Spectrophotometry of small bodies of the Solar System with the TNG

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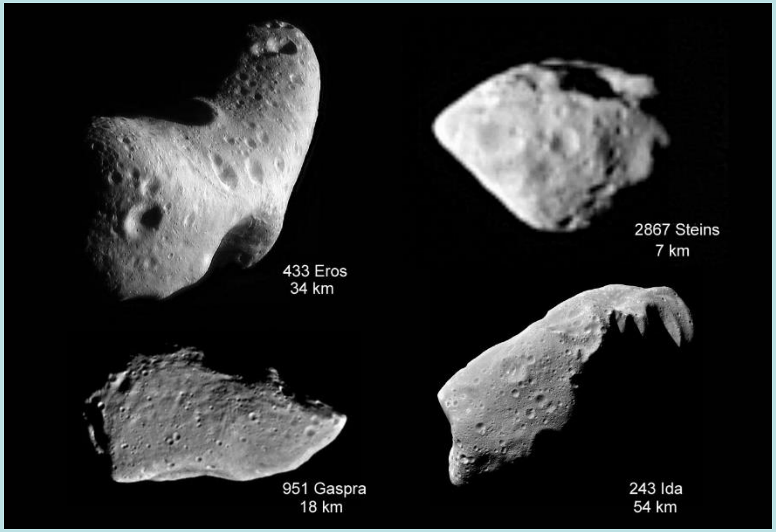
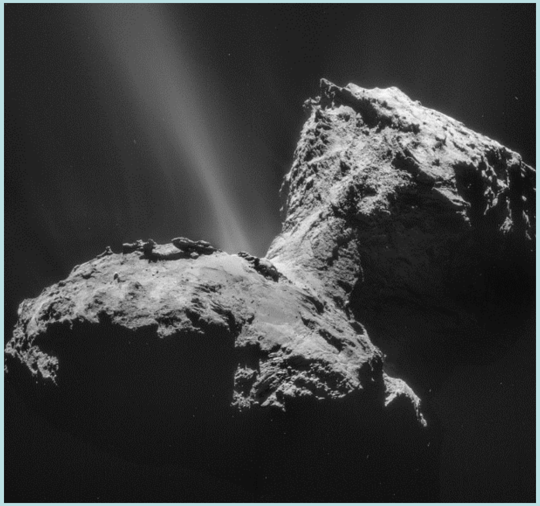
Which are the minor bodies?

ASTEROIDS



METEORITES

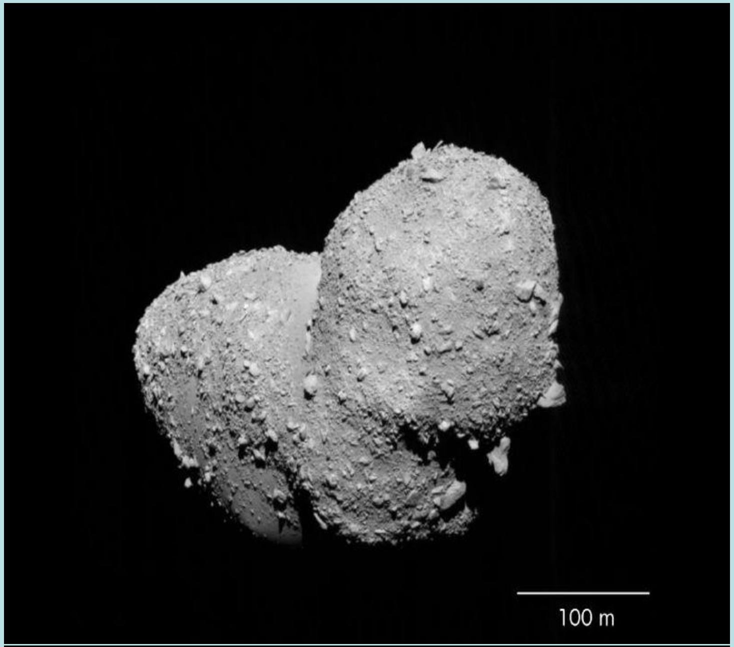
COMETS



Where are the minor bodies

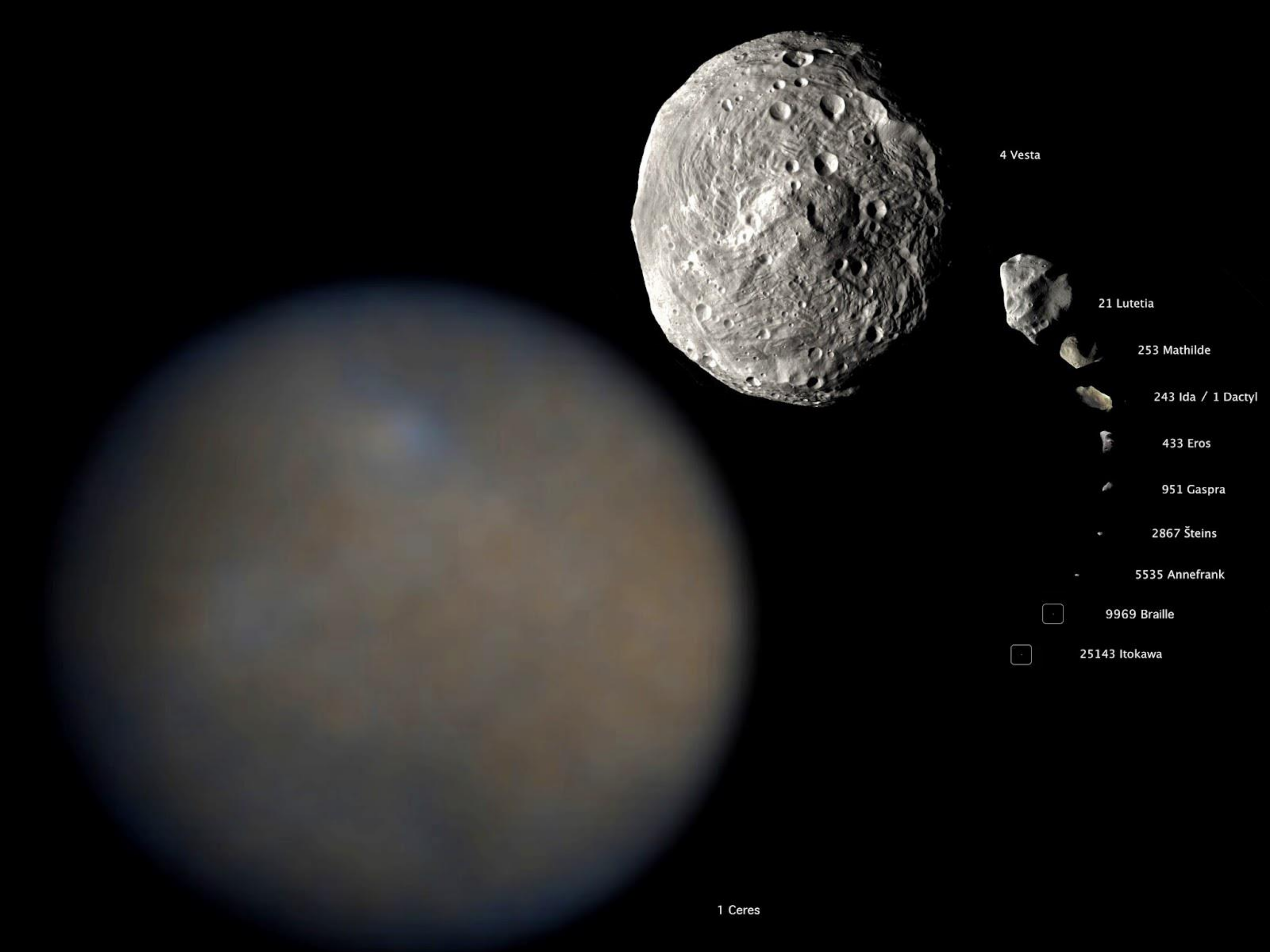
Main concentrations:

- Near Earth Objects
- Main Belt: 2.2-3.3 AU
- Kuiper Belt: > 40 AU
- Oort Cloud: 10^4 -- 10^5 AU
- Many objects in the region between the main concentrations (Trojans, Centaurs, transition objects,…)



Why are minor bodies (comets and asteroids) so important

- They are the most primitive objects in the Solar System, their study gives the possibility to investigate the primordial phases of its formation and its chemical, thermal anch dynamical evolution. In particular comets store the primordial material, partly frozen, present in the solar nebula
- They are the principal sources of the meteorites delivered on Earth
- The impacts by these bodies are likely the main cause of craterization of the inner bodies of the Solar System, so also of the Earth.
- So they represent a threat to the Earth and they may have been the responsible of mass extinctions in the past.
- They are the vehicles of organic molecules and of water and very likely the major contributors of the water present in our oceans and of the life on Earth.
- The knowledge of the properties of the small bodies, from the Oort cloud to the Near Earth Objects through the Kuiper Belt and the main-belt, is important for the comprehension of the formation and evolution of extra solar planetary systems.


4 Vesta
21 Lutetia
253 Mathilde
243 Ida / 1 Dactyl
433 Eros
951 Gaspra
2867 Šteins
5535 Annefrank
9969 Braille
25143 Itokawa
1 Ceres

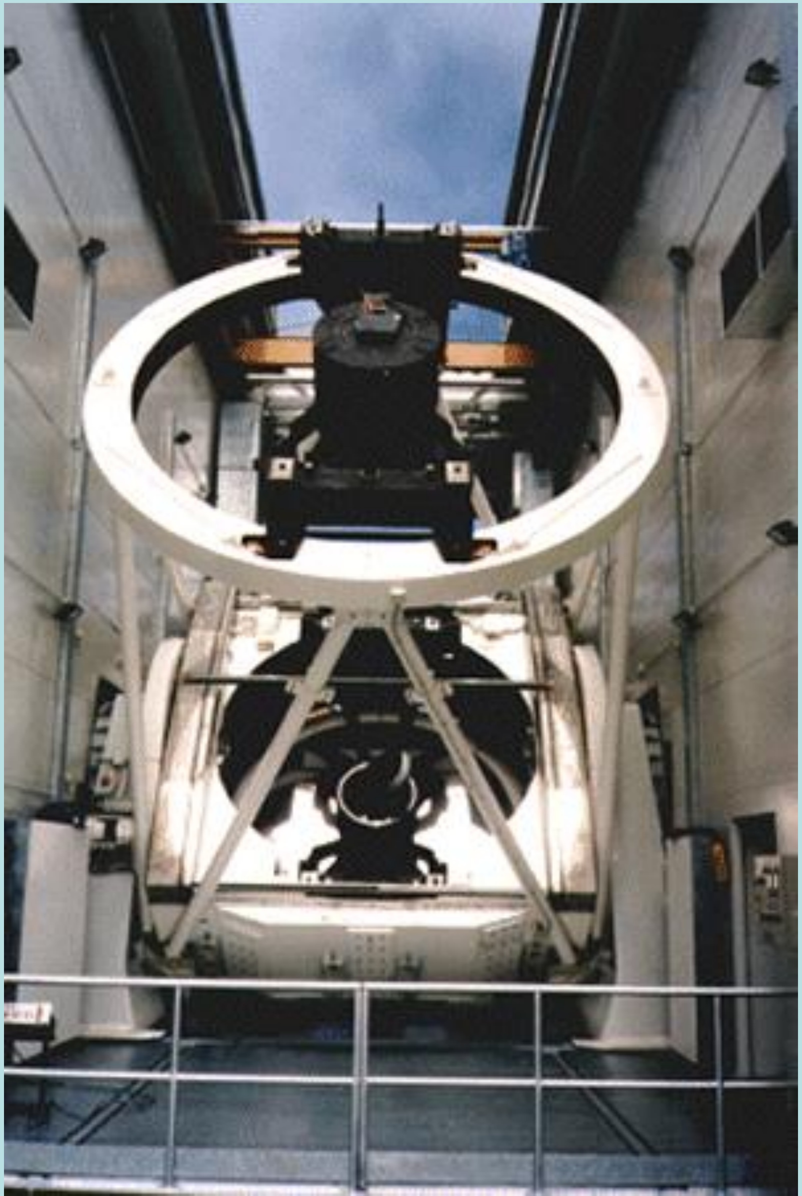
COMETS VISITED BY SPACECRAFT

THE PLANETARY SOCIETY

Modified 2014-08-04. For the latest version of this image, visit planetary.org/cometscale

Image credits: Halley: Russian Academy of Sciences / Ted Stryk. Borrelly: NASA / JPL / Ted Stryk. Tempel 1 and Hartley 2: NASA / JPL / UMD. Churyumov-Gerasimenko: ESA / Rosetta / NavCam / Emily Lakdawalla. Wild 2: NASA / JPL. Montage by Emily Lakdawalla.

Minor bodies investigation with the TNG

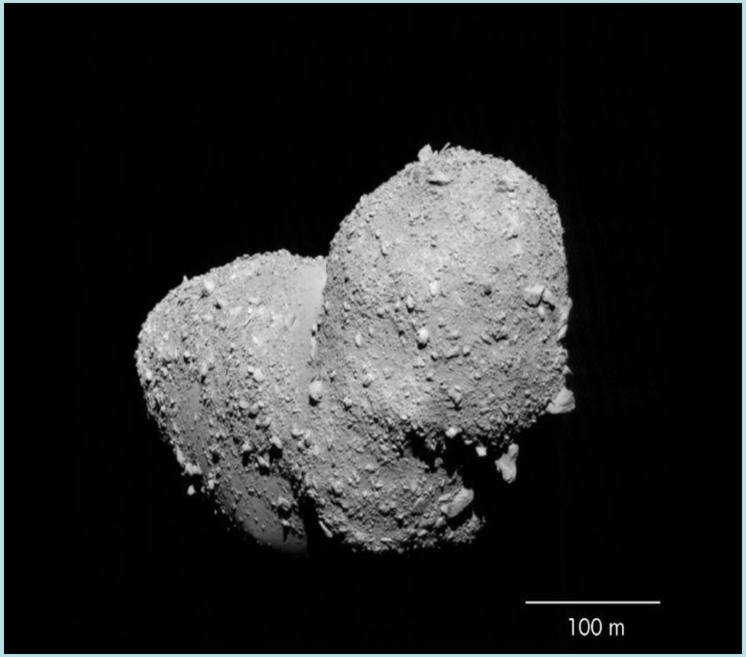


Groundbased observations are still the main tool to investigate big groups of objects as minor bodies are.

SINEO:

Spectroscopic Investigation of Near Earth Objects

M. Lazzarin, S. Marchi, S. Magrin, I. Bertini, F. La Forgia



Long term spectroscopic survey to investigate the surface composition of Near Earth Objects.

This project is connected with the ESA project **Space Situational Awareness-**Near Earth Objects segment, for the investigaton of potential threatening objects for the Earth and for mitigation strategies studies (**http://www.esa.int/esaMI/SSA),** the coordination center is at ESA-ESRIN Roma, inaugurated in may 2013 (Ettore Perozzi, Marco Micheli coordinators).

Near Earth Objects

Objects orbiting near to the Earth, inside its orbit or crossing it

NEOs components:

- **NEC** – comets $q<1.017$ $P<200$ yr
- **NEA** – asteroids:
- IEO – inside the Earth $a<1$ $Q<0.983$
- Aten - Earth Crossers $a<1$ $Q>0.983$
- Apollo - Earth Crossers $a>1$ $q<1.017$
- Amor - $1.017<q<1.333$

Instrumentation adopted for SINEO

- **Observations: low resolution spectra in the spectral range** *0.40 – 2.50* micron
- **Telescope used: ESO-NTT La Silla-Cile and TNG-La Palma-Canarias**

EMMI

Gr#1, D=5.9 Å/pix, Slit=5", seeing=1"

V=20 in T_{exp}=1h

S/N=20

DOLORES

LR-R Grm3, D=2.9 Å/pix, Slit=5", seeing=1"

V=20.0 in T_{exp}=1.0h

S/N=23

SOFI

GB, D=6.9 Å/pix, Slit=2", seeing=1"

J=16 (V≈17.5) in T_{exp}=1.5h

S/N=20

GR, D=10.2 Å/pix, Slit=2", seeing=1"

K=16 (V≈18) in T_{exp}=2.5h

S/N=20

NICS

Amici, D=30-100 Å/pix, Slit=2", seeing=1"

H=16.2 (V≈18.0) in T_{exp}=1.0h

S/N=30

web site:

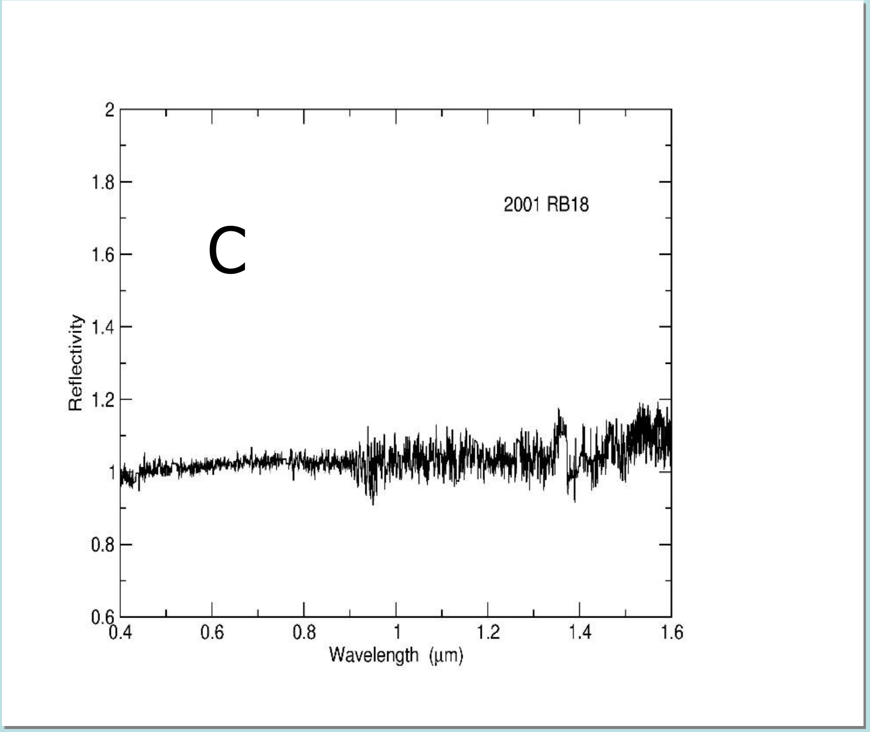
http://www.astro.unipd.it/planets/sineo.html

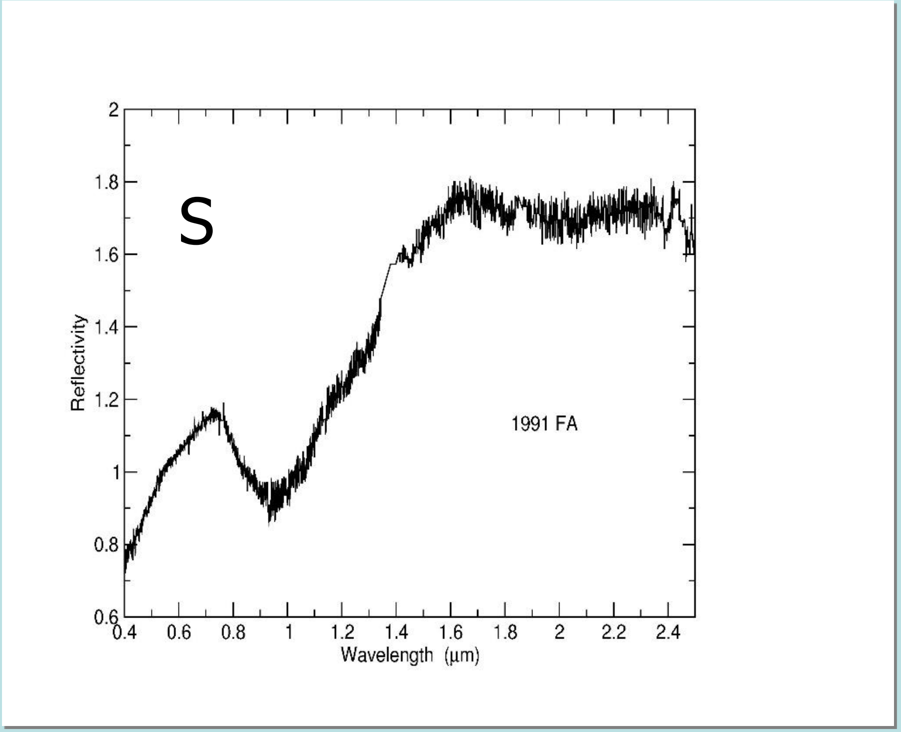
SINEO: **one of the largest spectroscopic data base** with about 180 spectra of NEOs in the visible and Near Infrared region (0.4-2.5 micron) partly published and not yet completely analyzed.

•150 spectra in the visible and 90 in the NIR,

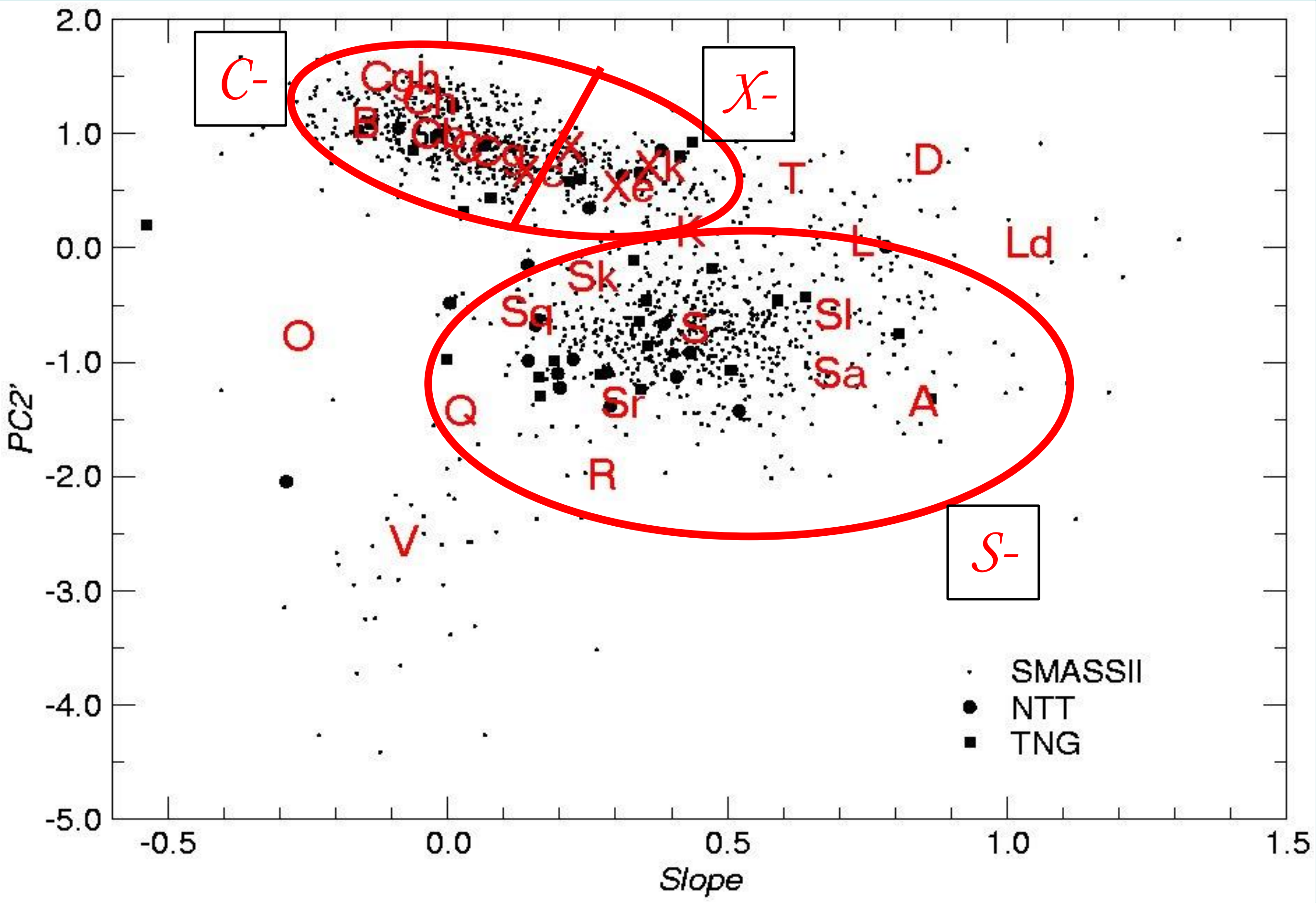
•50 at **TNG** (**three obs. runs for a total of nine nights, four in the visible and five in the near-infrared**)

Some examples:





•**Taxonomic classification:** needed for estimate the composition of the objects. Obtained almost all the taxonomic classes found in the MB that confirms NEOs variegate origin. The use of the Principal Component Analysis confirms the taxonomic classification obtained.



PCA:performed using SMASS II data (Binzel 2002). Our data distribute in the same clusters defined by SMASS II data.

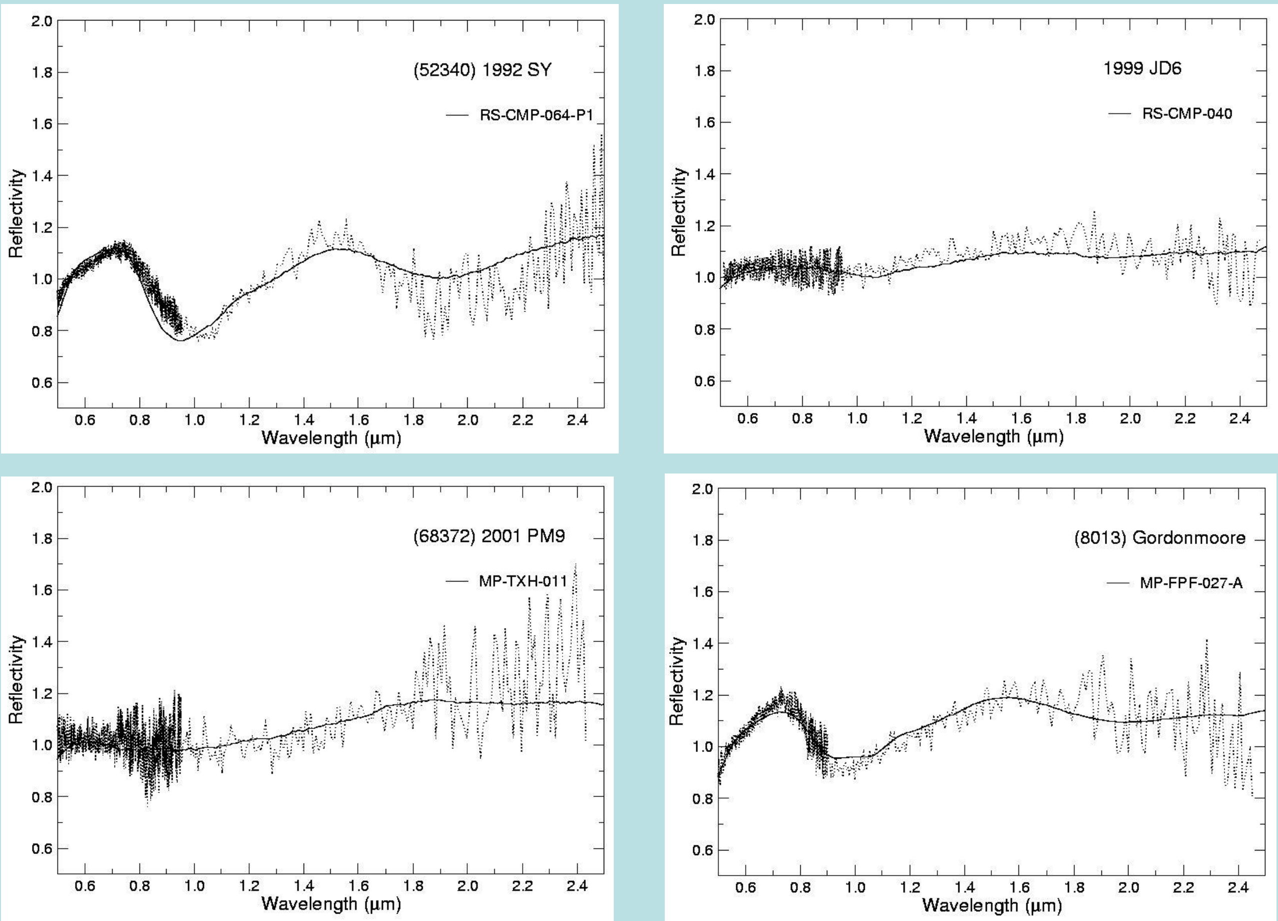
- **Comparison of NEO spectra with those of about 900 meteorites taken from RELAB catalog.**

  Most meterorites has not a clear origin.

  40% of NEOs have a meteoritic analogue; all C-types have a Carbonaceous Chondrite analogue

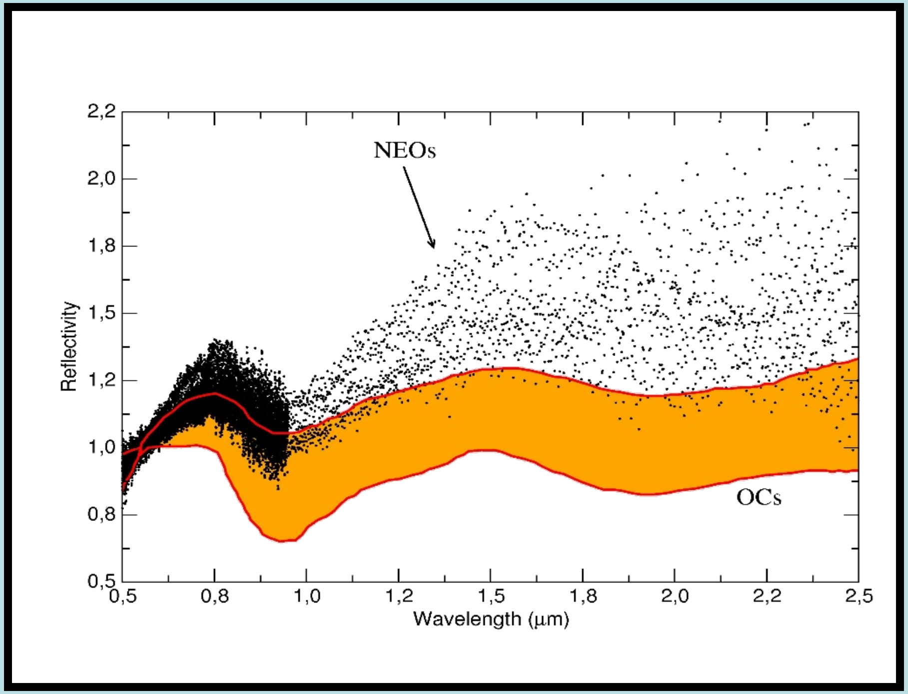
  25% of S-types have an Ordinary Chondrite analogue.

  A first conclusion is that NEOs are the principal parent bodies of meteorites that fall on the Earth.

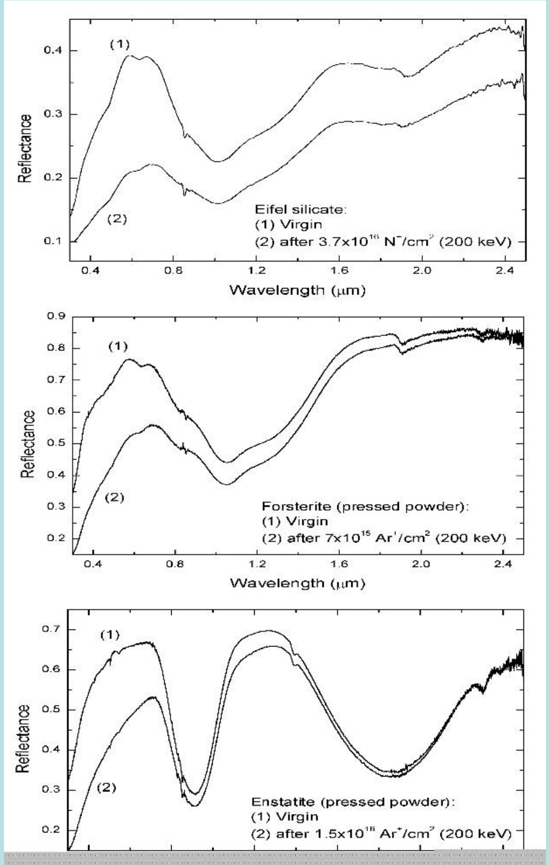


Most part of the investigated S-types NEOs does not fit with any meteorite: their spectra are typically redder

- **Study of space weathering**

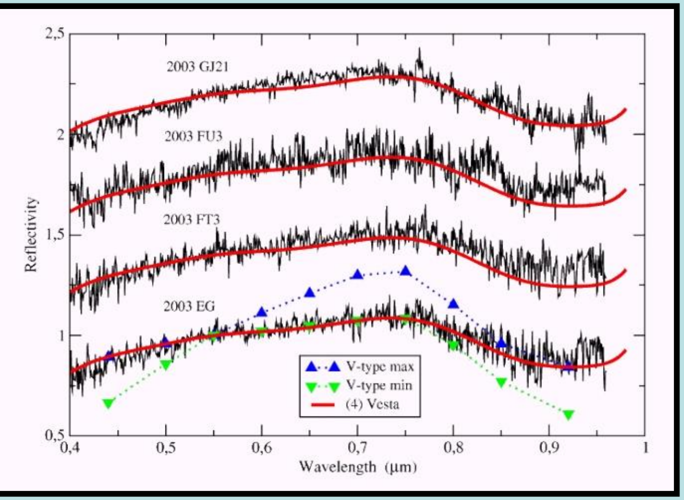


The S-type NEOs that do not match with any meteorite are typically redder than the reddest OC meteorites and we conclude that this is due to space weathering effects

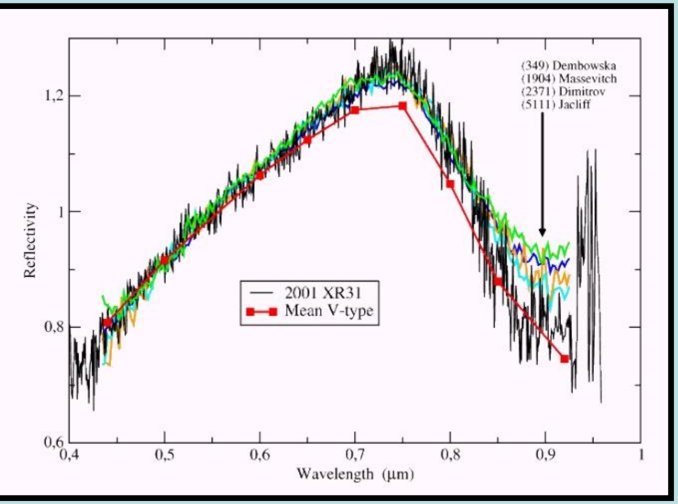


Laboratory experiments made in collaboration with Catania observatory on OC meteorites indicate that ion bombardment of OC meteorites is able to mimic SW effects on S-type objects due to solar wind

- **Peculiar objects: dead/dormant comets, family asteroids, rare taxonomic types…**

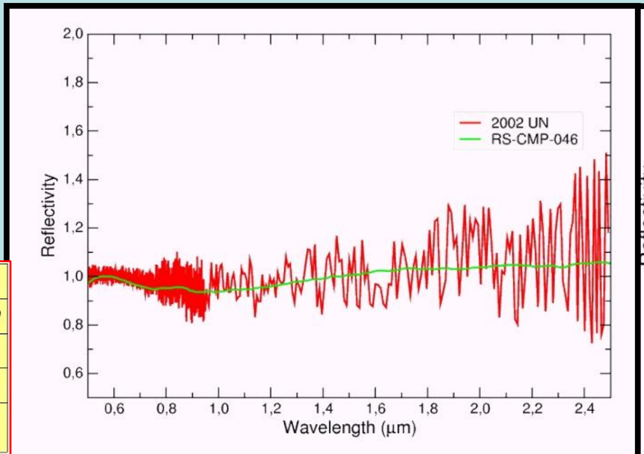


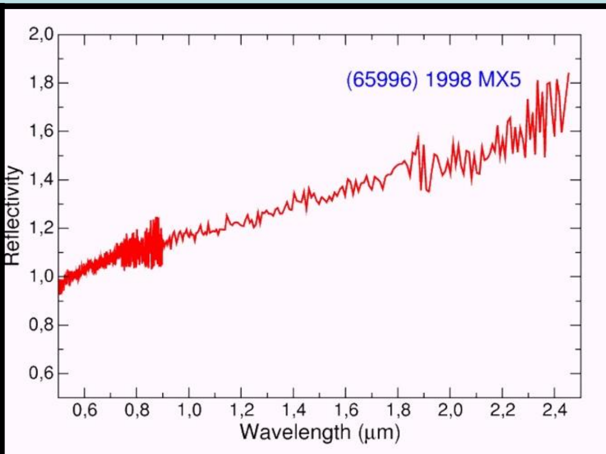
We have found some peculiar objects: the spectra of four V-type objects very similar to Vesta.



Then the spectrum of a NEO probably belonging to the rare R-class.

The spectra of 2 objects of primitive composition that could be of cometary origin. In fact they also have a Tj typically cometary and a high probability to come from the JFC channel.





			probability to origin from different channels (total = 1.00)						
	Tax	***T_J***	***3:1***	***IMC***	***JFC***	***v_6***	***OB***	***HUN***	***PHO***
2002 UN	B	**2.81**	0.02	0.01	**0.91**	0.00	0.05	0.00	0.01
65996	X	**2.95**	0.00	0.01	**0.61**	0.00	0.37	0.00	0.00

IMC: Inner Mars Crosser; *JFC*: Jupiter Family Comets; *OB*: Outer Belt; *HUN*: Hungarias; *PHO*: Phocaeas. *3:1* and v_6: a mean motion and a secular resonance, respectively.

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--Due assegni di ricerca dell’Universita’ di Padova

--Due Tesi di Dottorato

--Due tesi magistrali

--Tre tesi triennali

The NEOShield-2 EU Project – Science and Technology for Near-Earth Object Impact Prevention

The Italian contribution: S. Ieva, E. Dotto, E. Mazzotta Epifani, A. Di Paola, R. Speziali, M. Cortese, M. Lazzarin, I. Bertini, S. Magrin, M.A. Barucci, D. Perna, E. Perozzi , M. Micheli

Within the framework of the Horizon 2020 program the European Commission promoted the study on NEOs by approving and financing the NEOShield-2 project (2015-2017). The main aims of this project are: i) to study detailed technologies and instruments to conduct close approach missions to NEOs or to undertake mitigation demonstration, and ii) to retrieve the physical properties of a wide number of NEOs, in order to design impact mitigation missions and assess the consequences of an impact on Earth.

INAF-OAR and Padova University, the Italian contributors to the NEOShield-2 project, are responsible for the **Task 10.2.1 'Colours and Phase function',** with the aim to acquire photometric measurements for a wide sample of NEOs in order to obtain information on: i) phase function analysis, ii) surface color variation, and iii) preliminary taxonomical classification.

OBSERVATIONS AT TNG: 6 obs. runs, 4h each every semester and for 4 semesters for a total of 96 hours

V-Type Asteroids

M.C. De Sanctis, Alessandra Migliorini-IAPS-INAF Roma

Basaltic asteroids are thought to be fragments of Vesta, forming its famous dynamical family. Other basalt asteroids, however, do not appear to have a clear dynamical link suggesting, thus, the existence of other basaltic parent bodies.

So, the spectral investigation of the basaltic asteroids in the main belt can help understanding if there are V-type asteroids that show distinct mineralogy with respect to Vesta and its family members.

The spectroscopic observations with VIR on board the Nasa Dawn mission represent a unique opportunity to compare spectral properties of the Vesta surface (acquired with high spatial resolution) with ground-based observations of V-type asteroids.

Observations

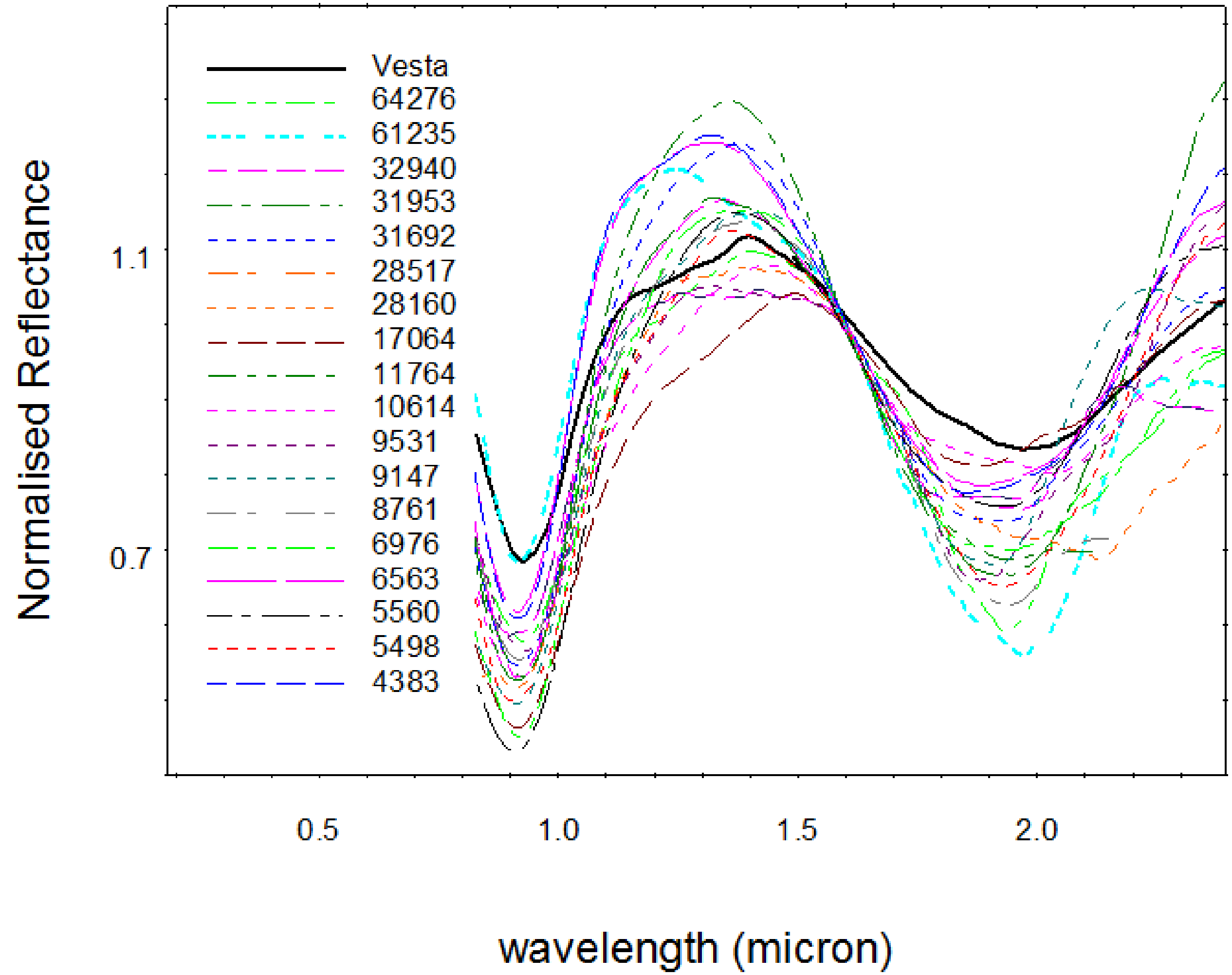
Four observational runs at TNG

- 21-24 April 2003 (19 asteroids, P.I. Duffard R.)
- 25-26 December 2007 (12 asteroids, P.I. De Sanctis M.C.)
- 16-21 March 2010 (18 asteroids, P.I. De Sanctis M.C.)
- 15-17 March 2012 (10 asteroids, P.I. De Sanctis M.C.)

Total of **59 asteroids**

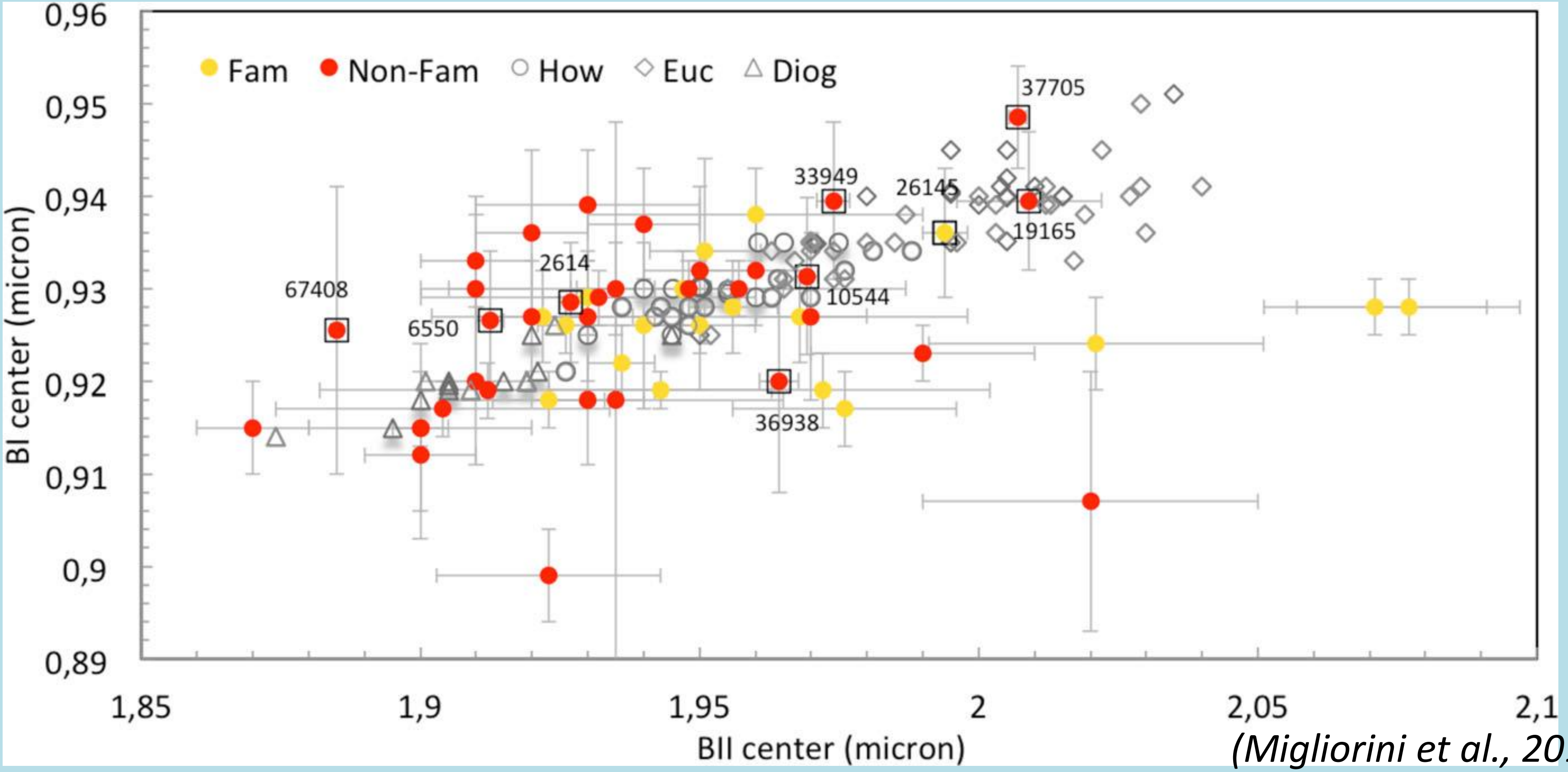
Setup: NICS + Amici grism + slit 2”
DOLORES + LR-R grm3 + slit 2” (the visible range is avaialble only for 8 asteroids)

Pubblications: 5 peer-review publications (+1 in preparation)
10 communications at meetings



Near-infrared smoothed spectra of asteroids observed in 2010 (De Sanctis et al.,2011), normalized to unity at 1.6 µm. All the asteroids are carachterized by the two bands at 1 µm and 2 µm, indicative of the presence of pyroxene. For comparison, the (4) Vesta spectrum taken from the SMASS survey (Burbine & Binzel 2002; Xu et al. 1995) is also plotted. Vesta spectrum shows also an inflection at about 1.25-1.3 µm, attributed to feldspar (Gaffey 1976).

Asteroid mineralogical properties compared with HEDs



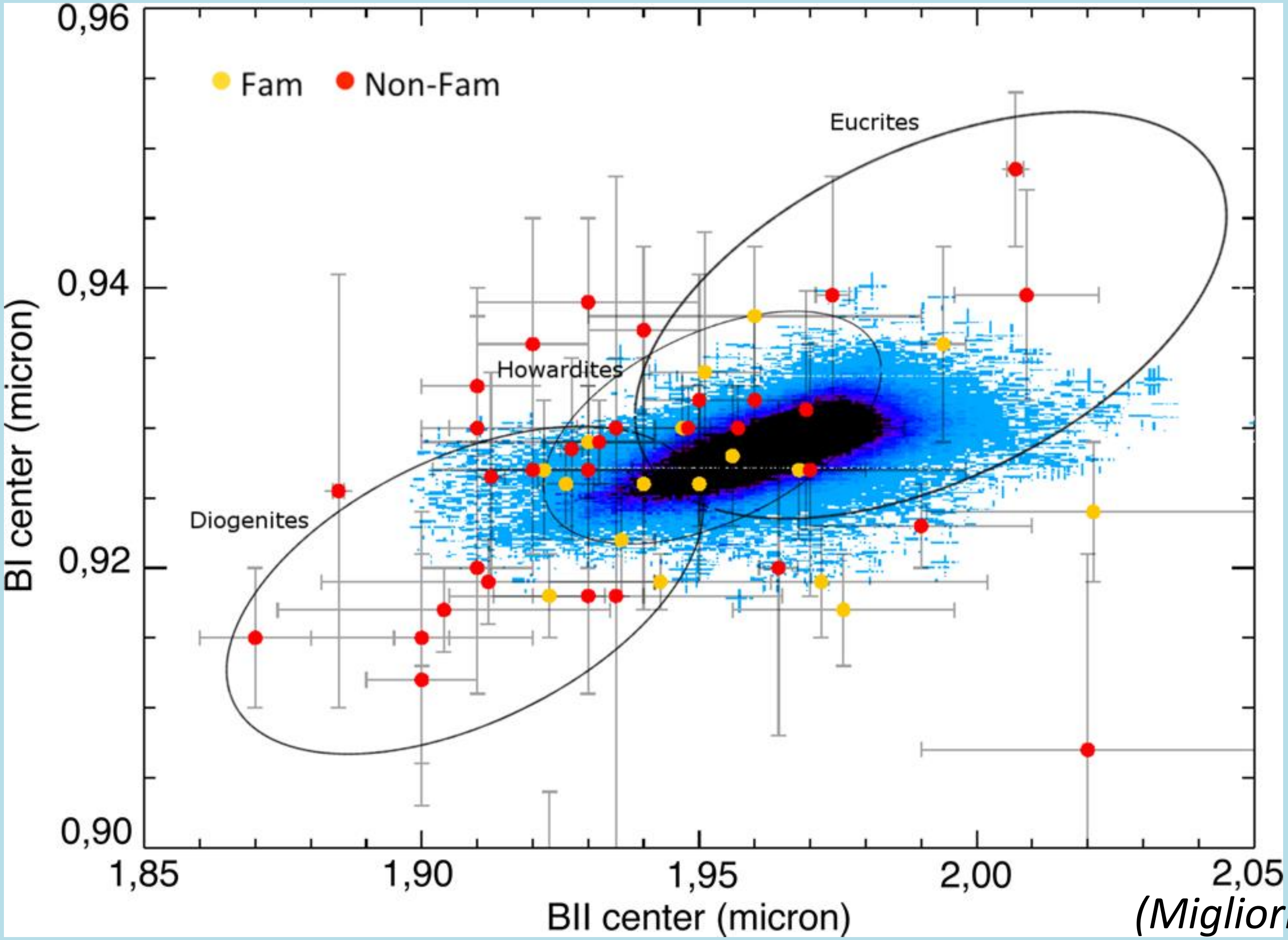
(Migliorini et al., 2017)

BandI center (0.9 micron) versus BandII (1.9 micron) center for the asteroids observed in 2007-2012, compared also to the same parameters derived for HEDs meteorites, possible analogues. The position of the center depends on the composition, so it is typical of a mineral mixture.

From the comparison of the band center position for the asteroids with those of HEDs, it is possible to obtain information on the surface composition of the asteroids.

It is believed that HED come from different strata of Vesta (Eucrites e Howardites from the surface of Vesta, the Diogenites from the internal strata). Most V-type are similar to Howardites and Diogenites. Not yet strong evidence for differences between family and non family members

Comparison with Vesta surface mineralogical properties (data from VIR/Dawn)



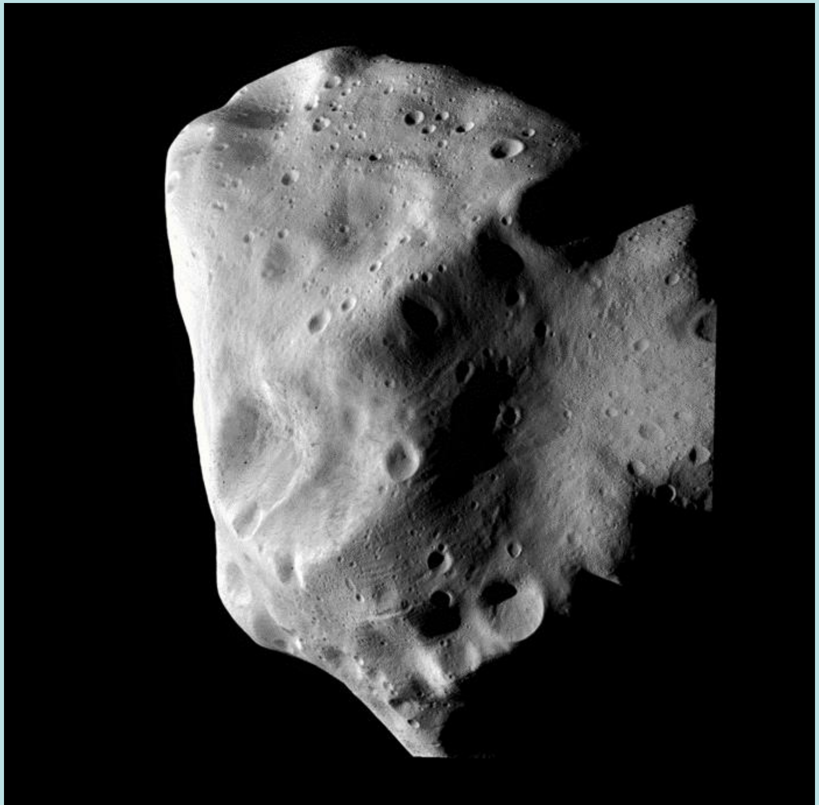
(Migliorini et al., 2017)

Comparison of the BI and BII centres calculated for V-type asteroids, observed in the period 2007–2012, HEDs and values derived from the Vesta surface, observed with VIR on DAWN mission (from De Sanctis et al., 2013). V-types members of the Vesta family are indicated with a yellow circle, while those not belonging to the Vesta family with the red symbol.

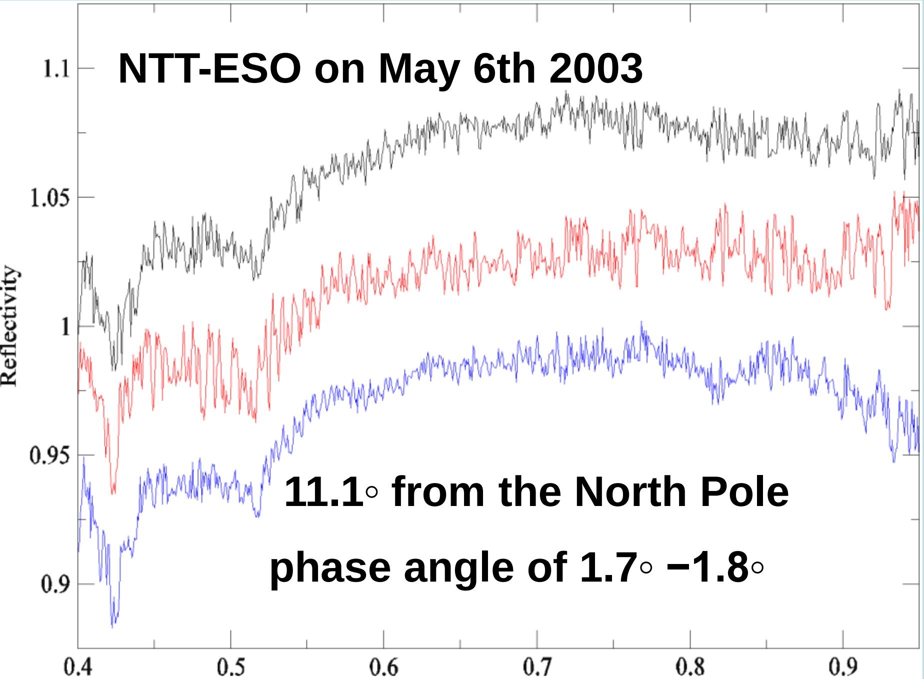
Observations of spatial mission targets:
(21) Lutetia asteroid

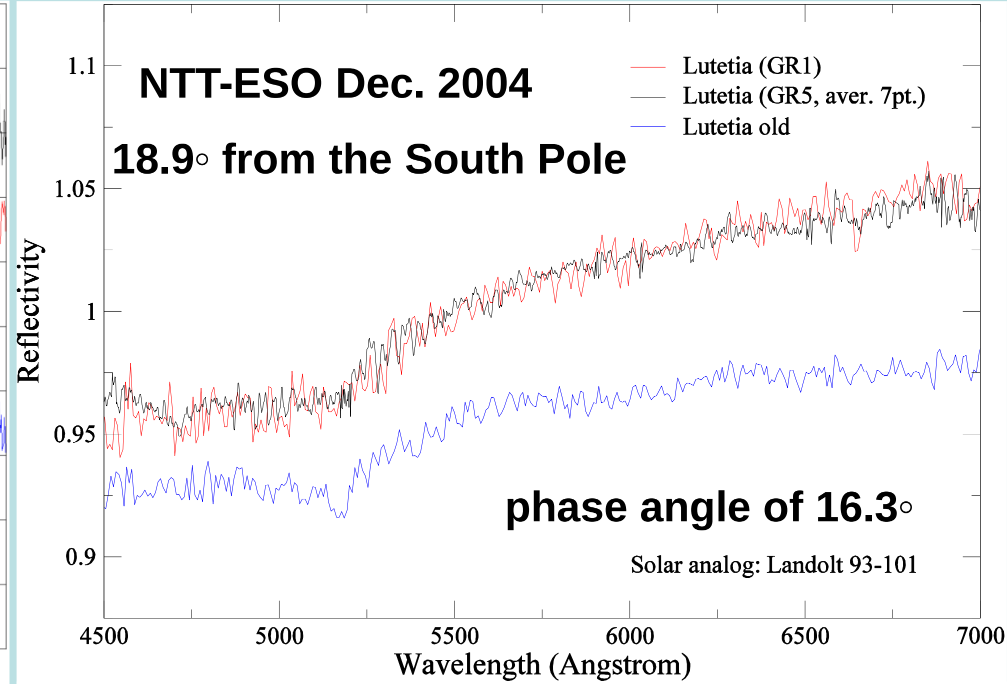
10 July 2010: from a distance of 3162 km Rosetta encounters the second asteroid: (21) Lutetia, dimensions about 120 km, rotational period about 8 hr.

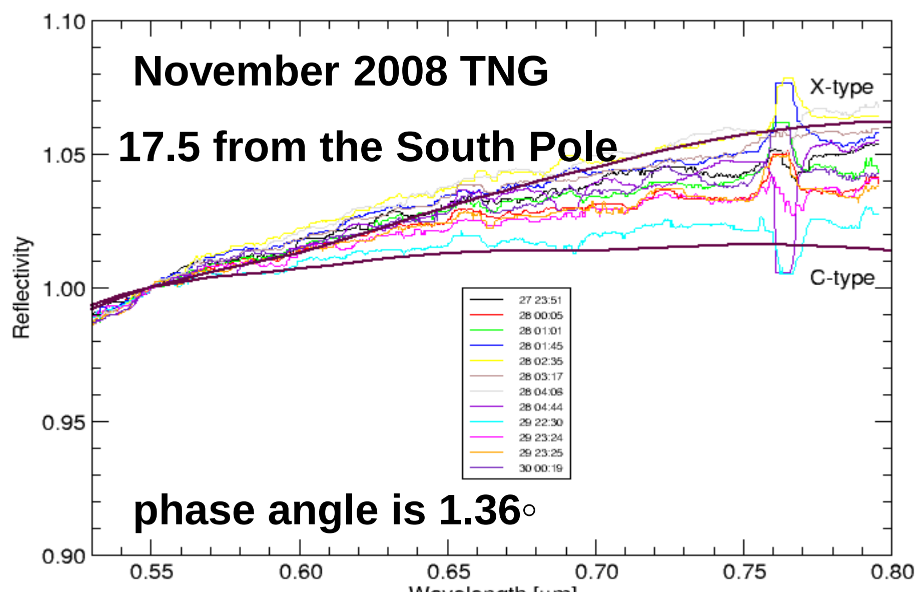
Before the encounter we have performed a deep observational campaign of the object with **two** obs runs at NTT and **one at TNG**.



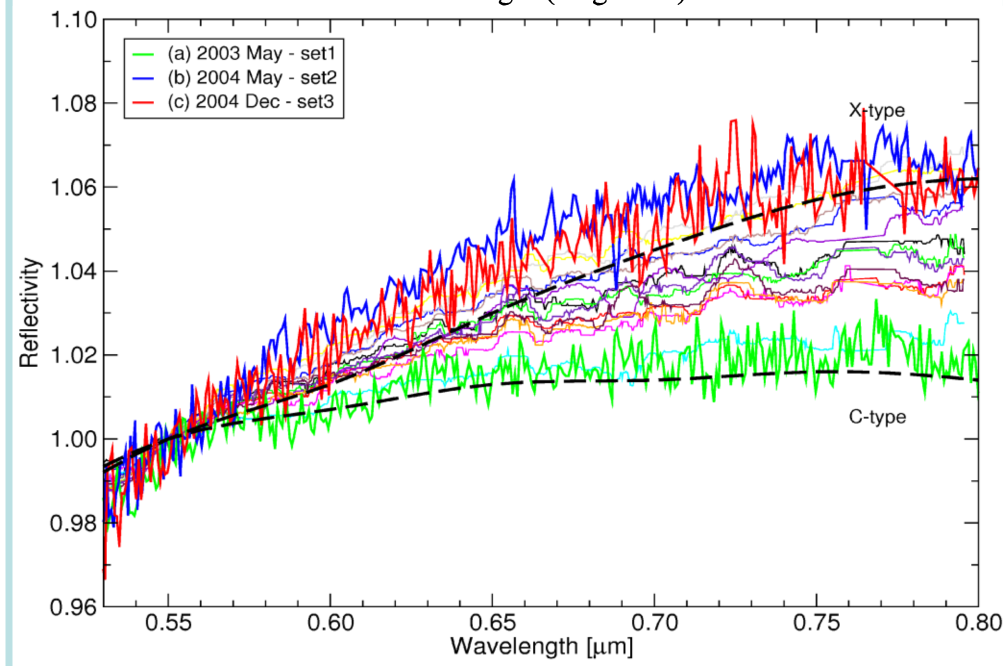
Ground based observations of Lutetia







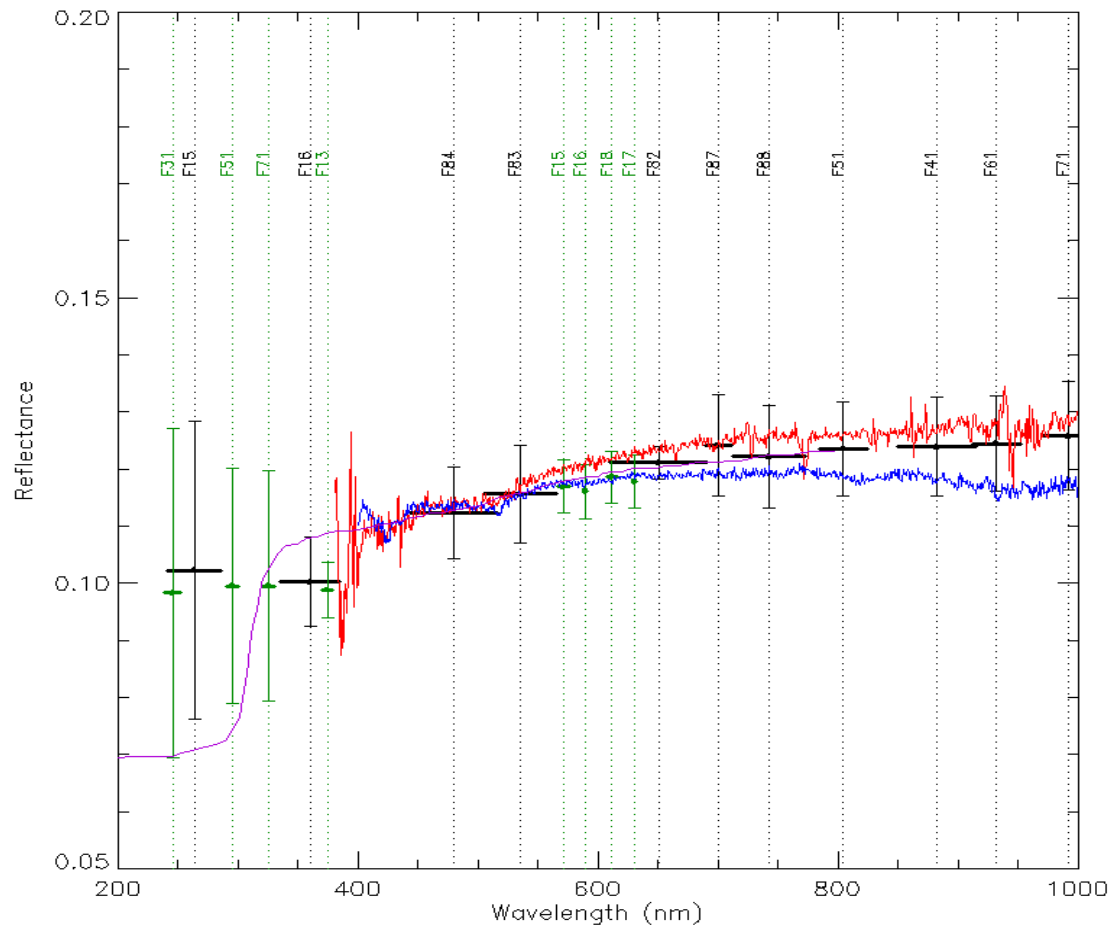
Lazzarin et al., 2010



Comparison of groundbased reflectance with Osiris data

Magrin et al. 2012

OSIRIS observed Lutetia at different phase angles, ranging from 0◦ to 140◦, values impossible to reach from the Earth (from where Lutetia phase angle is always less than about 30◦). Obtained low resolution spectra at different phase angles during the spacecraft fly-by (**resolved surface reflectivity** with multiband spectrophotometry of Lutetia in different filters).



Compared the bluest and the reddest ground based spectra with the Osiris ones.
Good match inside error bars longward 400 nm and the spectral behavior seems more compatible with the reddest groundbased spectrum.
Suggested **a composition intermediate between X (more metallic) and C-type (more carbonaceous)**.

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--Una Tesi di Dottorato

--Un assegno di ricerca dell'Universita' di Padova

Some proposal for the future
1. **Observation of NEOs**

About 12550 **NEO** are known and the number increases with a rate of 700 new asteroids per year.
Only 5% has been characterized

OBJECTIVE: Enlarge the dataset to better know these asteroids in order to set up a strategy for mitigation. Possible reservoir of minerales are also foreseen (see the NASA ARRM mission).

OBSERVING constraints: VIS-NIR spectroscopy (**DOLORES and NICS**)

OUTCOME: We estimate that about **80 objects** per semester could be characterised with this program in the vis-nir, assuming a 8-hour night long and about 14 nights.

Some proposal for the future
2. **Observation of CENTAURS**

Objects located in the transition region between the inner Solar System and the Kuiper belt, not well characterised.

OBJECTIVE: Spectral properties are important to investigate the chemisty and dynamics of our Solar System. Possible comparison with comets and other objects in the Kuiper belt may help in built a more complete picture of our Solar System.

OBSERVING constraints: VIS-NIR spectroscopy (DOLORES and NICS)

OUTCOME: We estimate that about 50 objects per semester could be characterised with this program in the vis-nir, assuming a 8-hour night long and about 10-12 nights

Some proposal for the future
3. **Observation of main-belt comets**

New objects, identified very recently. They are target of the ESA M5 Castalia mission.

OBJECTIVE: Characterization of these comets to better define and constraint the observing strategy of future space missions.

OBSERVING constraints: VIS-NIR spectroscopy (DOLORES and NICS)

Not a large program but ToO.

Some proposal for the future
4. **Observation of C-type**

The Dawn mission identified organics on Ceres' surface. This material might be present also on other asteroids, classified as C-types.

OBJECTIVE: investigate the properties of C-type asteroids in the Near infrared, to identify possible organics signatures.

OBSERVING constraints: NIR spectroscopy with **NICS**.

OUTCOME: We estimate that about **50 objects** per semester could be characterised with this program in the vis-nir, assuming a 8-hour night long and about 8-10 nights. The number might change, according to the brightness (and dimensions) of the targets.

Some proposal for the future
5. **Observation of V-type asteroids**

More than 5000 asteroids are suggested as V-type on the basis of the photometric colors. Vesta family and non-family are included.

OBJECTIVE: Enlarge the dataset to better understand if the non-family asteroids located in the outer main belt region are really V-type, and understand their origin.

OBSERVING constraints: VIS-NIR spectroscopy (**DOLORES and NICS**)

OUTCOME: We estimate that about **70 objects** per semester could be characterised with this program in the vis-nir, assuming a 8-hour night long and 12-14 nights.

POSSIBLE COLLABORATION WITH US COLLEAGUES

Some proposal for the future
6. **Observation of Gaia targets**

Gaia is supposed to observe thousands of asteroids, with potential new detections and possibily new ones.

OBJECTIVE: Follow-up of the asteroids identified with Gaia, once the preliminary orbits will be available. Sudden observations are required, especially for newly discovered NEOs.

OBSERVING constraints: VIS-NIR spectroscopy (**DOLORES and NICS**)

OUTCOME: We estimate that about **70 objects** per semester could be characterised with this program in the vis-nir, assuming a 8-hour night long and 12-14 nights. The number might change, according to the brightness (and dimensions) of the targets.