# Probing asteroids with remote sensing and sample return

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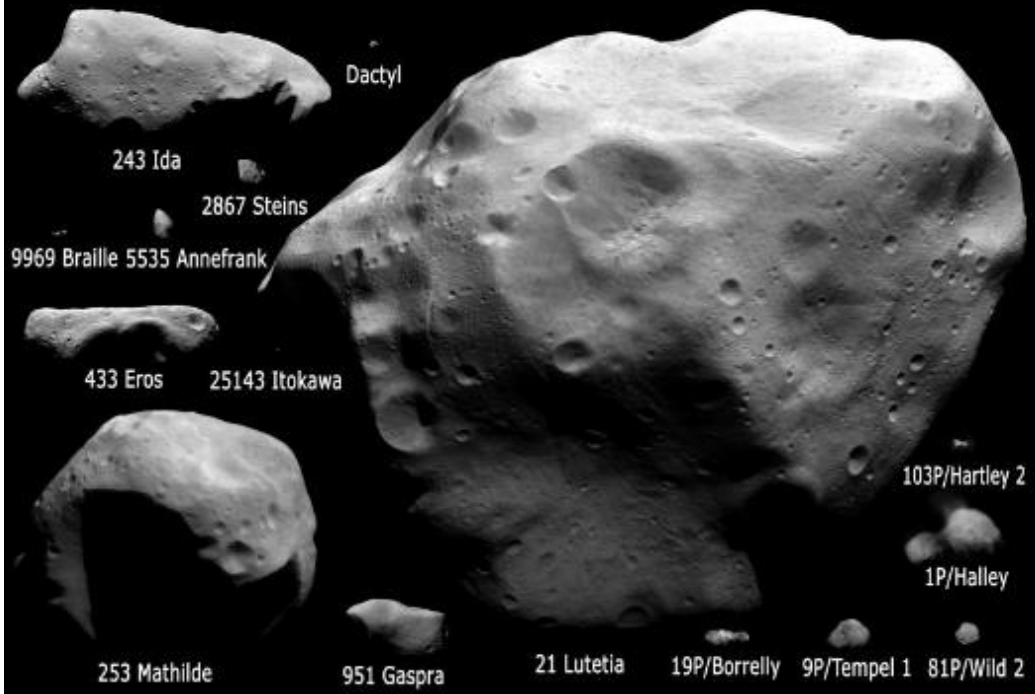
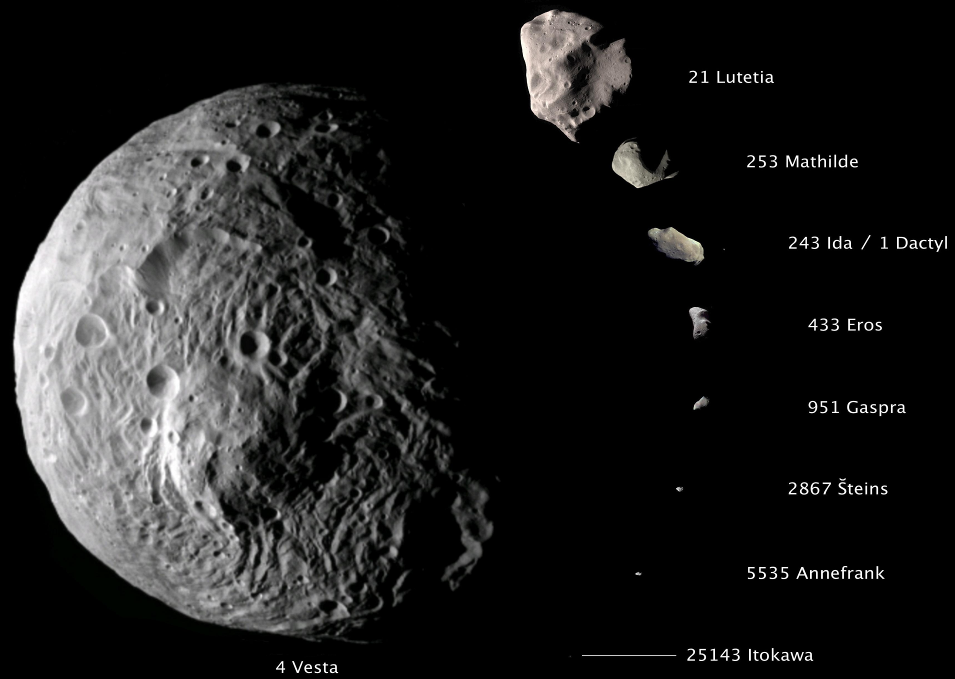
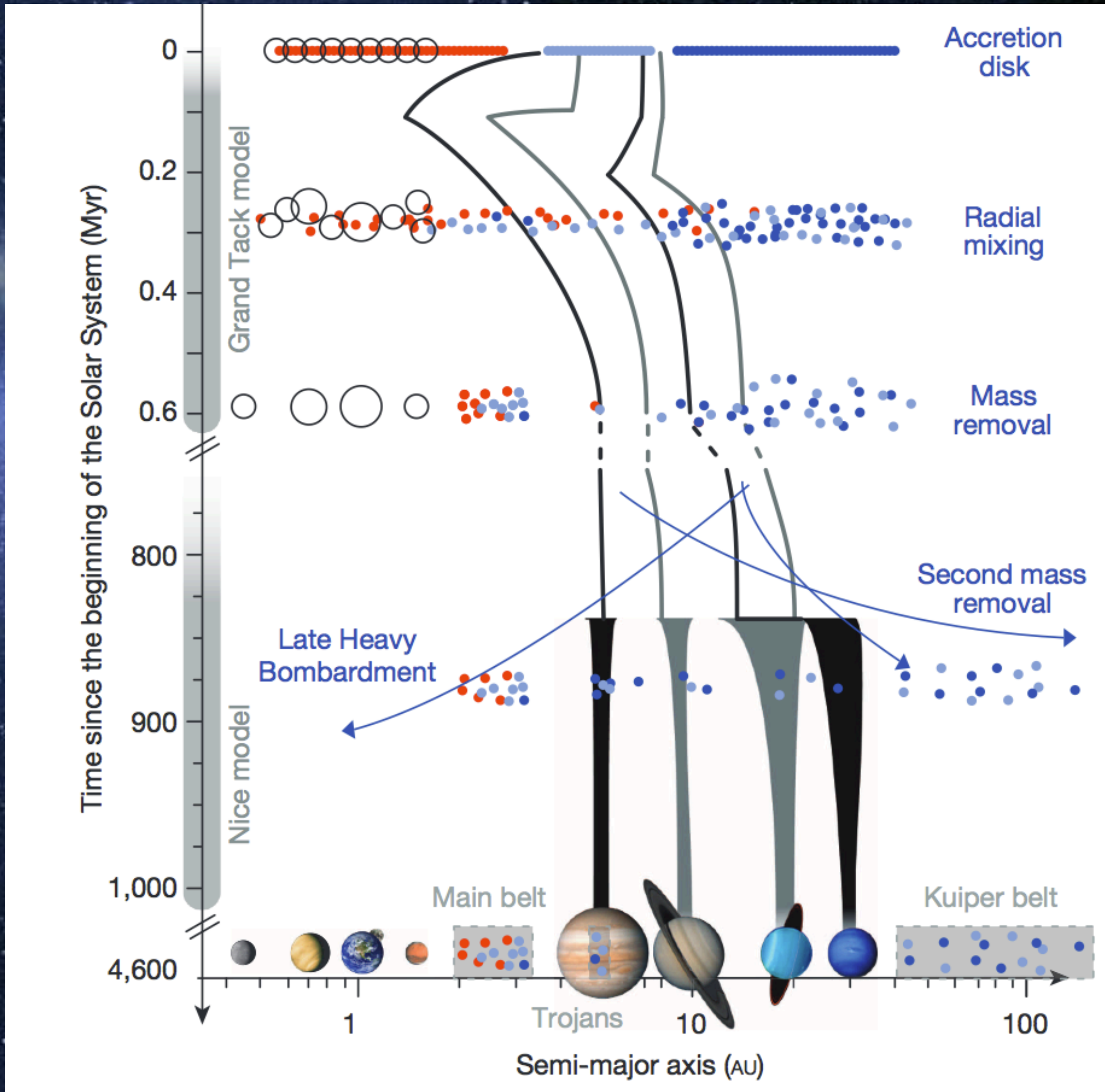
# Diversity



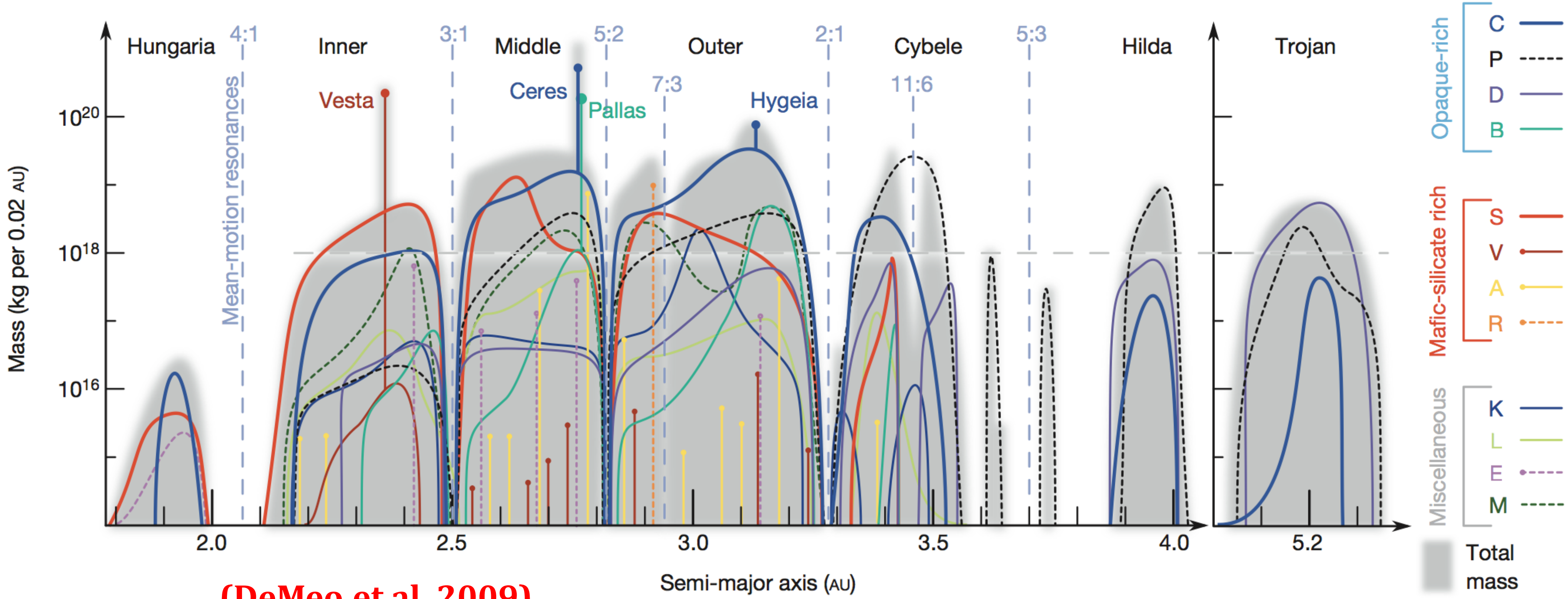

~100 km

~500 km

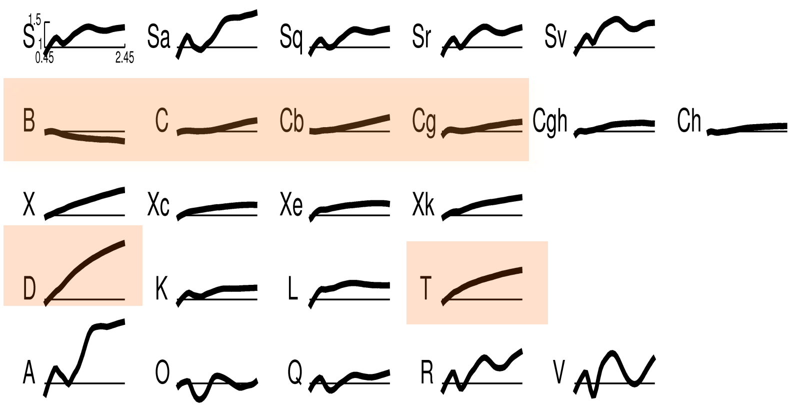



DeMeo et al. 2014

# Asteroid Types



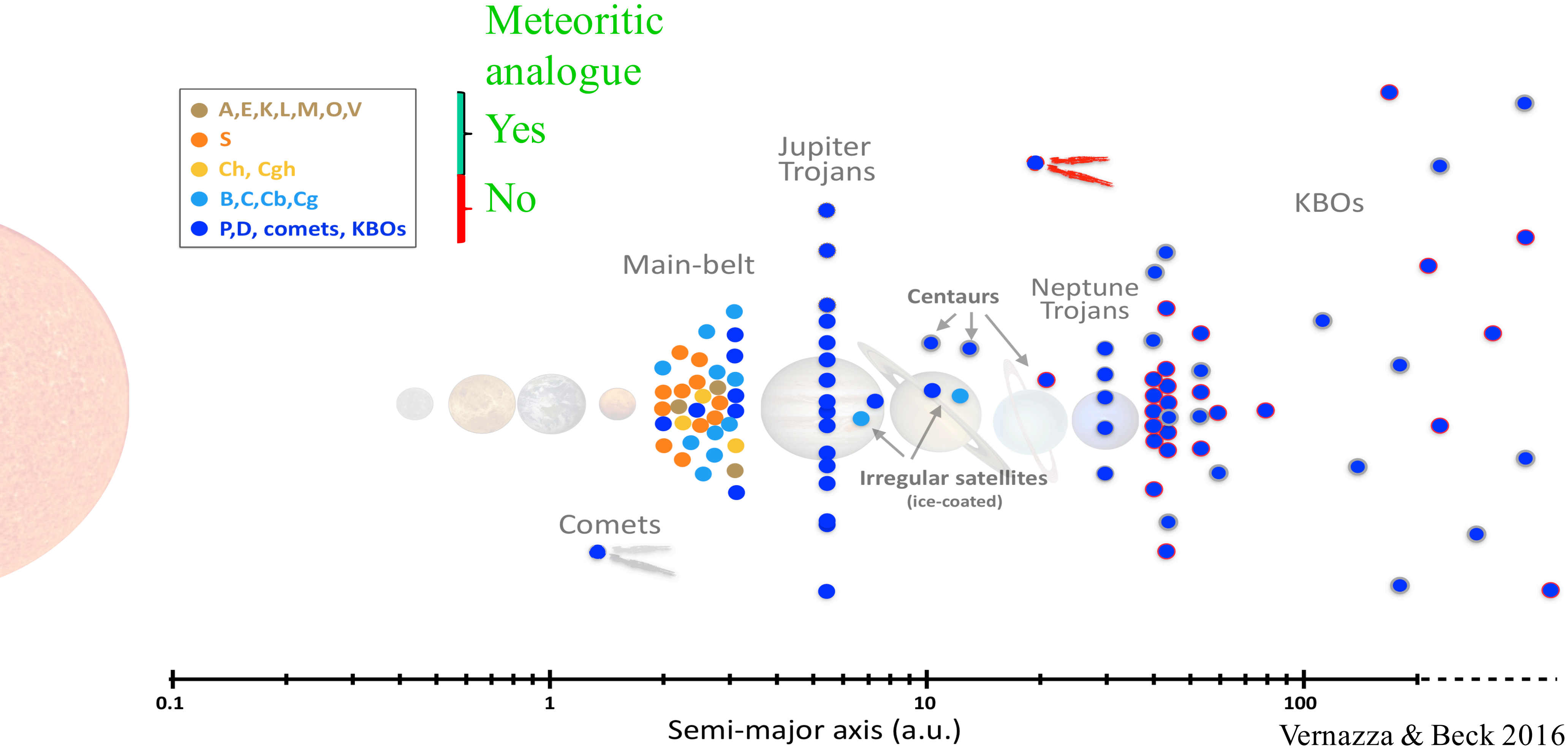

**(DeMeo et al. 2009)**




**6 asteroid types, ~2/3 of the mass of the asteroid belt seems absent from our meteorite collections**

# What is in common on low albedo objects ?

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

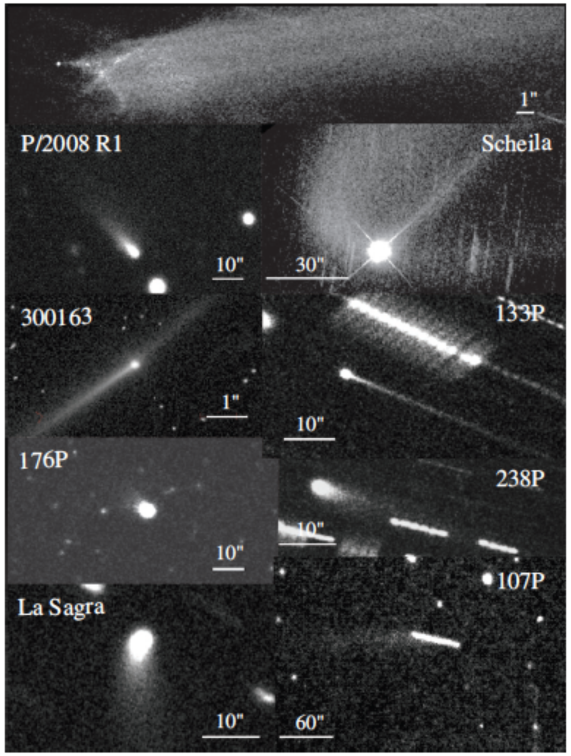



Vernazza & Beck 2016

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

-- very fragile material
-- volatile-rich as implied by their low density (0.8-2 g/cm$^3$)
-- comet-like activity in some cases
-- ??

## Main belt comets




## Water ice on Ceres

CombE et al. 2016
De Sanctis et al. 2016

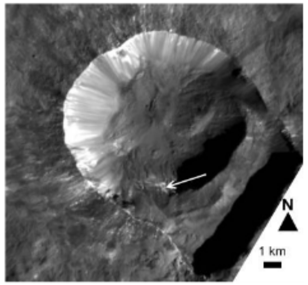
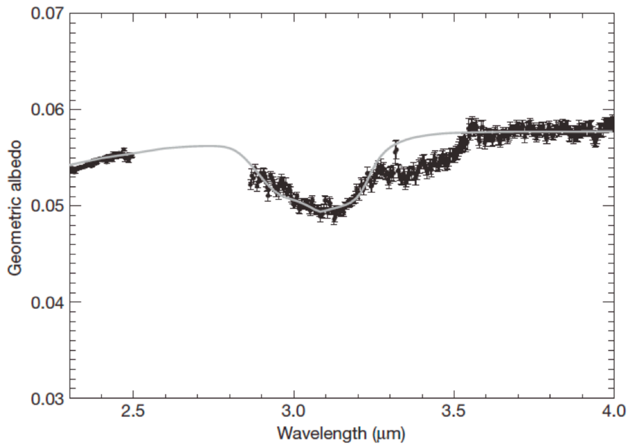


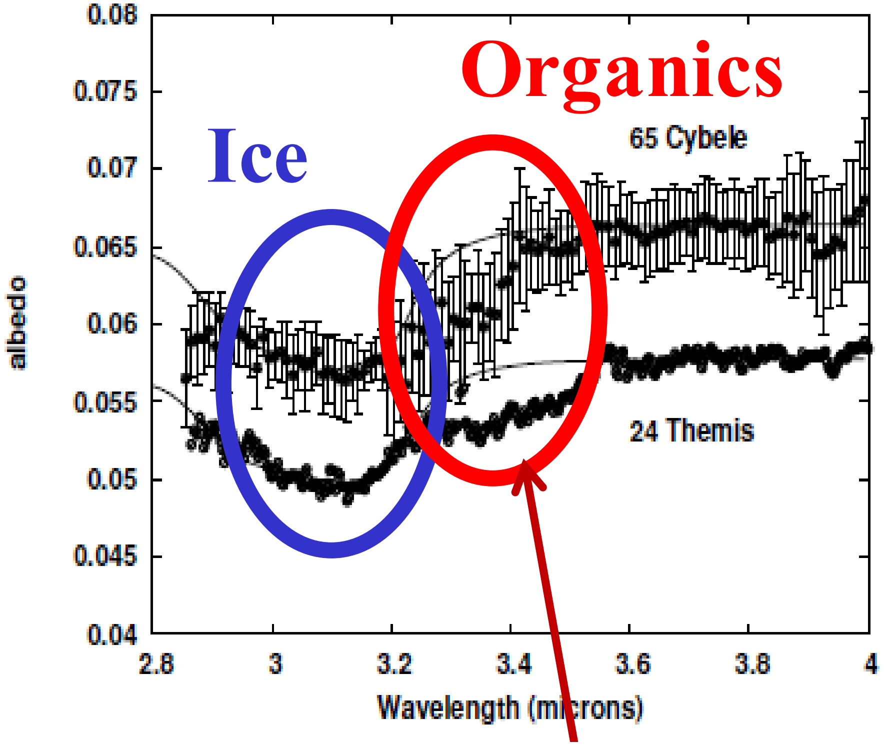

Fig. 1:Crater Oxo observed by the Dawn spacecraft Framing Camera during the Low altitude Mapping Orbit. The white arrow indicates the location of the $H_2O$ detection by VIR.


## Water ice at the surface of Themis & Cybele and probably Trojans




Campins et al. 2010
Rivkin & Emery, 2011
Licandro et al. 2011

# Ice + Organics on asteroids 24 Themis and 65 Cybele



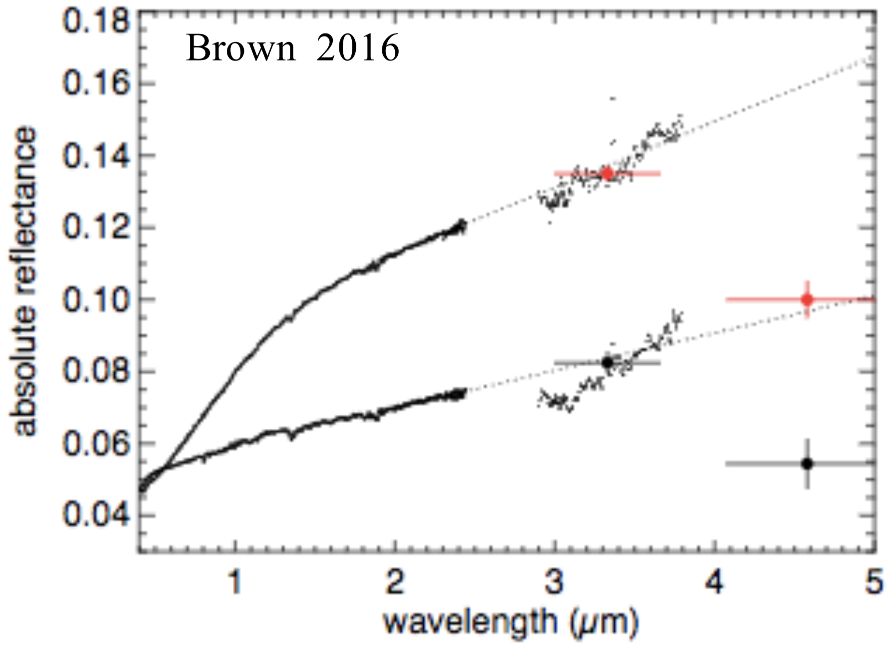

**Ice Tholin" added to the mixture of water ice and anhydrous silicate**
**Campins et al. 2010**

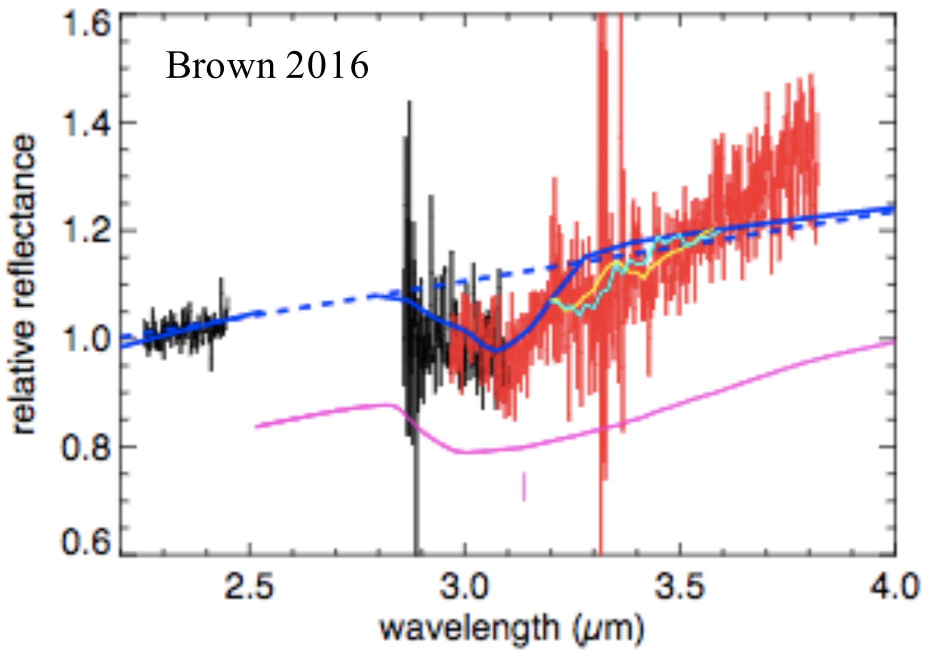
**Themis:** largest fragment of a family
orbiting near 3.2 AU
Diameter ~ 200 km
Albedo of ~0.07

**Cybele:** largest of dynamical group between 3.3 & 3.7 AU
orbiting near 3.4 AU
Diameter ~ 300 km
Albedo of ~0.07

# Trojans survey (16 asteroids)

2 sub-populations



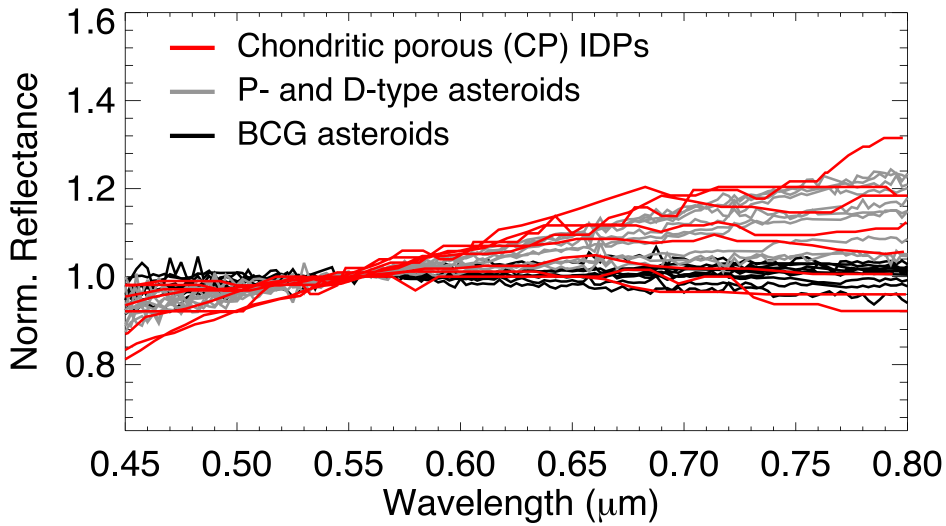



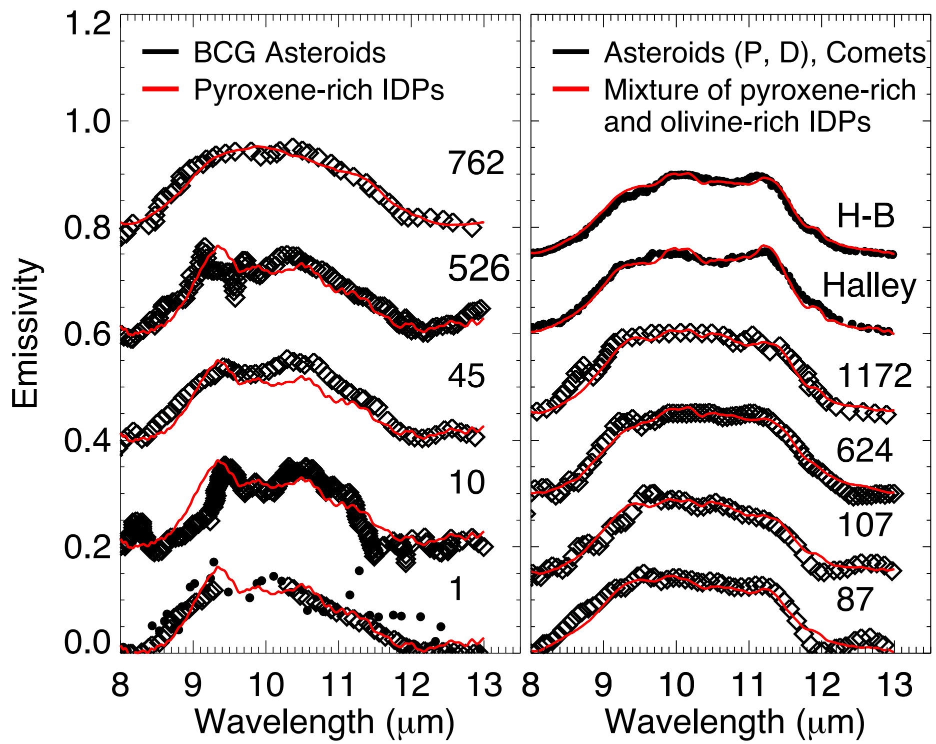

**Dark blue: water ice frost ??**
Other picks: similar aromatic aliphatic hydrocarbons Phoebe & Hyperion)

N-H stretch ? O-H ?
magenta: laboratory spectrum after irradiation of N2+CO+CH4

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

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



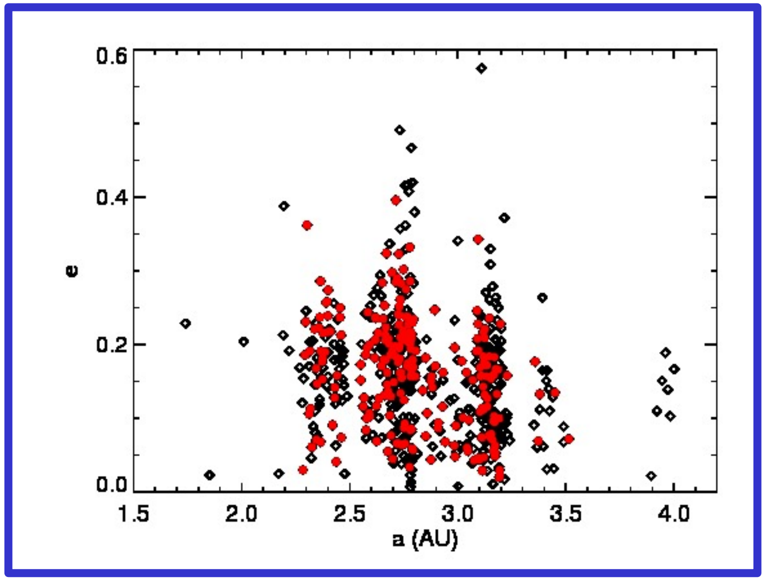

Vernazza et al. 2015
Marsset et al. 2016

# Water in Asteroids

- 70% of C-type asteroids show the presence of aqueous altered minerals
- carbonaceous condrites (only 5% of meteorites collection) meteorites contain up to 22% of water

# AQUEOUS ALTERATION ON PRIMITIVE ASTEROIDS

| λ (μm) | width (μm) | Transition |
|---|---|---|
| <0.4 | >0.1 | $Fe^{2+} \rightarrow Fe^{3+}$ intervalence charge |
| 0.43 | 0.02 | $Fe^{3+}$ spin forbidden (as in jarosite) |
| 0.60-0.65 | 0.12 | 6Al $\rightarrow$ 4T2(G) $Fe^{3+}$ in Fe alteration minerals |
| 0.70 | 0.30 | $Fe^{2+} \rightarrow Fe^{3+}$ in phyllosilicates |
| 0.80-0.90 | 0.08 | 6Al $\rightarrow$ 4T1(G) $Fe^{3+}$ in Fe alteration minerals |
| 3.0 | >0.7 | Structural OH interlayer and adsorbed $H_2O$ |
| 3.07 | 0.2 | $H_2O$ ice, $NH_4$ bearing saponite |

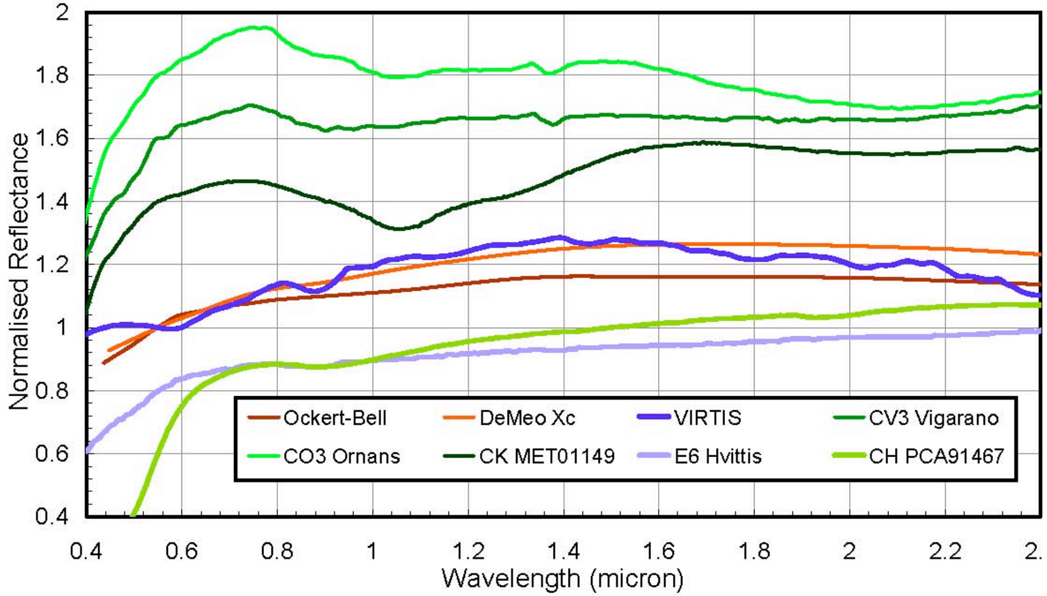


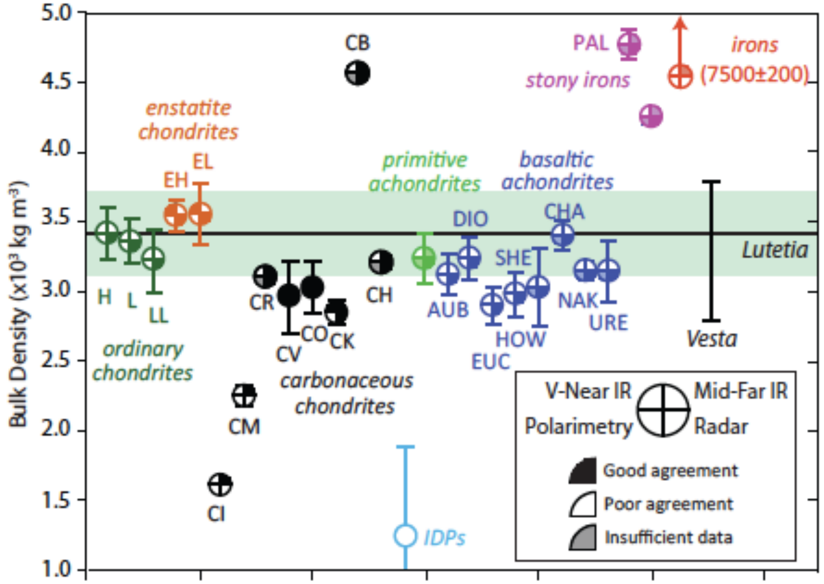

**Vilas et al., 1993, 1994**
**Barucci et al., 1998**
**Fornasier et al., 1999, 2014**

# Mixture of incompatible materials: 21 Lutetia

Weiss et al. 2012

Coradini et al. 2011



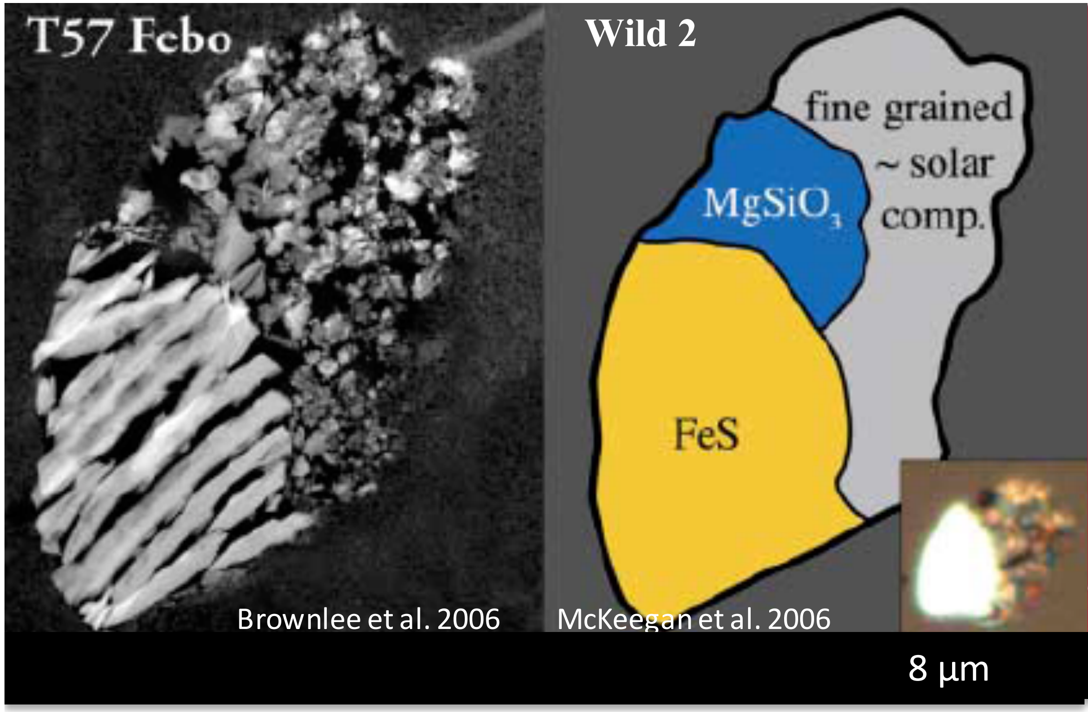




**Lutetia is an old object (with a surface age of 3.5 Gy) with a primitive chondrite crust and a possible partial differentiation with a metallic core.**

**The surface seems a mixture of "incompatible" types of materials: carbonaceous chondrite (for the majority) and enstatite chondrite (in minor percentage).**

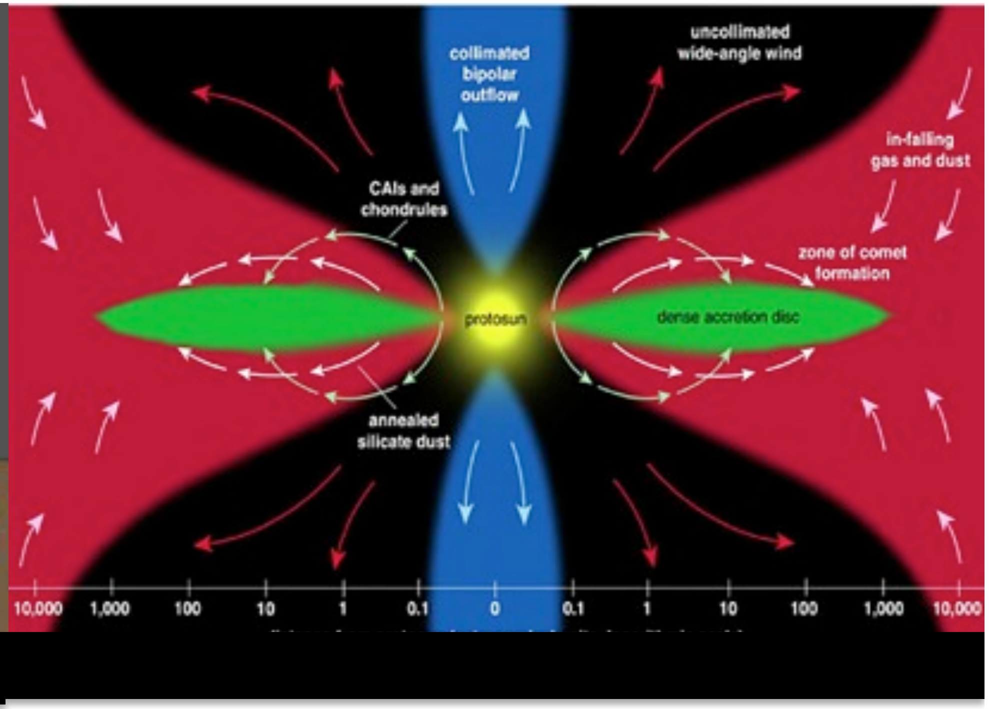
# A comet-asteroid continuum ?

- Stardust material resembles primitive meteorite (Olivine, pyroxene, sulfides…)
- The presence of high-temperature minerals (forsterite and CAIs), that formed in the hottest regions of the solar nebula, provided evidence of extensive radial mixing at early stages of the solar nebula (Brownlee et 2006)
- **Bownlee 2016: "amazing potpourri of materials made in numerous nebular environments"**



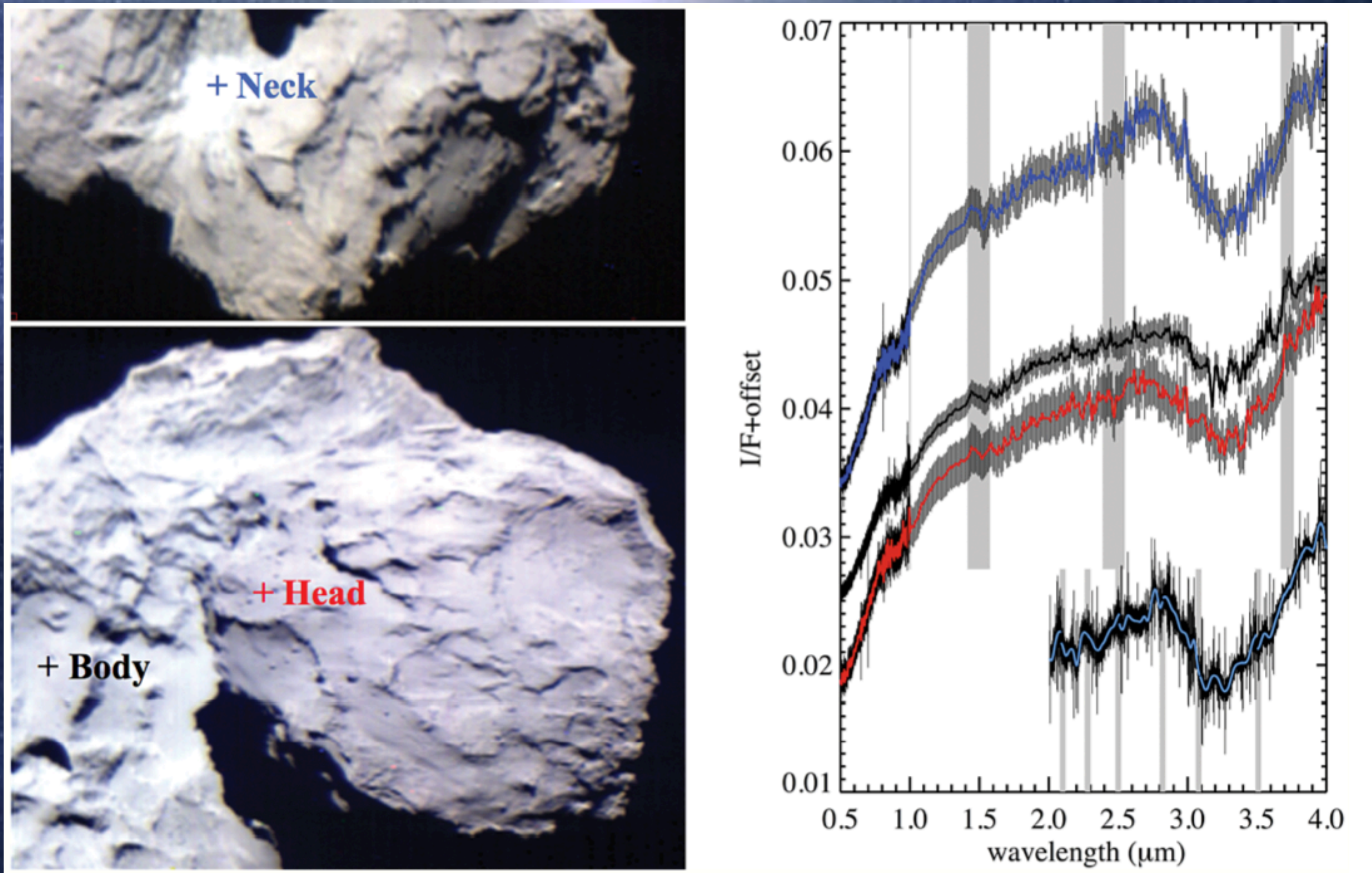

**Cometary grains from Stardust**

Nuth & Johnson 2012




**Complex Protostellar Chemistry**
**Transport & Mixing in the protoplanetary disk**

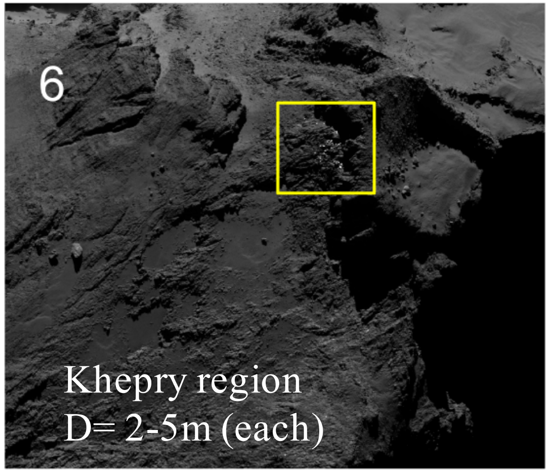
# The organic-rich surface of comet 67P/Churyumov-Gerasimenko

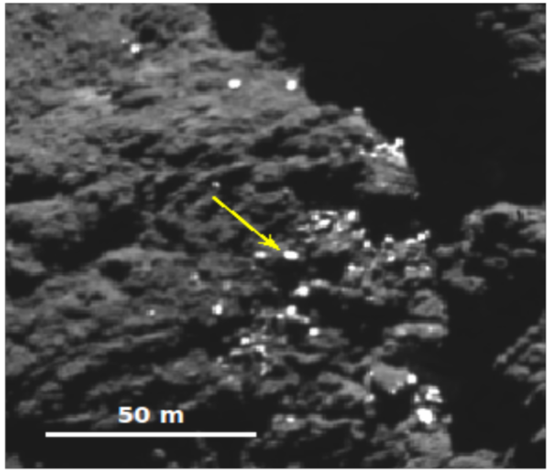


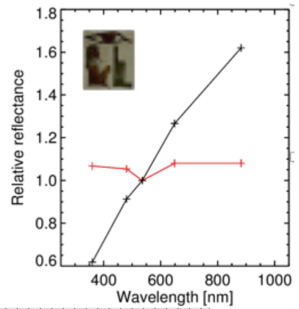

Capaccioni et al. 2015 Science, 347, aaa0628

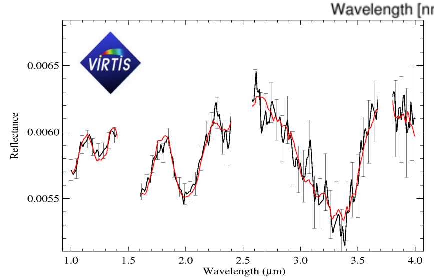
**Quirico et al. 2016:** Dark refractory polyaromatic carbonaceous component mixed with opaque minerals.

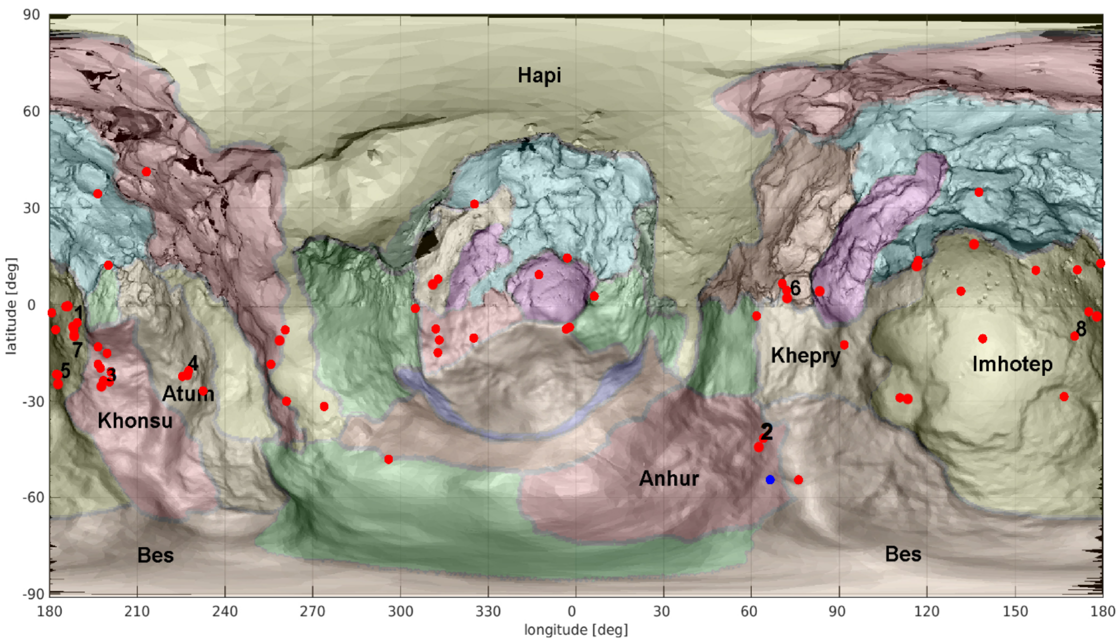
# Many ice spots on the 67P surface



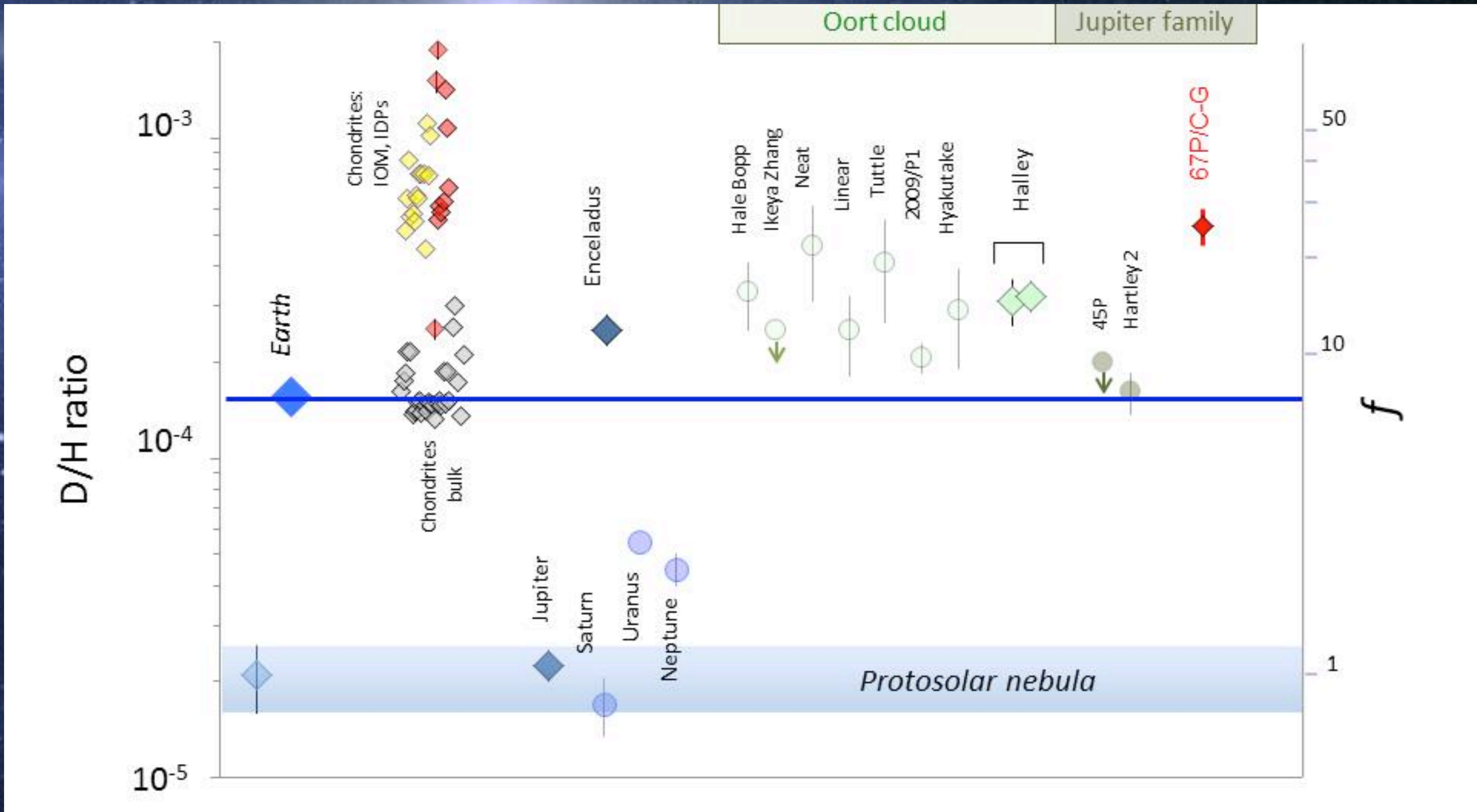




**Modelled with « Dark material »**

Barucci et al. 2016, 2017

# D/H ratios in different objects of the solar system

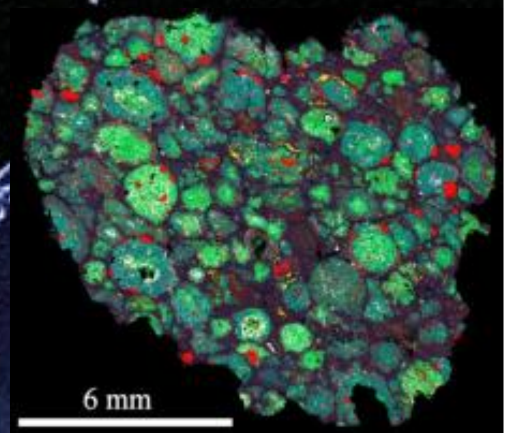



Altwegg et al. 2015

# Laboratory investigation is needed

## High spatial resolution and analytical precision

- High precision analyses - including trace element abundances to ppb levels and isotopic ratios approaching ppm levels of precision
- High spatial resolution - a few microns or less
- Requires large, complex instruments – e.g. high mass resolution instruments (large magnets, high voltage), bright sources (e.g. Synchrotron) and usually requires multi-approach studies



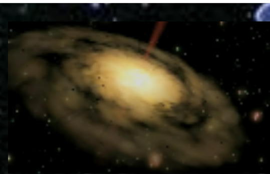
# Sample Return Missions of primitive asteroids

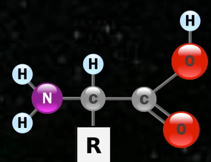
**Hayabusa-2 (JAXA):**
**To asteroid Ryugu (C-type)**
- Launched 3 December 2014
- 2018-2019: science in orbit + impact
- Retour on Earth dec. 2020

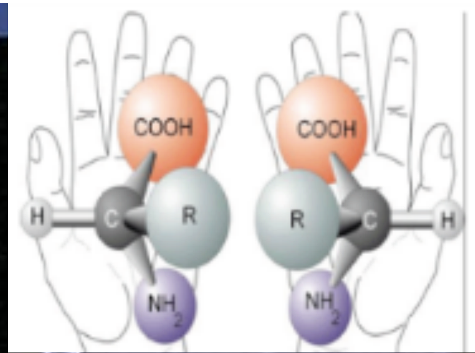
**OSIRIS-Rex (NASA):**
**To asteroid Bennu (B-type)**
- Launched 8 September 2016
- 2018-2020: science in orbit
- Retour on Earth (>60 grams) in 2023

**Primitif objects** =>

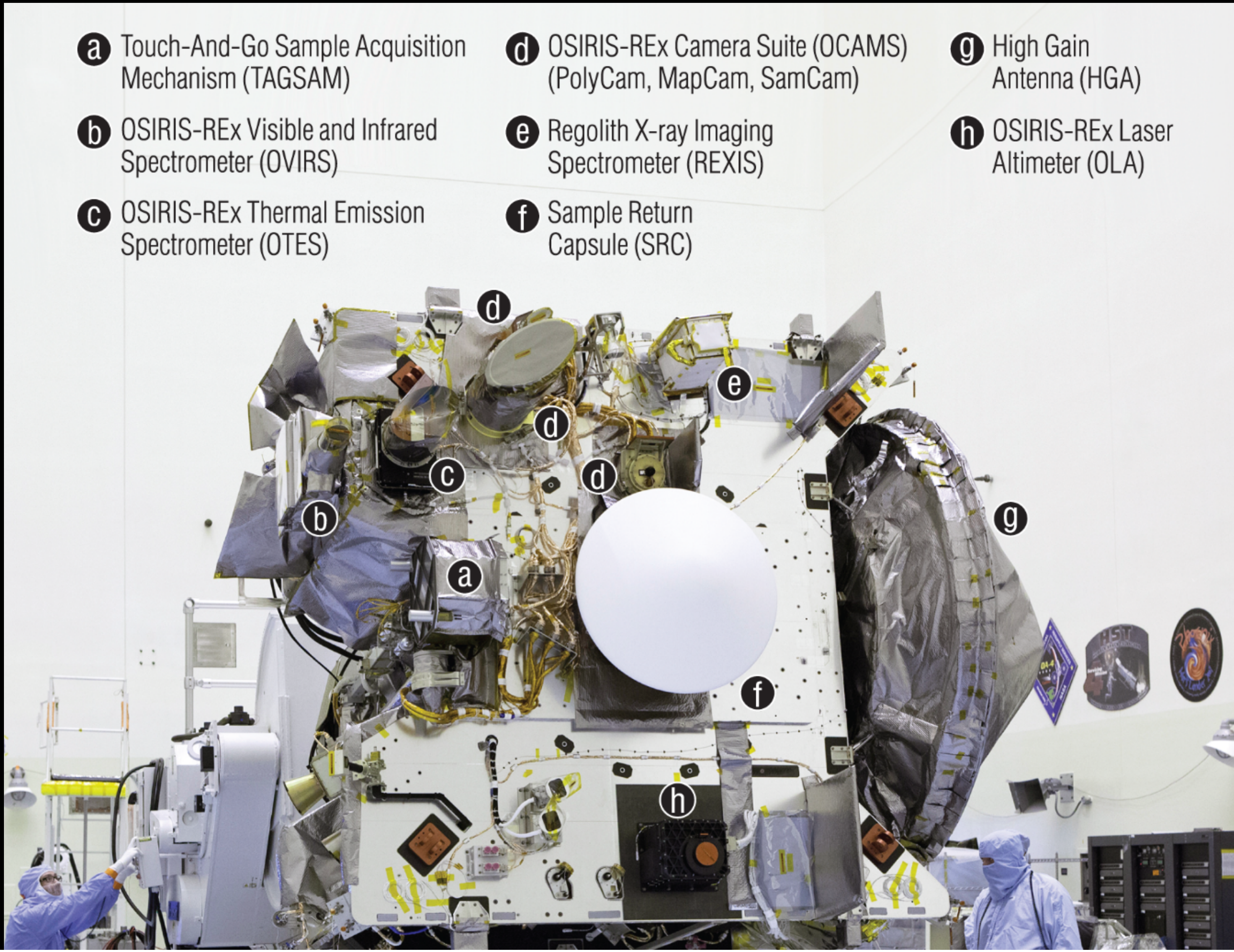
- Origin and evolution of solar system
- Conditions for the emergence of Life (organic matter & water )



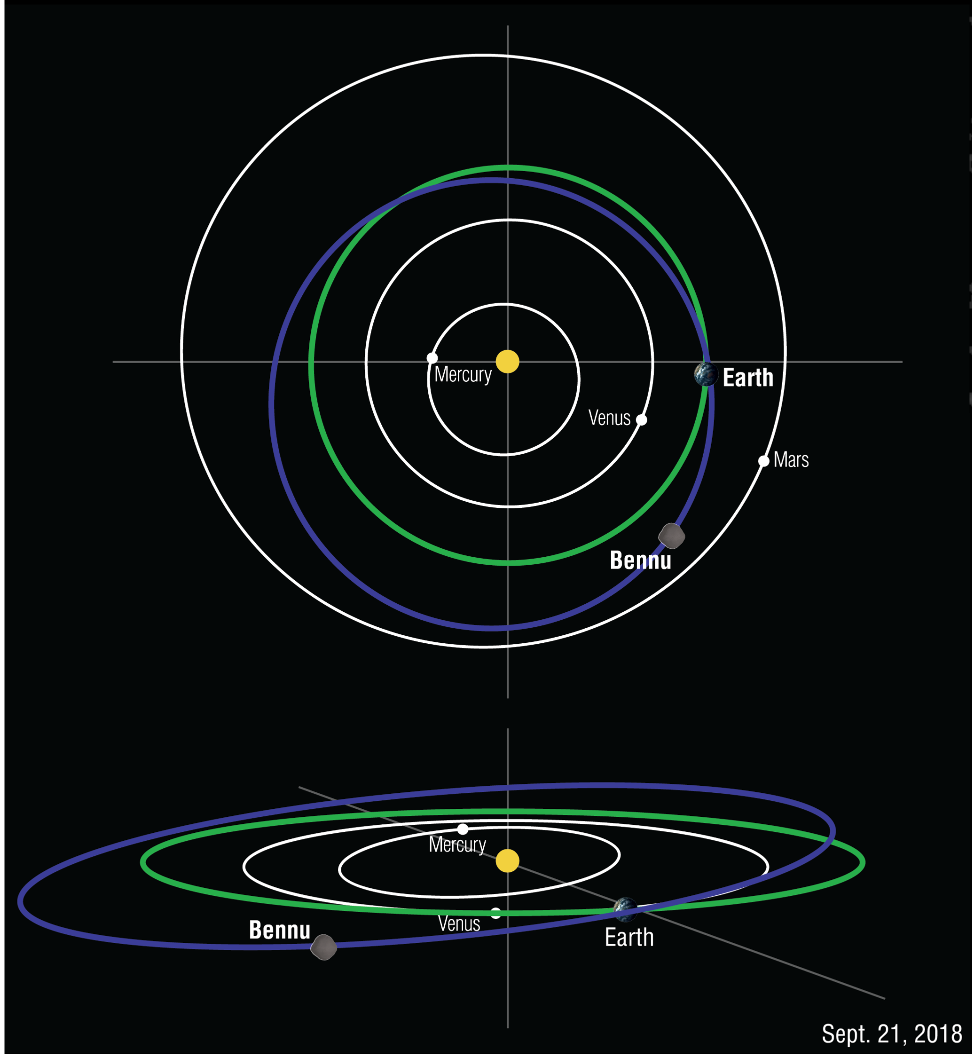


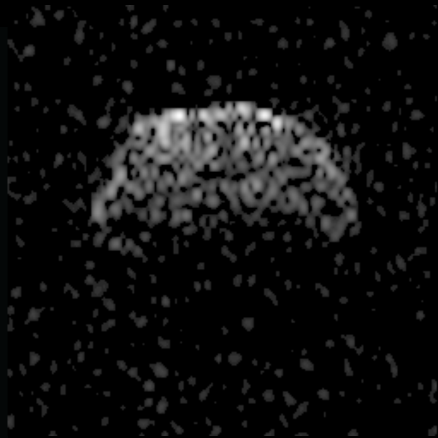



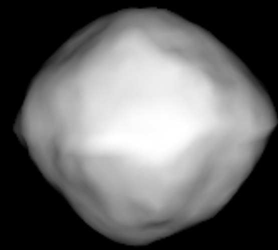
# OSIRIS-Rex spacecraft



# (101955) Bennu



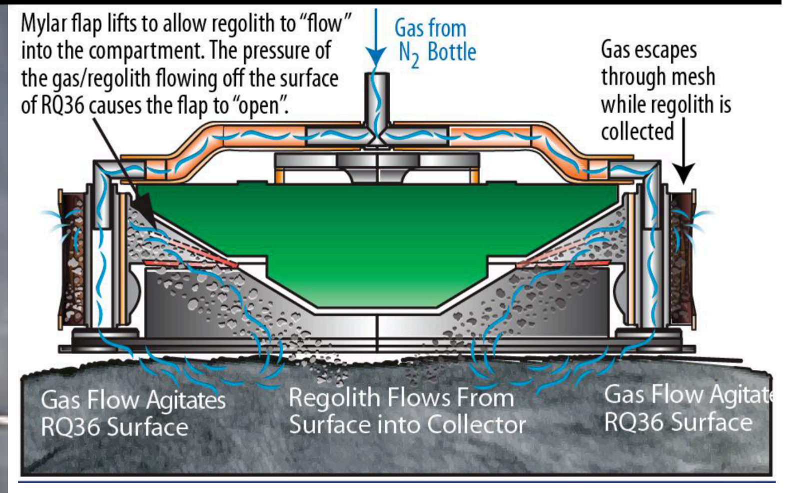





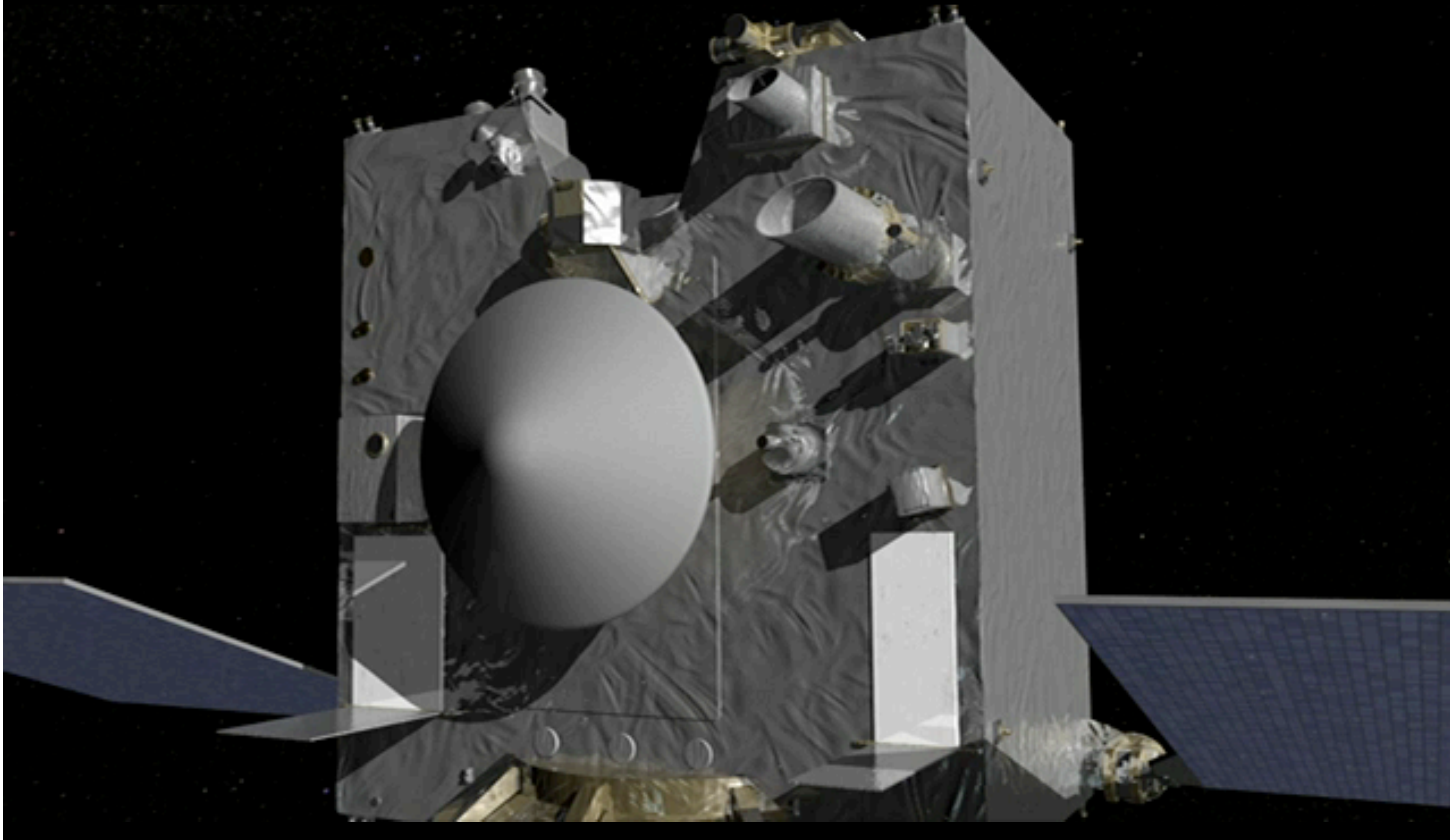
## 101955 BENNU

- **Size =** 492-m (±20 m, mean diameter)
- **Shape =** spheroidal “spinning top”
- **Rotation state =** 4.3 hr period, 180±5º obliquity
- **Bulk Density =** 1260 ± 60 kg/m3
- **Albedo =** 0.045 ± 0.005
- **Spectral Type =** B

# TAGSAM (Touch and Go Sample Acquisition Mechanism): **Simulated 0 g Environment**



# Sample analysis in 2023!



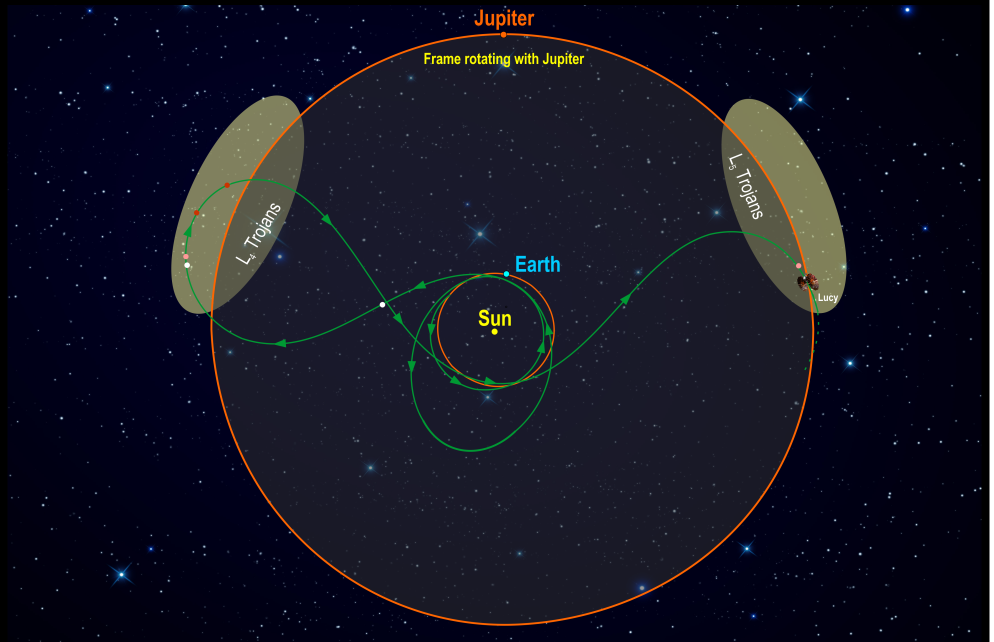
# DISCOVERY program (NASA): Two asteroid missions have been selected

Psyche: Journey to a Metal World

Diameter: 226 km
Metallic
(protoplanetary core))
Band of water at 3 microns

Launch in 2022
Arrival in 2026
21 Months of exploration

Lucy: The First Mission To Jupiter's Trojans




Fly-by of a main belt asteroid
Visit of 6 Trojans including 1 binary

Launch in 2021
Fly-by of  main belt asteroid in 2025
Visits of Trojans in 2027 and 2033

# Space Science Exploration of CAST

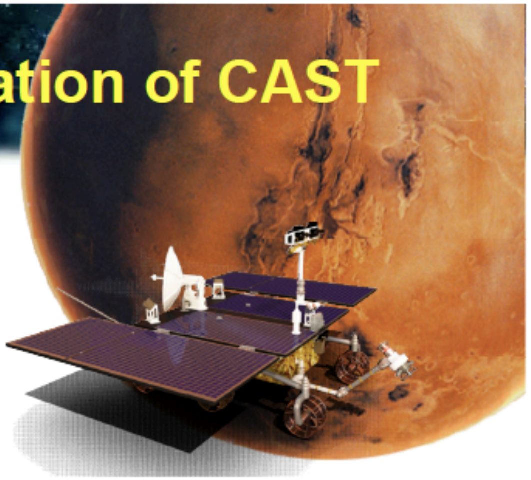
**Prime contractor of China's Lunar & Mars Exploration Program**

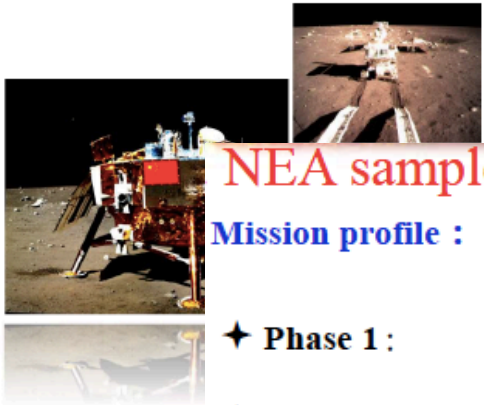
**Orbiting** - **Chang'e 1&2**
Orbiting around the moon

**Landing** - **Chang'e 3 & Chang'e 4**
Soft-landing on the moon surface

**Returning** - **Chang'e 5**
Sample collection of moon surface and returning

**The 2020 Chinese Mars Mission** is a planned project by China to place a Mars orbiter, lander and rover on Mars.



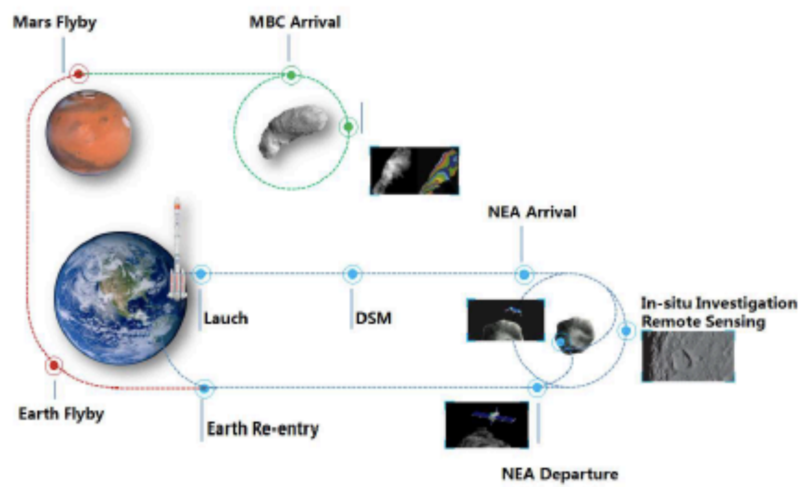


## Asteroid project (2022-24 ? ):
## CAST-Zhenghe mission

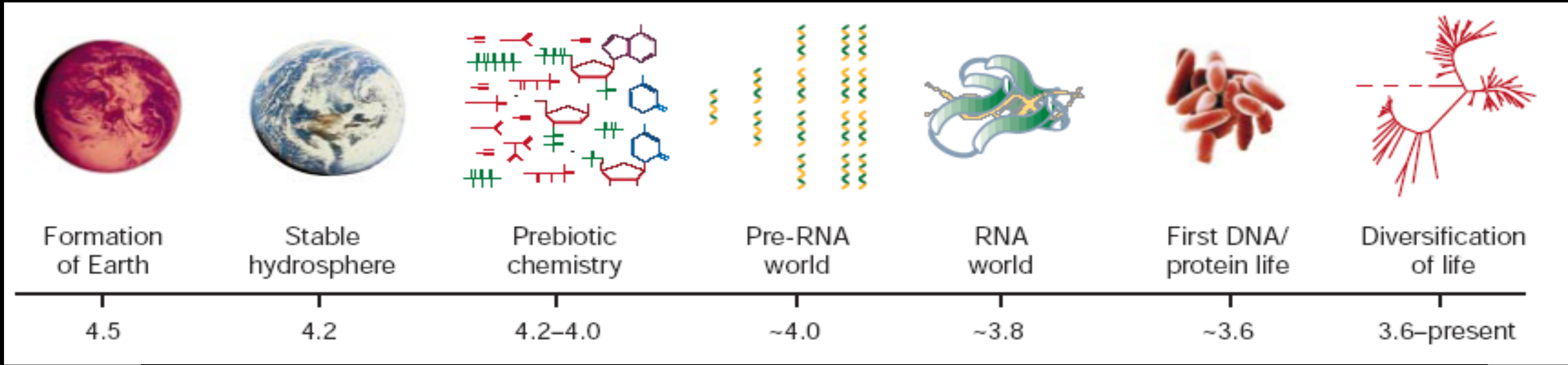
## NEA sample return and main-belt comet mission

**Mission profile：**

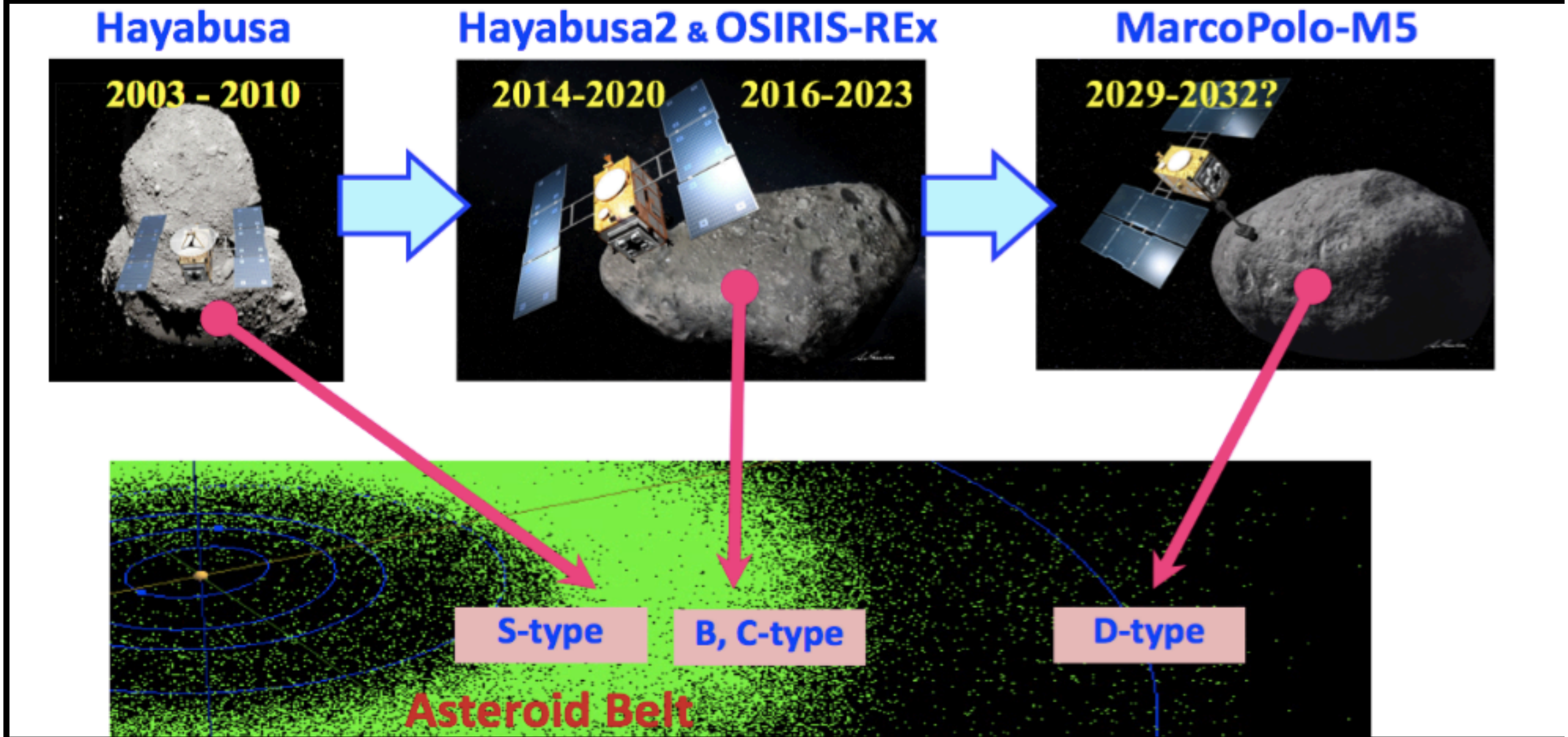
- **Phase 1 :** NEA Sample return In-situ analysis Remote sensing
- **Phase 2 :** MBC Investigation



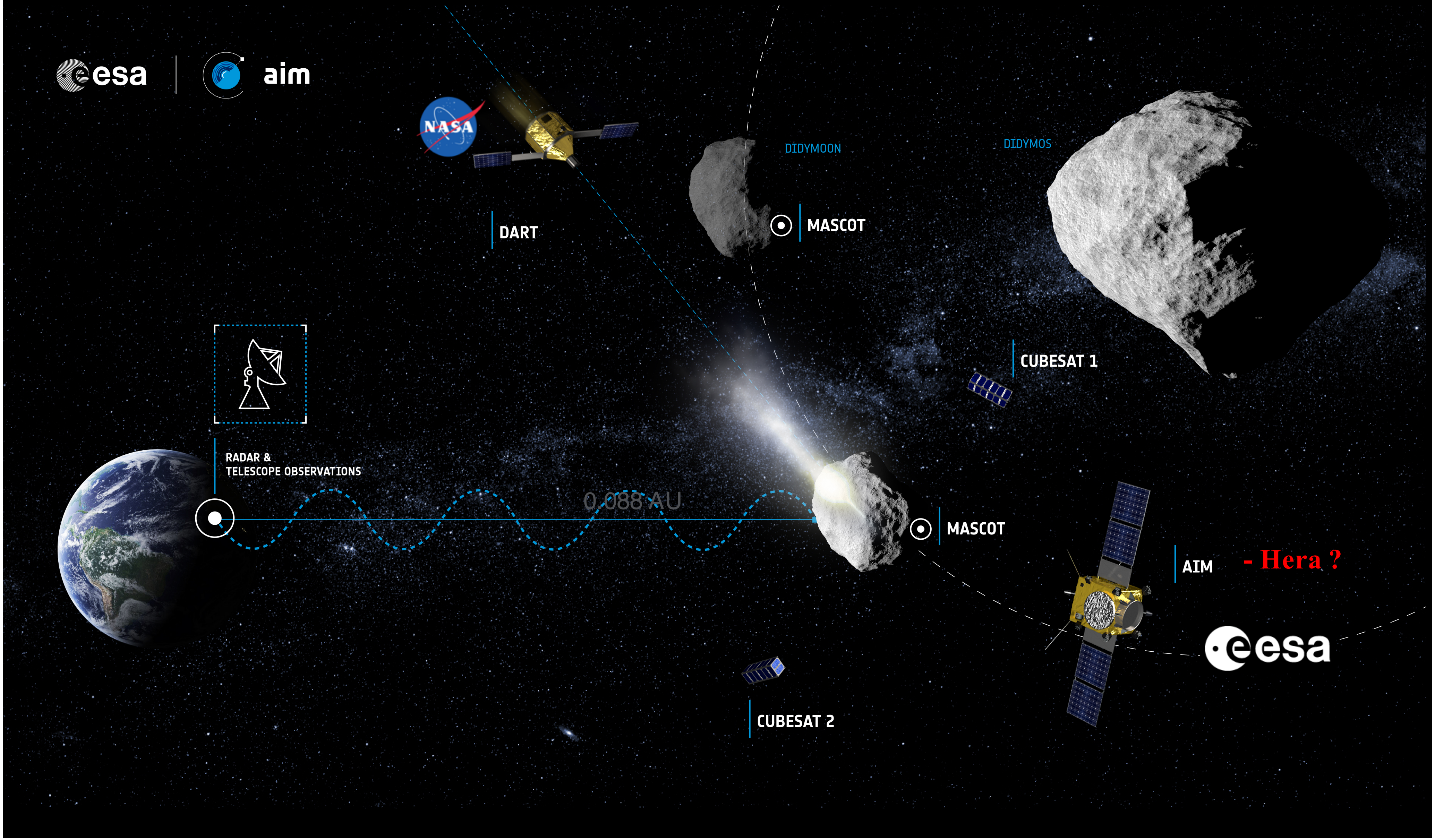
## Theoretical models suggest that water was brought to Earth by asteroid impacts at the end of Earth formation



# What we need next?

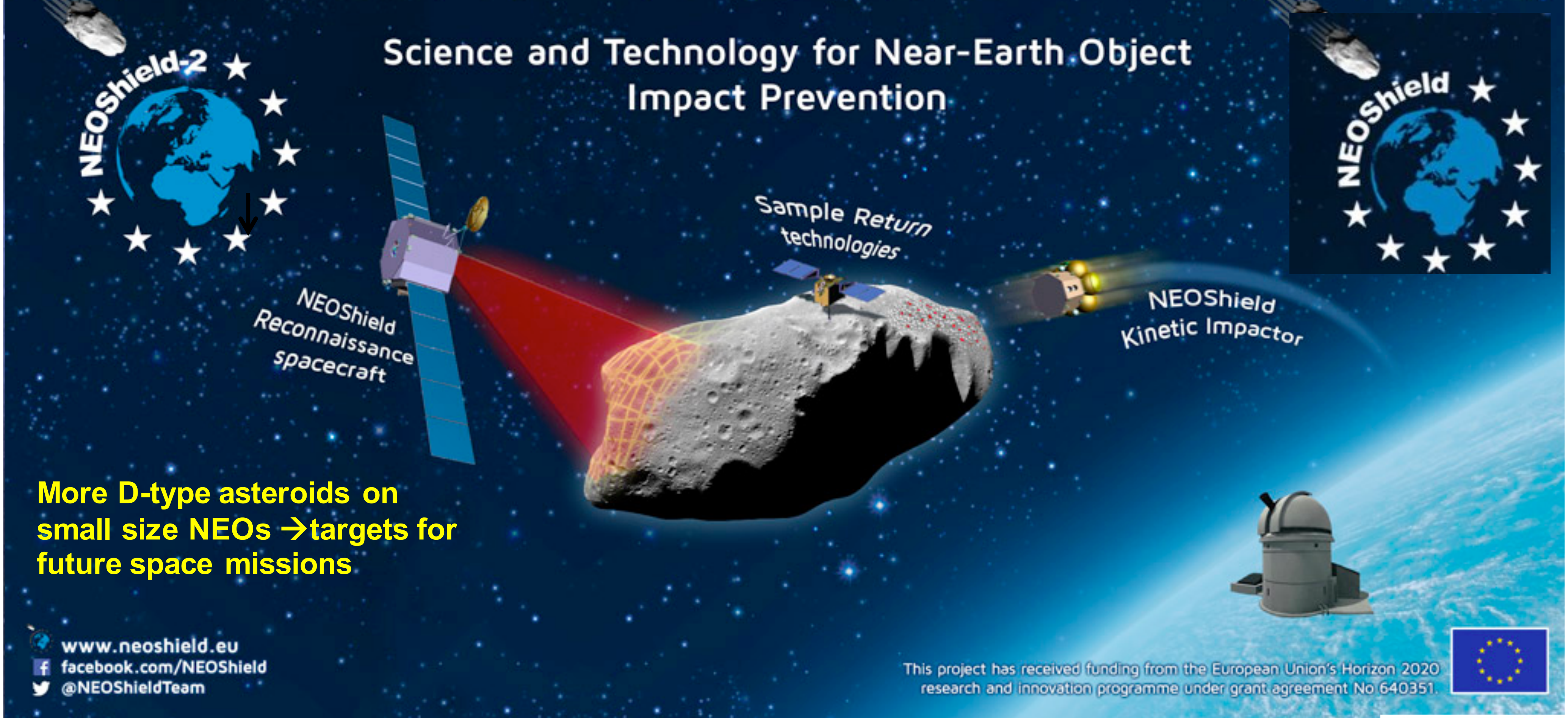


# AIDA INTERNATIONAL COOPERATION - ??



# EUROPEAN PROJECT NEOSHIELD1-2

- Consortium — NESshield 1&2 — demo-mission — characterization of NEOs



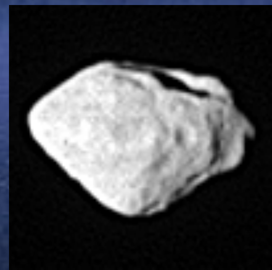

More D-type asteroids on small size NEOs →targets for future space missions

# Why have we to explore asteroids ?

## Science:

- Origin of solar system
- Origin of Life

Lutetia/Rosetta



Steins/Rosetta

## Risks:

- Planetary Defence

## Ressources:

- Metals, water to be used as energy surces and means to sustain human life

# More asteroid exploration

Asteroids could be used in an exploration effort beyond the asteroids. Mission costs could be reduced by using the available water from the asteroids.

Primitive asteroids also have a lot of organic matter, carbon, phosphorus, and other key ingredients for fertilizer which could be used to grow food……..