Solar System small bodies : composition and materials of high exo-biological interest with NIR spectroscopy

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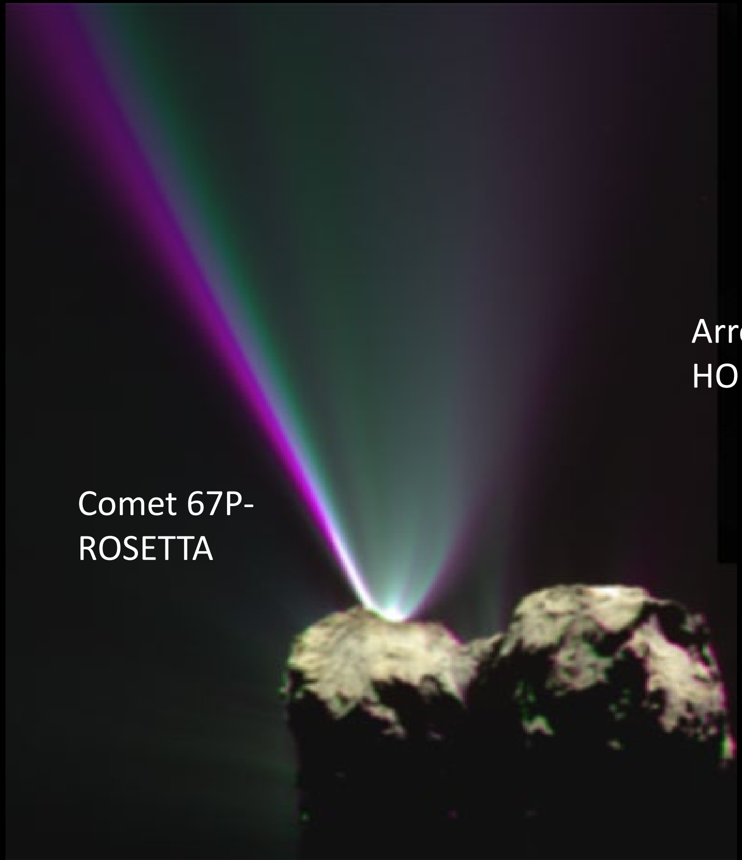
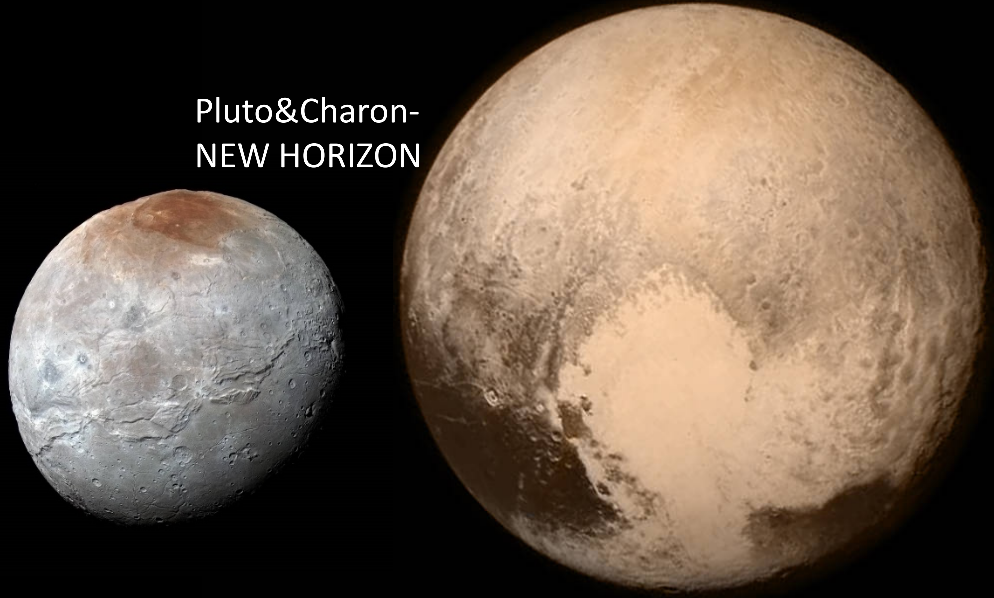


Comet 67P-ROSETTA

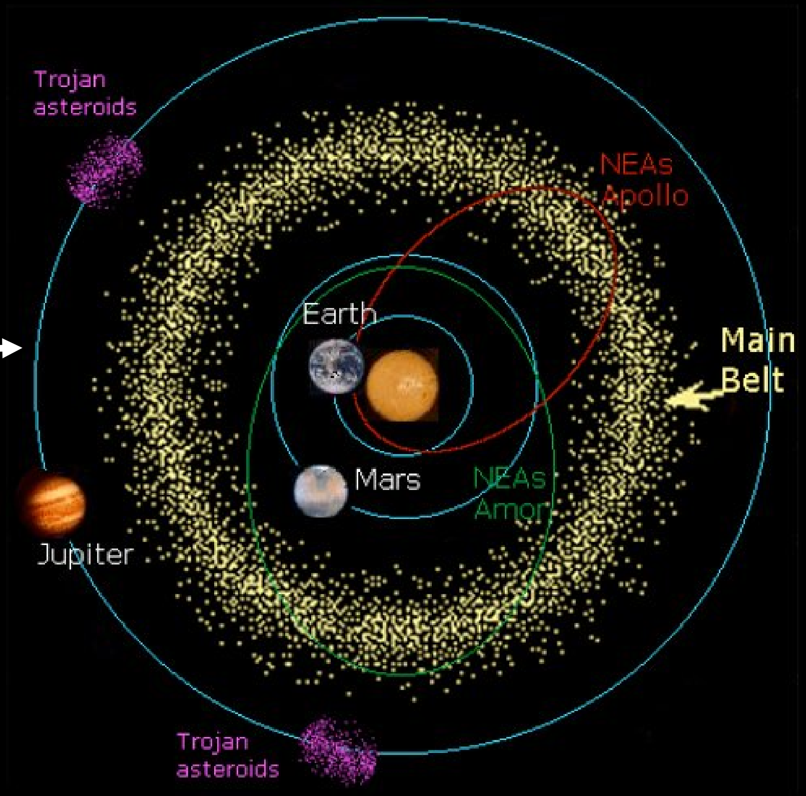
Arrokoth –NEW HORIZON

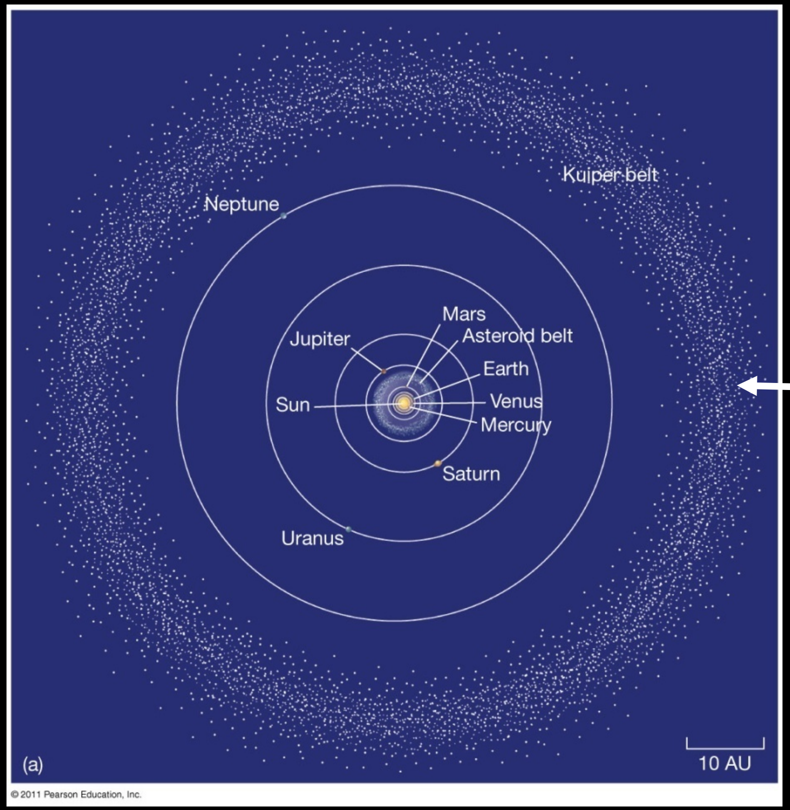


Pluto&Charon-NEW HORIZON

The solar system debris disks

Asteroid main belt 2-3.2 AU

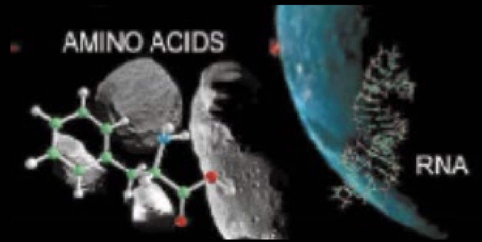


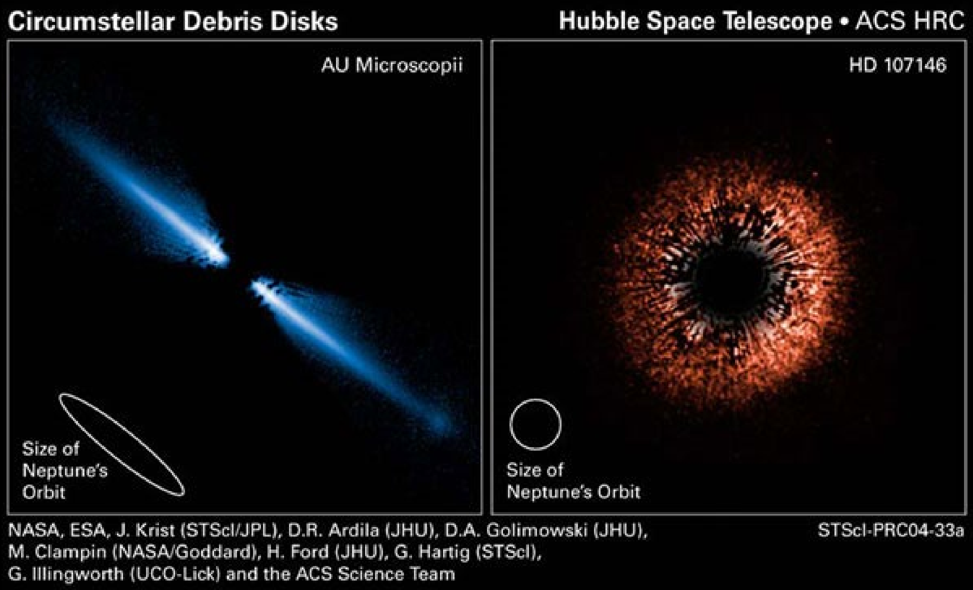


Kuiper belt > 40 AU

Small bodies: why they are important

- They are relatively unprocessed and preserve the composition of the early Solar System
- They cast light on the Solar System formation and evolution
- Delivery of volatiles and organics to the Earth



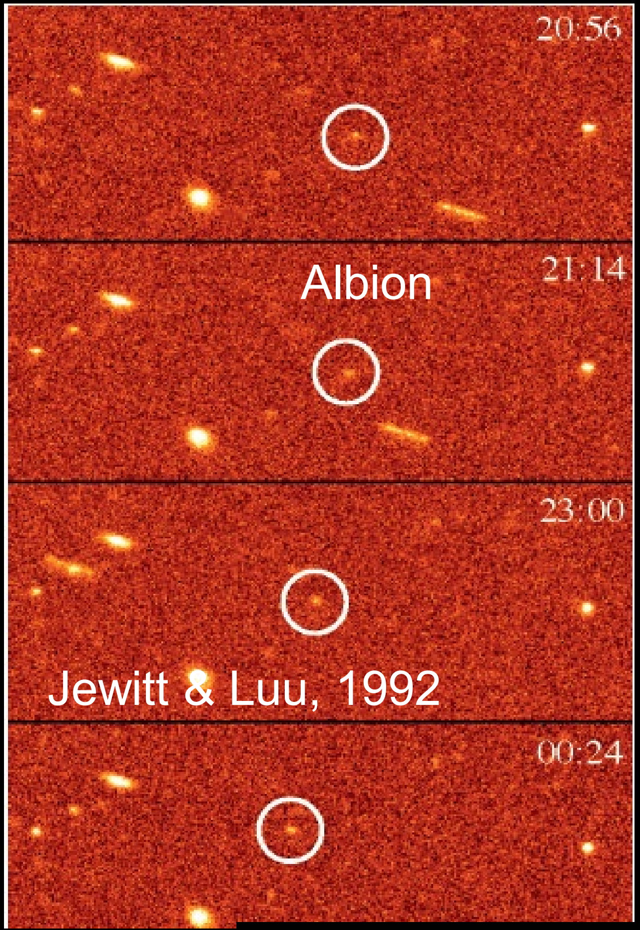


Extrasolar debris disks

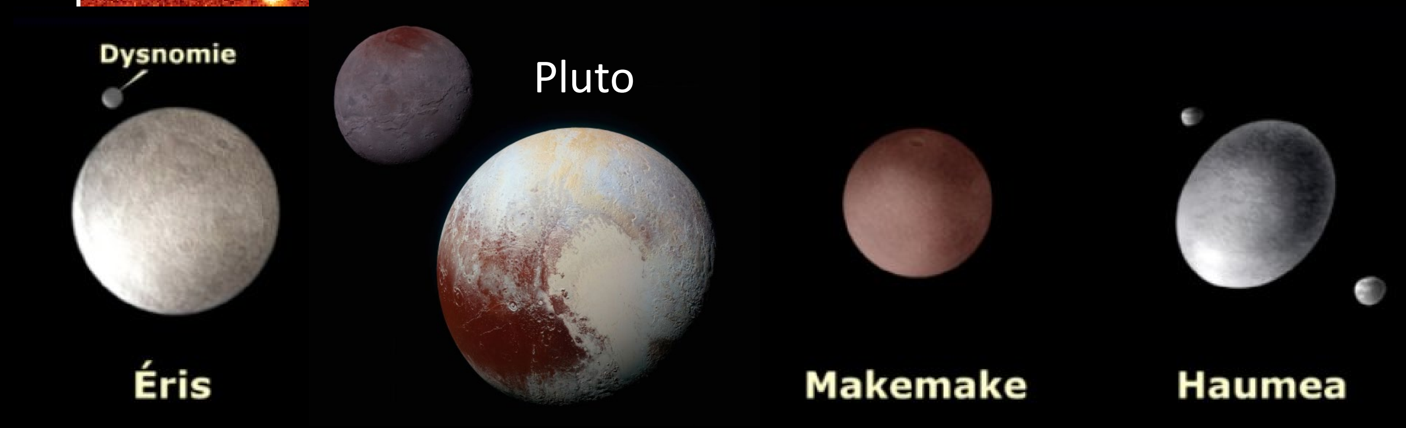
Analogies with the Kuiper Belt (size), but
- Younger (10-100 Myr)
- Dust visible, not individual bodies
- More massive

+ interstellar visitors in our Solar System

Centaurs and Transneptunians



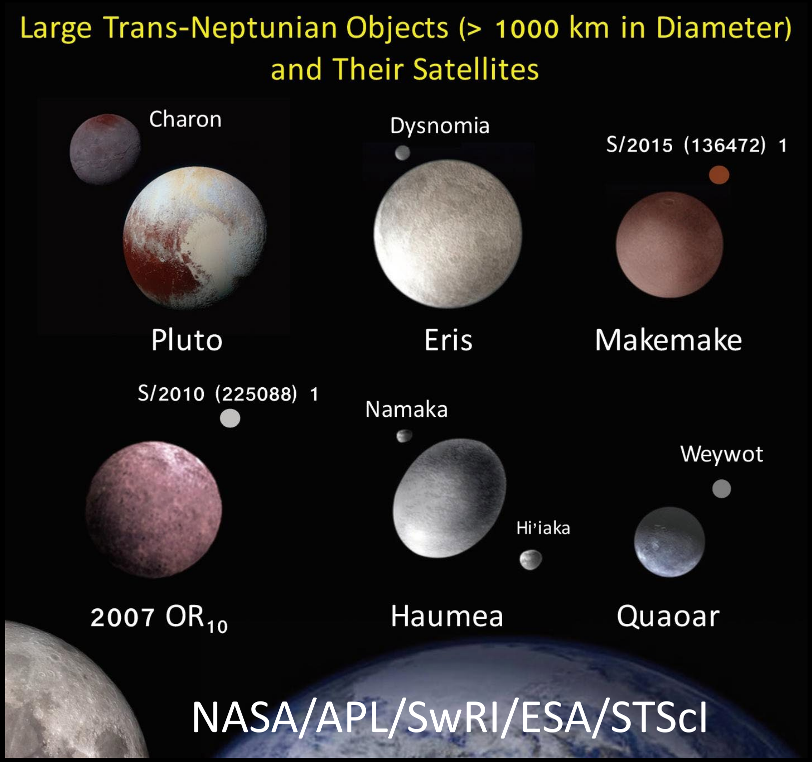
- Presence of the Kuiper belt predicted in 1940-50 by Edgeworth and Kuiper
- ‘First’ TNO discovered in 1992 (Jewitt & Luu, 1992): 15760 Albion (V=23.5 !) ….. but the very first TNO discovered was Pluto!
- In 2005 discovery of large bodies in the Kuiper Belt → dwarf planets
- Complex words: binaries, rings, diversity in colors, albedo and composition!

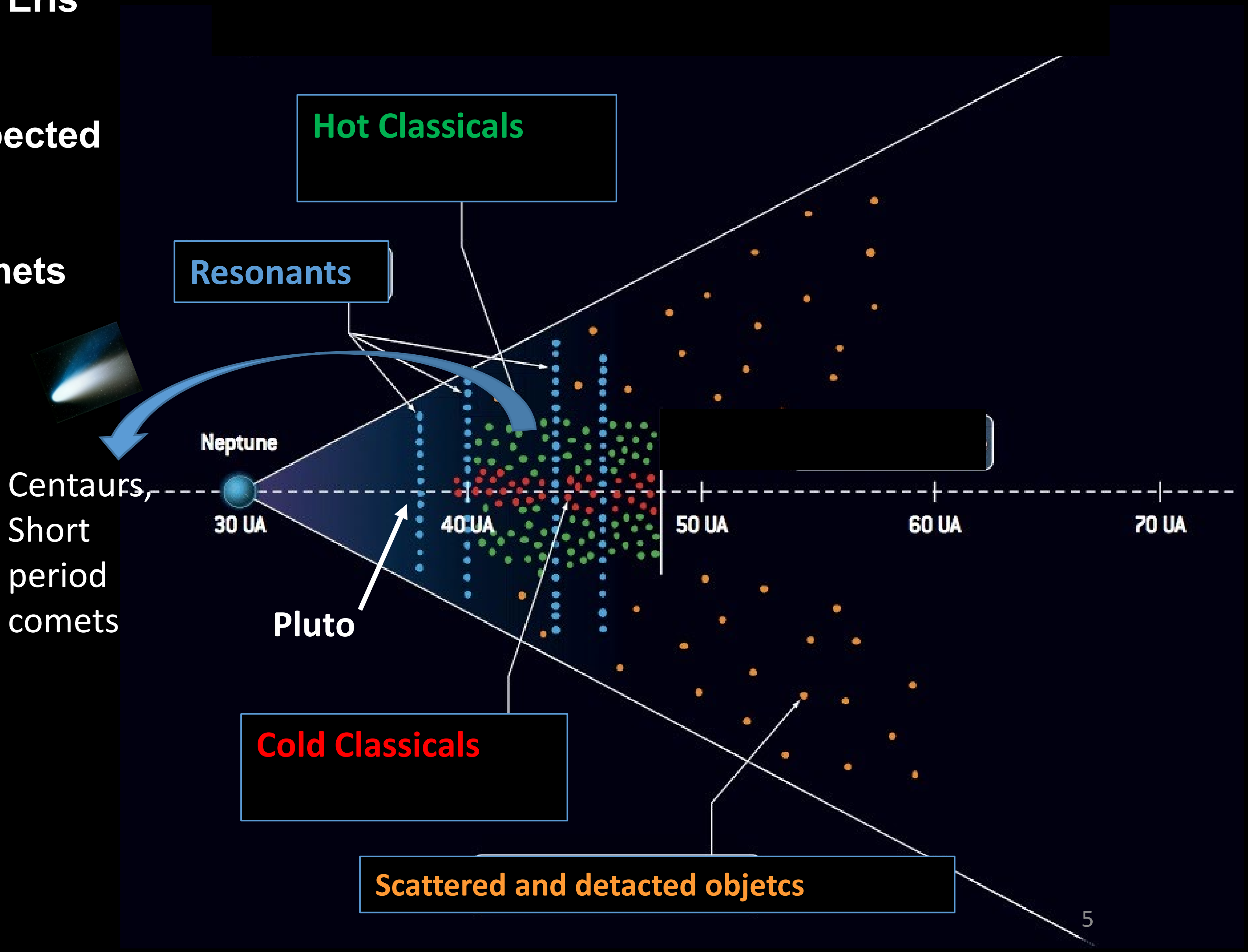


The Kuiper Belt: bulk properties

- **~3000 objects known, largest Pluto & Eris**
- **200,000 estimated with D > 100 km**
- **Cold (about 30-50 K) → water ice expected**
- **Different dynamical populations**
- **Source of Centaurs, Short period comets**

•Total mass ˜ 0.01-0.1 Earth Mass

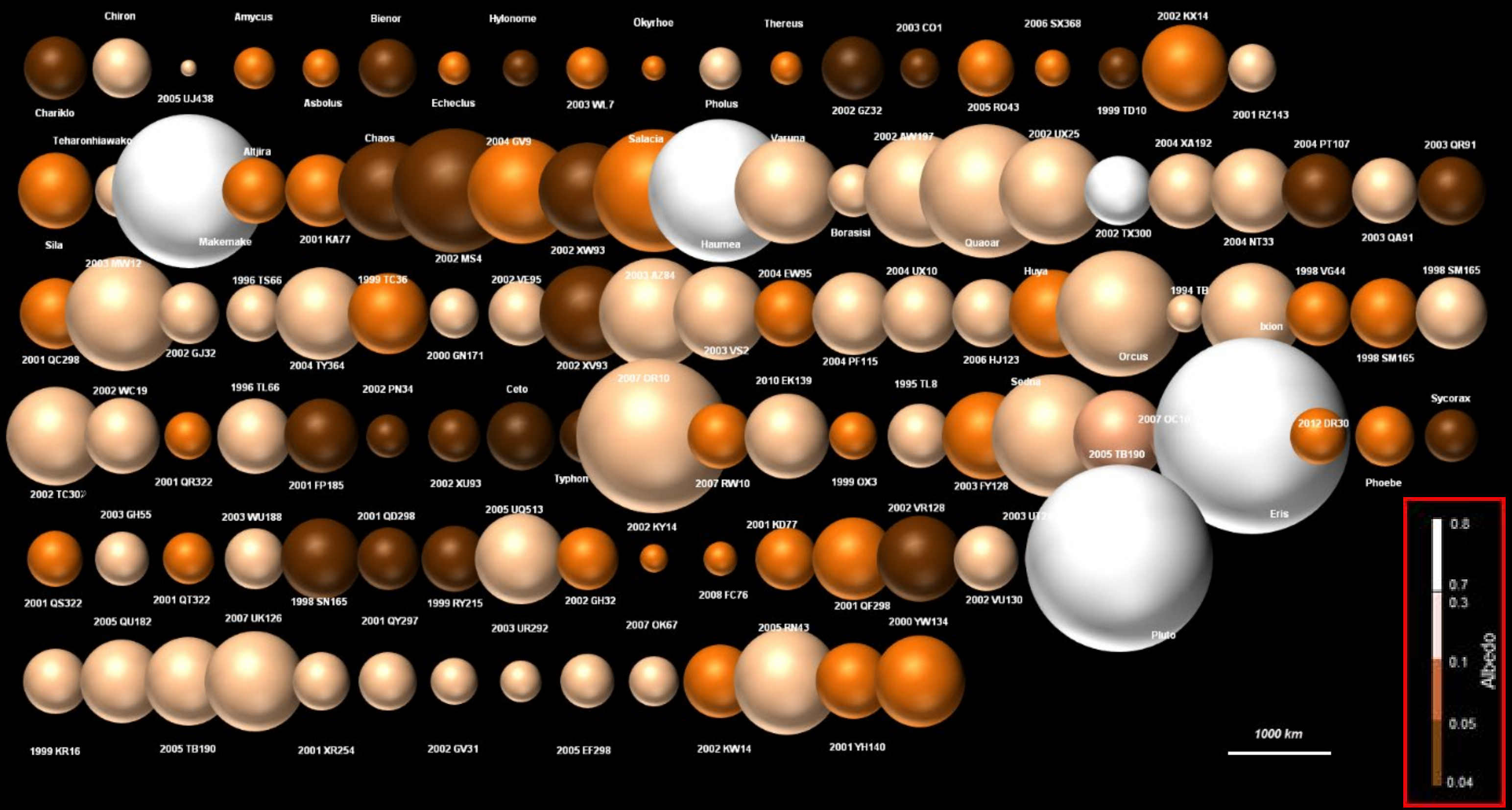


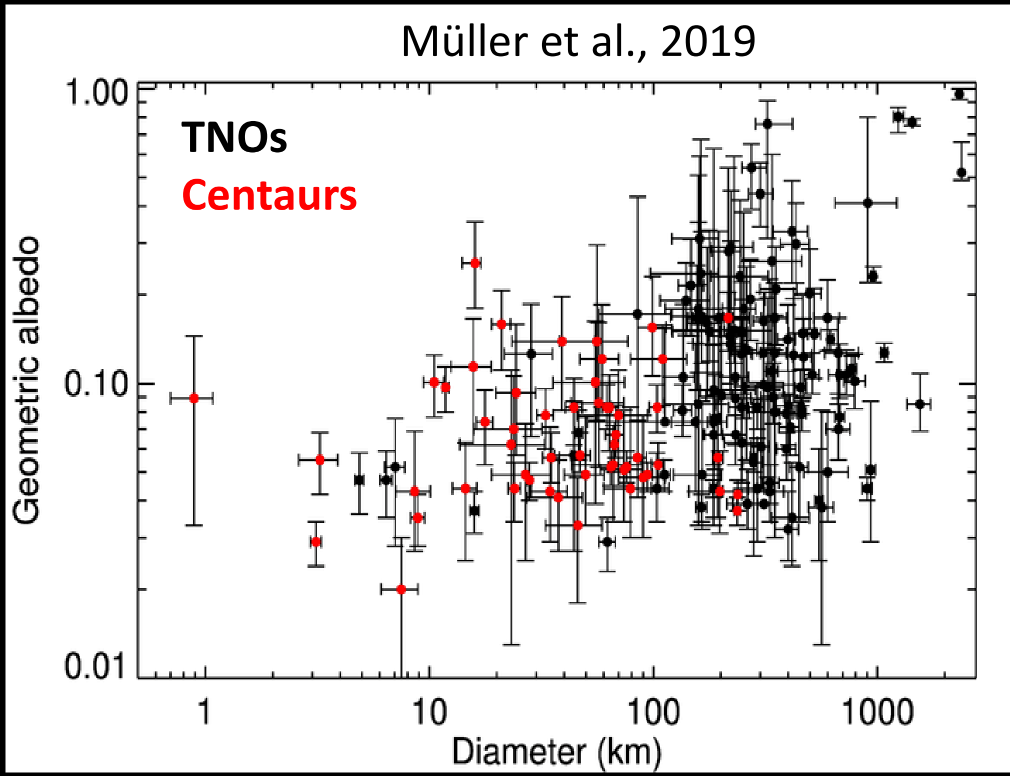


Size and albedos

HERSCHEL ~140 objects

170 TNOs/Centaurs





- •sizes ranging from below 100 km to 2400 km (Pluto/Eris)
- •albedos ranging from 3 to 96% (a factor of 30!)!
- •Excluding volatiles rich dwarf planets and Haumea family members, TNOs have 3< albedo < 33 %, mean value of 11.4% -→ they have dark surfaces

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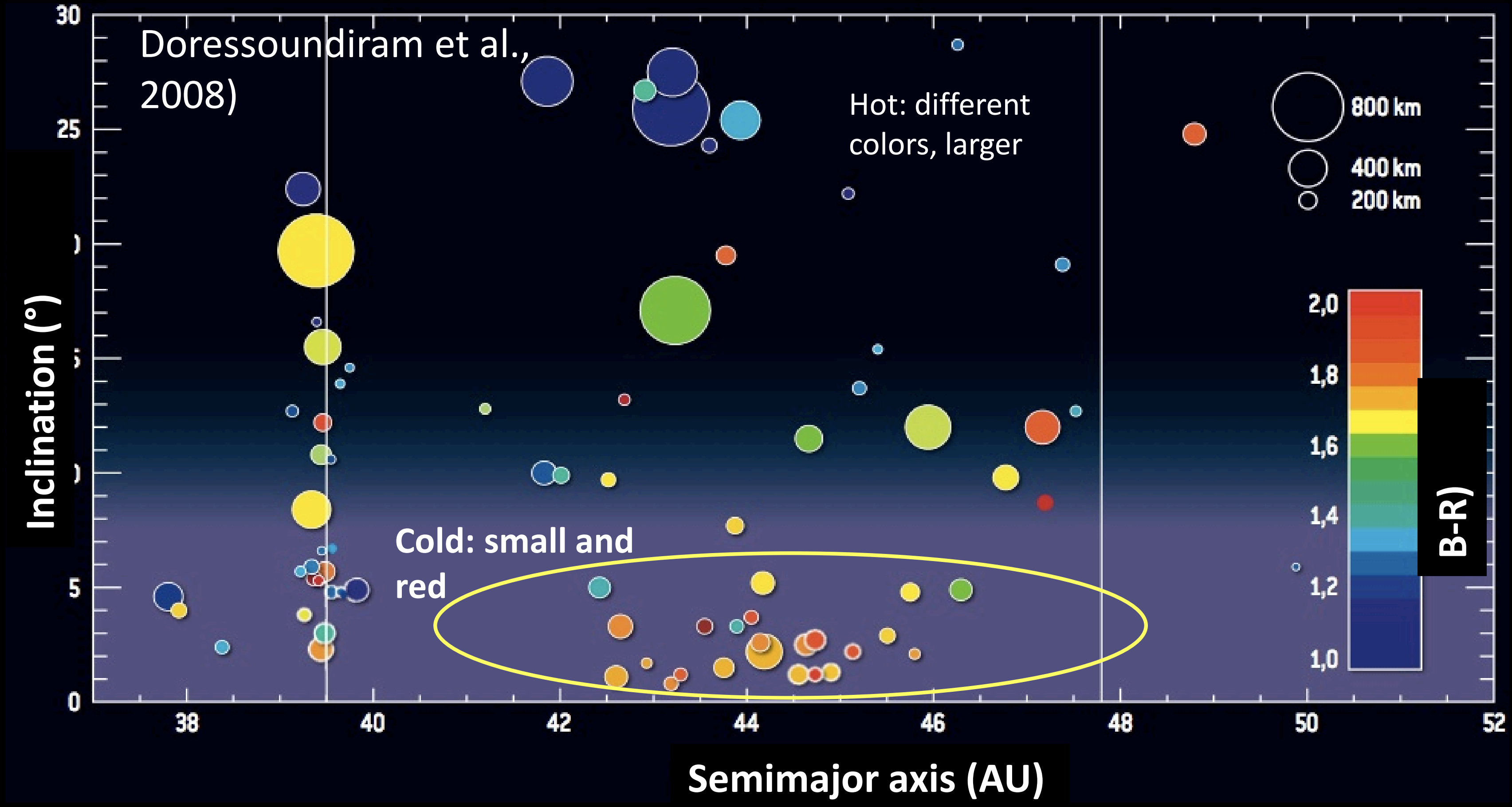
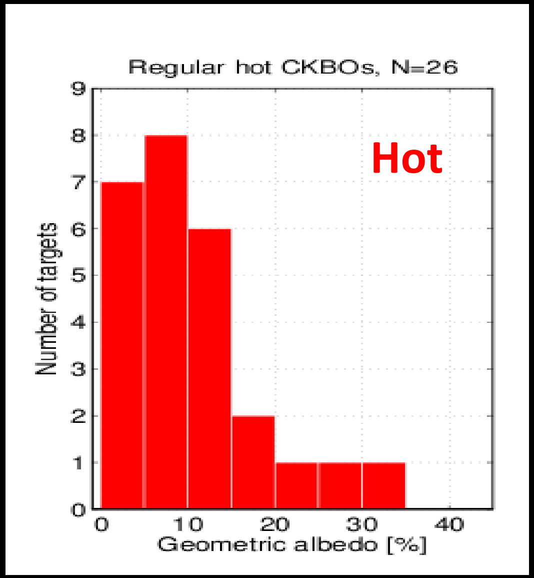
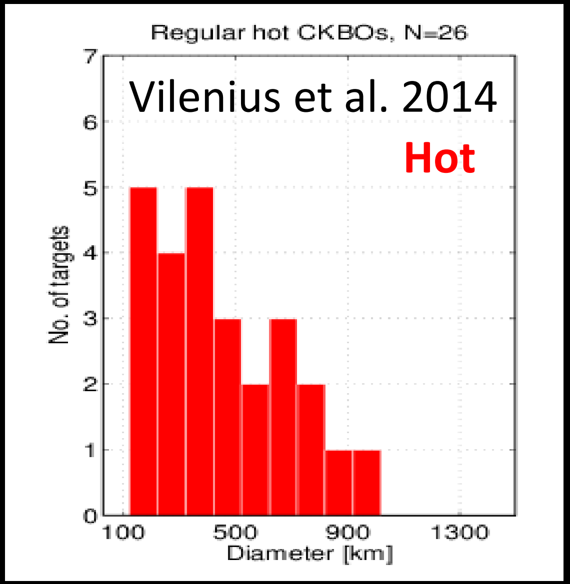
Color diversity

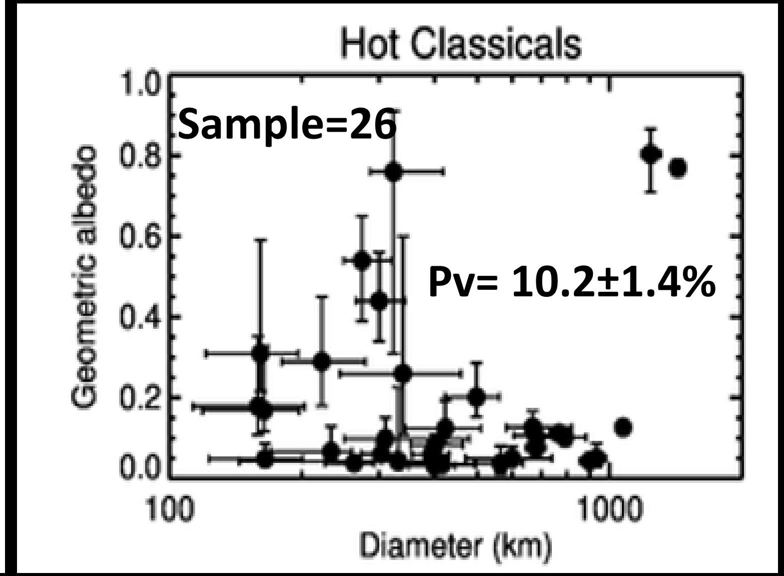


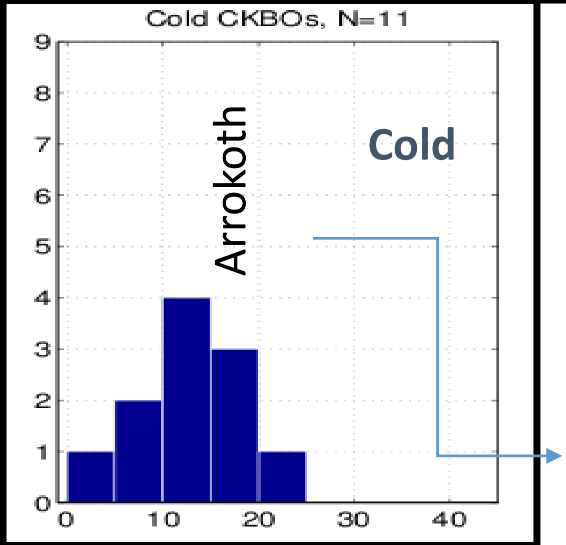
- **Photometry is the most powerfull tool to study TNOs colors**
- **Large color diversity**
- **No correlation between color and dynamical parameters**
- **Exception: « cold » classicals which ~all « very red » → primordial population**

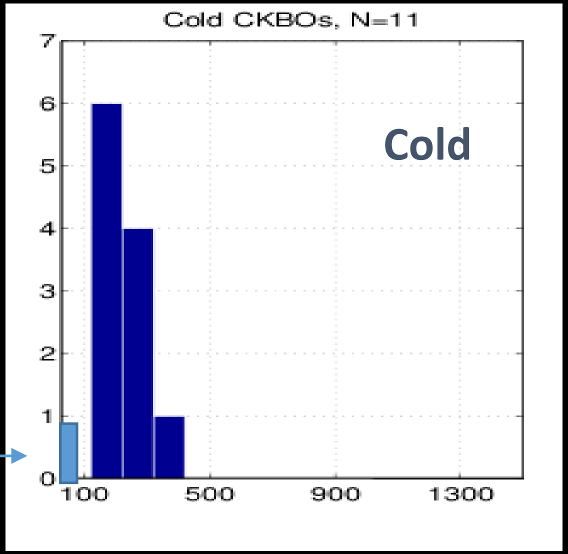
Classicals: hot (i> 5°) vs cold (i<5°)

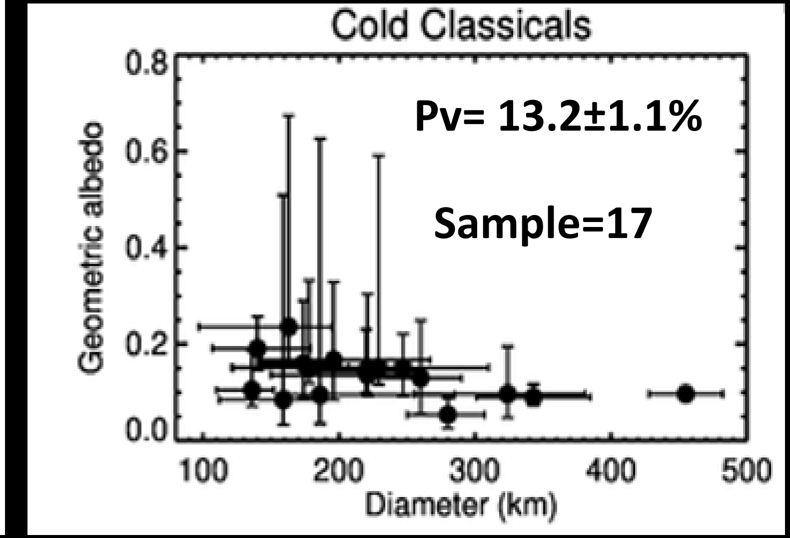










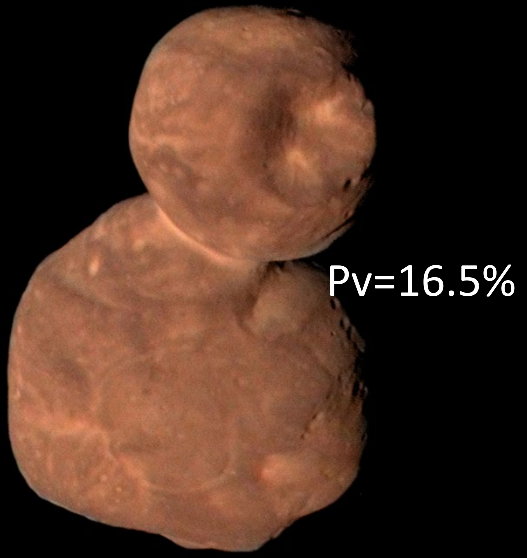


ALBEDO **DIAMETER**

Cold classicals:

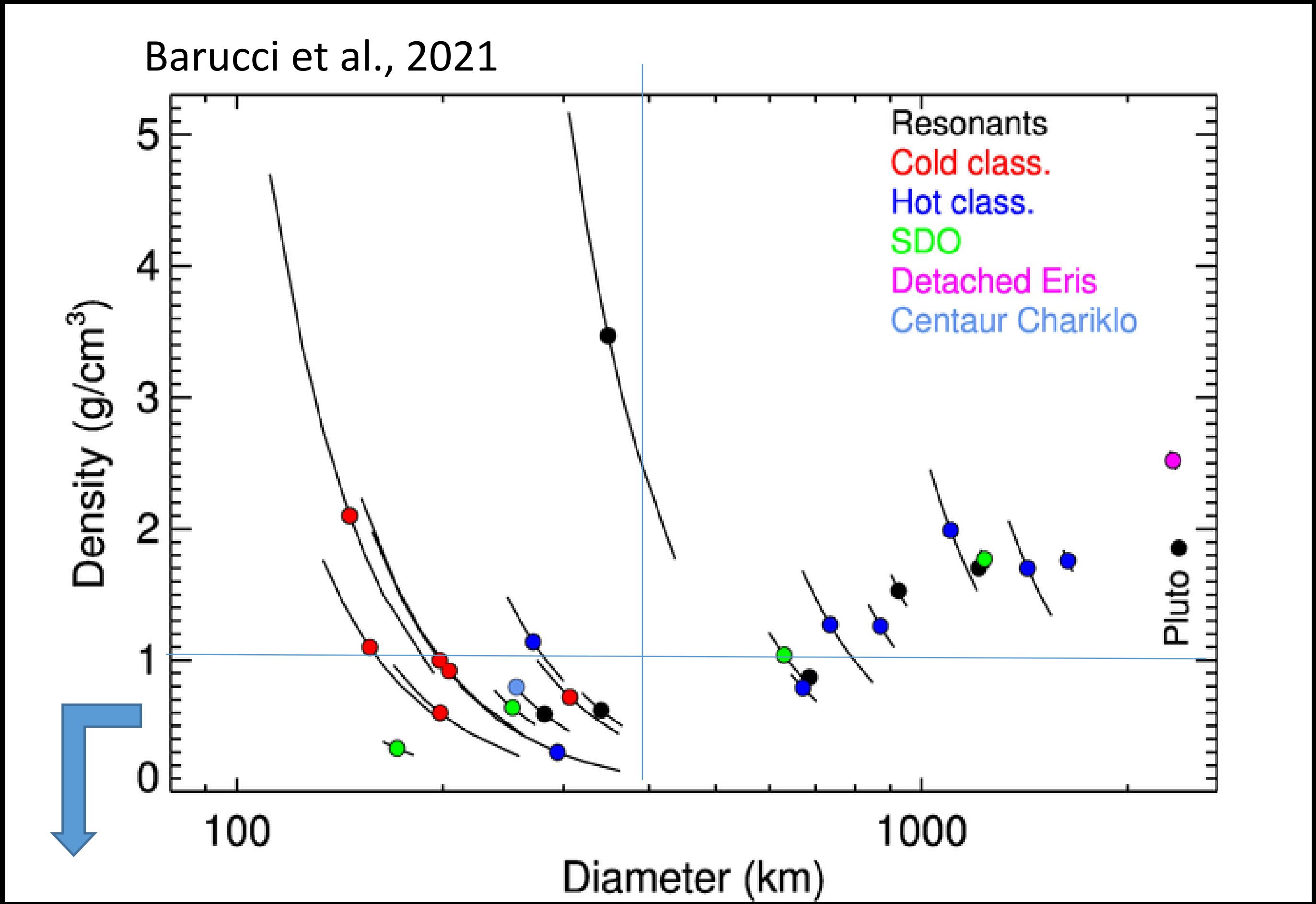
-smaller than 500km
-Red colors
-Higher albedos than Hot classicals

cold population is unique, formed in situ



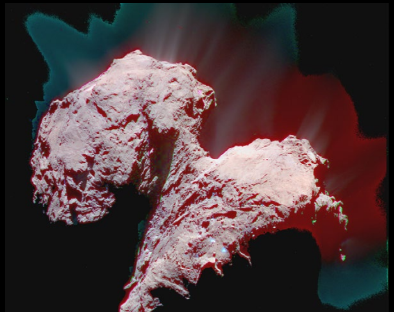
Arrokoth –NEW HORIZON

Densities

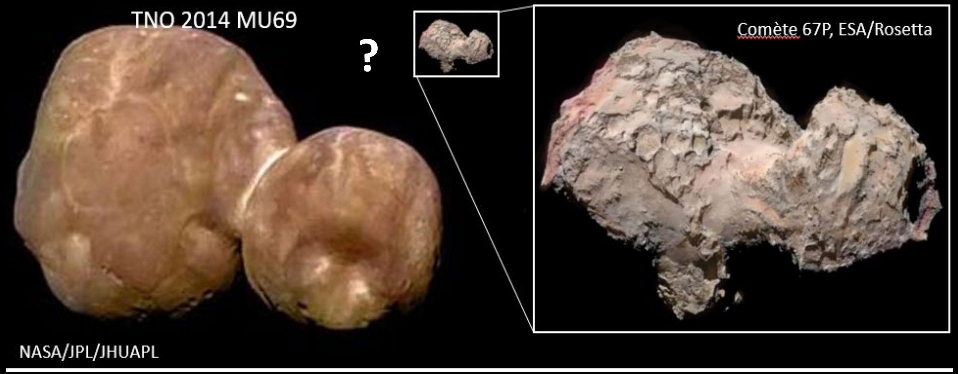


- Most objects < 400 km have density < 1 → small rock-ice ratio + porosity
- Rock/ice ratio increases with size

- Density increase with size in a larger way than what expected due to compaction



For comparison:
67P/CG: 0.53 g cm $^{-3}$



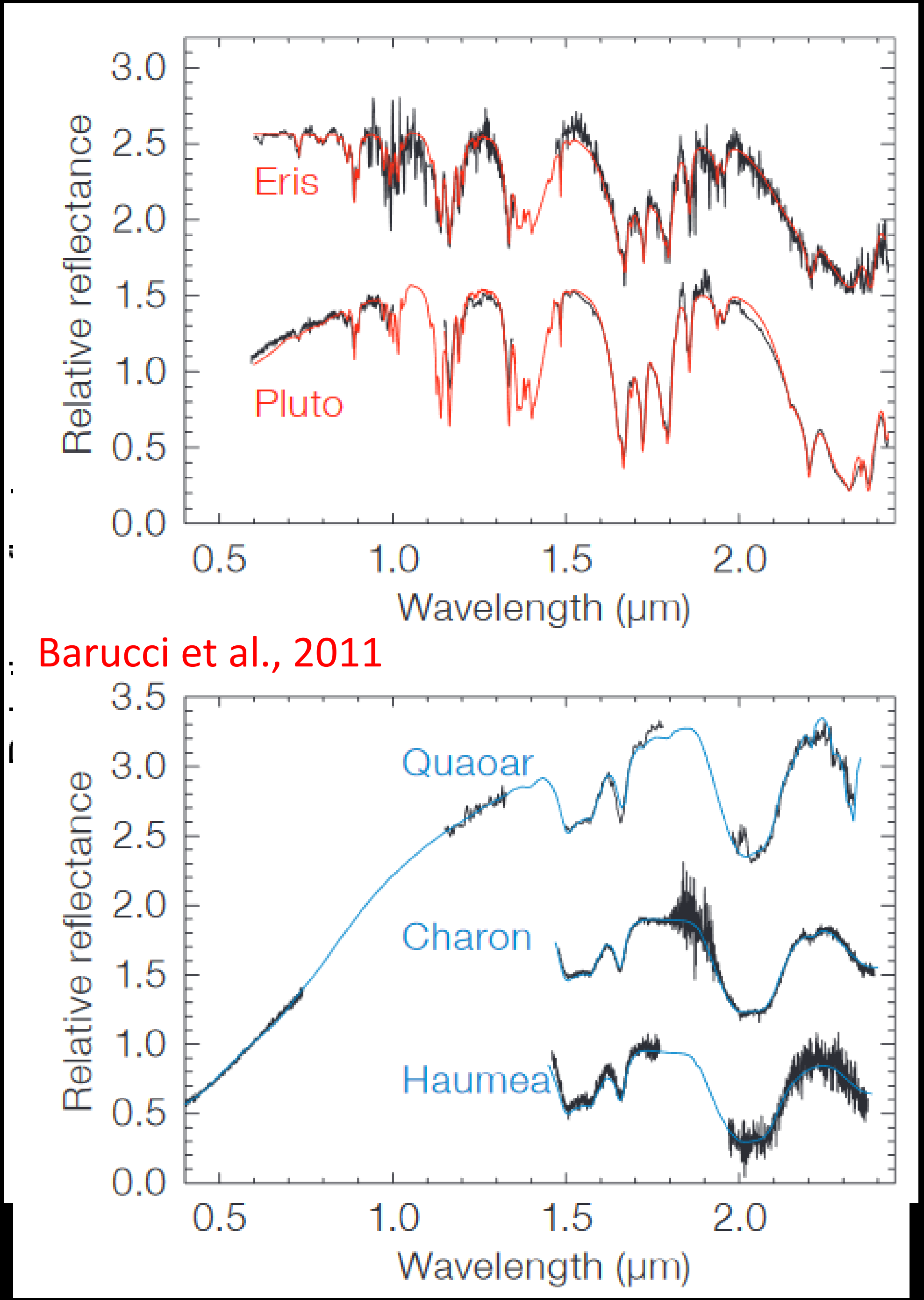
> ➢ Different formation scenarios for large and small TNOs:
>
> • dwarf planets: direct collapse from over dense regions of the disk?
>
> • smaller TNOs: standard pairwise accretion

Surface composition

- Difficult, spectroscopy limited to less than 70 objects (but S/N good for half of them); high variety; 3 groups:

-featureless, often red (organic rich)
-dominated by water ice
-dominated by methane (largest bodies)

minor species detected:
- methanol (Sedna, Pholus, 2002 VE_{95}, Arrokoth)
- N_2 on Pluto, Sedna, Quaoar Eris,Makemake
- NH_3 on Orcus & Quaoar
- Products of irradiation (ethane, ethylene…) on Makemake

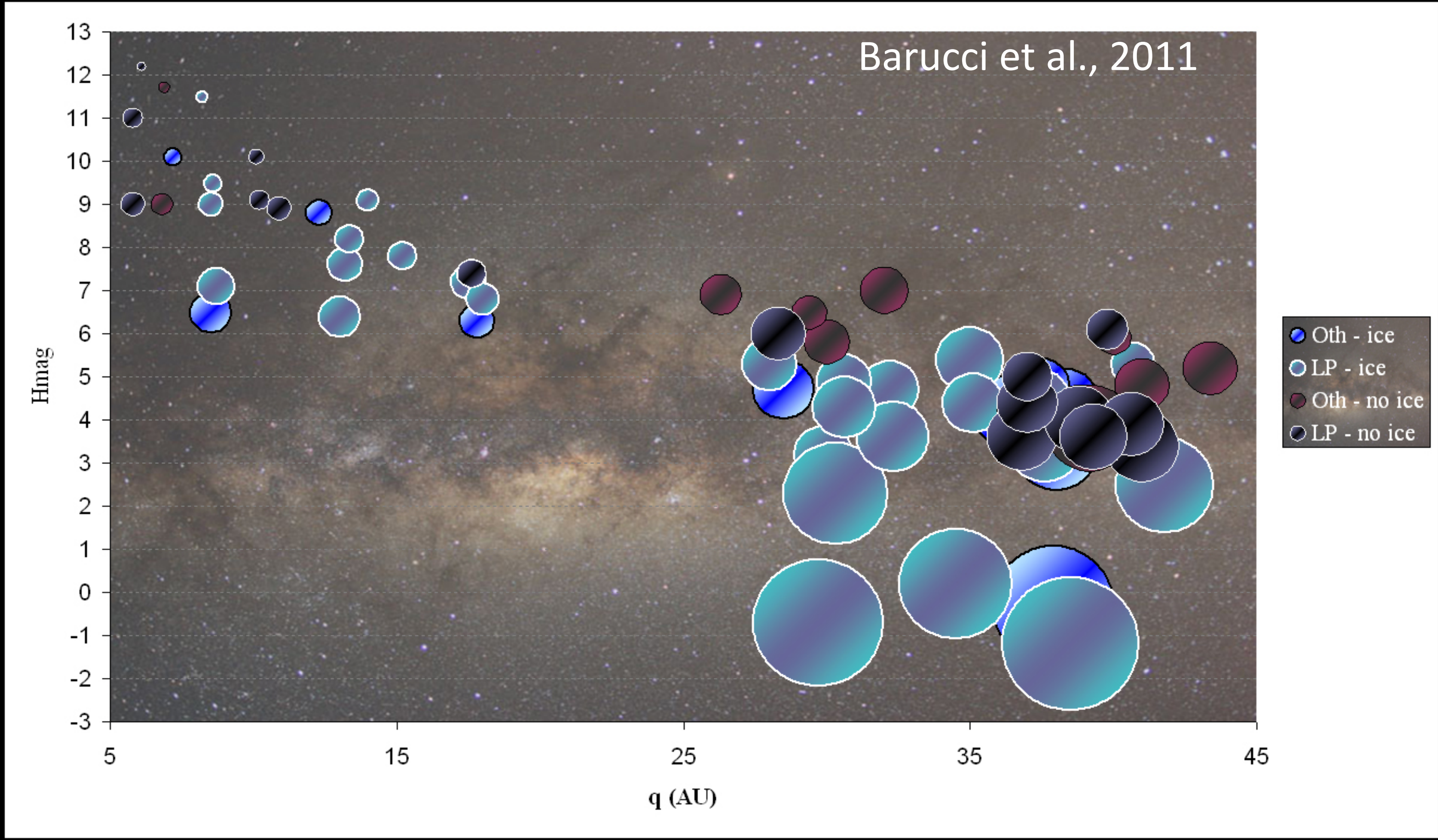


WATER ICE

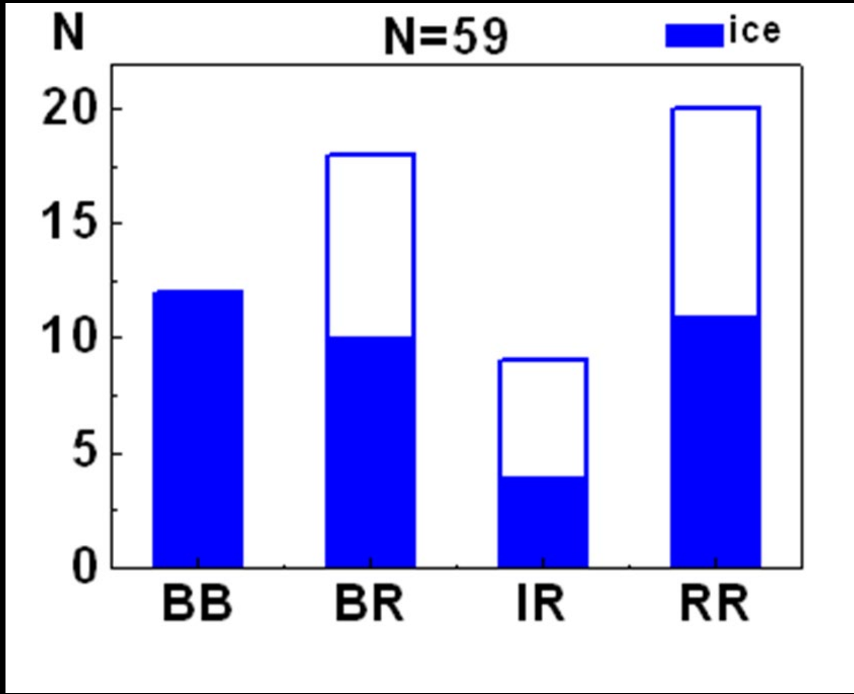
-All bodies > 600 km show water ice features.

- >60% of objects have H_2O (amorphous + crystalline); larger objects have higher water ice abundance (Barucci et al., 2011, Brown et al., 2012)

-All BB type have water ice; for the other classes there is a similar ratio of icy vs non icy bodies

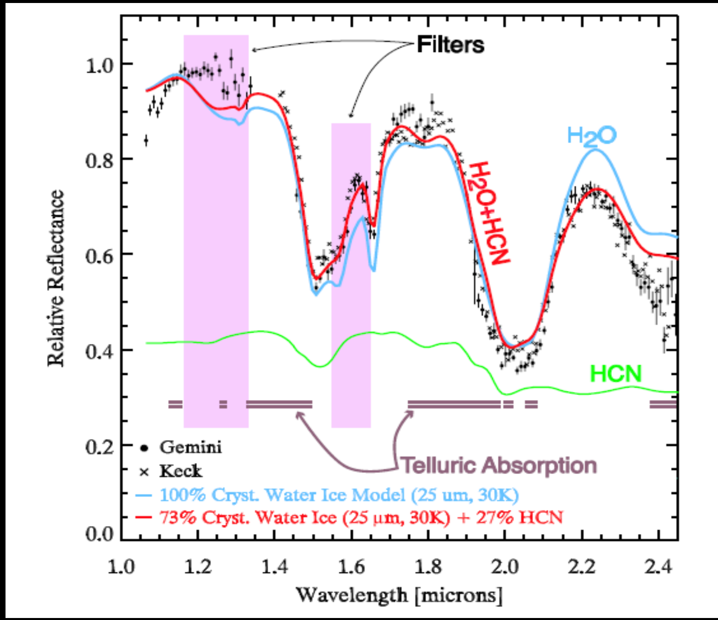


bodies as a function of their taxonomy



Crystalline water ice

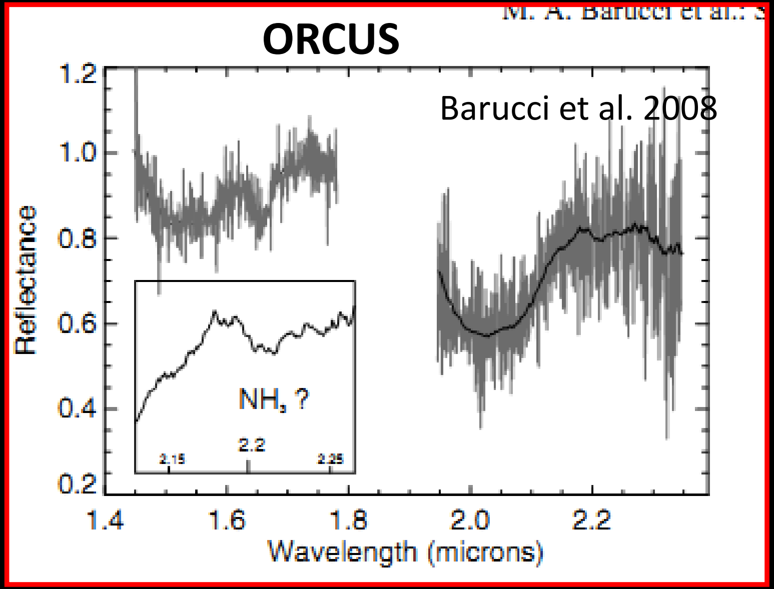
HAUMEA

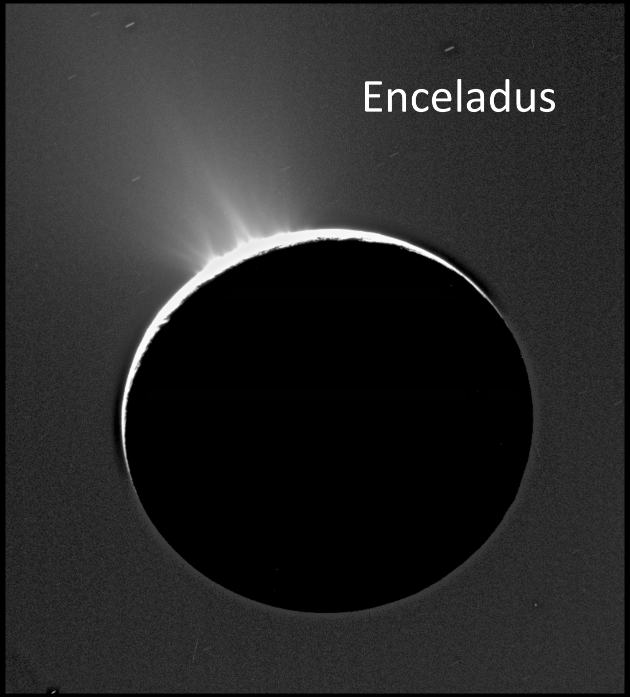


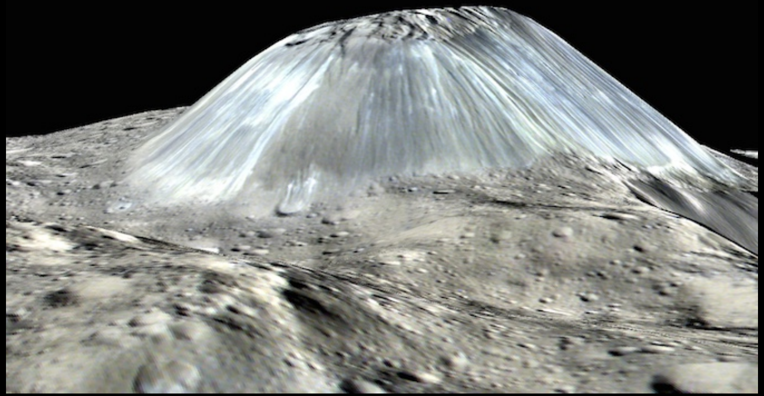
Crystalline water ice needs 100/110 K ,

But TNOs surfaces are colder (30-60 K) !

- Heating needed to form crystalline water ice produced by:
  - internal heating or cryo-volcanisme
  - impacts







Ahuna mons on Ceres

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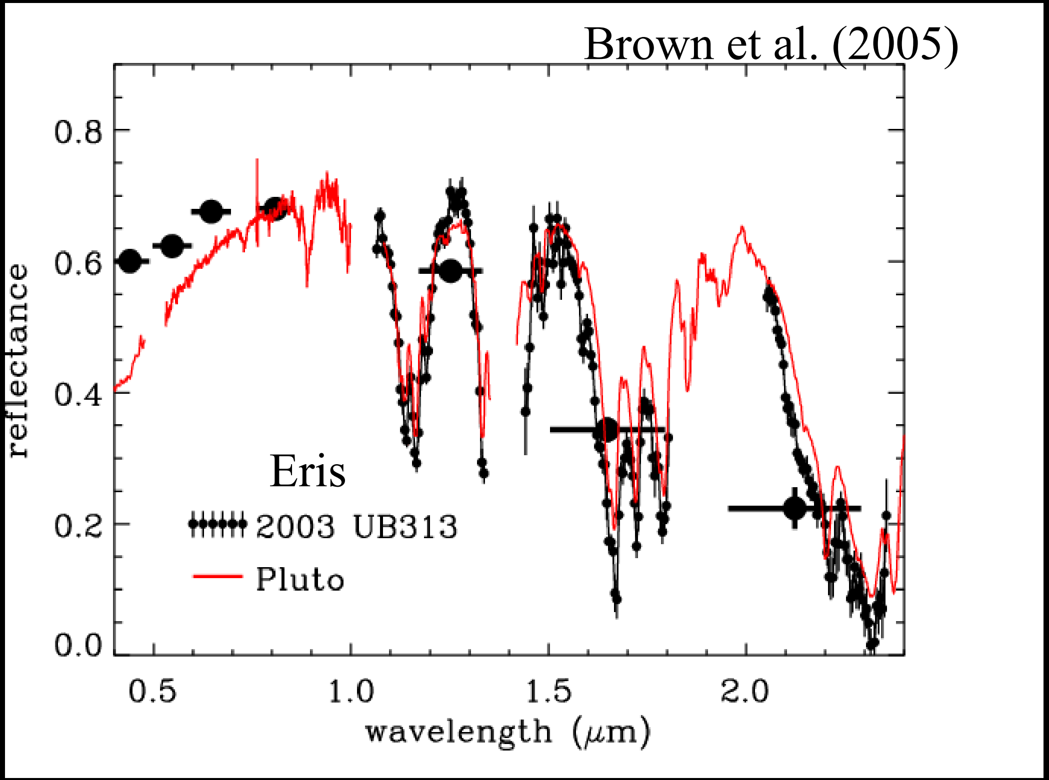
Methane ice on TNO on Pluto, Eris, and Makemake



ERIS

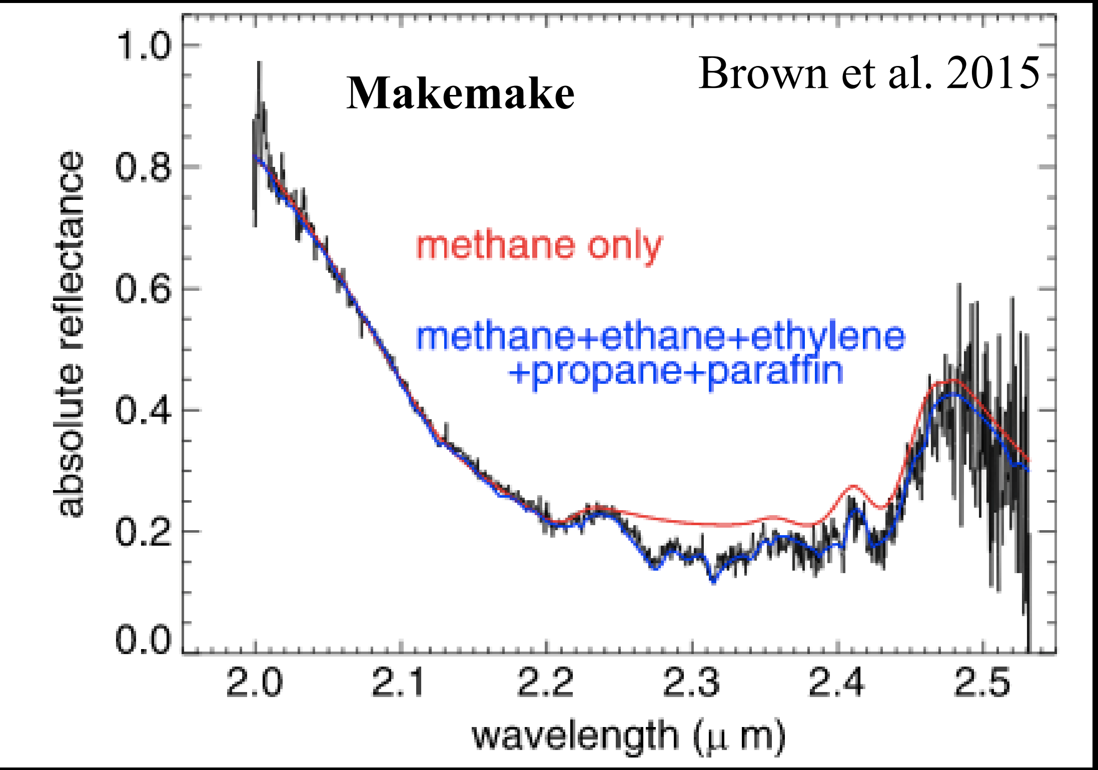
Absorption bands position indicate the presence of **nitrogen ice and dilution of methane in N_2**, (Licandro et al. 2006; Brown et al., 2005)

Merlin et al. 2009: **stratification of CH_4 (different grain size) in Eris**

Makemake

-evidence of methane in large grains (2cm) over 80% of the surface (Brown et al., 2015)

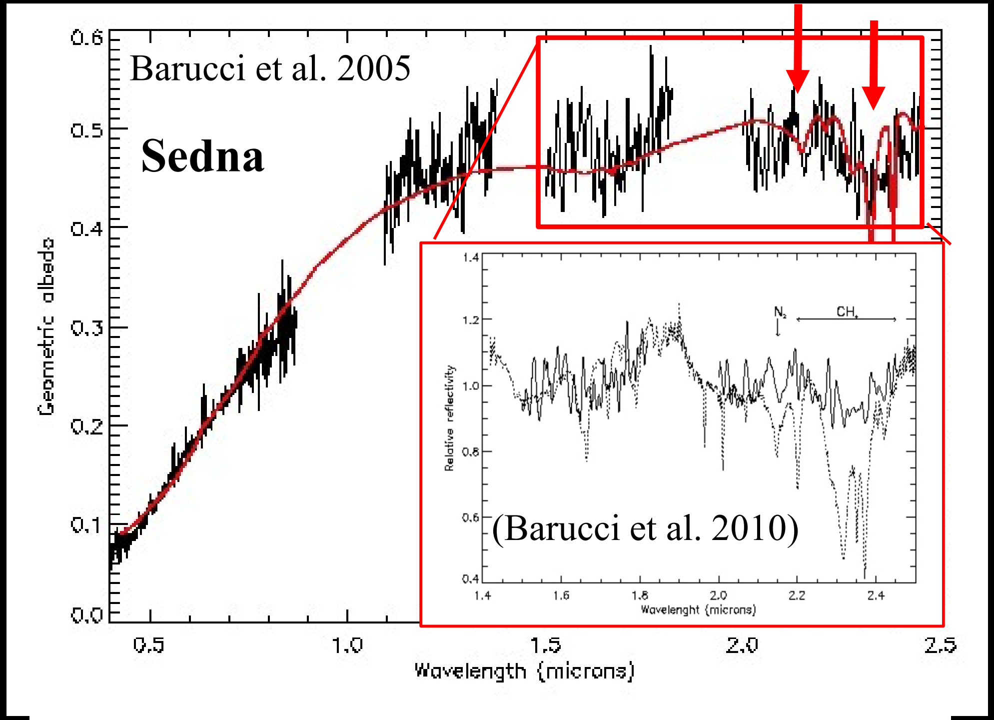
- bands associated with irradiation products of methane: ethane, ethylene, hydrocarbon products

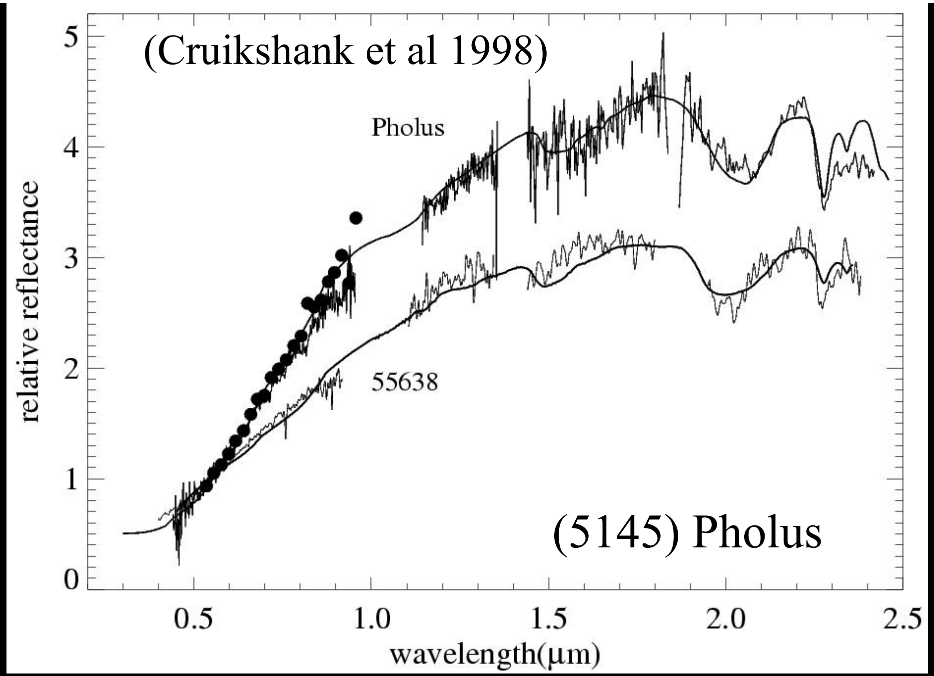


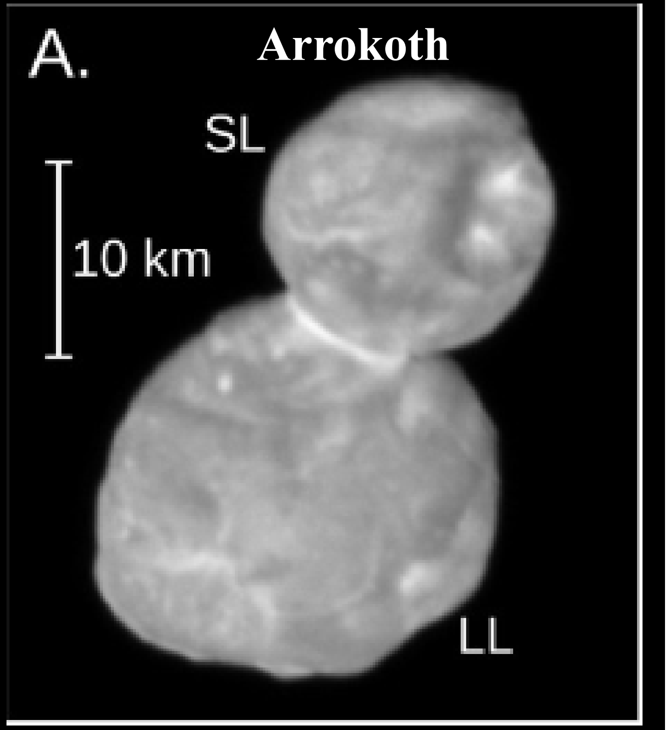
Methanol

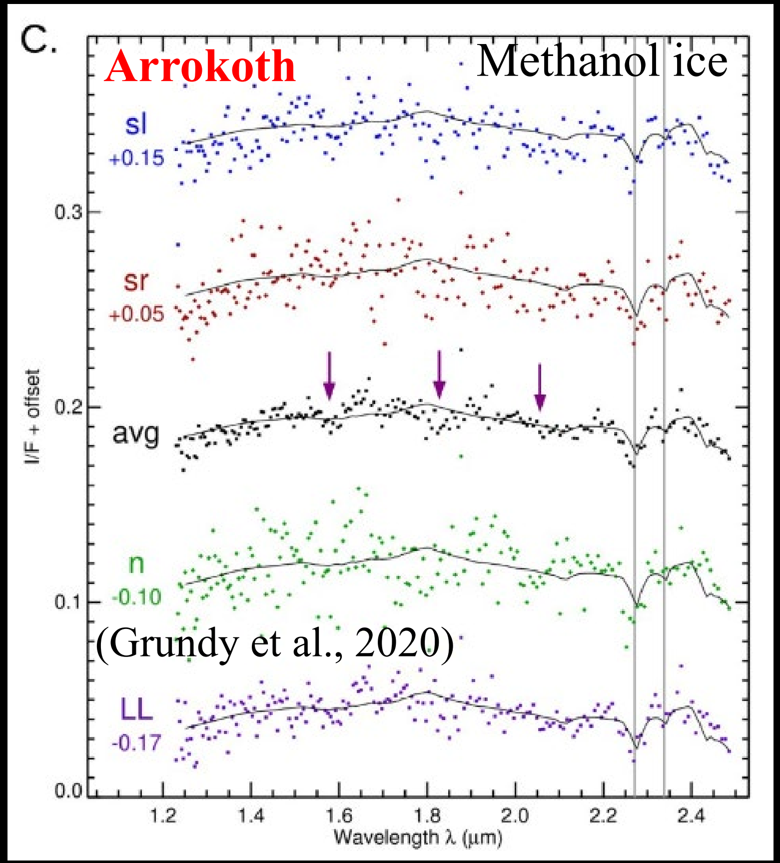
Methanol detected on Sedna, Pholus, (55638) 2002 VE95, and Arrokoth

Sedna is a very red object – RR: Methane, Methanol and N2 detected, the surface is heavily irradiated by galactic cosmic rays
Surface heterogeneities reported : Local rejouvination by internal activity is possible



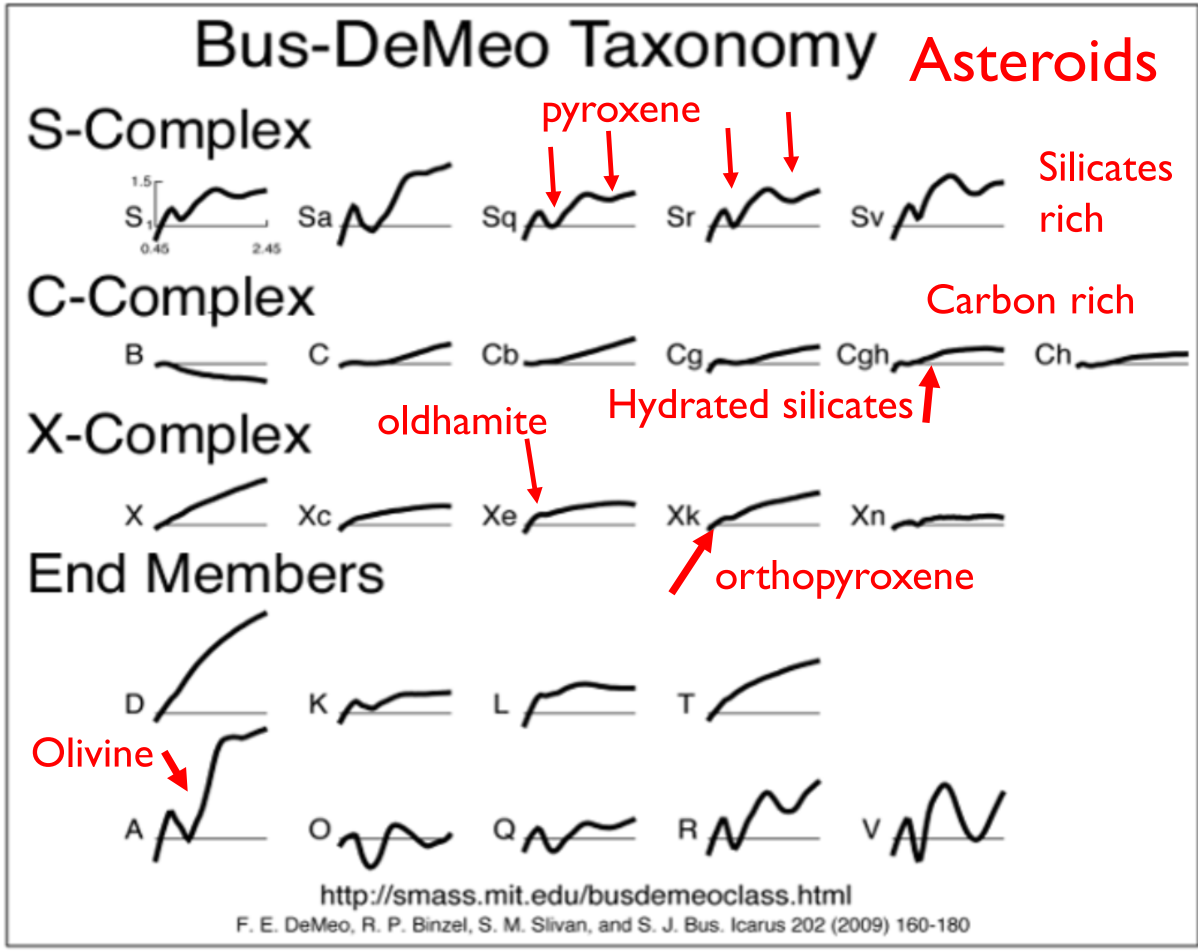


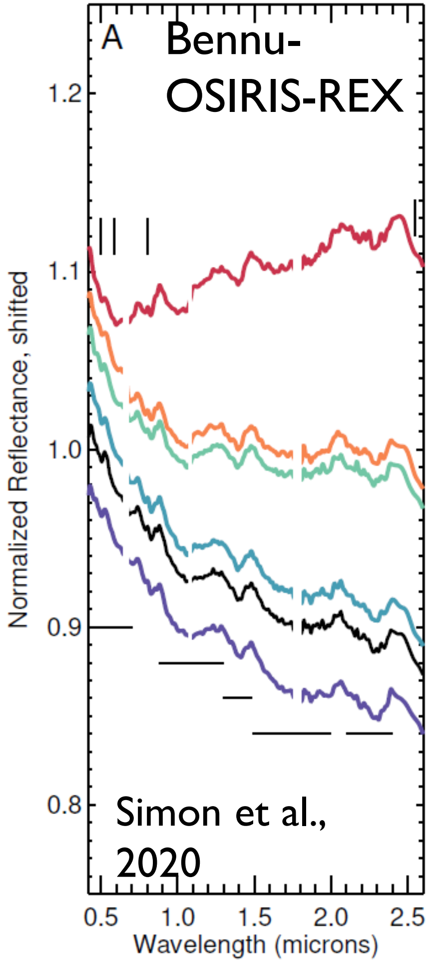




Infrared spectroscopy

- The 1-4 micron range is highly diagnostic of the composition of small bodies.
- From the ground-based telescope, the 0.4-2.5 micron is the most "easily" covered : minerals in asteroids. Deep but also faint (few %) absorption features



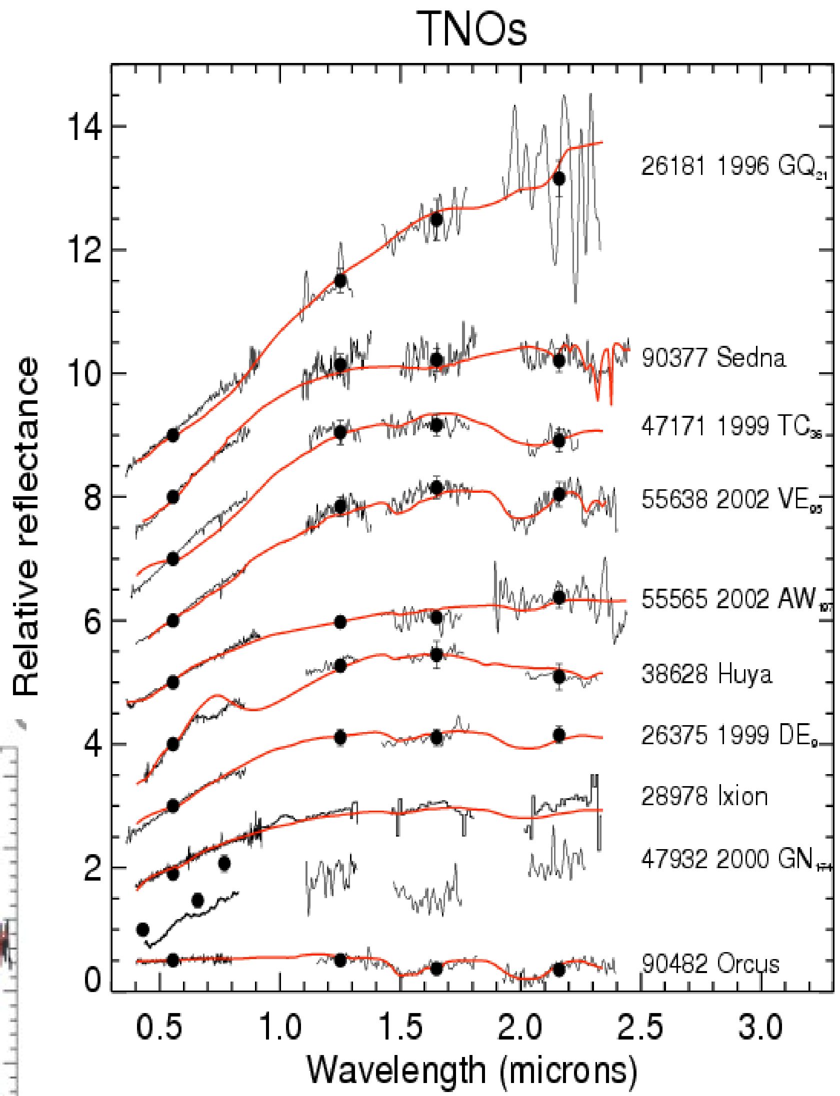


Phase	Absorption band position (µm)	Cause
Serpentines	~0.90–0.94	Octahedral Fe^{2+}
	~1.1–1.2	Octahedral Fe^{2}
	~1.4	OH
	~1.9	OH/H_2O
	~2.3	Mg–OH
Saponites	~0.9	Octahedral Fe^{2+}
	~1.1–1.2	Octahedral Fe^{2+}
	~1.4	OH
	~2.3	Mg-OH
Ferrihydrite	~1.4	OH^{+}
	~1.9	OH/H_2O
Magnetite	~1–1.3	Fe^{3+}spin-forbidden Octahedral Fe^{2+}
Hexahydrite/epsomite	~1.45	H_2O
	~1.95	H_2O
	~2.5	H_2O
Carbonates	~2.3	C–O
	⩾2.5	C–O

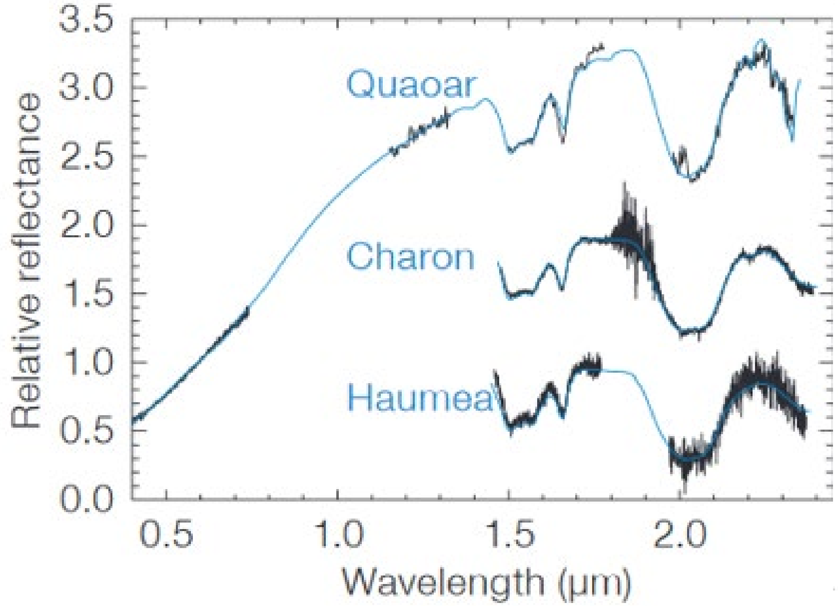
Major absorption bands positions observed in laboratory on CI constituent minerals (Cloutis et al., 2011)

Infrared spectroscopy

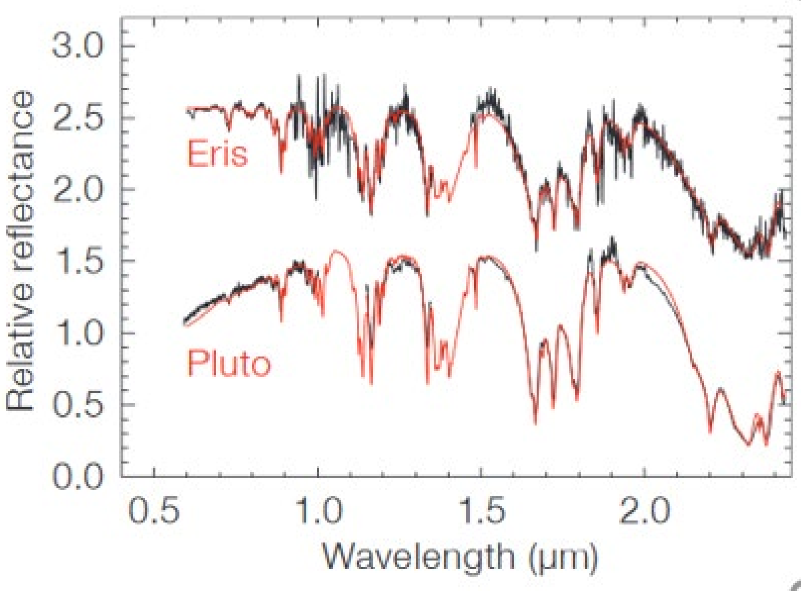
- 0.5- 2.5 micron: minerals and volatiles in TNOs and Centaurs : water ice bands (1.5, 1.65, 2 μm)
  N2 ice (2.15 μm) , methanol (2.3 μm) ,
  Methane (a number of features @ 1.1-1.5 , 1.6-1.9 μm)
  Silicates (0.9-1 and 2 μm)



Water ice rich bodies

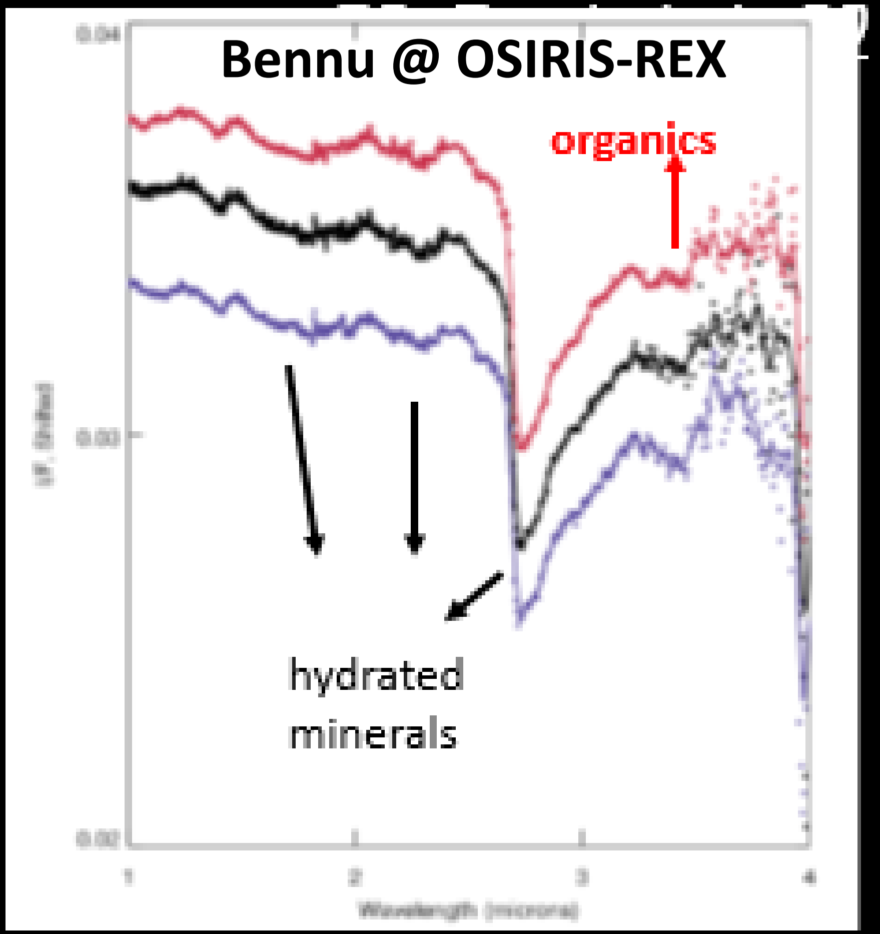


Methane rich bodies



Infrared spectroscopy : the 3 micron region

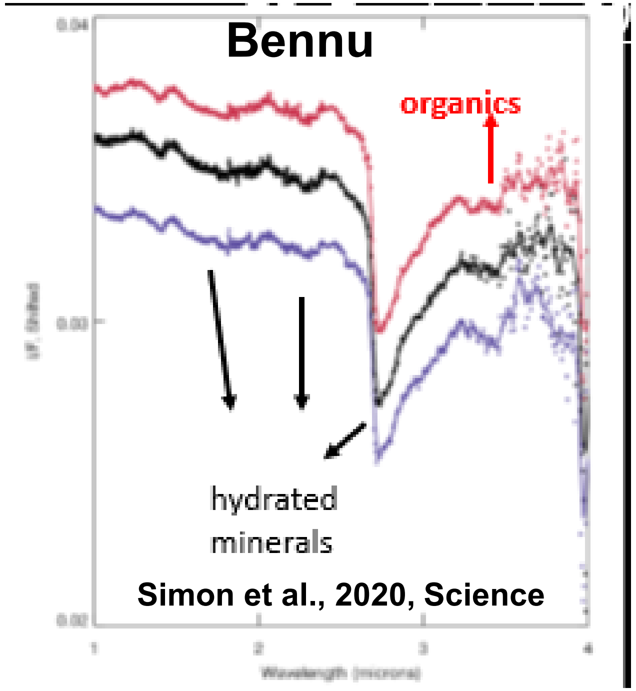
- Water ice : ~ 3.0, 3.1 and 3.2 micron, accurate position depends on the ice state (crystalline or amorphous) , and temperature (Mastrapa et al., 2009)
- Signature of hydroxyl (2.7-2.8 micron)
  → aqueous alteration process
- Methane and organic materials: 3.3-3.4 micron
- Ammonium (NH^{4+}): 3.1 micron (Ceres)
- Organics

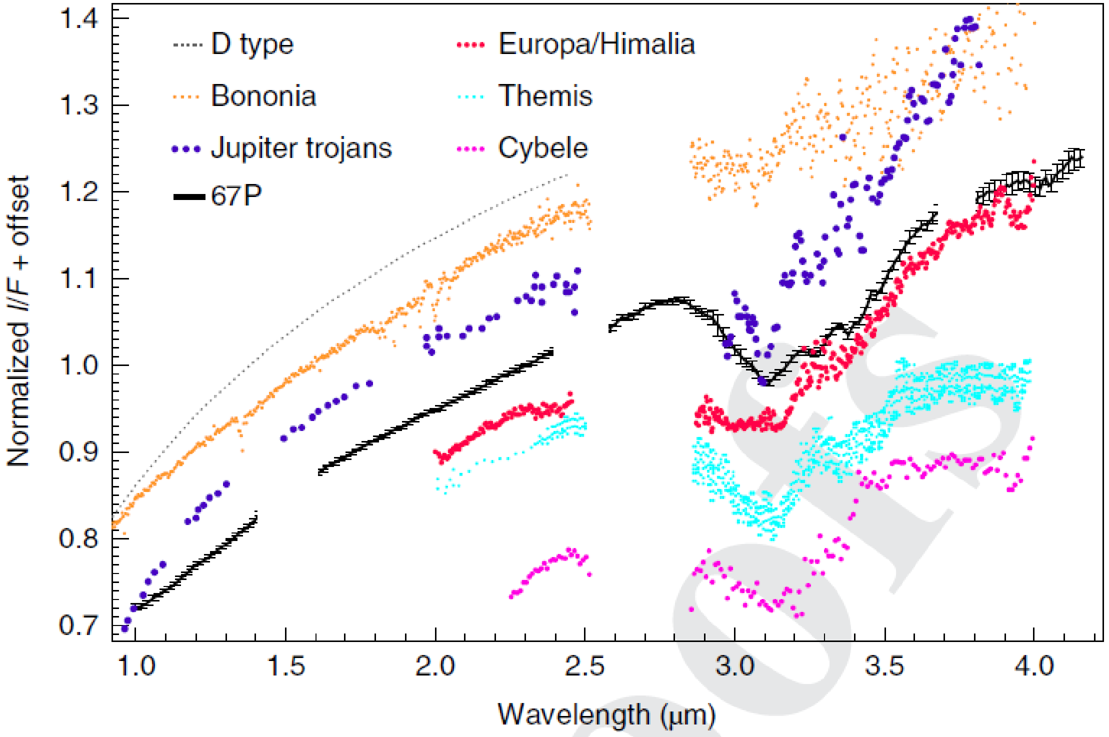


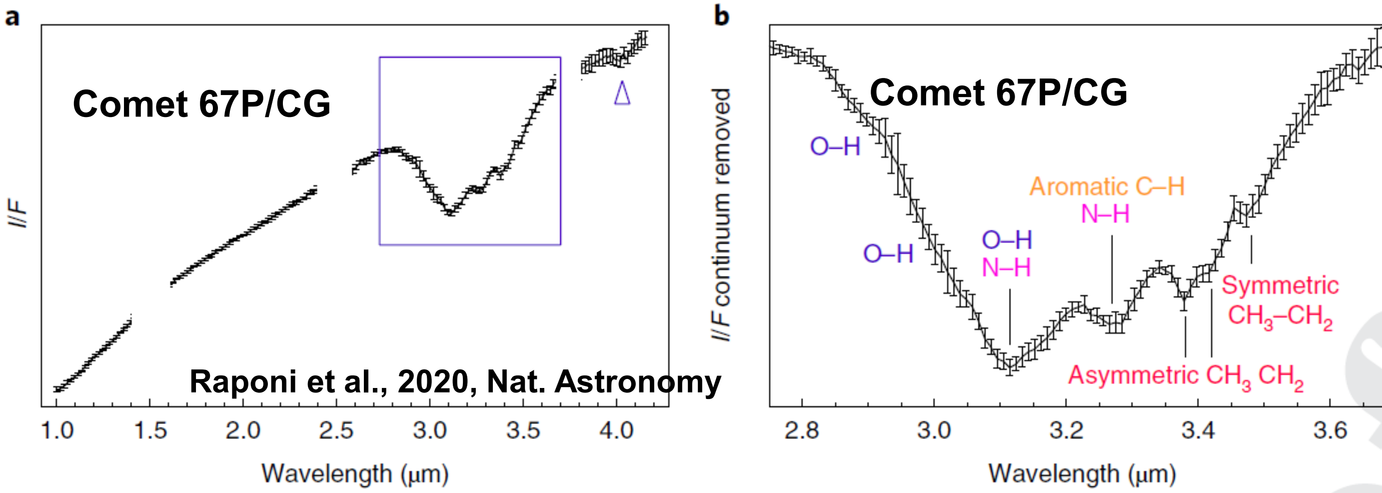
These diagnostic features can be investigated by Atlas, especially for brighter targets !

Organics

- Organics have been detected on the surface of many asteroids, and on comets (glycine also found on comet 67P)
- Absorption bands in the 3.1-3.4 region due to aliphatic and aromatic CH modes in CH2 and CH3, or N-H groups
- Absorption features are usually faint (3-8 few %), require S/N ratio > 20-40







The promise of ATLAS studies on solar system small bodies

- ATLAS will permit the first statistical significative survey of TNOs composition (spectral slopes, deep absorption bands). About 3000 TNOs with r’ < 22.5 are expected to be detected at 3 sigma limit with Atlas in single exposure of 2500s (Wang et al., 2019)

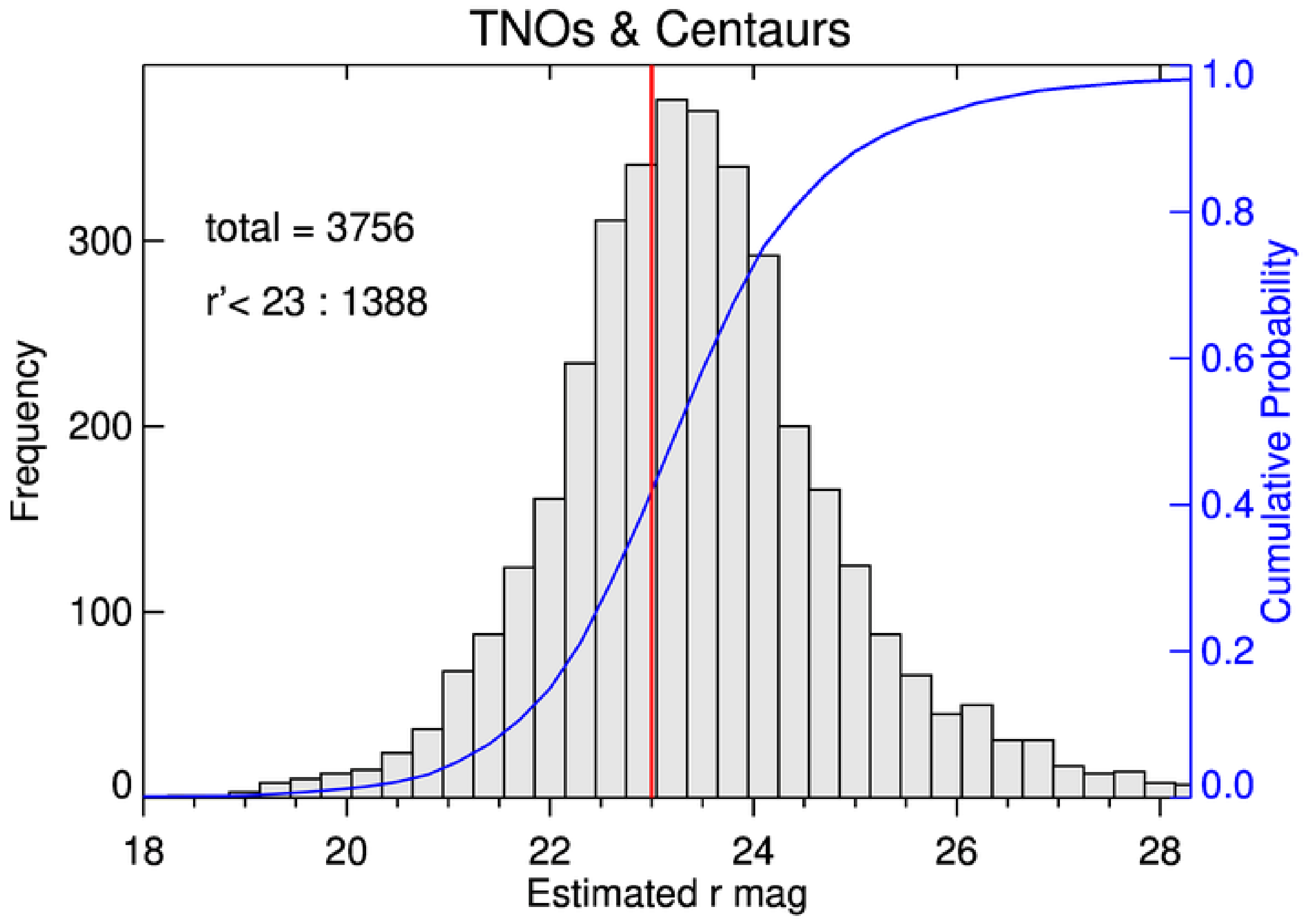
- Spectroscopy in the 1-4 micron range: several features diagnostic of minerals and volatiles

- Composition, presence of material of high exobiological interest like water (hydrated minerals, ice), other volatiles, organic species, silicates
- red colors & organic content-irradiation products

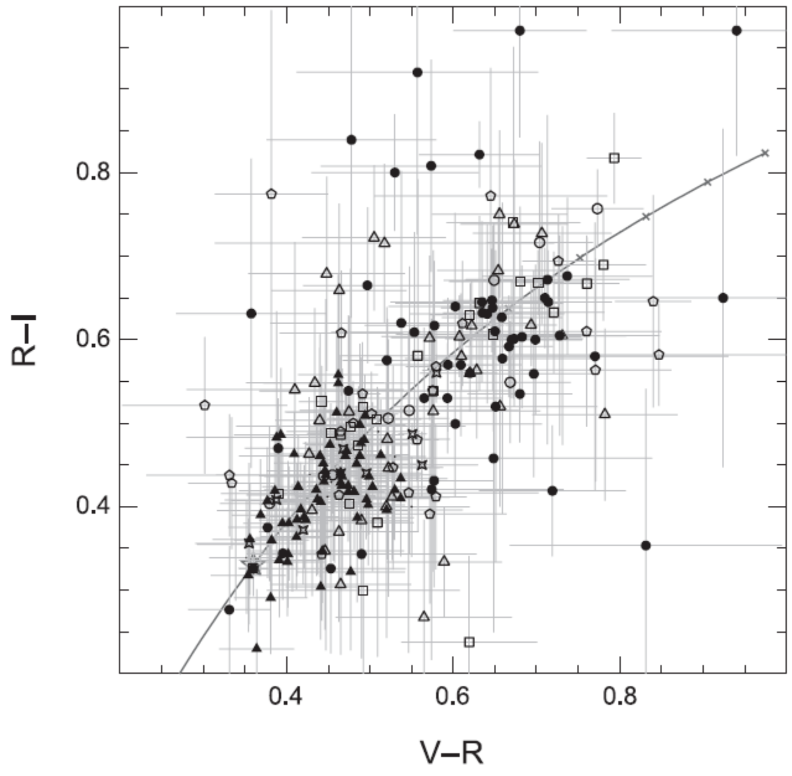
- JWST will permit detailed spectroscopy studies of few tenths of TNOs & Centaurs, not a global survey

Number of TNOs and Centaurs (known nowadays) observable from Atlas

- About 300 TNOs have been investigated in photometry, and 70 in spectroscopy so far



Doressoundiram et al., 2008)



Mag R is roughly estimated from the H absolute magnitude (from the minor planet center) and considering a V-R color of ˜0.6 . We consider heliocentric distance=observer distance= orbit semimajor axis.
Taking distances closer to perihelion, the observed objects jump to ˜ 2000, but this is condition is quite unlikely

The promise of ATLAS studies on solar system small bodies

- A considerable fraction of TNOs will be investigated by ATLAS at S/N ratio of about 10 (→ detection of relatively deep absorption features, overall NIR spectral slope)

- Detailed compositional analysis with detections of relatively faint features (a few %, organics, silicate, volatiles species) require however S/N ratio > 40. Spectral binning could be applied to increase the S/N ratio.

- Atlas will help in constraining the compositional gradient in the early Solar System and its evolution over time, linked to different dinamical and space weathering processes

- Other interesting Solar System bodies which can be observed with Atlas are:

  - Jupiter Trojans (believed to be TNOs captured by Jupiter),
  - asteroids (primitive classes, small family members, …)

Concluding remarks

ATLAS will allow to:

- understand the composition of different Solar System minor bodies in a wavelength range highly diagnostic of the composition and mineralogy
- Do the first large compositional survey of TNOs/Centaurs
- constrain the water content in the outer Solar System
- detect and characterise material of high exobiological interest such as organics and volatiles, for the brighter targets where a S/N ratio > 30-40 could be achieved