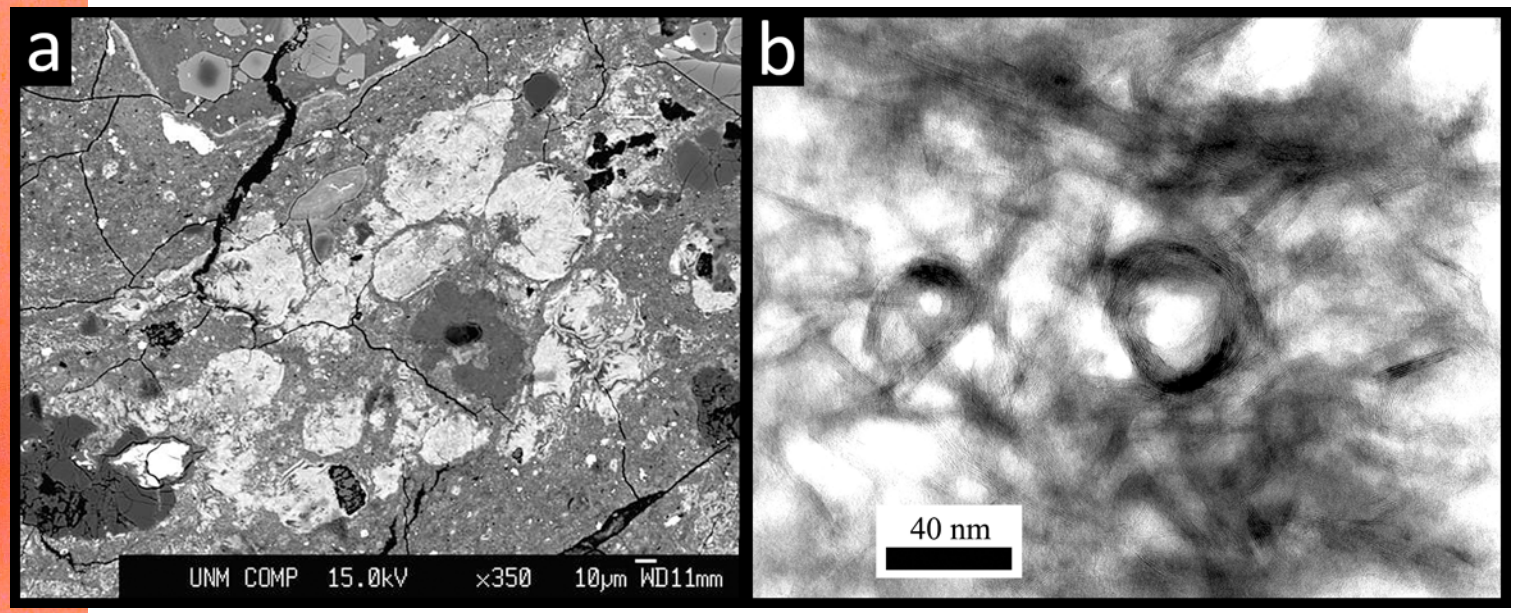
Some perspectives from meteorites

Meteorite breccias demonstrate that asteroids trade rocks, probably less likely for comets (KBOs)



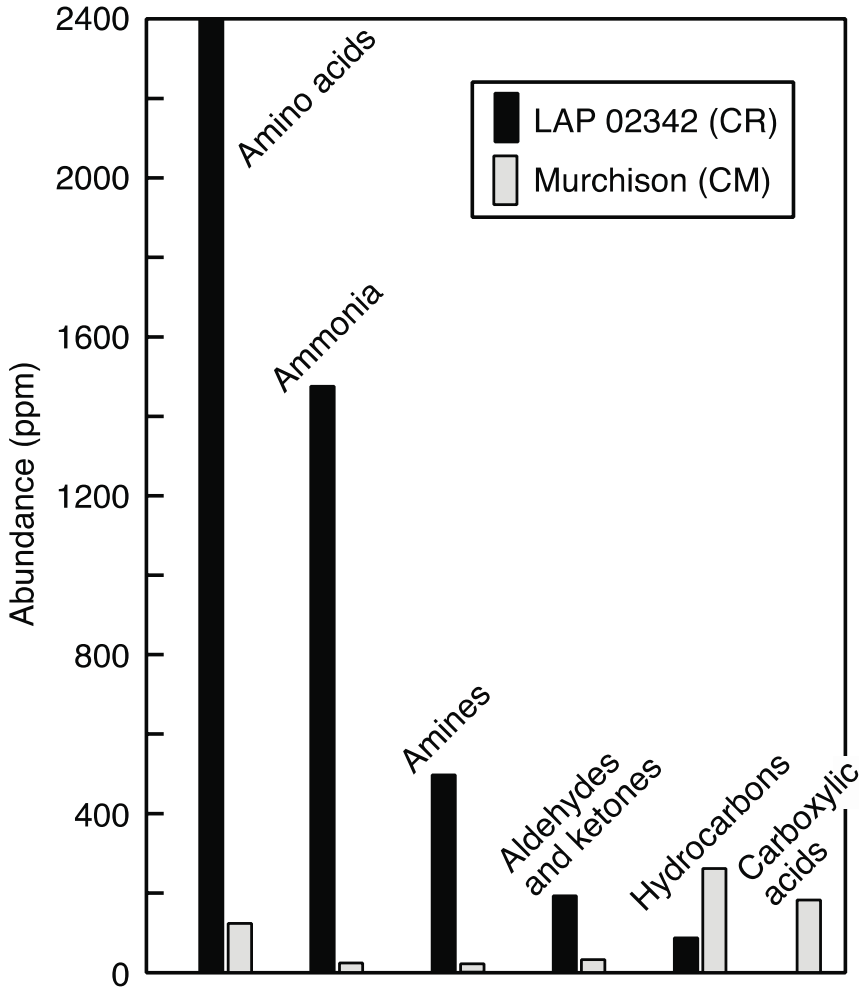
Astrobiologically interesting(?) samples come from aqueously altered carbonaceous chondrite asteroids

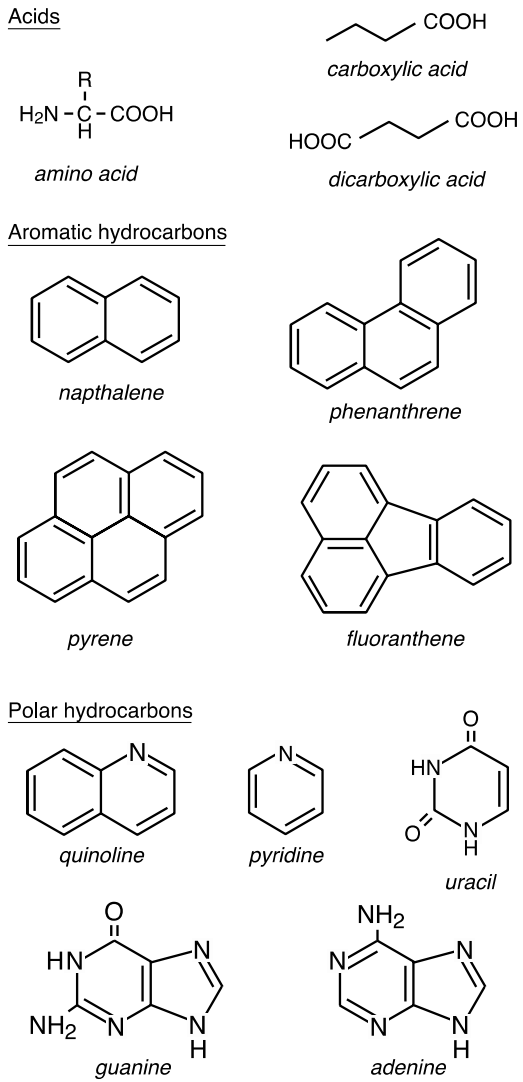
But, with the exception of Ceres, aqueous fluids only existed ~4.5 billion years ago



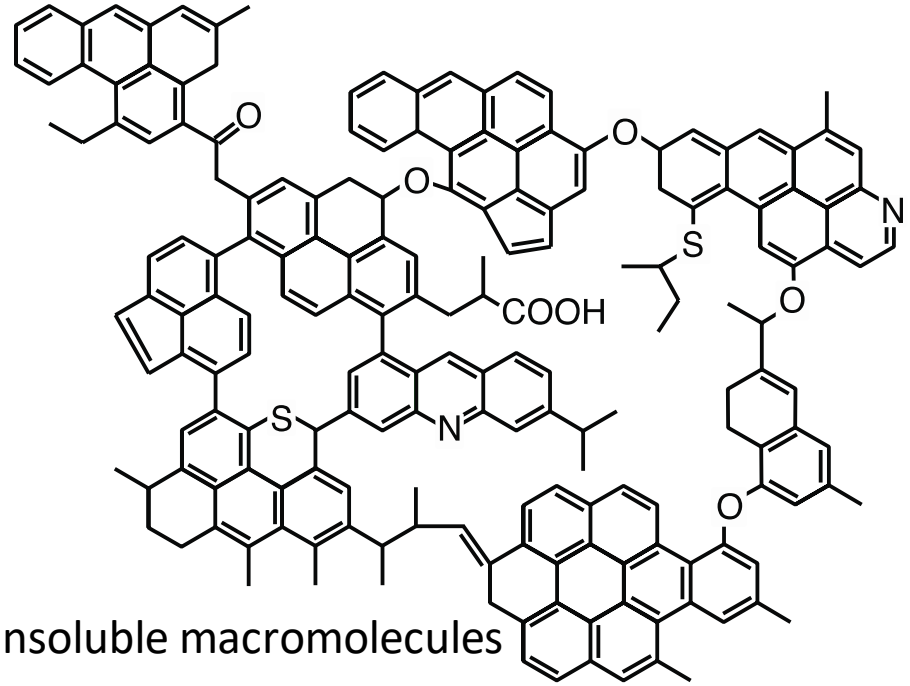
Organics in carbonaceous chondrites

Precursors for life, but no real indicators of life

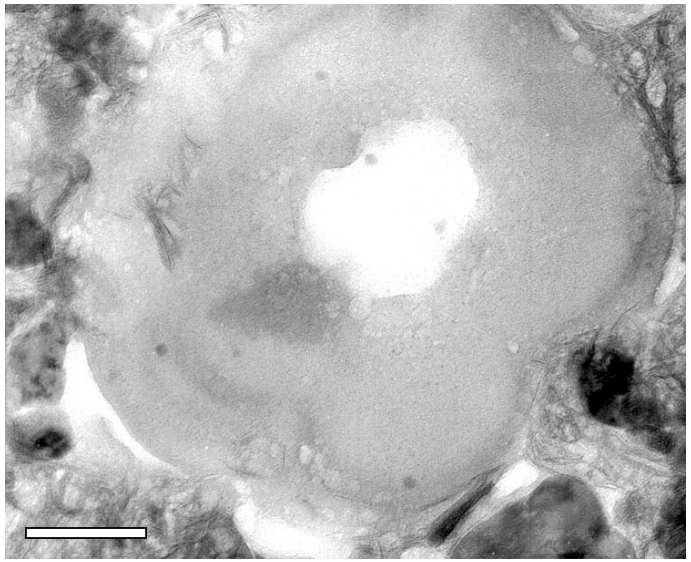




Soluble compounds



Insoluble macromolecules



Some takeaways – background on small body science

- Asteroids exhibit a range in thermal history, which correlates roughly with orbital distance, but significant mixing has occurred.

- Heating of small bodies by short-lived radionuclide decay occurred very early and produced liquid water in some ice-bearing bodies, or metamorphism/melting/differentiation in ice-free bodies; comets appear to be relatively unaltered; no effective heat source persists today except impacts.

- Most asteroids, and possibly KBOs(?), are collisional rubble, with only a few intact bodies surviving, and reaccreted rubble piles are common, as revealed by low bulk densities.

- Migration of giant planets in the early solar system may have scattered small bodies outward to the Kuiper Belt and and inward to the Main Belt.

- Resonance escape hatches in the Main Belt offer a means of scattering/sampling modern asteroids.

- Two of the largest, best-studied small bodies reveal melting and differentiation of silicate and metal (Vesta) or pervasive aqueous alteration and fractionation of ice/silicate (Ceres); these processes occurred early in solar system history, although aqueous fluids continue to erupt on Ceres.

Some possible takeaways relating to your study

- Organic matter is ubiquitous in comets and asteroids; it is inherited from interstellar space, as revealed by extreme isotopic fractionations, but has been further processed in the nebula and/or within small bodies after accretion.

- Organic compounds in meteorites and IDPs are aliphatic or aromatic, often occurring as complex macromolecules, but they show no evidence of life, past or present.

- Ongoing aqueous eruptions on Ceres (if you consider it to be small) offers the only known liquid water (possibility for extant life?) in small bodies.

- The fact that most asteroids are collisional fragments and the common occurrence of asteroids with rubble-pile structures indicate that catastrophic collisions have affected most small bodies.

- Meteorite breccias that are samples of regoliths (on Vesta, and on chondritic asteroids) demonstrate that small bodies are already contaminated with foreign material.

Science perspectives on your task

How unique are small bodies, and can we risk contaminating some of them by spacecraft missions?

- Most small bodies are not unique, but large, intact asteroids and some comet nuclei may be unique.

- Although sampling is biased and limited, what we have learned from meteorites, IDPs, and a few returned samples of asteroids and comets suggests that we can recognize terrestrial biologic contaminants.

- Many, perhaps most, small bodies may already be cross-contaminated with exogenic organic (albeit abiotic) material.