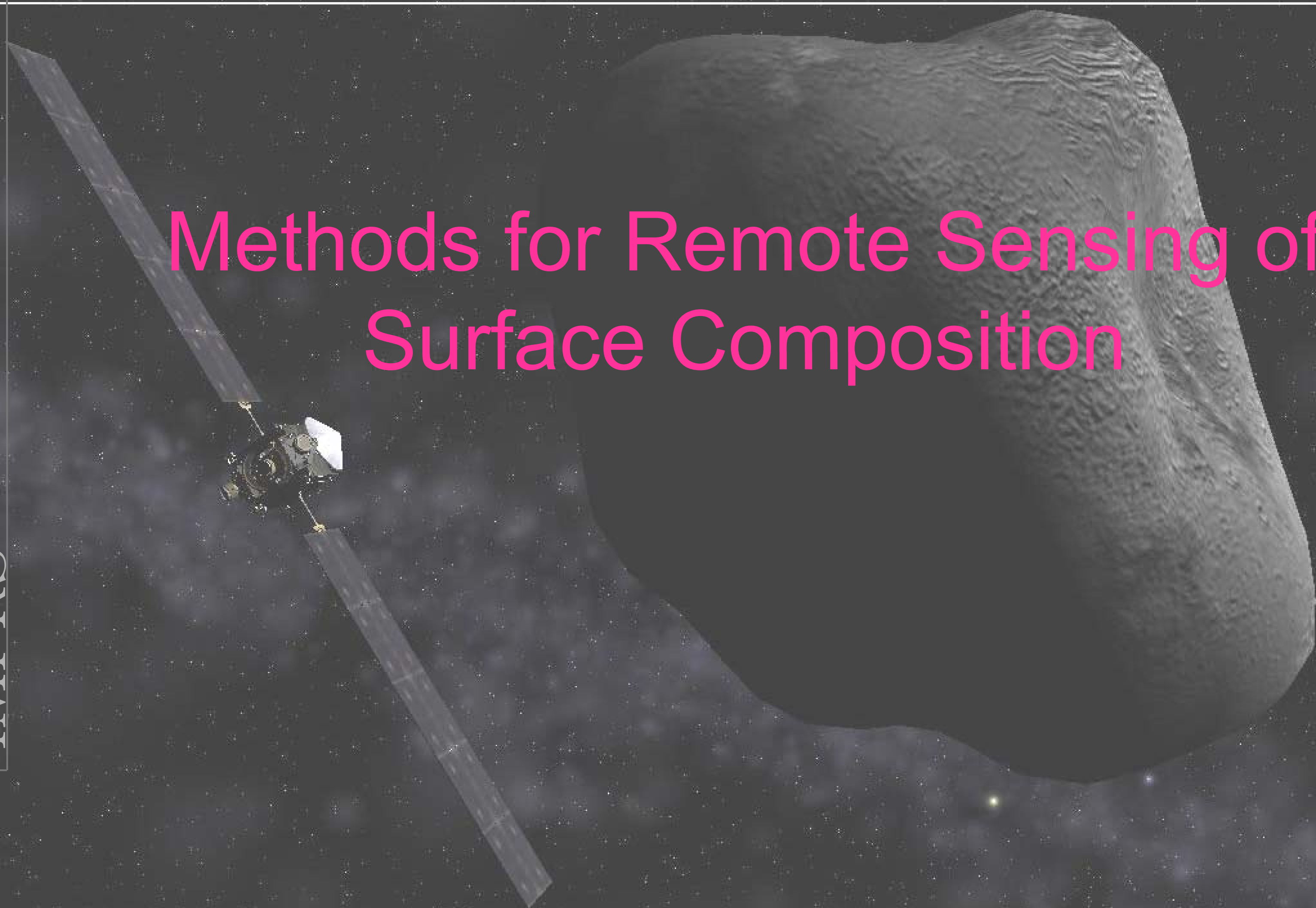

Methods for Remote Sensing of Surface Composition

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Outline

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- What is remote sensing?
- Instuments used for surface composition analysis
- Why compositional information is essential
- Rocks, regolith and minerals
- Extraction of the mineralogical composition
- Origin of VNIR spectra and their features
- What influences the spectral shape?
- Techniques of getting spectra
- Examples

What is Remote Sensing?

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Physical definition

The acquisition of information about a target in the absence of physical contact

Measure changes in:

- Electromagnetic fields (spectroscopy)
- Acoustic fields (sonar)
- Potential fields (gravity)

Methods for investigating the composition

- Chemical composition:
  - Gamma and neutron spectroscopy
  - X-Ray spectroscopy
  - VNIR reflectance spectroscopy (limited)

- Mineralogical composition:
  - VNIR reflectance spectroscopy
  - MID NIR emission spectroscopy

Why remote sensing the surface composition?

- In general, remote sensing is the only way to determine the surface composition of inaccessible targets.
- Compositional information is important for constraining the history of a target. Thus compositional information is the key to understand the origin and evolution of planetary bodies.
- Compositional information allows conclusions to be drawn about the processes that are or were acting on a planetary body.
- Is required to identify potential landing sites and potential recourses for humans.

➔ let's have a closer look on remote sensing by using reflectance spectroscopy and color photometry.

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The Question

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The following question is often raised by geologists:

- Given a reflectance curve (spectrum/color spectrum) obtained by a spectrometer/camera, what is the composition and structure of the material within the field of view of the instrument?

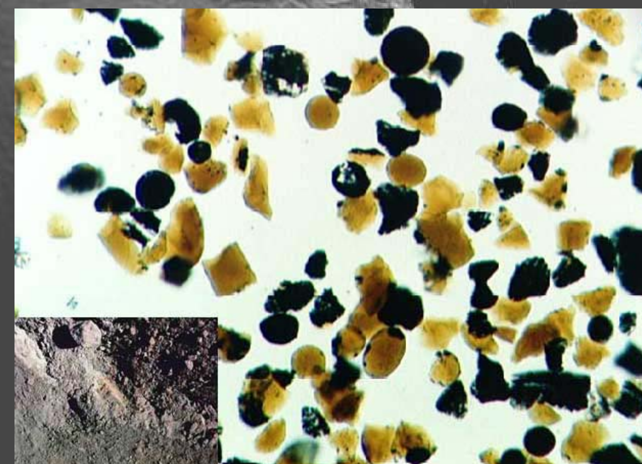
- Or in other words… "What kind of rock, regolith or ice am I looking at?"

What is a rock?

- Naturally-occurring aggregates showing similar composition and texture; composed of minerals or their fragments (+ organics on Earth)
- Groups:
  - igneous rocks (e.g. basalt)
  - sedimentary rocks (e.g. sandstone)
  - metamorphic rocks (e.g. gneiss)

What is regolith?

- Fragmental incoherent rocky debris (dust, soil) that covers the most areas of atmosphere-less bodies, e.g. Moon and asteroids



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Rock and regolith are composed of minerals

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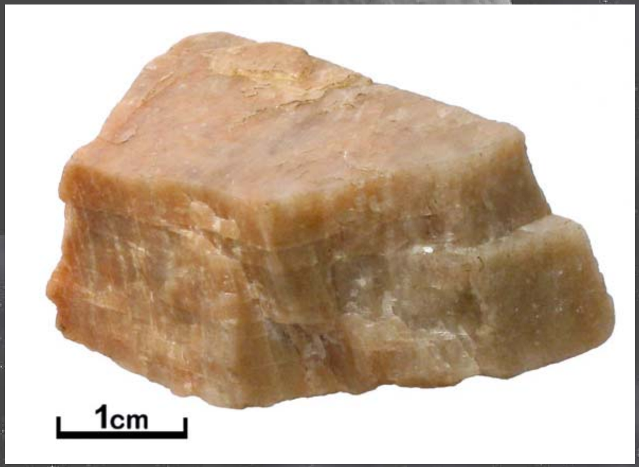
- Naturally-occurring inorganic substances with a definite and predictable chemical composition and physical properties

- Major groups:
  - Silicates
  - Carbonates

- Rocks and regolith can contain also glassy components



How one can extract the composition?

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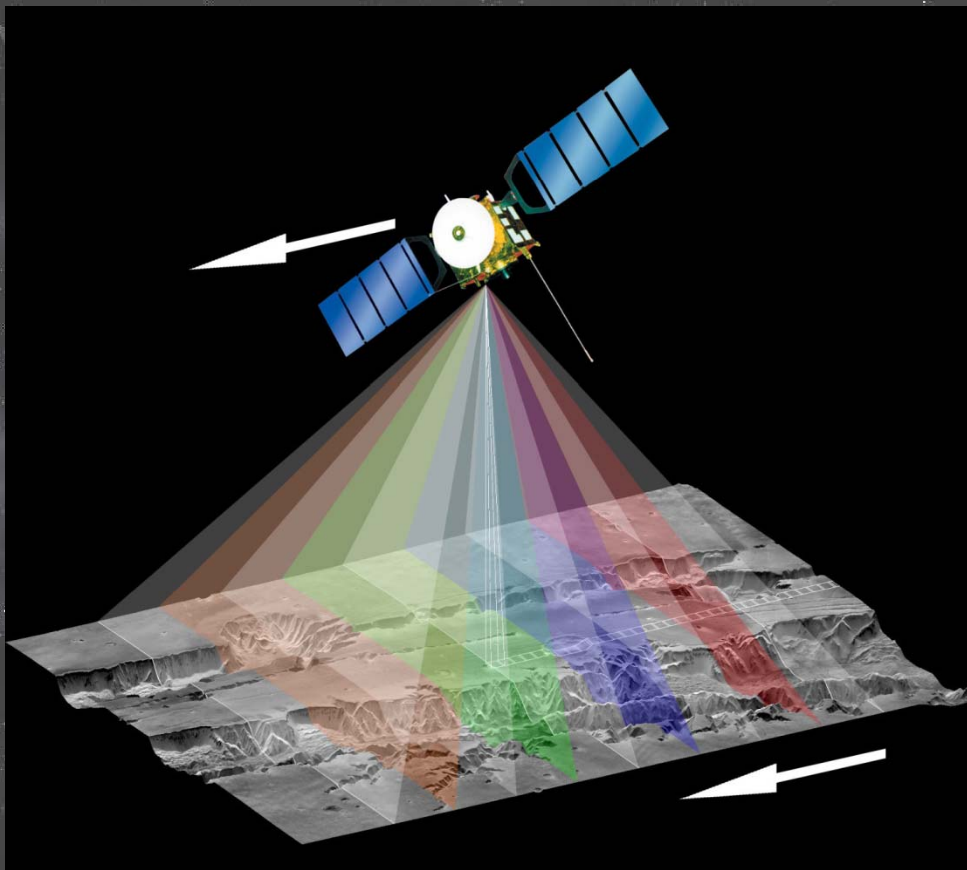
With the knowledge of (simplified view):

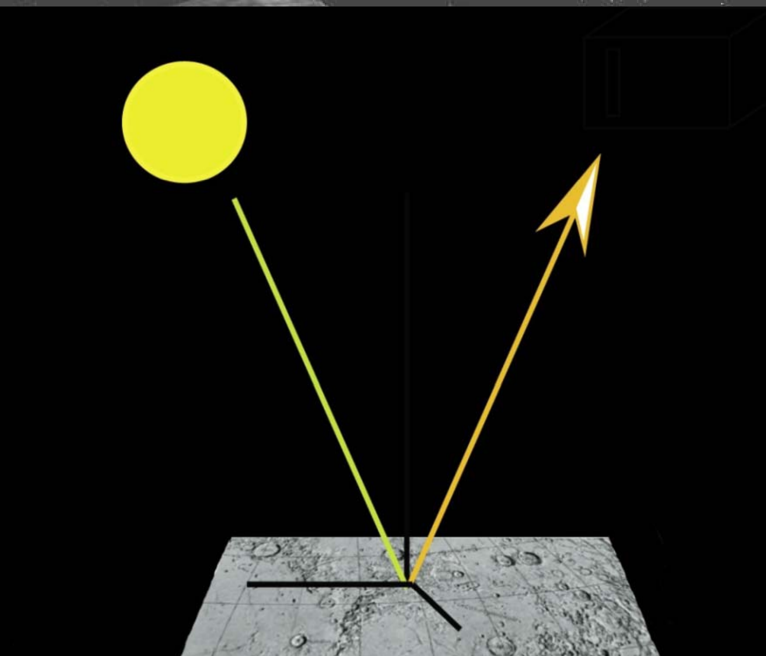
1) known optical constants of various minerals and

2) the observation geometry (phase, emission and incidence angle)

One can MODEL the reflectance of a rock/regolith with mixed grain sizes and minerals!

Operation Principle





Operation principle of a scanning camera (HRSC / Mars Express).
Several line sensors in series are scanning the surface.

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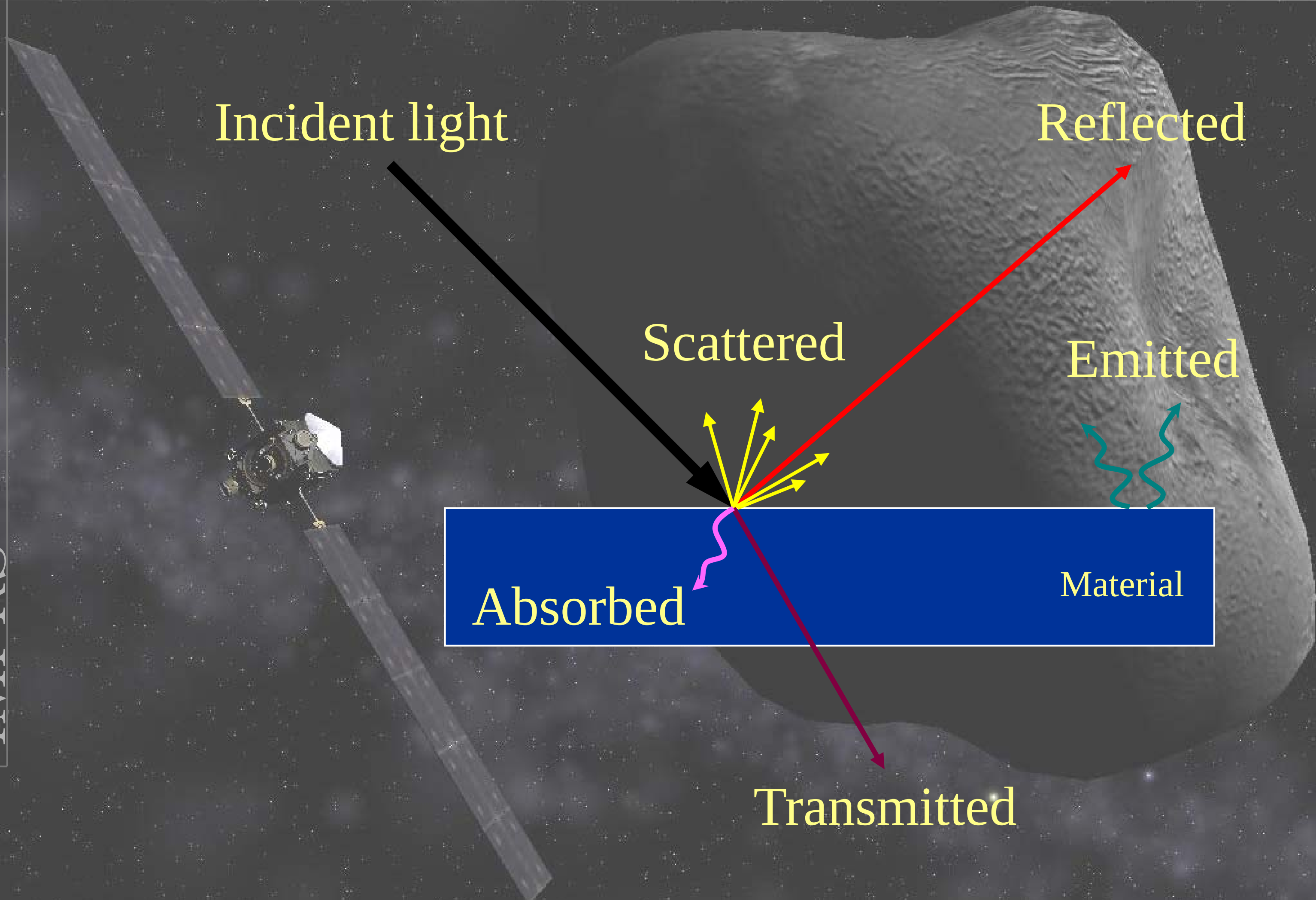
What happens when light hits a rock?



What is a spectrum?

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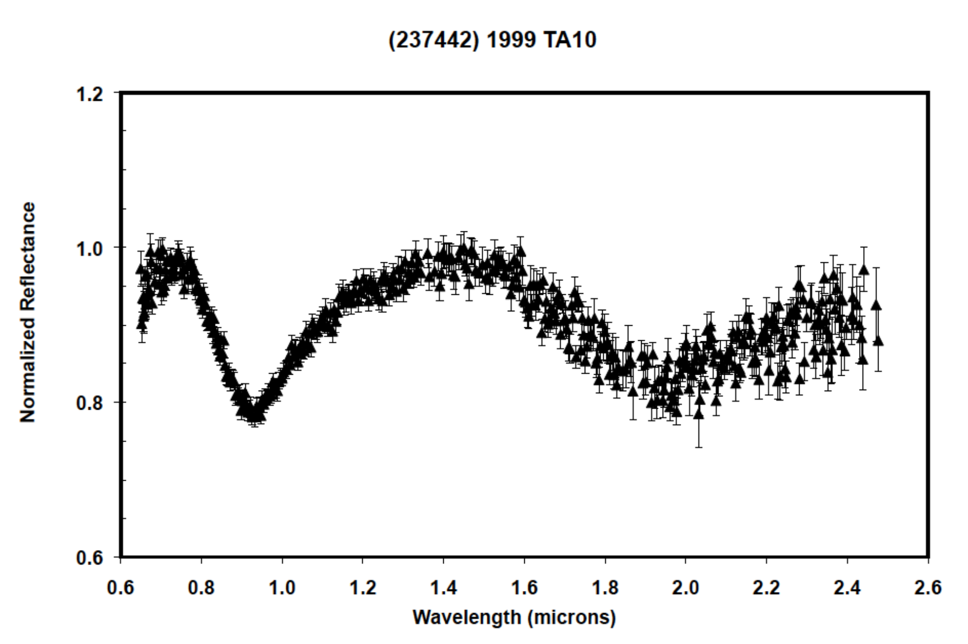
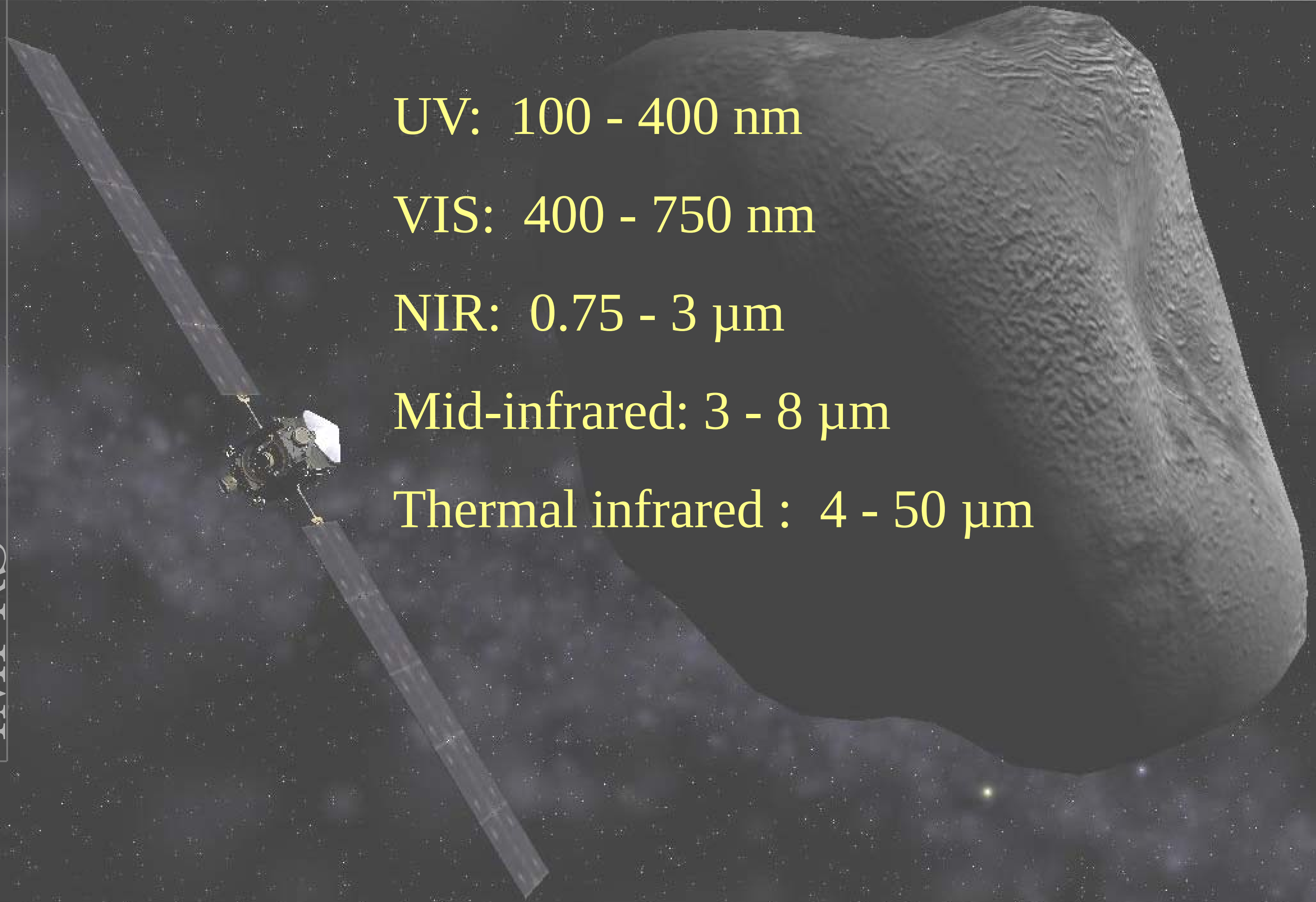
- Variation in a quantity as a function of wavelength.
- “Spectral reflectance” is the reflectance measured in a narrow band of wavelength as a function of wavelength.



Spectral Ranges (in Planetary Science)



UV: 100 - 400 nm

VIS: 400 - 750 nm

NIR: 0.75 - 3 µm

Mid-infrared: 3 - 8 µm

Thermal infrared : 4 - 50 µm

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Why do we get spectra ?

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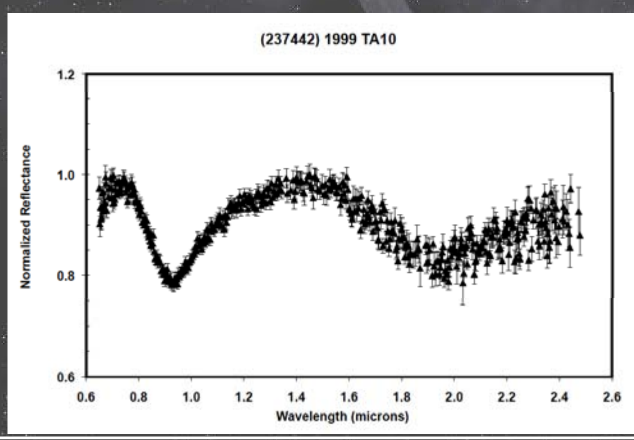
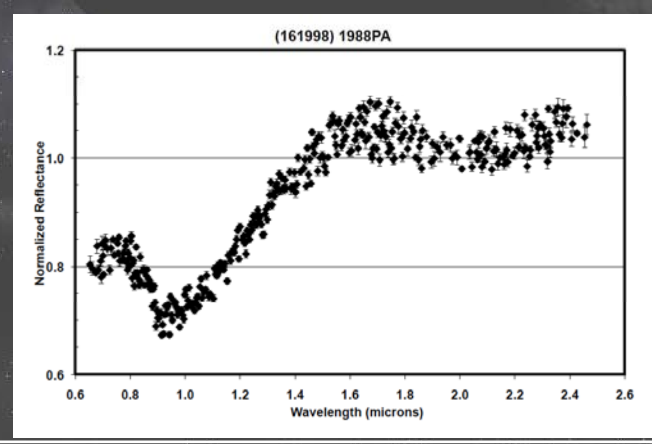
•We can measure the light energy at various wavelengths: spectrum is born

•We examine the maxima and minima of spectral reflectance curves – minima are caused by molecular **absorption**, and we call these **absorption features** or **absorption bands**.

•Differences in absorption and scattering for different wavelengths can be used to identify the minerals.





What causes absorption features?

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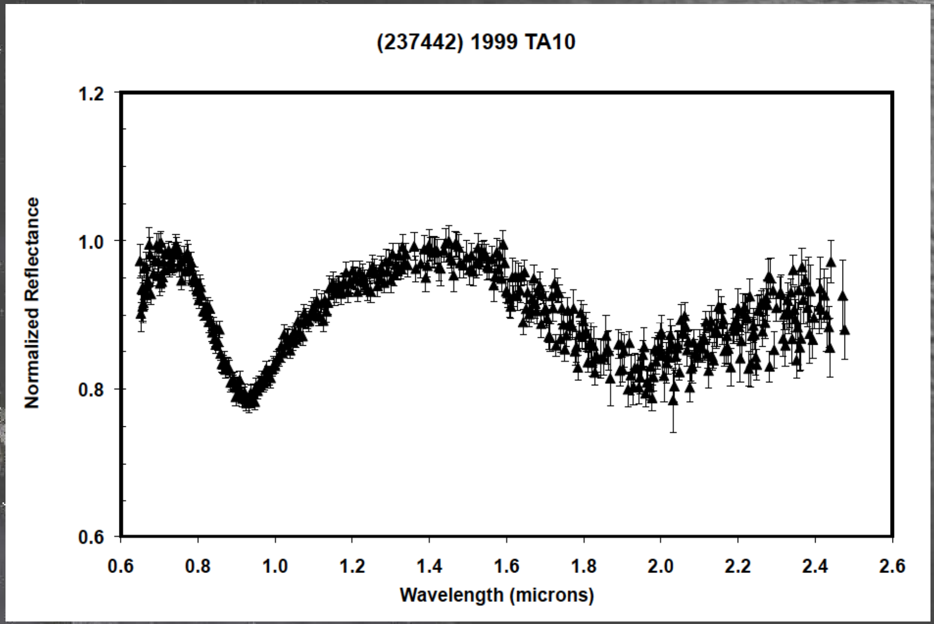
1. Electronic processes (~ 0.1 to 3 µm)
   - Crystal field effect
     - High-energy photons absorbed by bound electrons
     - Energy states/wavelength controlled by the atom and the crystal
     - Primarily interactions with transition metals (e.g., Fe, Ti)
     - Crystal Field Theory (CFT) is used to describe absorptions
   - Charge transfer absorptions (affecting mainly the UV)

2. Vibrational processes (>~6 µm)
   - Excitation of fundamental vibrational motions of bonds in a lattice or molecular compound
     - Wavelength related to strength and length of bonds
   - ~1.5 - ~6 µm are weaker overtones and combination bands
     - Complex transitional region between reflection & emission

Please remember !



Depressions are where things are happening. Peaks are where things are not happening (VIS and NIR only).

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Spectra of rock forming minerals

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- Absorption features that occur in reflectance spectra are a sensitive indicator of mineralogy and chemical composition for a wide variety of materials.

- The investigation of the mineralogy and chemical composition of surfaces delivers insights into the origin and evolution of planetary bodies.

  – e.g. Pyroxene mineralogy and chemistry are important for determining the petrogenesis
  – e.g. Iron content crucial for the degree of body differentiation

Lab spectra and remote sensing

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- Lab spectra of well–characterized minerals and mineral mixtures are the basis for the analysis of remote sensed spectra since only laboratory measurements allow to investigate homogeneous samples in which all parameters can be controlled.

- Lab Tasks

1. Characterization of individual phases (minerals, ices, glasses)
   - mineralogy
   - chemistry
   - particle size
2. Characterization of rocks and mineral mixtures
   - mineralogy
   - chemistry
   - particle sizes
   - packing
3. Characterization of effects caused by the physical environment
   - temperature
   - viewing geometry
   - maturation processes (Space Weathering)

Spectra of rock forming minerals

1) Silicates
   - Olivine: strong absorption at ~ 1 µm due to three overlapping bands
   - Pyroxene:
     - Opx displays strong absorptions around 0.9 µm and 1.9 µm
     - Cpx displays strong absorptions around 0.9 µm and sometimes around 2.2 µm
   - Feldspars: often faint absorption bands
     - Plagioclase for example displays absorption around 1.3 µm
   - Phyllosilicates: partly very sharp and narrow absorptions!

2) Carbonates
   - show a number of narrow, sharp absorption features for wavelengths > 1.6 µm

3) Oxides
   - e.g. spinel (lunar rocks) display strong absorptions near 2 µm
   - iron oxides show strong absorptions in UV

4) Sulfides and Sulfur are barely investigated - Jupiter moons to come -

5) Hydrates (H_2O) and hydroxides (OH^-) - the Moon story -
   - bands located often > 3 µm

6) Metals
   - no absorption features, but reddish spectra, identification via suppressed absorption bands

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Most relevant minerals for remote sensing

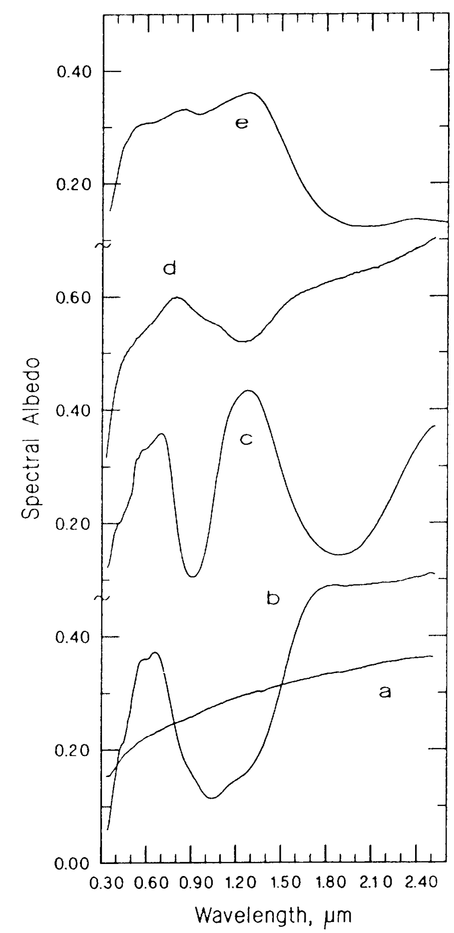
a) Ni-Fe metal

b) Olivine

c) Pyroxene, here Orthopyroxene (offset)

d) Plagioclas (offset)

e) Spinel (offset)



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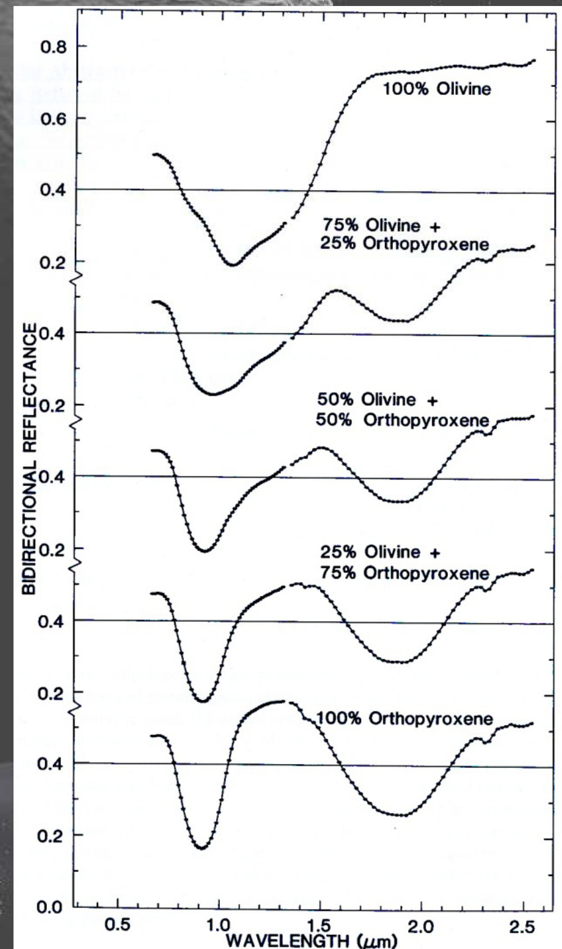
Mineral Mixtures

- Almost all by remote sensing investigated solid surfaces consist of polymict rocks / mineral mixtures and show a wide range of grain sizes
- It's often not possible to uniquely define the contributions of each parameter without independent constraints ➔ ground reference sample helpful for remote sensing



Most regoliths need nonlinear mixing models for composition determination, purely empirical and more quantitative methods including "Gaussian fitting" have been developed

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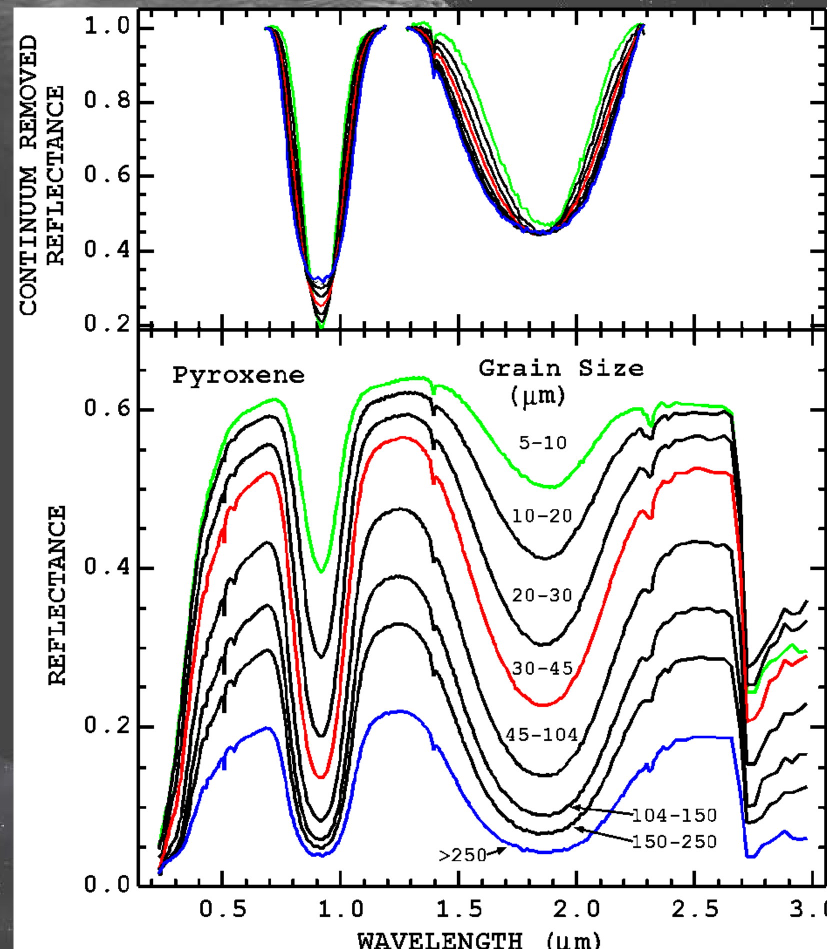
Physical Effects (1) - Grain Size and Albedo

- Particle size and albedo
  - The reflectance of weakly absorbing minerals increases with decreasing particle size
  - The refectance of very strongly absorbing minerals decreases with decreasing particle size
- Particle size and contrast
  - Absorption band contrast varies with particle size but <u>does not affect positions of absorption features</u>



Grain size needs to be considered.

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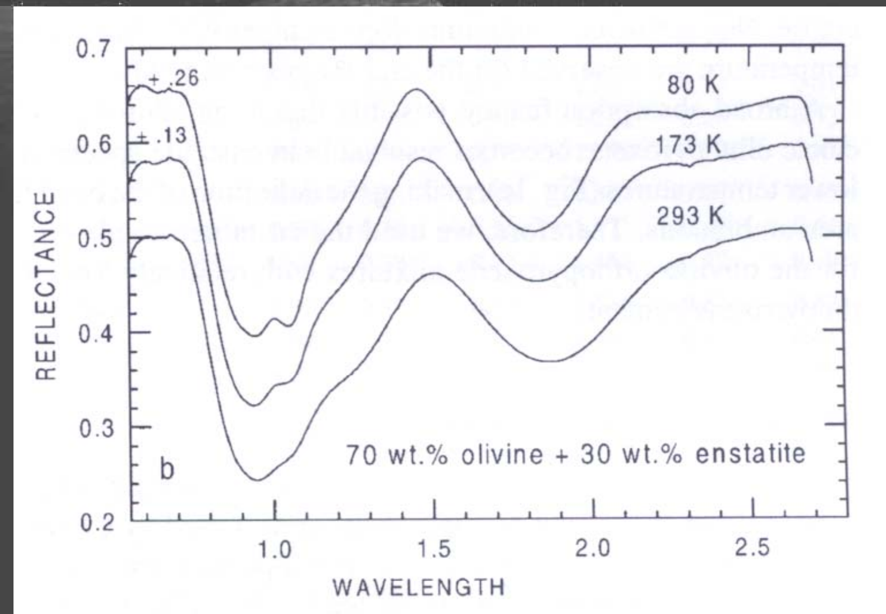
Physical Effects (2) - Temperature

- Lowering of sample temperature can lead to:
  1) Slight negative shifts of absorption band positions
  2) Splitting of absorption bands



For detailed investigations: Temperature difference between observed surface and lab sample to be considered

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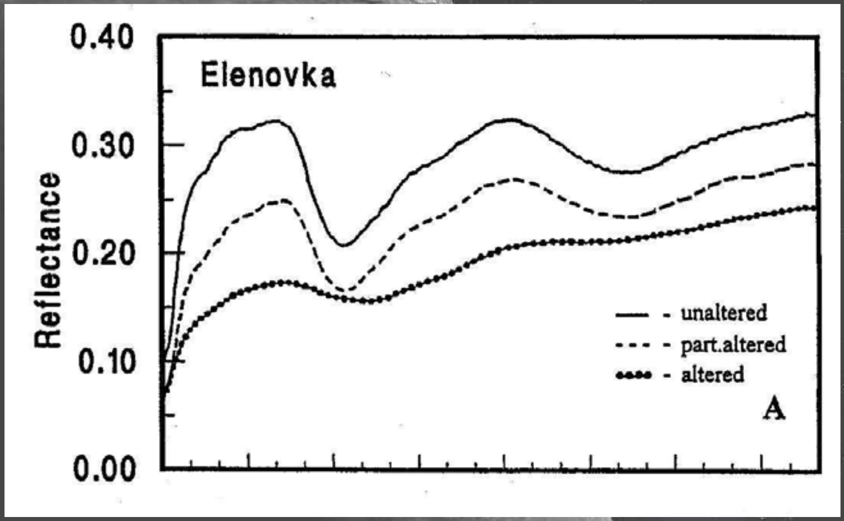
Physical Effects (3)
Maturation – Space Weathering

Solar and cosmic radiation + micrometeoritic bombardment



- Lowering of albedo
- Reddening of spectral slopes
- Weakening of absorption bands

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Physical Effects (4) - Geometry

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Phase angle increase leads to:

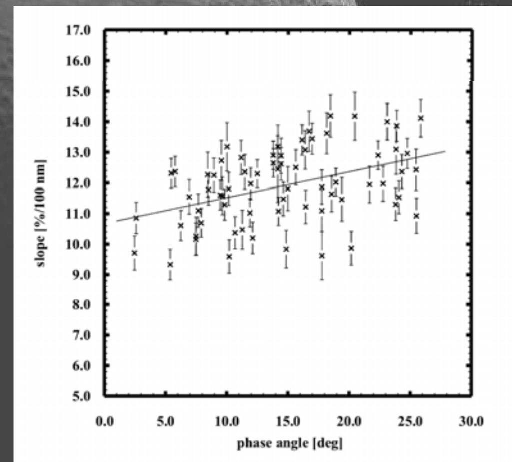
1) "phase reddening", i.e. the steepness of the spectral slope outside of absorption features increases

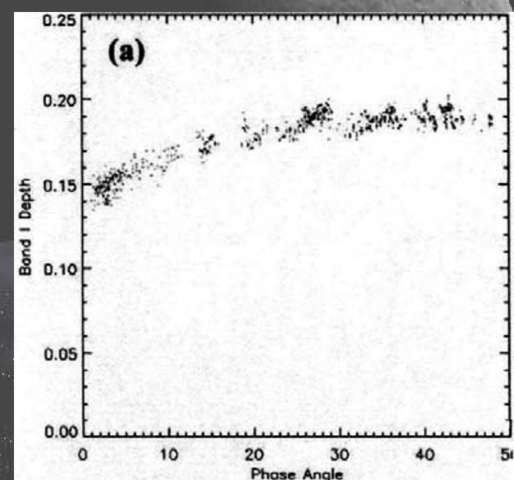
2) Absorption band depth increase for several targets detected

3) The phase angle influence on the spectral shape seems to depend also on the observed target

→

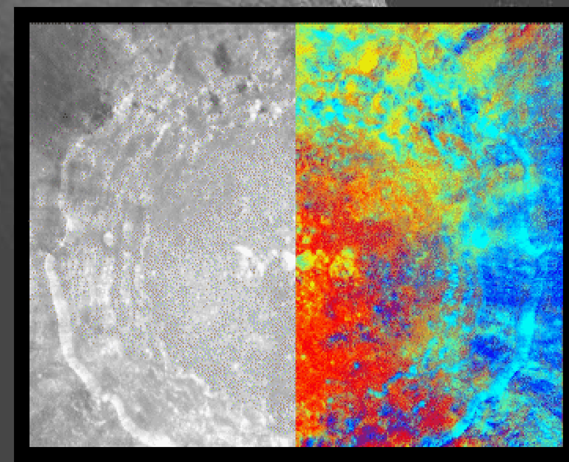
Photometric correction required



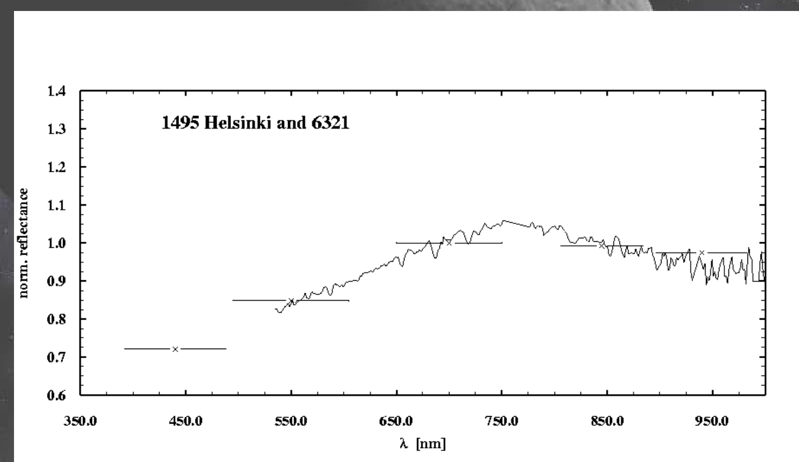


Color Photometry + Spectroscopy

- Color photometry (filter):
  - Advantages:
    - Large surface area coverable in one exposure
    - Morphological information
  - Disadvantages:
    - Often low spectral resolution ➔ raw mineralogical analysis
    - Colors not measured simultaneously ➔ further calibration/correction required



- Spectroscopy:
  - Advantage:
    - High Spectral resolution and simultaneous measurements ➔ best possible composition analysis
  - Disadvantage:
    - No or limited morphological information



Sources of spectra information

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Ground-based Telescopes

- Low costs
- Large number of targets
- Low spatial resolution

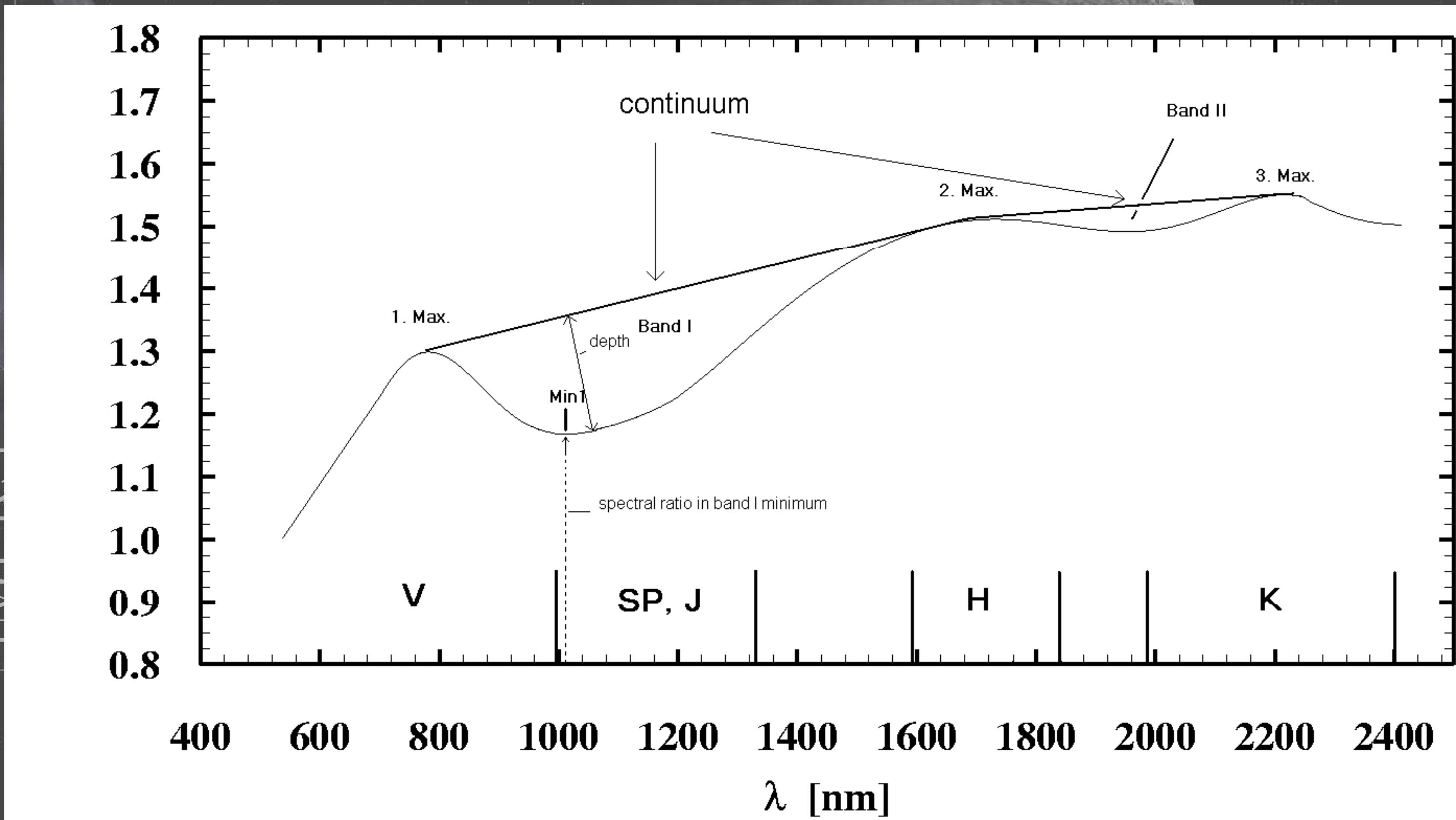
- Invisibility of surface areas (e.g. lunar poles and far-side)
- Disturbances by Earth atmosphere (except e.g. HST)
- Time slots for observations to be watched

Spacecrafts

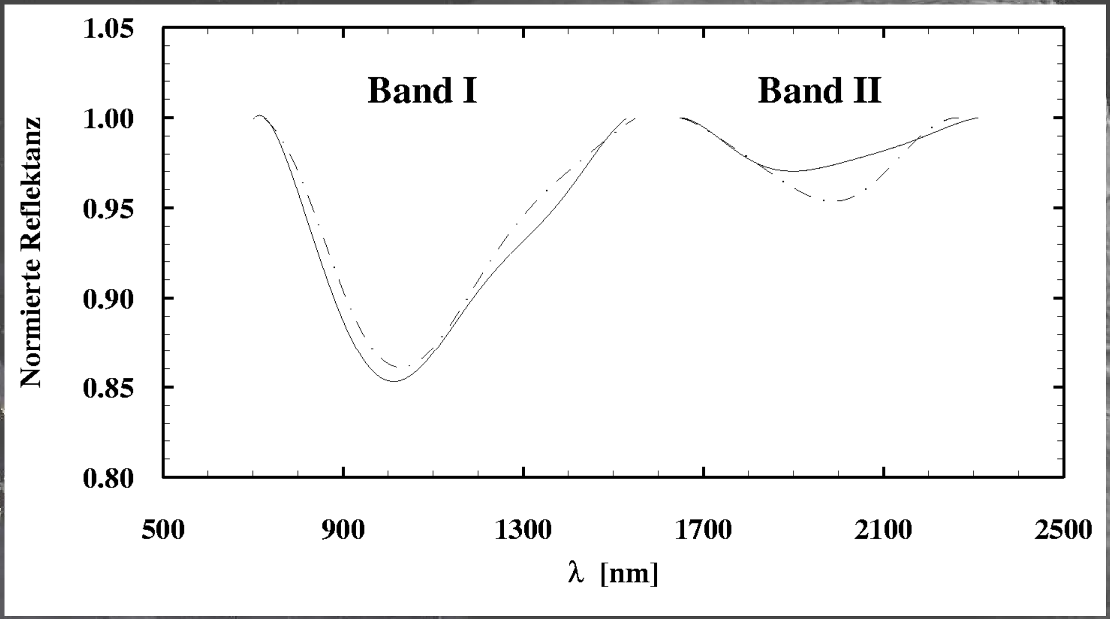
- High spatial resolution
- Visibility of the whole (illuminated) surface

- Higher risk
- High costs
- Low number of targets

Mineralogical analysis of spectra
calibrated spectrum



Continuum corrected spectrum



- Band I and Band II depths and band centers
  - → Cation content of pyroxene and olivine (olivine: Band I only)
  - Type of Pyroxene
- Band II / Band I area ratio
  - → Olivine-Pyroxene abundance ratio

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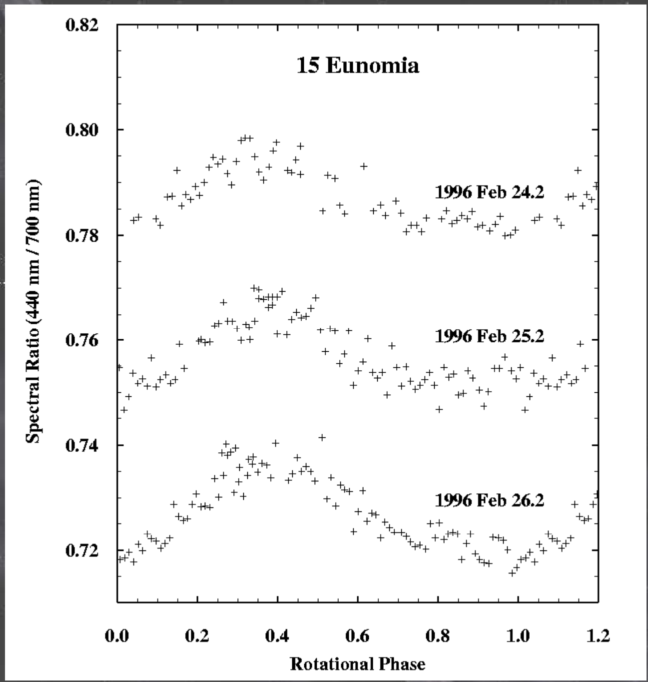
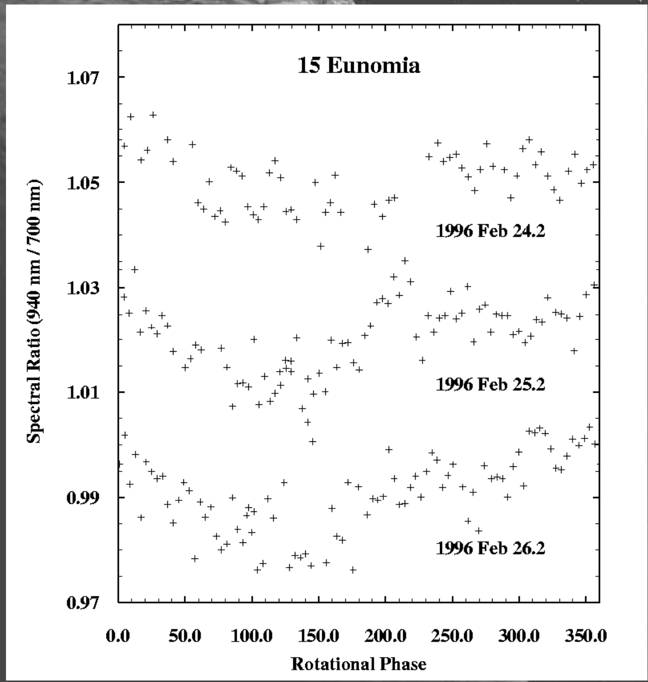
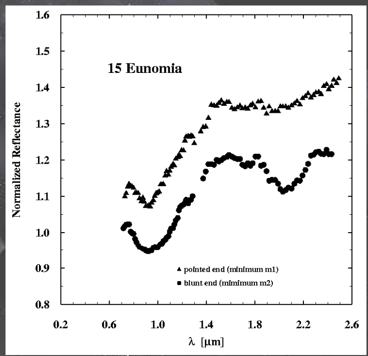
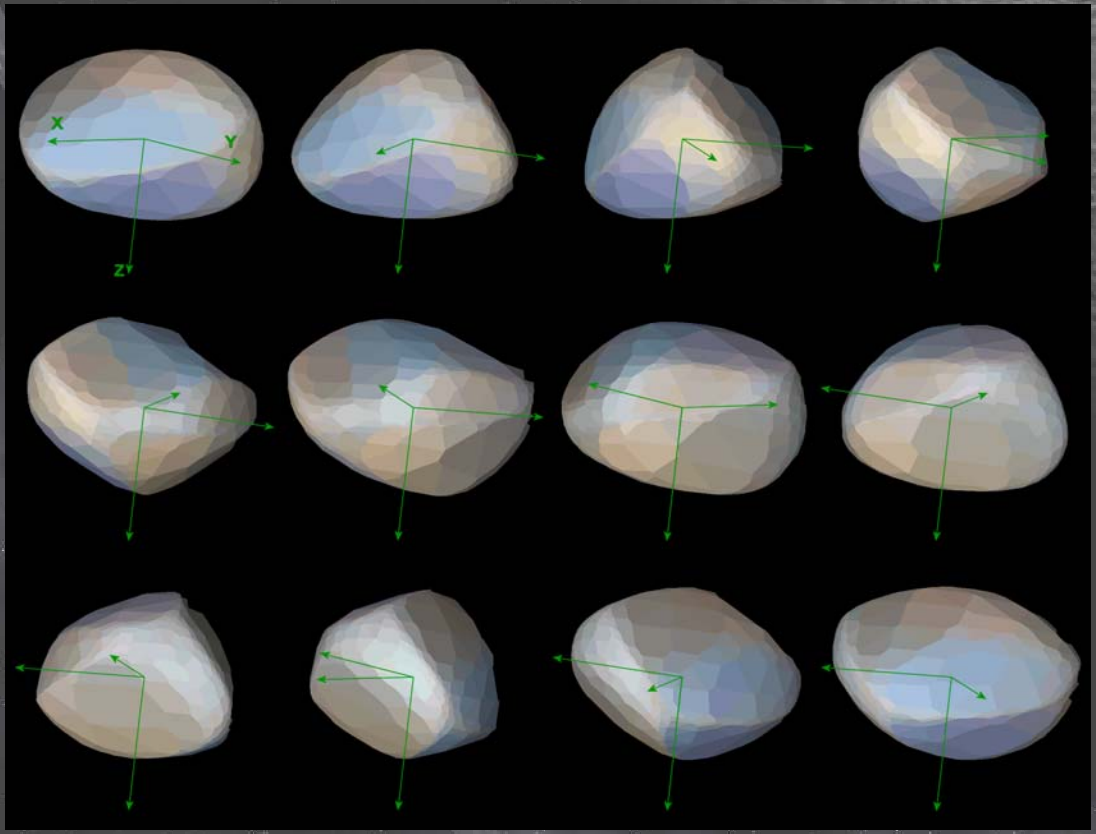
Spectral variations as indication for mineralogical variation on15 Eunomia (1)





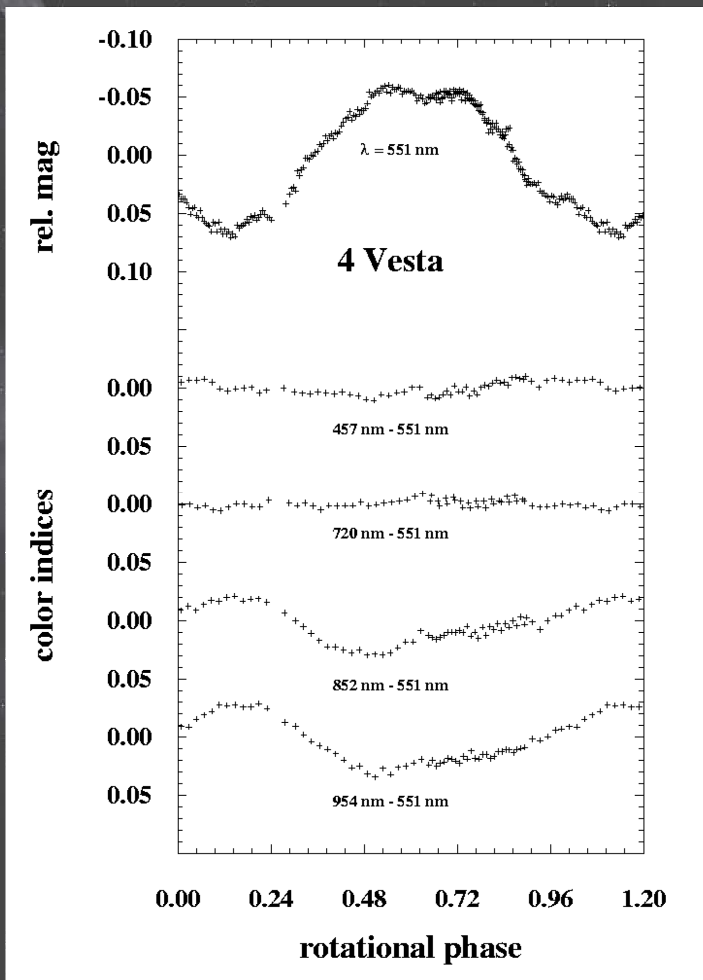


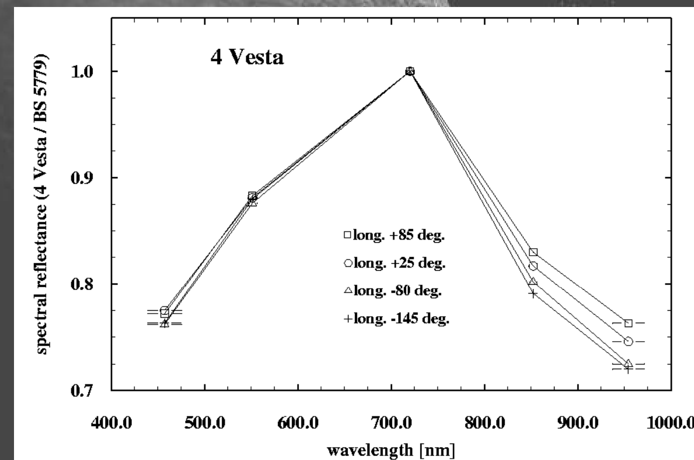
Spectral variation as indication for mineralogical variations on 15 Eunomia (2)

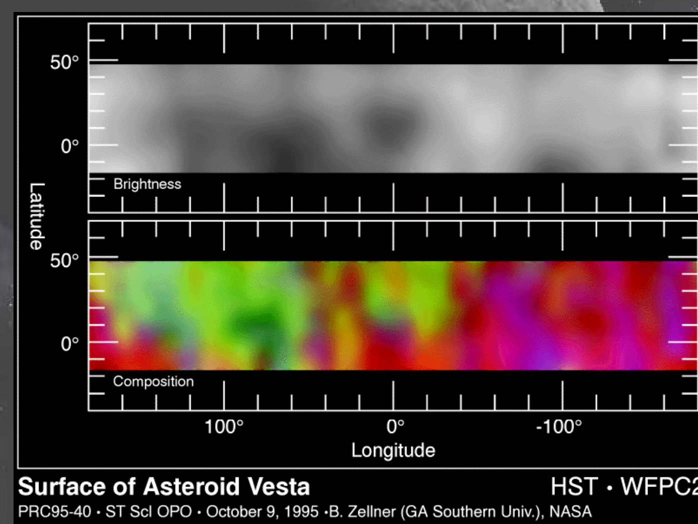


Color-shape model of 15 Eunomia according to Nathues et al. (2005). False color representation: blue – 440 nm, green – 700 nm and red – 940 nm.

Spectral variations as indication for mineralogical variation on 4 Vesta







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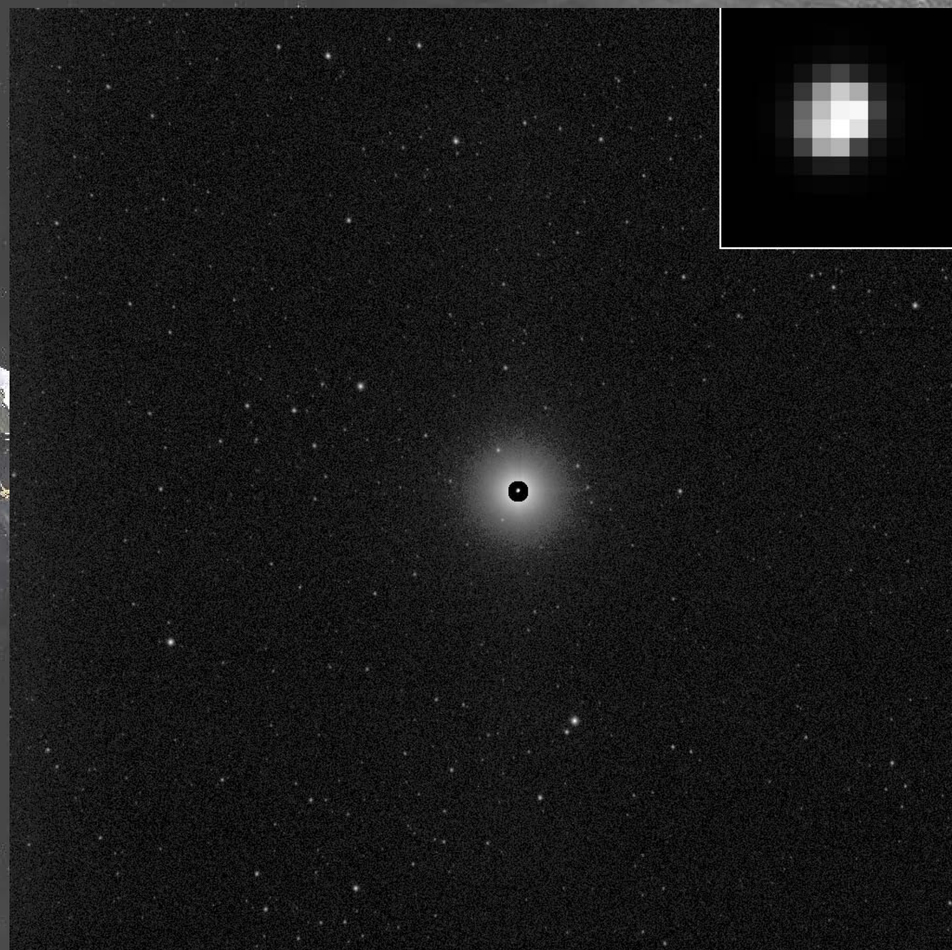
Watch out: Dawn approaches Vesta



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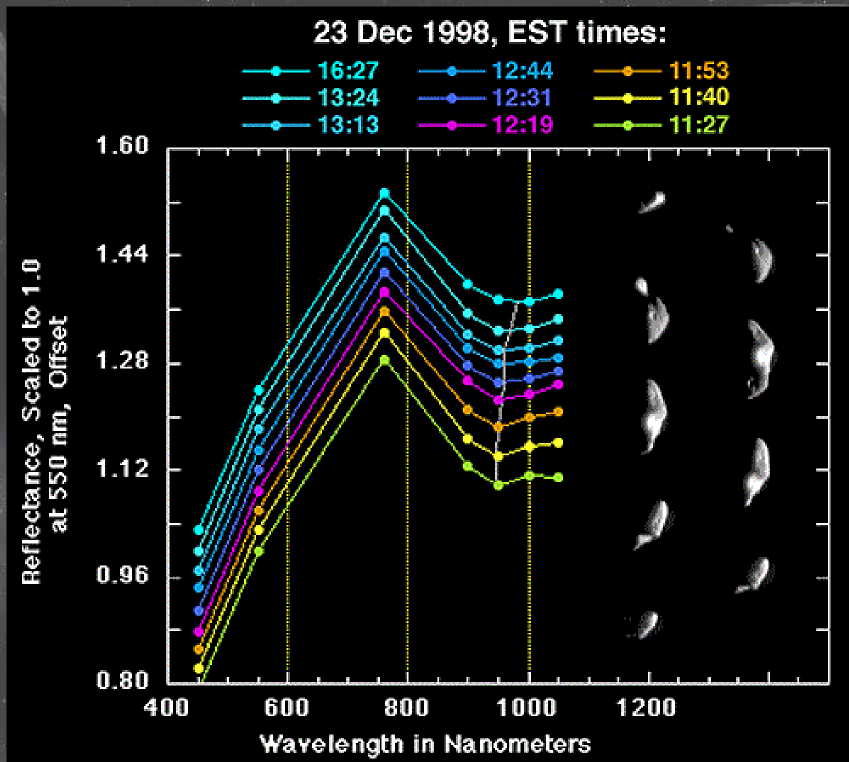
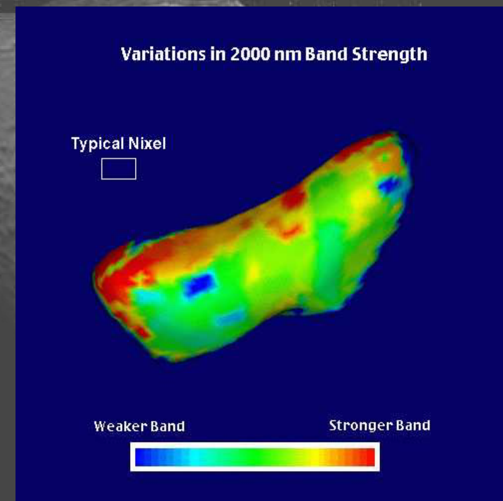
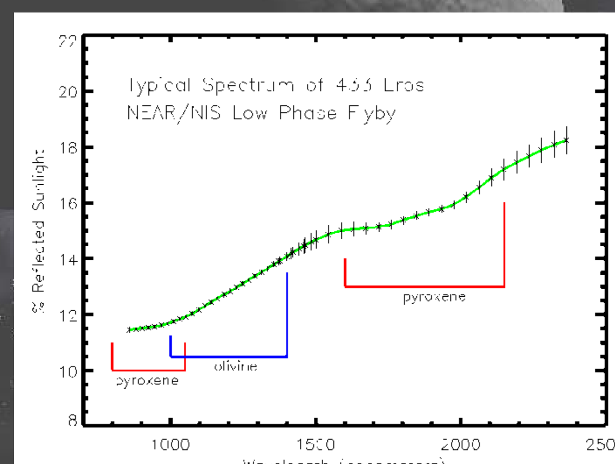
NEAR at 433 Eros







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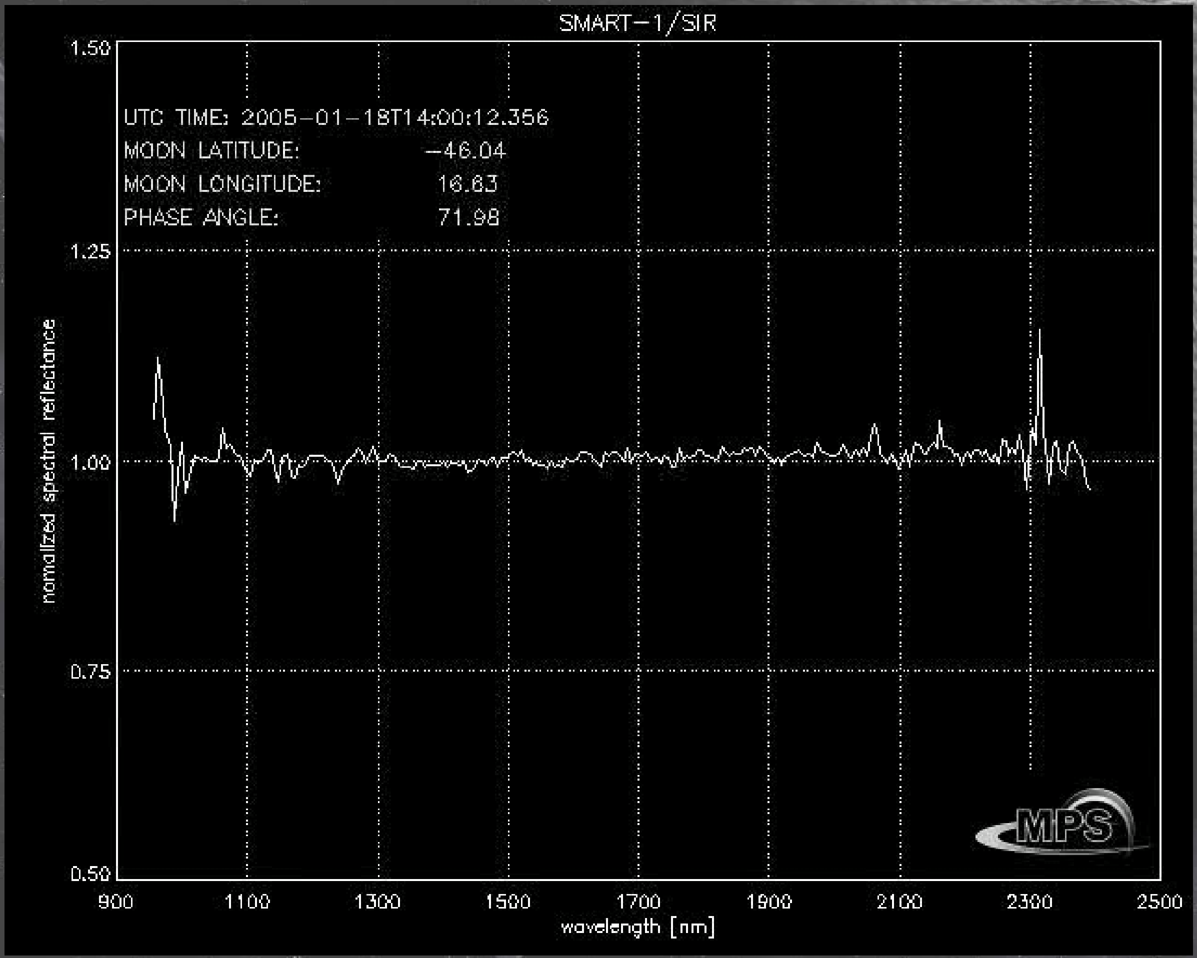
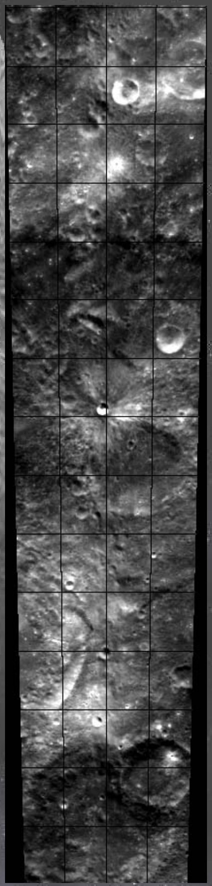
SMART-1 / SIR lunar scans





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