Spectrophotometry of small bodies of the Solar System and comparison with meteorites

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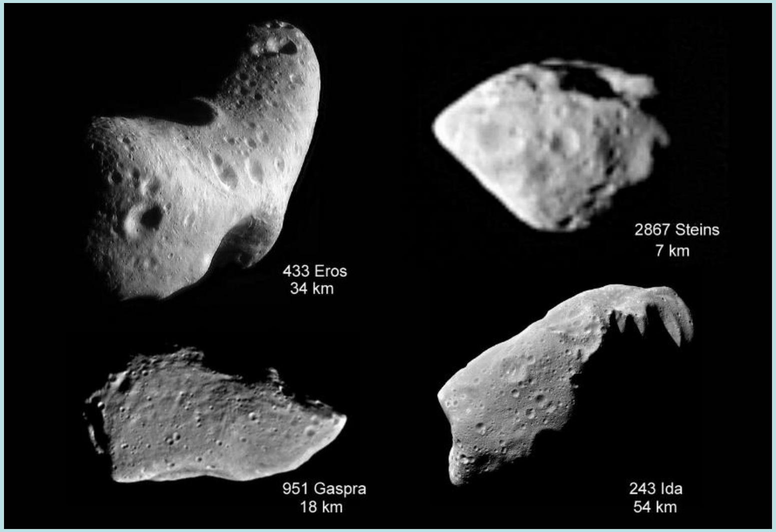
PRISMA DAY 16 May 2017

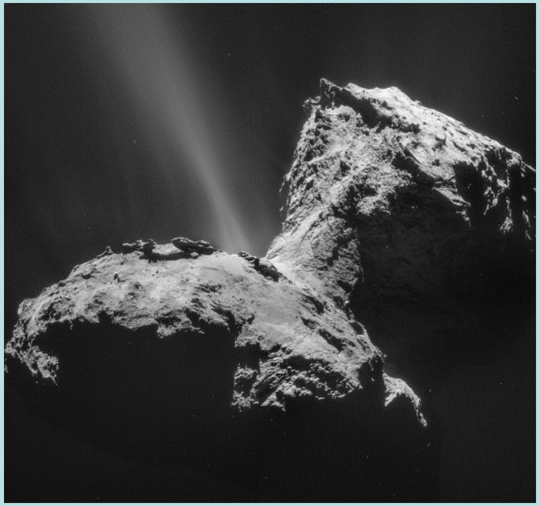
Which are the minor bodies?

ASTEROIDS



METEORITES

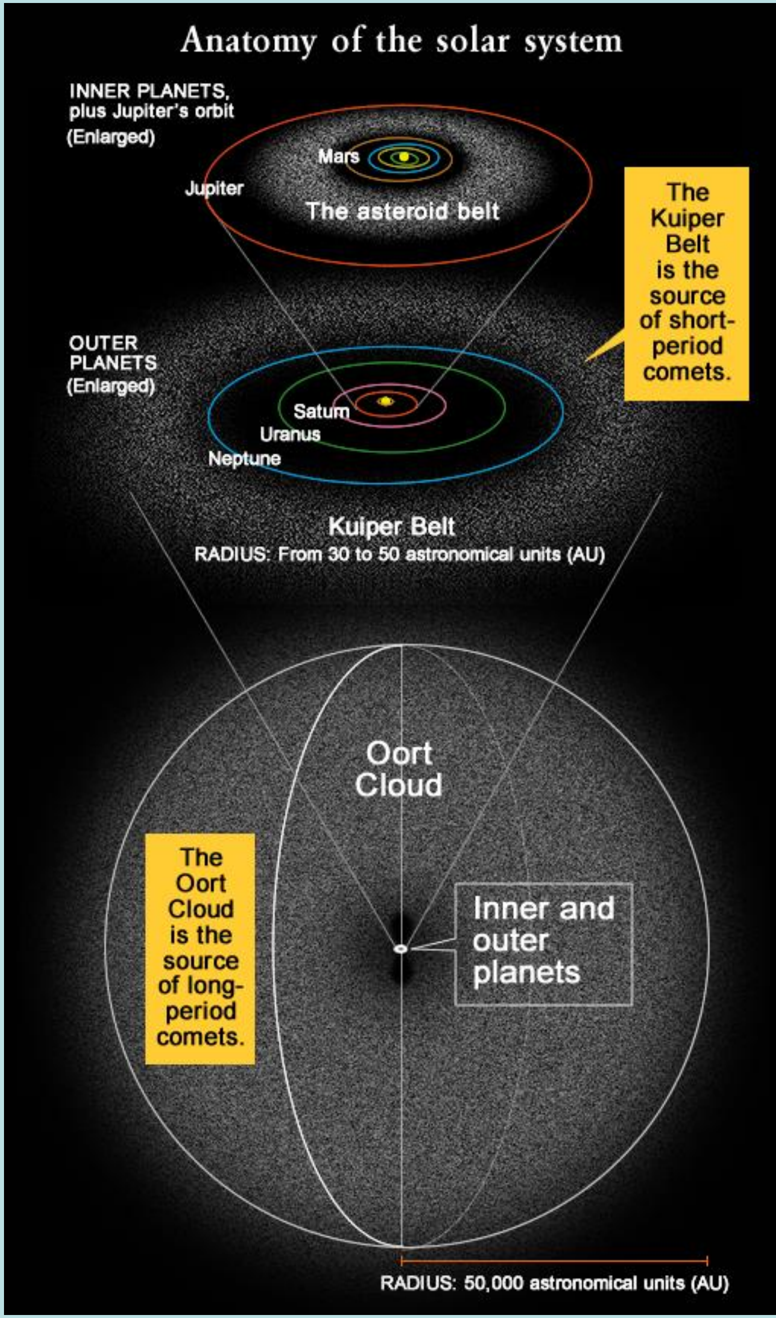
COMETS



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,…)

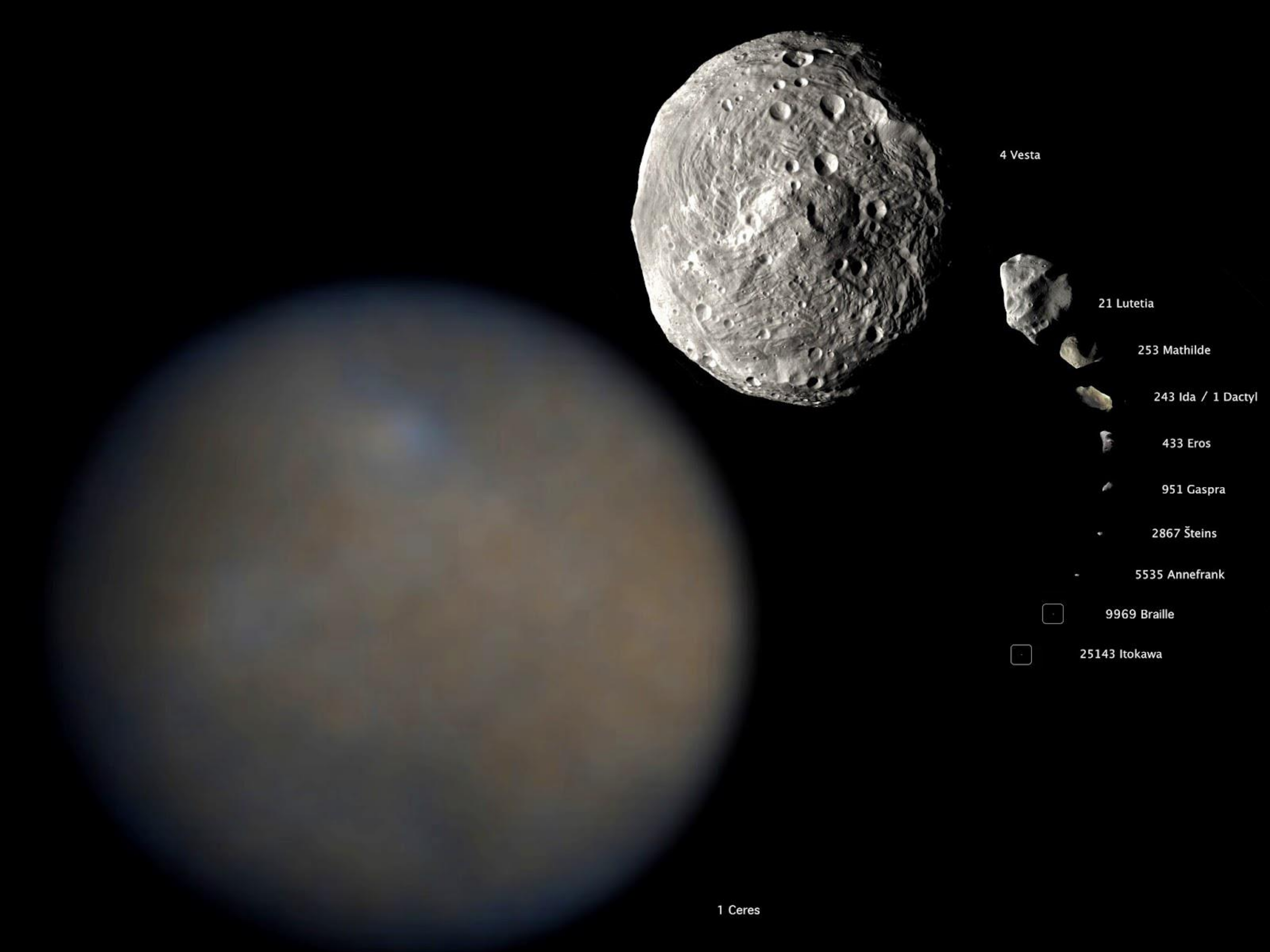


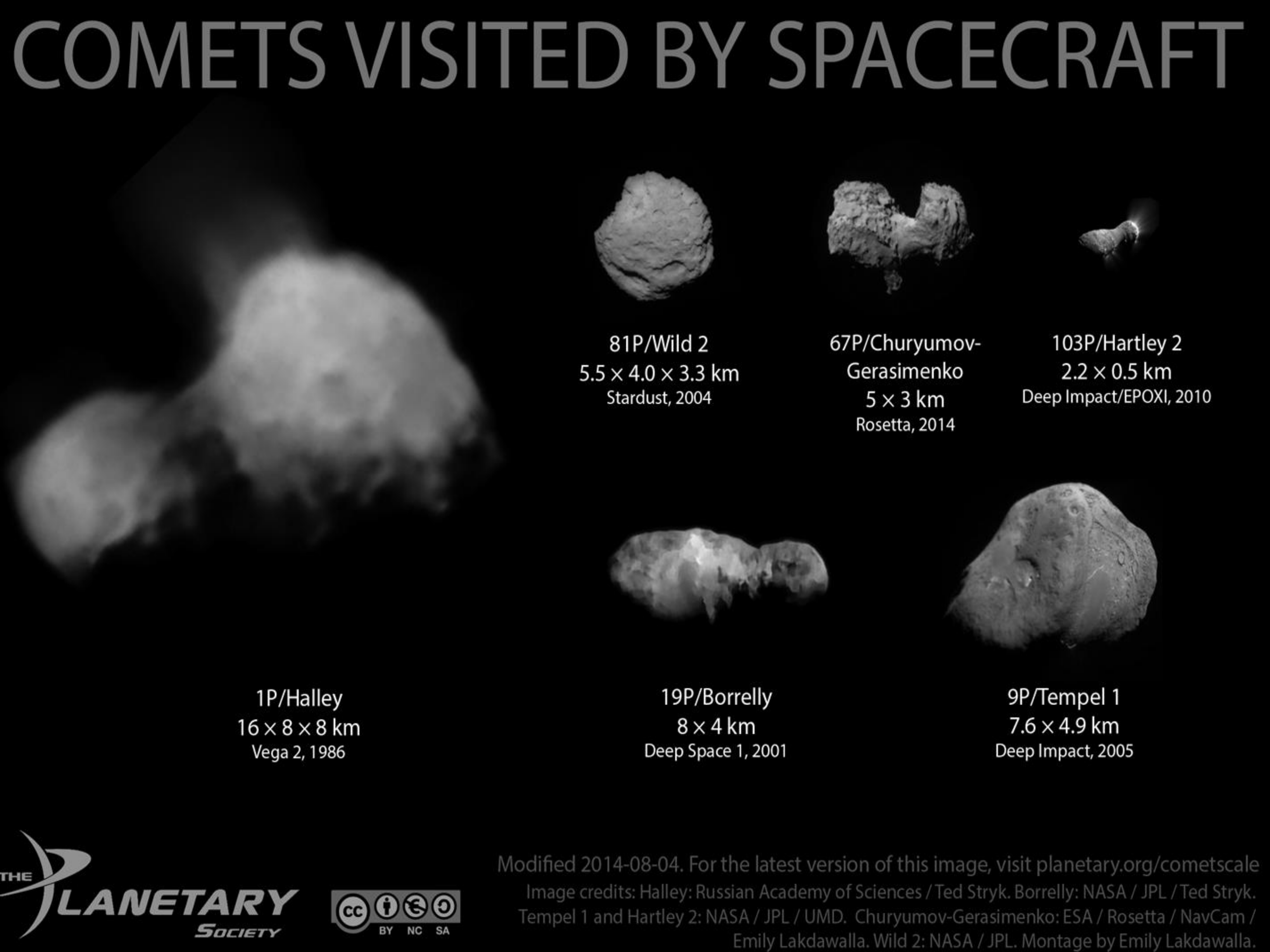
Why are minor bodies so important

- 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 and dynamical evolution. In particular comets store the primordial material, partly frozen, present in the solar nebula

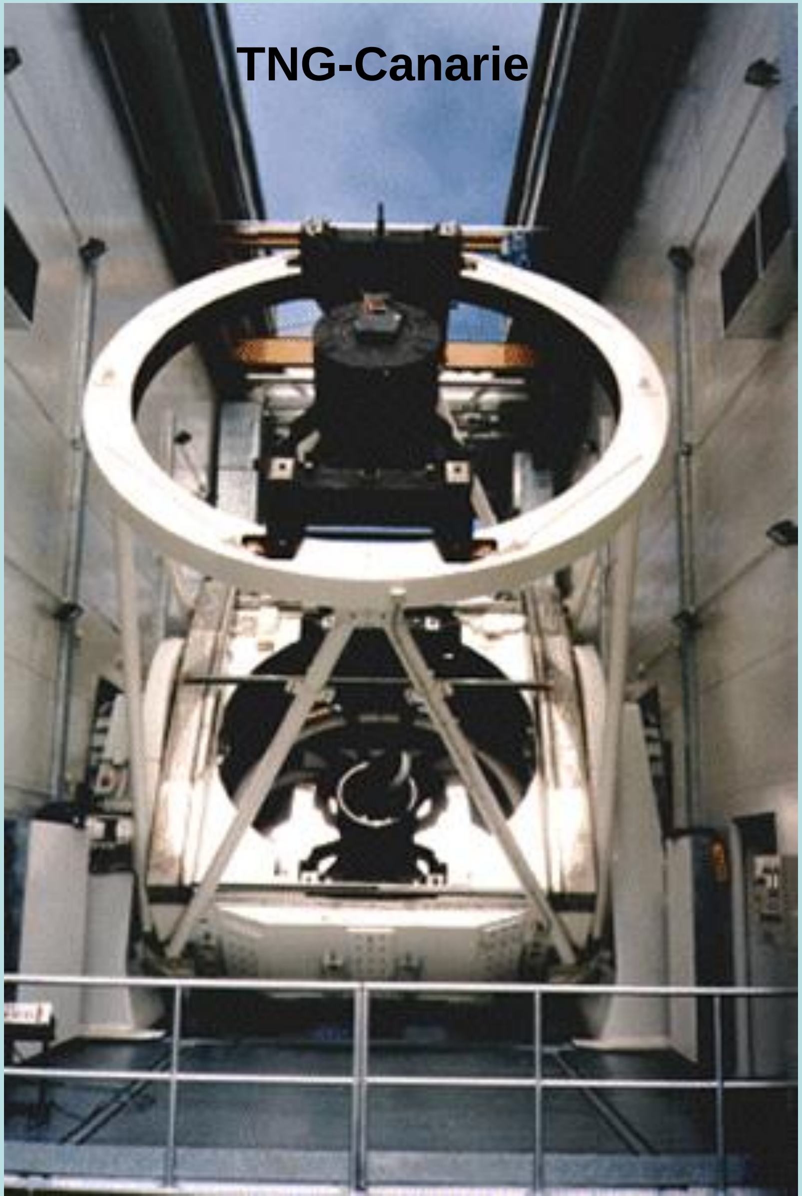
- **They are the principal sources of the meteorites delivered on Earth**

- 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 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
81P/Wild 2
5.5 × 4.0 × 3.3 km
Stardust, 2004
67P/Churyumov-Gerasimenko
5 × 3 km
Rosetta, 2014
103P/Hartley 2
2.2 × 0.5 km
Deep Impact/EPOXI, 2010
1P/Halley
16 × 8 × 8 km
Vega 2, 1986
19P/Borrelly
8 × 4 km
Deep Space 1, 2001
9P/Tempel 1
7.6 × 4.9 km
Deep Impact, 2005
THE PLANETARY SOCIETY
BY NC SA
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.

Groundbased investigation of asteroids



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

Spectroscopy of asteroids: surface compositional investigation

Mauna Kea-Hawaii Observatory

Lo studio della composizione è fondamentale per conoscere l’origine e l’evoluzione di questi oggetti e quindi per investigare i processi evolutivi del Sistema Solare

ESO-La Silla-Cile

Agiago 1.80m

Confronto con meteoriti: importante stabilire i legami fra meteoriti e asteroidi per capire l’origine delle meteoriti e ottenere info su composizione, storia termica e dinamica dei possibili corpi parenti. Alcuni legami ormai riconosciuti tra meteoriti e classi di asteroidi (condriti carbonacee CC e asteroidi C, condriti ordinarie e asteroidi S, HED e asteroidi V…)

TABLE I

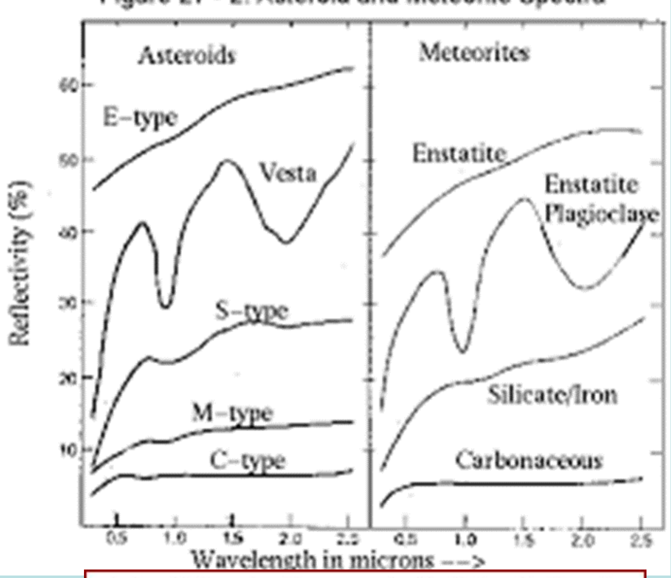
Inner Belt Asteroids

Type	Interpreted Surface Mineralogy	Meteorite Analogs
V	Pyroxene, feldspar	HED association
A	Olivine or olivine-metal	Brachinites
S	Metal, olivine, pyroxene	Pallasites, mesosiderites CV/CO chondritex (K-type), ordinary chondrites
M	Metal, trace silicates (enstatite?)	Irons (enstatite chondrites?)
R	Pyroxene, olivine	none
B,C, F,G	Hydrated silicates, carbon, organics, opaques, shock-darkened silicates?	CI, CM chondrites, black/gas-rich ordinary chondrites?
Q	Olivine, pyroxene, metal	Ordinary chondrites
E	Enstatite	Enstatite achondrites
T	Organic-rich silicates, carbon	none

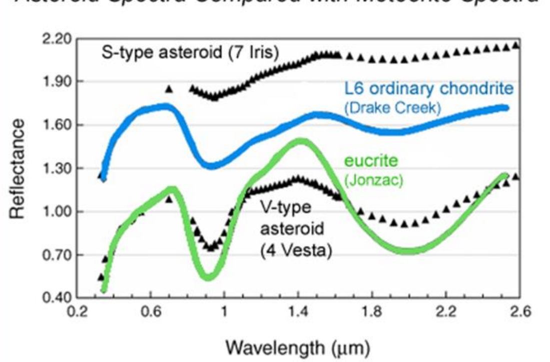
Outer Belt Asteroids

Type	Interpreted Surface Mineralogy	Meteorite Analogs
D	Organic-rich silicates, carbon	none
P	Organic-rich silicates, carbon	none

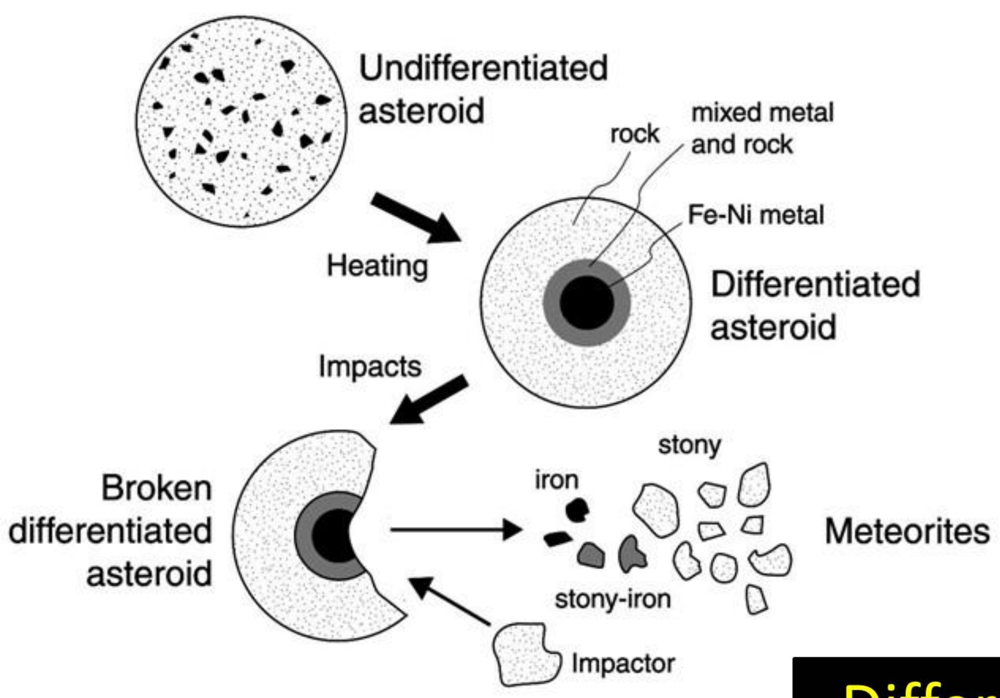
Figure 27 - 2: Asteroid and Meteorite Spectra



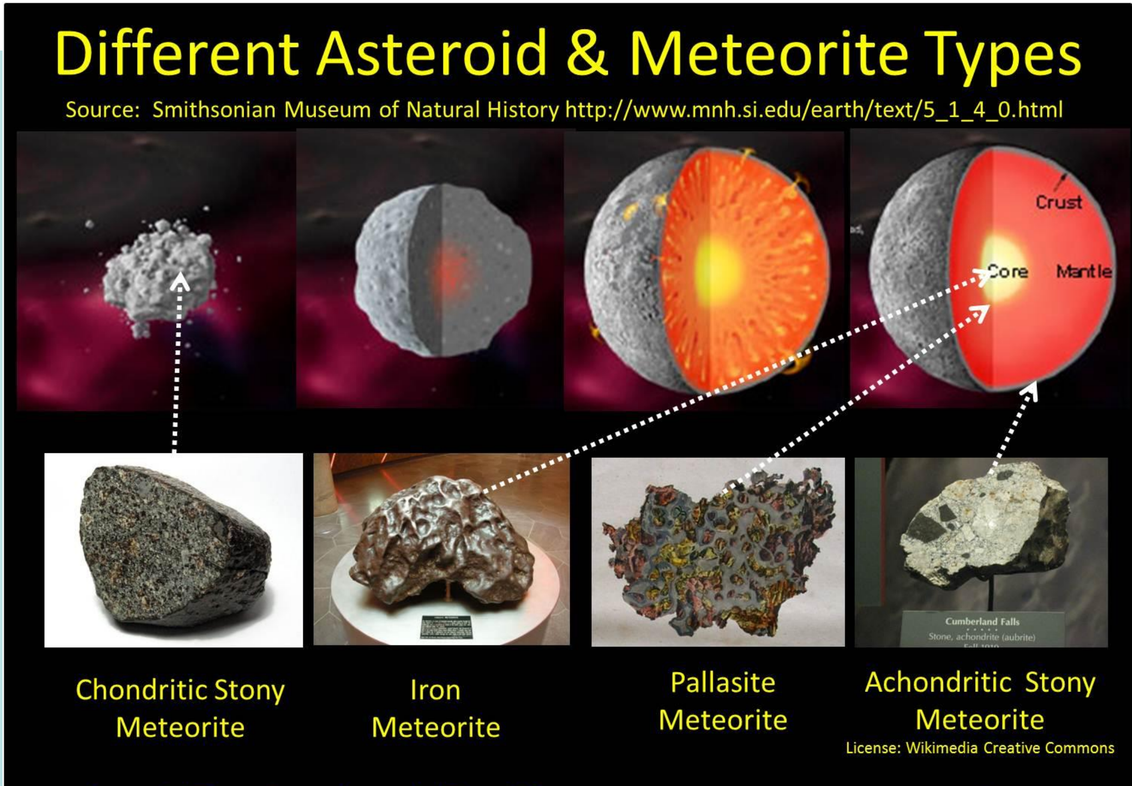
Asteroid Spectra Compared with Meteorite Spectra

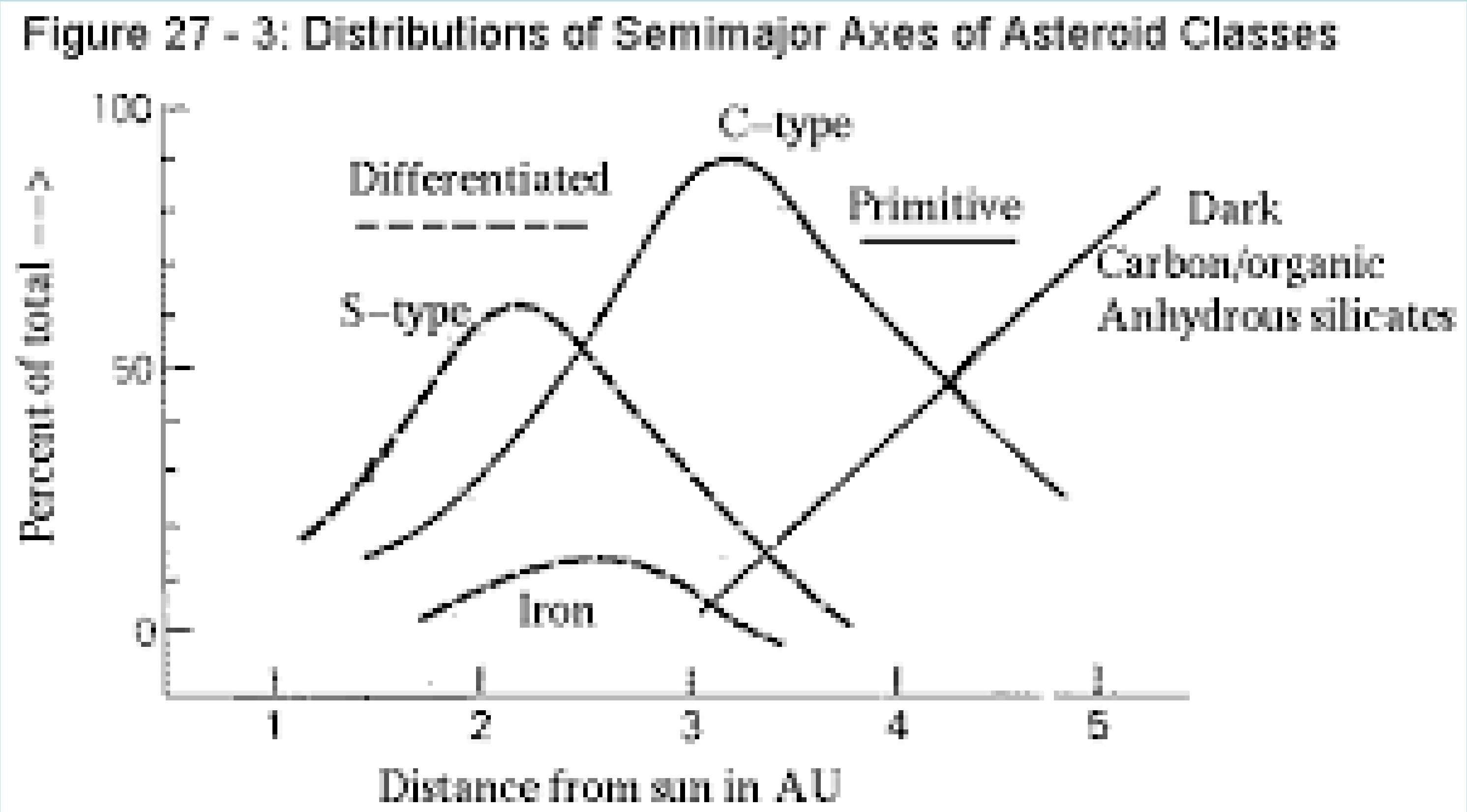


(From Clark *et al.*, (2002) Asteroid Space Weathering and Regolith Evolution, in *Asteroids III*, p.585-599.)



Diverse meteoriti corrispondono quindi a diverse zone dell’asteroide (nucleo, mantello o superficie) nel caso di asteroidi differenziati o all’asteroide stesso se indifferenziato





I **tipi S** rappresentano il 17% circa, elevata albedo, 10-22% e **simili alle CO**
I **C type** rappresentano piu' del 75% degli asteroidi conosciuti. Hanno albedo moto bassa circa 0.01-0.03 e **simili alle CC**
I **tipi M** rappresentano quasi tutti i rimanenti: albedo elevata 10-18%, di ferro-nichel puri (metalli). **Non chiaro analogo meteoritico**
Nella parte piu' esterna ci sono i **D,** con silicati anidri e organici, albedo bassa, i piu' primitivi. **Non chiaro analogo meteoritico**.

Oggetti primitivi (tipo D)

Attorno a **2.7 UA** avviene un passaggio da oggetti ricchi in silicati a oggetti ricchi in materiale organico sempre piu’ simili ai nuclei cometari.

L’indagine spettroscopica di asteroidi di tipo primitivo D ha contribuito a confermare che **gli asteroidi della fascia piu’ esterna abbiano mantenuto parte della composizione originaria** e mostrano caratteristiche spettrali e mineralogiche molto simili a quelle dei nuclei cometari (composti del carbonio, ghiaccio, silicati anidri). **Difficile il confronto di questi oggetti con meteoriti, no chiaro analogo (Tagish Lake?)**

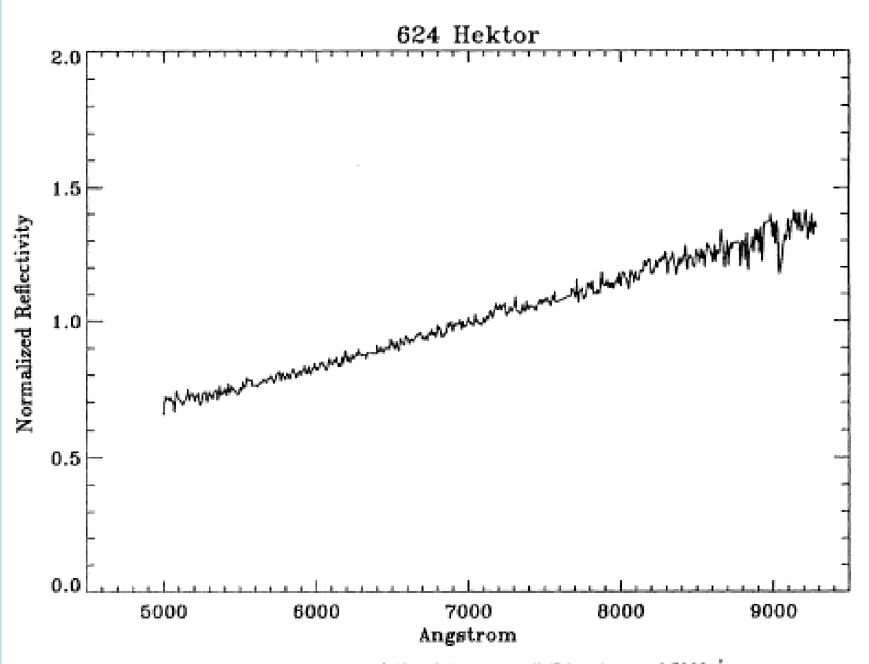
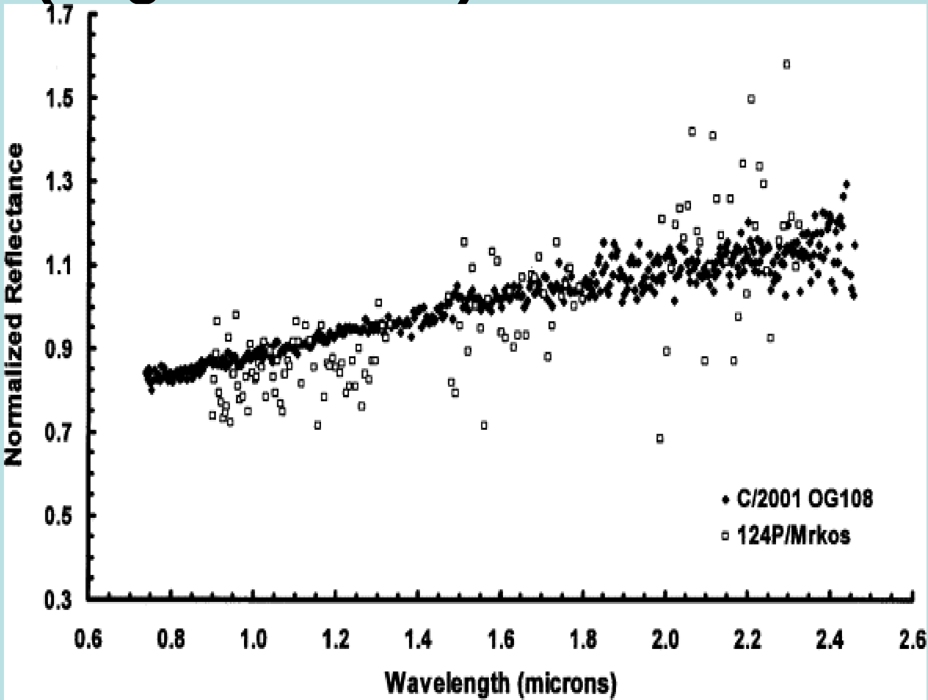


FIG. 15. Reflectivity spectrum of 624 Hektor normalizEd at 1 around 7000 Å.



La meteorite Tagis Lake sembrerebbe l’analogo piu’ probabile degli asteroidi primitivi, in particolare di 773 Irmintraud (D-type) da cui si ritiene potrebbe provenire

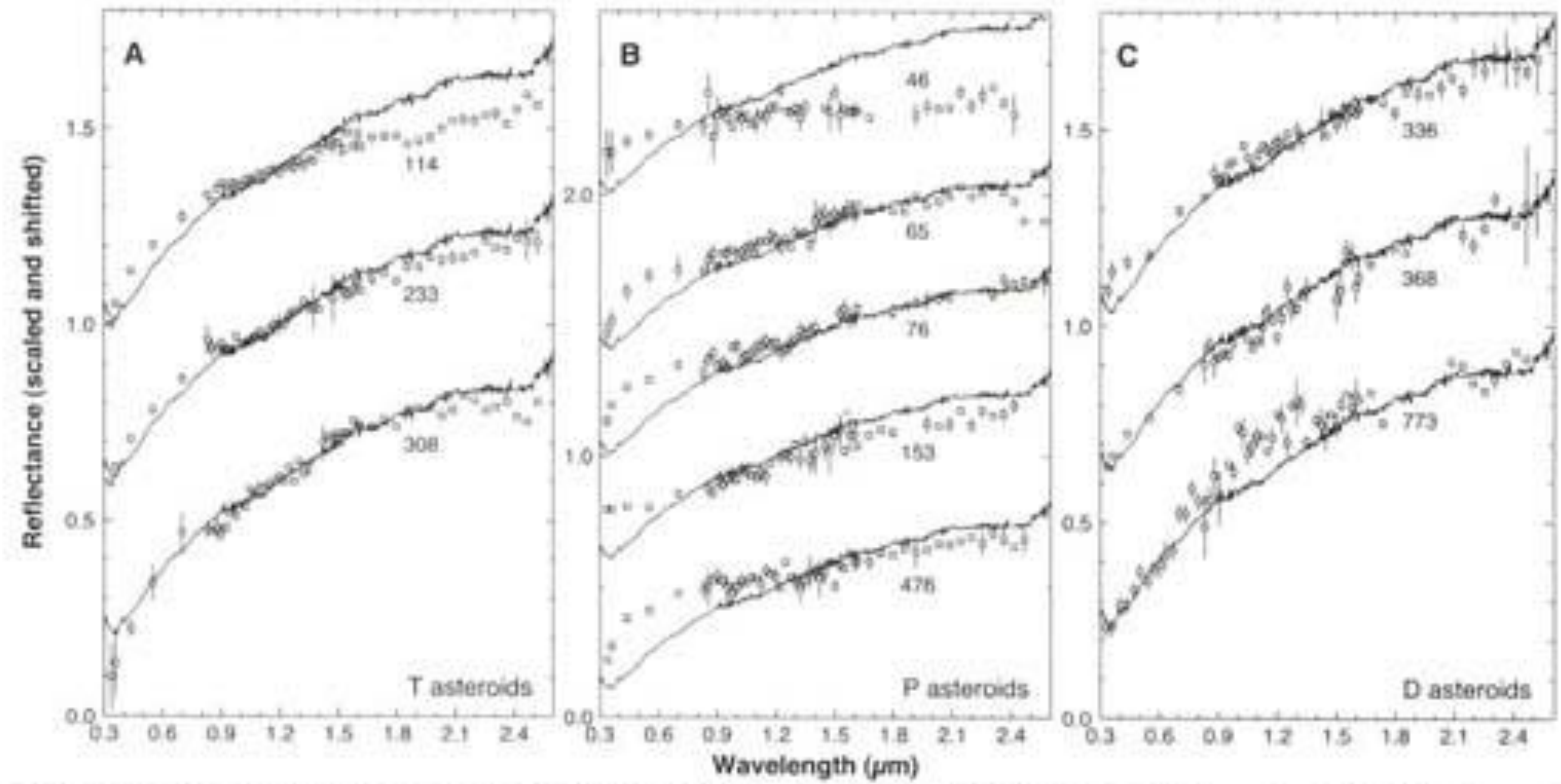
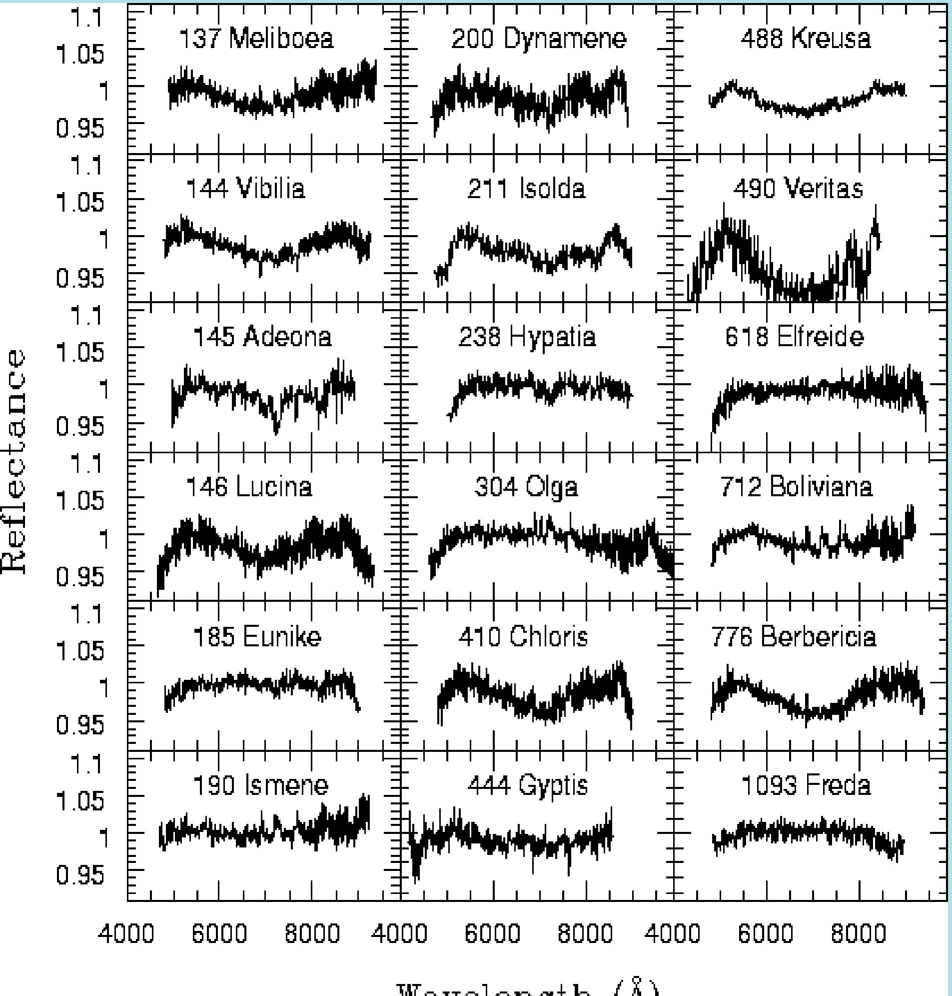


Fig. 1. (**A** to **C**) Comparison of reflectance spectra (5) of the Tagish Lake meteorite with individual reflectance spectra of the T-, P-, and D-type asteroids (6, 7). Each of the reflectance spectra of the asteroids (open squares) and that of the Tagish Lake meteorite (solid line) are scaled for the best fit with each other for spectral shape comparison. The asteroid-meteorite spectra are then offset from one another for clarity.

Hiroi et al. 2001, Science

Alterazione acquosa

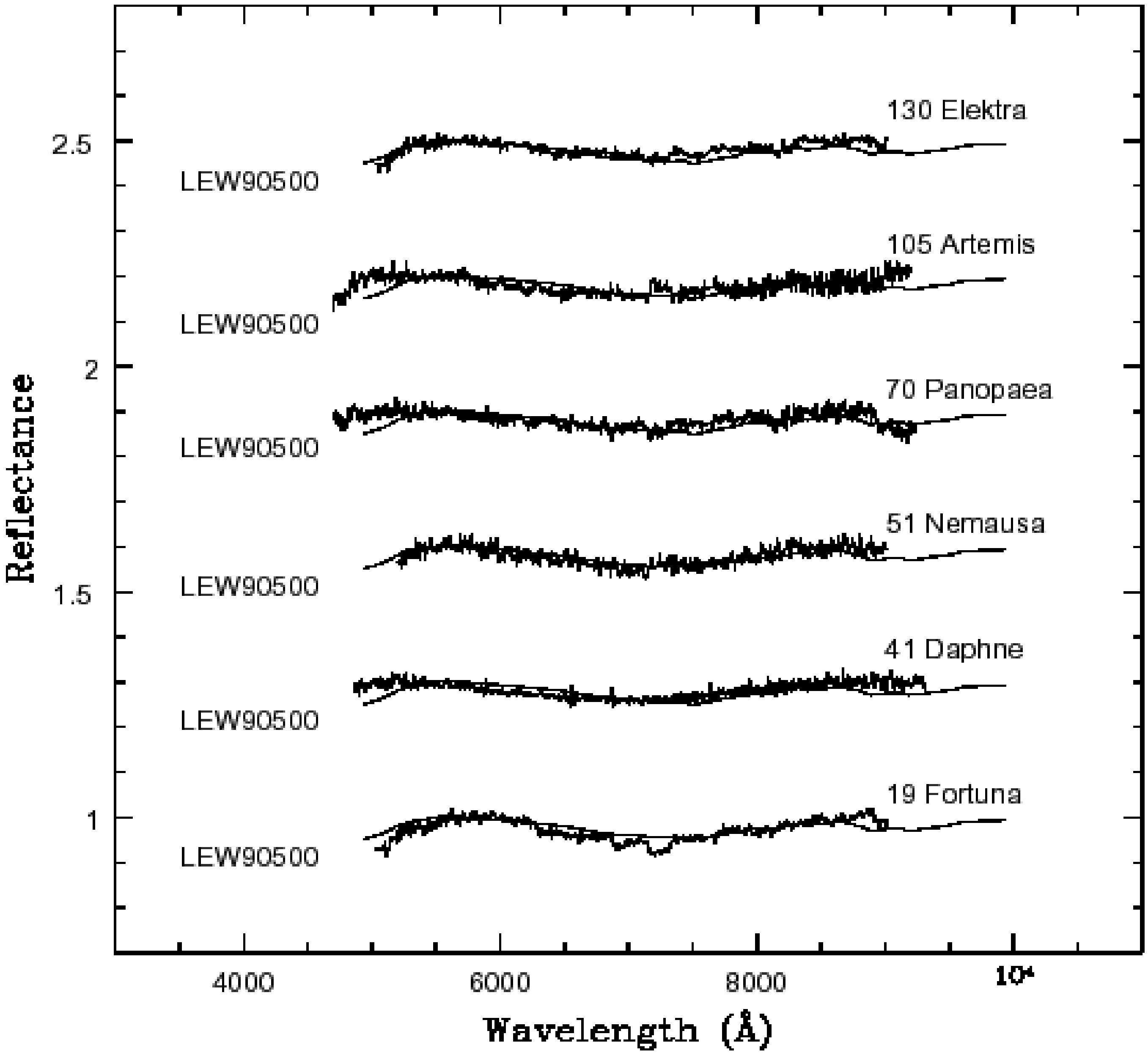
La regione tra circa 2.6 e 3.5 AU sembra dominata da oggetti che hanno subito processi di alterazione acquosa (alterazione chimica a bassa temperature di materiali da parte di acqua liquida che agisce come un solvente e produce fillosilicati, solfati, ossidi,carbonati e idrossidi). Lo studio di questi processi aiuta a ricostruire i diversi stadi evolutivi della storia chimica e termica della MB e del SS.



Survey di circa 110 oggetti di tipo tassonomico C, composizione intermedia tra primitivi (D) e processati (S) tra 2.5 e 3.2 UA. Circa 60% degli oggetti investigati contiene questi materiali (banda di assorbimento centrata a 0.7 micron) confermando evento termico durante le prime fasi di formazione del SS.

Lazzarin et al., 1999 e 2014

Confronto C alterati con meteoriti



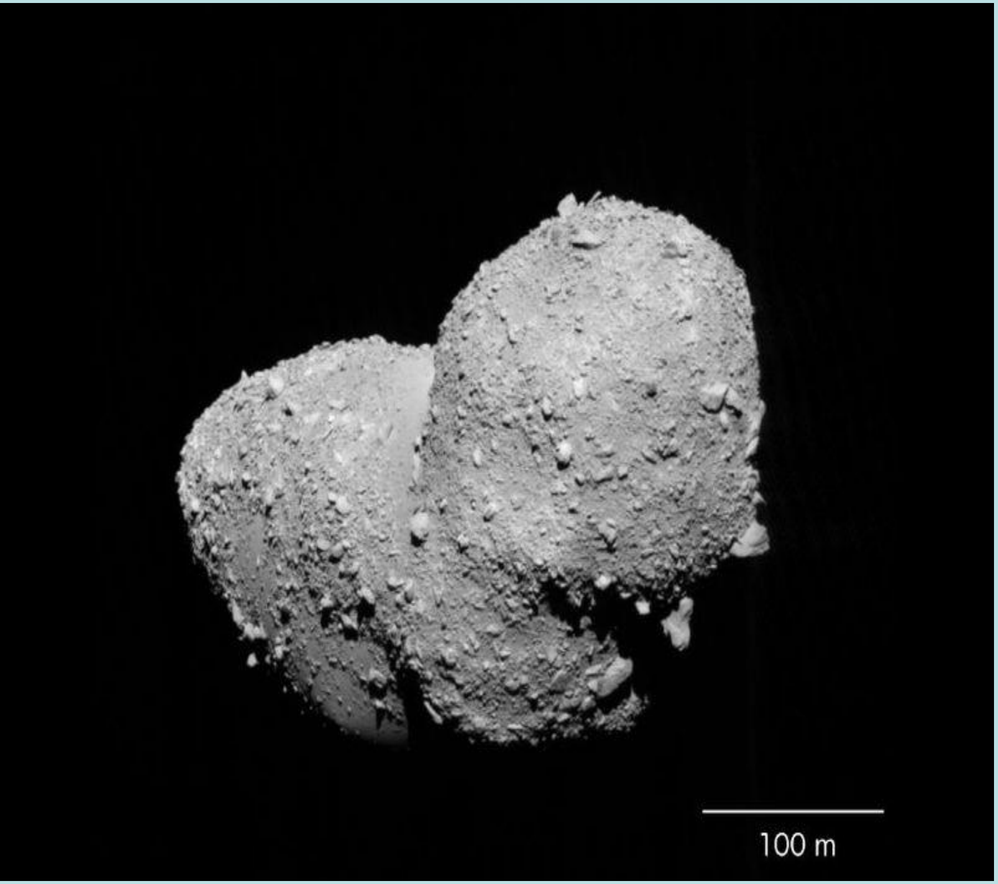
Il confronto con varie (100) CM da' la condrite carbonacea LEW90500 come migliore analogo.

In generale gli asteroidi di tipo C con alterazione acquosa sembrano i parenti piu' plausibili delle CM2 anche se alcune differenze esistono ad esempio nella posizione del centro della banda a 0.7 micron: diverse abbondanze di minerali? Effetto dovuto alle dimensioni dei grani? Oppure le CM2 collezionate a Terra non sono rappresentative dell'intera popolazione degli asteroidi con alterazione acquosa?

SINEO:

Spectroscopic Investigation of Near Earth Objects

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



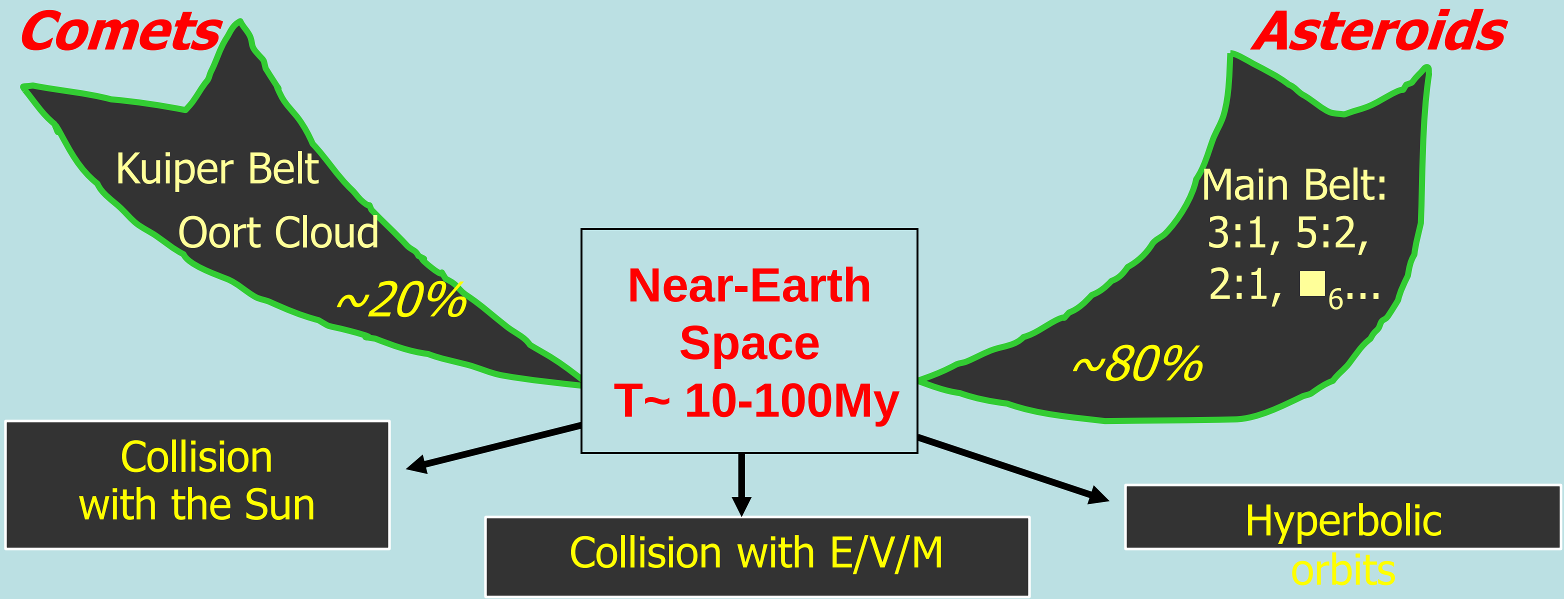
Objects orbiting near to the Earth, inside its orbit or crossing it

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

Motivations for NEO investigation:

Where do NEOs originate?



Why NEO spectroscopy?

Surface composition and mineralogy

relationships with comets, MBOs
and meteorites

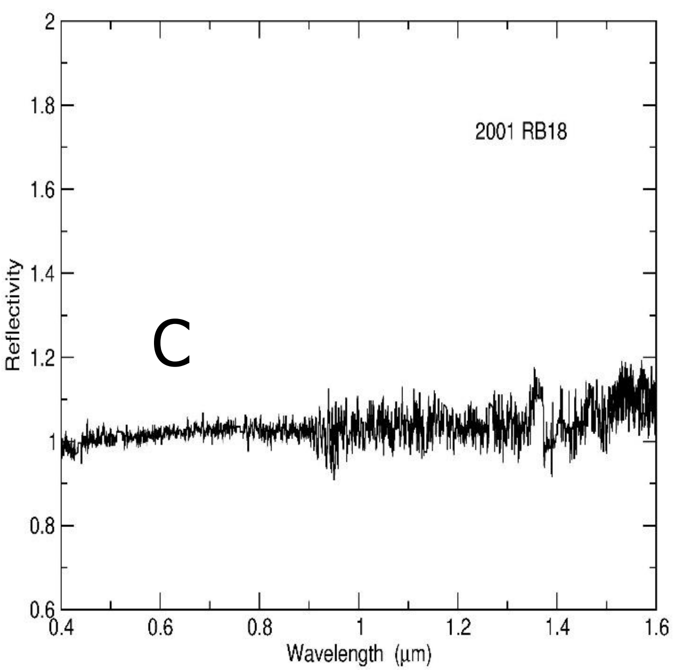
- NEOs origin
- Solar System formation
- Solar System dynamic
- Solar System evolution
- **Origin of meteorites**

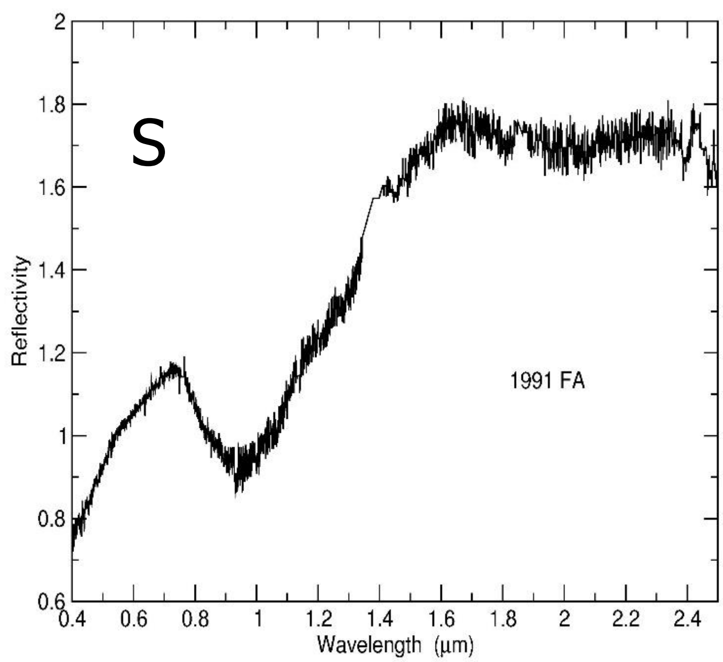
SINEO: **one of the largest spectroscopic data base** with about 180 low resolution spectra of NEOs.

Spectral range: visible and Near Infrared region (0.4-2.5 micron).

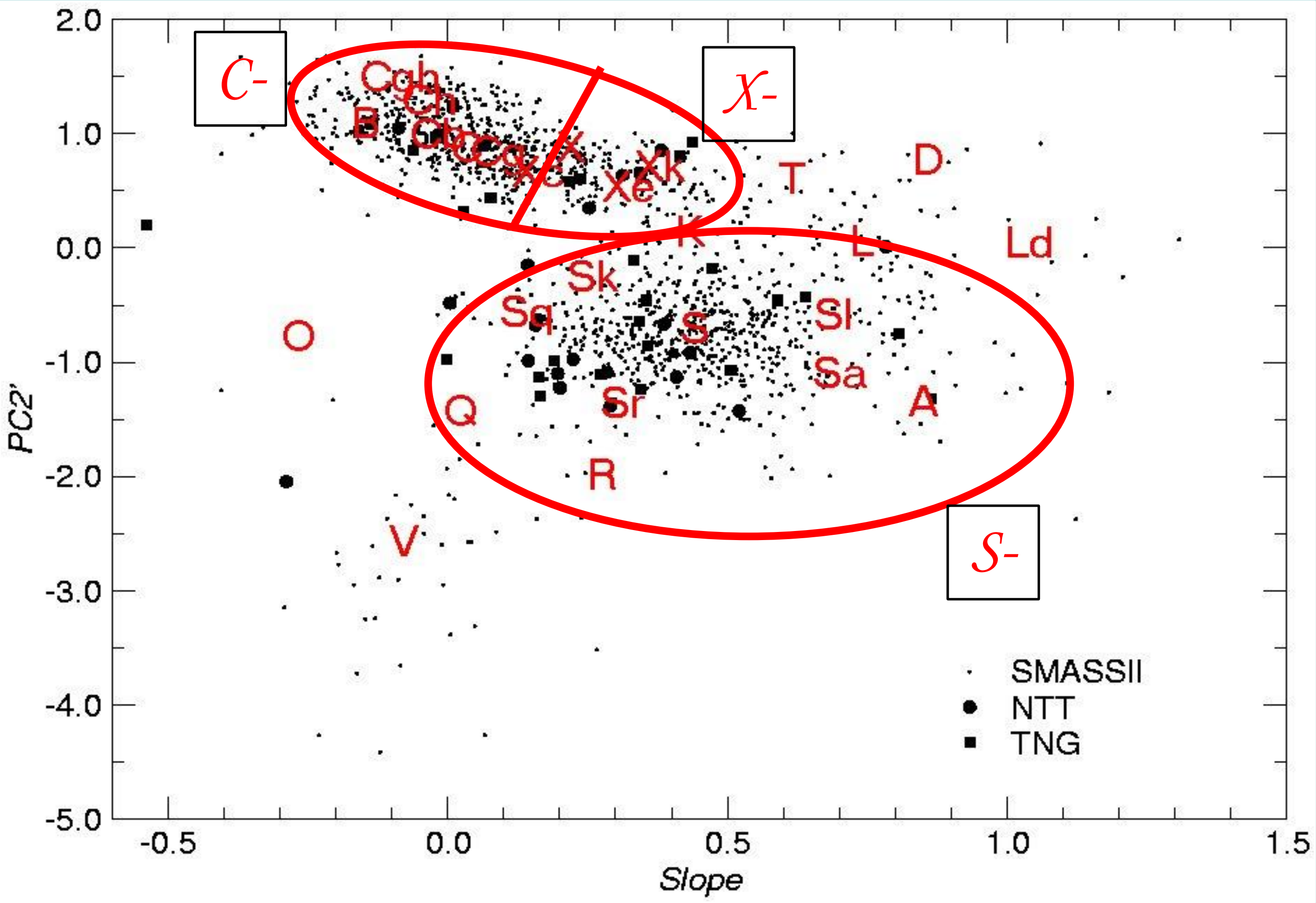
T**elescopes**:ESO-NTT (EMMI and SOFI), TNG (Dolores and Nics)

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.

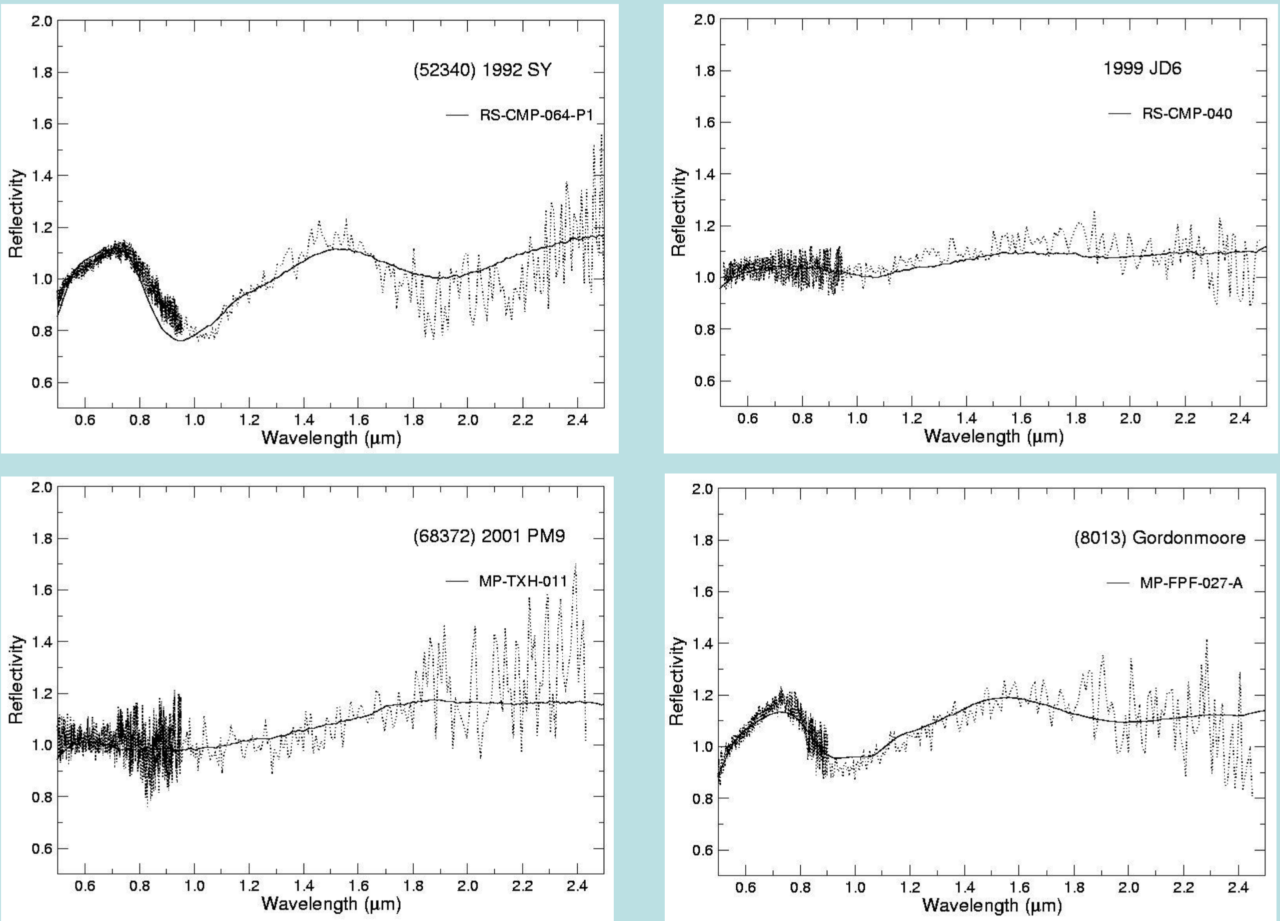


PCA:performed using SMASS II data (Binzel 2002). Our data distribute in the same clusters defined by SMASS II data.

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

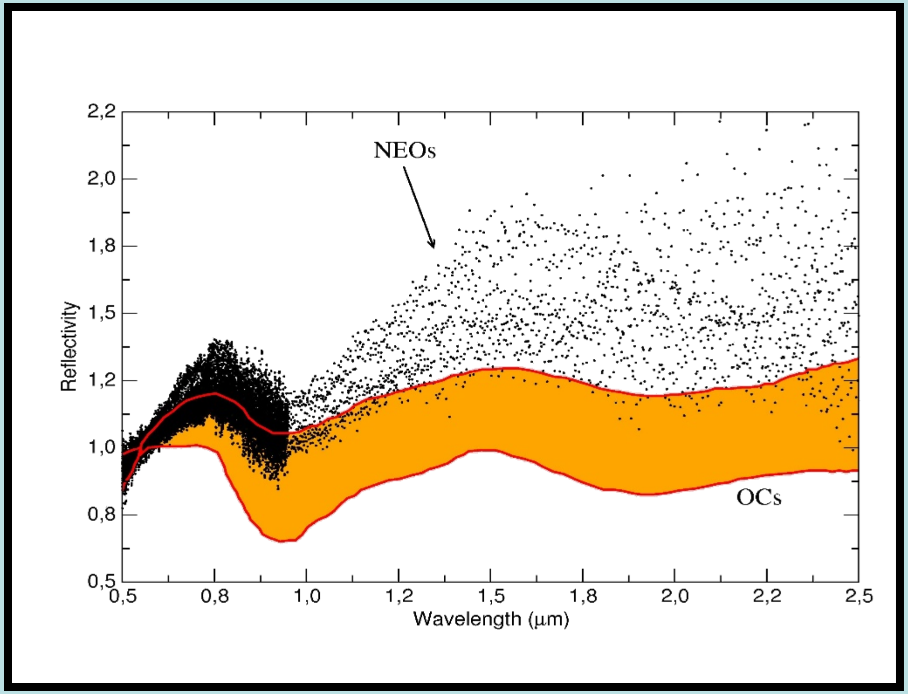
- 40% of investigated NEOs has a meteoritic analogue;
- all C-types have a Carbonaceous Chondrite analogue
- 25% of S-types have an Ordinary Chondrite analogue.

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

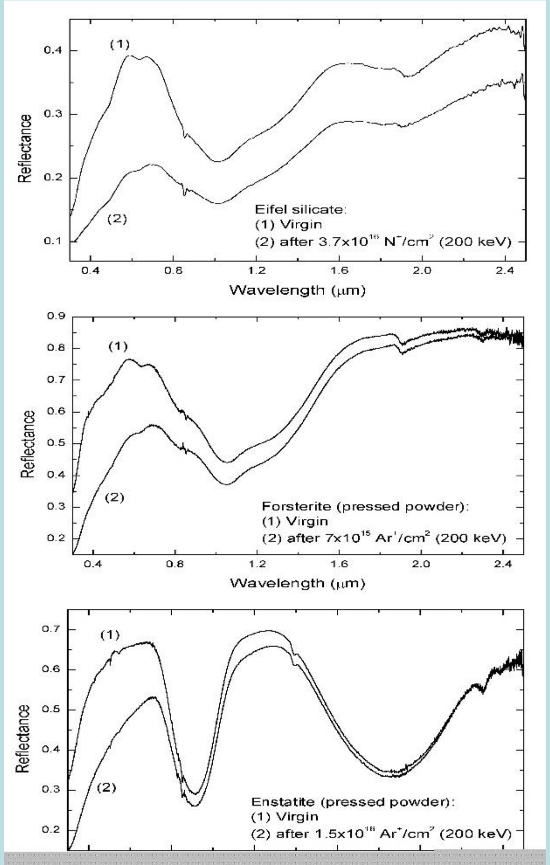


Most part of the investigated S-types NEOs does not fit with any meteorite: their spectra are typically redder

- **Study of space weathering**

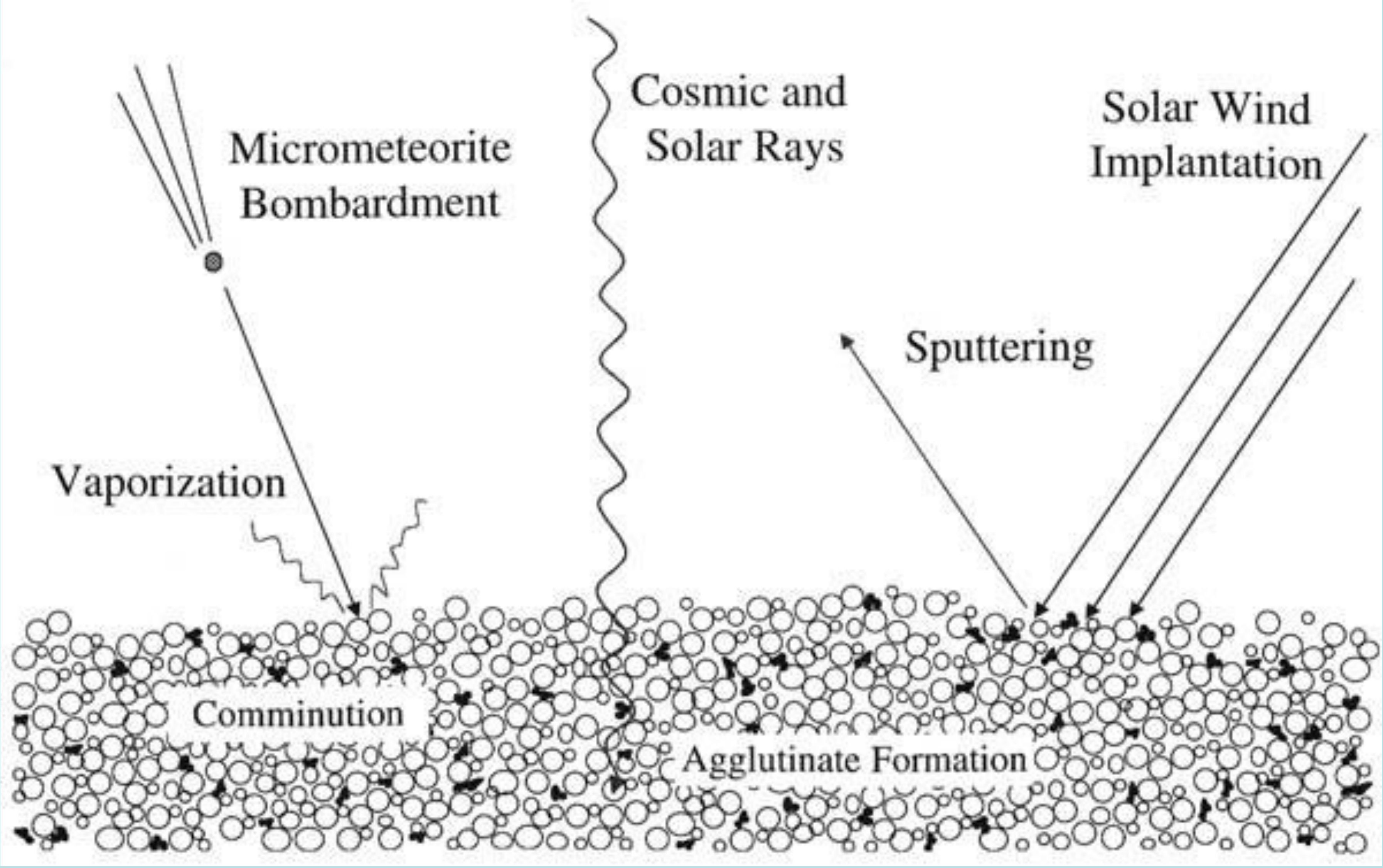


The S-type NEOs that do not match with any meteorite are typically redder than the reddest OC meteorites and we conclude that this is due to space weathering effects



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 (reddening of the spectra)

Space Weathering

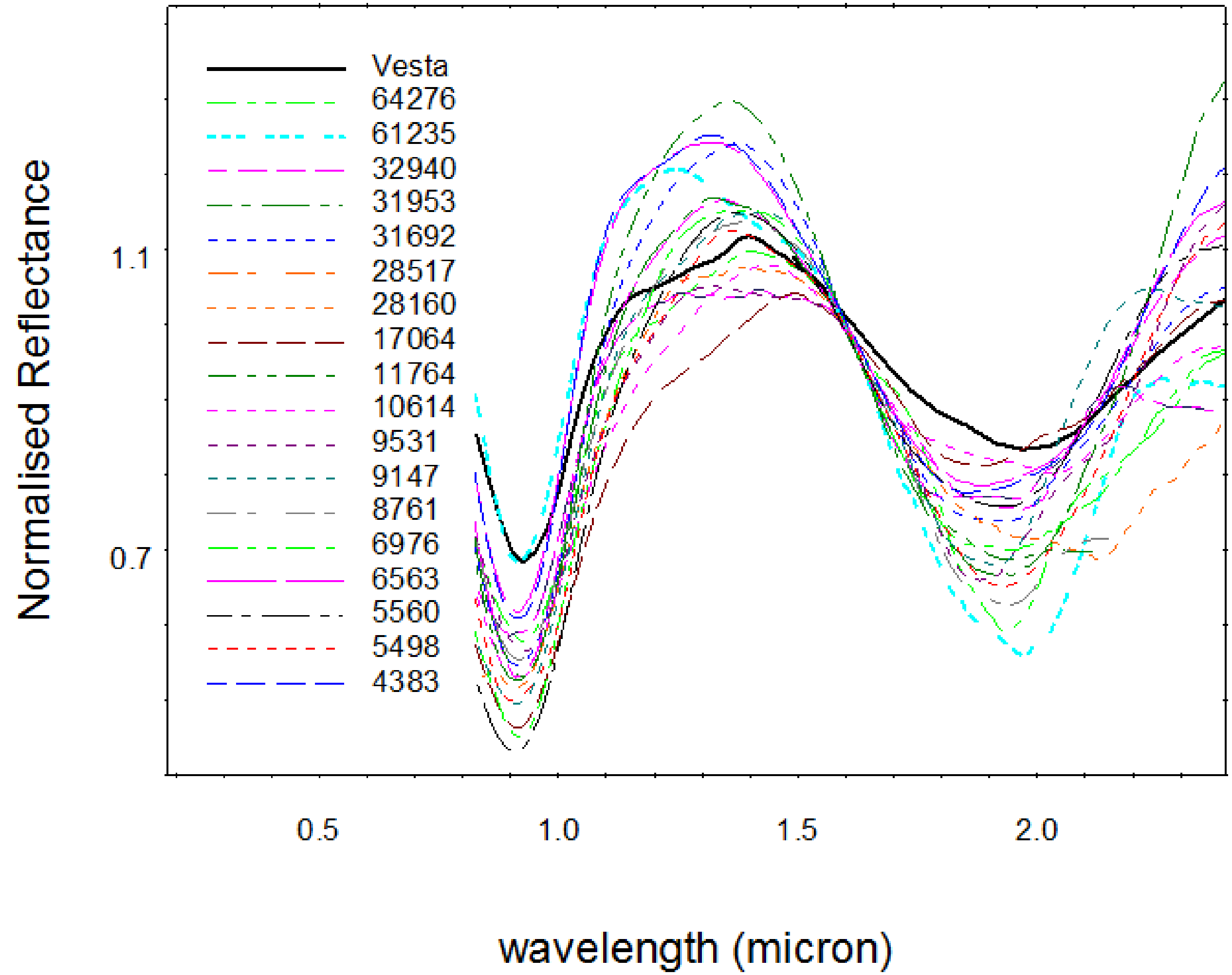


V-Type Asteroids

In collaborazione con M.C. De Sanctis e 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 and the comparison with meteorites can help understanding if there are V-type asteroids that show distinct mineralogy with respect to Vesta and its family members.

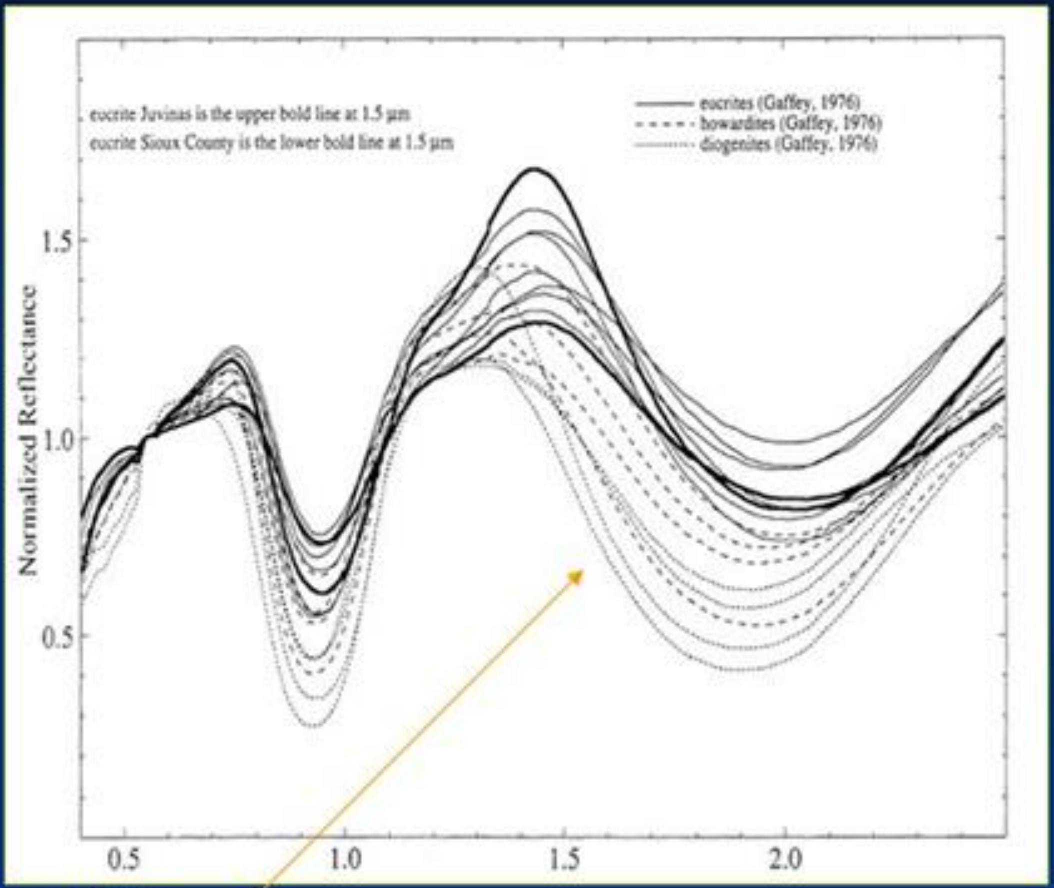
The spectroscopic observations with VIR on board the Nasa Dawn mission represent a unique opportunity to compare spectral properties of the Vesta surface (acquired with high spatial resolution) with ground-based observations of V-type asteorids.



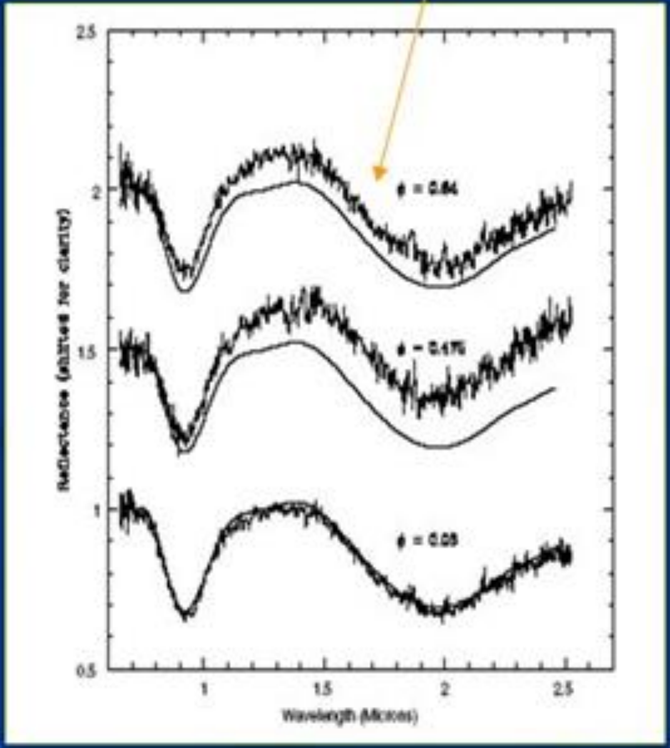
Four observational runs at TNG (Doloes + NICS) for a total of **59 asteroids**

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).

Meteoriti di tipo HED: mineralogia



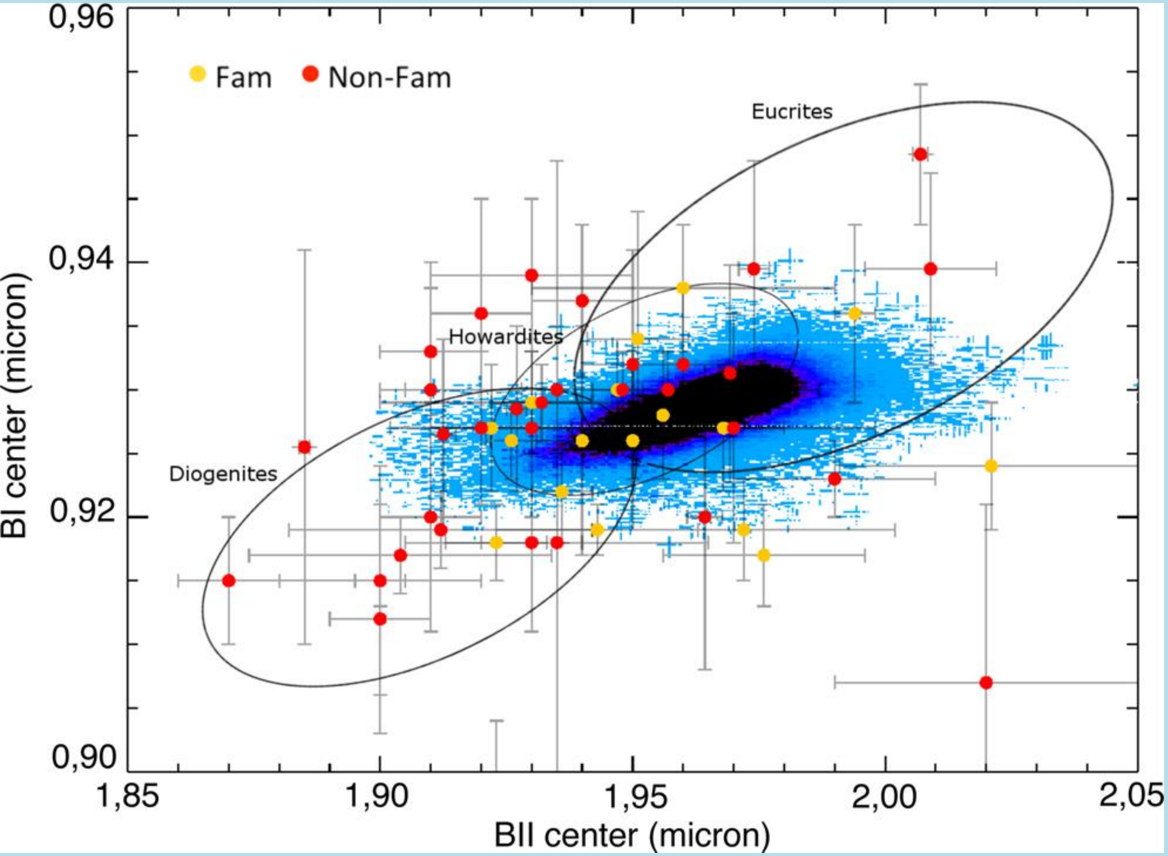
VESTA



HED

ASTEROIDE PROGENITORE DELLE METEORITI HEDS: VESTA

Comparison of family and non family V-type with Vesta surface mineralogy (data from VIR/Dawn) and HED meteorites



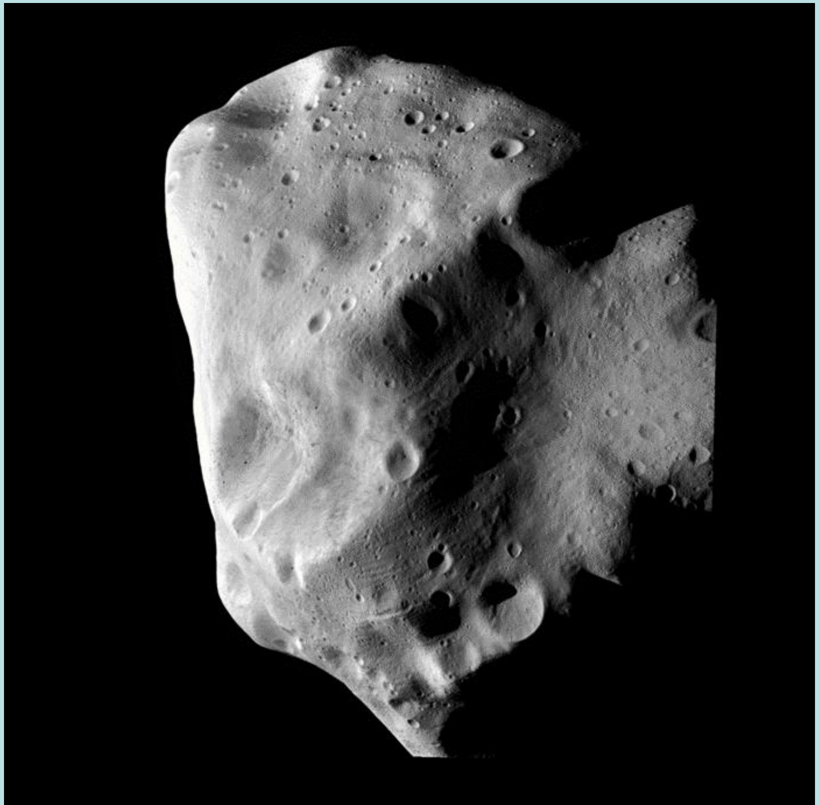
BandI center (0.9 micron) versus BandII (1.9 micron) center for the asteroids observed at TNG, compared to the same parameters derived for HEDs meteorites, possible analogues and for Vesta surface (Dawn). The position of the center depends on the composition, so it is typical of a mineral mixture. From 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.

HED come from different strata of Vesta (Eucrites e Howardites from the surface, 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

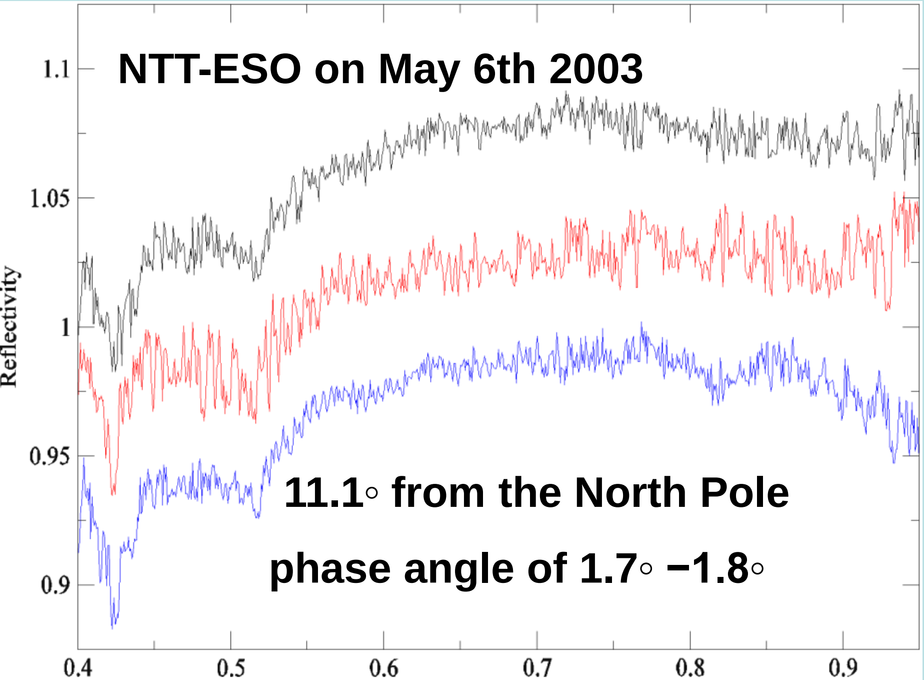
Observations of spatial mission targets: (21) Lutetia asteroid

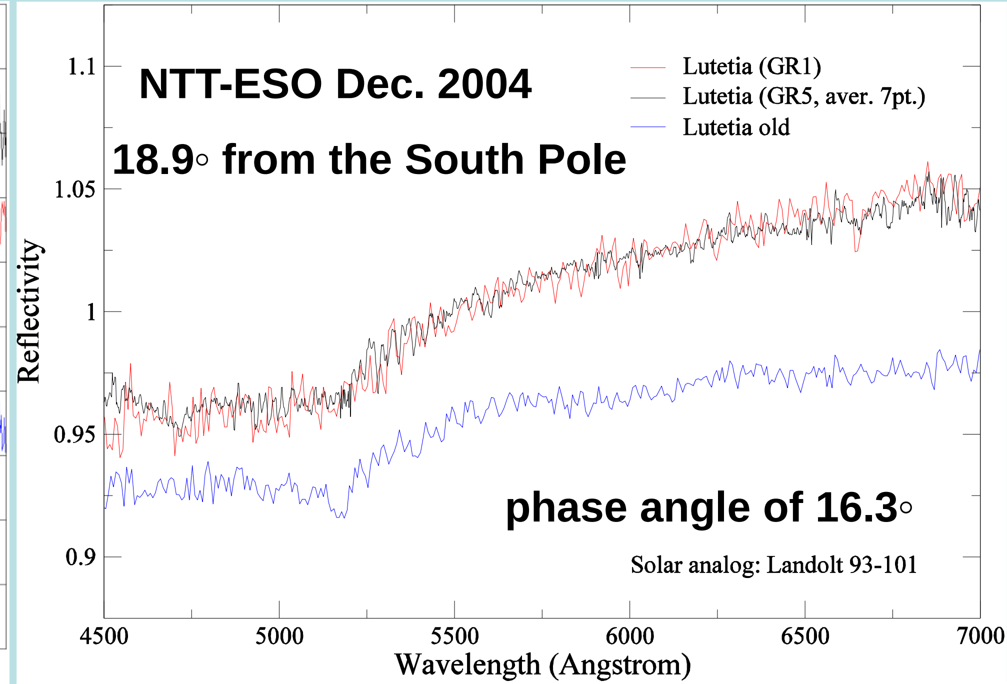
10 July 2010: from a distance of 3162 km Rosetta encounters the second asteroid: (21) Lutetia, dimensions about 120 km, rotational period about 8 hr.

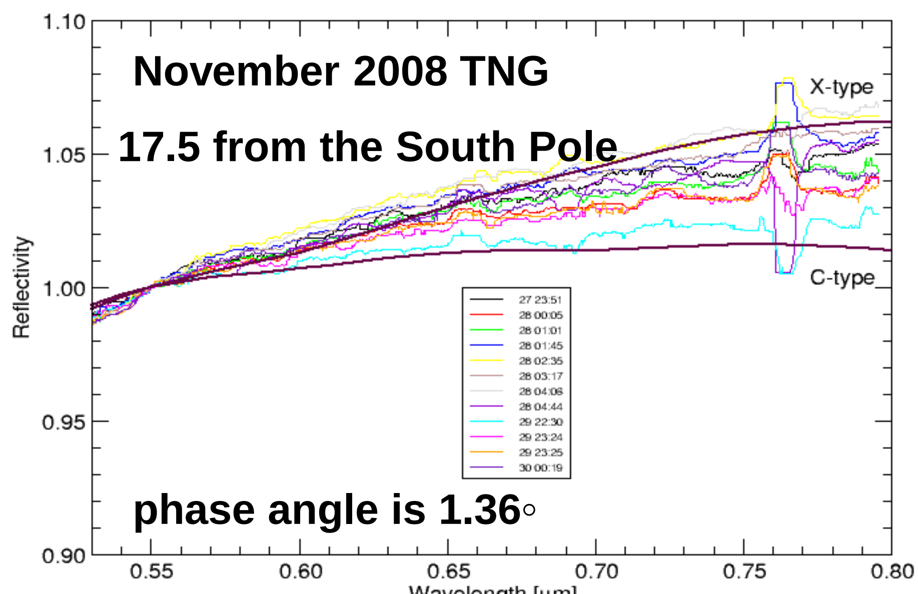
Before the encounter we have performed a deep observational campaign of the object with **two** obs runs at NTT and **one at TNG**.



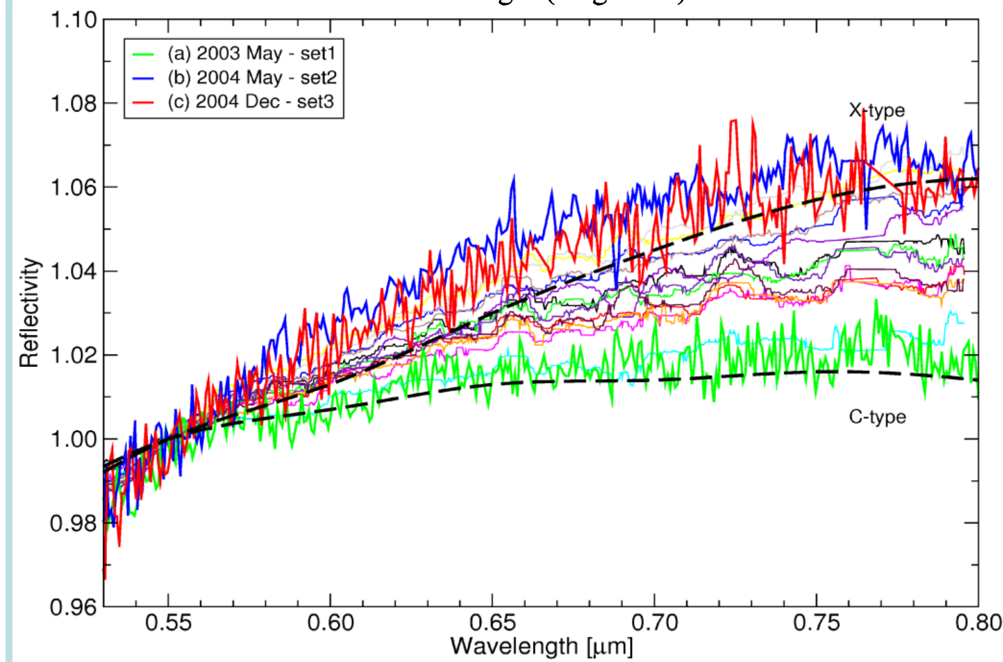
Ground based observations of Lutetia





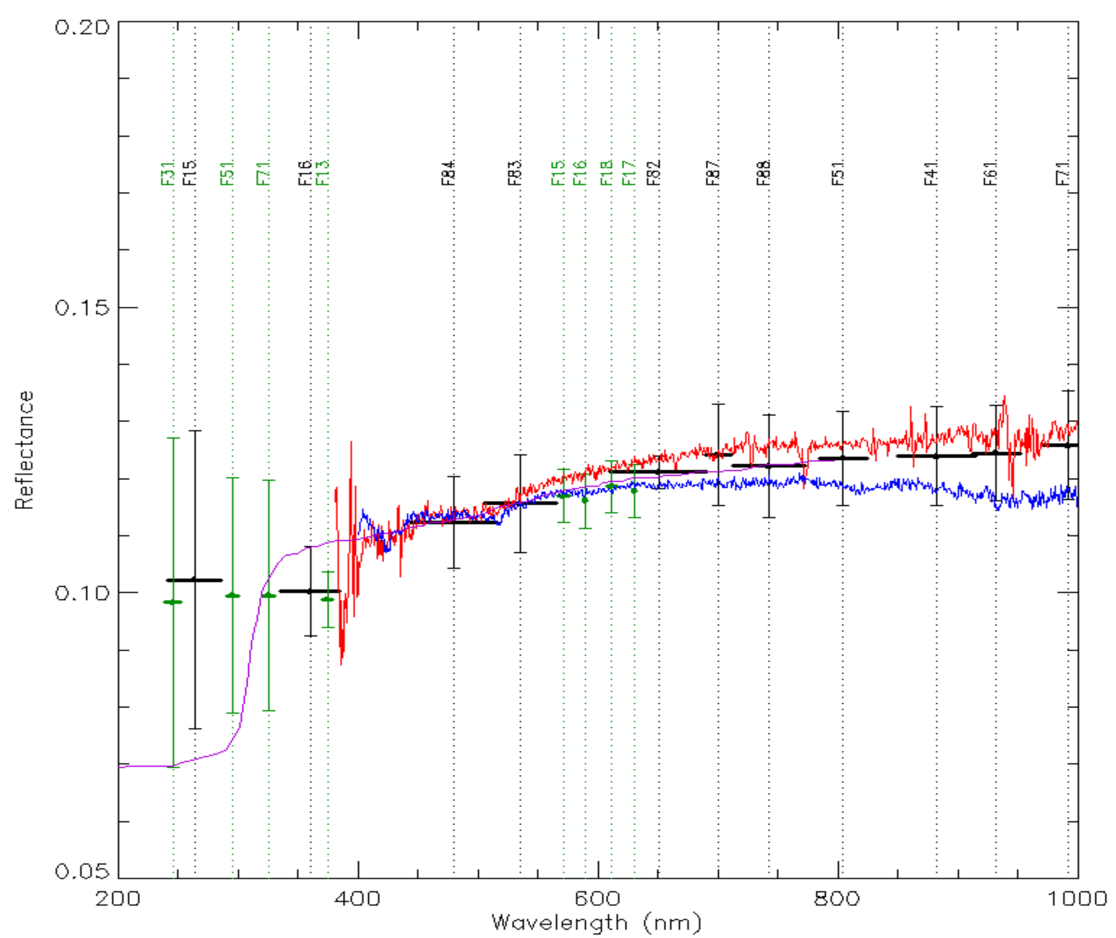


Lazzarin et al., 2010



Comparison of groundbased reflectance with Osiris data

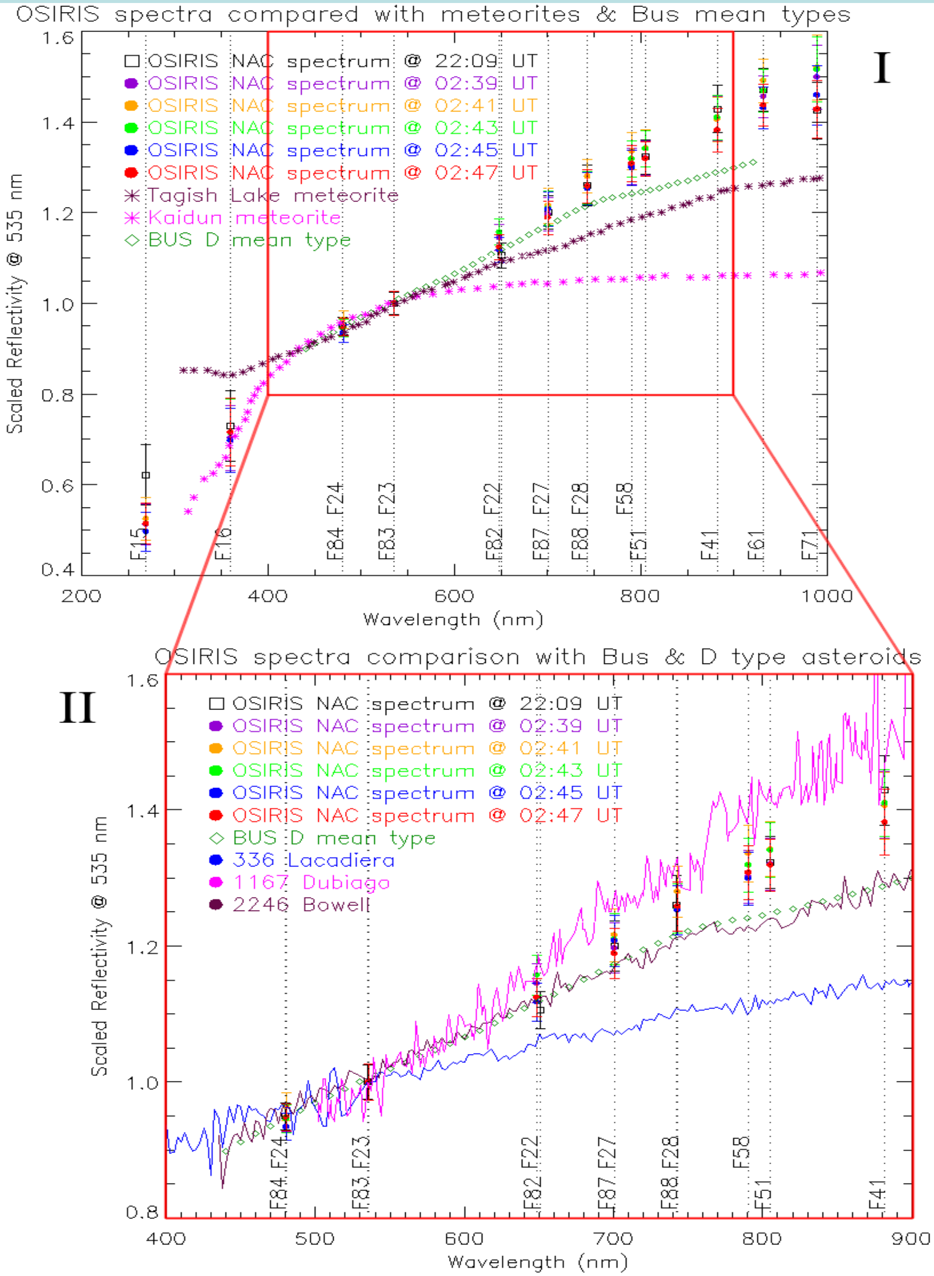
OSIRIS observed Lutetia at different phase angles, ranging from 0◦ to 140◦, values impossible to reach from the Earth (from where Lutetia phase angle is always less than about 30◦). Obtained low resolution spectra at different phase angles during the spacecraft fly-by (**resolved surface reflectivity** 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)**. **CH meteorites possible analogue?**

Phobos, asteroidi primitivi, Tagis Lake e Kaidun meteorite



Abbiamo confrontato dati di Phobos ottenuti dalla camera OSIRIS di Rosetta con:

- i D-medi
- **Kaidun meteorite** (probabile frammento di Phobos)
- **Tagish Lake meteorite** (simile ai D)
- vari asteroidi di tipo D

Phobos mostra colori che rientrano nella riflettanza tipica degli asteroid di tipo D. Non mostra una relazione chiara con la meteorite Kaidun o la Tagis Lake.

Contributo di PRISMA

Lo studio delle meteoriti e il confronto con gli asteroidi e' importante per la comprensione della loro origine e per la caratterizzazione dei corpi parenti.
In particolare PRISMA potra' contribuire a:

- Approfondire lo studio di possibili analoghi degli asteroidi primitivi utilizzando le eventuali CC che potranno essere raccolte senza che abbiano subito profonde trasformazioni a causa di lunghe permanenze sul suolo terrestre

- Approfondire il legame tra le CM2 e gli asteroidi che mostrano alterazione acquosa appunto con meteoriti di «recentissima caduta», meno processate

- Approfondire l'effetto dello space weathering sulle meteoriti

- Approfondire la relazione tra le HED e gli asteroidi di tipo V e in particolare capire se gli asteroidi non di famiglia che si trovano nella regione piu' esterna della main belt sono veramenete dei V-type. Migliorare il data base di queste rare meteoriti