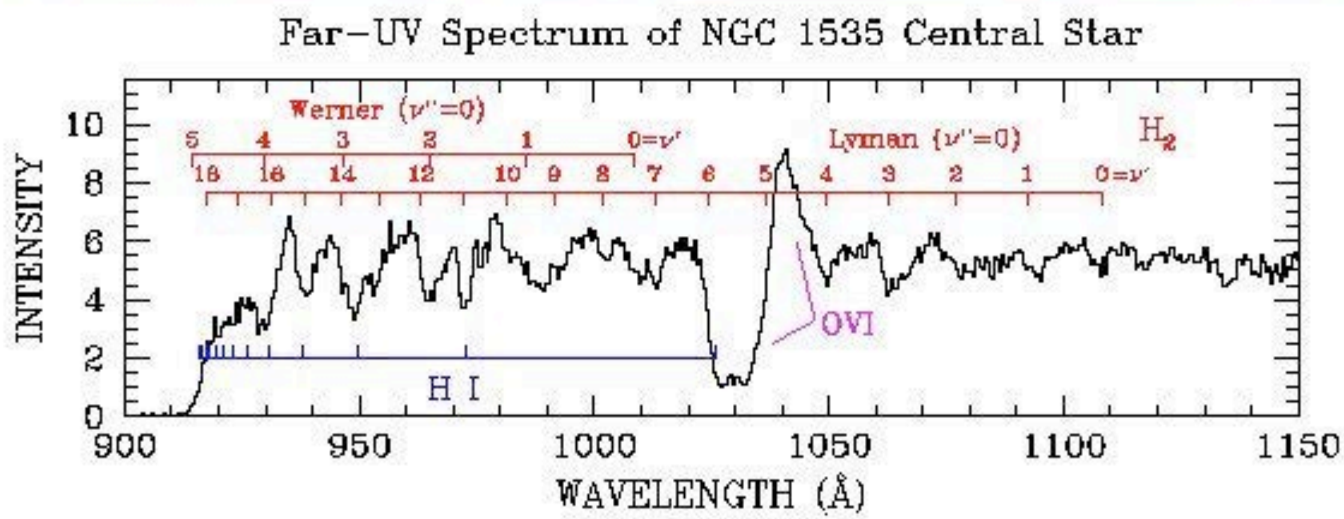
Spectroscopy: The Study of Squiggly Lines

[Astronomical Distances] [Basics of Light] [Tools for Light Analysis]
[Measuring Light] [Electromagnetic Spectrum] [Fun with Units]
[Atmospheric Transmission] [Space Links]

What are Those Squiggly Lines?

Using Light to Learn About the Universe



Spectroscopy in Curiosity's site selection

Eberswalde Crater | Holden Crater | Gale Crater | Mawrth Vallis

←→

Morphologic ... **Spectral**

Evidence for water

Interaction of Radiant Energy and Matter

What causes absorption features in spectra?

1) Rotational absorption (gases)

2) Electronic absorption

3) Vibrational absorption

Rotational Processes

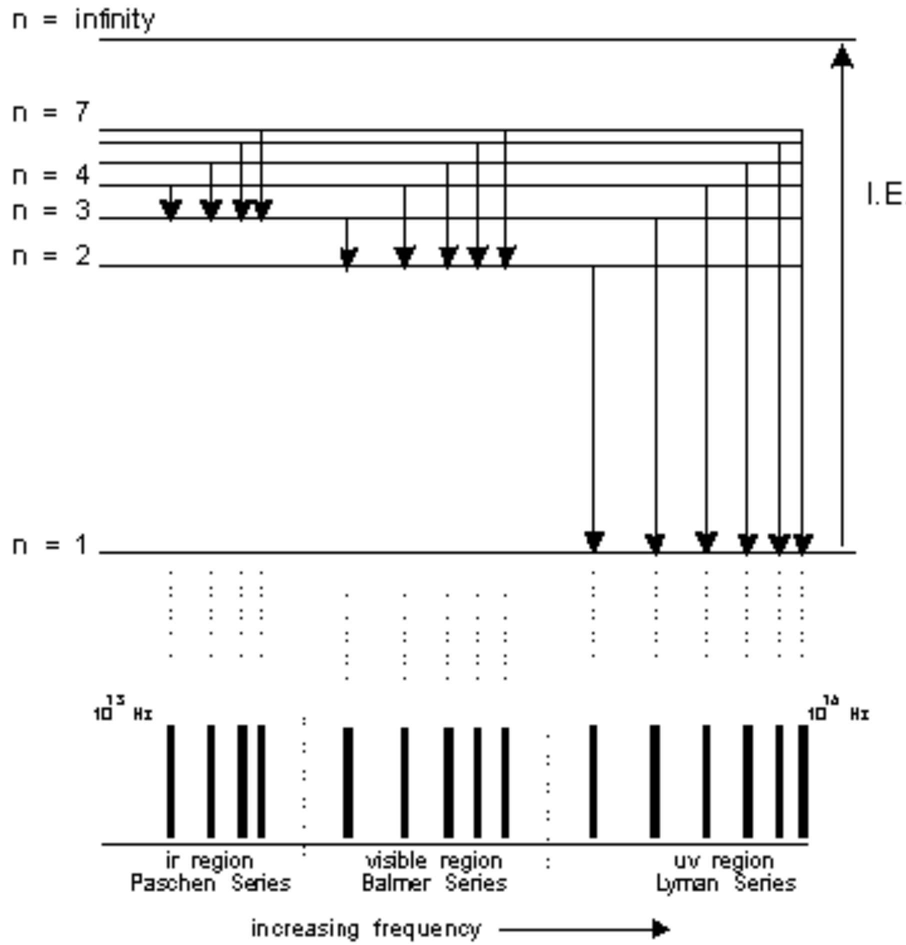
Photons striking *free* molecules can cause them to rotate. The rotational states are quantized, so there are discrete photon energies that, when absorbed, cause the molecules to spin.

Rotational interactions are low-energy interactions and the absorption features are at long infrared wavelengths.

Not important in remote sensing of solid materials

Electronic Processes

Isolated atoms and ions have discrete energy states. Absorption of photons of a specific wavelength causes a change from one energy state to a higher one.



In solids, four types:

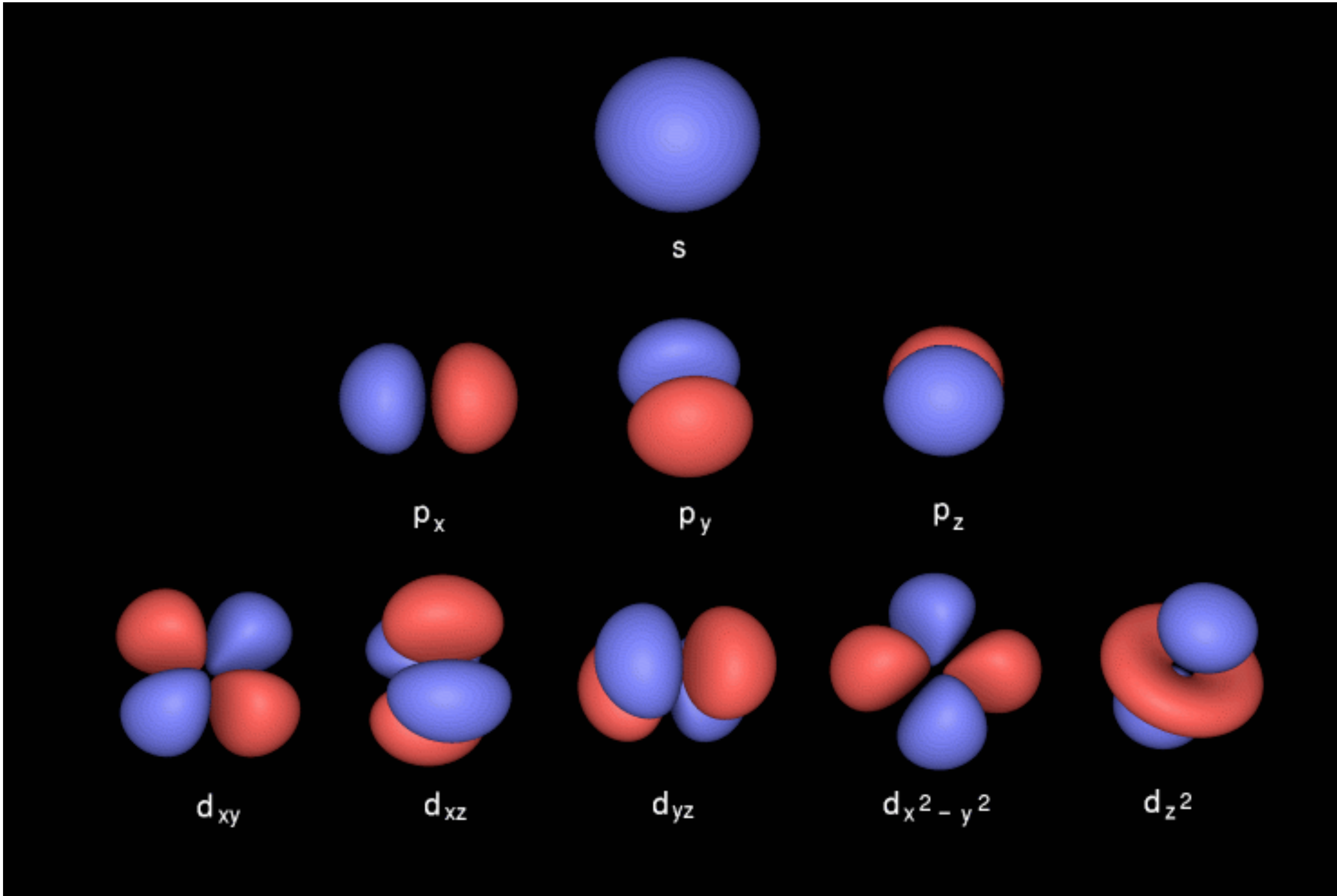
Crystal Field Effects
Charge Transfer Absorptions
Conduction Bands
Color Centers

Electronic Processes

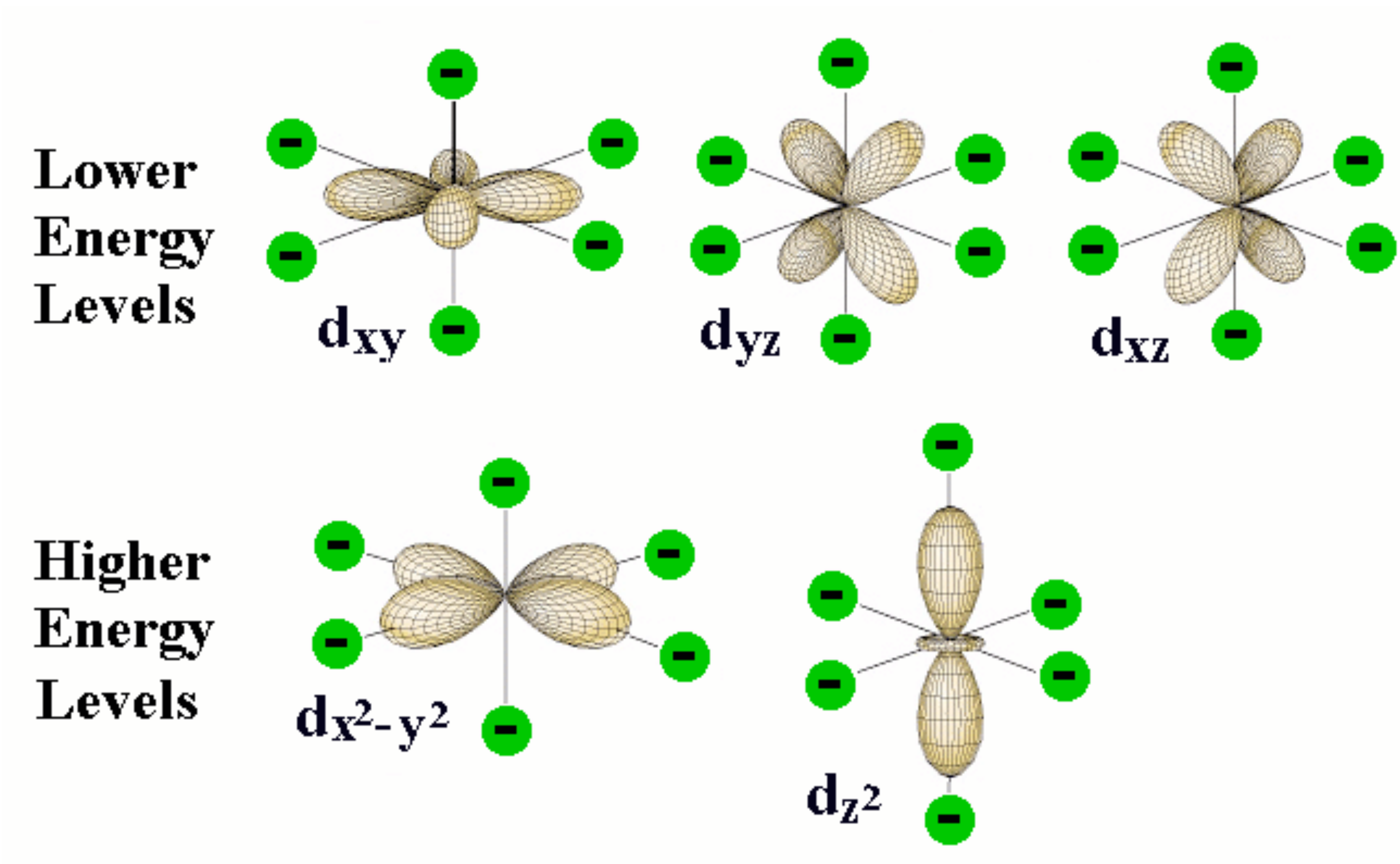
Crystal Field Effects

The electronic energy levels of an isolated ion are usually split and displaced when located in a solid. Unfilled d orbitals are split by interaction with surrounding ions and assume new energy values. These new energy values (transitions between them and consequently their spectra) are primarily determined by the valence state of the ion (Fe^{2+}, Fe^{3+}), coordination number, and site symmetry.

Electron Orbits

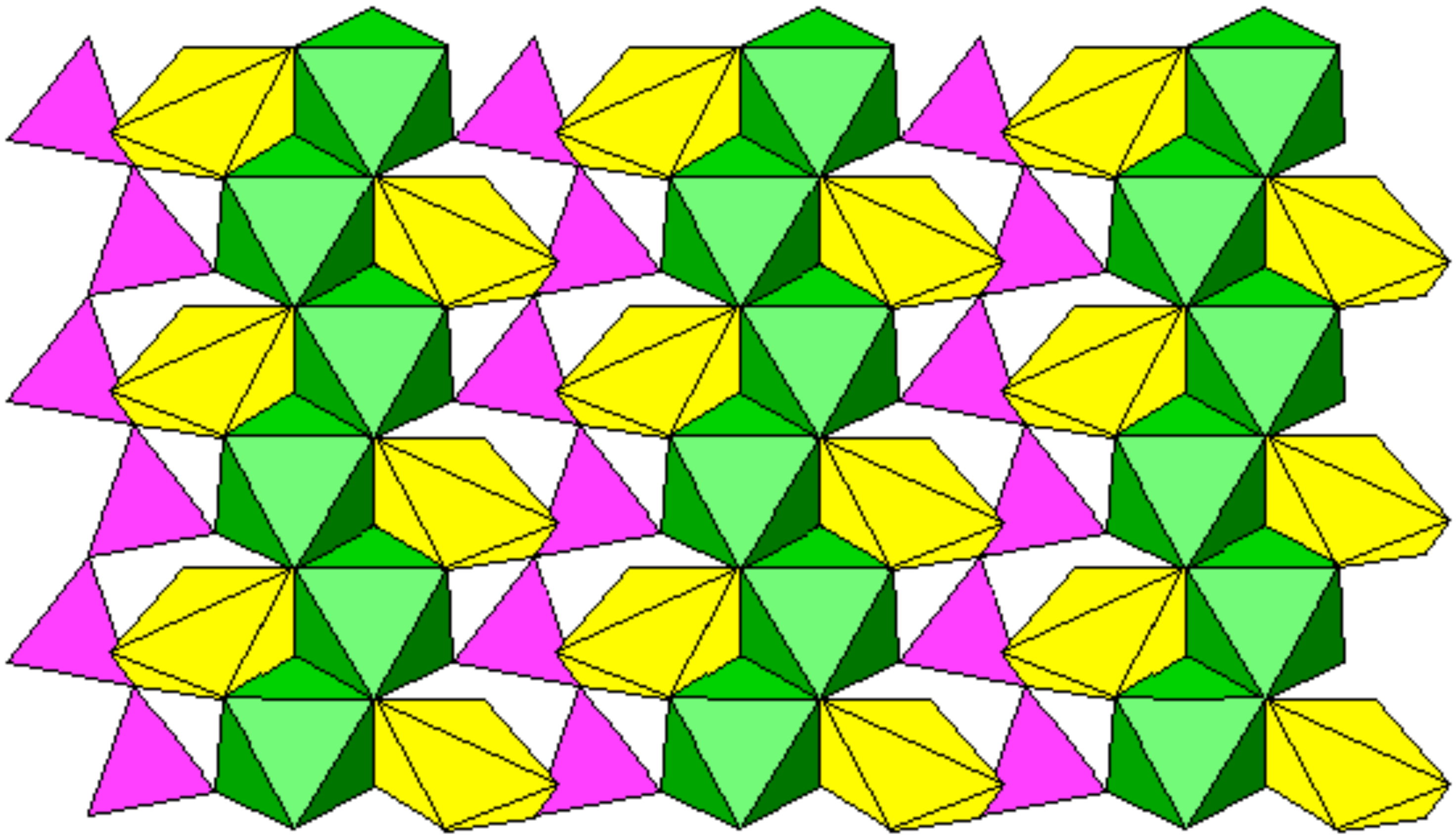


Energy Level Splitting in Solids: Part 1



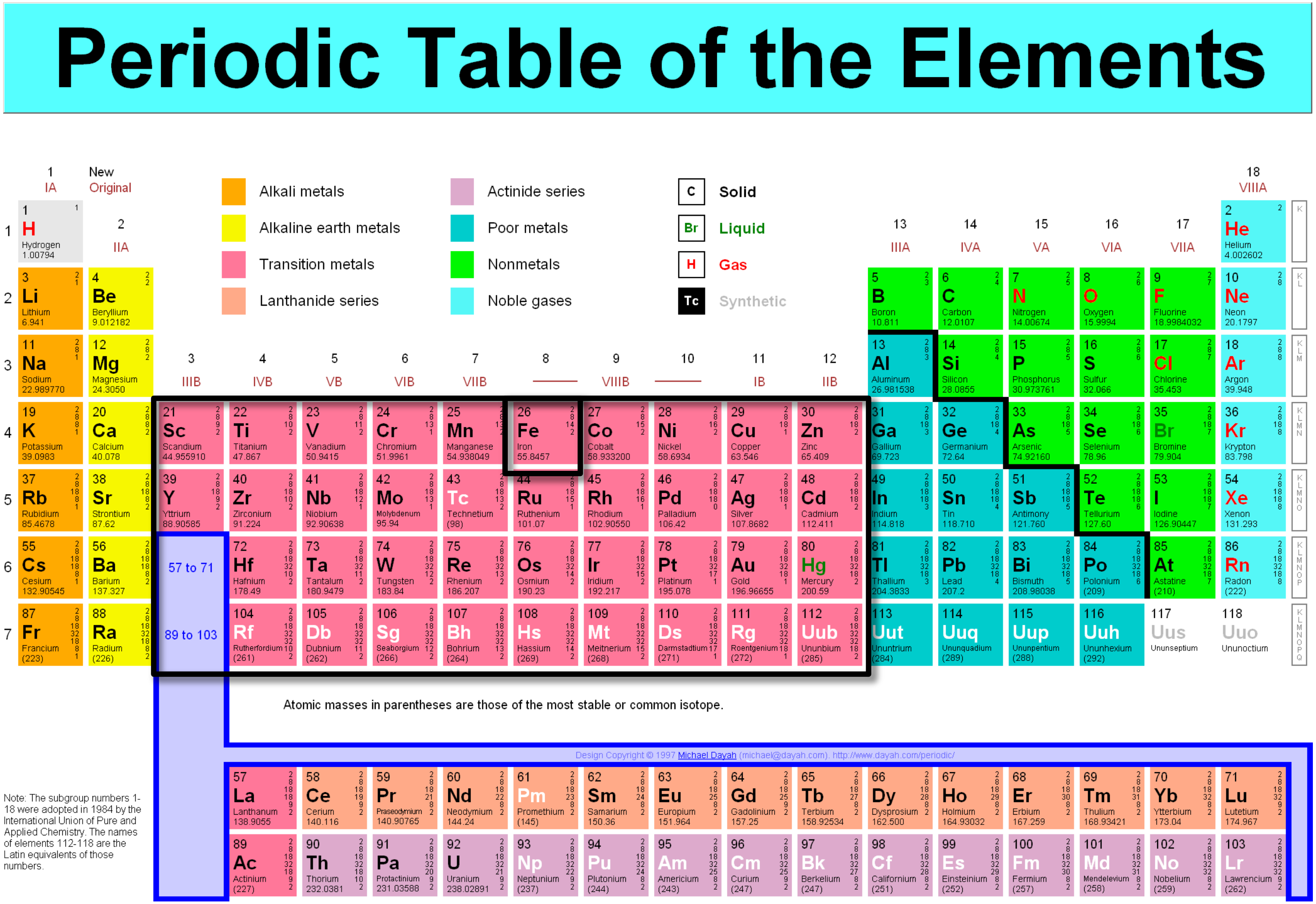
In a free atom these have equal energy, but not in a crystal…

Energy Level Splitting in Solids: Part 2



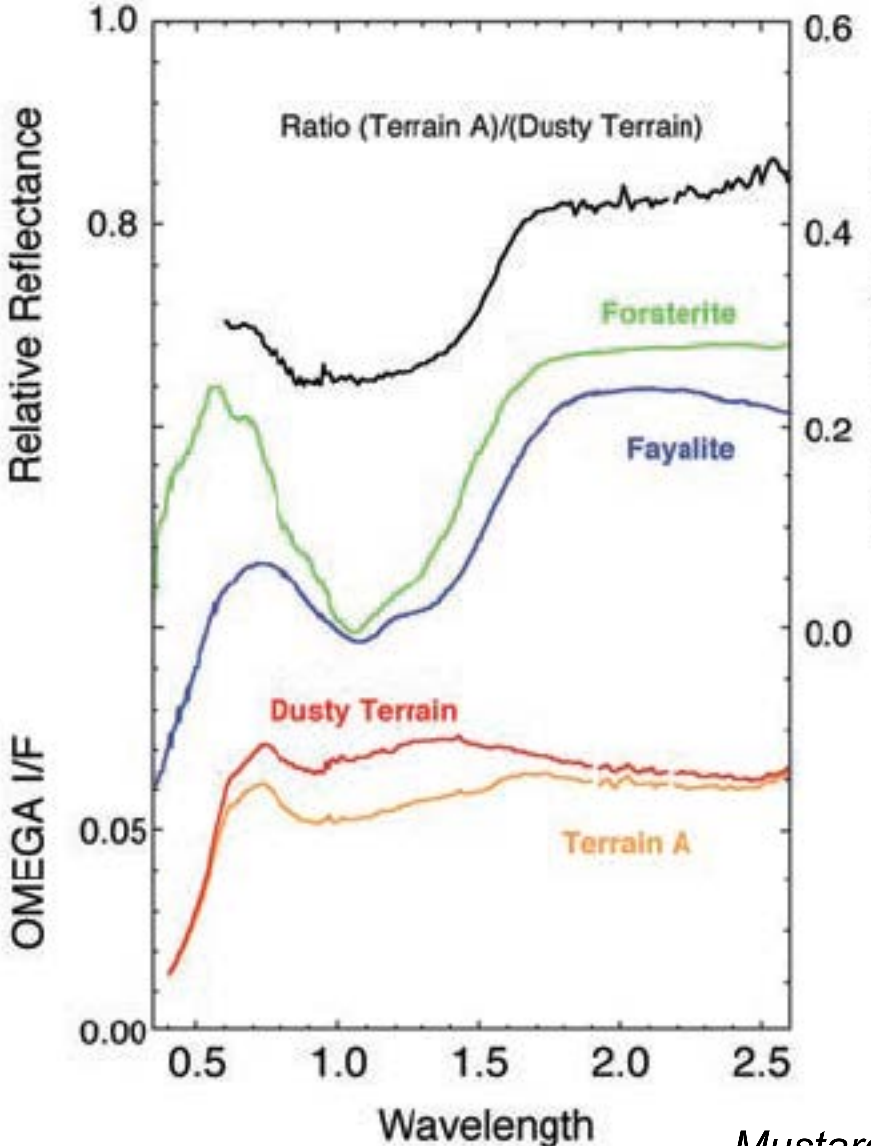
Distortion of some “sites” in a crystal ➔ further energy splitting
→ *diagnostic of mineralogy*

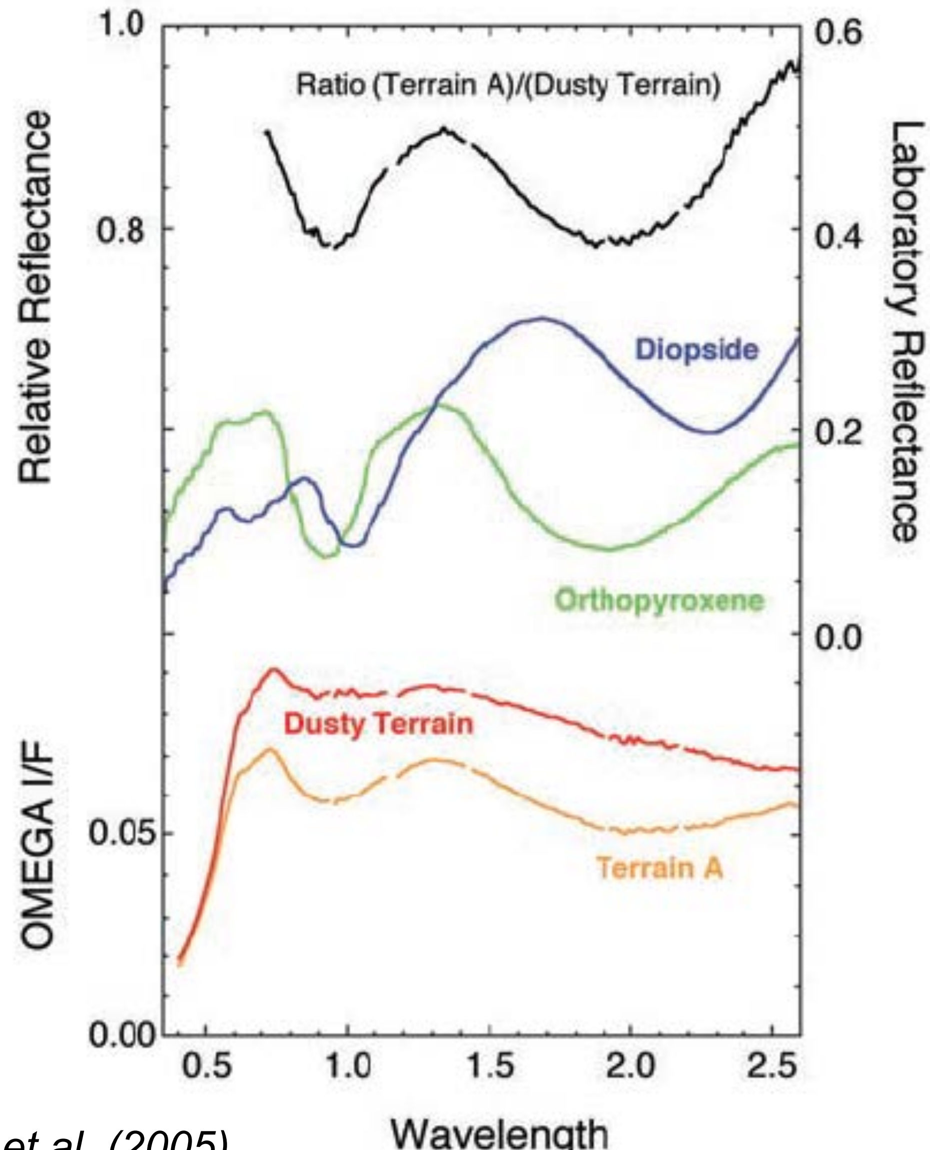
Unfilled *d* orbitals: the transition metals



Iron is the most geologically abundant transition metal

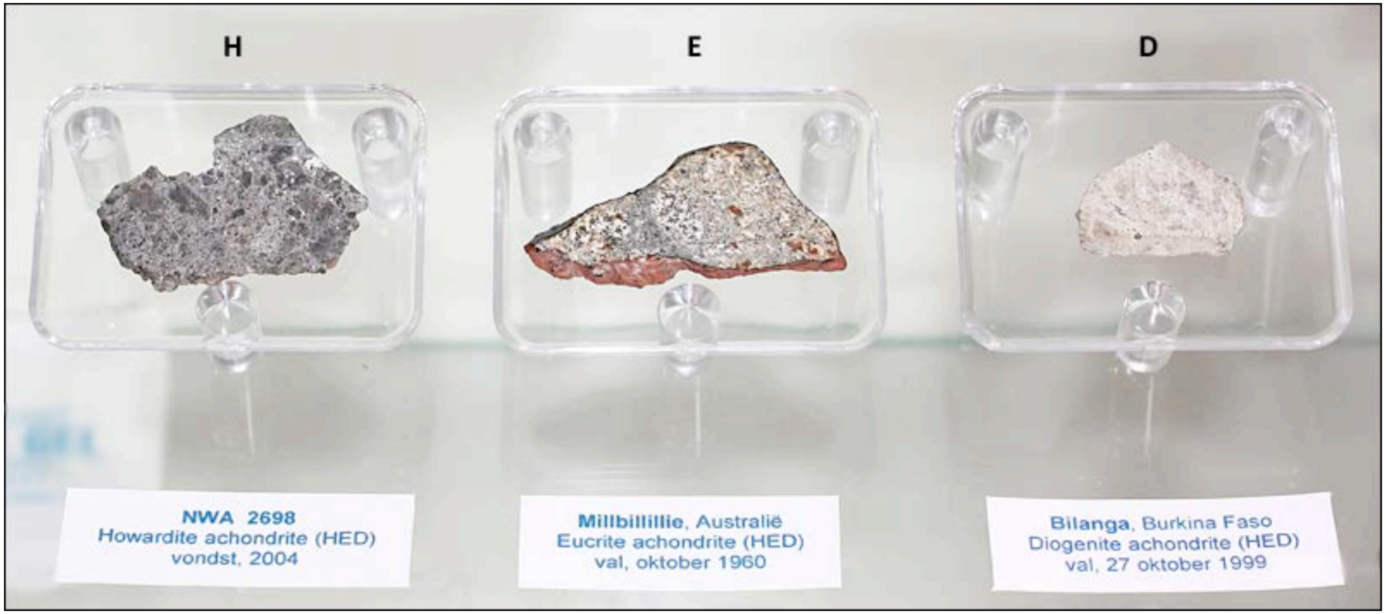
Fe electronic transitions in olivine, pyroxene

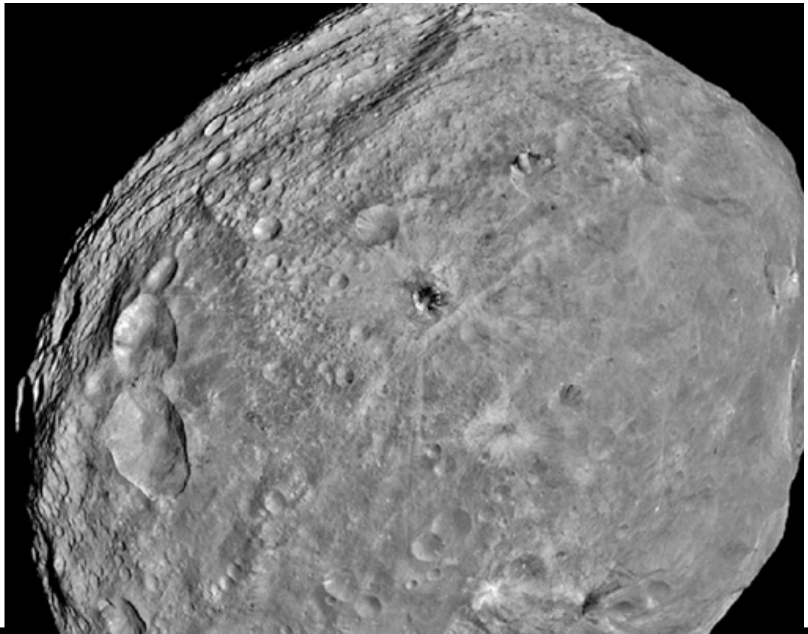




Mustard et al. (2005)

Spectroscopy: linking meteorites to asteroids





Electronic Processes

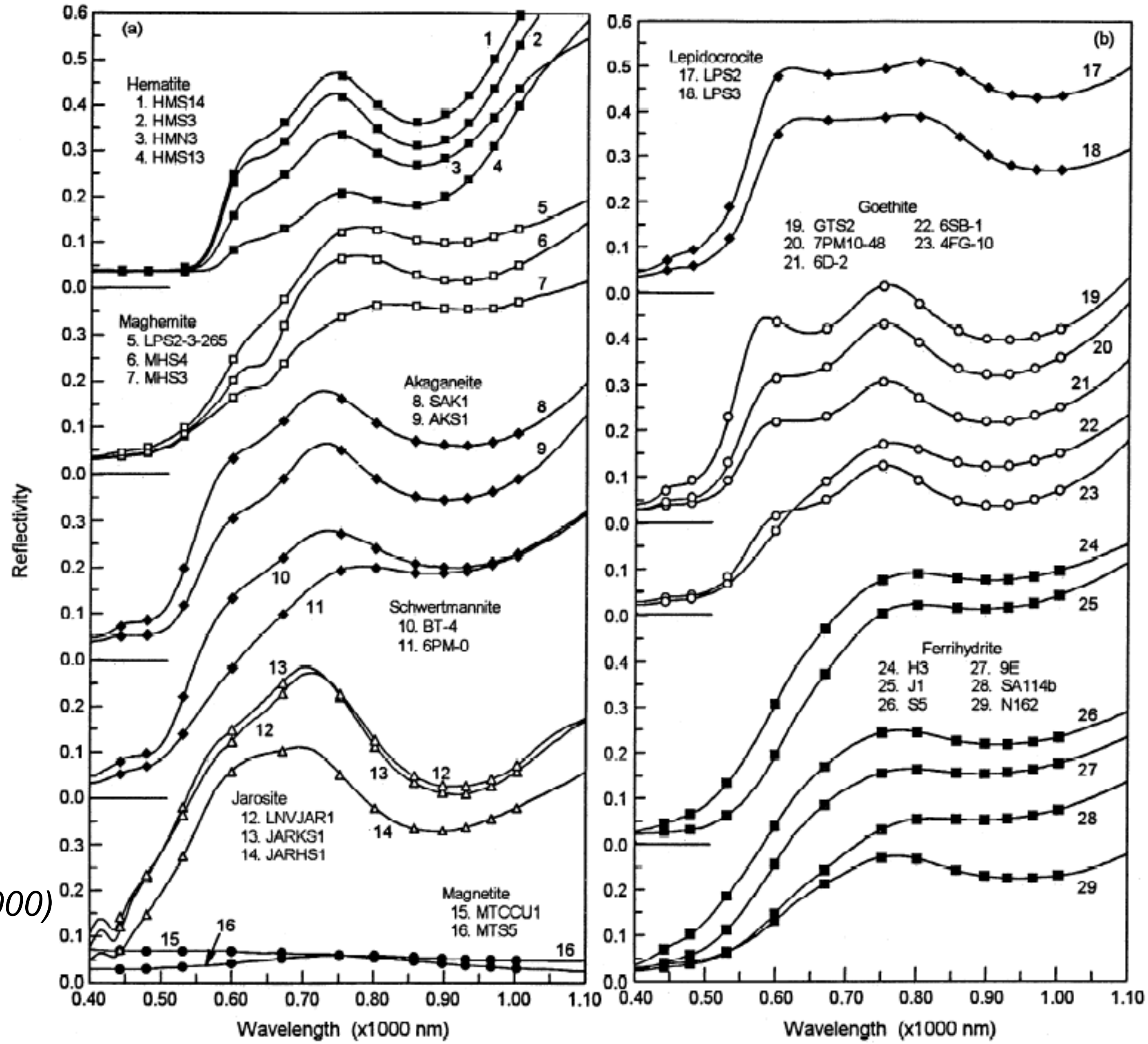
Charge-Transfer Absorptions

Absorption bands can also be caused by charge transfers, or inter-element transitions where the absorption of a photon causes an electron to move between ions. The transition can also occur between the same metal in different valence states, such as between Fe^{2+} and Fe^{3+}. Absorptions are typically strong. A common example is Fe-O band in the uv, causing iron oxides to be red.

http://en.wikipedia.org/wiki/Image:Hematite.jpg

http://www.galleries.com/minerals/silicate/olivine/olivine.jpg

Electron charge transfer: why Mars is red!



Morris et al. (2000)

Electronic Processes

Conduction Bands

In metals and some minerals, there are two energy levels in which electrons may reside: a higher level called the "conduction band," where electrons move freely throughout the lattice, and a lower energy region called the "valence band," where electrons are attached to individual atoms. The yellow color of gold and sulfur is caused by conduction-band absorption.

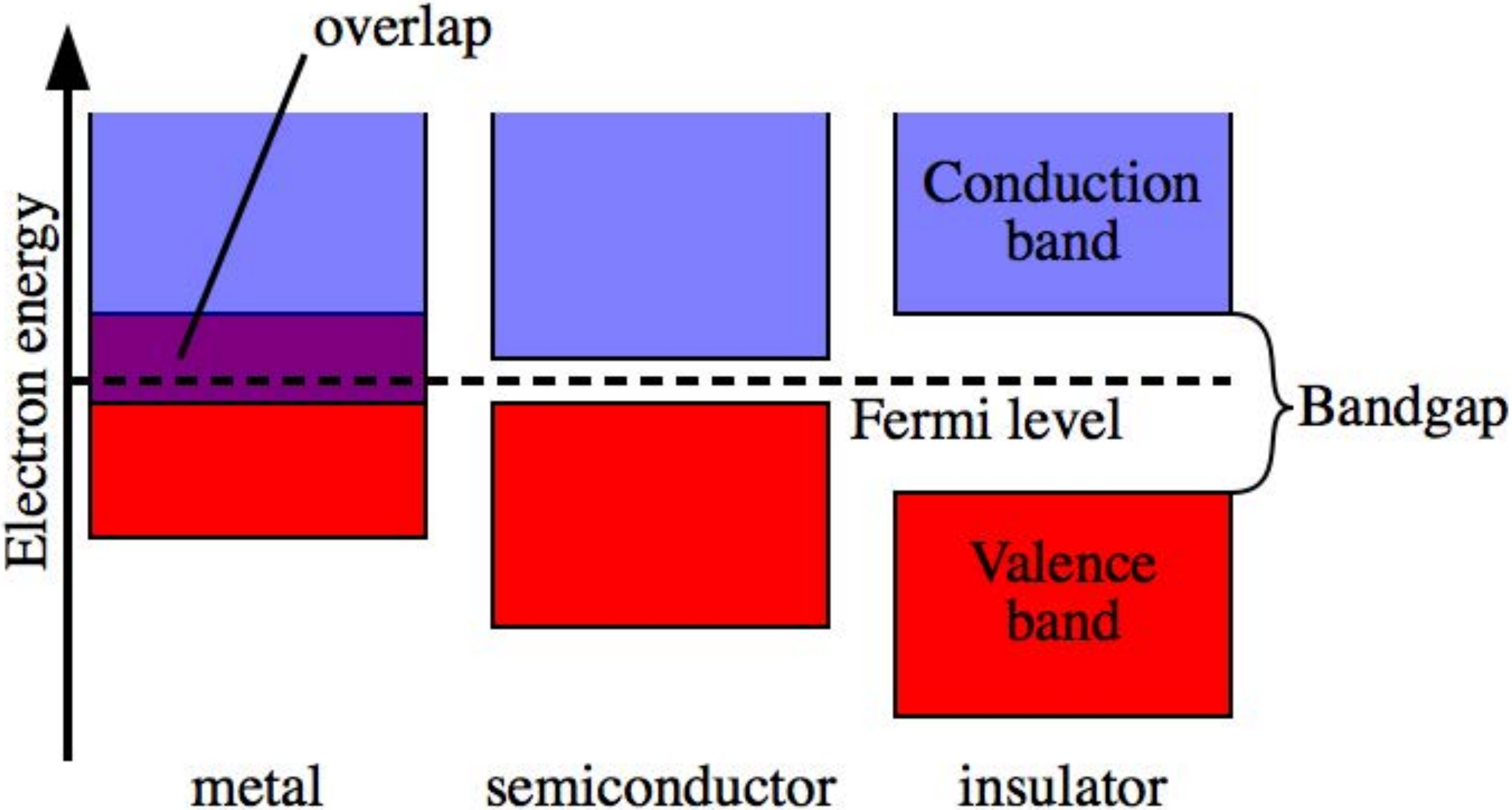
Gold

www.egyptcollections.com

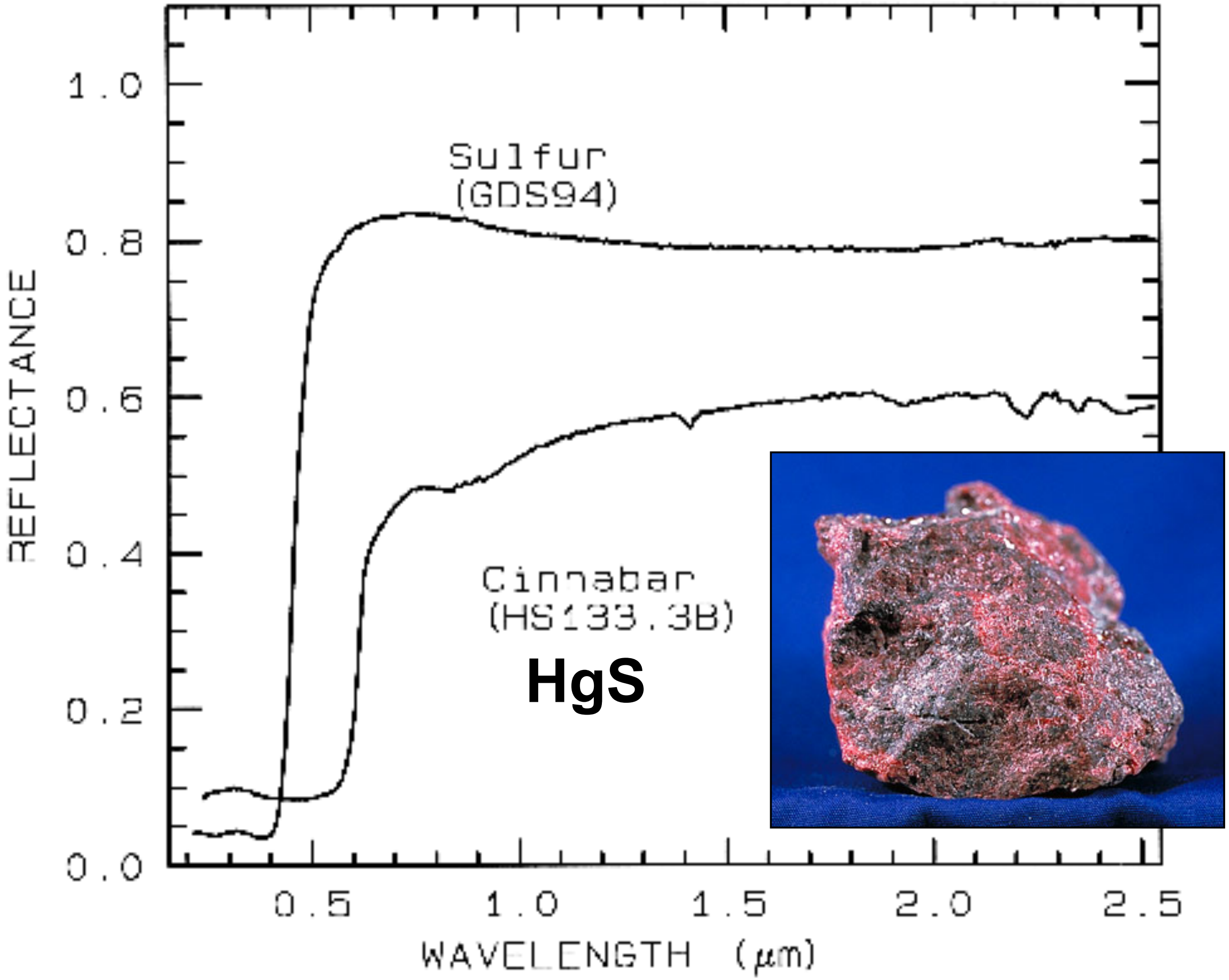
Sulfur

web.syr.edu/~iotz/Gallery.htm

Semiconductor physics



Conduction band processes

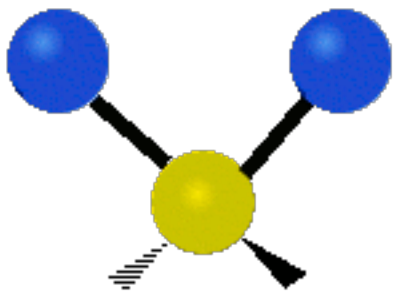


http://www.mii.org/Minerals/Minpics1/Cinnabar.jpg

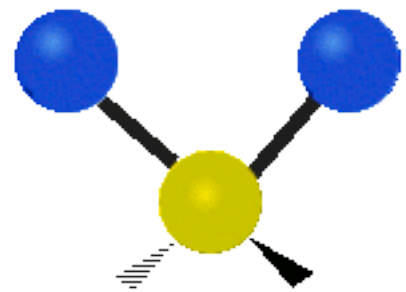
Yellow color of sulfur (e.g., on Io) due to band gap transitions

Molecular vibrations

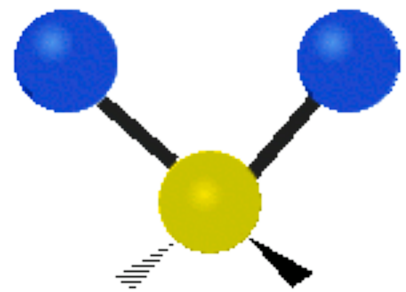
Symmetric stretch



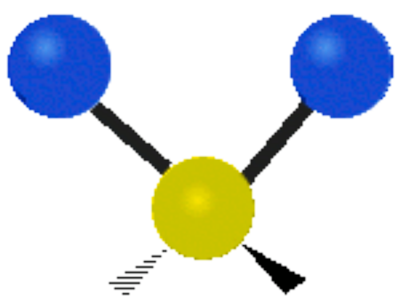
Asymmetric stretch



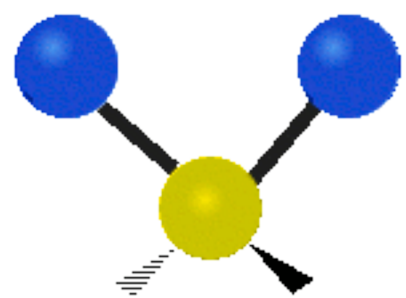
Scissor/bend



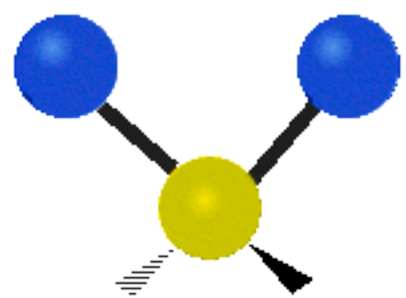
Rocking



Wagging



Twist

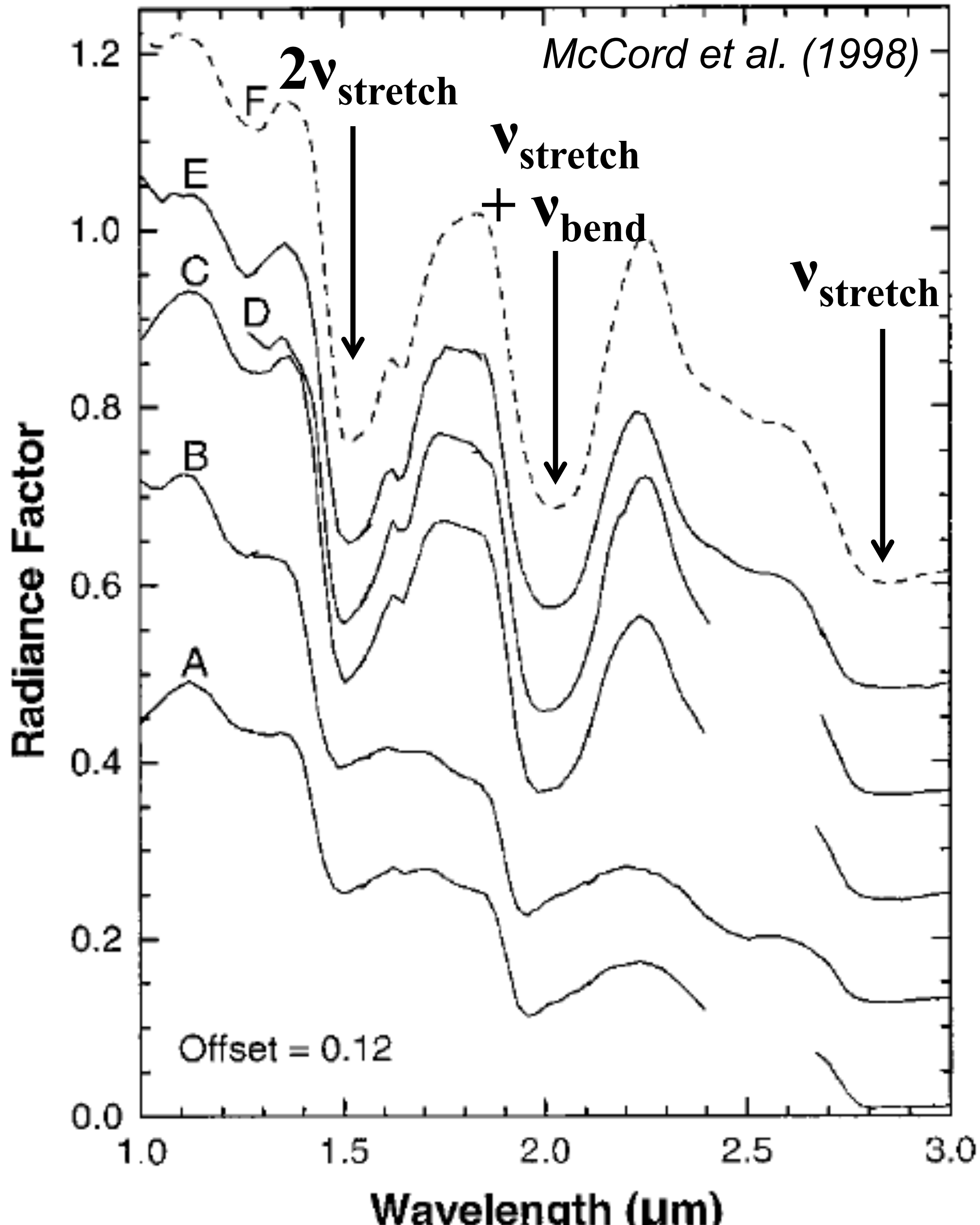


Water vibrations: ice vs. hydrated minerals

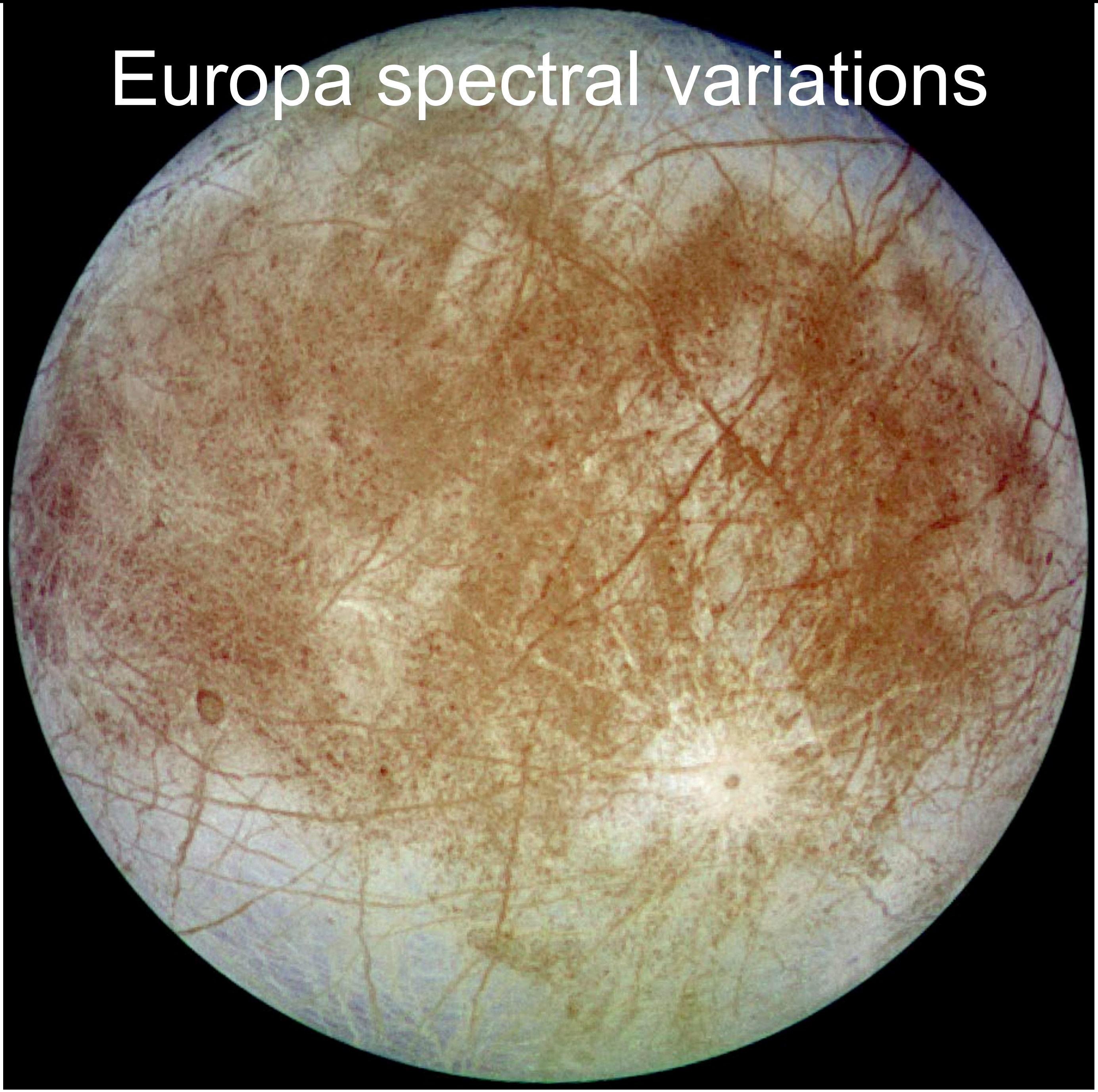
A – D are Europa,

E is Ganymede,

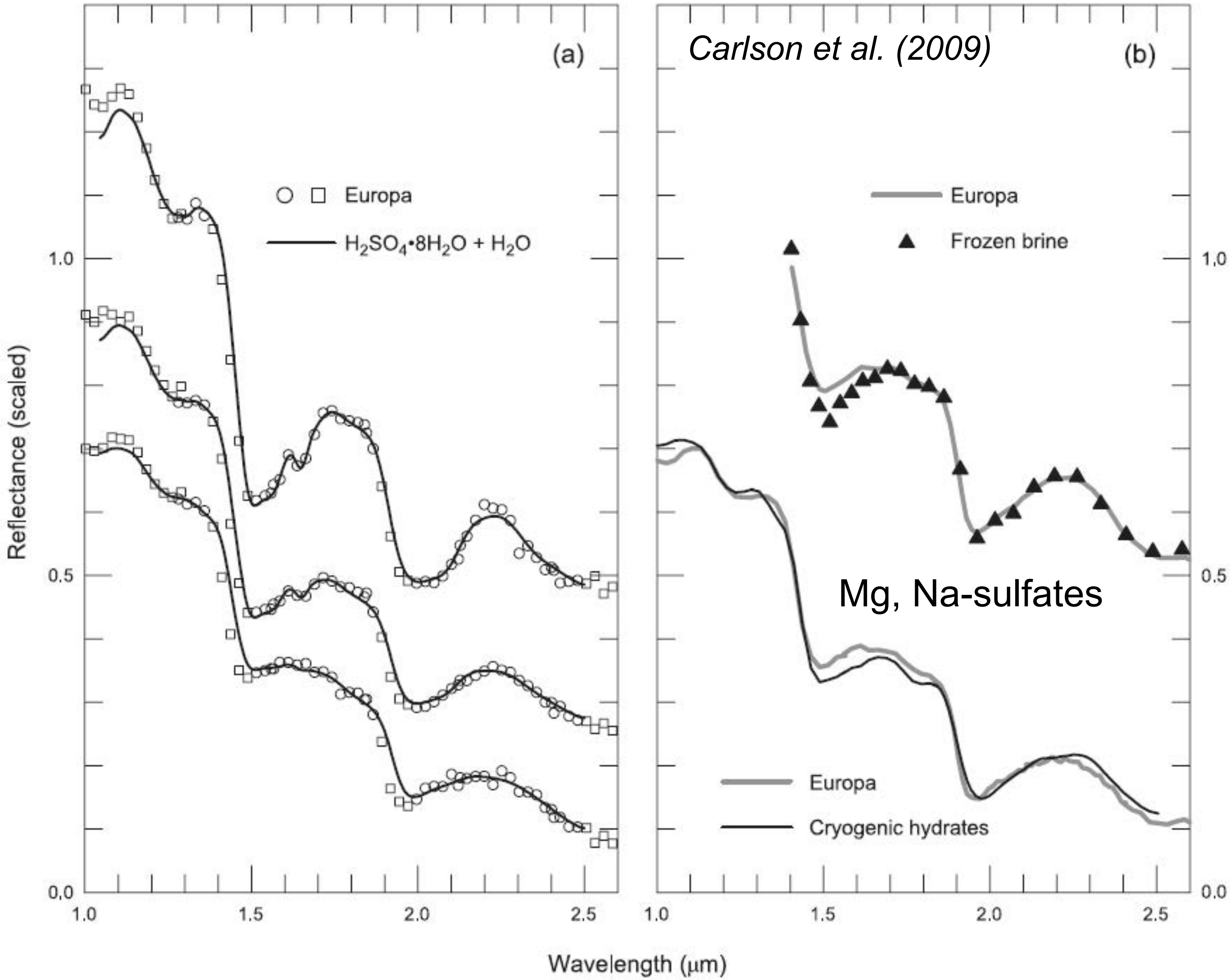
F is model ice spectrum



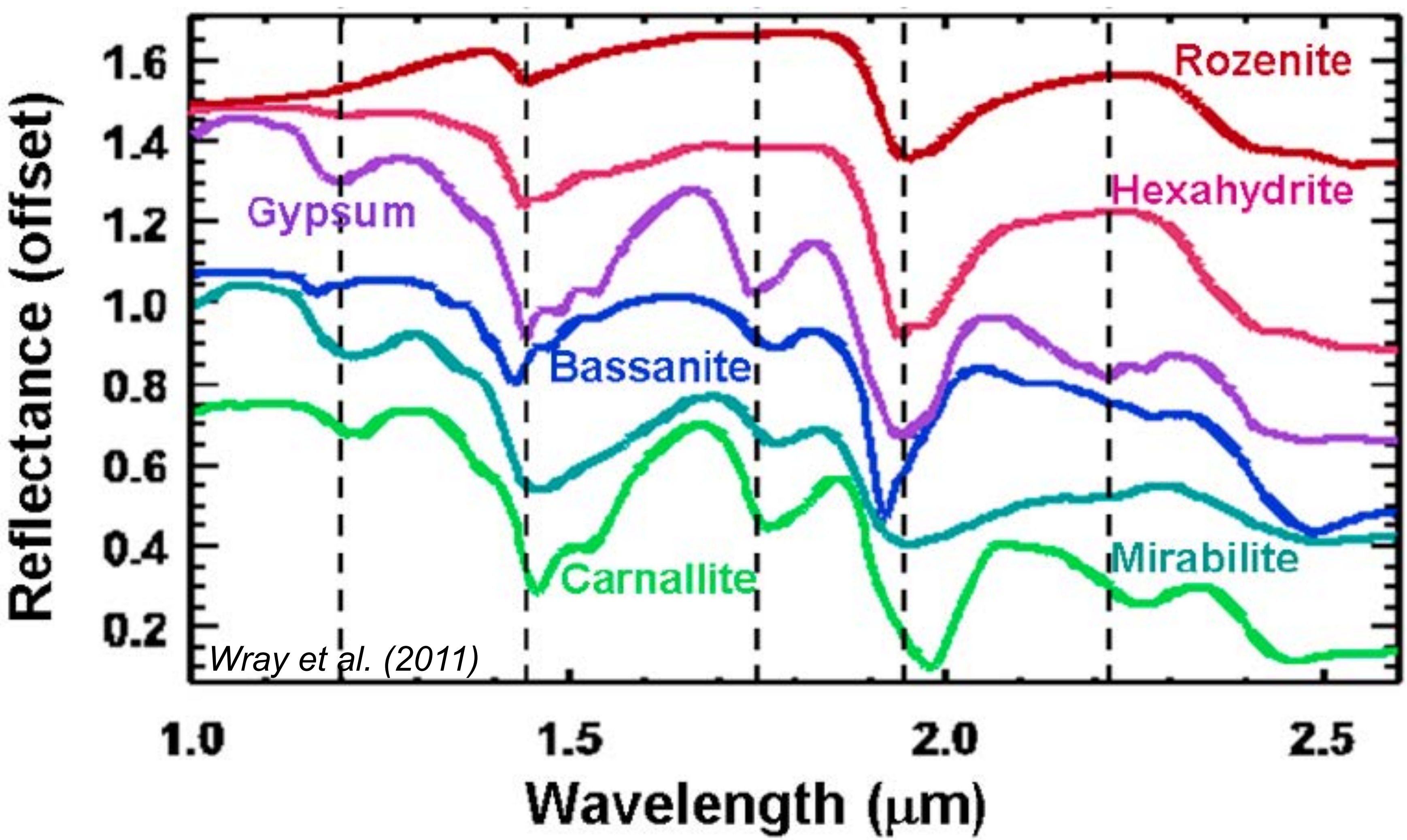
Europa spectral variations



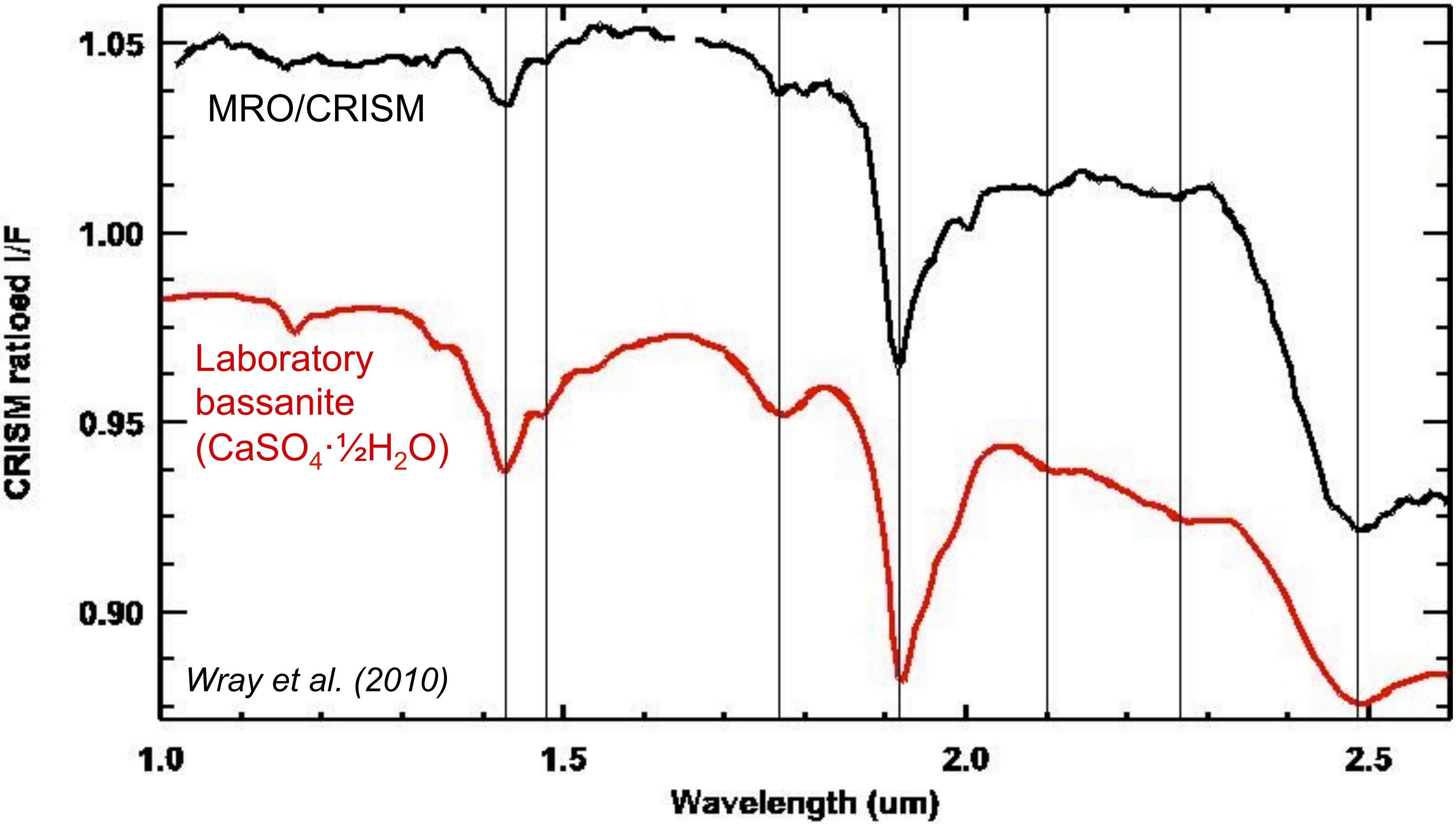
Europa's hydrates: acid or salts?



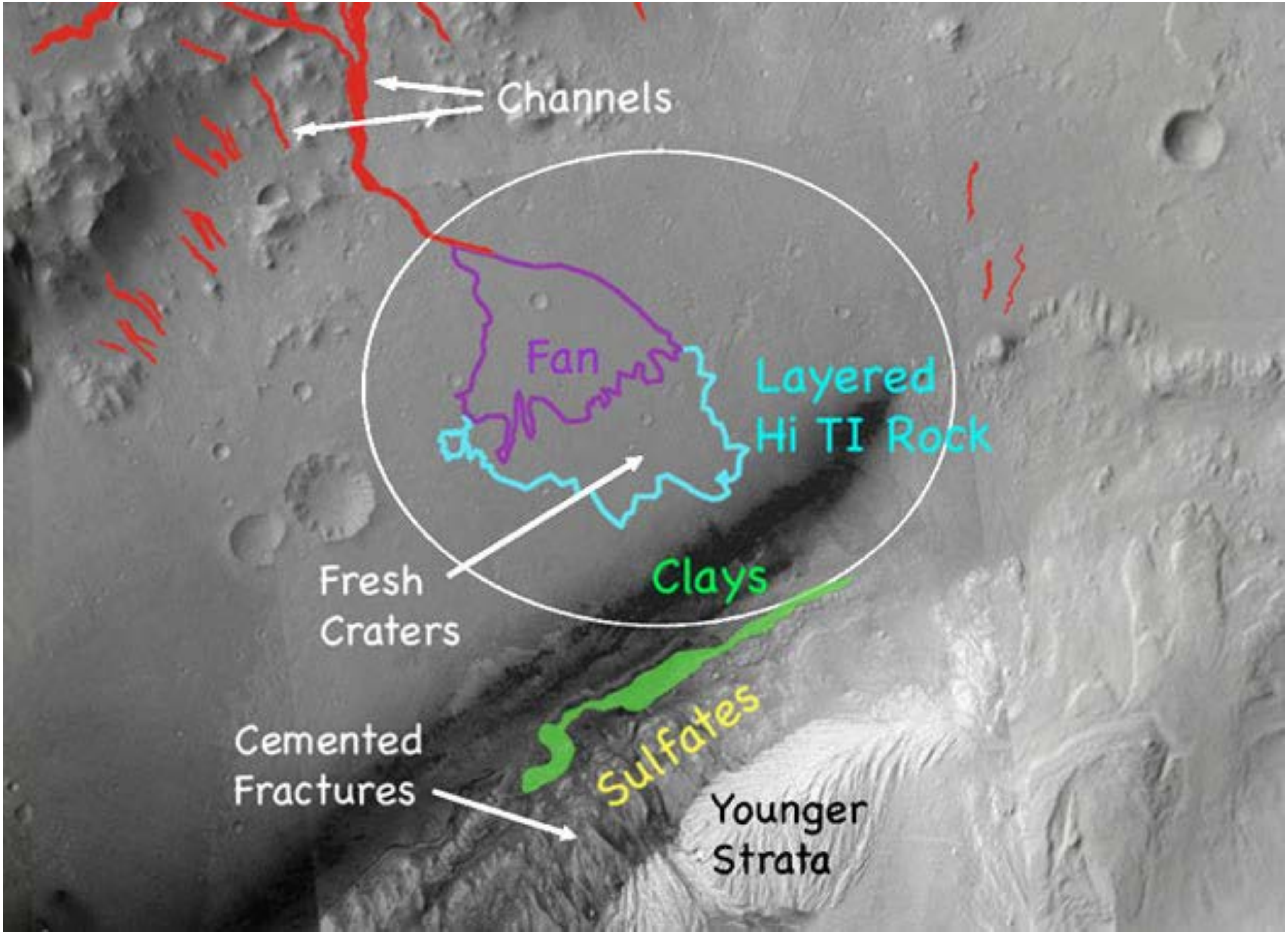
Hydrated salt spectra



Hydrated salts on Mars: e.g., bassanite

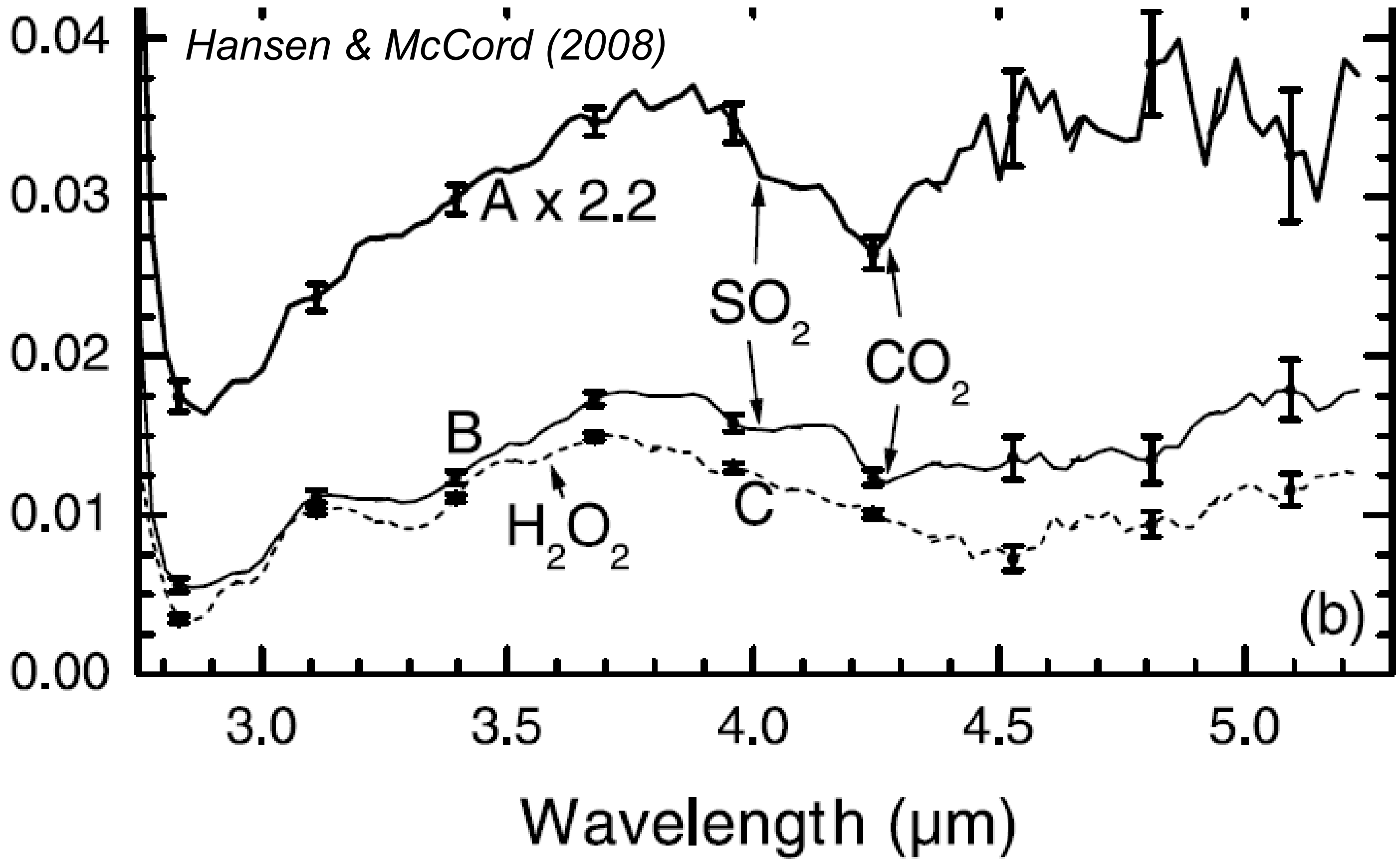


Spectroscopy-guided roving

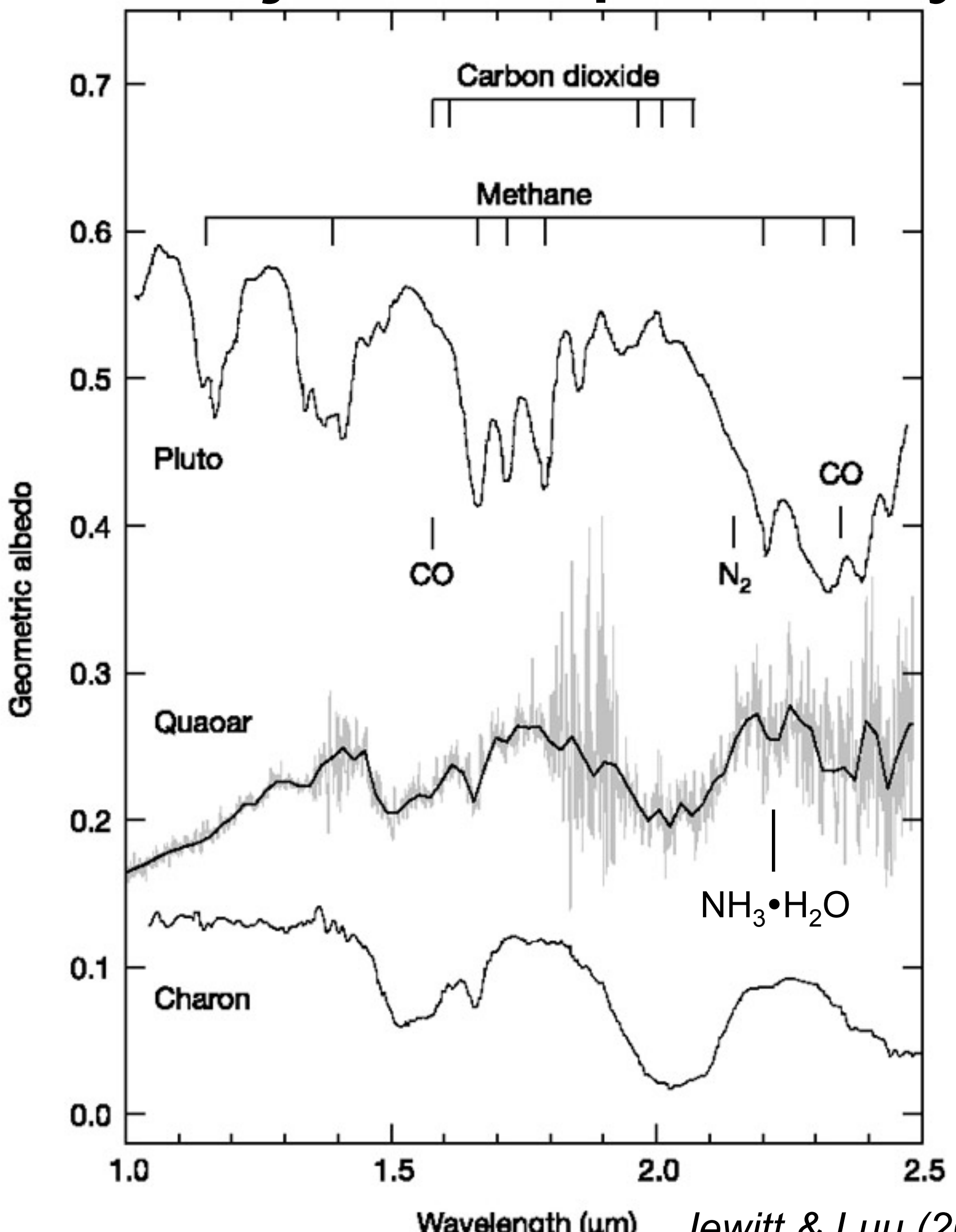


Peroxide, CO_2 and more on Europa

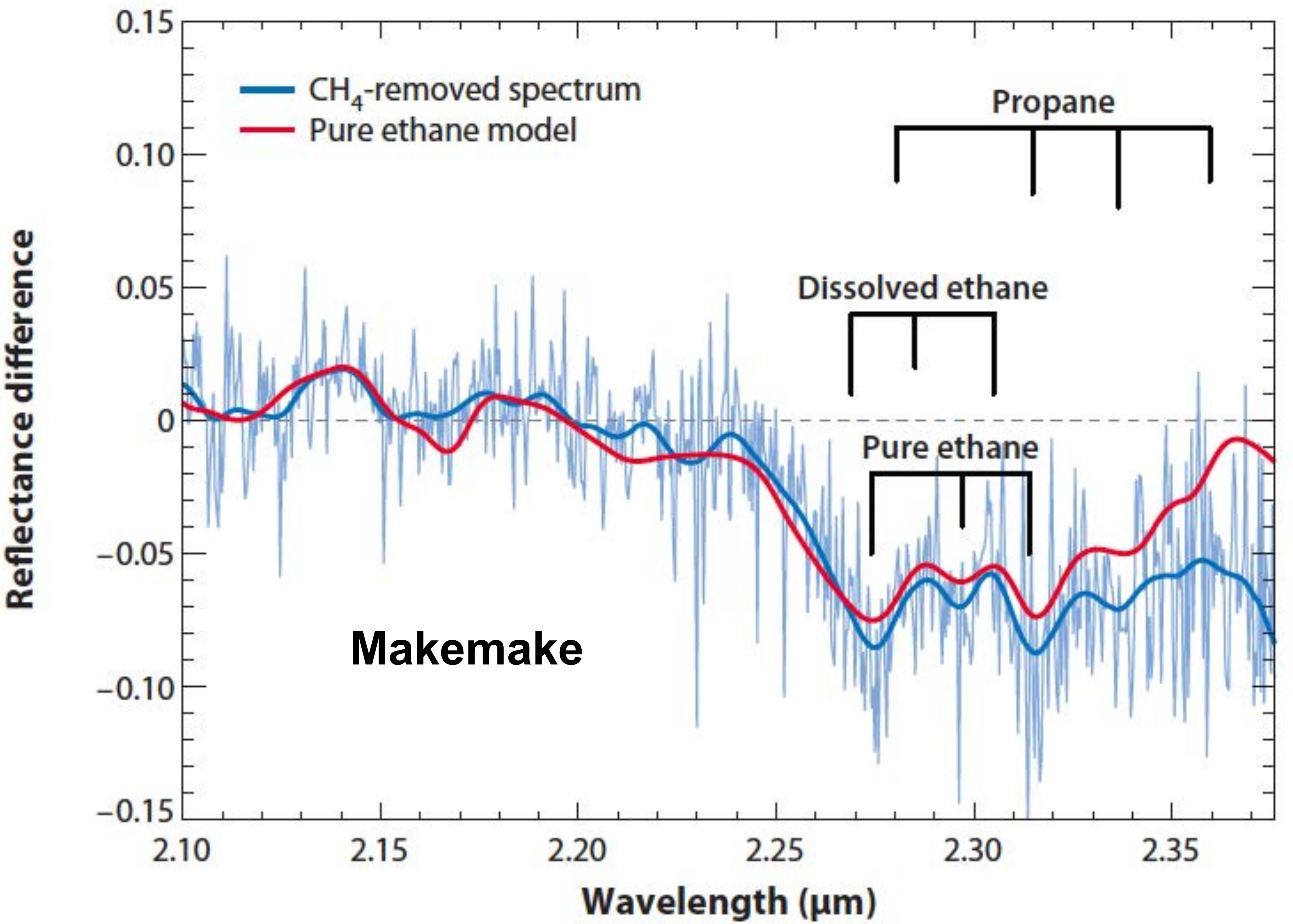
(and Ganymede, Callisto)



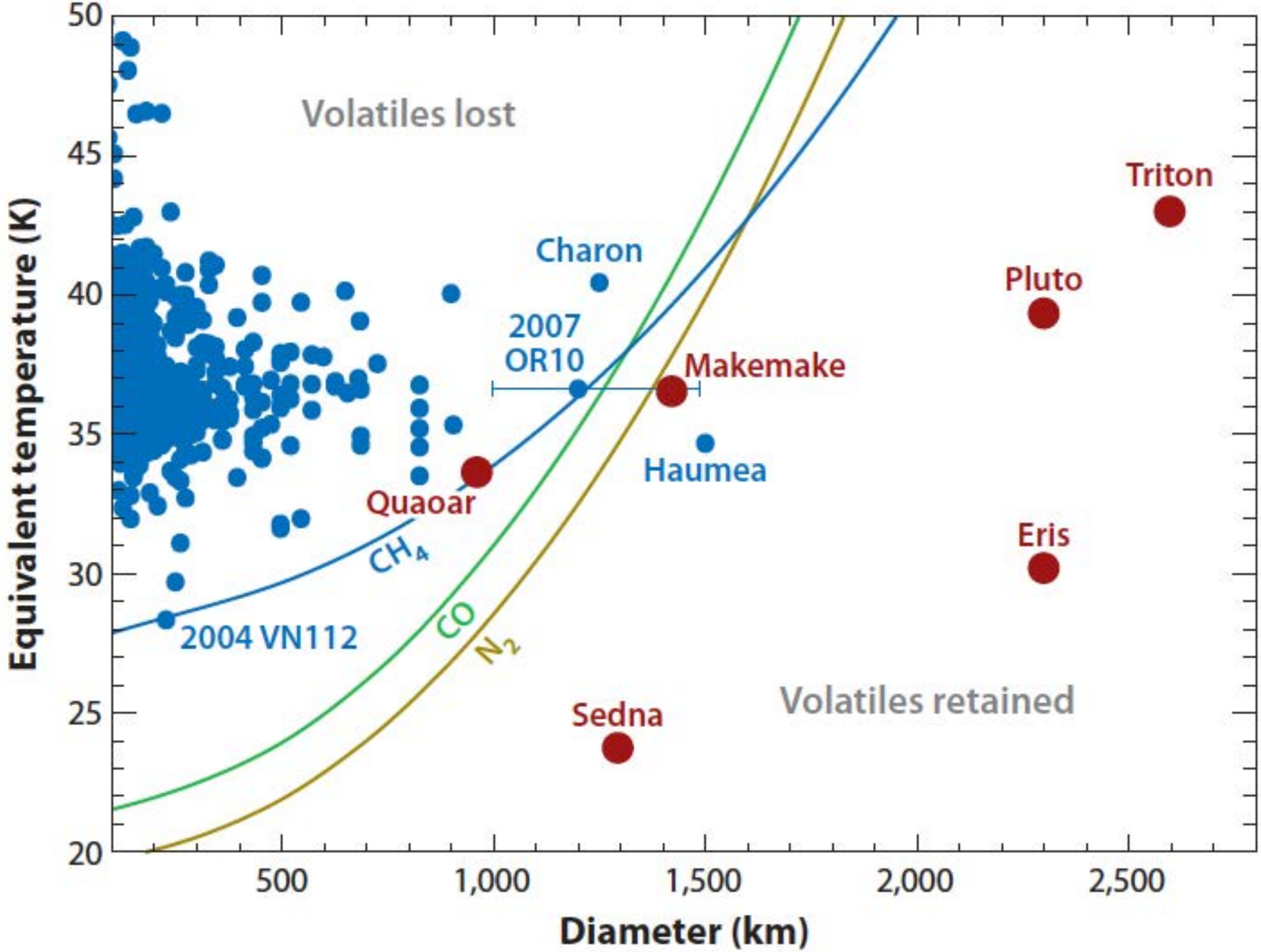
Kuiper belt objects: spectrally diverse



Jewitt & Luu (2004)


0.15
0.10
0.05
0
−0.05
−0.10
−0.15
Reflectance difference
2.10
2.15
2.20
2.25
2.30
2.35
Wavelength (μm)
CH4-removed spectrum
Pure ethane model
Propane
Dissolved ethane
Pure ethane
Makemake

Brown (2012)


Volatiles lost
Volatiles retained
Equivalent temperature (K)
Diameter (km)
50
45
40
35
30
25
20
500
1,000
1,500
2,000
2,500
Charon
2007
OR10
Makemake
Haumea
Quaoar
Triton
Pluto
Eris
Sedna
2004 VN112
CH4
CO
N2

Brown (2012)

Organic molecules

Identified on Callisto, Ganymede, Iapetus, Phoebe, …