Solar System Science for SOFIA

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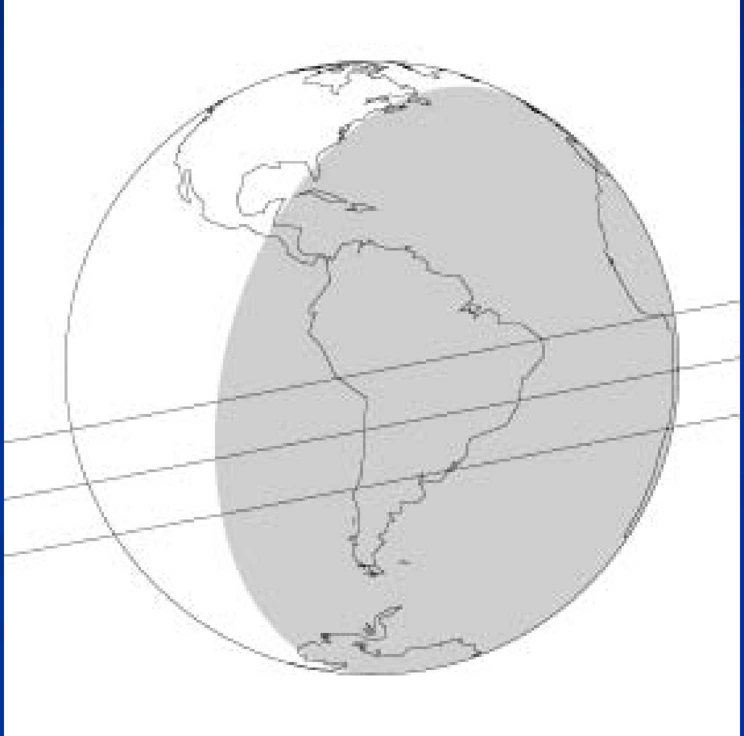
Solar System science in the SOFIA science vision document, 2009

- Primitive bodies
  - Trans-Neptunian objects (TNOs), centaurs and asteroids
    - Atmospheres of TNOs from stellar occultations
  - Comets—mineralogy, water, organic molecules
- Extrasolar planetary material
- Giant planets
  - Global studies, atmospheric chemistry, spatial/temporal variations
- Venus
  - Atmospheric structure, chemical and isotopic composition
- Titan, a prebiological organic laboratory
  - Atmospheric chemistry

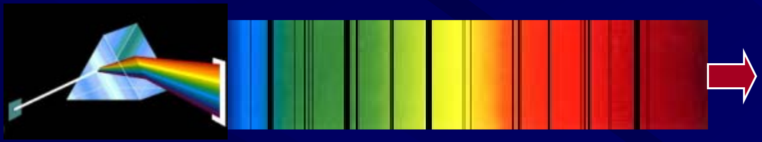
Occultations of stars by Trans-Neptunian Objects (TNOs) with SOFIA

- Objectives
  - Establish accurate diameters
  - Probe for atmospheres ←
  - Search for close companions
- Approach
  - Target brightest TNOs
  - Observe from optimum locations
  - Make simultaneous optical/IR observations with HIPO and FLITECAM
- Prediction Strategy
  - Improve orbits for the largest (~30) KBOs
  - Maintain list of possible events
  - Refine astrometry for the best possibilities
  - Select events to observe (error ≤ 1500 km)
  - Final prediction refinement in flight?



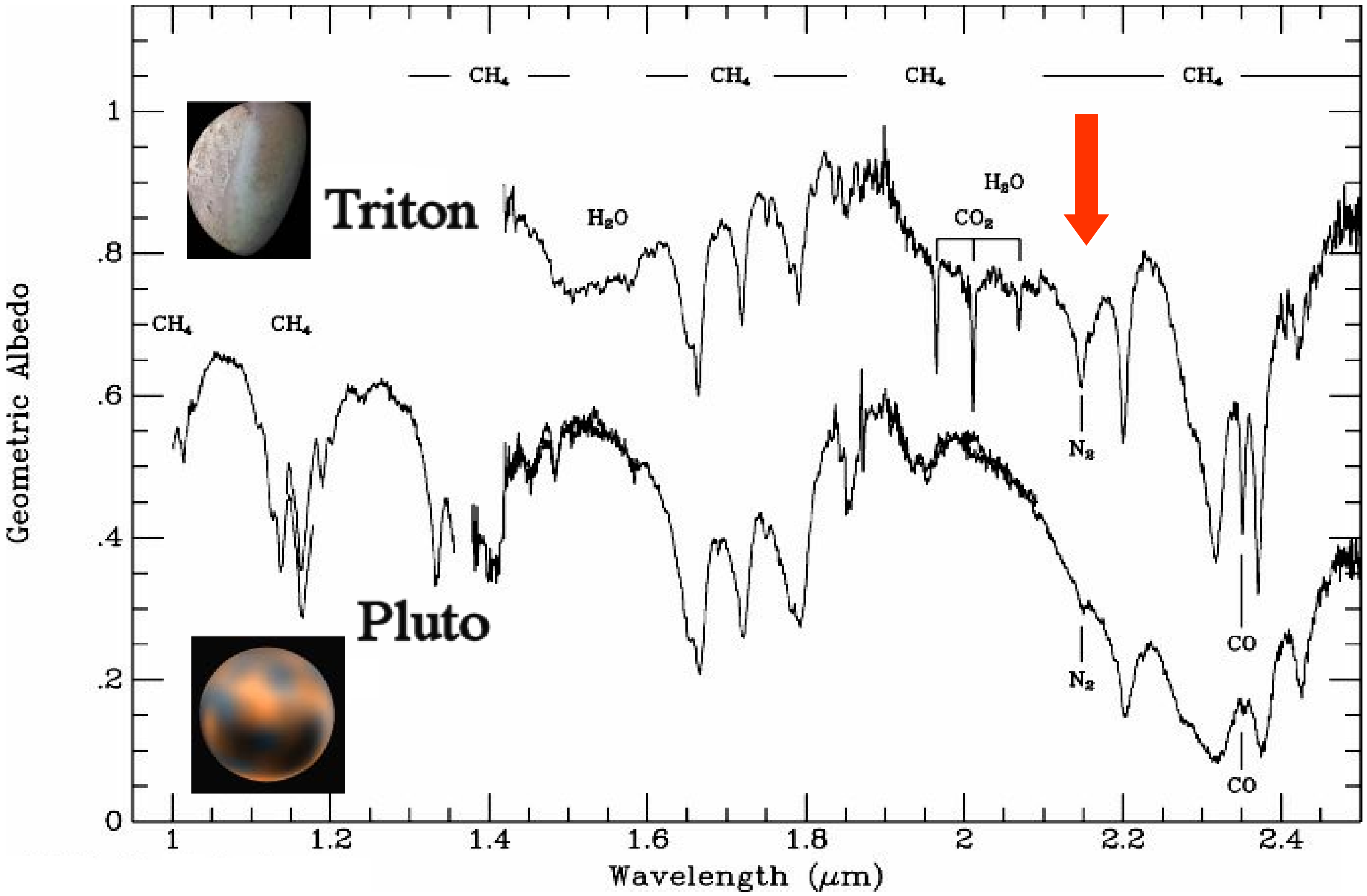
Typical large TNO shadow path

Slide from Ed Erickson



The ices of Triton and Pluto

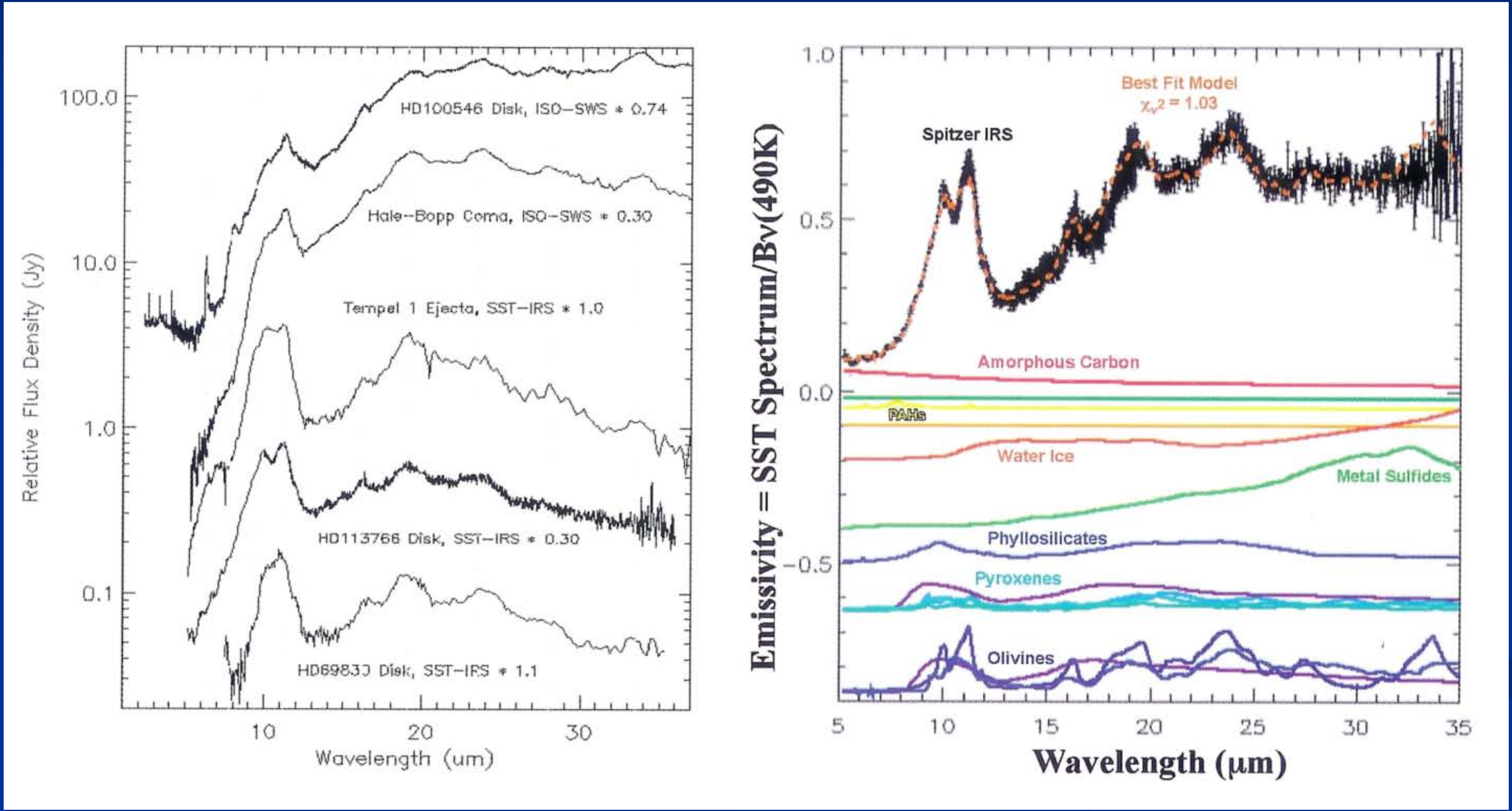
N_2 CH_4 H_2O CO (CO_2)



Trans-Neptunian Objects: Spectral evidence for thin atmospheres

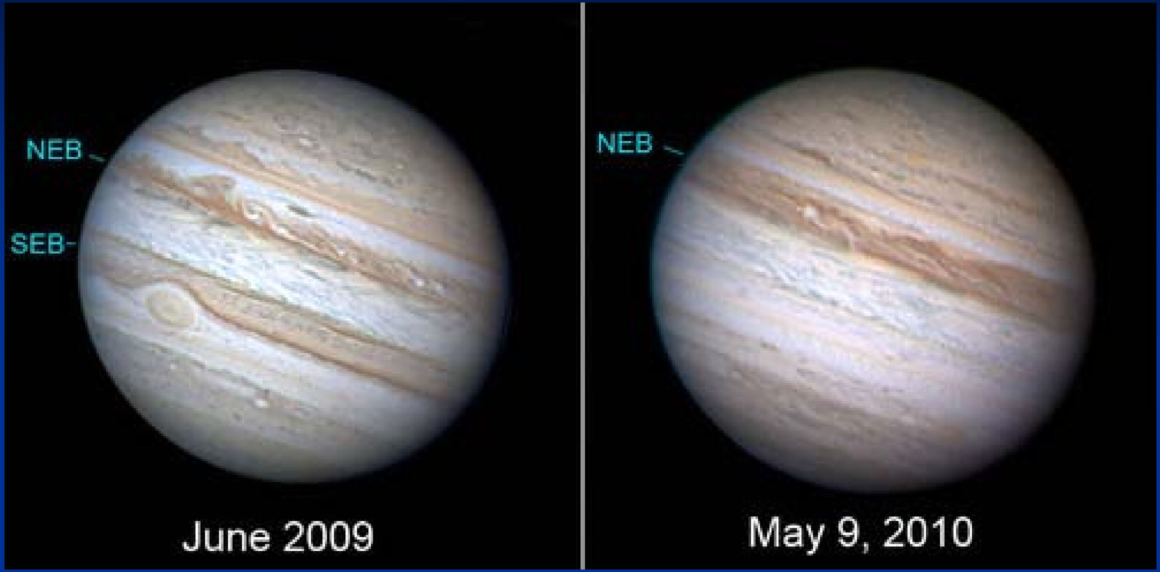
- CH_4 ice bands shifted in wavelength
  - Indicates that CH_4 occurs in an N_2 matrix
- Presence of the 2.15- µm N_2 ice band
  - The β – phase of N_2 implies that $T > 36$ K
- Therefore, the “high” temperature implies an atmospheric pressure of several microbars of N_2
- Occultation lightcurves from SOFIA can give information on atmospheric structure and presence of haze layers

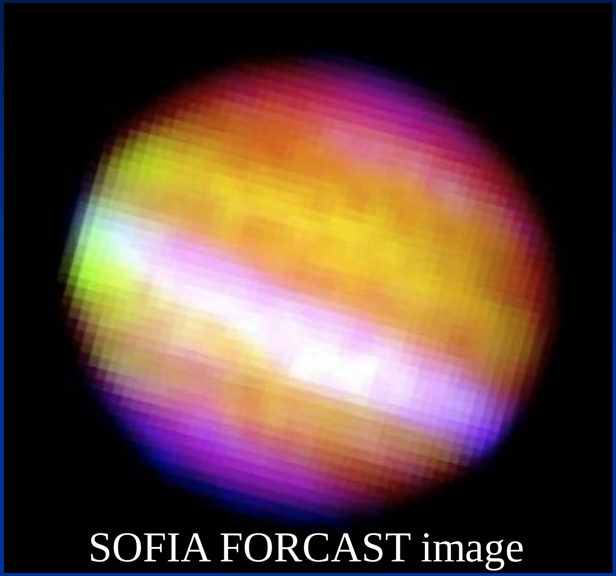
Comet spectra and protoplanetary and debris disks compared



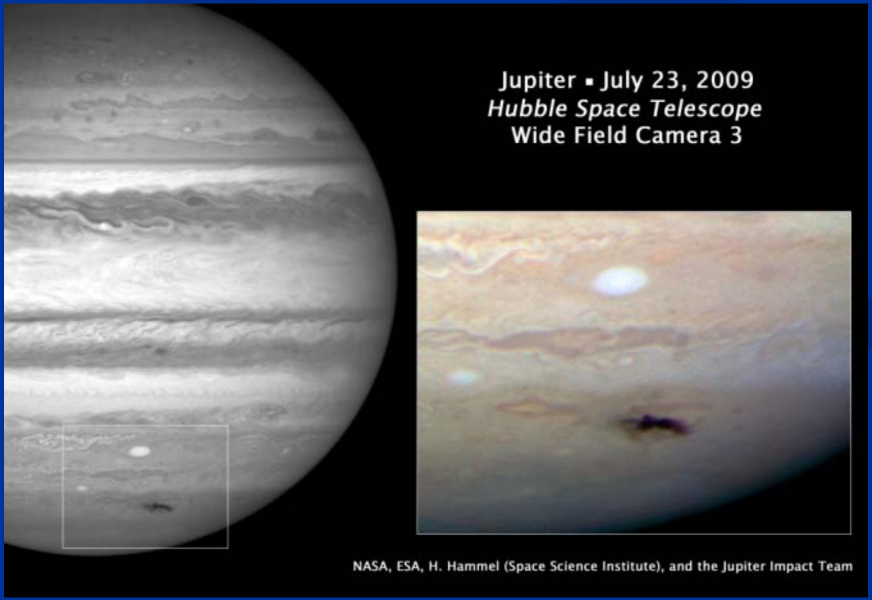
Lisse et al., 2008

Jupiter is a changing planet …




SOFIA FORCAST image

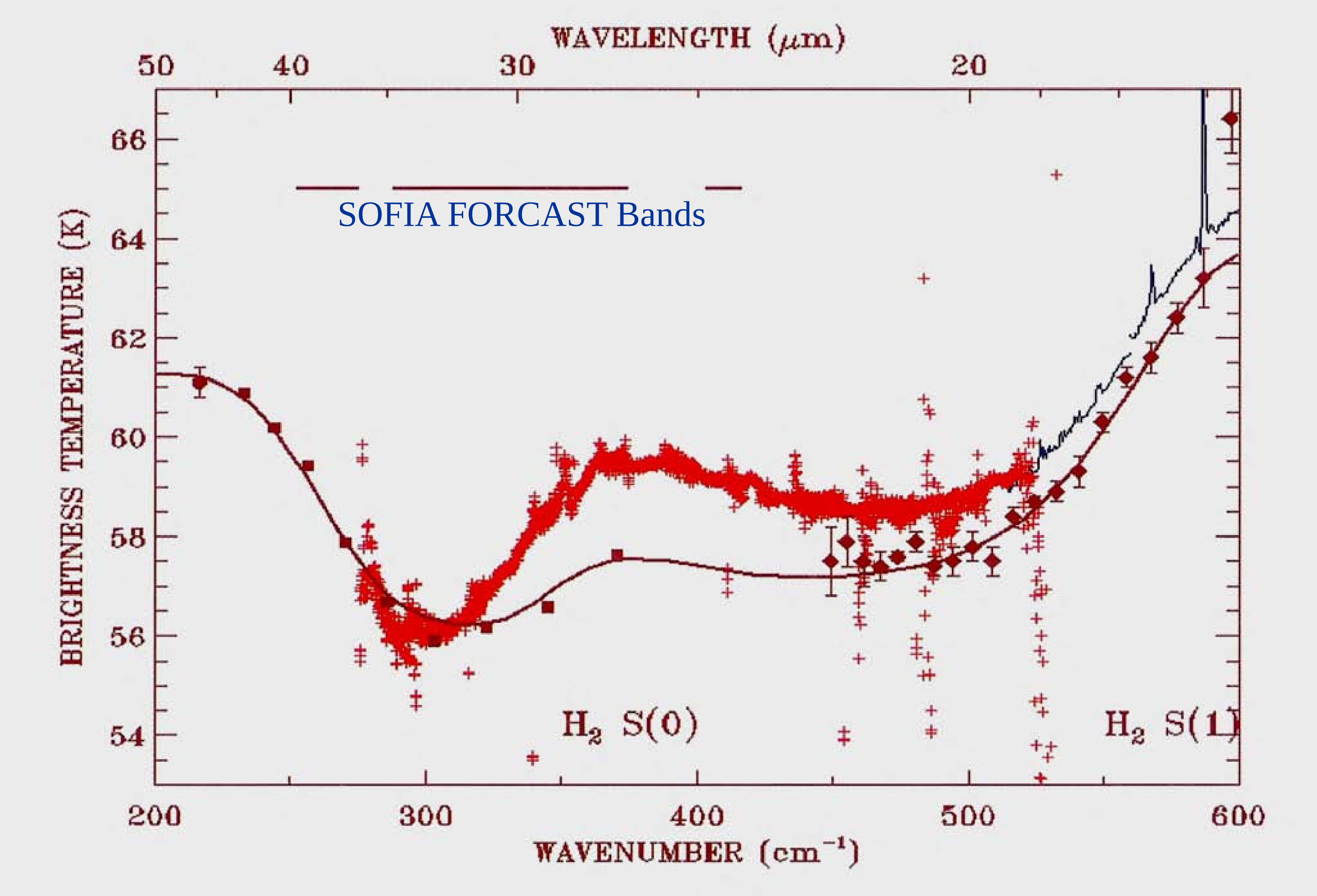
Disappearance of the South Equatorial Belt, 2009-2010



NASA, ESA, H. Hammel (Space Science Institute), and the Jupiter Impact Team

Impact scar in the atmosphere, 2009

Neptune’s pressure-induced H_2 spectrum



Key: ■ ISO SWS, ♦ Orton’s model, + Spitzer IRS LH

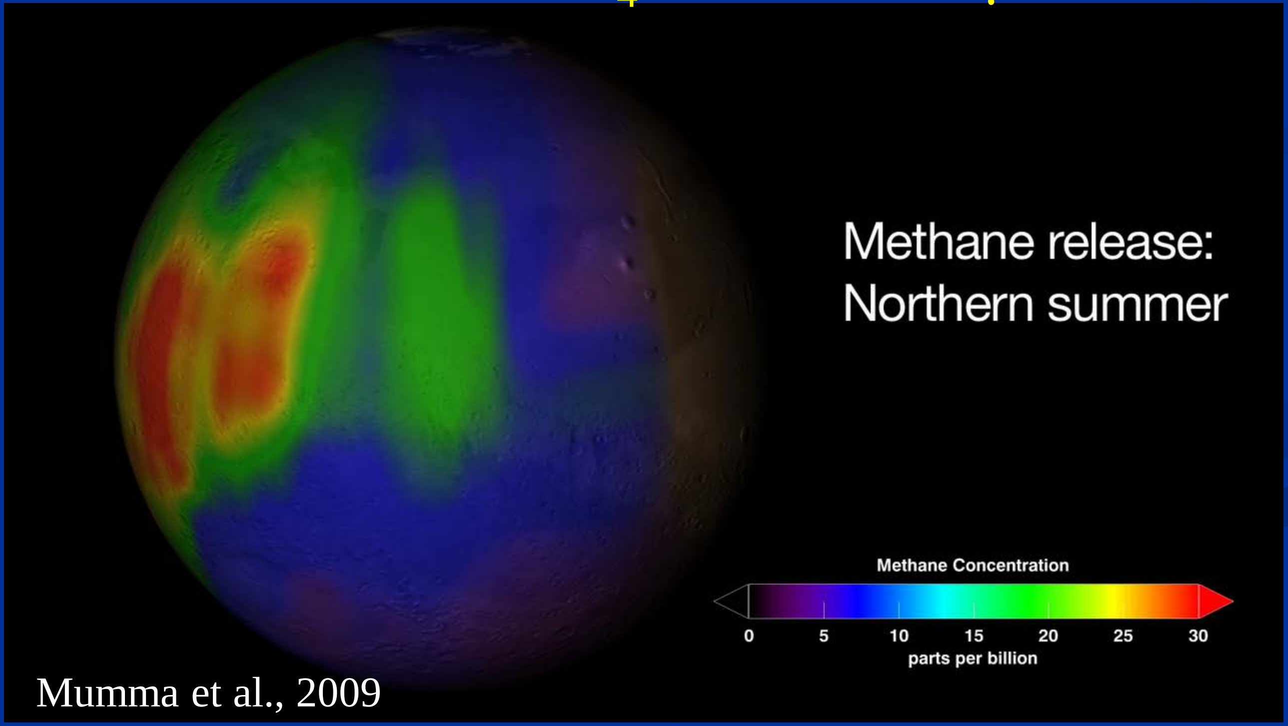
- The atmospheres of Saturn, Uranus and Neptune are seasonally variable

- The 20-year lifetime of SOFIA corresponds to the transition of Uranus from equinox to solstice

An outstanding problem: Methane on Mars?

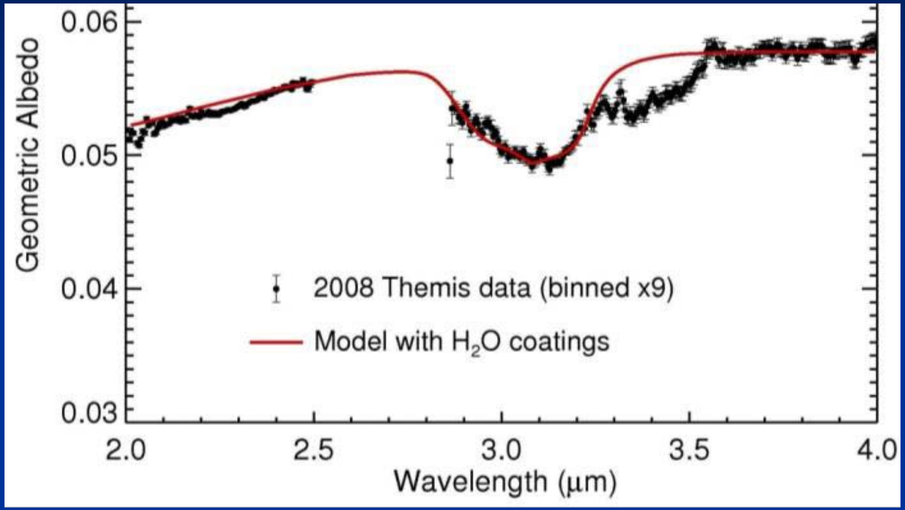
A problem for EXES at high spectral resolution and smaller telluric CH_4 column abundance

The CH_4 detection is based on a doppler-shifted Mars lines seen on the wings of lines in the telluric CH_4 band at 3.35 μm

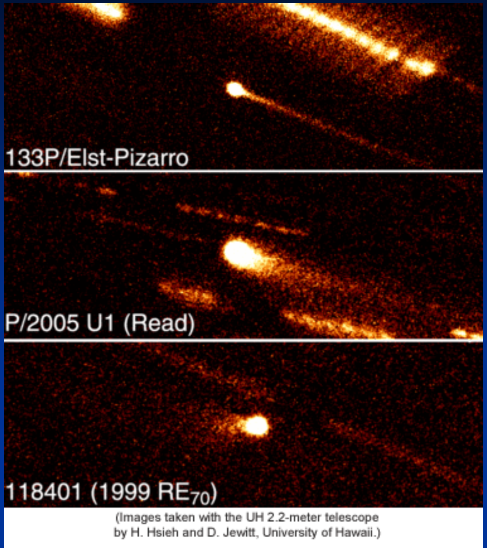


Mumma et al., 2009

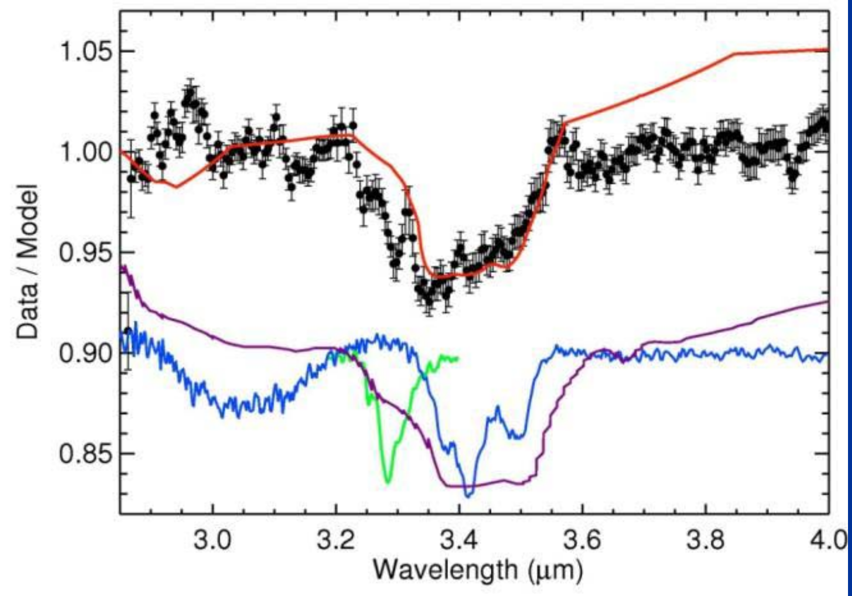
Recent Discoveries, 2.5-5 µm – H_2O ice and Organic Solids on an Asteroid



H_2O ice coating on surface grains, asteroid 24 Themis



"Main Belt" comets may have near-surface ice



Organic signatures on 24 Themis after removal of H_2O ice band:

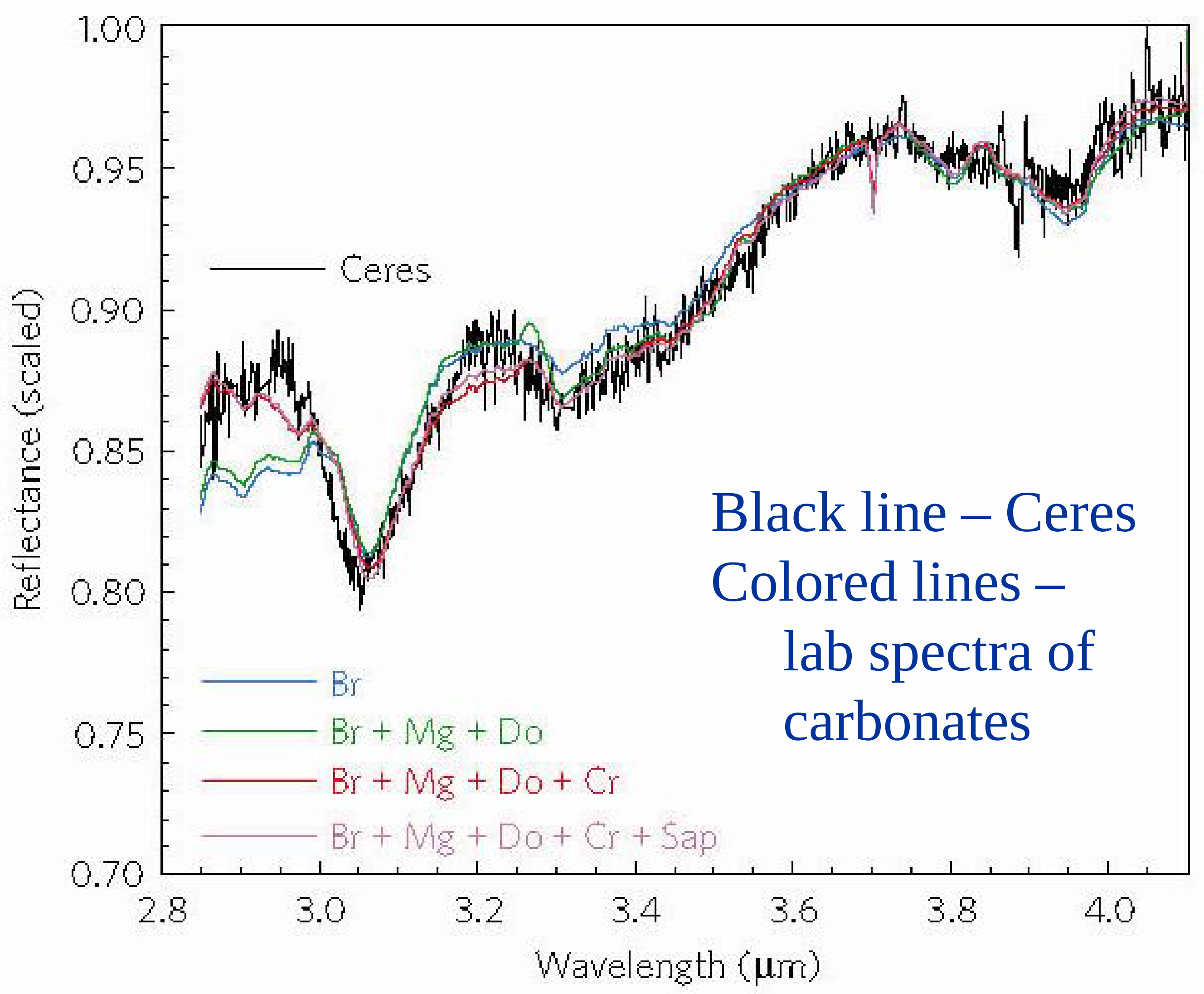
Green = PAHs

Violet = Asphaltite

Blue = Carbonaceous meteorite

Rivkin et al., Campins et al. 2010

Recent Discoveries, 2.5-5 μm – Carbonate minerals on an asteroid reveal a history of liquid water



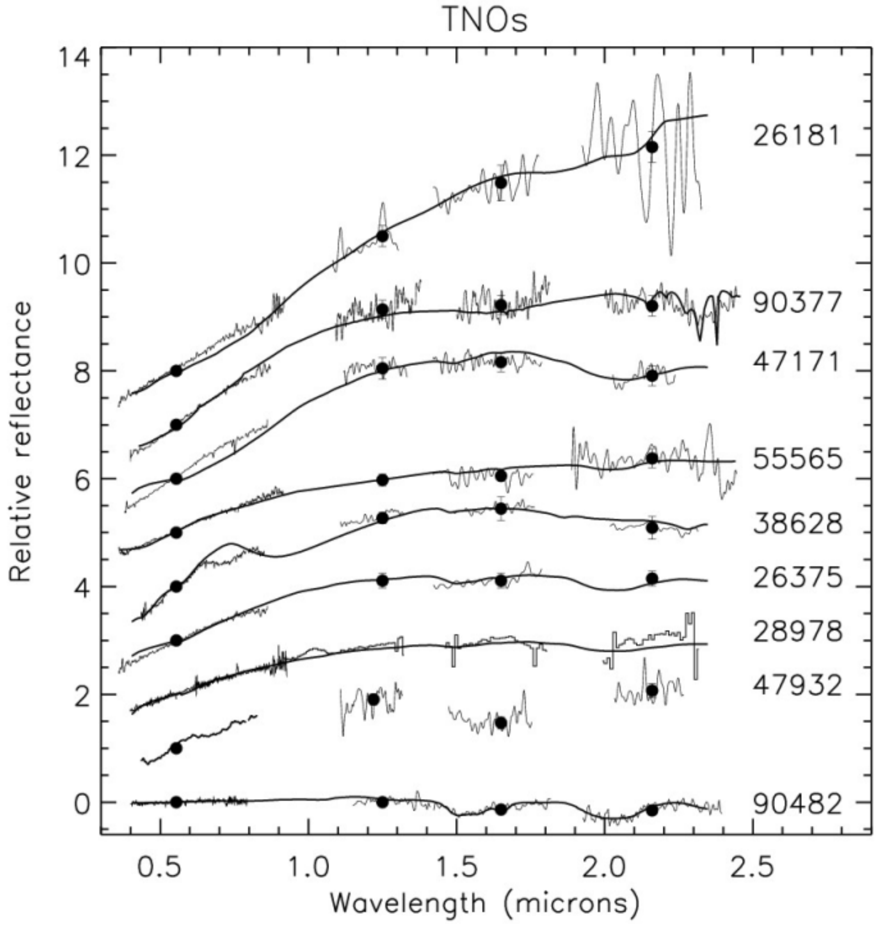
Black line – Ceres

Colored lines –
lab spectra of carbonates

The asteroid parent bodies of carbonaceous meteorites were also altered by liquid H_2O

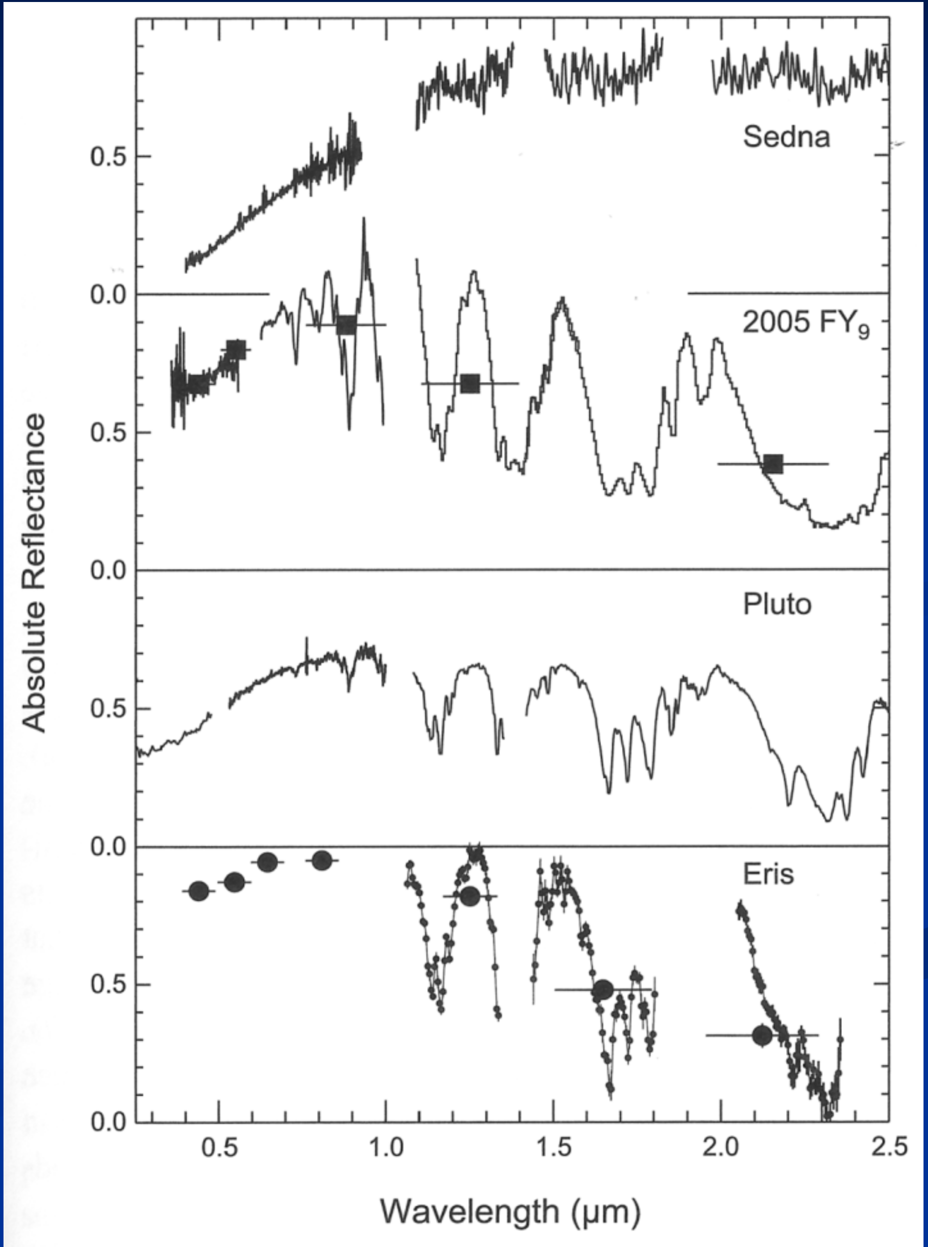
Spectroscopy of Trans-Neptunian Objects 0.5-2.5 μm

Colors range from neutral to red, both with and without H_2O ice.

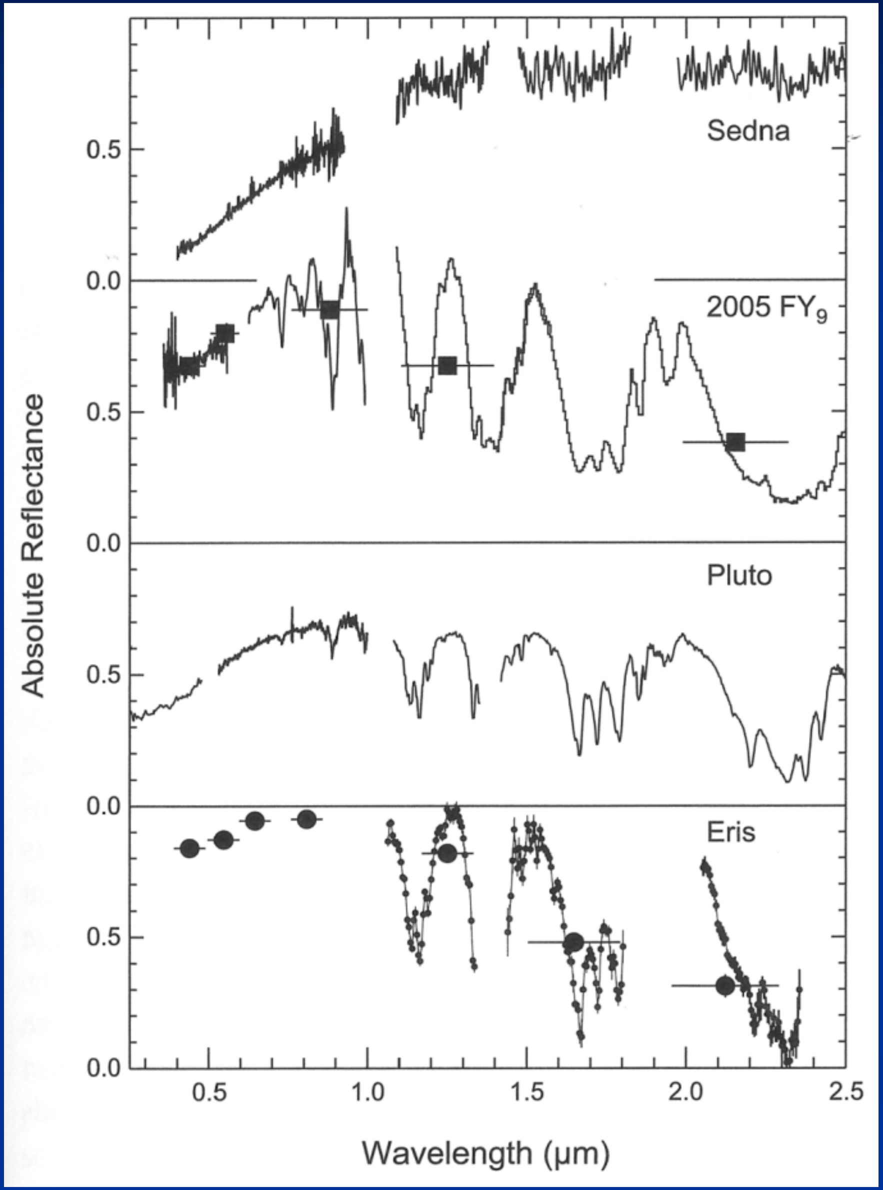


Barucci et al.

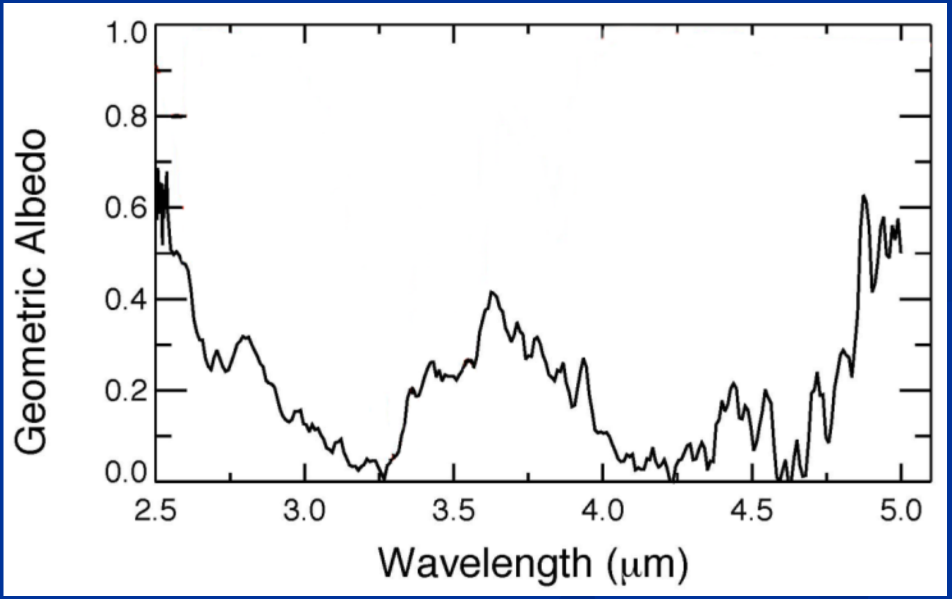
CH_4 -bearing TNOs



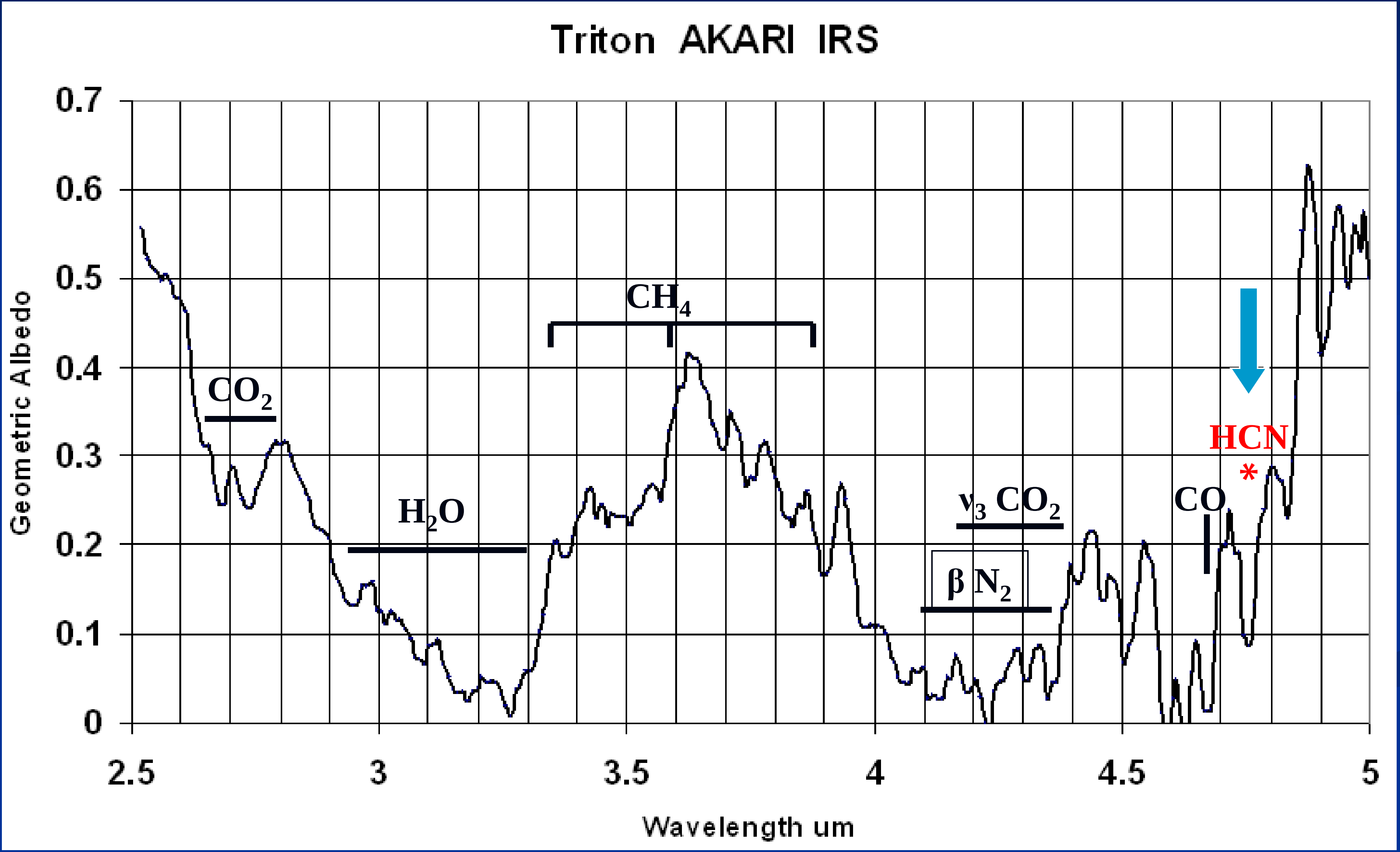
Importance of Extending Spectral Coverage to 5 µm



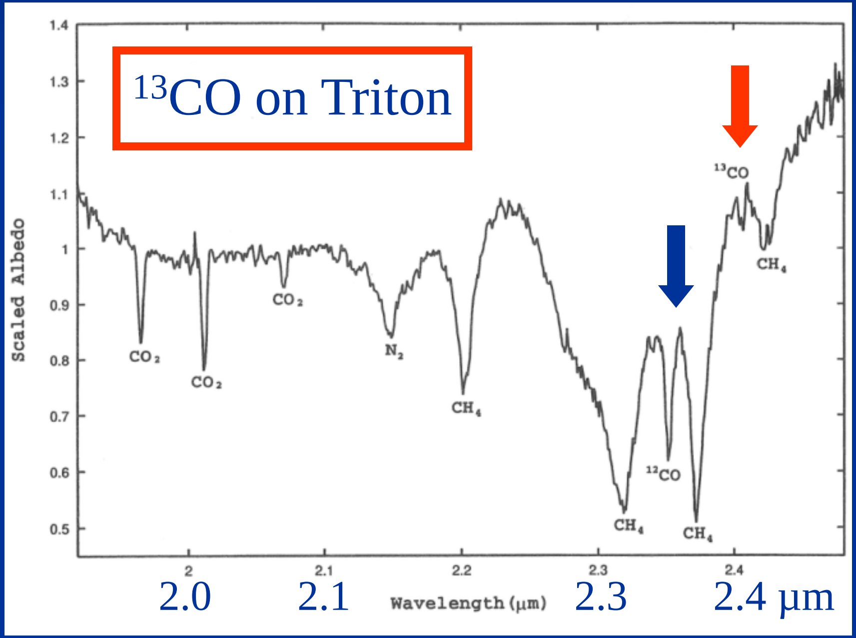
Triton spectrum
2.5 - 5 µm (Akari)



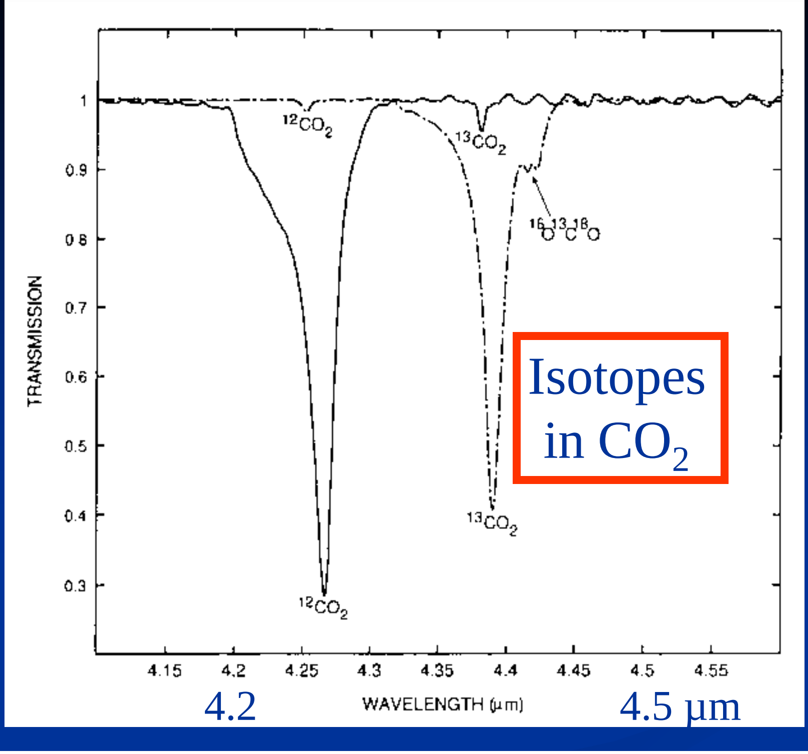
AKARI spectrum with grism. Resolution $\lambda/\Delta\lambda = 135$
(Preliminary version of the figure)



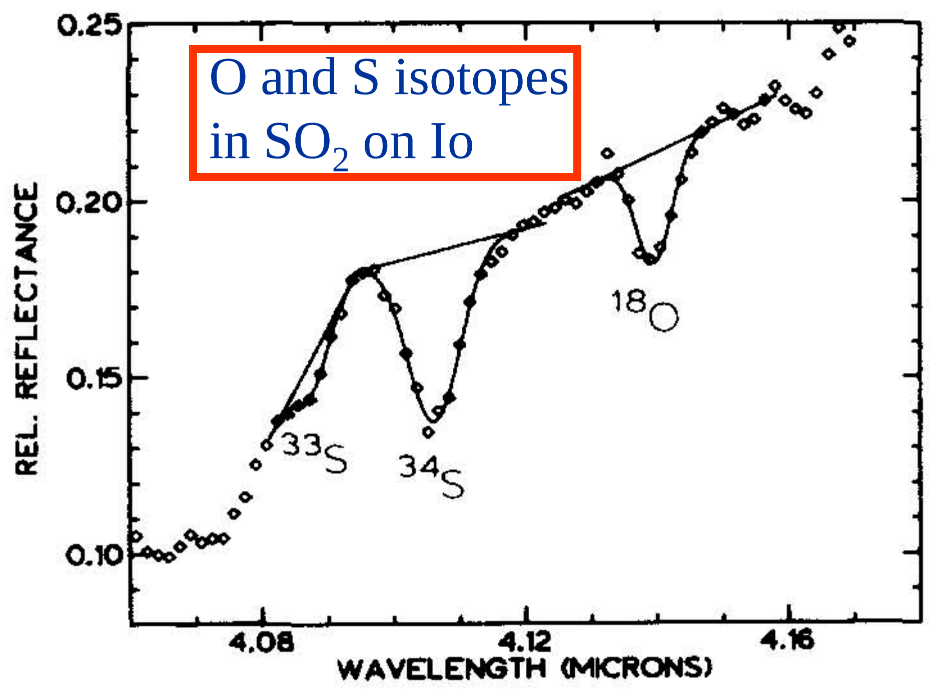
Isotopes in Ices



^{13}CO on Triton

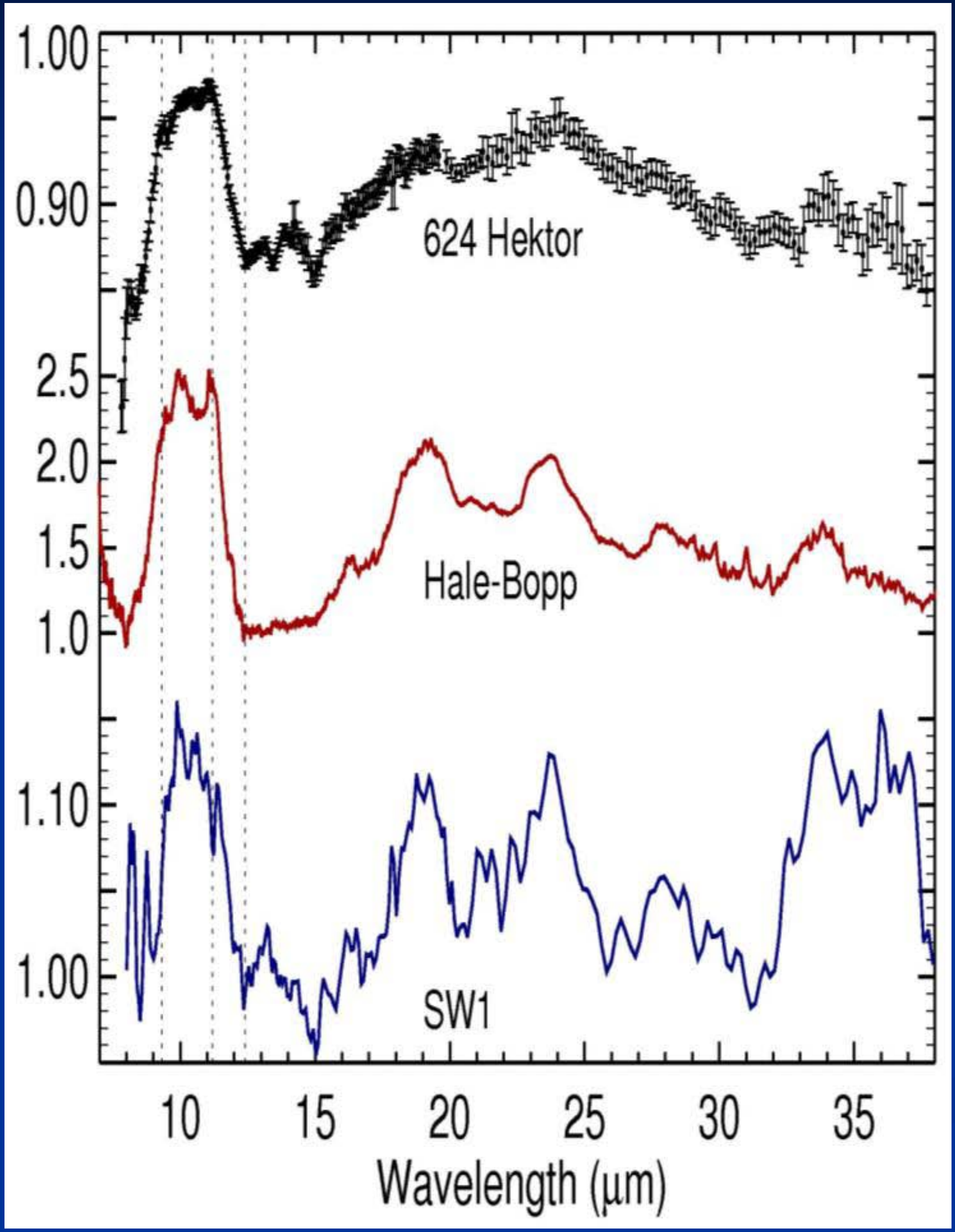


Isotopes in CO_2



O and S isotopes in SO_2 on Io

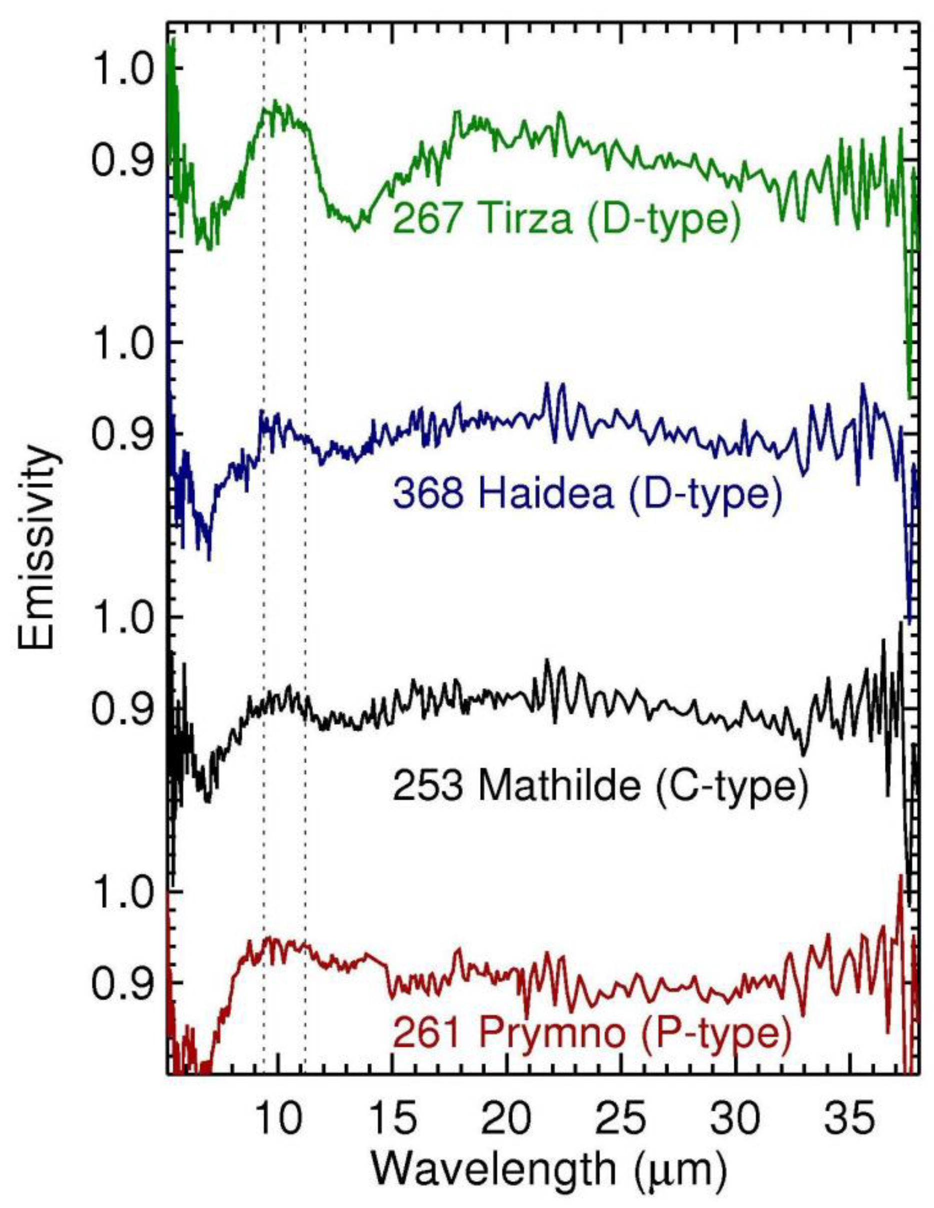
5 – 25 µm Thermal Emission Spectra (*Spitzer*) I.



Trojan asteroid 624 Hektor and two comets.

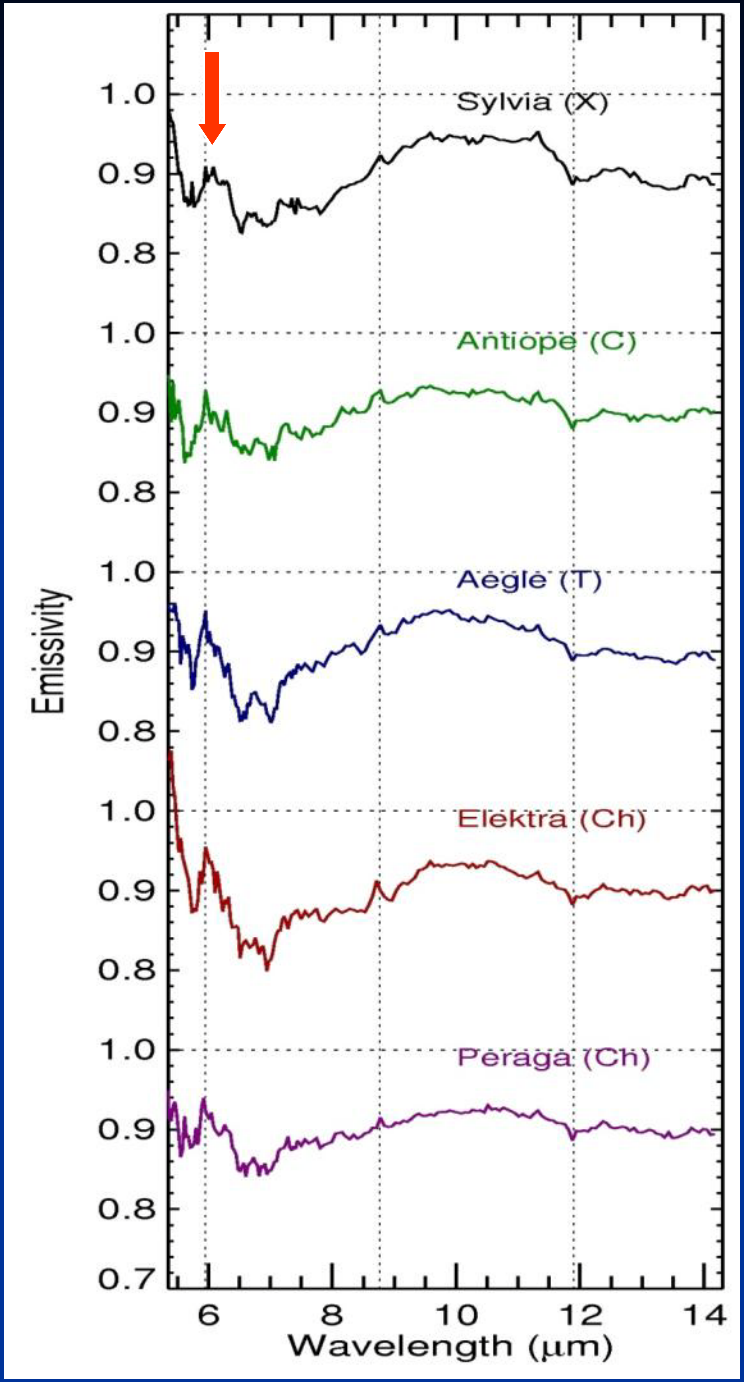
All show similar mineral emission features (primarily olivine)

5 – 25 µm Thermal Emission Spectra (*Spitzer*) II.



Other primitive asteroids *(C, P, and D types)* having <u>no diagnostic mineral bands</u> in the near-IR, show mineral emission bands with differing detailed structures.

5 – 25 µm emission spectra may be the only way to determine their compositions.



6.2-µm Emission Feature on Asteroids (*Spitzer* spectra)

Most asteroids show an emission feature at 6.2 µm that is presently unidentified.

May be hydrous silicates, organics, or carbonates. It is seen on asteroids showing no other evidence of hydration or organic materials.

Summary - I

- The region 2.5 - 5 µm is especially rich in molecular bands in ices and organic solids
- The region > 5 µm is especially valuable for mineral identification, surface thermal properties, and comparisons of Solar System bodies to other sources

Summary - II

- High-speed photometry is well addressed by HIPO
- High-resolution spectroscopy for Solar System bodies is well in hand in the first generation SOFIA instruments
- Low-resolution (R = 100 – 1000) spectra measured <u>simultaneously in a broad spectral range</u> (2.4 - 25 µm) are needed
  - Many small bodies can be observed
  - This spectral region includes reflected sunlight and thermal emission regions
  - Opens previously unobserved spectral regions of great importance in understanding origin and evolution of Solar System bodies.
  - High sensitivity more important than spectral resolution