Solar System Science with ESO Facilities

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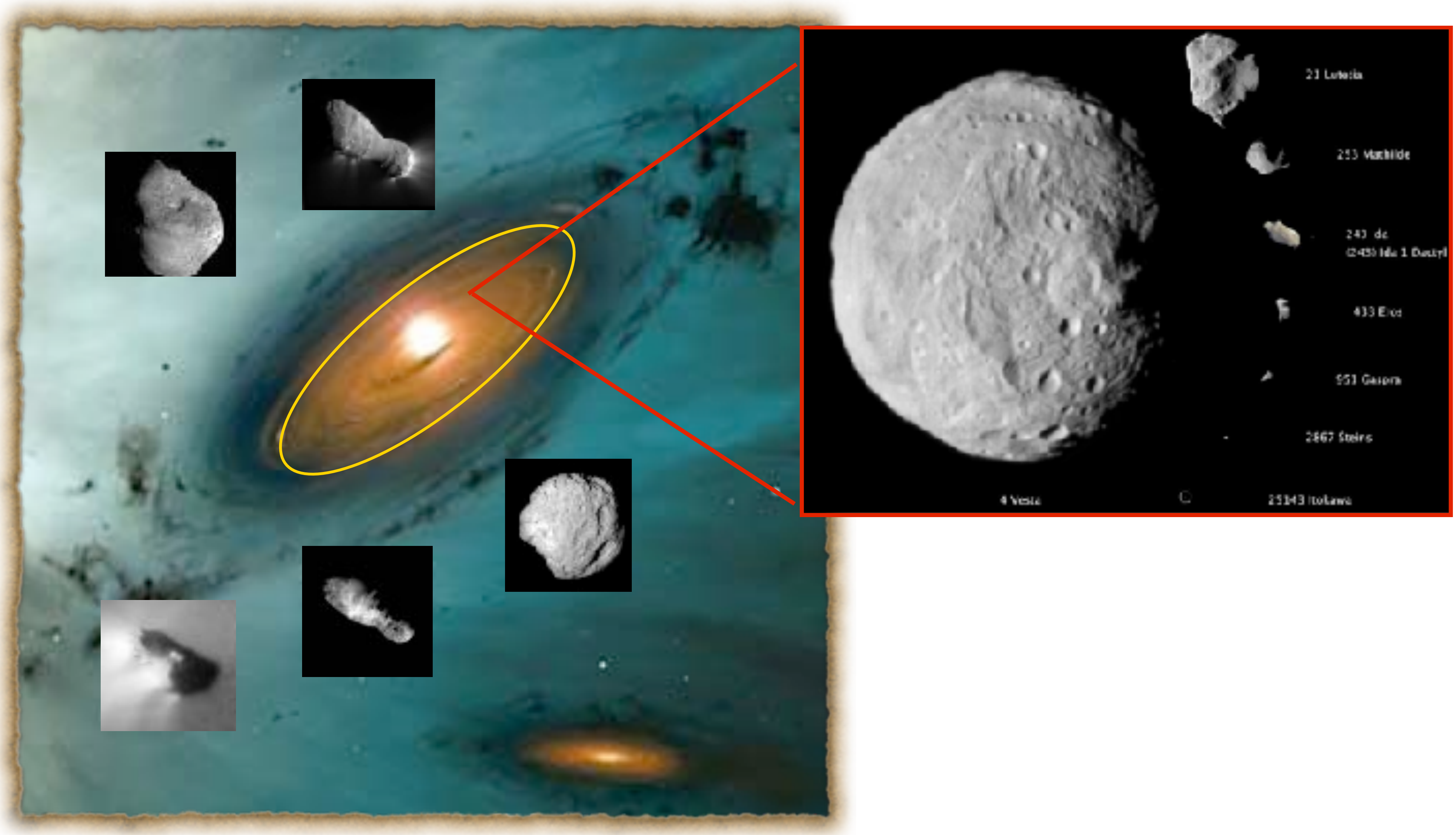
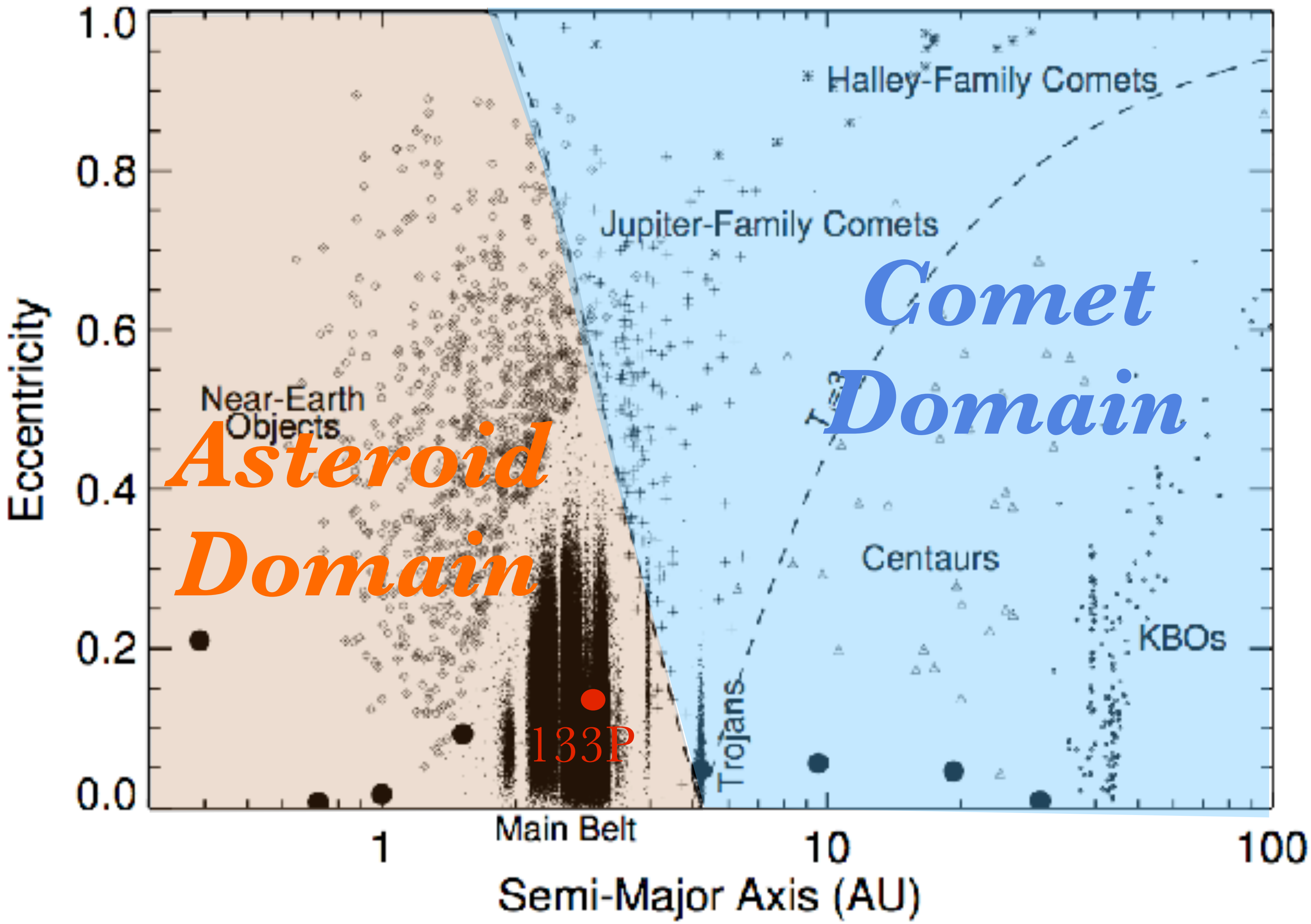
How did our solar system come to be?
NASA
It all began about 4.6 billion years ago in a wispy cloud of gas and dust.
At some point, part of the cloud collapsed in on itself—possibly because the shockwave of a nearby supernova explosion caused it to compress.
The result: a flat spinning disk of dust and gas.
When enough material collected at this disk's center, nuclear fusion began. Our sun was born. It gobbled up 99.8% of all the material.
These clumps became planets, dwarf planets, asteroids, comets, and moons.
4.6 Billion Years Ago
This cloud was a small part of a much bigger cloud.
Nuclear fusion occurs when hydrogen atoms fuse into helium.
The material left behind by the sun clumped together into bigger and bigger pieces.
Present
Only rocky things could survive close to the sun, so gaseous and icy material collected further away. That's how our solar system came to be the place it is today!
Comets and asteroids are the left over remains of the solar system's formation.
Space Place in a Snap!

Snow Line

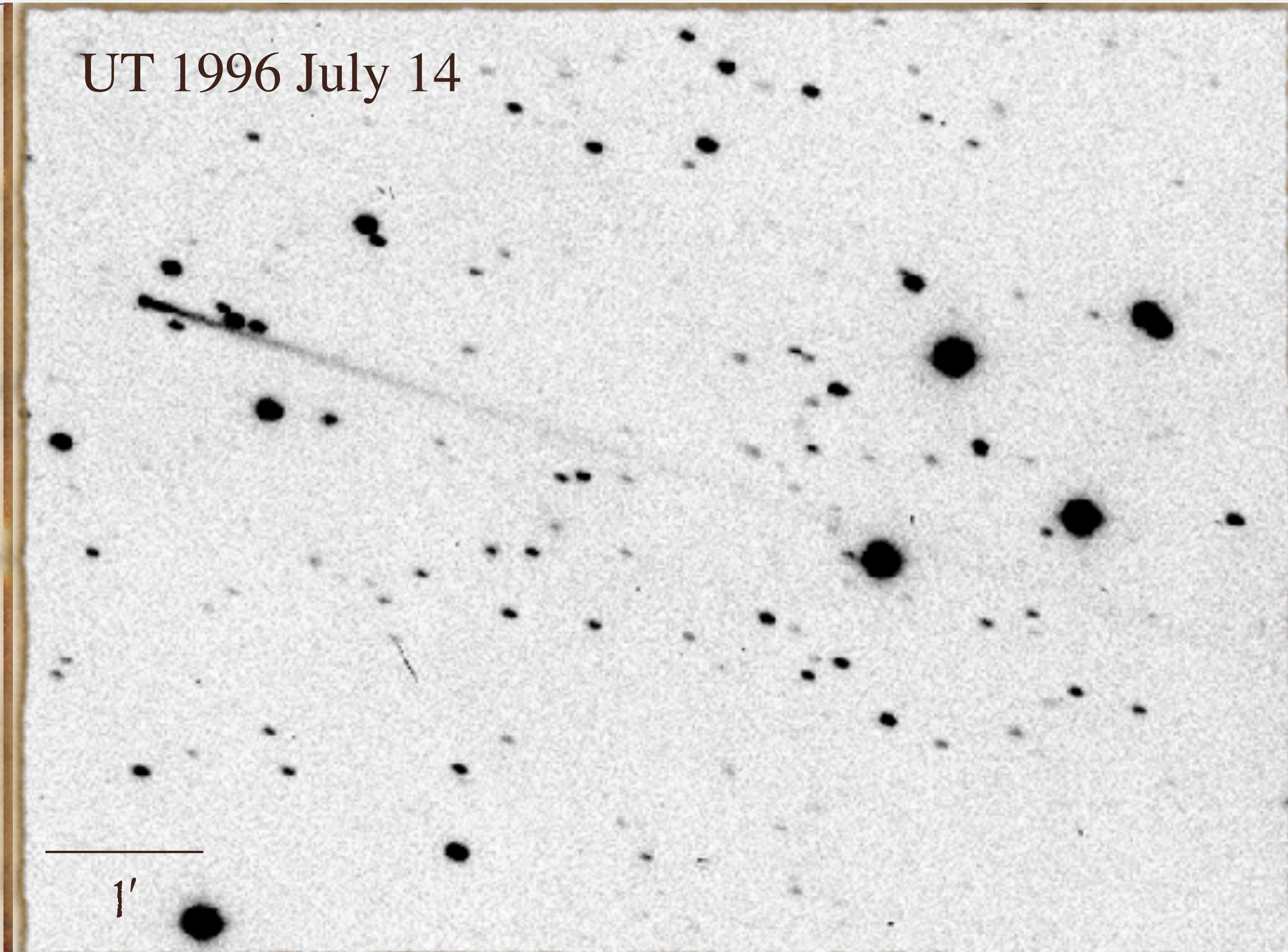


21 Lutetia
253 Mathilde
433 Eros
951 Gaspra
2867 Steins
4 Vesta
25143 Itokawa



Halley-Family Comets
Jupiter-Family Comets
Comet
Domain
Near-Earth
Objects
Asteroid
Domain
Centaurs
KBOs
Trojans
133P
Main Belt
Eccentricity
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
Semi-Major Axis (AU)

133P/Elst-Pizarro

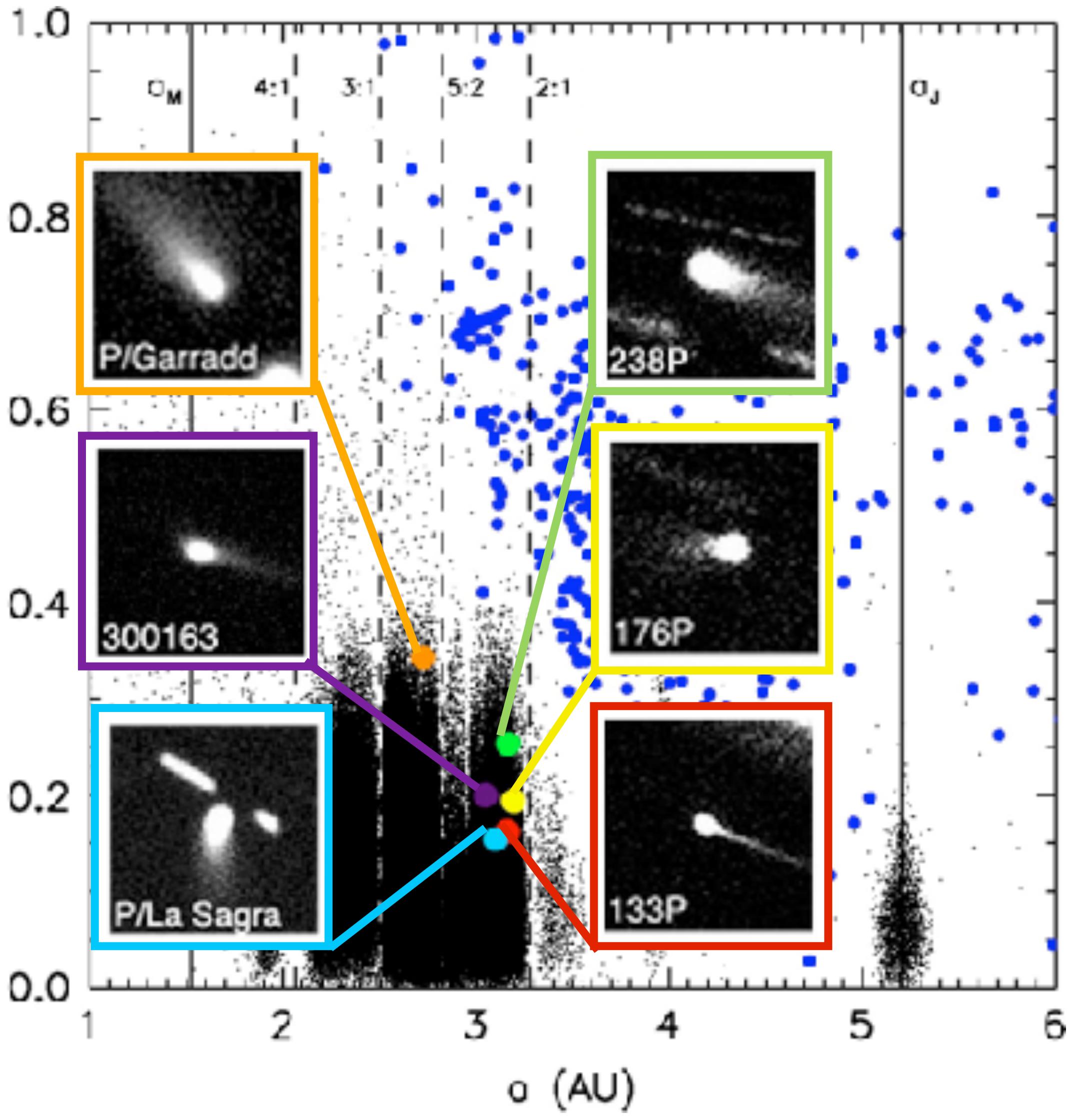


Taken by Guido Pizarro with 1.0-m ESO Schmidt Telescope

From Hsieh et al. 2004

Main Belt Comets (MBCs)

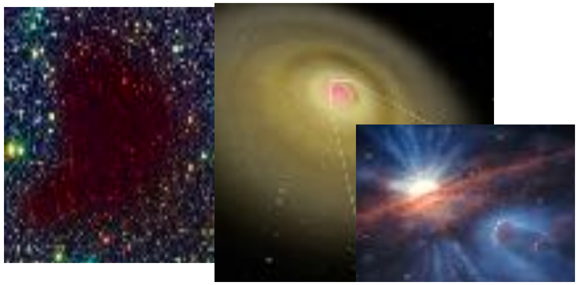
- Asteroidal Orbits
- Cometary Appearances
- Sublimation -driven



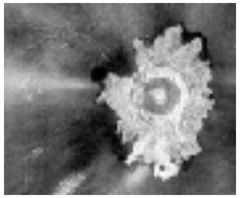
Earth's Water Problem

Origin of Earth's Water

- Capture from the nebula?

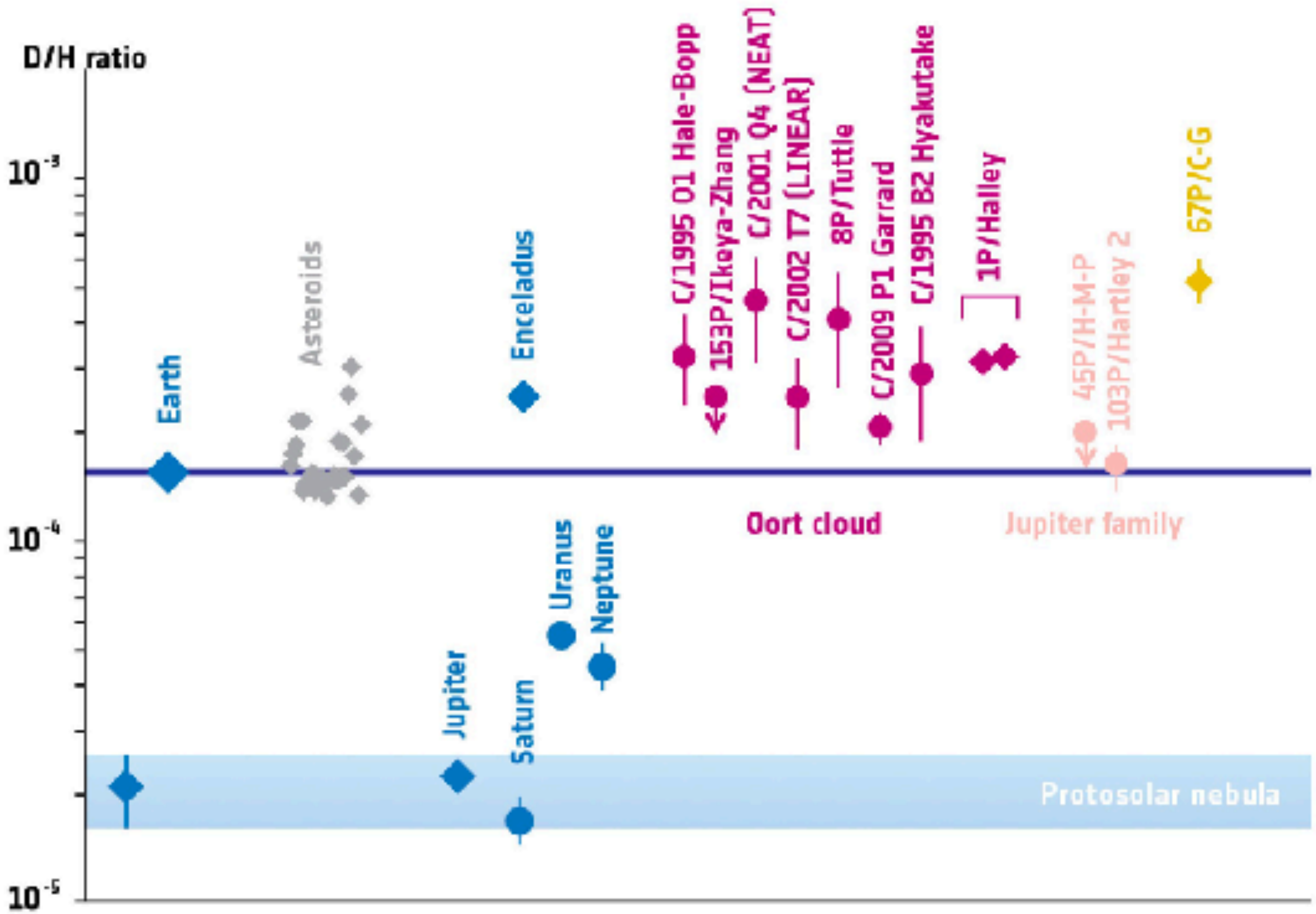


- Early Earth Manufactured its own water?

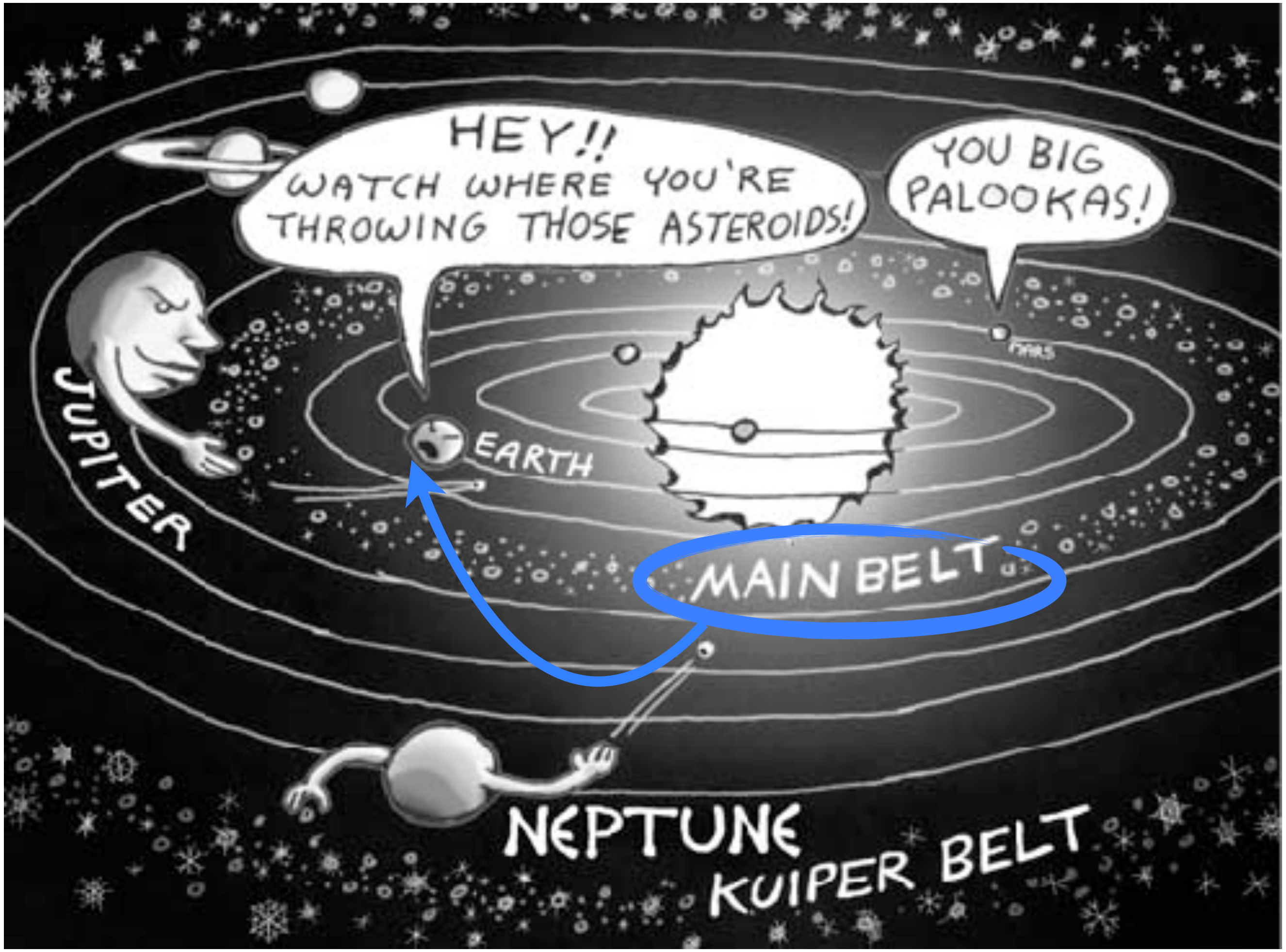


- Brought in by distant icy planetary building blocks?

Cometary Origin?

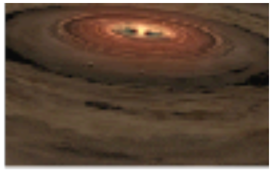
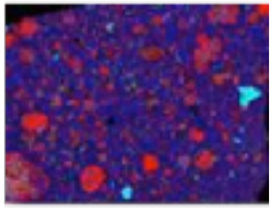


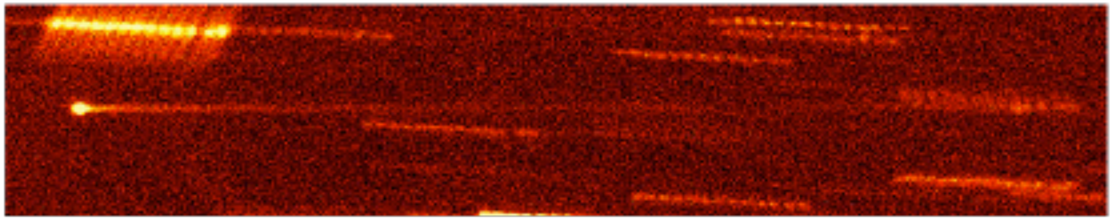
A Promising Reservoir



The Significance of MBCs

- New knowledge of the history of Earth's water
- The third comet reservoir in the Solar system
- Sample different parts of the proto-planetary disk
- The location of the snow line and planet formation

Colors & Sizes of MBCs

176P
D= 4.0 ± 0.4 km

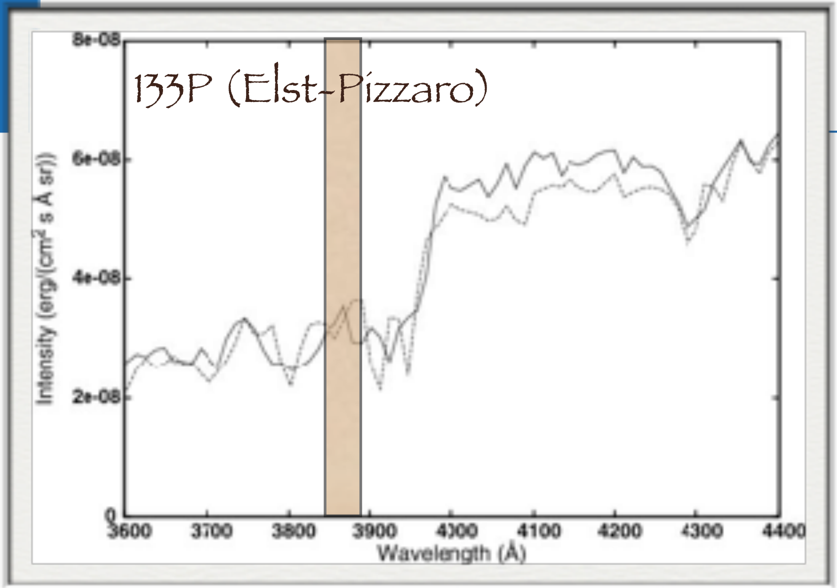
133P
D= 3.8 ± 0.6 km

P/2006 VW139
D~3.5 km

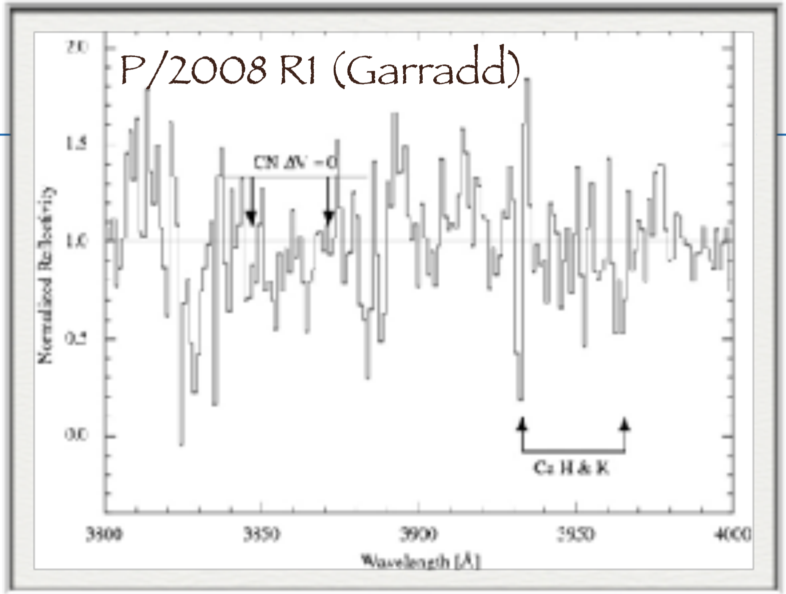
P/La Sagra
D~1.4 km

238P
D~0.8 km

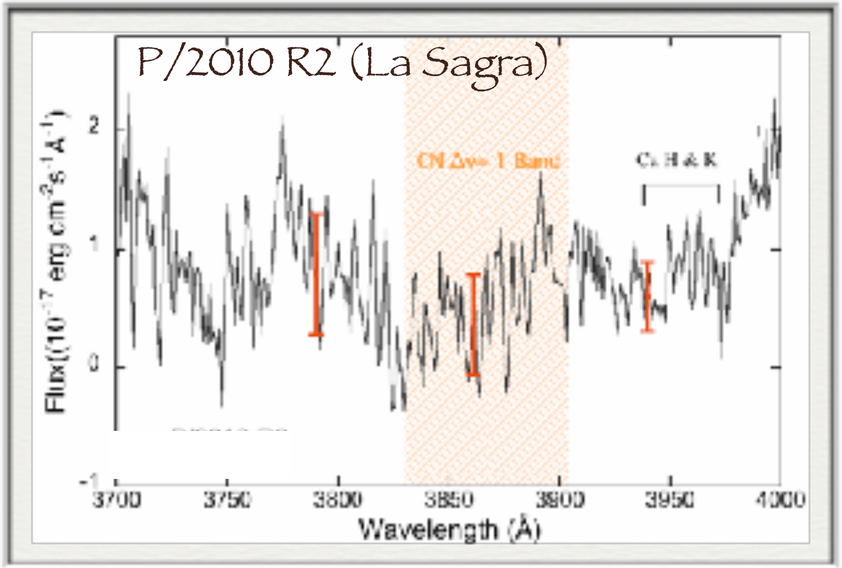
P/Garradd
D~0.4 km



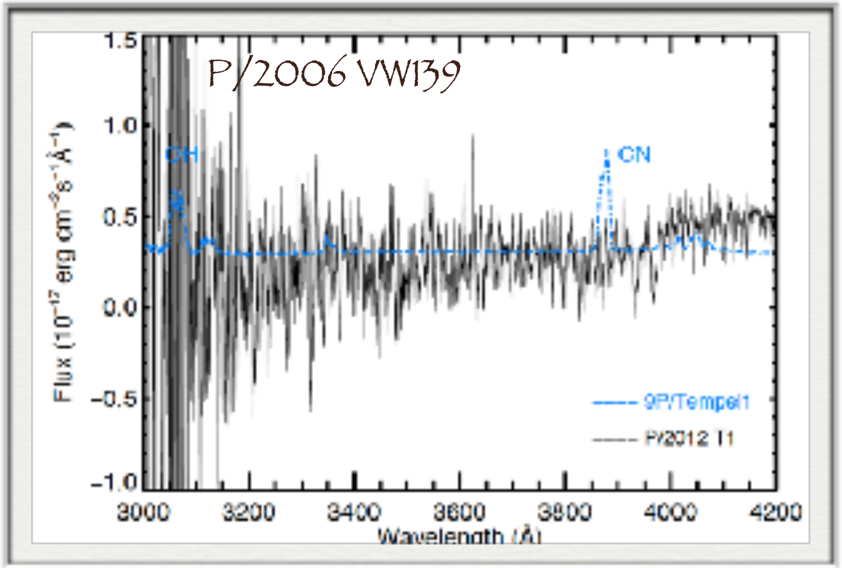
From Licandro et al. (2011)



From Jewitt et al. (2009)

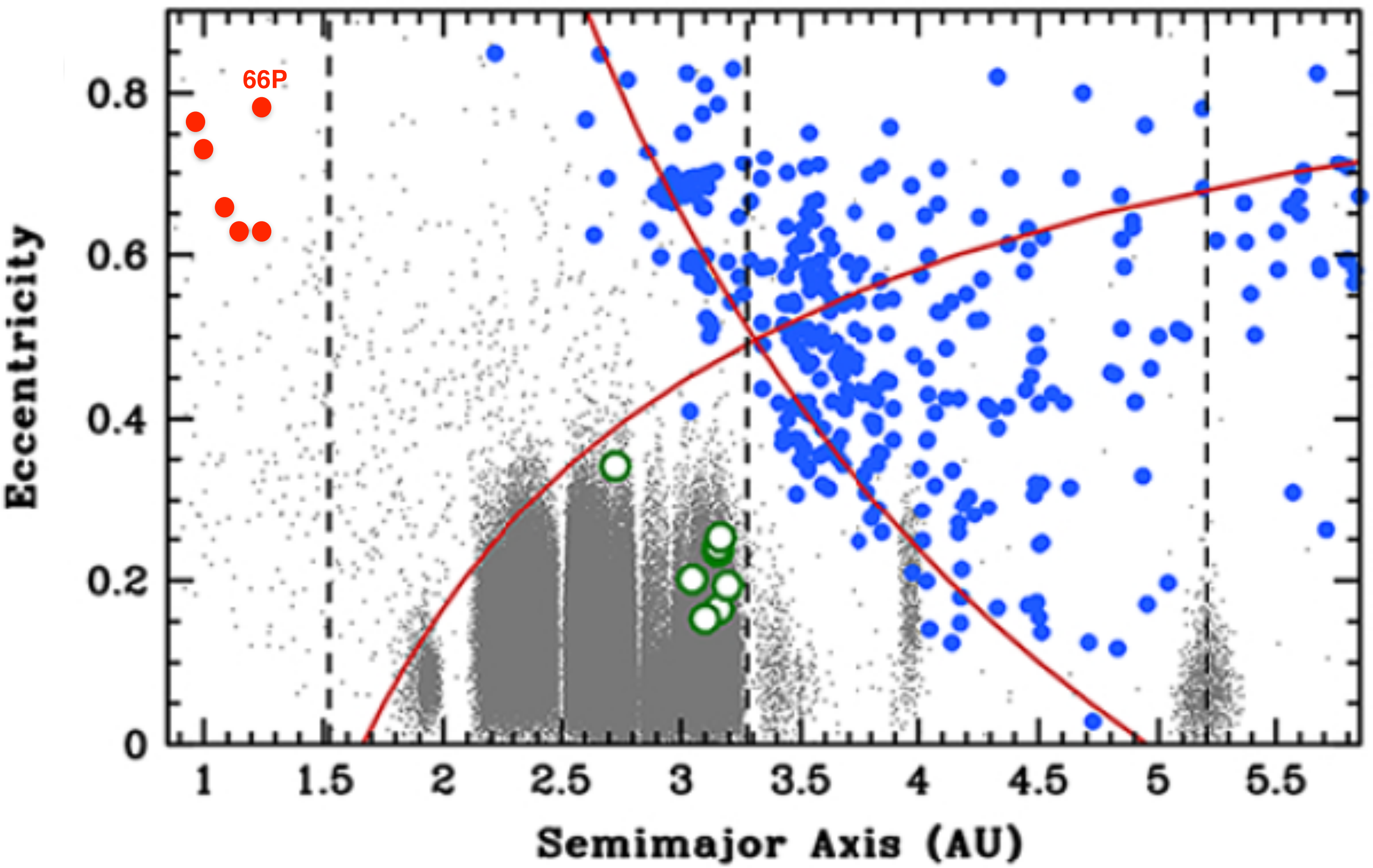


From Hsieh et al. (2012a)

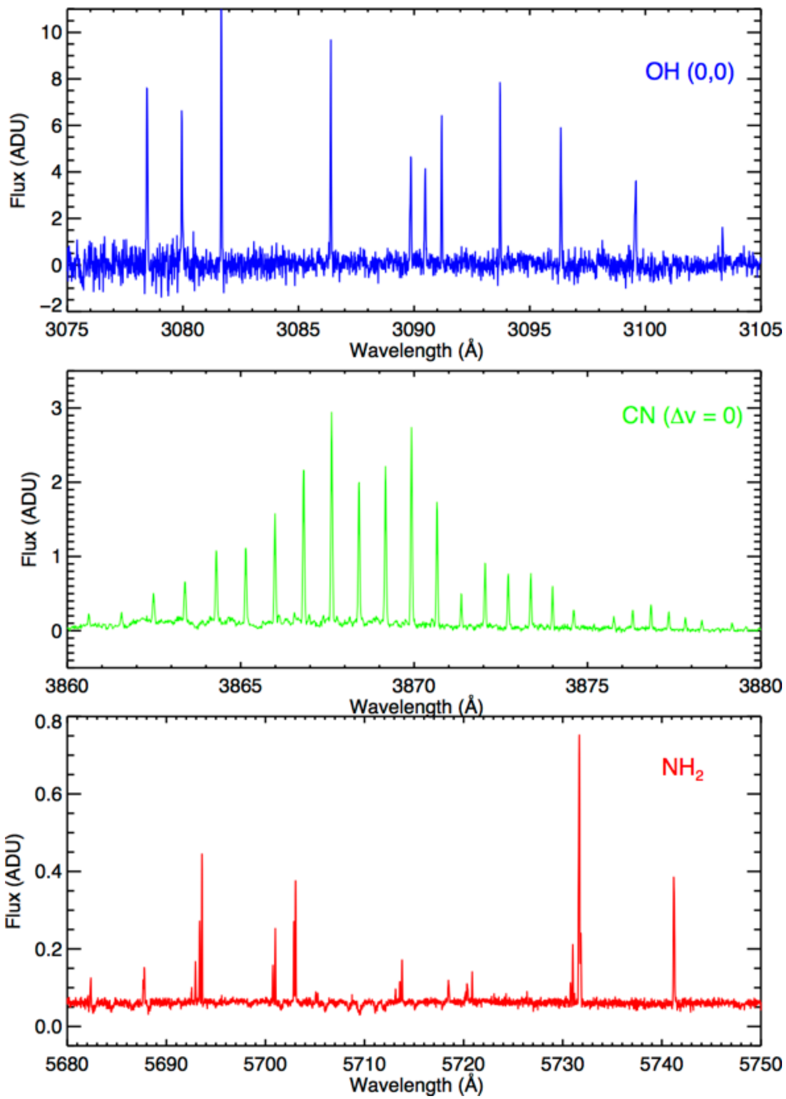


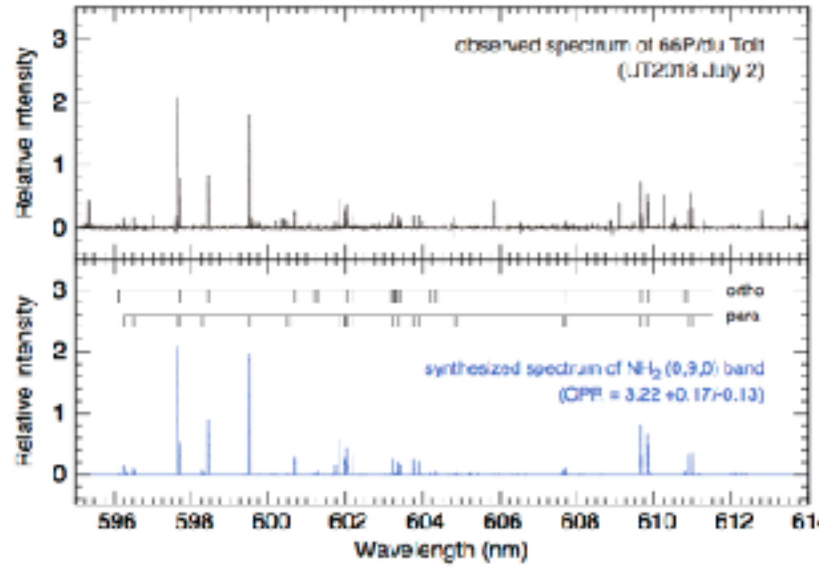
From Snodgrass et al. (2017b)

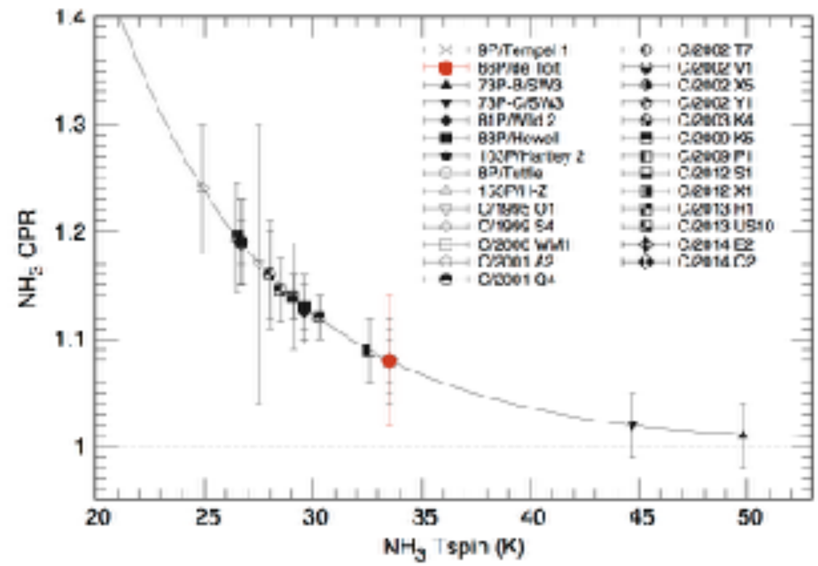
Near Earth MBCs?



VLT/UVES Observations of 66P

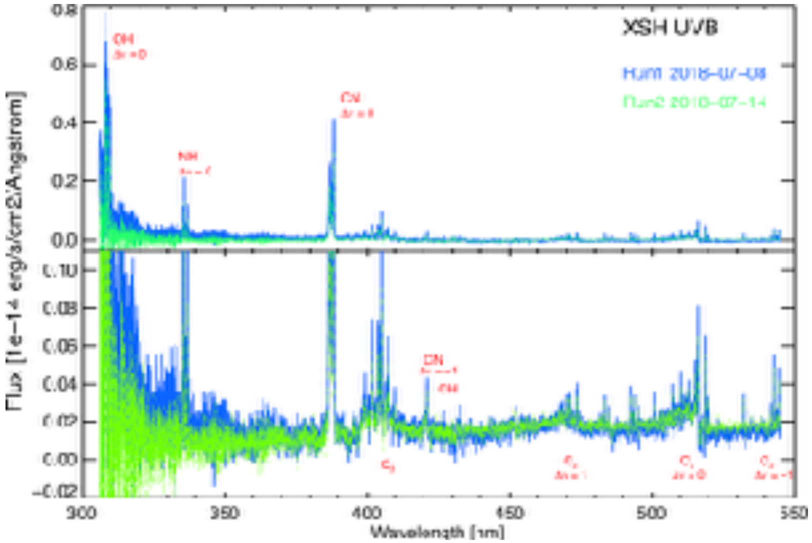


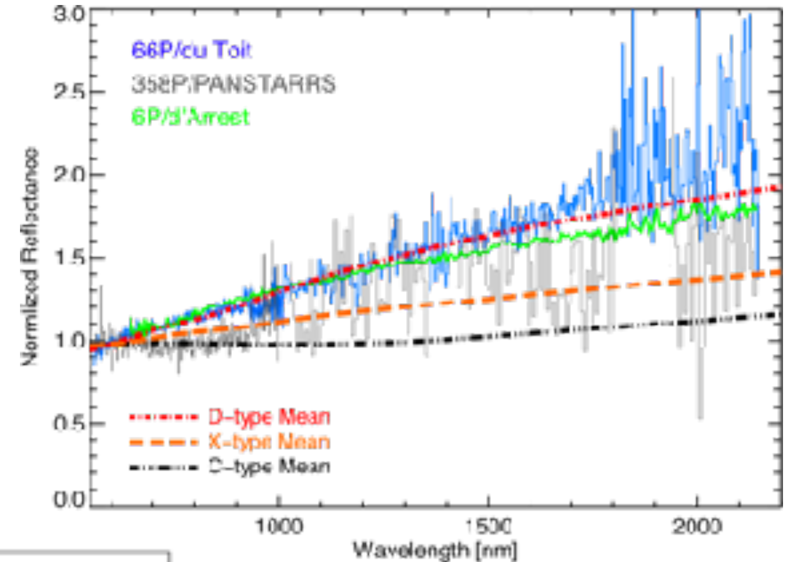


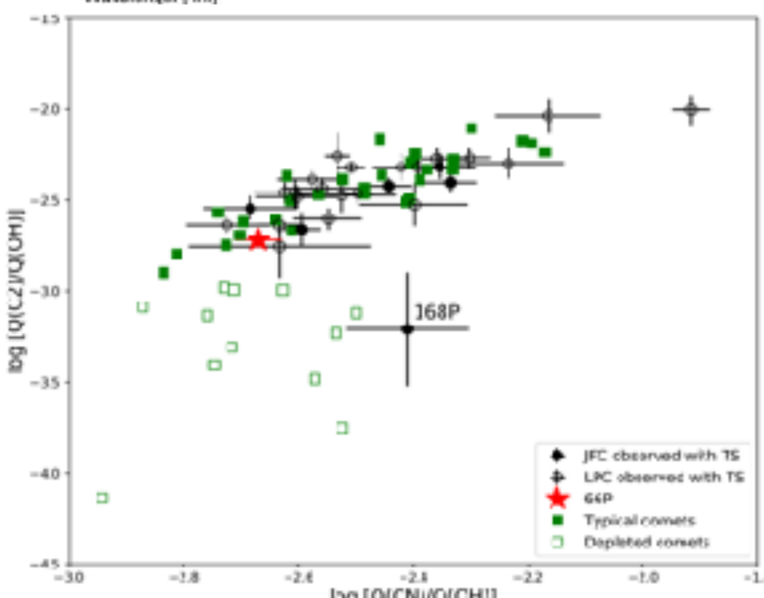


From Yang et al. (2019)

VLT/XSH Observations







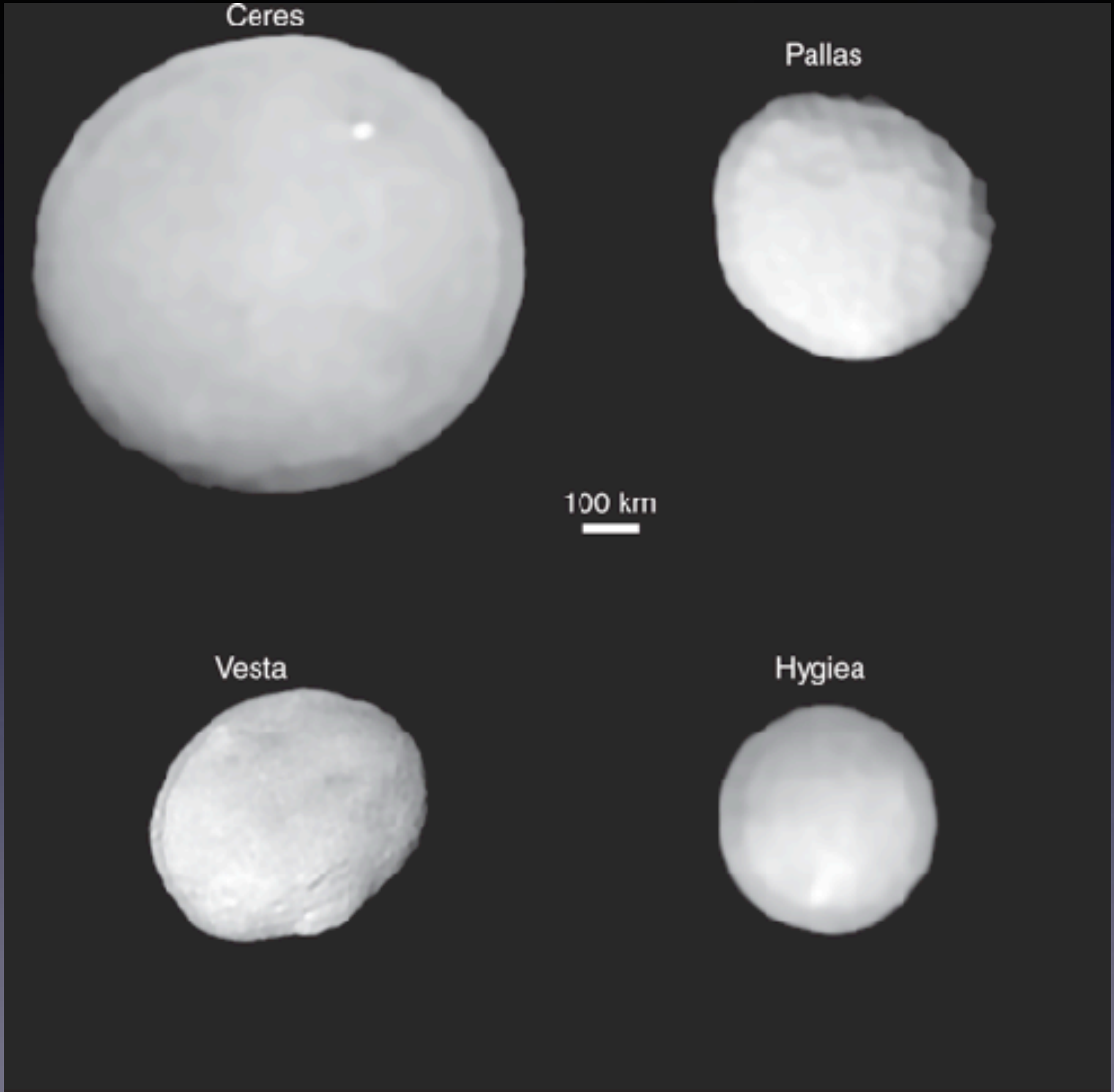
From Yang et al. (2019)

Summary & Conclusion

- The NH_3 OPR =1.08 and T_{spin}=34K for 66P, which are consistent with the values observed in others JFCs
- The composition, molecular abundance, and coma evolution of 66P are comparable to typical JFCs
- The XSH spectrum of 66P is much redder than those of MBCs but more similar to the spectra of active JFCs
- The dust model suggests an active region at low latitude, which differs from other known MBCs

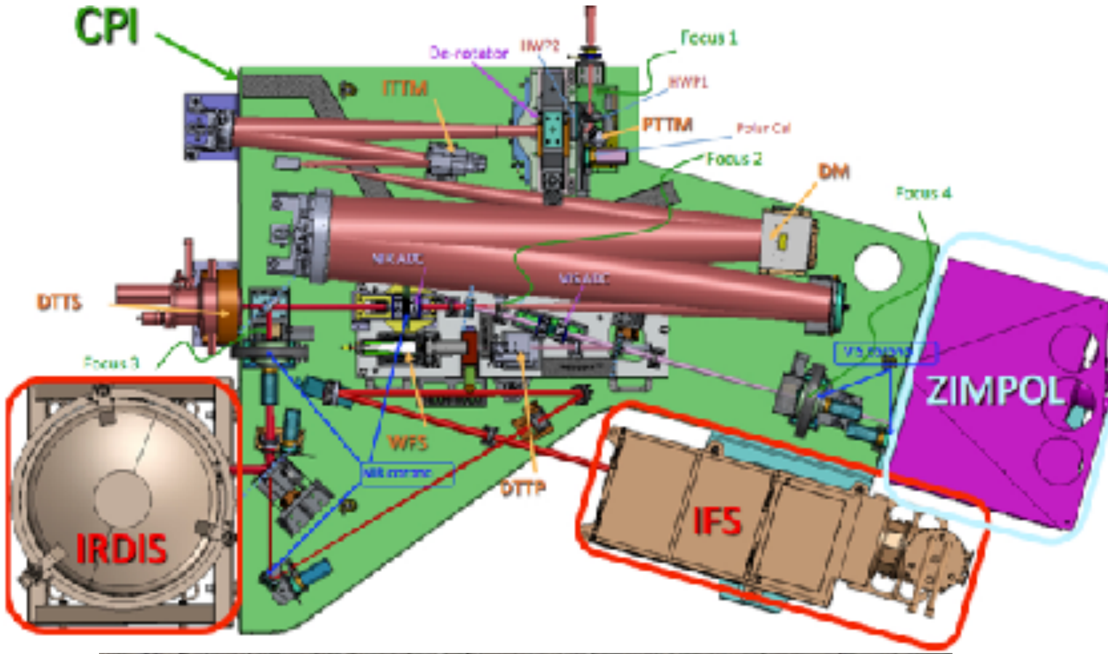
66P is unlikely to have originated from the Main belt and it is NOT an NEMBC!

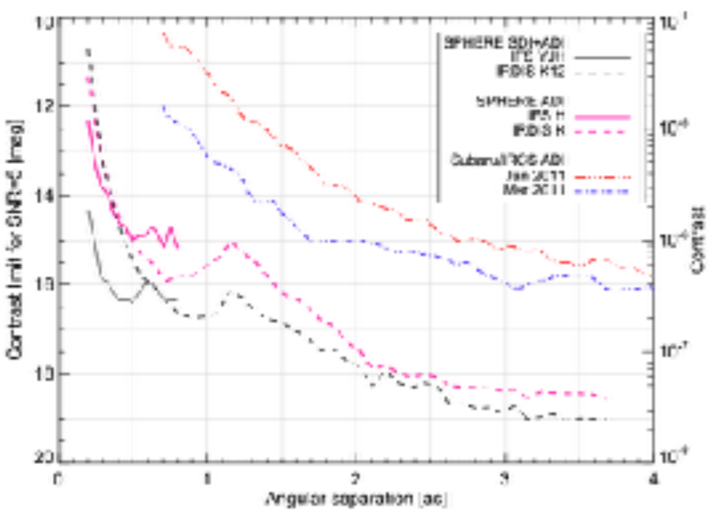
Extreme AO Observation of Asteroids



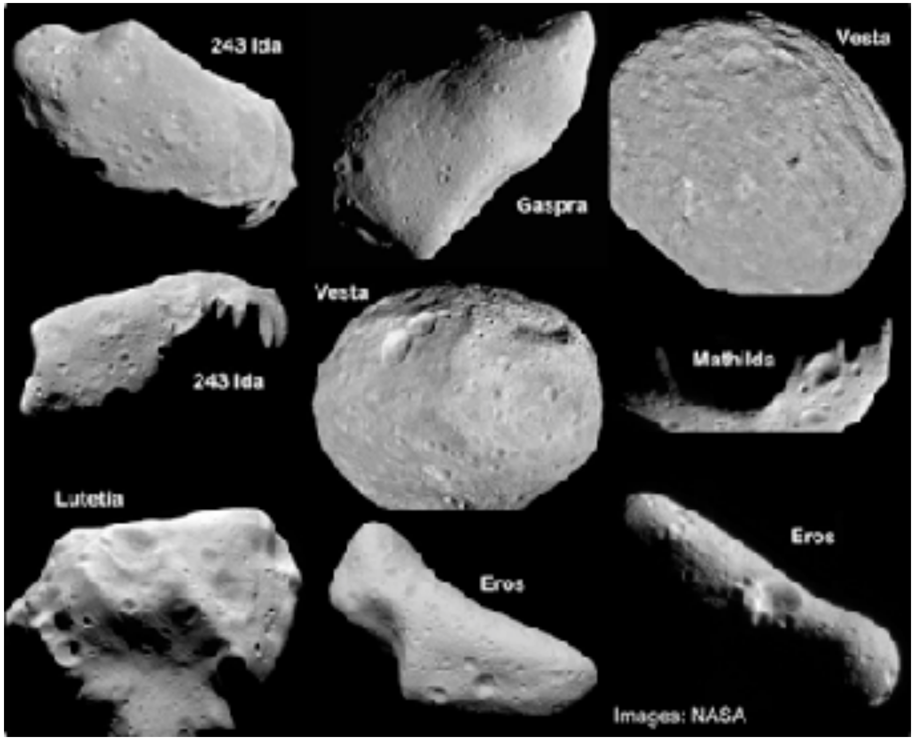
Spectro-Polarimetric High contrast Exoplanet REsearch (SPHERE)

- Extreme adaptive optics (AO) system and coronagraphic instrument at ESO.
- Capable of doing dual-band imaging, LR-spectroscopy, polarimetry.



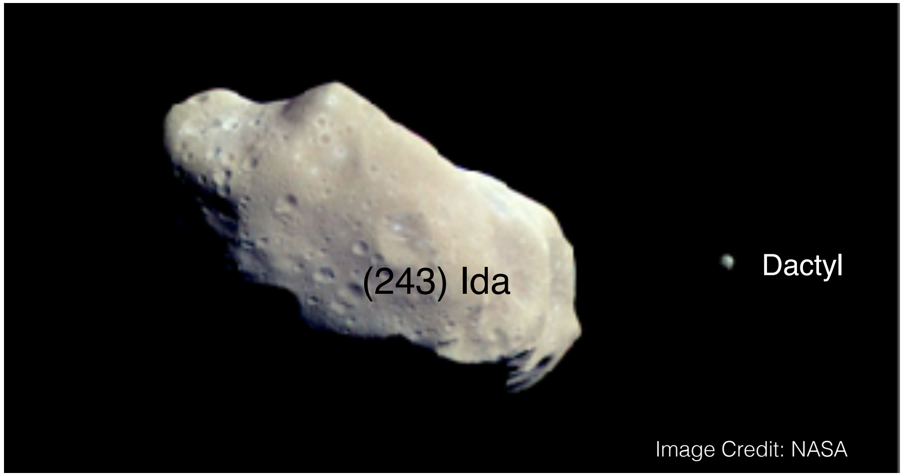


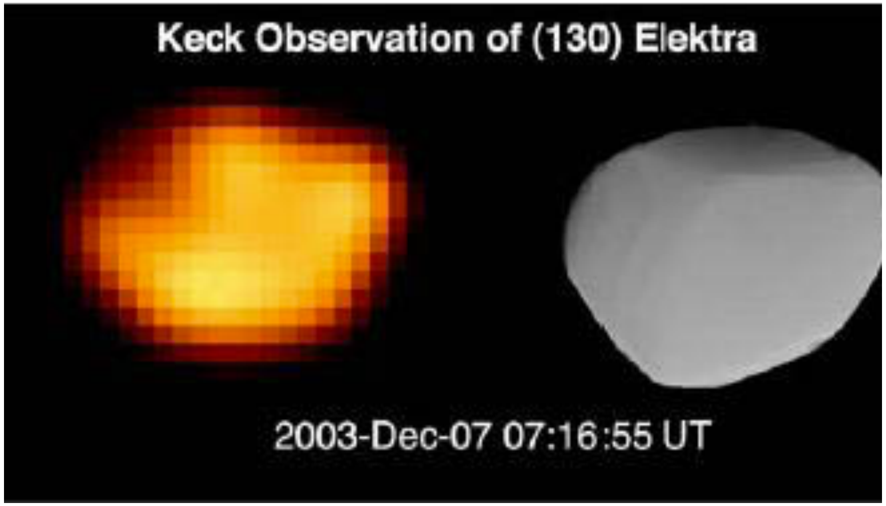
SPHERE Survey of Large Asteroids



- Observe ~ 40 large (D > 100 km) main-belt asteroids.
- Derive 3-D shape, the size distribution of the largest craters, and densities.
- What was the collisional environment in the inner solar system in the past?
- What was the shape of planetesimals at the end of the accretion process?

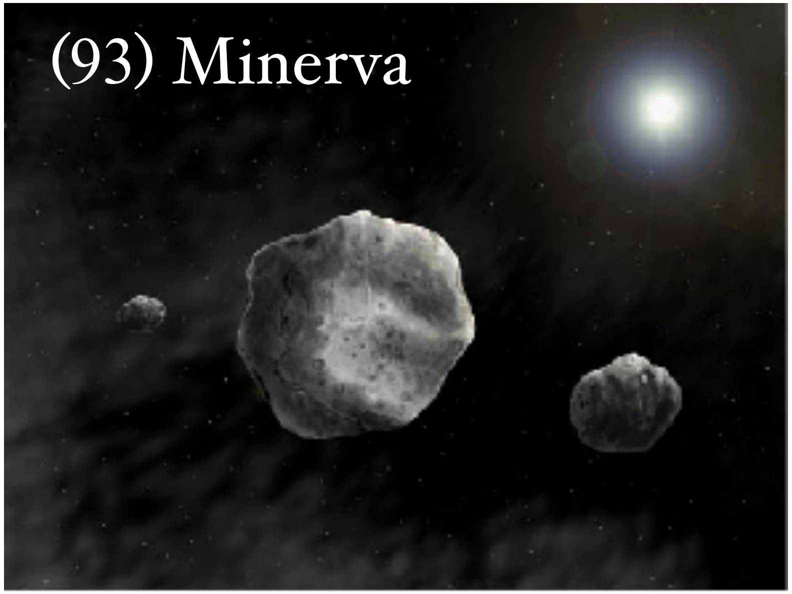
Asteroids with Moons





- Asteroids with satellites are of particular importance because their formation mechanisms, accretional and collisional processes, are critical in planet formation and evolution.

- Multiple asteroids provide otherwise unattainable information about the intrinsic properties of the system: composition, interior structure and evolutionary processes.



Original Science Goals

V.S.

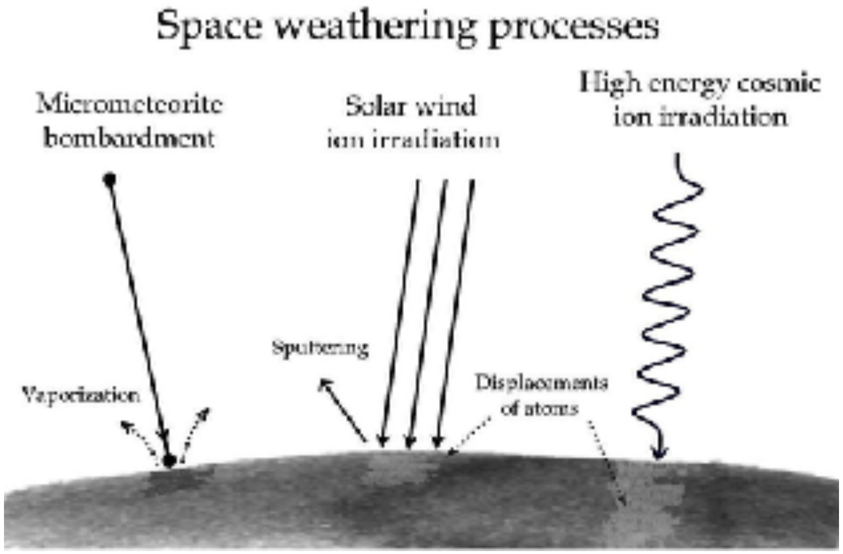
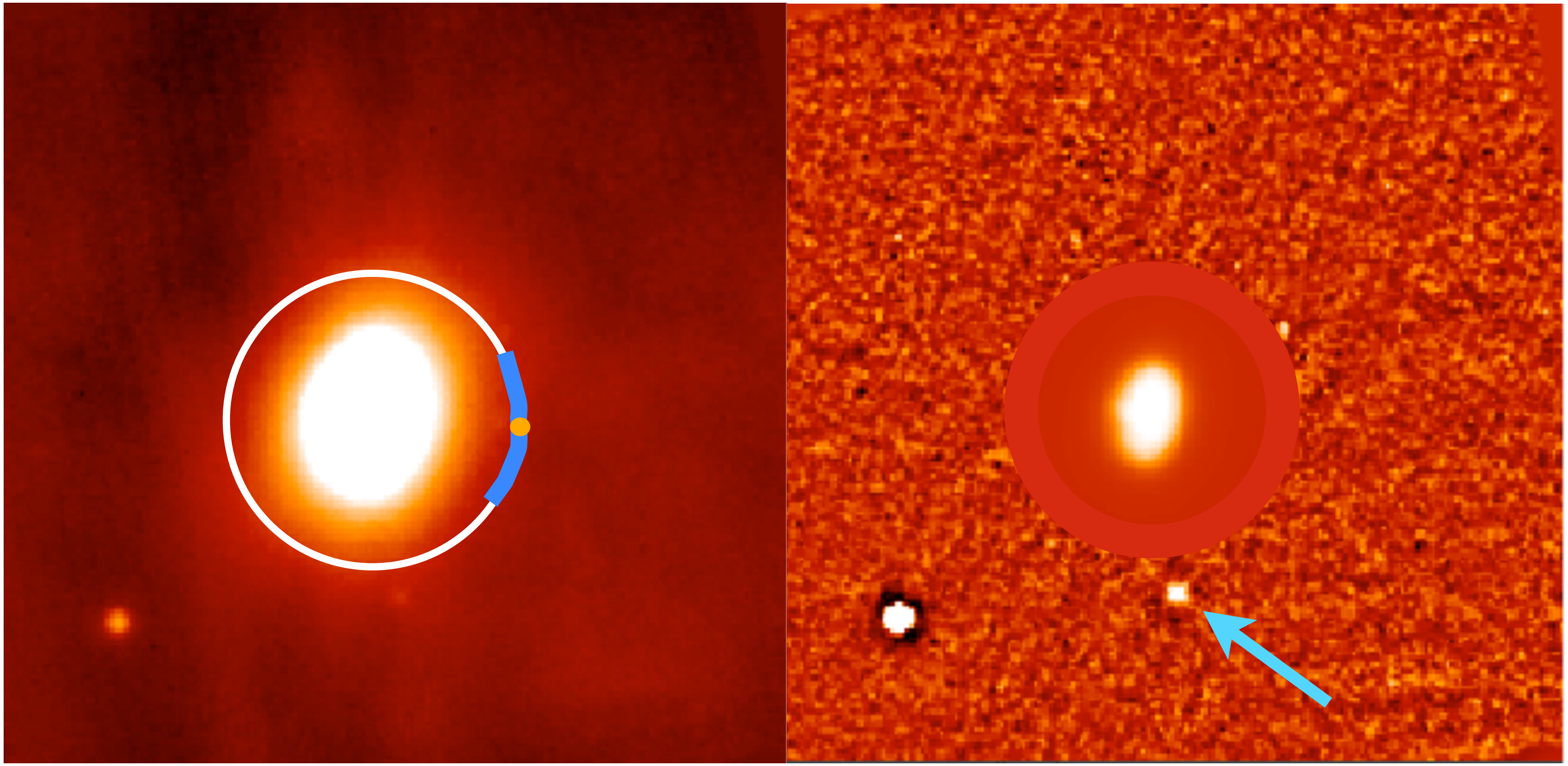
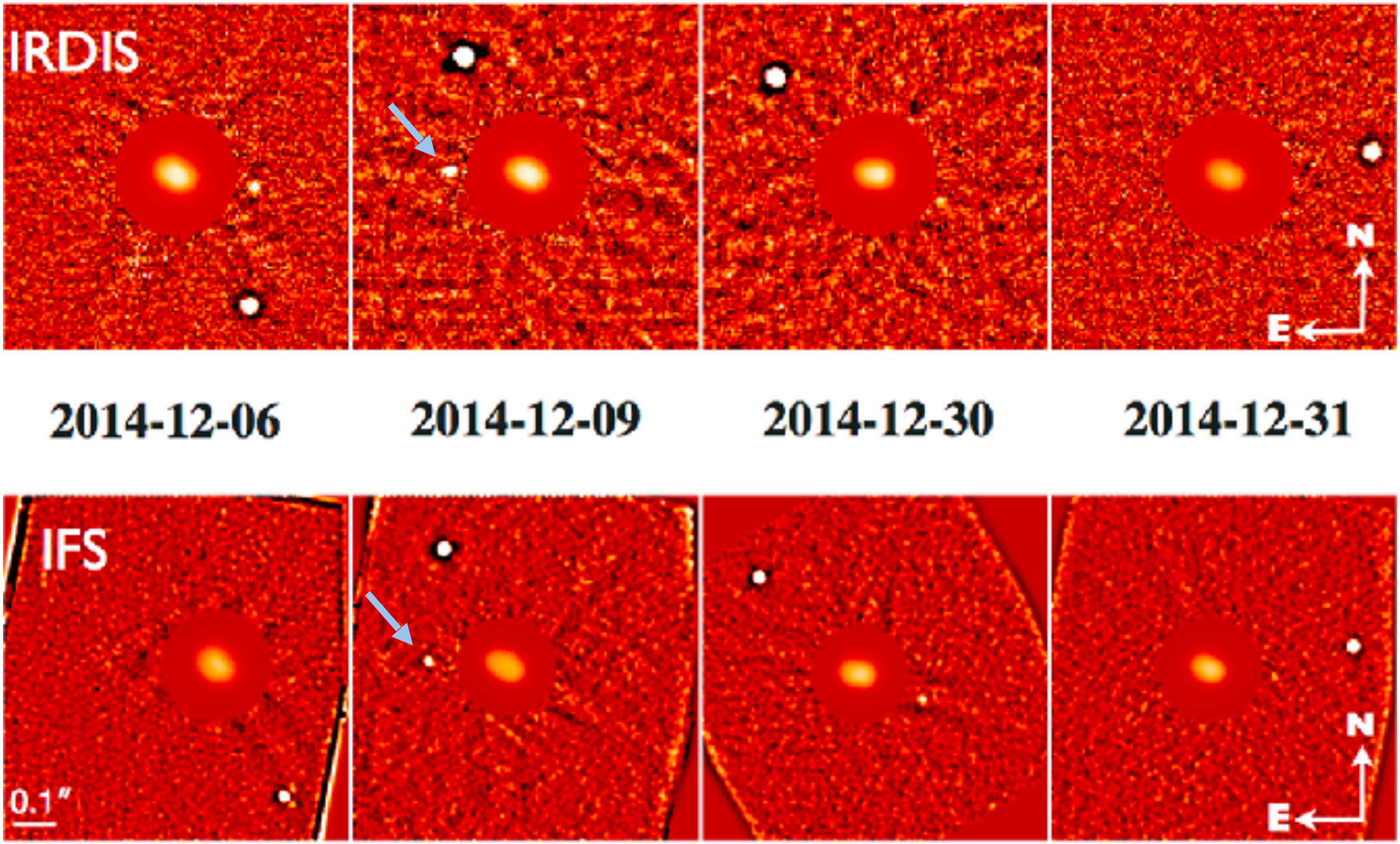


Image Processing

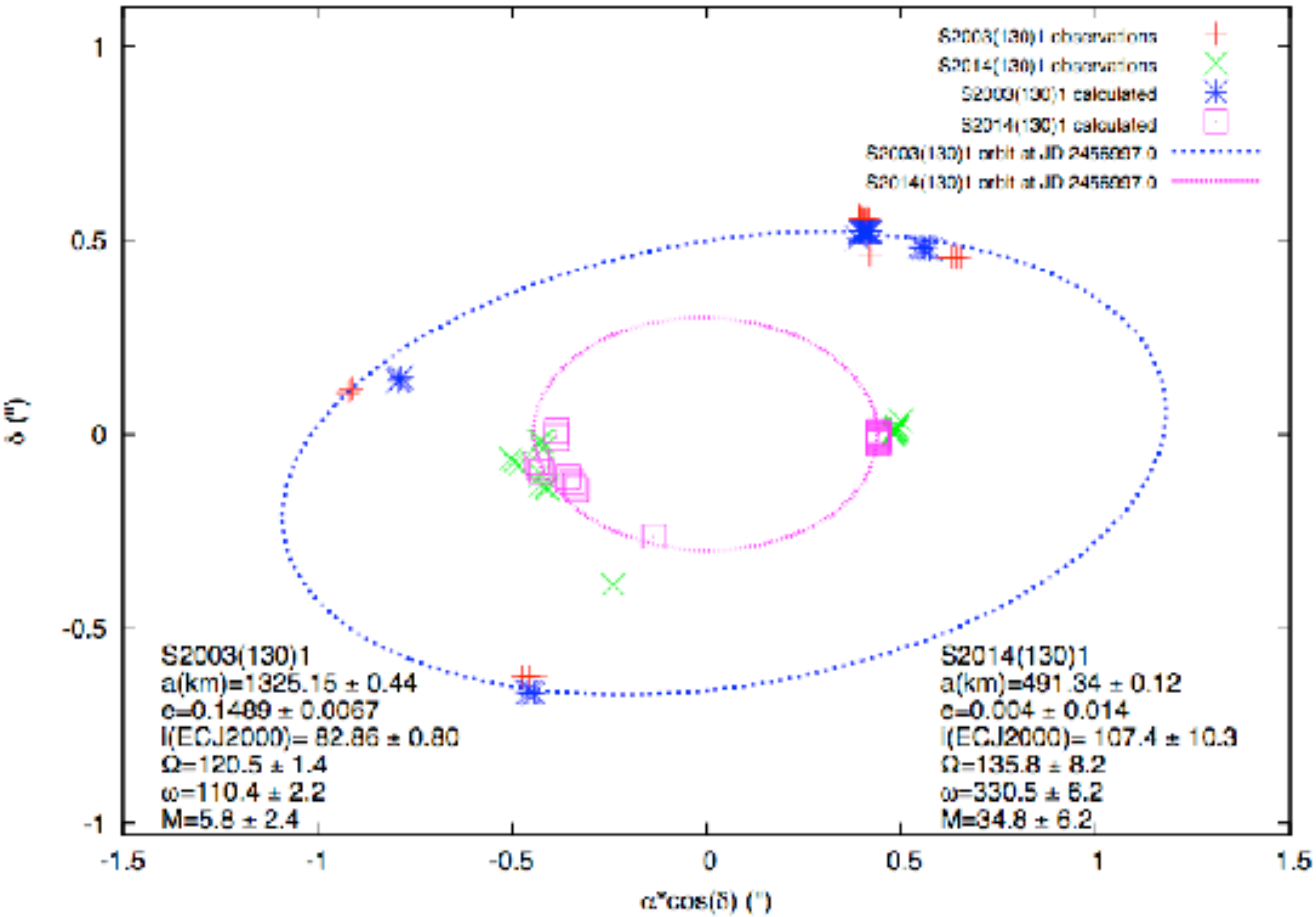


Detecting A New Asteroidal Moon



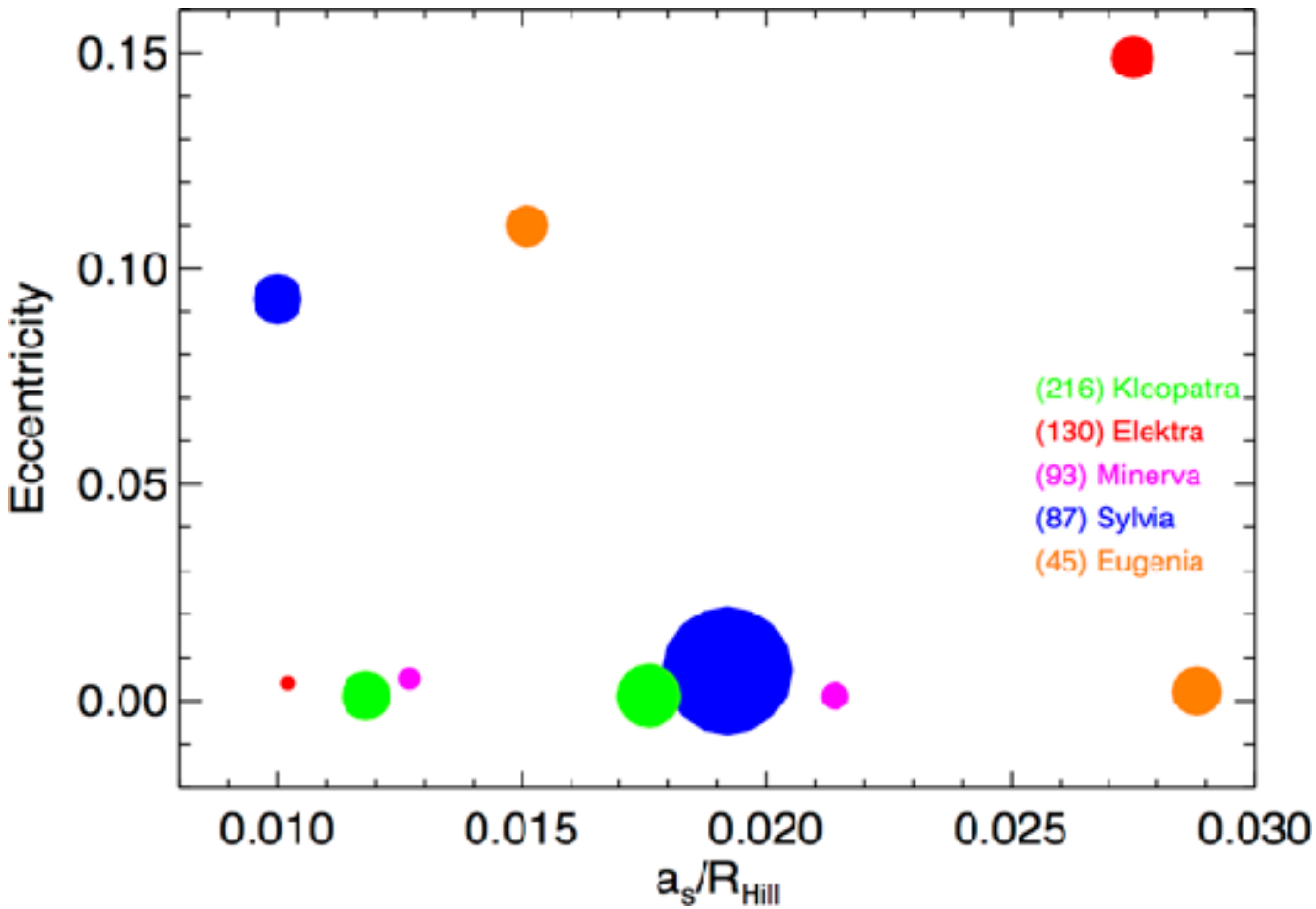
Yang et al. (2016)

Dynamical Analysis

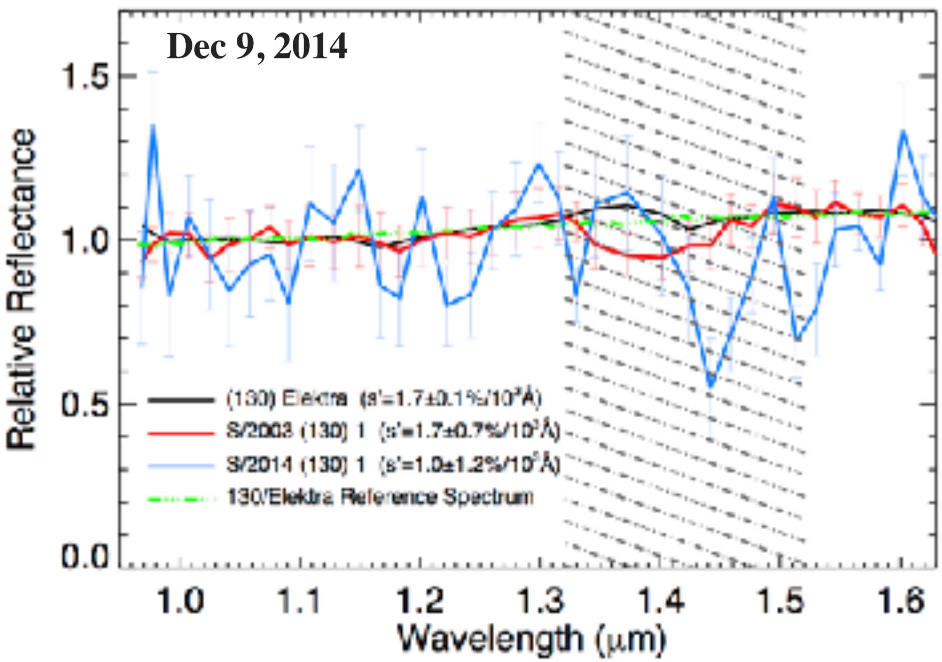


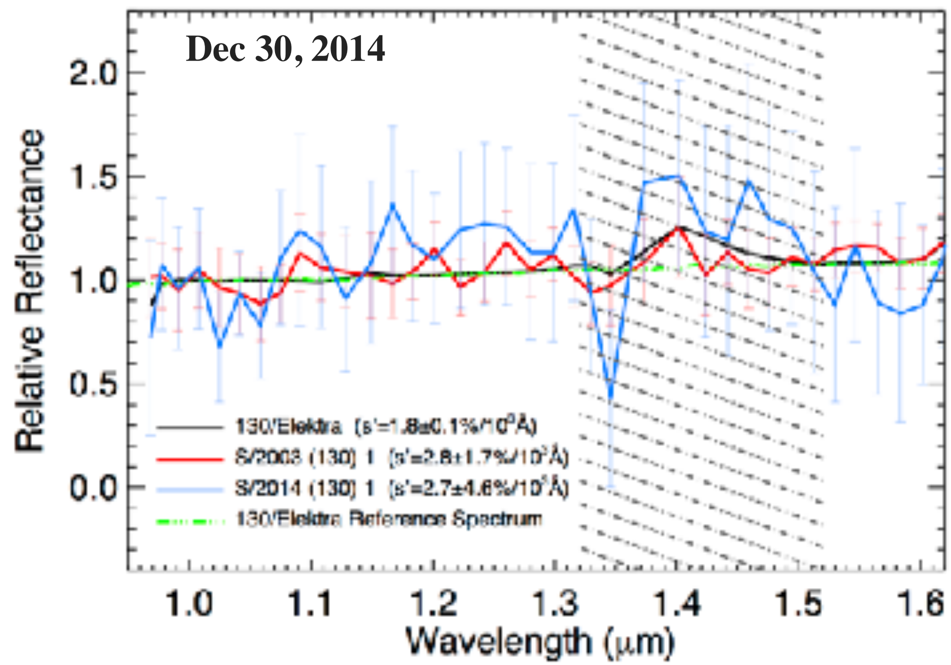
From Yang et al. (2016)

Orbital Distribution

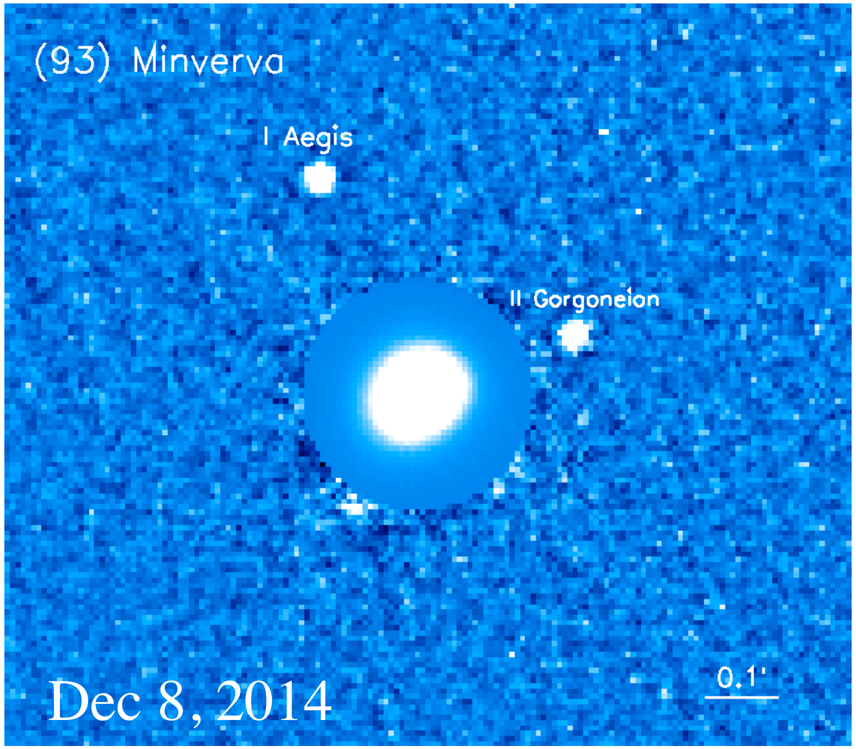


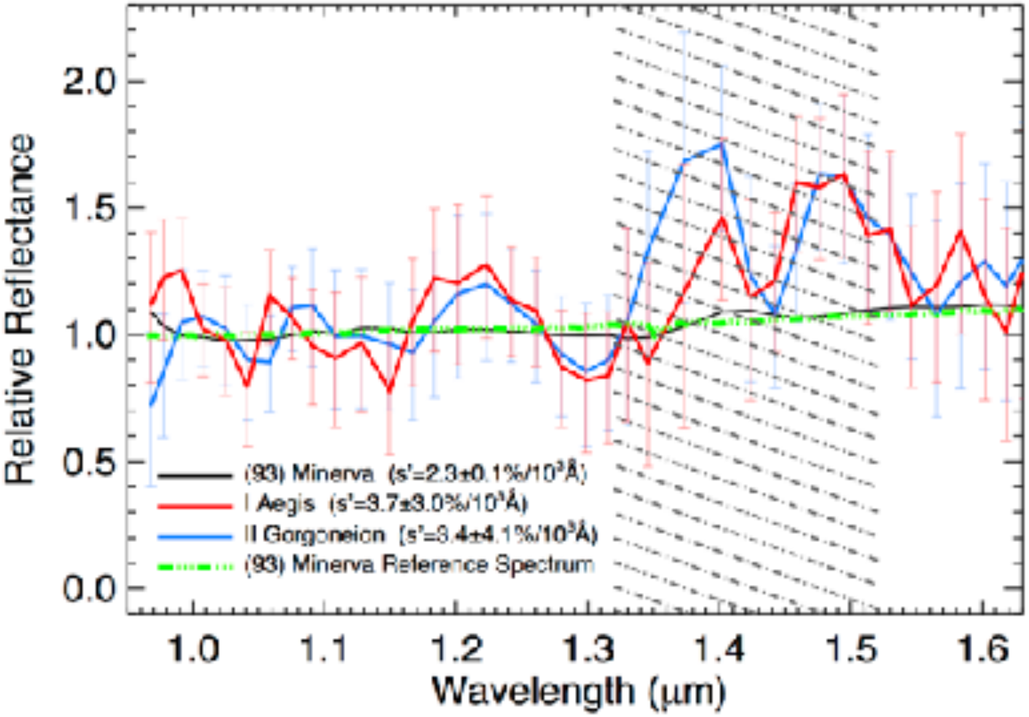
Spectroscopy for (130)





Spectroscopy for (93)





From Yang et al. (2016)

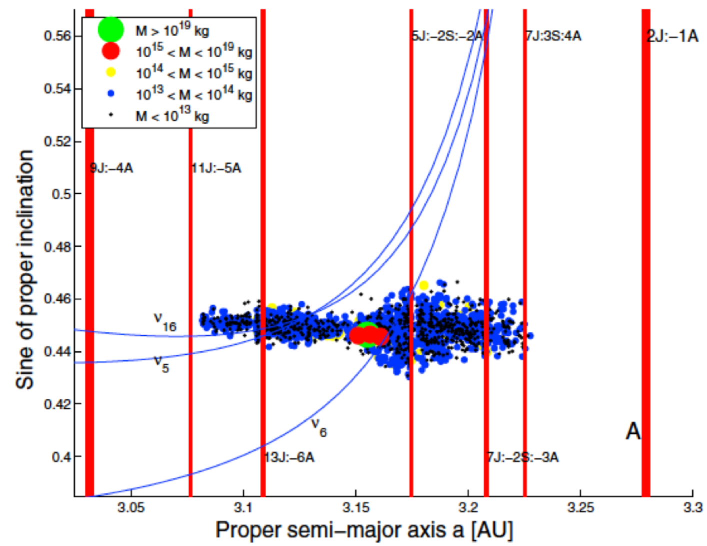
Summary

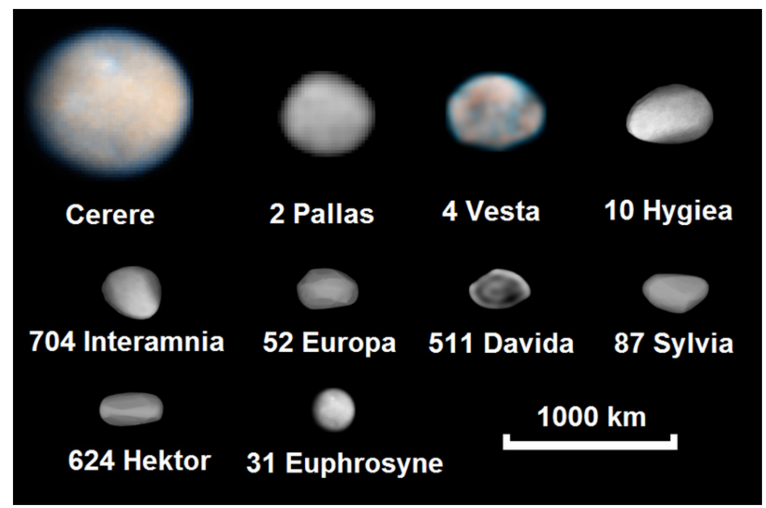
- ✦A new moon of (130) Elektra was detected, D_e~2km.
- ✦ S/2014 (130) 1 is on a nearly circular orbit while the orbit of S/2003 (130) 1 is eccentric.
- ✦No significant difference was observed between the reflectance spectra of the two satellites and that of the primary.
- ✦The Elektra and the Minerva systems are likely results of a disruptive impact rather than capture.

Impact —> Asteroid Family

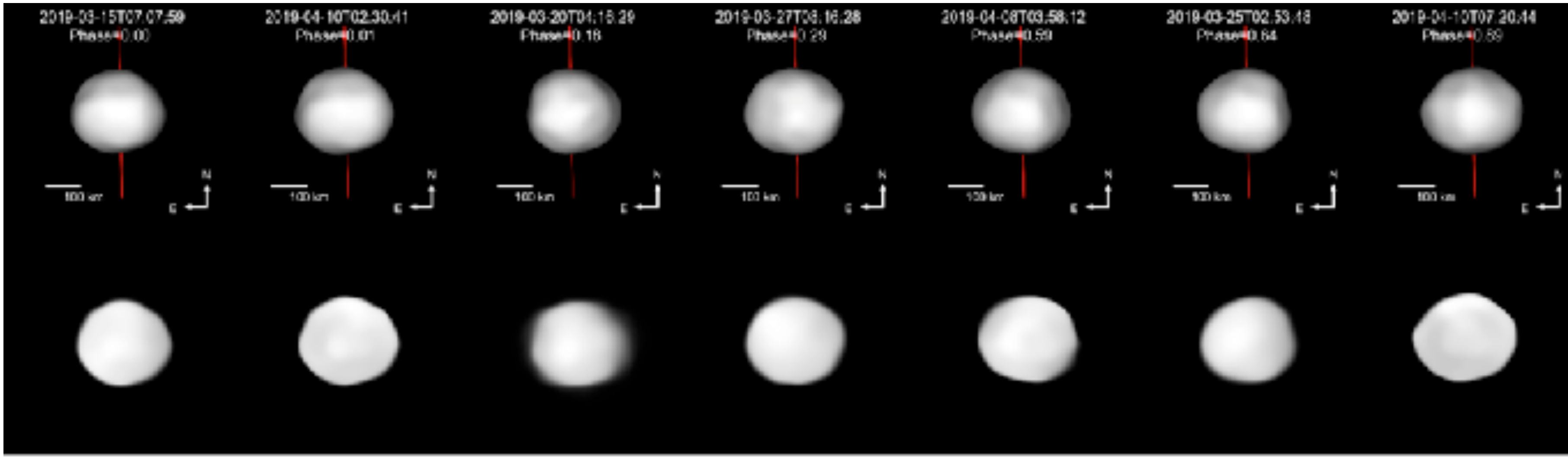
PECULIAR EUPHROSYNE Family

- The Euphrosyne family occupies a highly inclined region, bisected by the ν6 secular resonance.
- It is one of the most populated families, with more than 1000 associated members
- The family exhibits a very steep SFD, α=-4.4, depleted in large- and medium sized asteroids



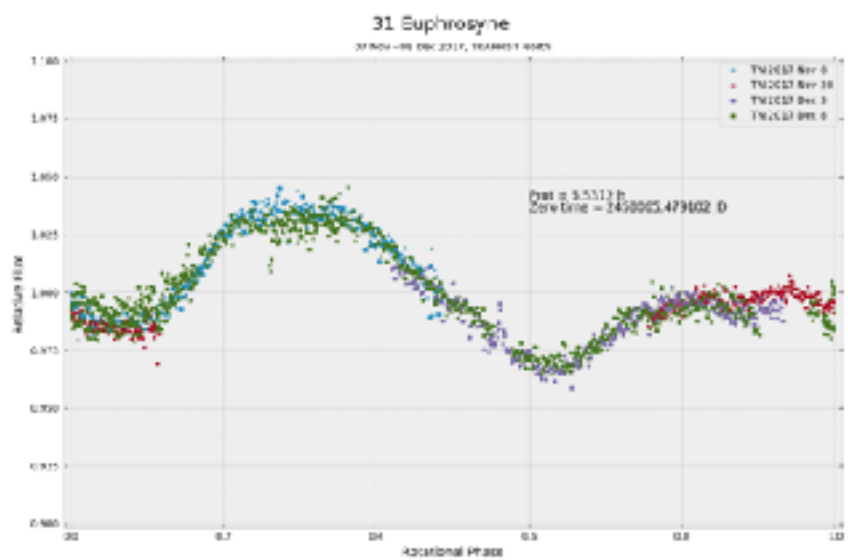


3D Shape model



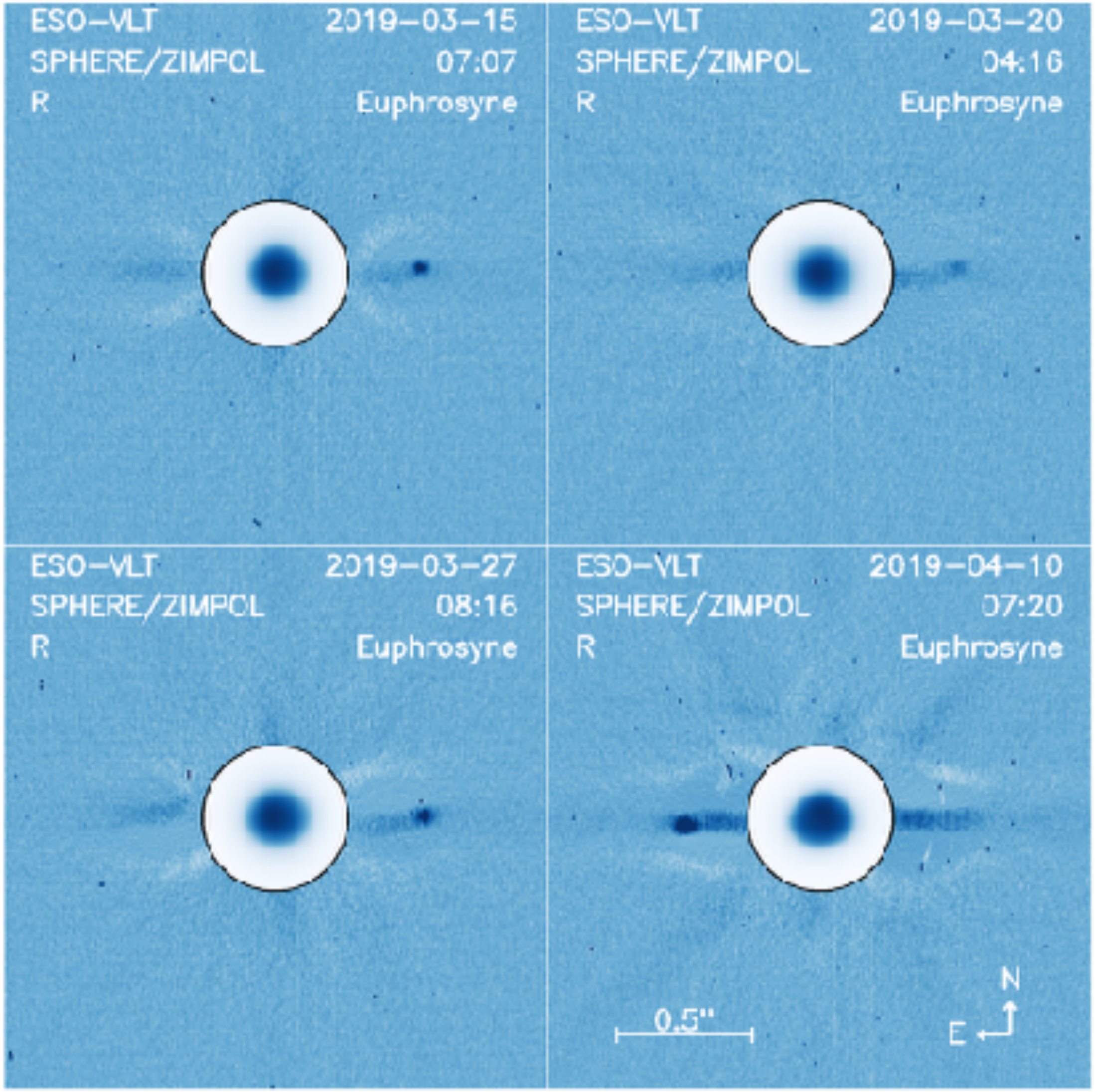
- 34 lightcurves were used to derive a convex shape model

- The ADAM algorithm (Viikinkoski et al. 2015) is used to fit the optical data and the disk-resolved images simultaneously.



Detection of a Satellite

- On 2019 Mar.15, the satellite was at a separation of 0.398" (projected separation 651 km) and p.a. 268.49°
- On 2019 April 10, the satellite was found at a separation of 0.384" and p.a. 87.0°.
- The mean contrast between (31) and its companion is 8.0±0.8, suggesting the size of the satellite $D_s \sim 6\pm1$ km.



Physical properties of Euphrosyne

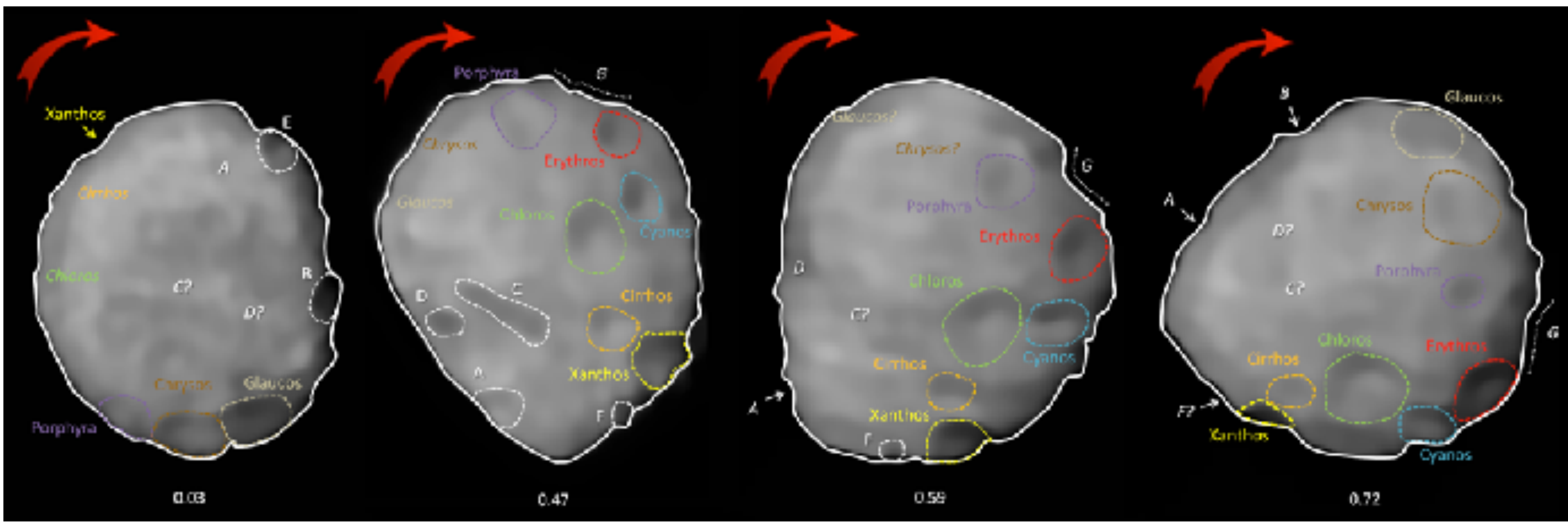
Parameter	Unit	Value
P	h	5.529595(1)
λ	deg.	94±5
β	deg.	67±3
D	km	268 ± 6
a	km	294±6
b	km	280±10
c	km	248±6
a/b		1.05±0.03
b/c		1.13±0.04
M	10^{19} kg	1.7 ± 0.3
ρ	$\mathrm{kg \cdot m^{-3}}$	1 665 ± 242

Summary

- The spin and 3-D shape model of (31) Euphrosyne are derived, the diameter is estimated D= 268+/-6 km.
- A satellite of 6 km was detected on a nearly circular orbit around (31) Euphrosyne.
- The density of (31) Euphrosyne is derived as 1665+/-242 kg/m^3 .
- The members may be mostly composed of materials that are similar to the carbonaceous chondrites.

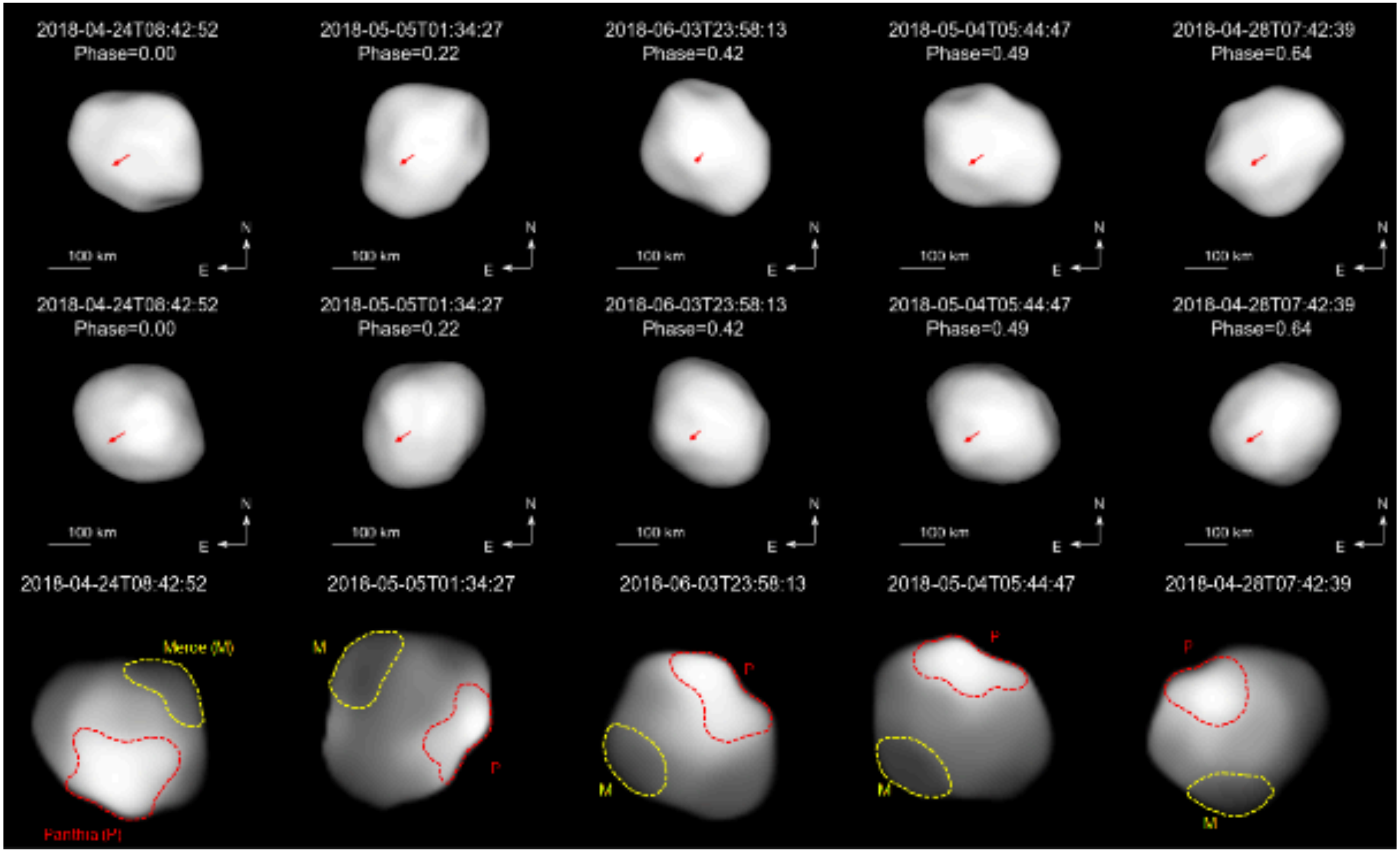
(7) Iris: A Relic of an ancient large impact

- D=214km, ρ=2700±300 kg·m^{-3}
- Several impact craters, 20-40 km in diameter
- Depth/size ratio (~0.4) larger than other rocky asteroids



Hanus et al. (2018)

(16) Psyche: A Possible metallic Asteroid



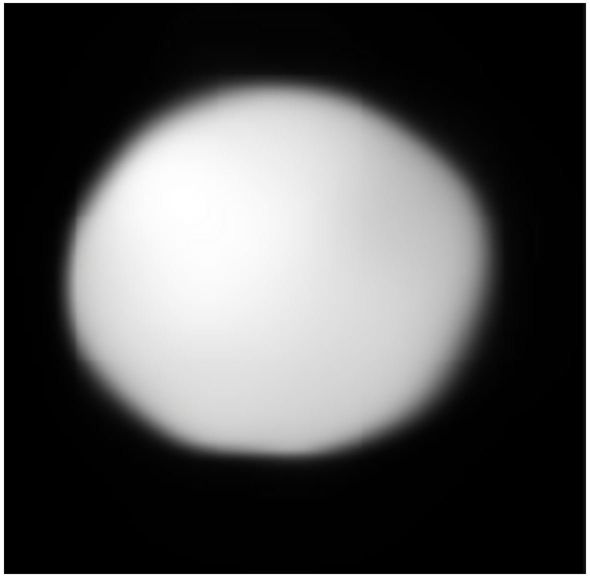
D=211km, ρ=3990±260 kg·m^{-3}

Viinkinkoski et al. 2018

Large C-type Asteroids

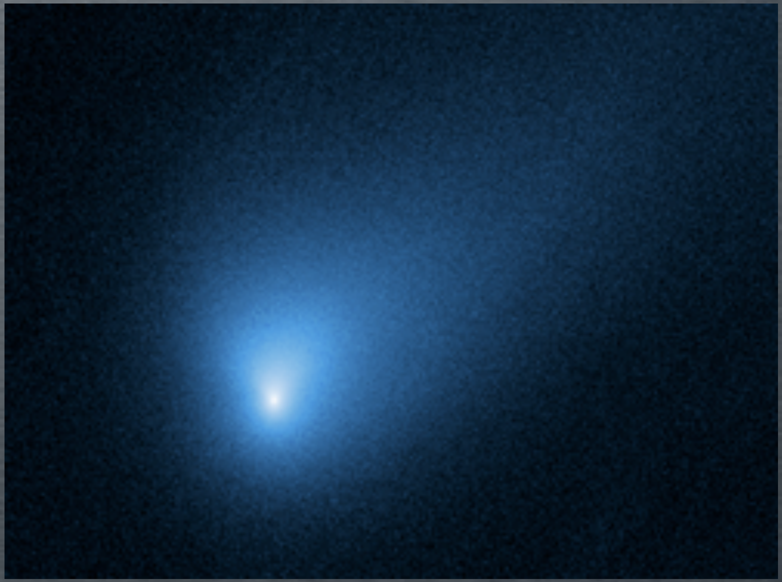
1 Ceres
D=945km
ρ=2162±8 kg·m^{-3}

10 Hygiea
D=434km
ρ=1940±190 kg·m^{-3}

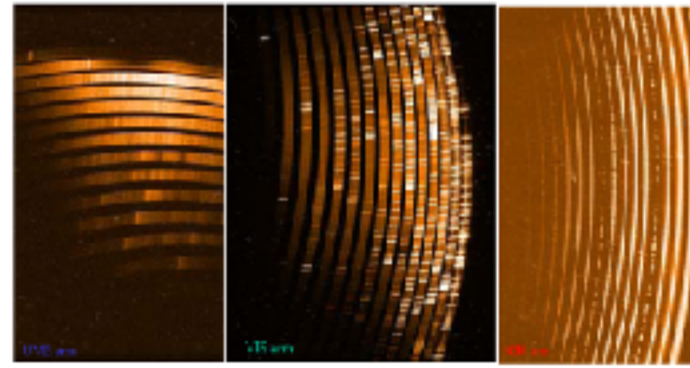


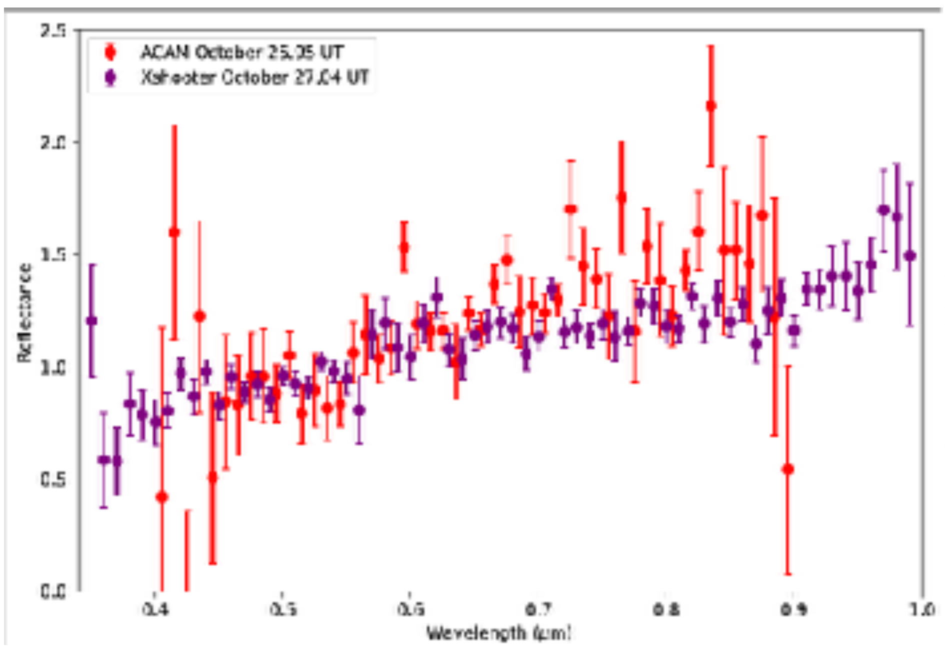
31 Euphrosyne
D=268km
ρ=1665±242 kg·m^{-3}

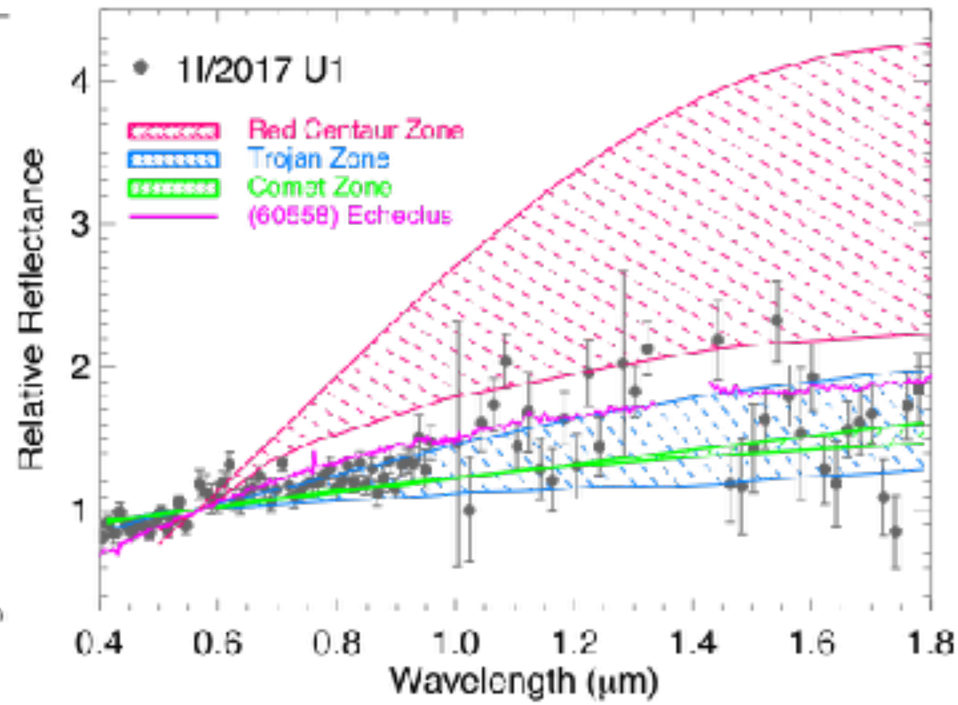
Interstellar Objects



Interstellar visitor #1

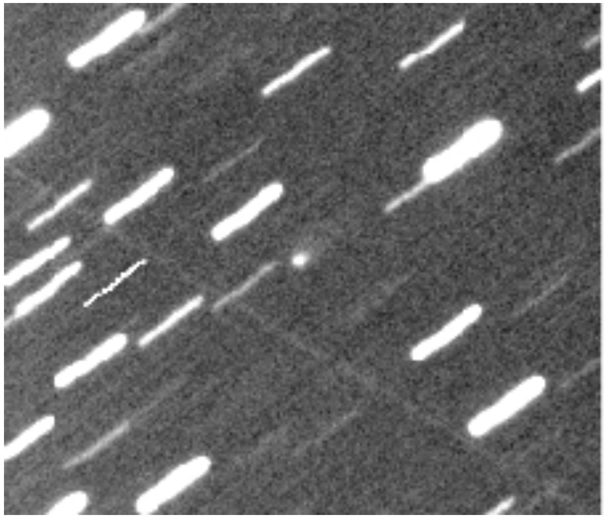






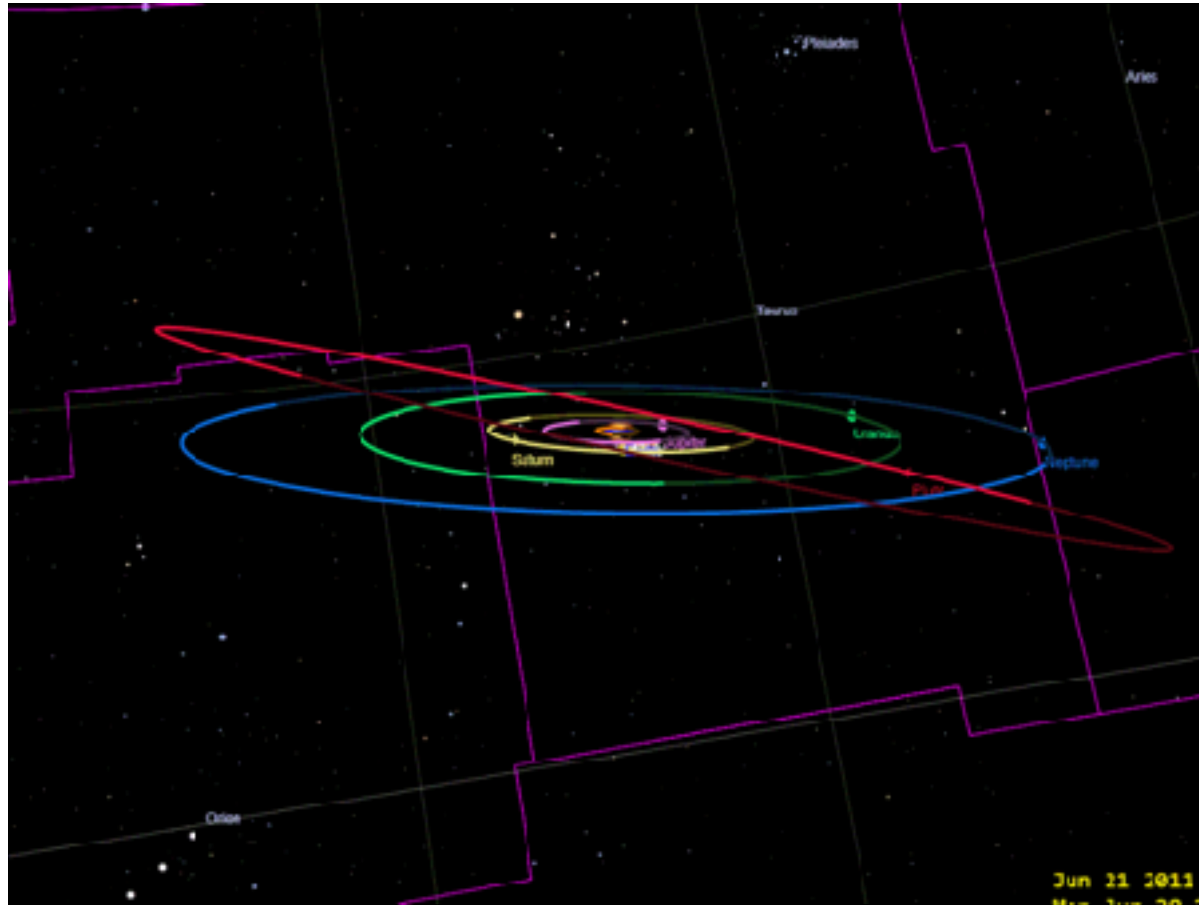
Fitzsimmons et al. (2018)

Interstellar visitor #2

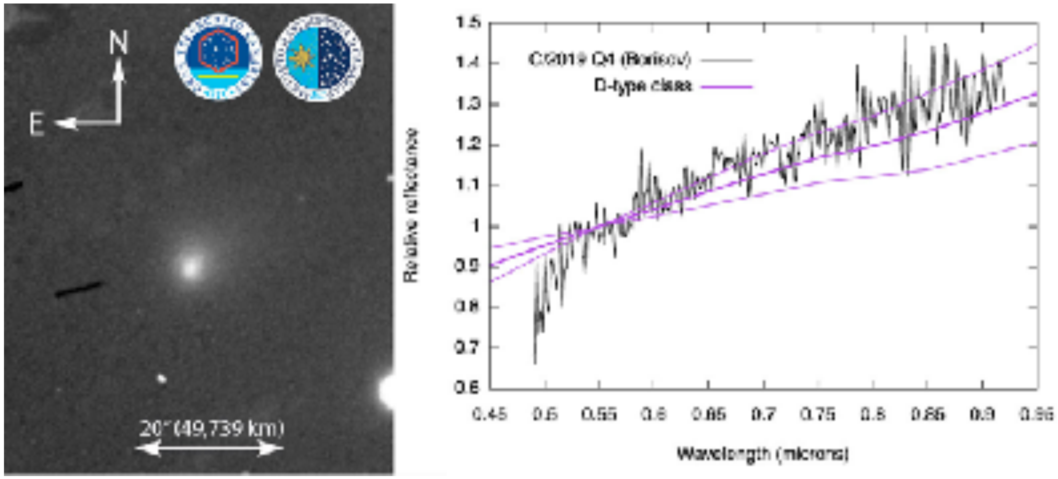


The second interstellar comet 2I/Borisov. A short tail is visible above and right of the coma. Gennady Borisov

The amateur astronomer Gennady Borisov captured this object on August 30, 2019, at the MARGO Observatory near Nauchnij, Crimea when it was about 3 astronomical units (a.u.) from the Sun.

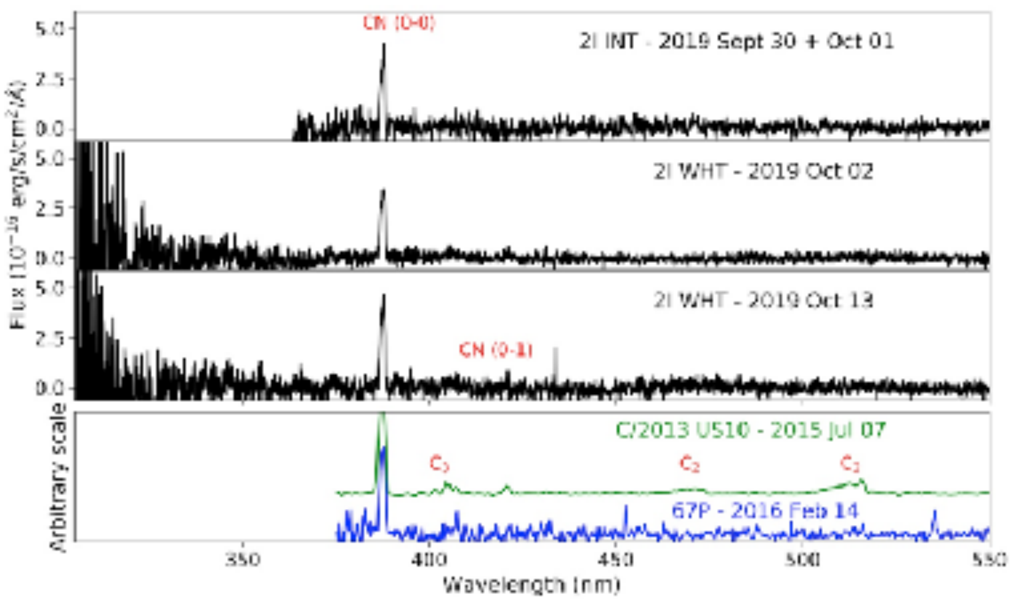


Current Observations

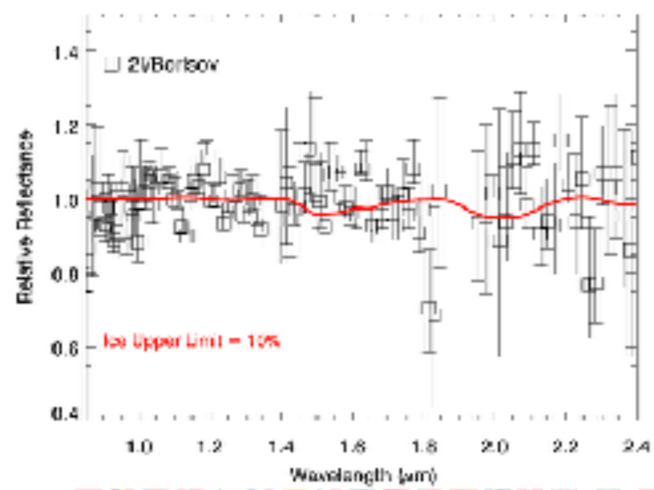


Credit: Instituto de Astrofísica de Canarias

Credit: NASA, ESA and D. Jewitt (UCLA)

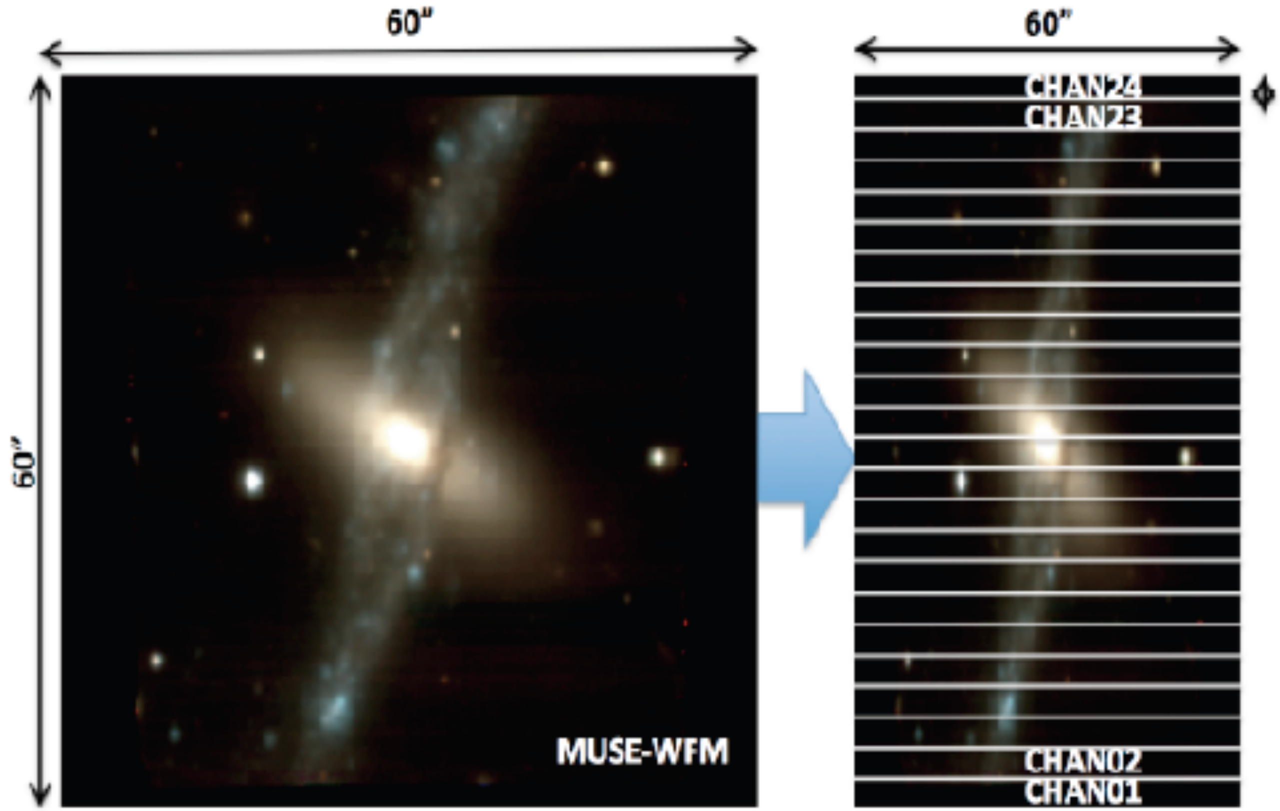


Opitom et al. 2019



Yang et al. 2020

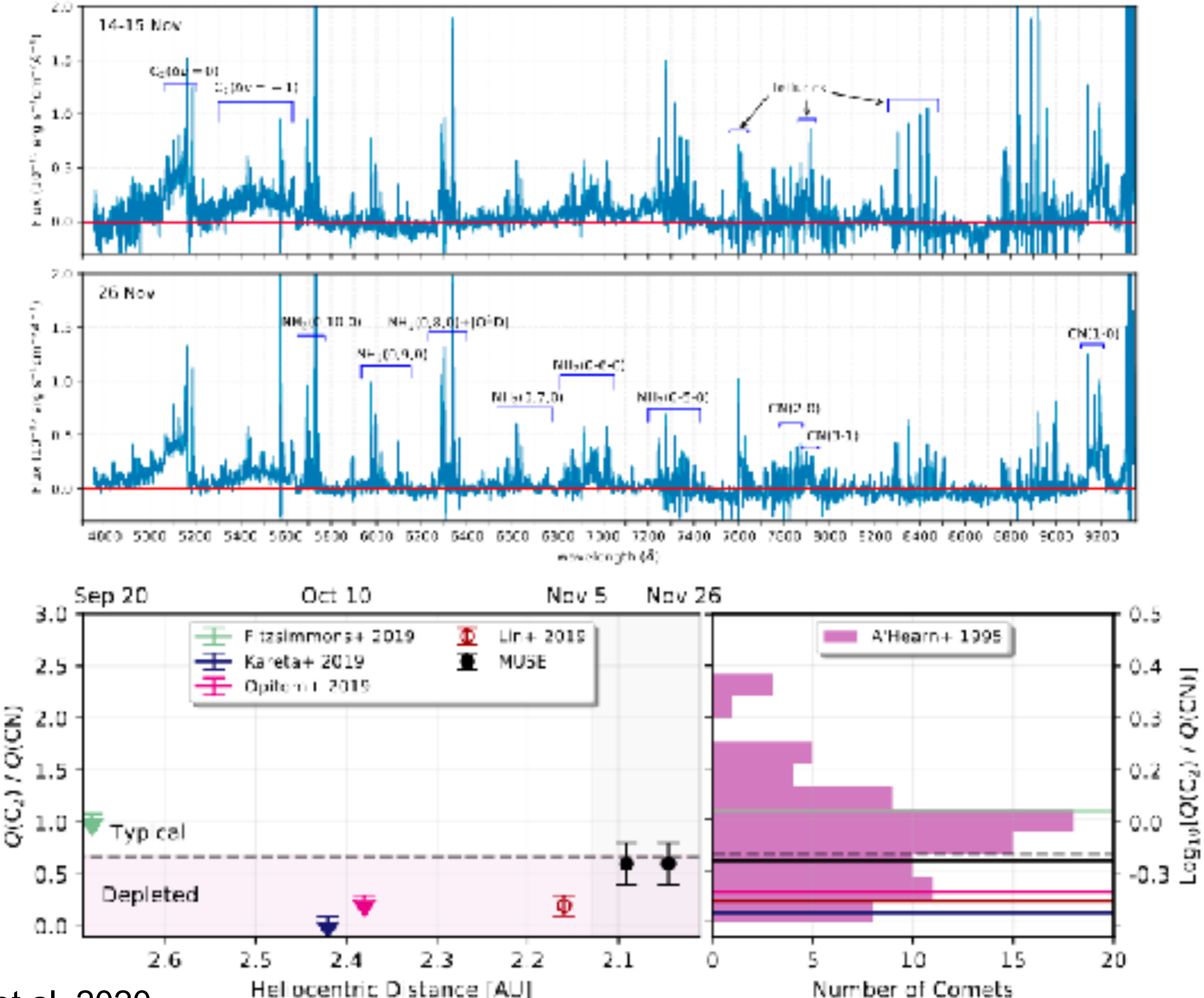
The Multi Unit Spectroscopic Explorer (MUSE)



MUSE

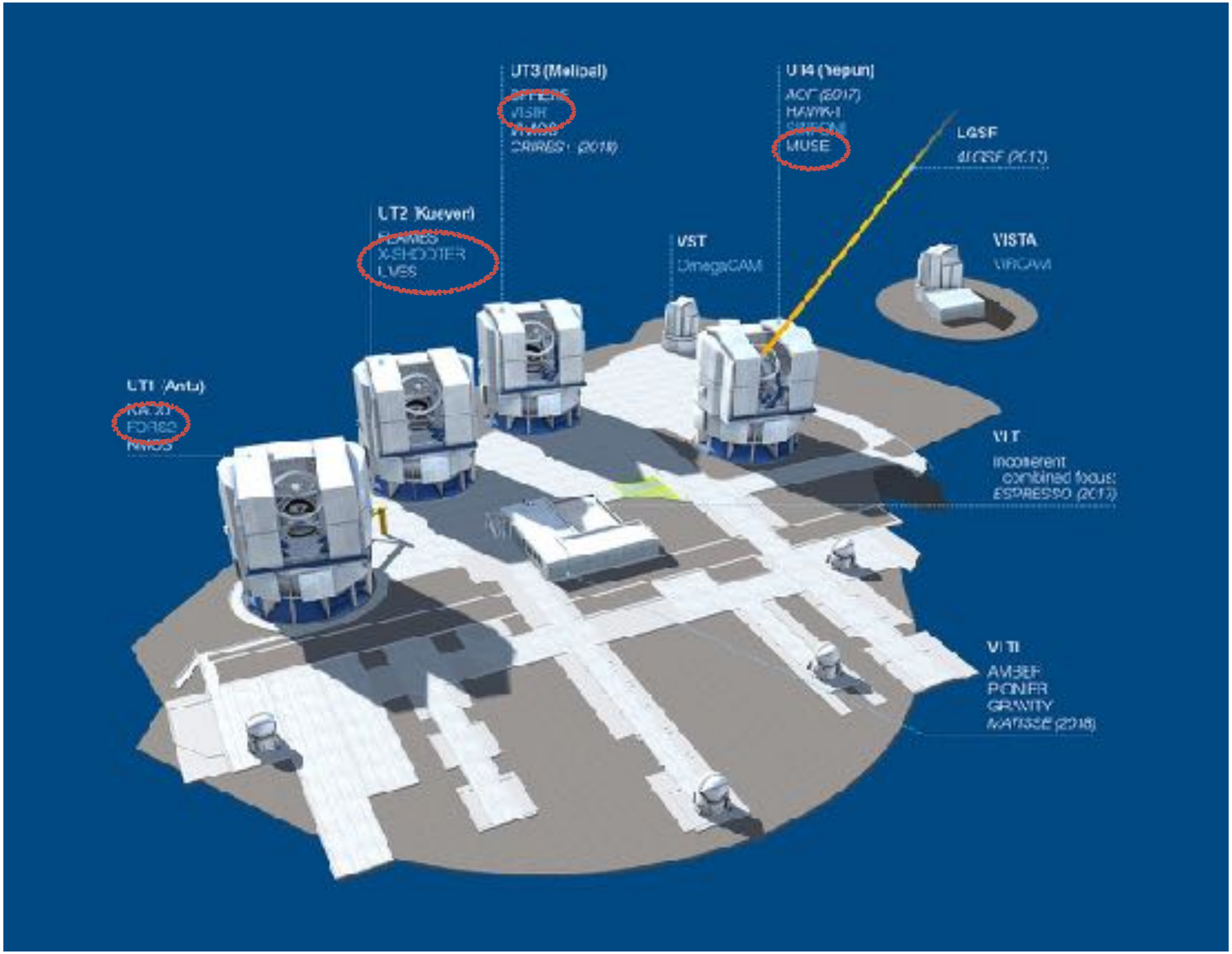
λ: 480 -930 nm

MUSE Results



Bannister et al. 2020

On-going Observations



Questions?