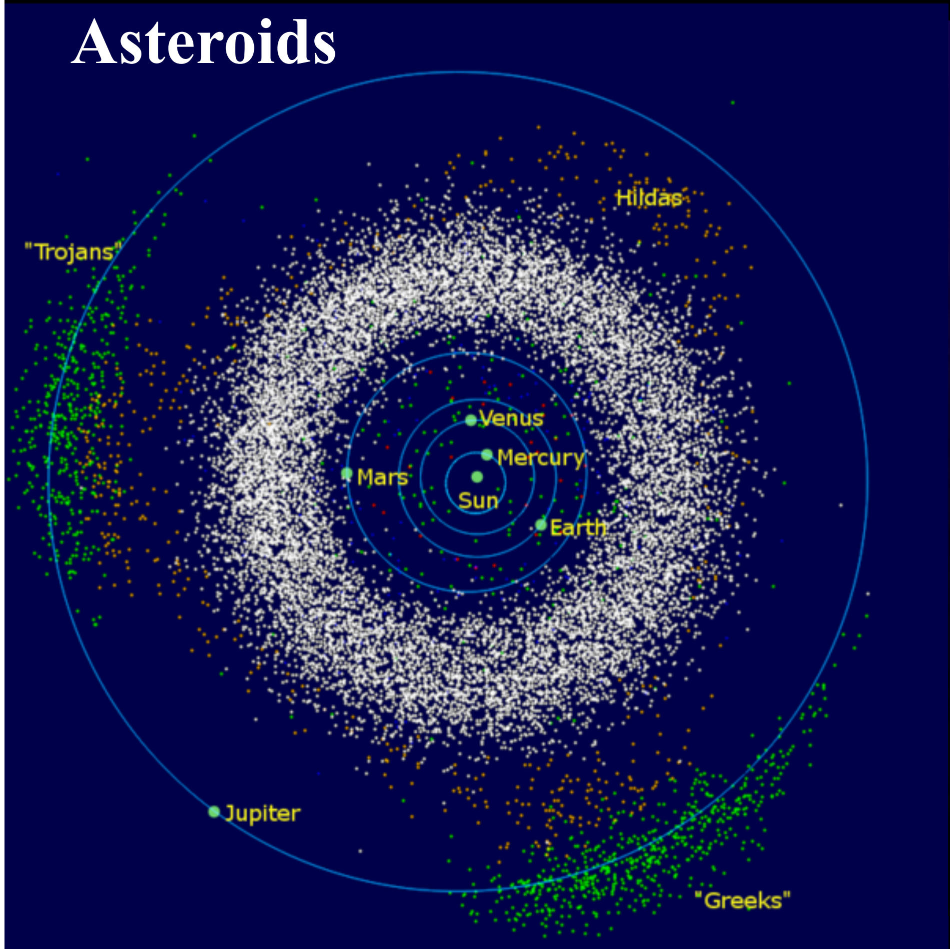
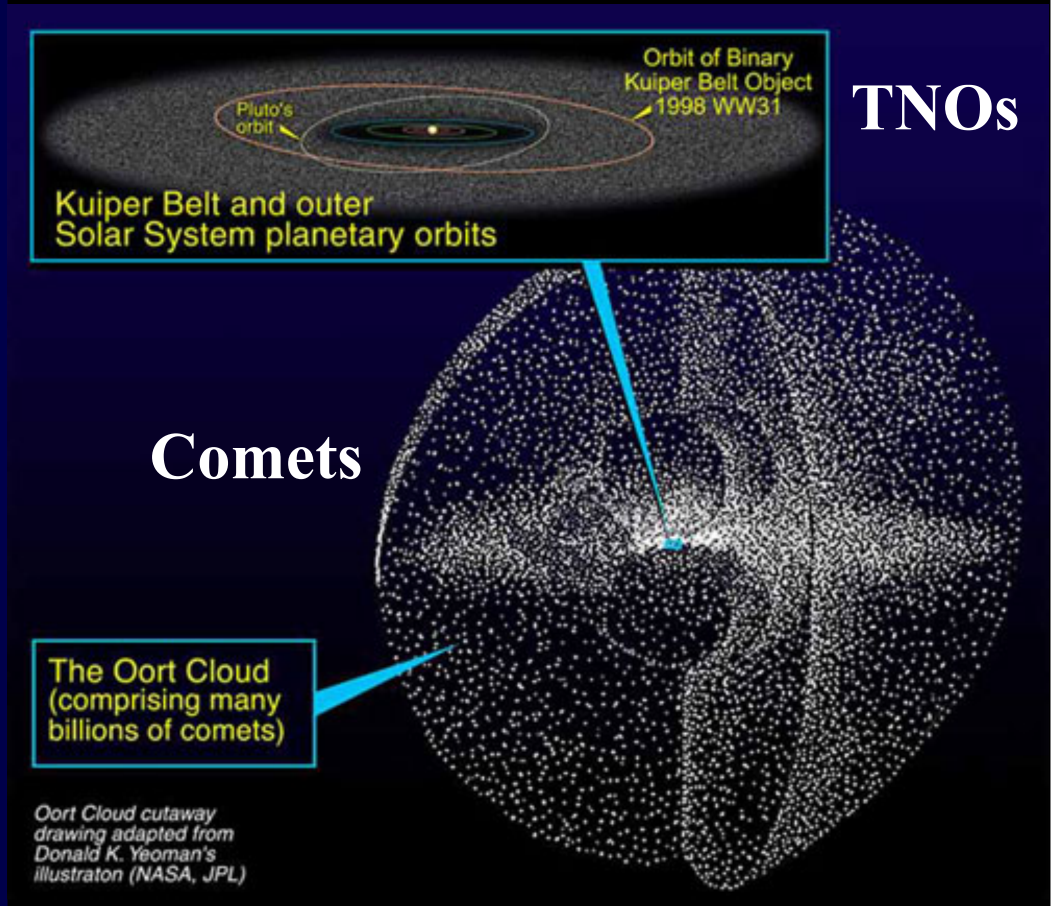
# Solar System Small Bodies



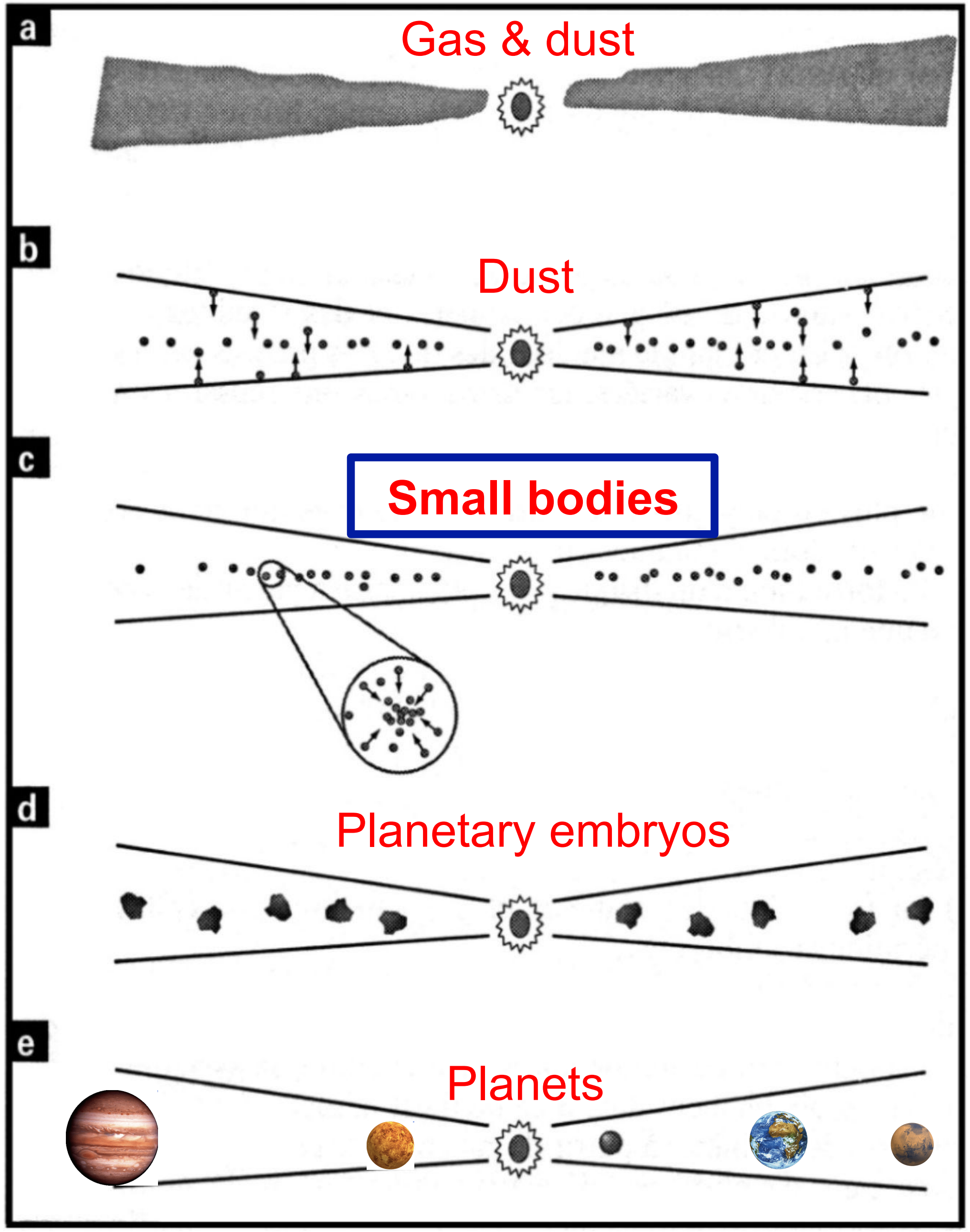
Pierre Vernazza - ESO, Garching

# Solar System Small Bodies



# Deciphering the Early History of the Solar System




**The small bodies**

**asteroids**

**comets**

**TNOs**

**tell us about:**

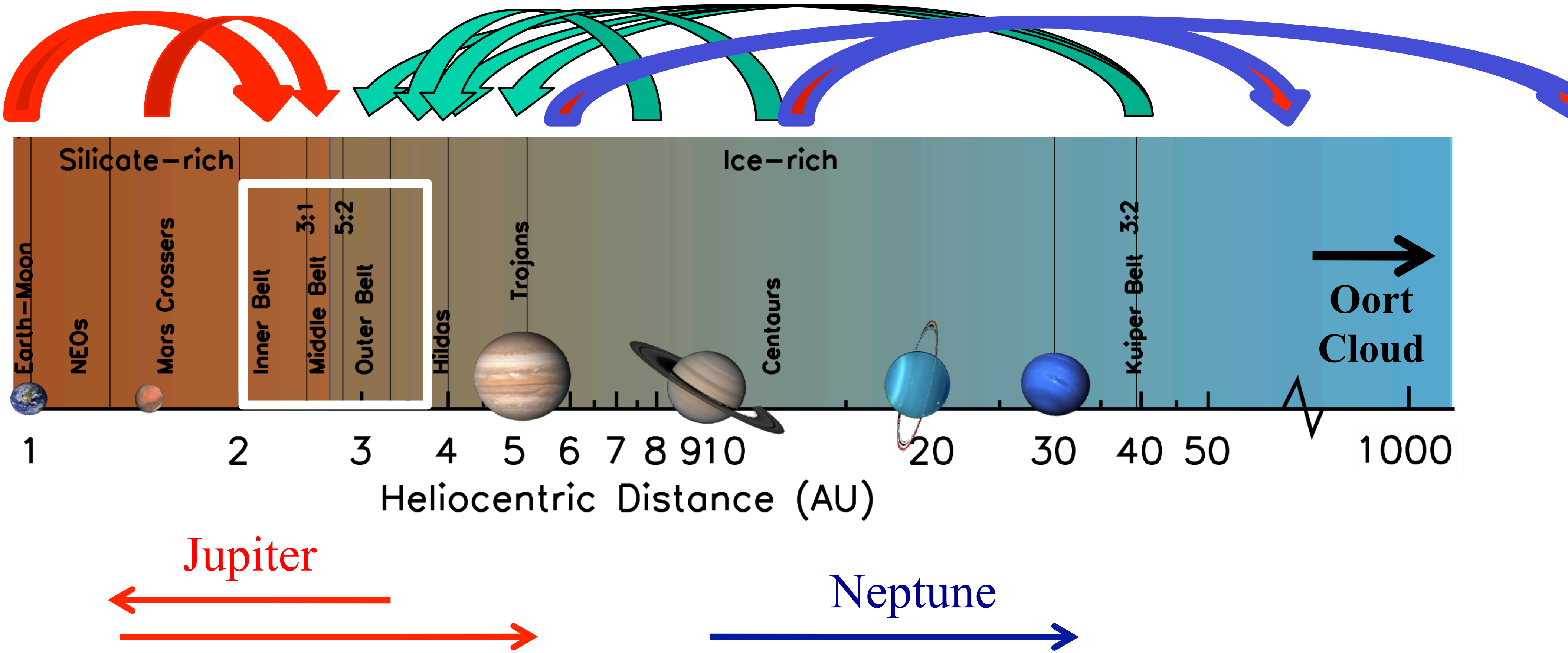
**the migration of dust prior to the accretion process**

**the primordial chemical composition from which planets once accreted**

**the migration of bodies during the formation of the Solar System**

**Small Bodies:** **Provide key constraints on the early migration of the planets**

Predicted displacement from Dynamical simulations



# Contribution of ground-based observations to the study of the formation of the Solar System

Constrain the physical and chemical properties

- Albedo
- Composition
- Density

Of **Solar System small bodies** (Asteroids, TNOs, Comets) which tell us about their origin and evolution

$\Rightarrow$ **constrain the dynamical evolution of the Solar System**

# Comets observed by ESO: Summary

Minor contribution from ESO to the greatest discoveries

ESO should not feel too 'guilty' because *it does not cover the right wavelength range*, although it could have been favoring a little bit more cometary science (as the US did).

Most interesting observations so far:

- Space (in-situ, HST, ISO, Spizter, Herschel)
- Radio (mm)

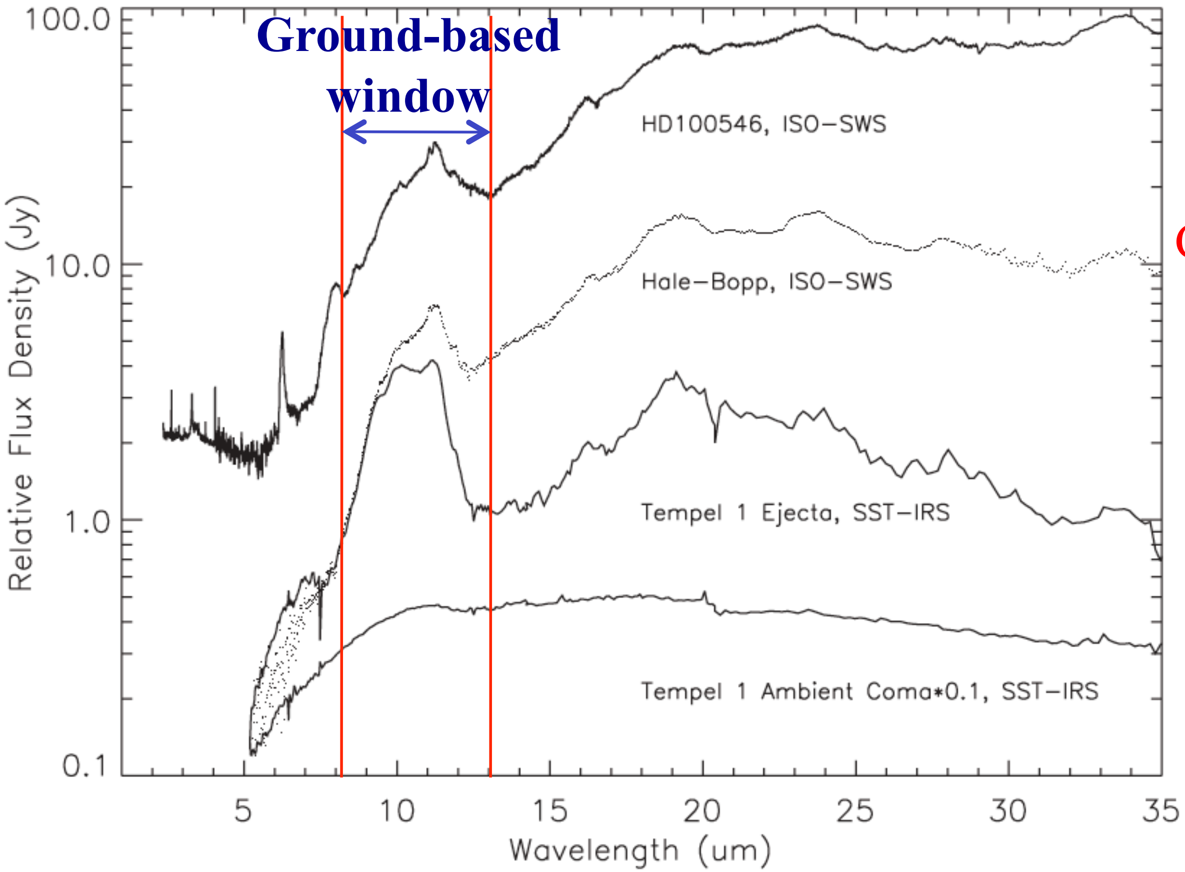
# Characterization of the Nucleus:
## Size, shape, spectrum and rotational properties

- Main difficulty, their faintness (V>22):
  - Absence of activity occurs at r>5-10AU
  - Comets are usually very small (D<5km)
  - Comets are very dark (A~0.04)

- Characterization has mainly been done with HST and US telescopes, with a modest contribution from ESO

# Composition of the dust

- Mid-IR spectroscopy is perfect for that.
- Space much better than the ground because of the atmosphere. Not ESO's fault..




Crovisier et al. 1997

Lisse et al. 2006

# Composition of the volatiles

- Constrained from UV-VIS, IR and radio spectroscopy
- ESO contribution from UVES, FORS and CRIRES (e.g. Jehin et al.)
- Radio (millimetre) spectroscopy has discovered most of the species (great contribution from IRAM)

# Future

- ESO will be part of the golden age of cometary studies.

- ALMA will:
  - expand by one order of magnitude the sample of observed objects.
  - complete the inventory of volatiles
  - determine isotopic ratios (e.g., D/H)

- ELT's size will enable the characterization of a large sample of cometary nuclei.

# Asteroids observed by ESO: Summary

**In depth characterization of the asteroid population:**

**US telescopes**

Overall: The very few European ‘successes’ came not only from very short programs but usually ESO was only one of several observatories contributing to the new result.

nature Vol 436|11 August 2005|doi:10.1038/nature04018

LETTERS

# Discovery of the triple asteroidal system 87 Sylvia

Franck Marchis[1], Pascal Descamps[2], Daniel Hestroffer[2] & Jérome Berthier[2]

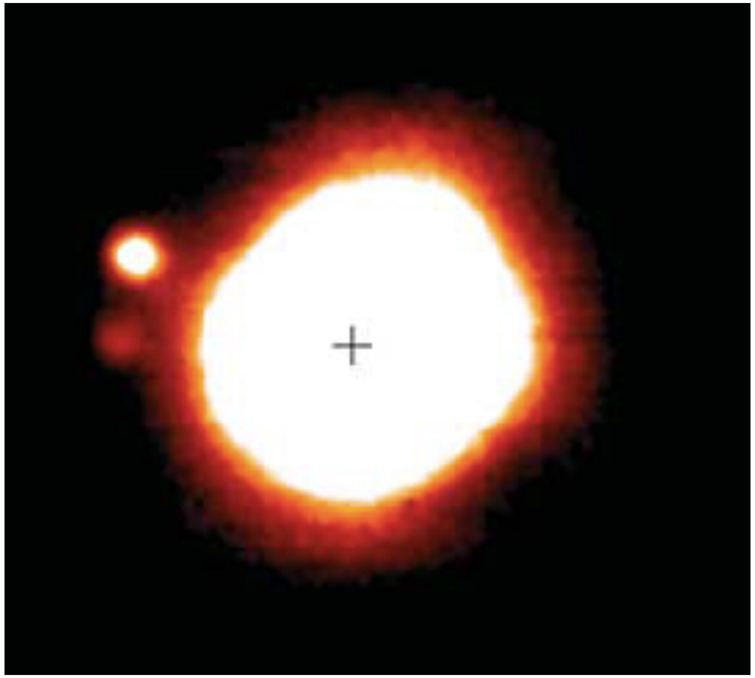
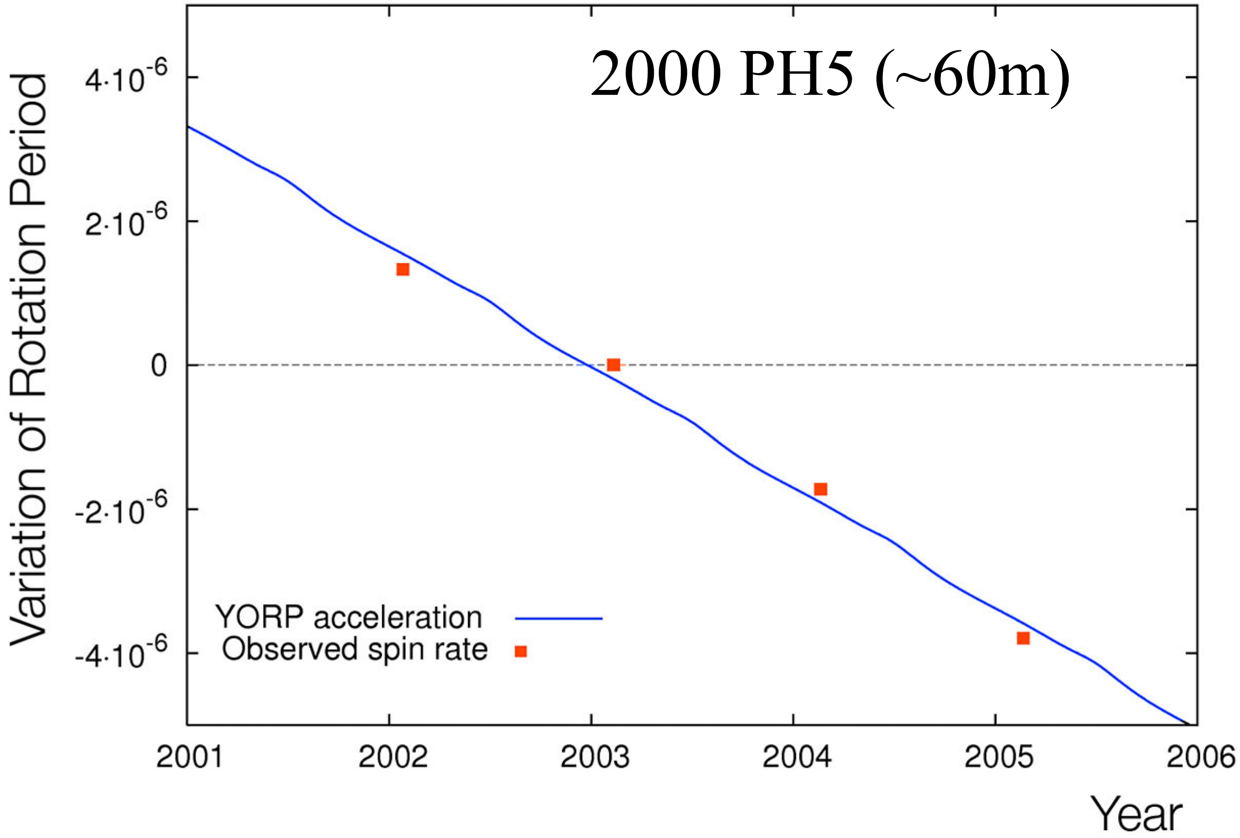


**Image obtained with NACO (VLT)**

**Direct Detection of the Asteroidal YORP Effect**
Stephen C. Lowry, *et al.*
*Science* **316**, 272 (2007);
DOI: 10.1126/science.1139040

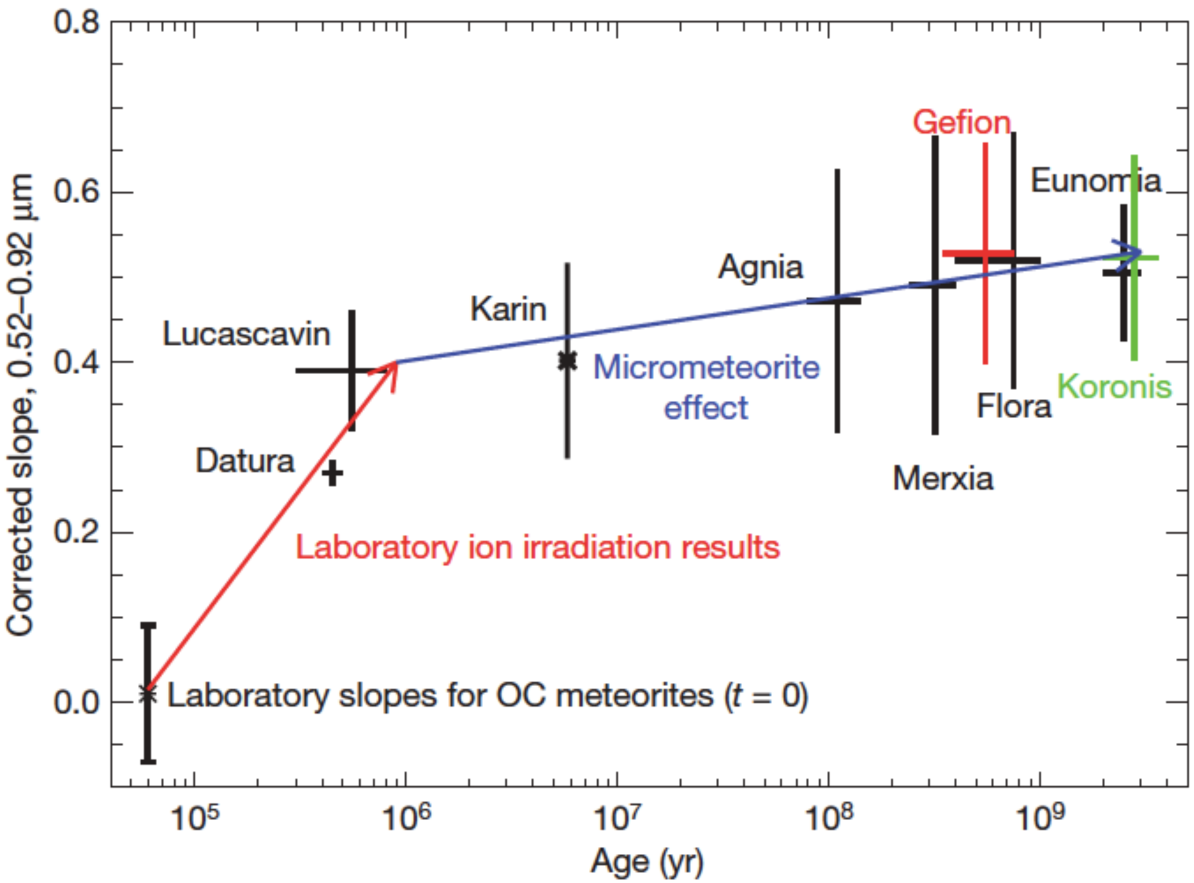
# 4 years of observations (ESO and other observatories)



Vol 458|23 April 2009|doi:10.1038/nature07956 nature

# Solar wind as the origin of rapid reddening of asteroid surfaces

P. Vernazza[1], R. P. Binzel[2], A. Rossi[3], M. Fulchignoni[4] & M. Birlan[5]



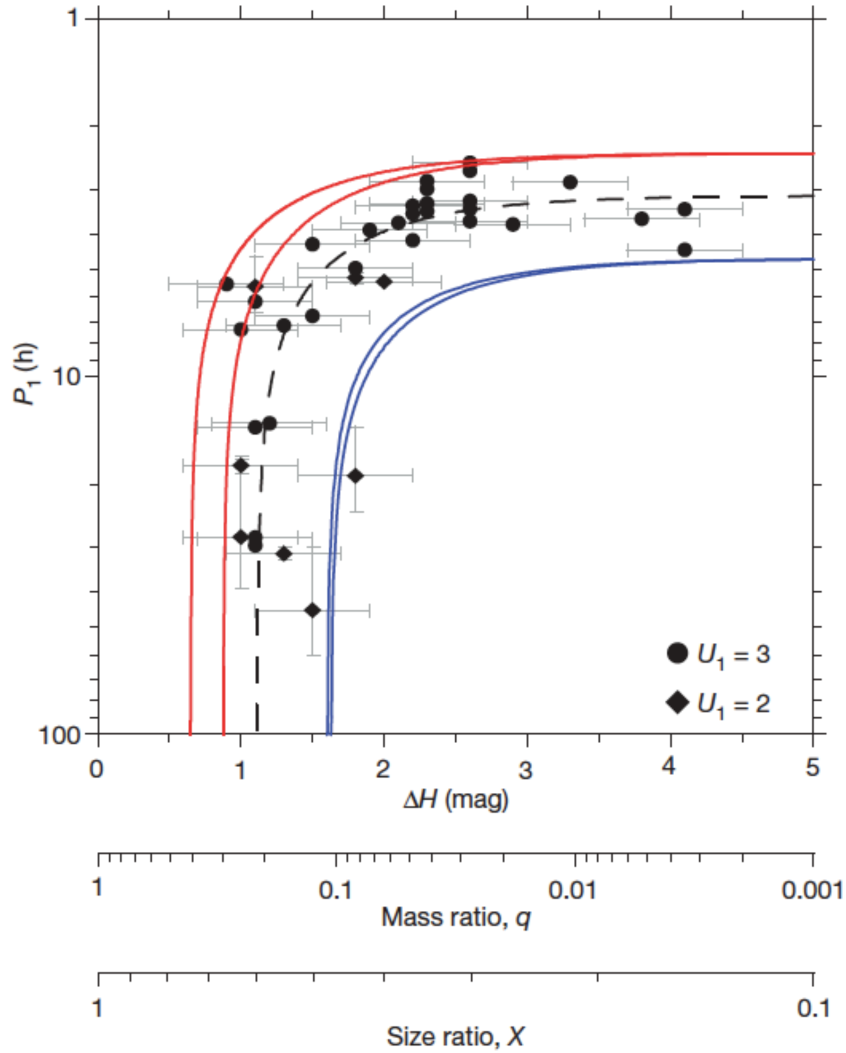

FORS (VLT)

Vol 466|26 August 2010|doi:10.1038/nature09315

nature

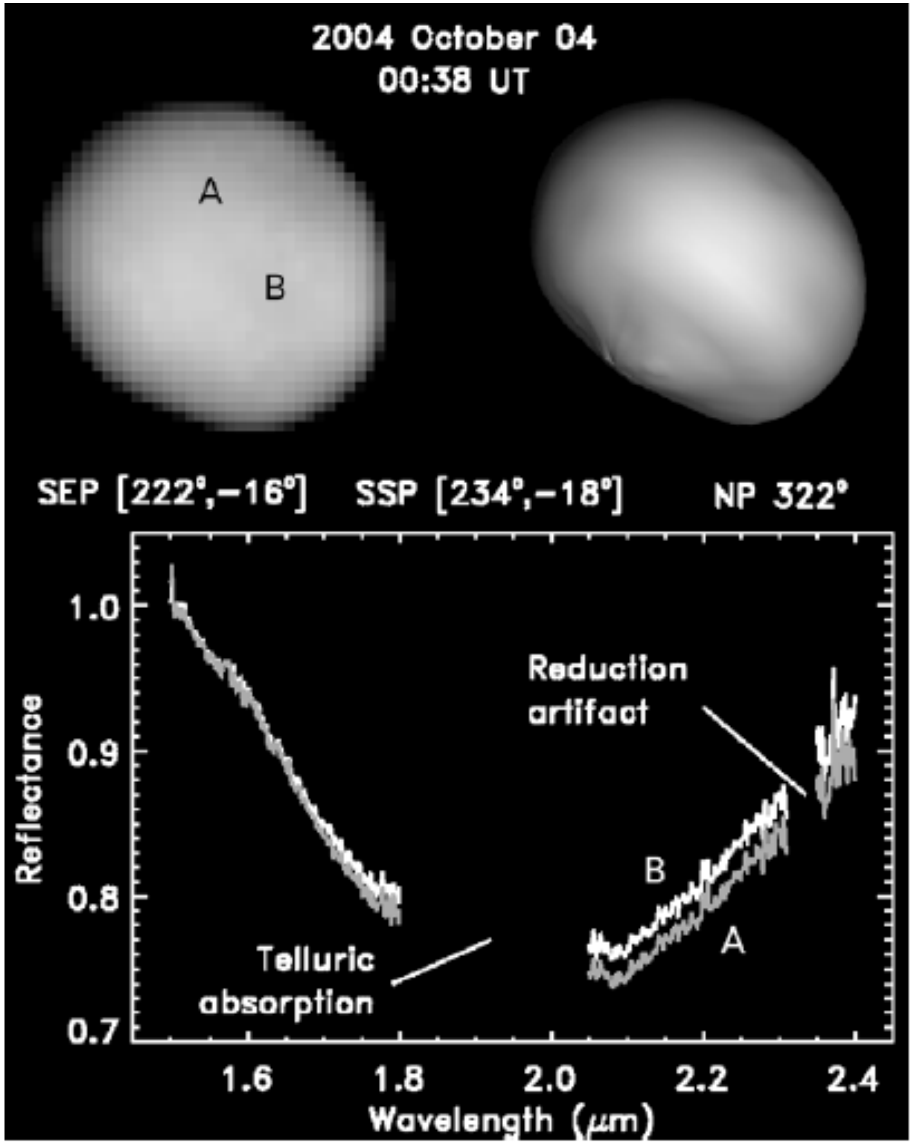
# Formation of asteroid pairs by rotational fission

P. Pravec[1], D. Vokrouhlický[2], D. Polishook[3], D. J. Scheeres[4], A. W. Harris[5], A. Galád[1,6], O. Vaduvescu[7,8], F. Pozo[7], A. Barr[7], P. Longa[7], F. Vachier[9], F. Colas[9], D. P. Pray[10], J. Pollock[11], D. Reichart[12], K. Ivarsen[12], J. Haislip[12], A. LaCluyze[12], P. Kušnirák[1], T. Henych[1], F. Marchis[13,14], B. Macomber[13,14], S. A. Jacobson[15], Yu. N. Krugly[16], A. V. Sergeev[16] & A. Leroy[17]




Observations:
La Silla and many other observatories

# First disk-resolved spectroscopy of (4) Vesta with SINFONI




Carry et al. 2010

# How about the future?

- ESO possesses all the necessary instruments for an efficient characterization of the asteroid population.

- We are still in the golden age of asteroid studies. There are still many unanswered questions (missing observations)

- While the VLT's size is sufficient for answering most of them, ELT may be the 'final' missing piece that will allow us to fully characterize this population.

# TNOs observed by ESO: Summary

ESO: 3 LPs on TNOs + countless regular programs

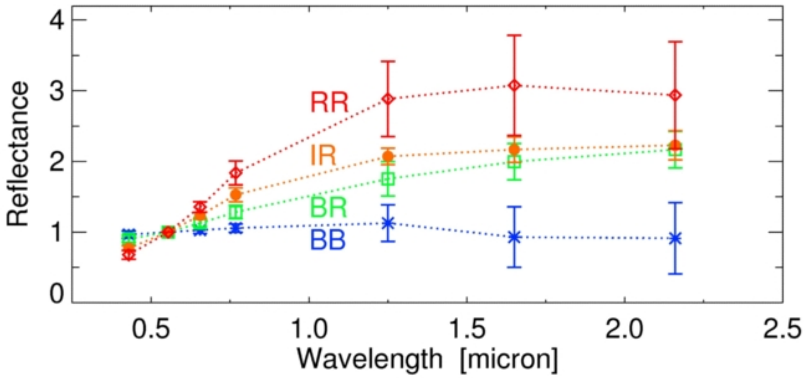
PIs: Hainaut (2000-2002), Boehnhardt (2001-2003), Barucci (2006-2008)

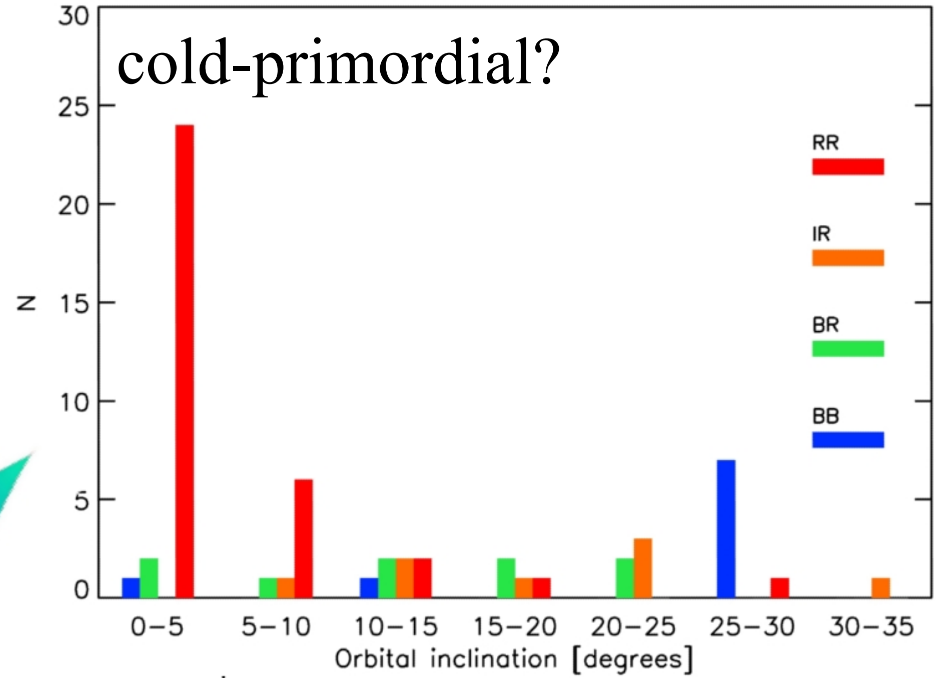
⇒ Characterization of the TNO population has mainly been done by ESO.

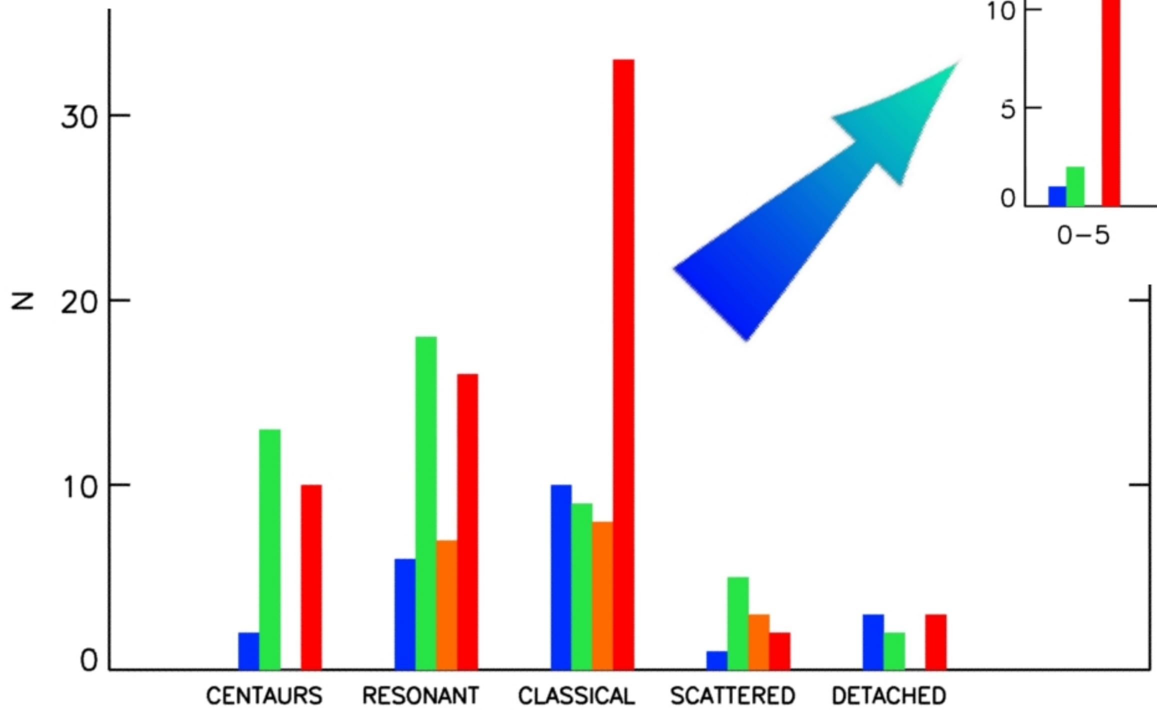
- Surface properties
  - Colours (photometry in the visible and near-IR)
  - Chemical composition (reflectance spectroscopy)
  - Albedo (photometry in the visible and far infrared)
- Shape & rotation (light curves)

# TNO colors (La Silla, Paranal)

**135 objects**

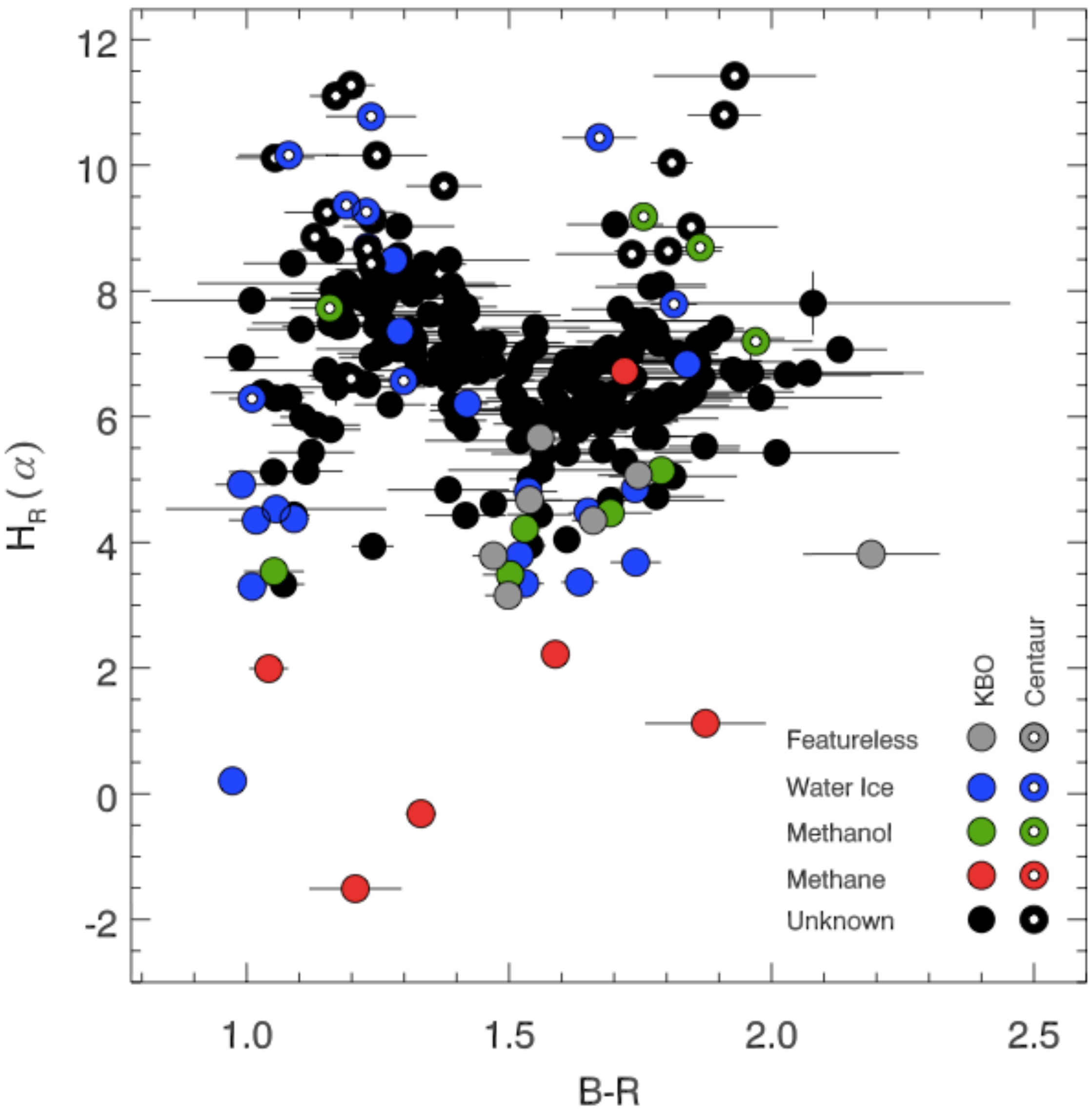



(Perna et al. 2010)

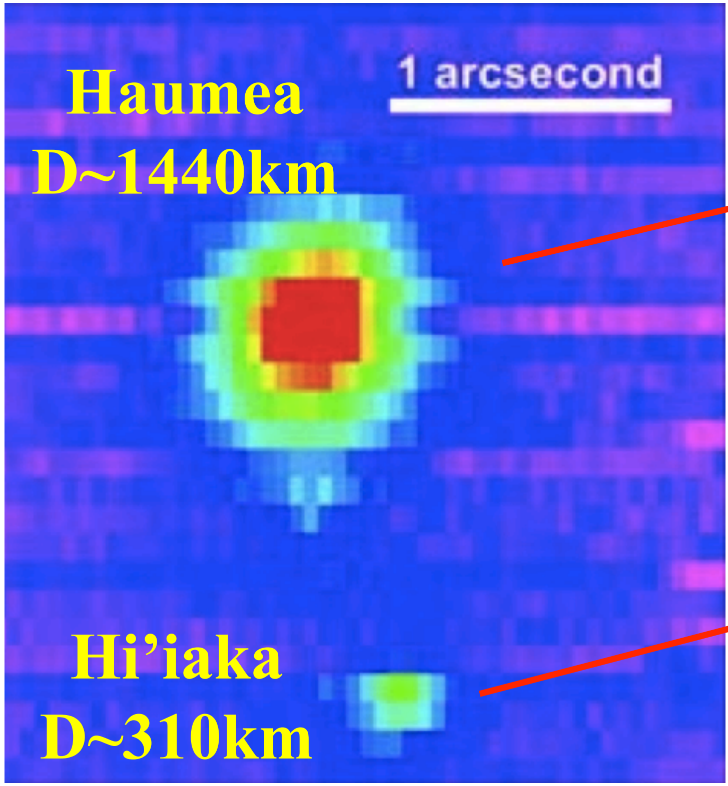
# The Bimodal Colors of Small Kuiper Belt Objects



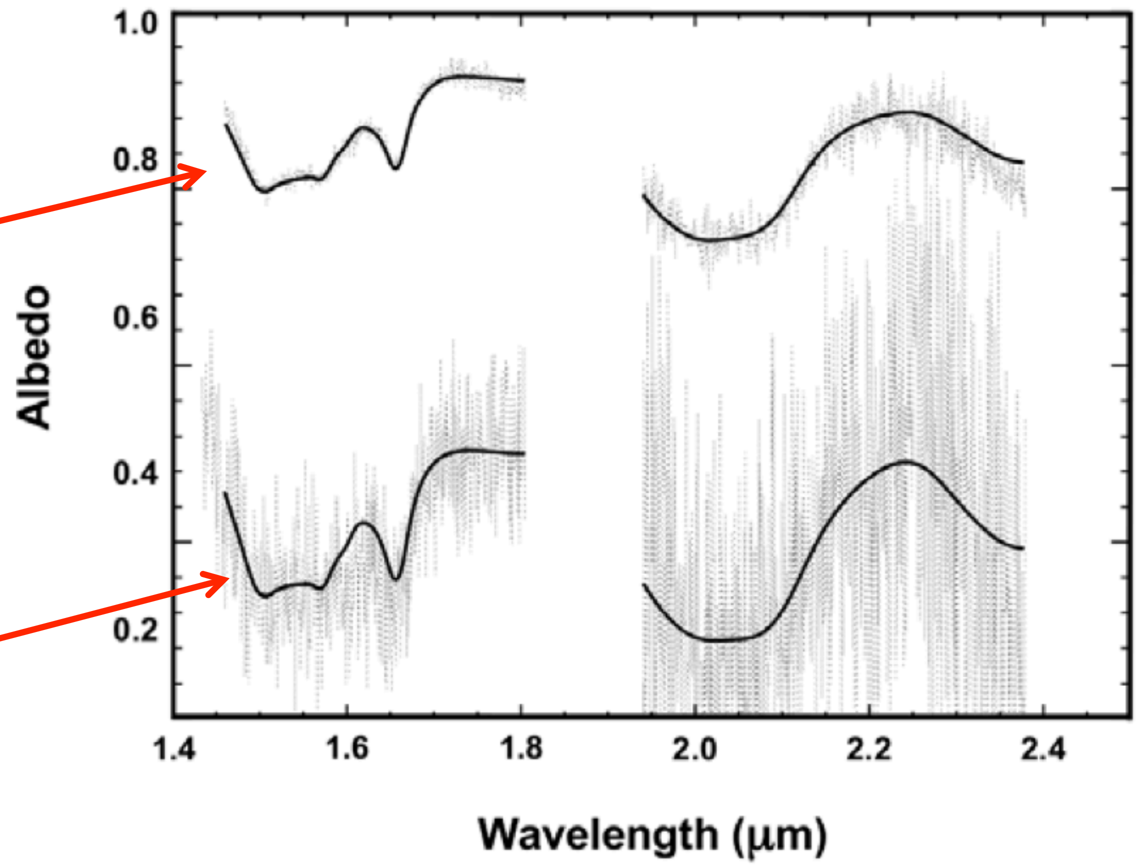

Peixinho et al. 2012

# Integral-field spectroscopy of TNOs with SINFONI

Dumas et al. 2011



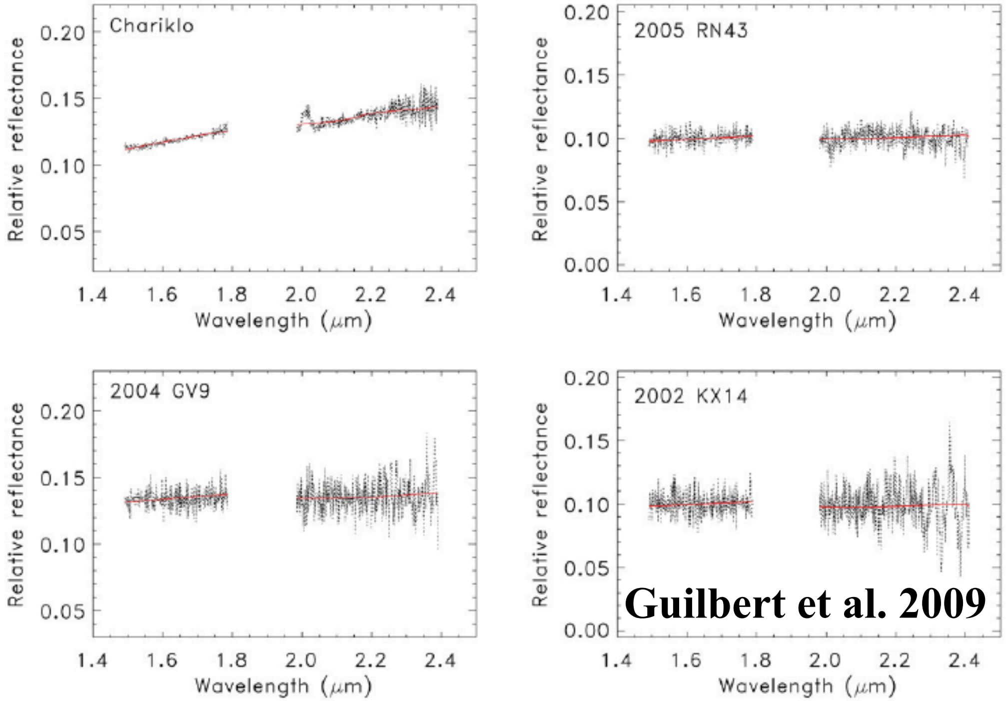

Crystalline and Amorphous water ice



# Integral-field spectroscopy of TNOs with SINFONI: Results

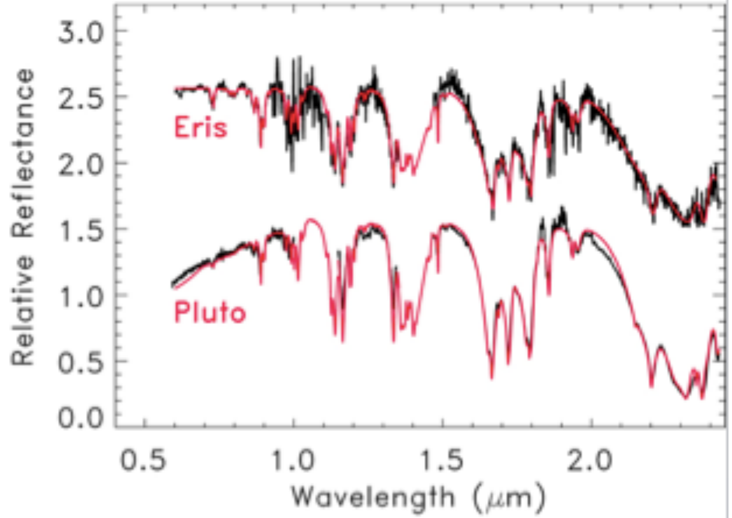
**Survey reveals 3 spectral classes !**

**Featureless spectra: Unknown composition**

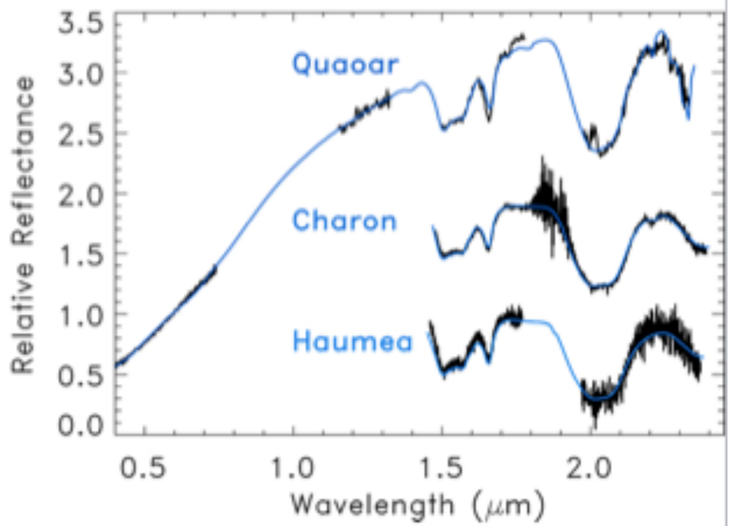



Guilbert et al. 2009

**Methane ice**



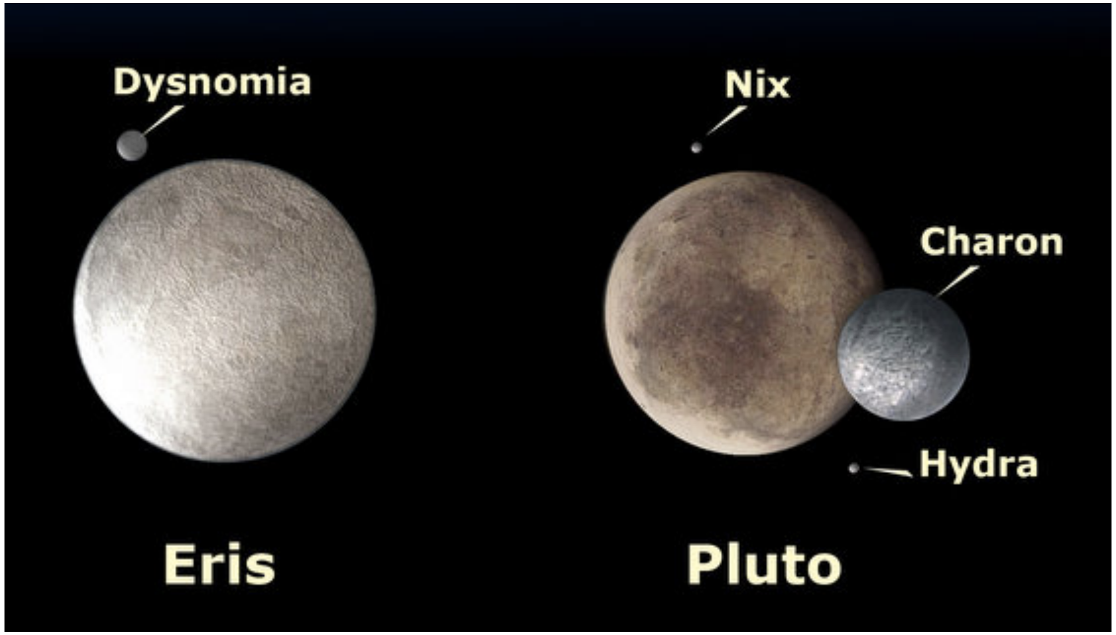

**Water ice**

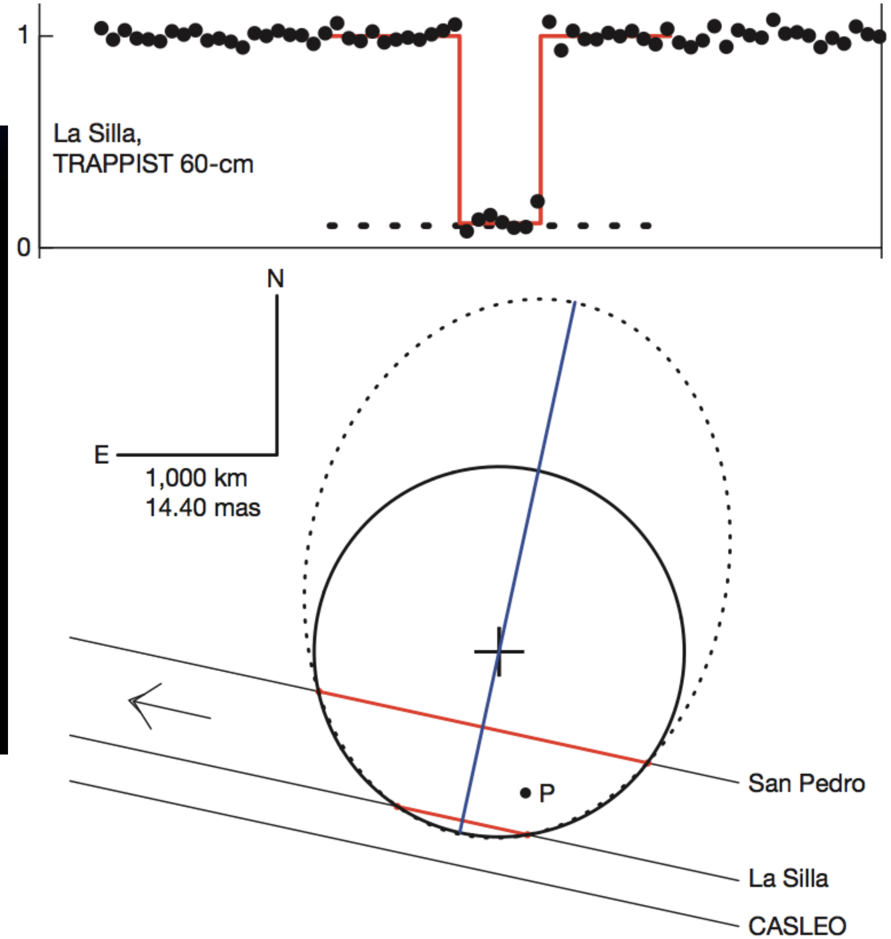


# LETTER

doi:10.1038/nature10550

# A Pluto-like radius and a high albedo for the dwarf planet Eris from an occultation




D=2330km D=2300-2400km

Sicardy et al. 2011

# TNO surveys: Conclusions

## Colors (135 objects):

- Taxonomy : 4 groups (BB, BR, IR and RR)
- Colour-inclination correlation ( « cold » are red and « hot » are blue)
- Bimodality among small TNOs => different origins

## Visible and near-Infrared spectroscopy (75 objects):

- 3 spectral classes (neutral, methane ice, water ice)
- 65% of TNOs have $H_2O$ ice on their surface
- All large TNOs (> 600km) have either methane or water ice on their surface
- All BB-type objects have ices on their surface
- In more than 50% of the cases, $H_2O$ ice is in crystalline state
- Detection of $CH_4$ and $N_2$ on Pluto, Eris, Sedna & Quaoar

# Future

- TNOs are faint and the VLT is reaching its limits.

  ⇒ ELT will be welcome

- A few other large TNOs are expected to be discovered in the near future

  ⇒ Good for VLT !

# Summary (1)

- The Solar System Small Body community has grown significantly in Europe over the last 10 years
- It covers all areas of research in this field, and the level of talent is comparable to the one in the US
- It is a very active community:
  Rosetta & Marco Polo + ground-based observations

# Summary (2)

- Most of the discoveries (>90%) have and will come from ground-based observations (not from in-situ missions)

- Small bodies (step 2 of the formation of a Planetary System) can only be studied in our Solar System !!

- ESO has also a future as Small Bodies require ELT:
  - Cometary nuclei
  - TNOs, Centaurs
  - Neptune Trojans
  - Asteroids (specific science cases)