Spectroscopy of asteroids

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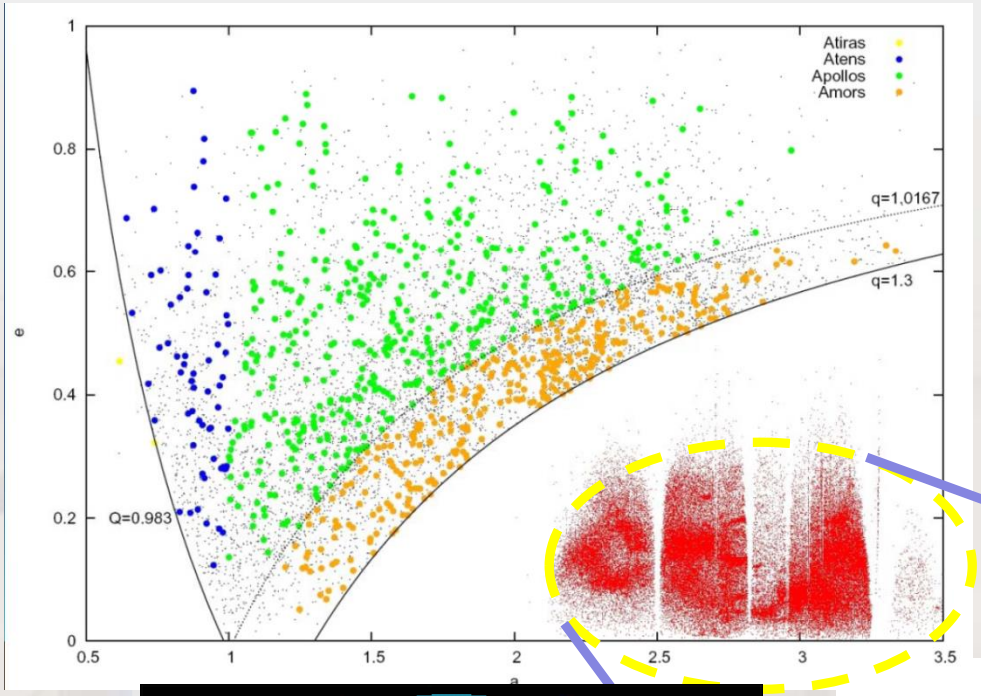
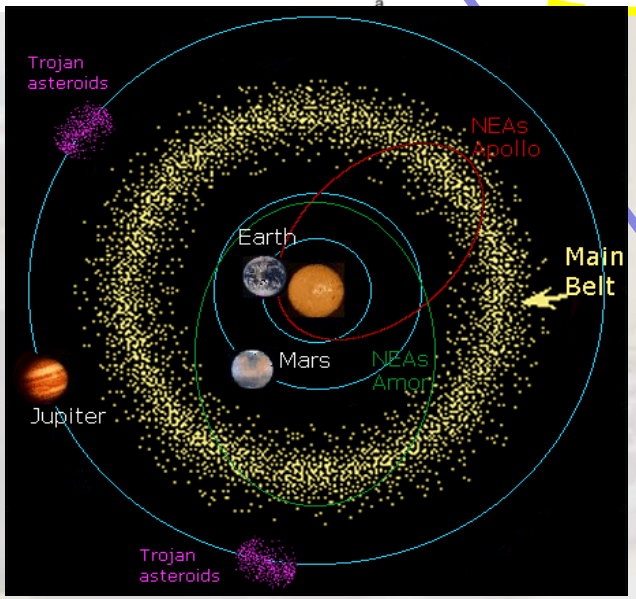
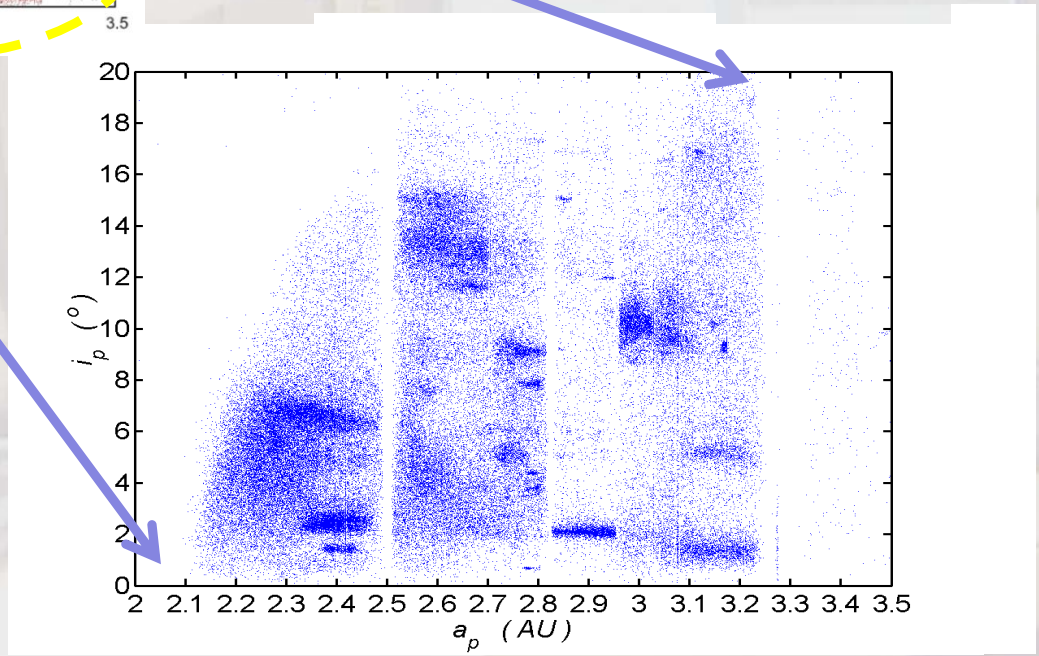
Asteroids

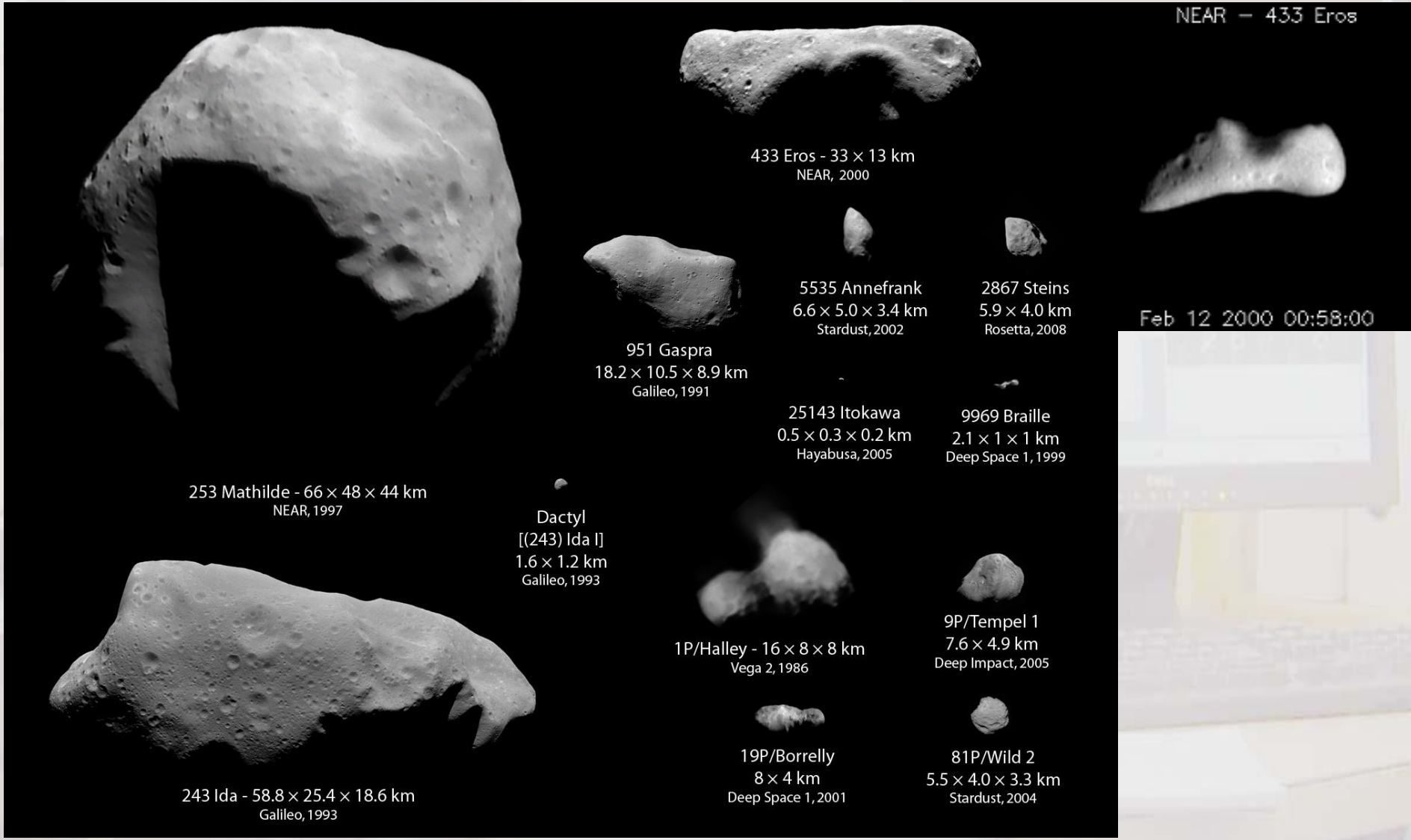
Inner Solar System minor bodies
~ 780,000 bodies





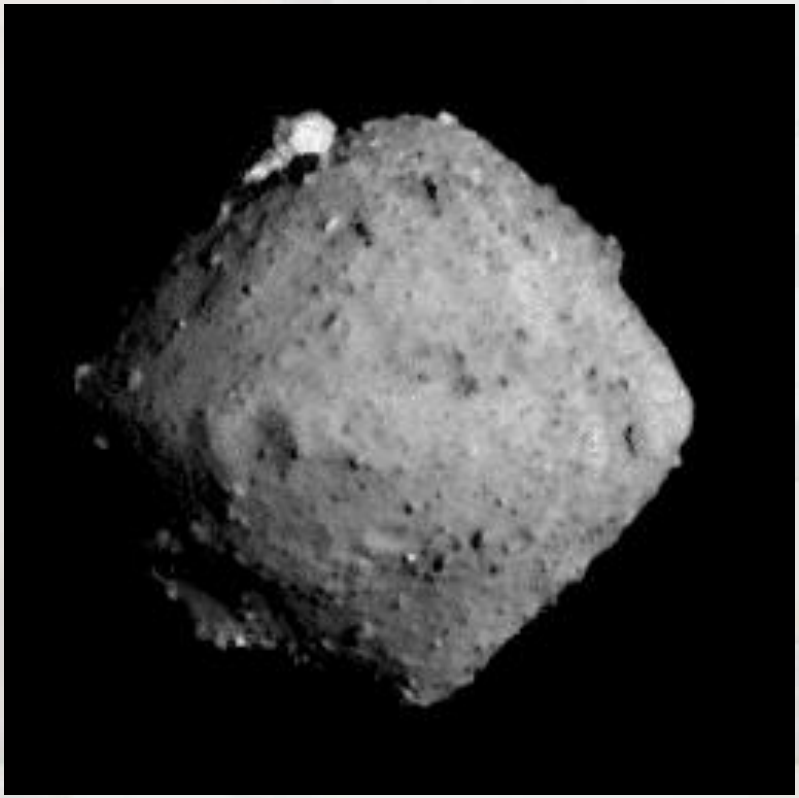


Images of asteroids by spacecrafts



Missions en cours

Bennu (OSIRIS-Rex)



Ryugu (Hayabusa-2)

How to characterize asteroid surface from the ground

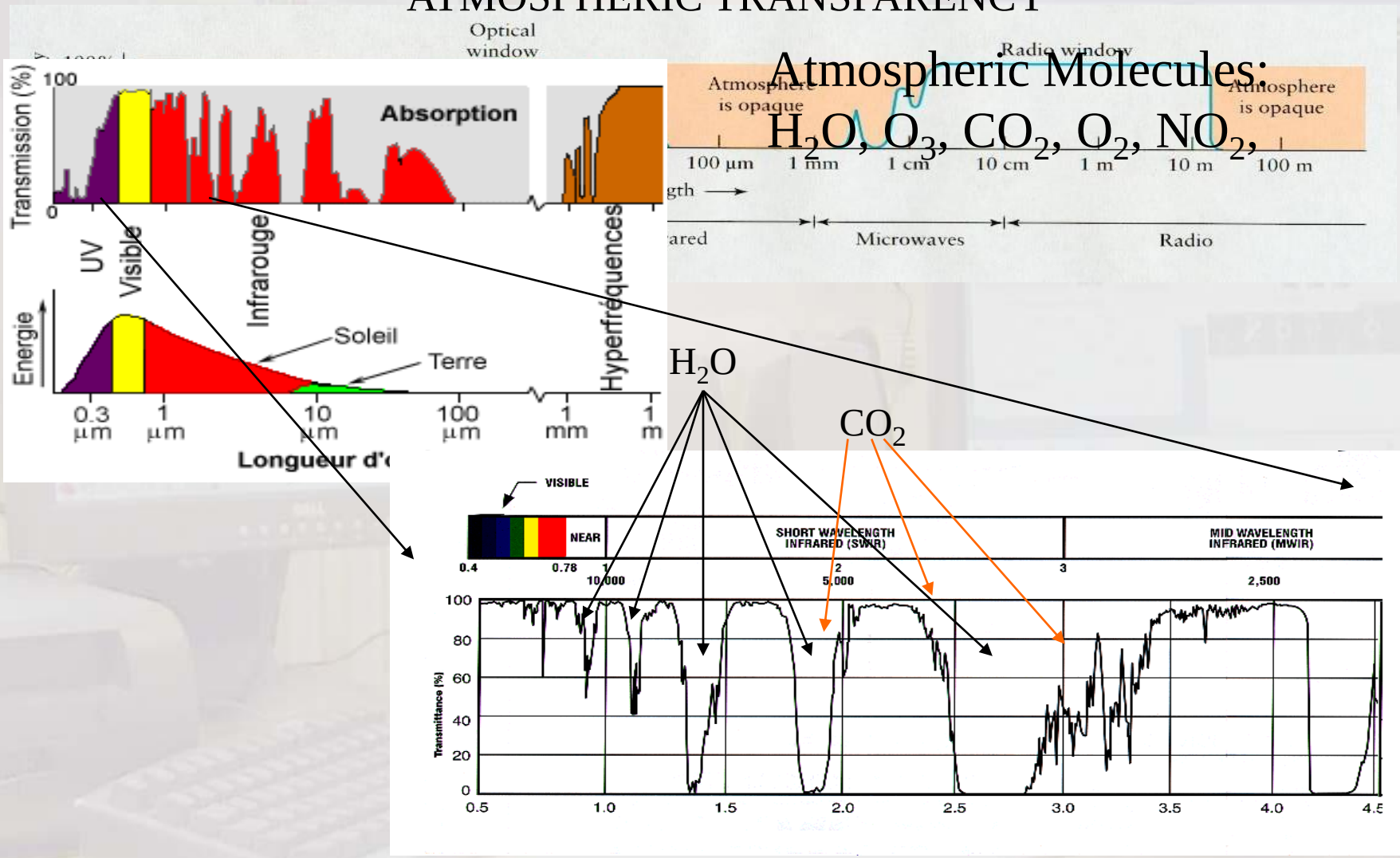
- **Reflectance spectroscopy (reflected radiation of the Sun)**
- Radio,
- Polarimetry
- Thermal albedo
- Emission spectroscopy (emission due to the heated surface)

SPECTROSCOPY

ATMOSPHERIC TRANSPARENCY

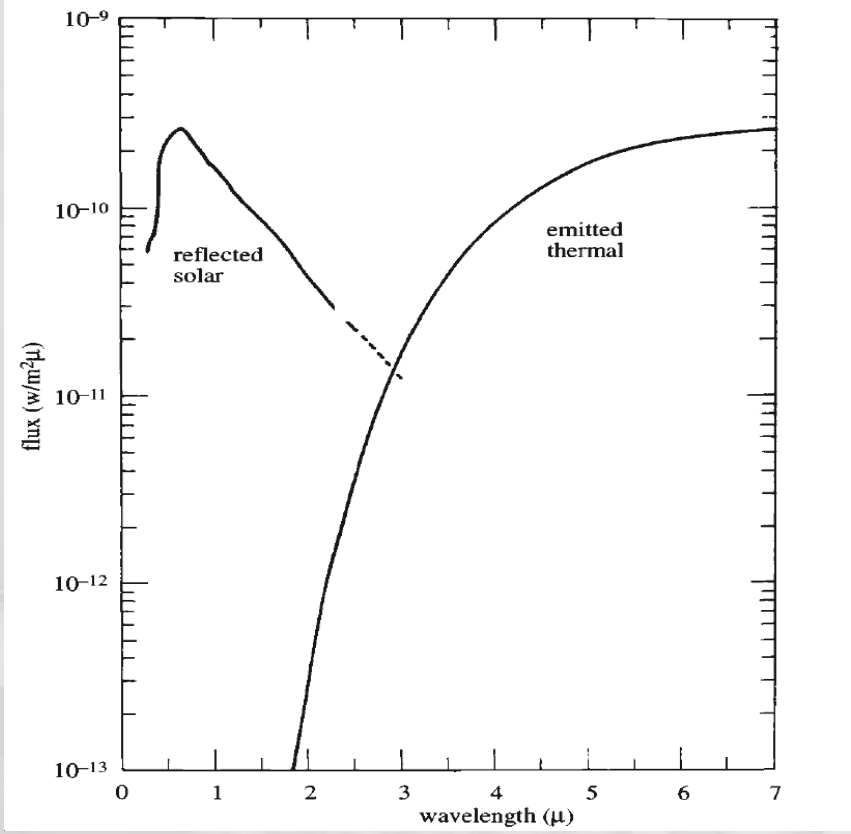
Atmospheric Molecules:

H_2O, O_3, CO_2, O_2, NO_2,

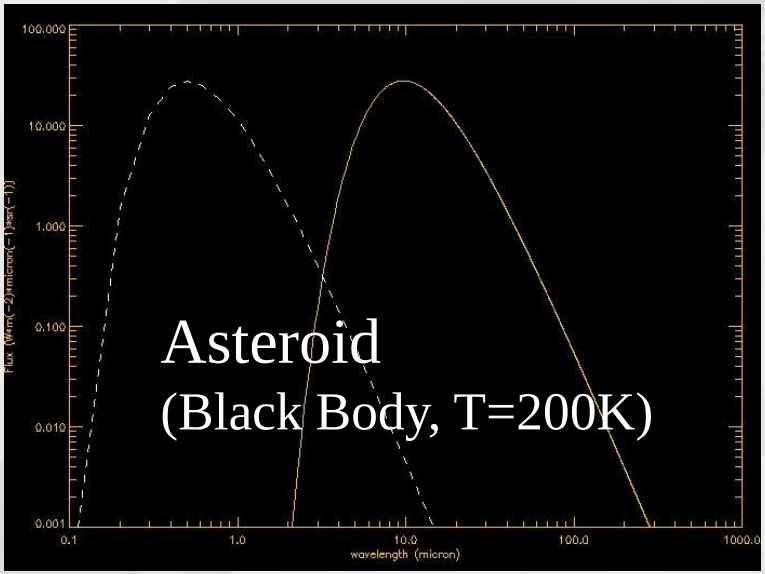


Reflectance spectroscopy

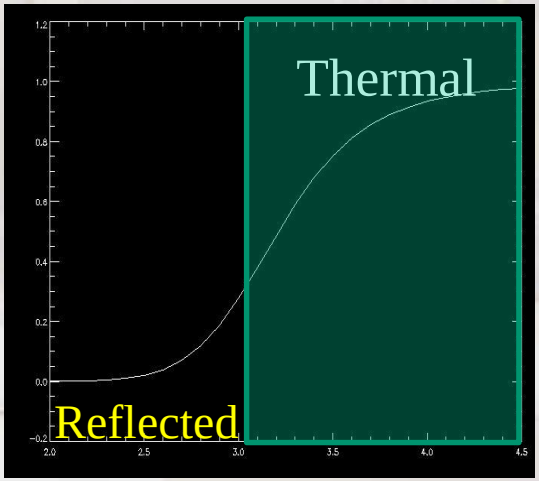
The spectral flux received on Earth from a square kilometre of sunlit mare basalt on the Moon's surface.



McCord & Adams, 1977 (***Use of ground-based telescopes in determining the composition of the surfaces of solar system objects***.)



Balance Ref/Therm

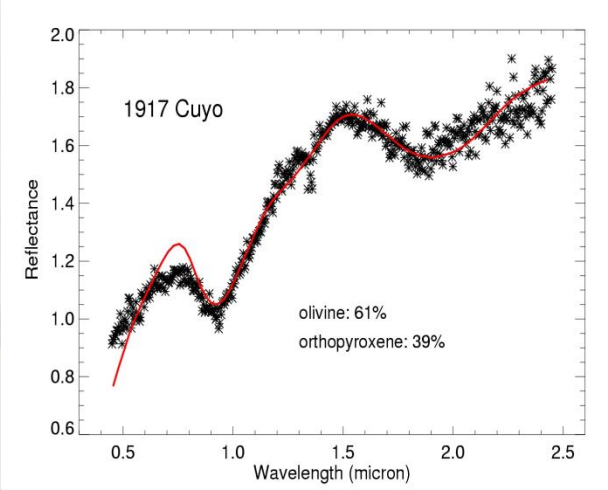


Asteroid reflectance spectroscopy

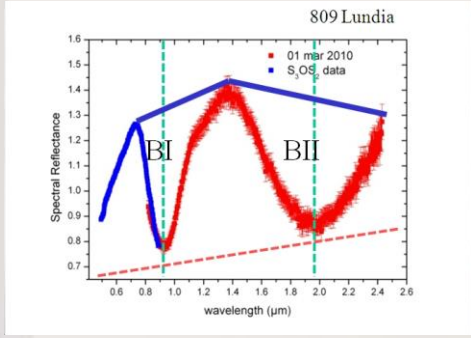
ITEMS

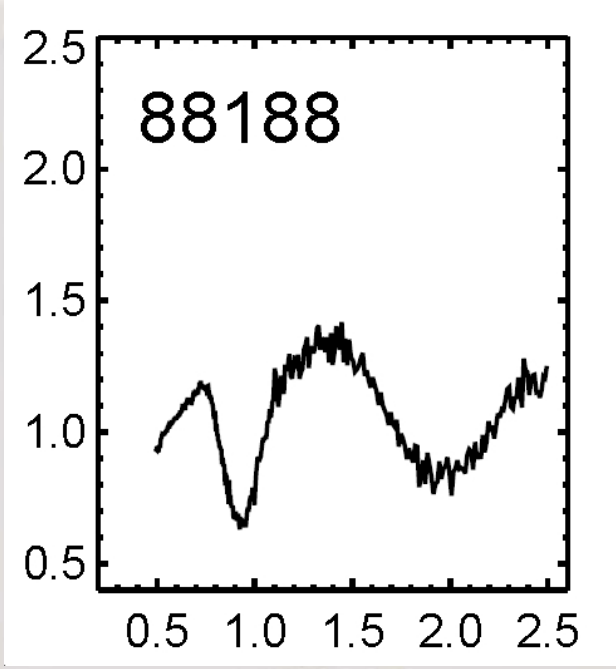
- Acquiring data (spectra)
- Build a statistically robust classification of spectra
- Do comparative planetolgy

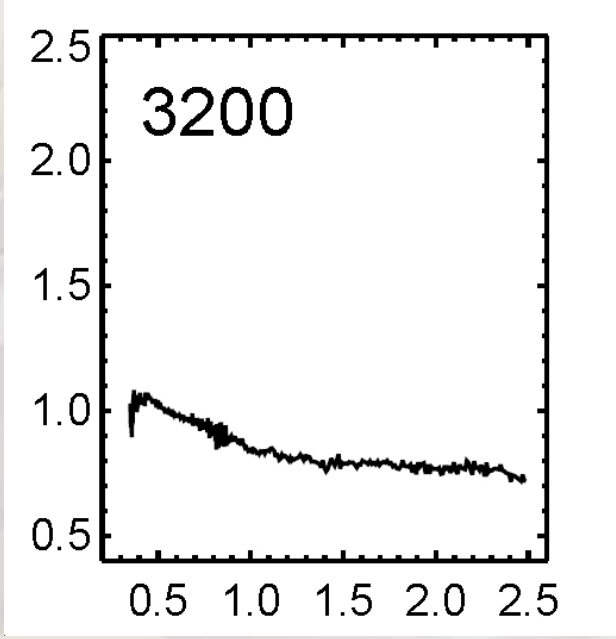
Asteroid spectral trends

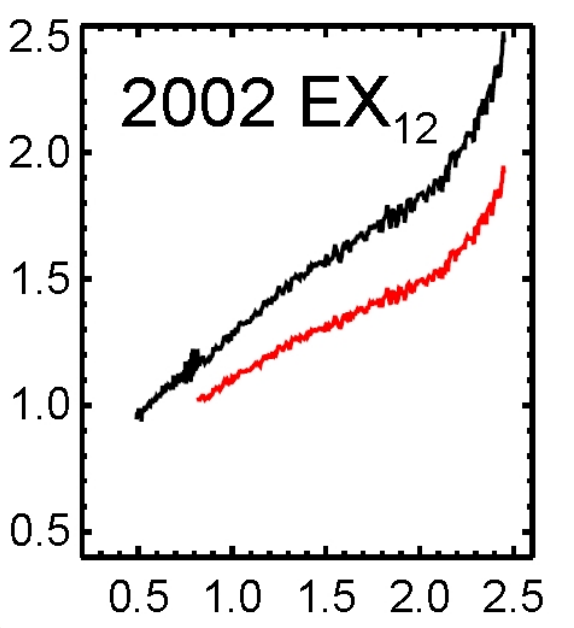


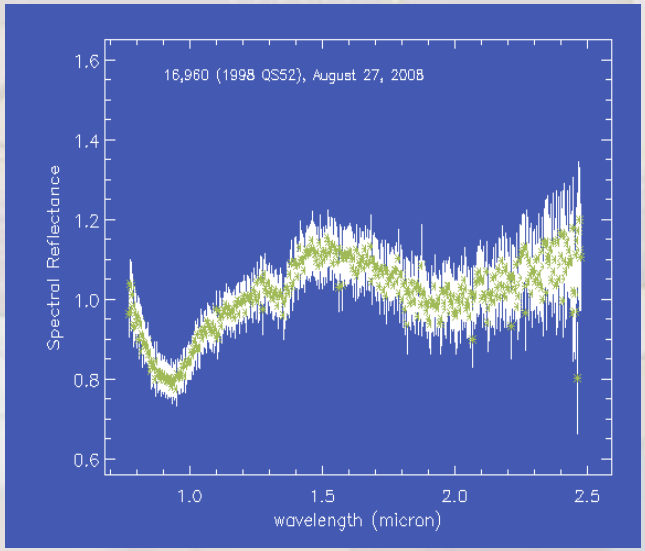
V and NIR are not covered by the same detector





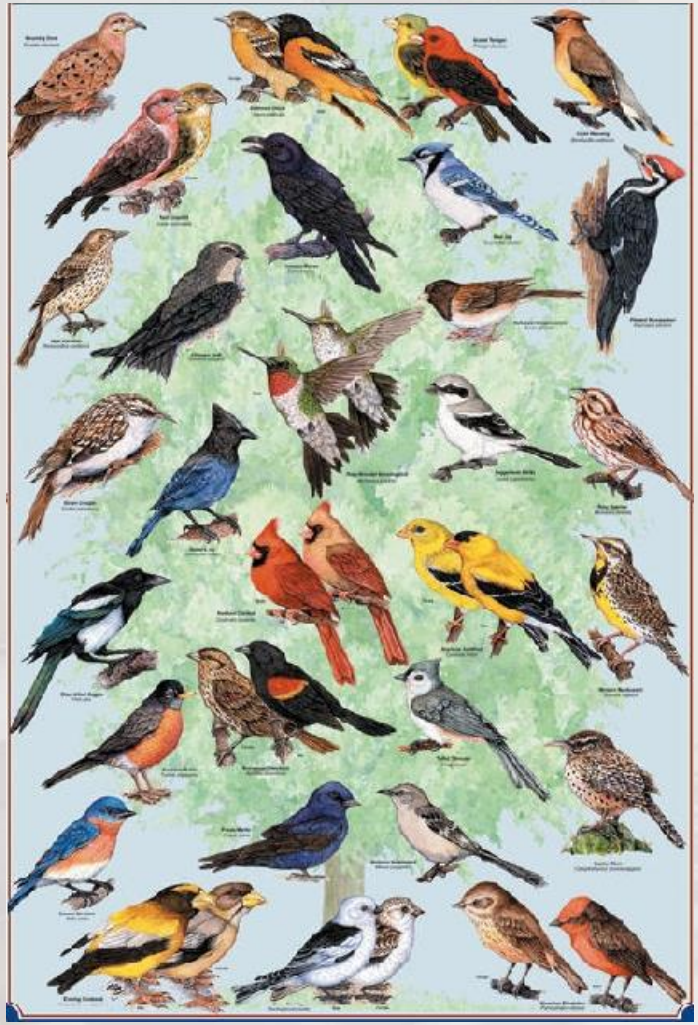






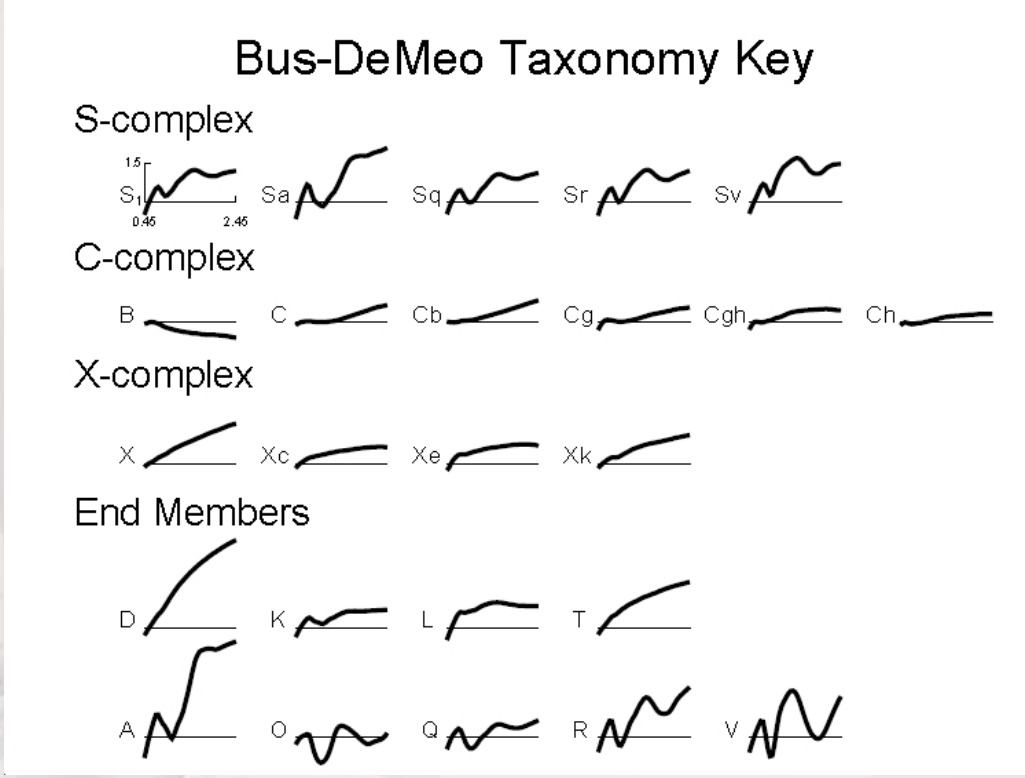
Classification => Taxonomy & mineralogy

Birds species



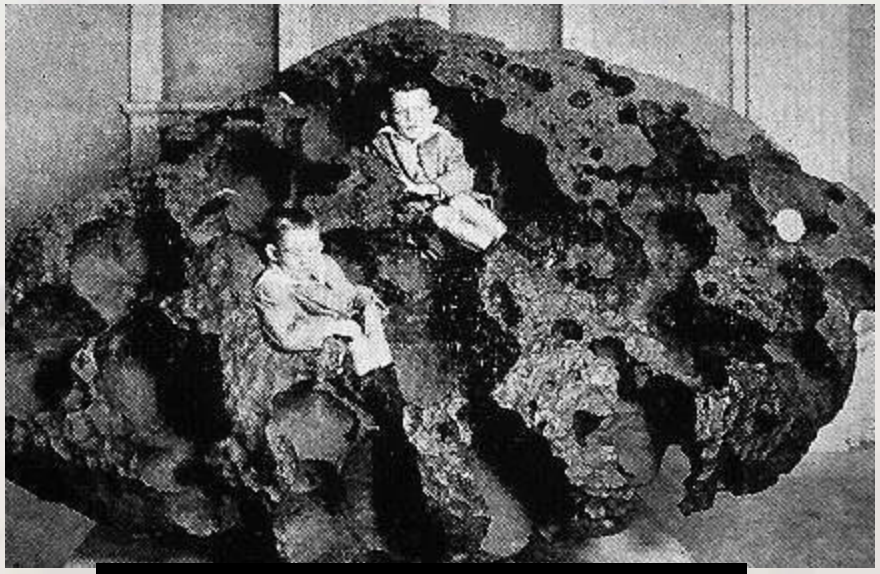
Asteroid taxonomy

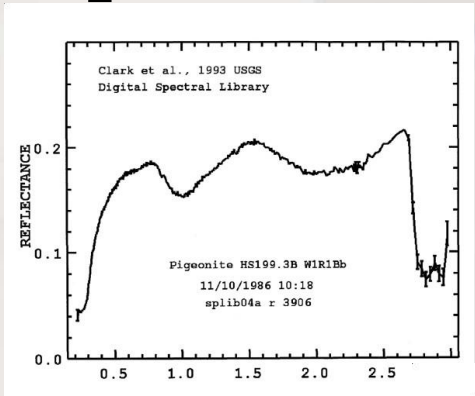
Visible and near-infrared spectra

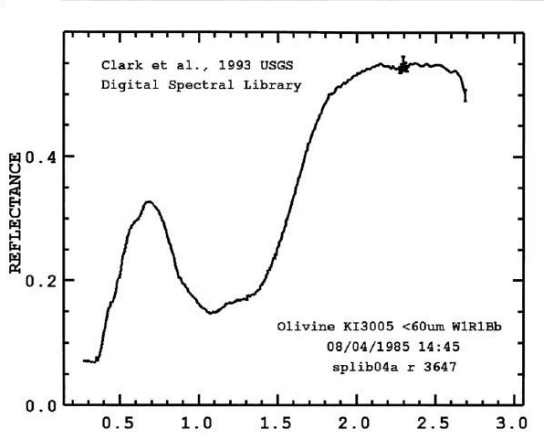


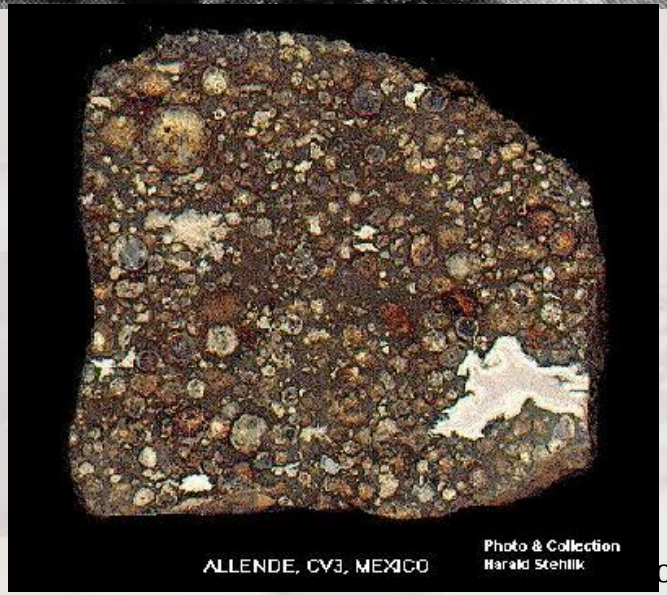
DeMeo et al, Icarus, 2009

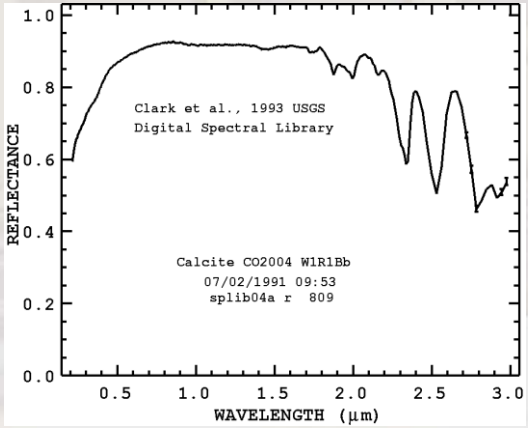
Laboratory Spectroscopy

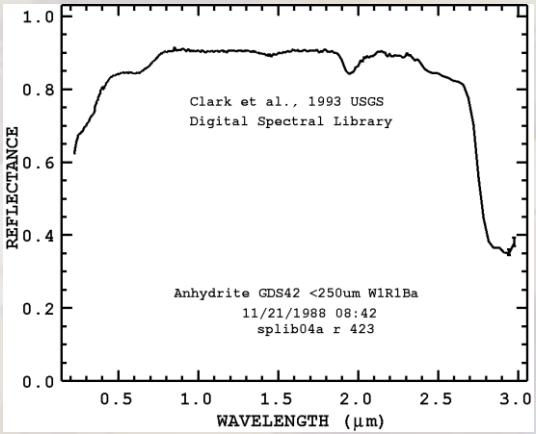








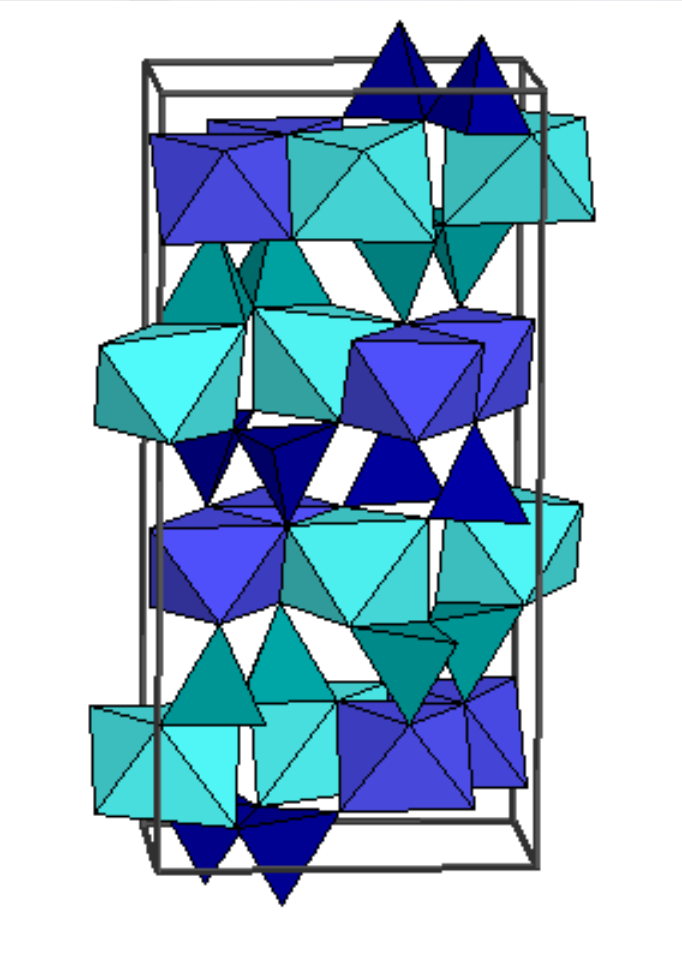




Toward a mineralogy of asteroids

Facts:

1) multiple mineralogical solutions
2) How representative for the bulk mineralogy of asteroid (segregation, space weathering,…) the surface is



Mineral species?

Cosmochemistry of the space minerals

Silicates crystalline:

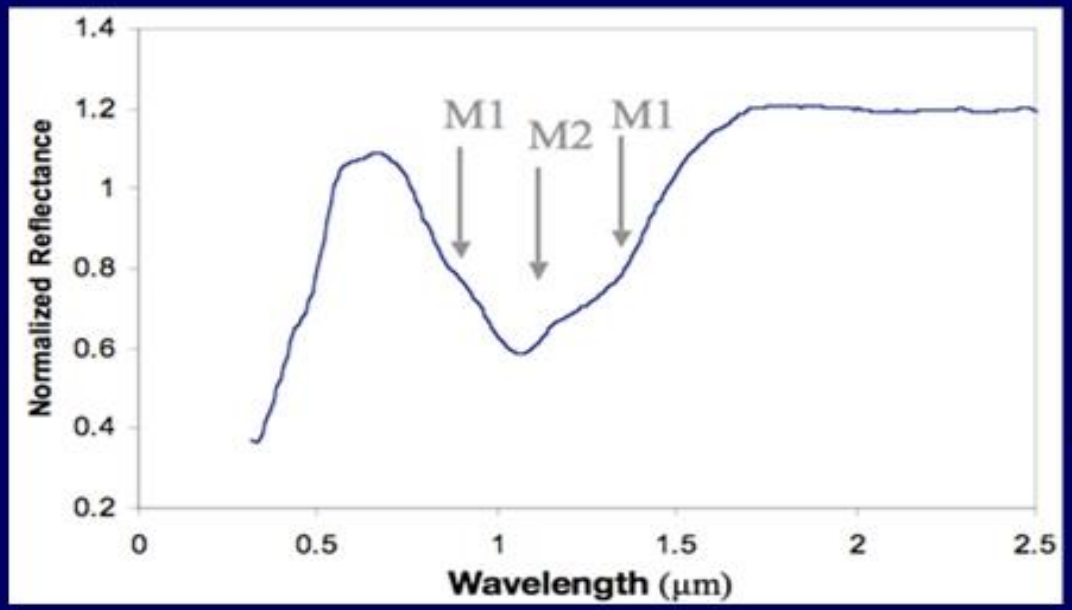
- Pyroxenes ($M2M1Si_2O_6$)
  1. Orthopyroxene
  2. Clynopyroxène

Ex: $(Ca,Mg,Fe)Si_2O_6$, $Ca(Mg,Fe)Si_2O_6$

- Olivine $(Fe,Mg)_2SiO_4$

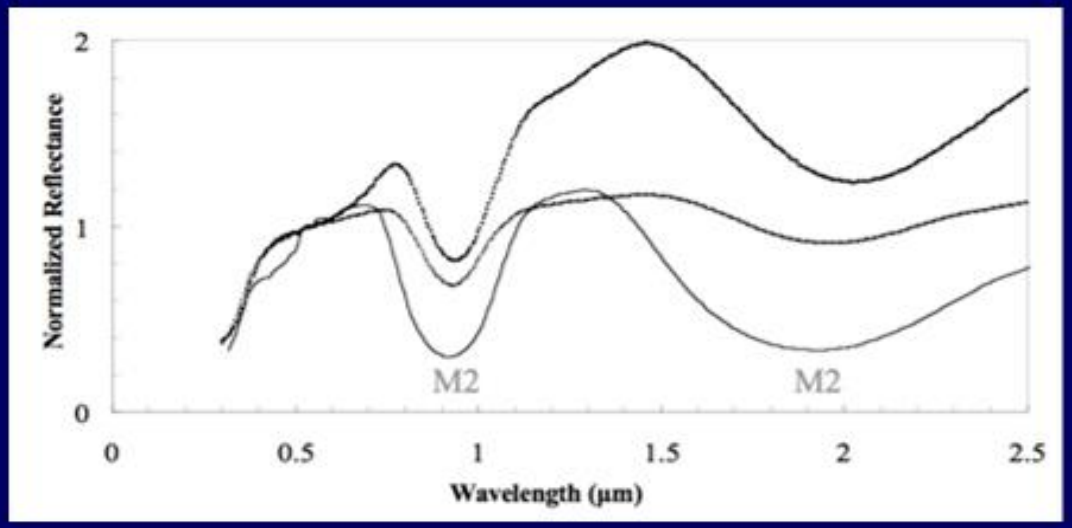
Al, C, H, Cr, Ni,……..

Cosmochemical representative elements ?



Olivine

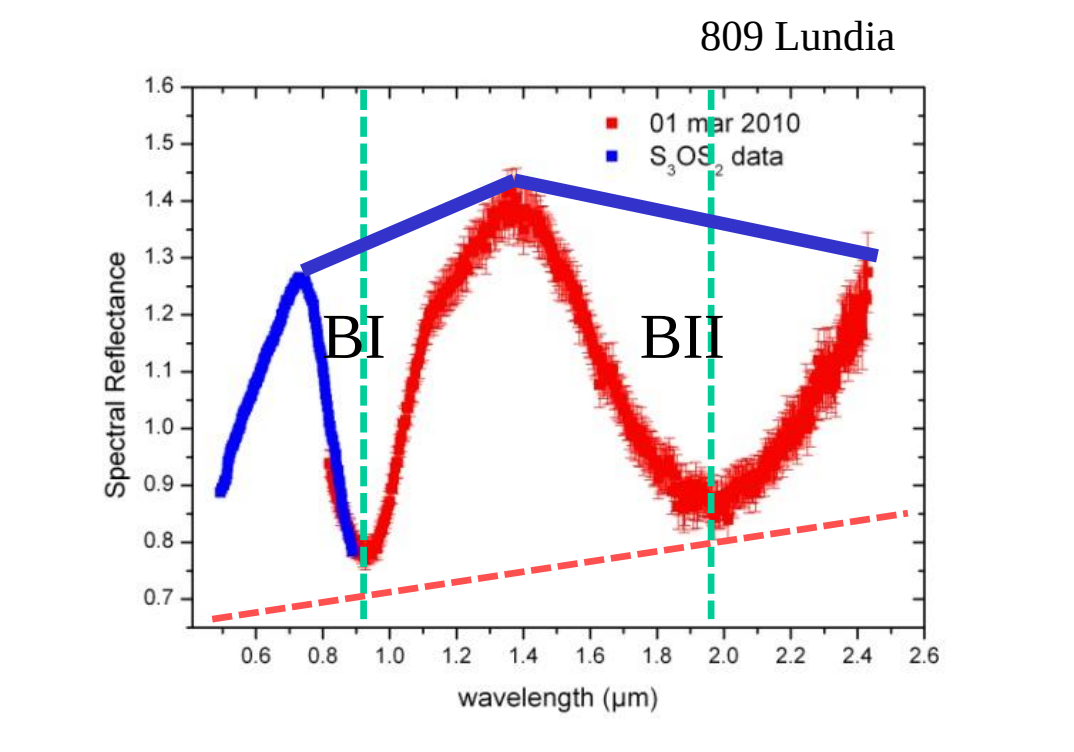
$(Mg, Fe)_2SiO_4$



Pyroxene

$(Mg, Fe)_2Si_2O_6$

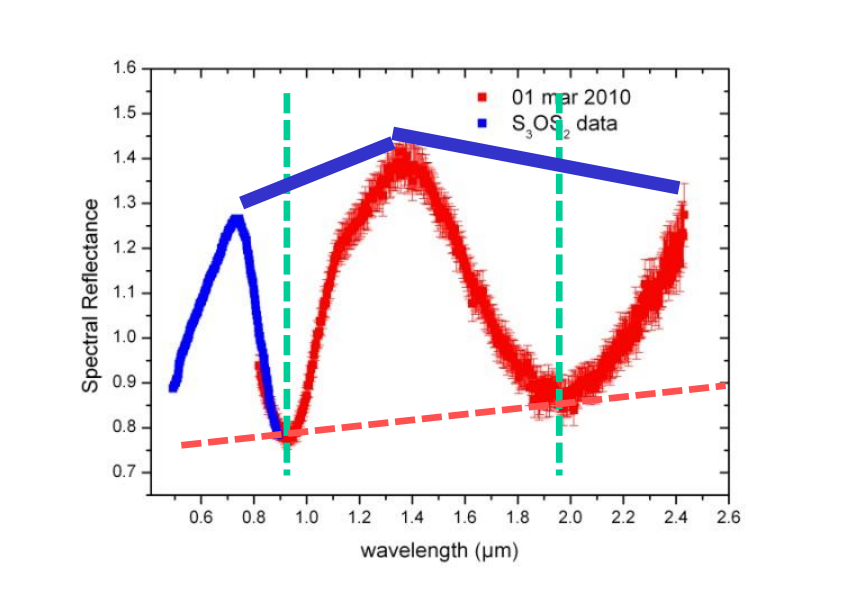
Mineralogical parameters

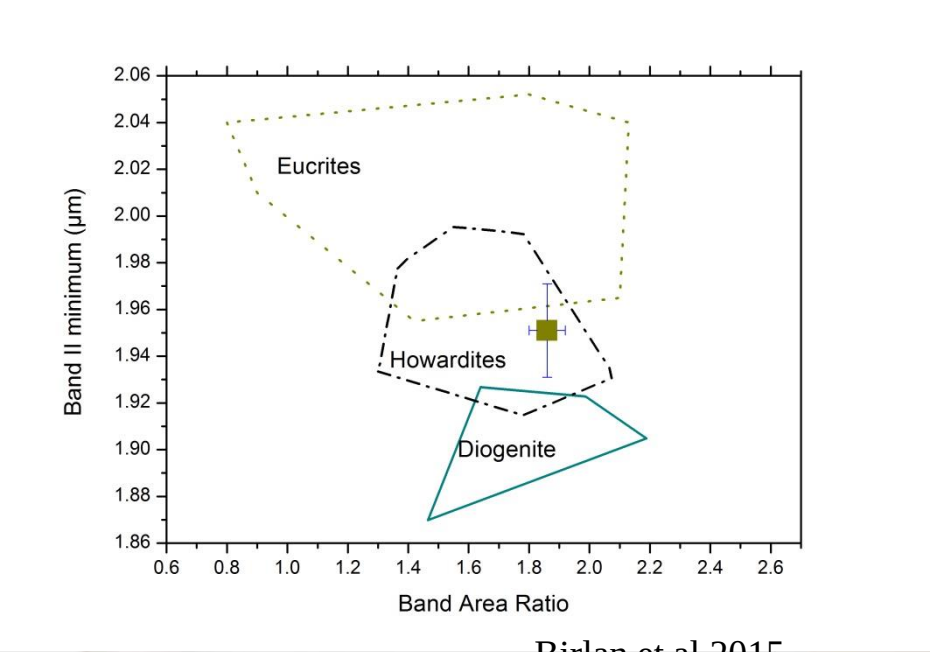


- Continuum slope (! ?)
- Center of bands
- Depth of bands
- Band Area Ratio (BAR) = BI / BII

2004 BL86 – PHA asteroid

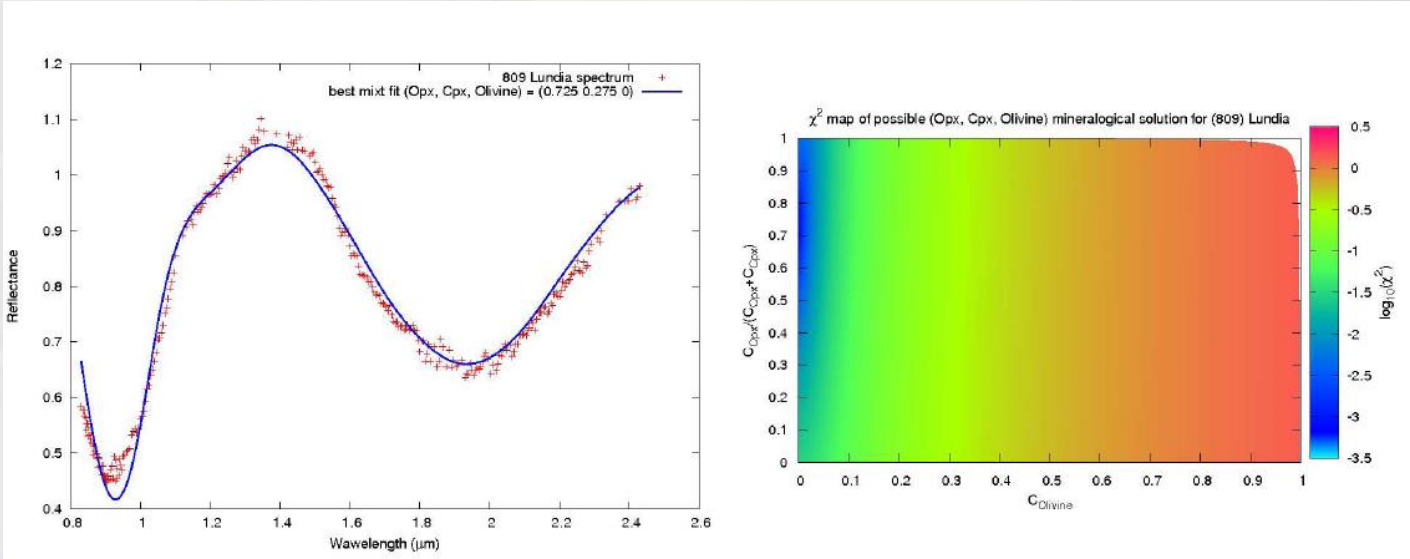
- BL86 is V-type asteroid
Mineralogical analysis: 2004 BL86 has a basaltic mineralogy
Thermal albedo of BL86 help in deriving a diameter of 290 ± 20





Birlan et al 2015

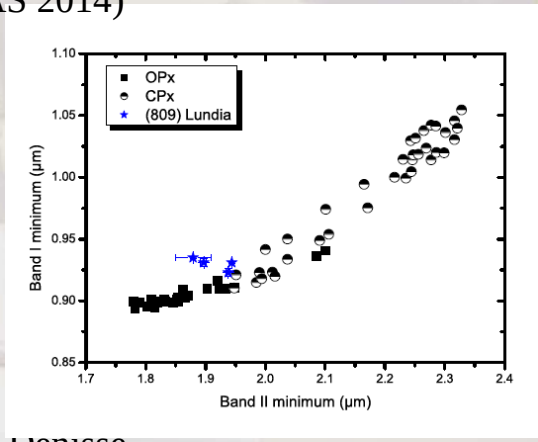
Mineralogical maps



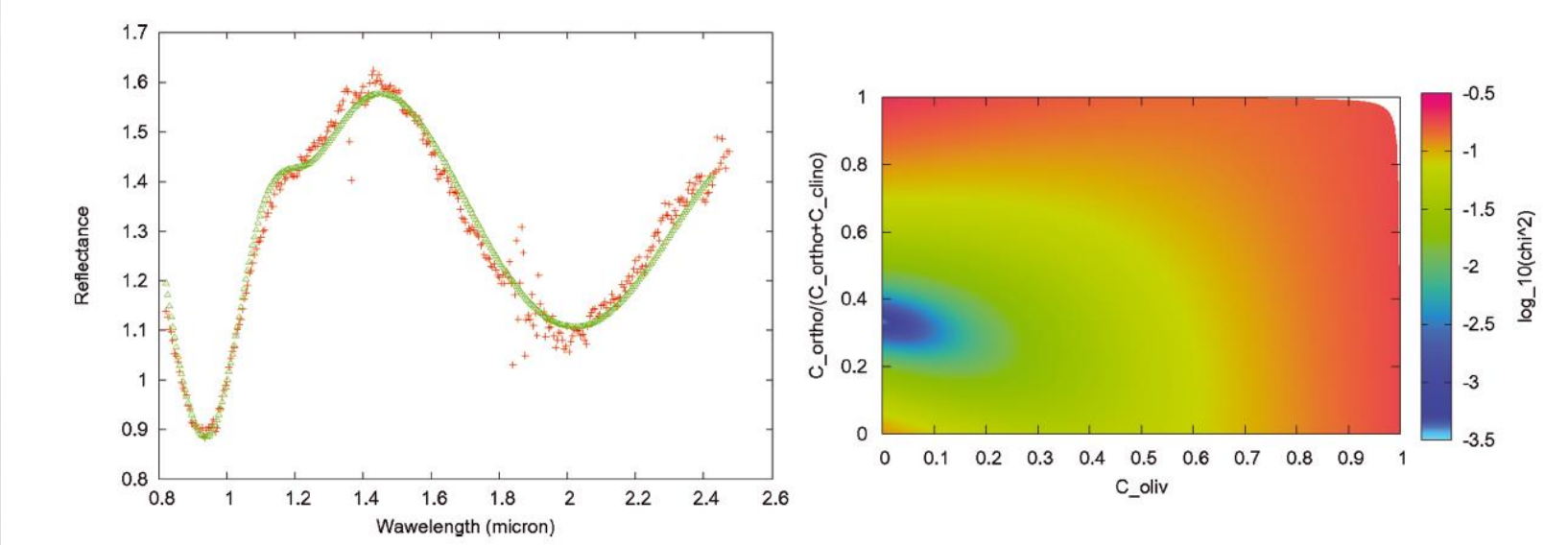
Mineralogical charts developed using linear mixtures of Ol, CPx and Opx (Birlan et al MNRAS 2014)

Degenerancy of mineralogical solutions
(in this case low abundance of CPx)

Opx/CPx diagram

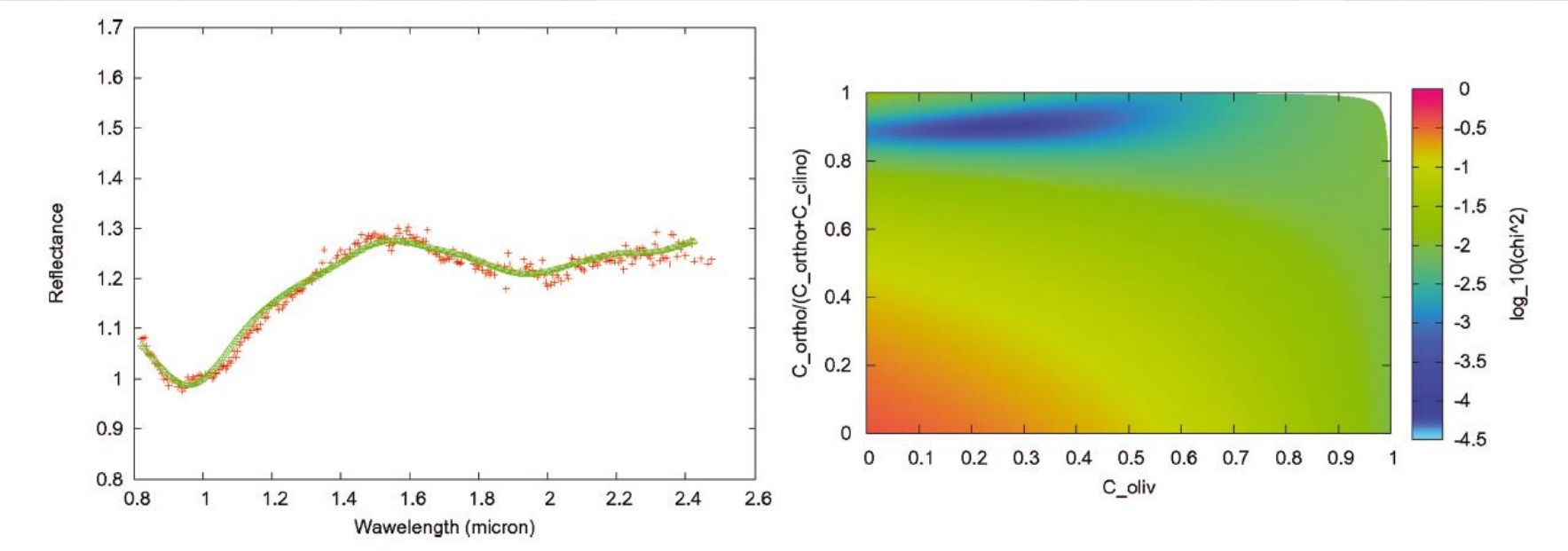


Mineralogical maps



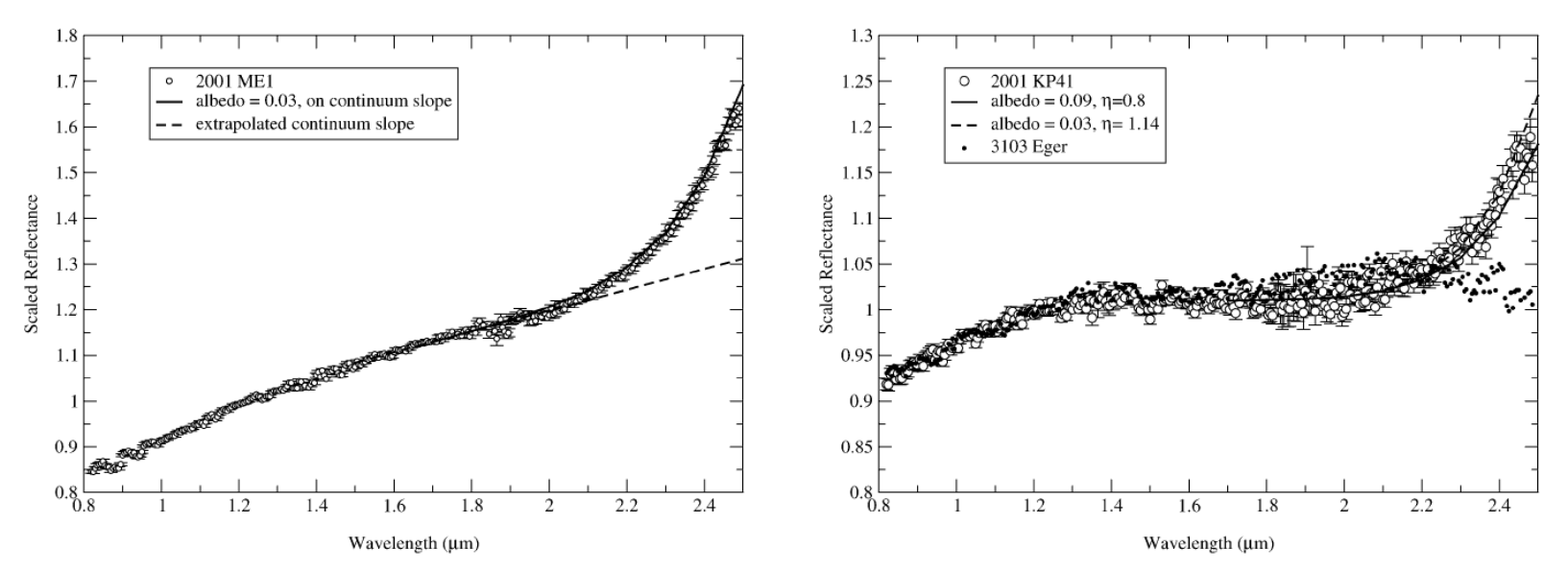
Mineralogical map of (854) Frostia. NIR spectrum shows the presence of feldspath at 1.3 µm. (Birlan et al 2011)

Mineralogical maps



Mineralogical map of (1333) Cevenola, an Olivine rich asteroid. (Birlan et al 2011)

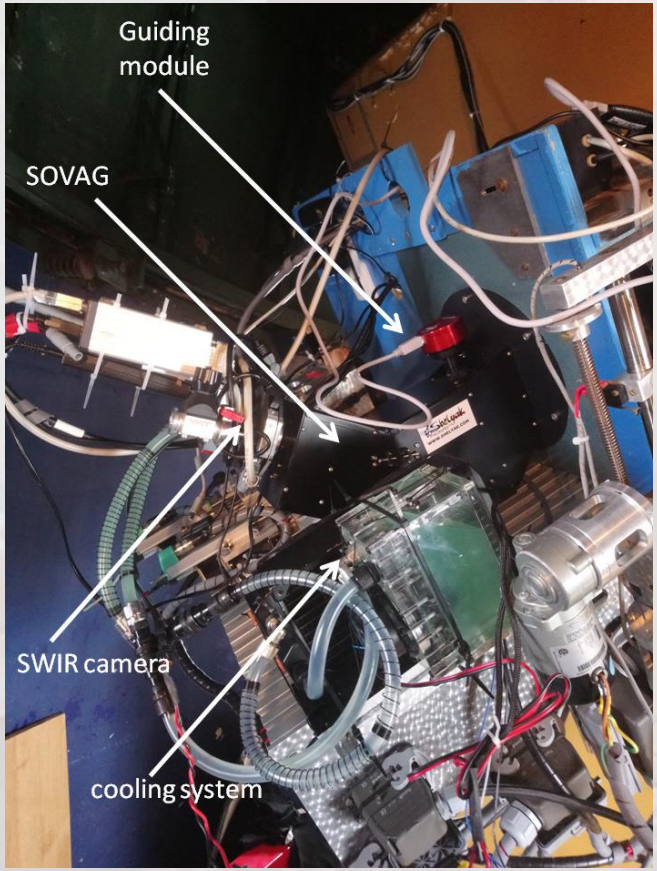
Featureless spectra



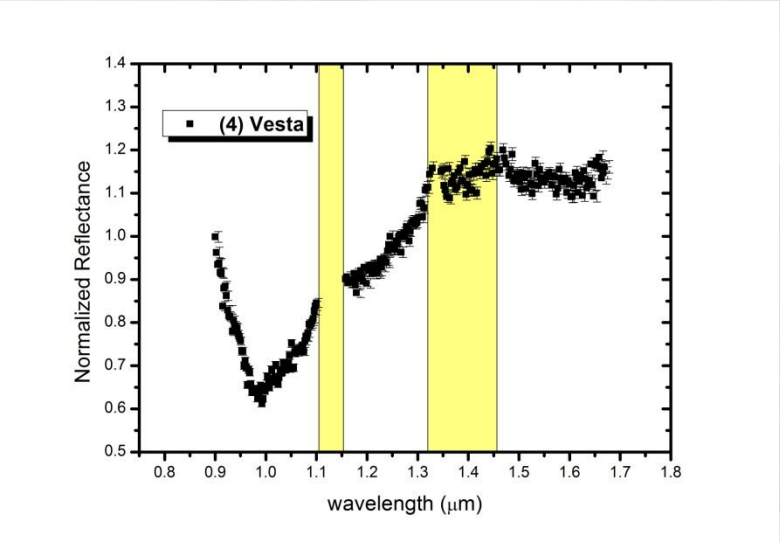
(Rivkin et al 2005)

Constrains thermal albedo by modeling thermal tail in reflectance spectra.

SOVAG – spectrograph for Pic du Midi



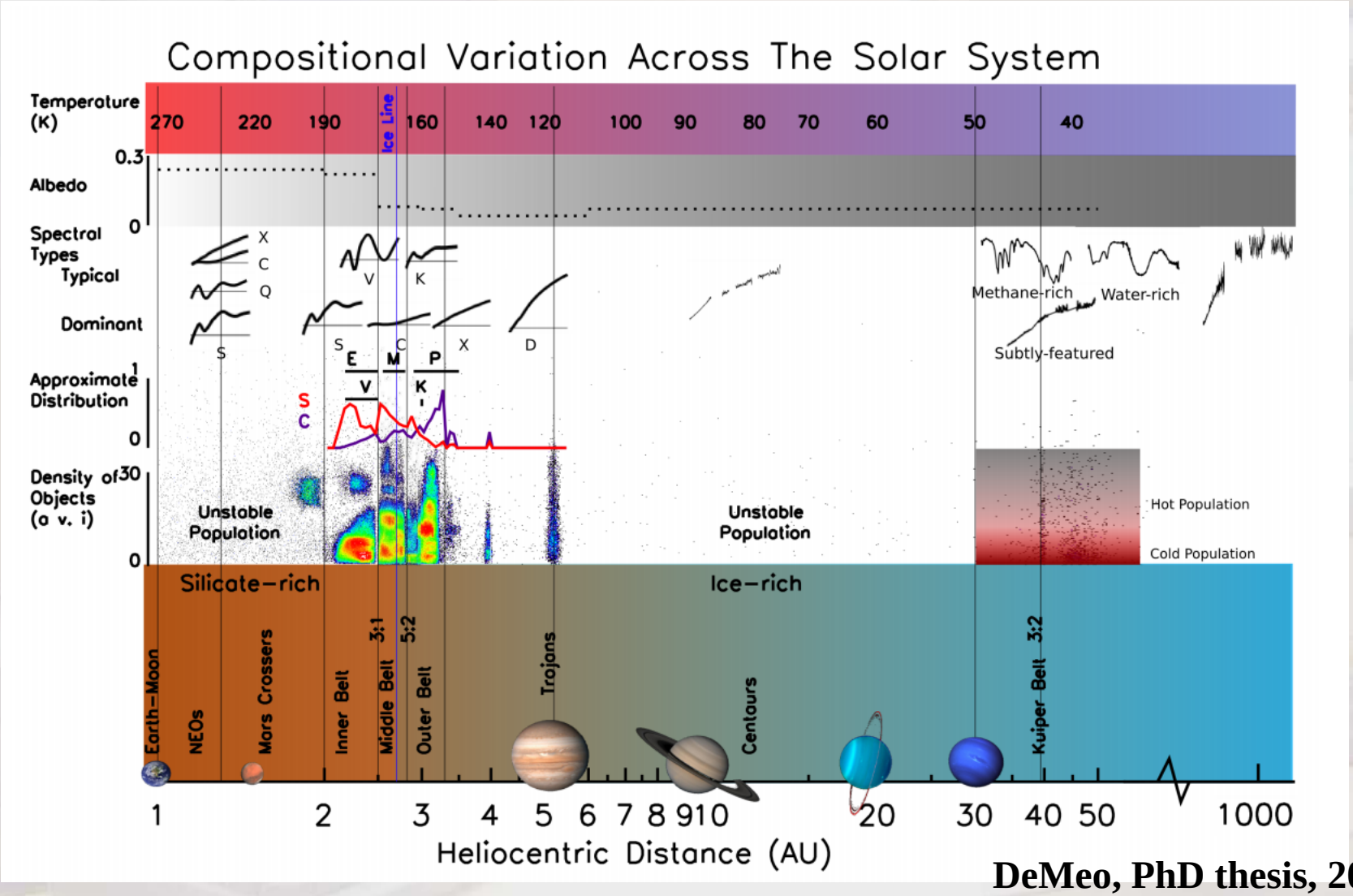
Spectral coverage: 0.5-1.6 µm
LowRes/Slit - Single order
June 2018 – First light



CONCLUSIONS / PROSPECTIVES

1. Spectroscopy – powerful interactive tool for astronomers
2. Near-infrared spectroscopy became very important and used in determining the mineralogical solution(s).
3. Complementary results (photometry, polarimetry, radiometry, radar, …) should be used for the most probable mineralogical solution

OUR SOLAR SYSTEM



DeMeo, PhD thesis, 2010