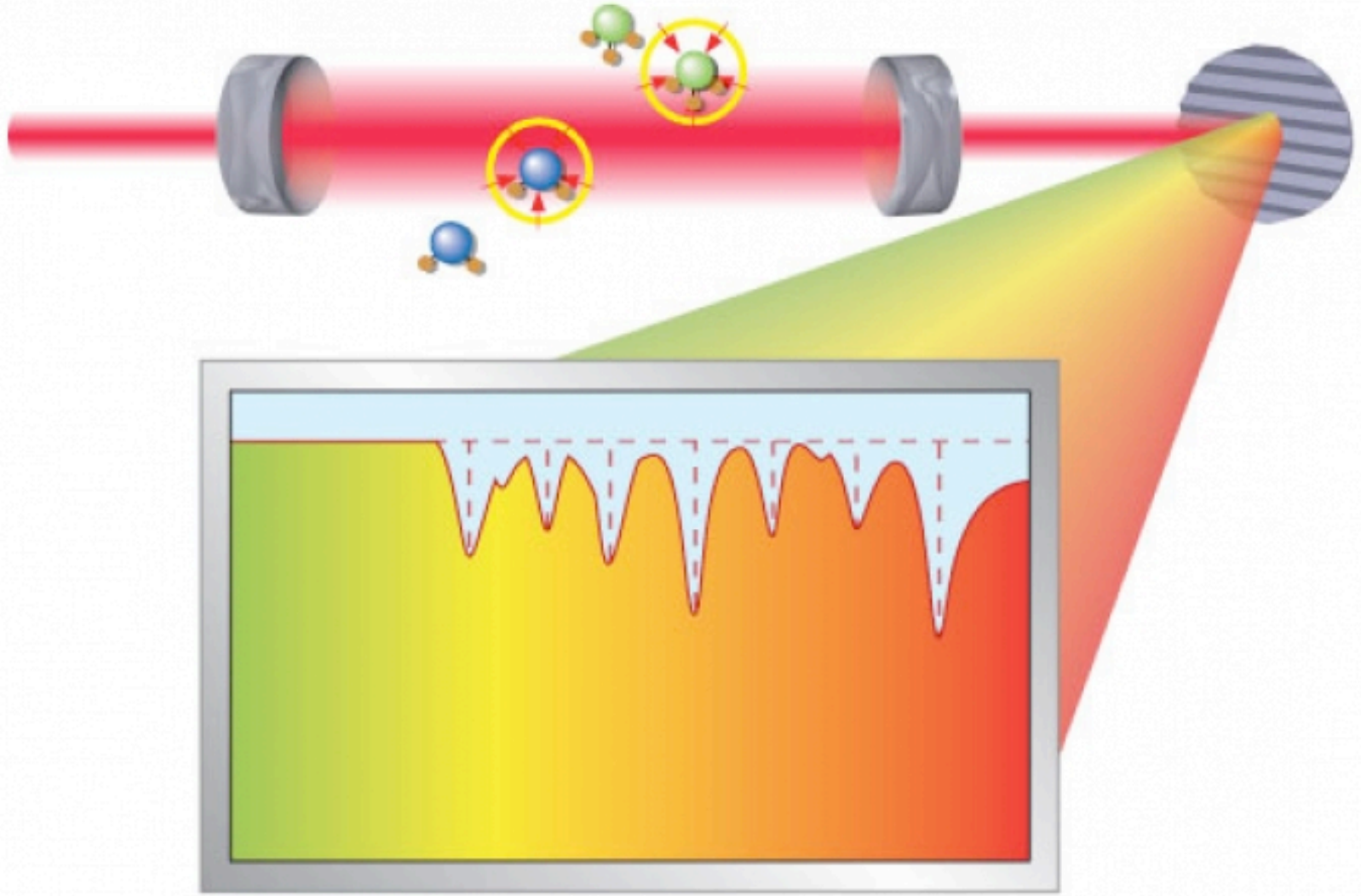


# Spectroscopy: The Study of Squiggly Lines



*Reflectance spectroscopy: light absorbed at specific wavelengths corresponding to energy level transitions*

TRENDING

- NASA:** Space Agency to Announce 'Major Science Finding' About Mars on Sept. 28
- McDonald's:** Woman Posts Photo Showing Fast Food Restaurant Employee Helping Disabled Man Eat
- Shigella:** 150 Cases of Infectious Disease Confirmed in Kansas City, Mo., Health Officials Say
- See more



11:30 AM 91%

Social Sciences **Study links U.S. political polarization to TV news deregulation following Telecommunications Act of 1996** (lofalexandria.com) 1600 comments science

5898 ▲ So is my Kinect broken, or is there something wrong with me that I don't know about... (imgur.com) 343 comments gaming

3040 ▼

▲ In case you didn't know, this is what moose babies look like (imgur.com) 5244 ▼ 563 comments aww

▲ What's considered trashy if you're poor, but classy if you're rich? (self.AskReddit) 2445 ▼ 1748 comments AskReddit

▲ **NASA Will Announce A Major Mars Discovery On Monday** (iflscience.com) 5472 ▼ 3412 comments worldnews

▲ Other I am Les Stroud (aka Survivorman), a filmmaker, outdoor adventurer, singer-songwriter and performer and I'm back for another AMA. Ask Me Anything! (self.IAMa) 4516 ▼ 1663 comments IAmA

▲ Original in Comments Johnny Carson's musical guest for the Tonight Show cancelled at the last minute, so Johnny invites a random audience member to play the piano during the

5237 ▼

# NASA to Announce Mars Mystery Solved

NASA will detail a major science finding from the agency's ongoing exploration of Mars during a news briefing at 11:30 a.m. EDT on Monday, Sept. 28 at the James Webb Auditorium at NASA Headquarters in Washington. The event will be broadcast live on...

NASA.GOV

# Spectral evidence for hydrated salts in recurring slope lineae on Mars

Lujendra Ojha<sup>1\*</sup>, Mary Beth Wilhelm<sup>1,2</sup>, Scott L. Murchie<sup>3</sup>, Alfred S. McEwen<sup>4</sup>, James J. Wray<sup>1</sup>, Jennifer Hanley<sup>5</sup>, Marion Massé<sup>6</sup> and Matt Chojnacki<sup>4</sup>

**Determining whether liquid water exists on the Martian surface is central to understanding the hydrologic cycle and potential for extant life on Mars. Recurring slope lineae, narrow streaks of low reflectance compared to the surrounding terrain, appear and grow incrementally in the downslope direction during warm seasons when temperatures reach about 250–300 K (refs 1–3), a pattern consistent with the transient flow of a volatile species<sup>1–3</sup>. Brine flows (or seeps) have been proposed to explain the formation of recurring slope lineae<sup>1–3</sup>, yet no direct evidence for either liquid water or hydrated salts has been found<sup>4</sup>. Here we analyse spectral data from the Compact Reconnaissance Imaging Spectrometer for Mars instrument onboard the Mars Reconnaissance Orbiter from four different locations where recurring slope lineae are present. We find evidence for hydrated salts at all four locations in the seasons when recurring slope lineae are most extensive, which suggests that the source of hydration is recurring slope lineae activity. The hydrated salts most consistent with the spectral absorption features we detect are magnesium perchlorate, magnesium chlorate and sodium perchlorate. Our findings strongly support the hypothesis that recurring slope lineae form as a result of contemporary water activity on Mars.**

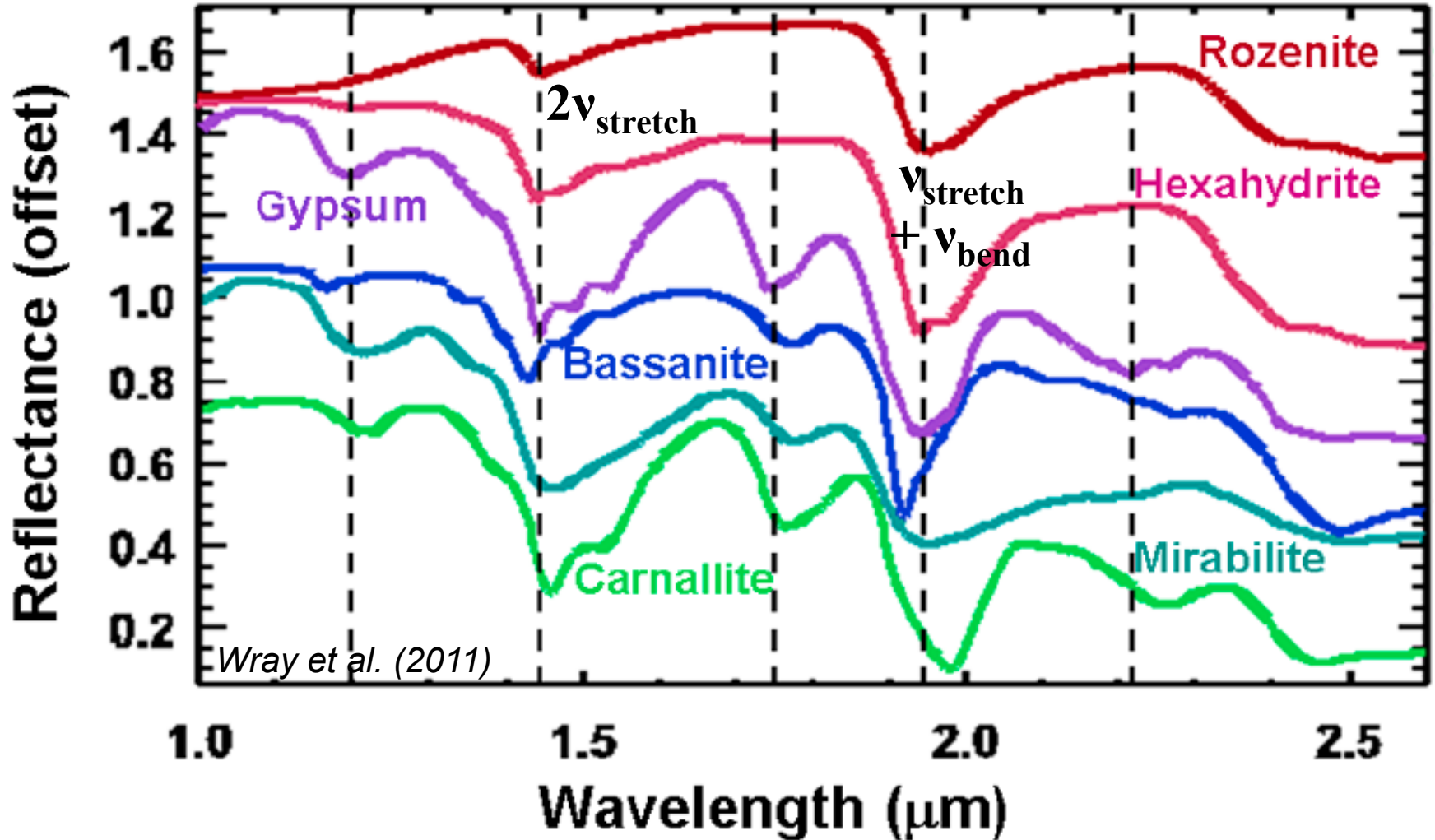
the surface, or detection of hydrated salts precipitated from that water.

The mineralogic composition of RSL and their surroundings can be investigated using orbital data acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on the Mars Reconnaissance Orbiter (MRO), which acquires spectral cubes with 544 spectral channels ( $\sim 0.4$  to  $3.92\ \mu\text{m}$ ; ref. 14). Within the infrared (IR) detector spectral range of CRISM ( $1$ – $3.92\ \mu\text{m}$ ), both liquid water and hydrated salts have diagnostic absorption bands at  $\sim 1.4\ \mu\text{m}$ ,  $\sim 1.9\ \mu\text{m}$  and a broad absorption feature at  $\sim 3.0\ \mu\text{m}$  (ref. 15; Fig. 1). In addition, hydrated salts may exhibit combinations or overtones at other wavelengths from  $1.7$  to  $2.4\ \mu\text{m}$ . Given the coarser spatial sampling of CRISM ( $\sim 18\ \text{m pixel}^{-1}$ ) compared to HiRISE, few locations exist in which RSL are wide or dense enough to fill even a single CRISM pixel. In this work, we devised a variety of methods to reduce uncertainties from extraction of CRISM spectra from individual pixels (Supplementary Information), allowing examination of pixels mostly filled by RSL.

At Palikir crater, RSL are observed to be longest and widest towards the end of the southern summer. In the HiRISE image acquired at the end of the southern summer of Mars Year (MY) 30, wide RSL were observed on the slopes of Palikir (Fig. 1

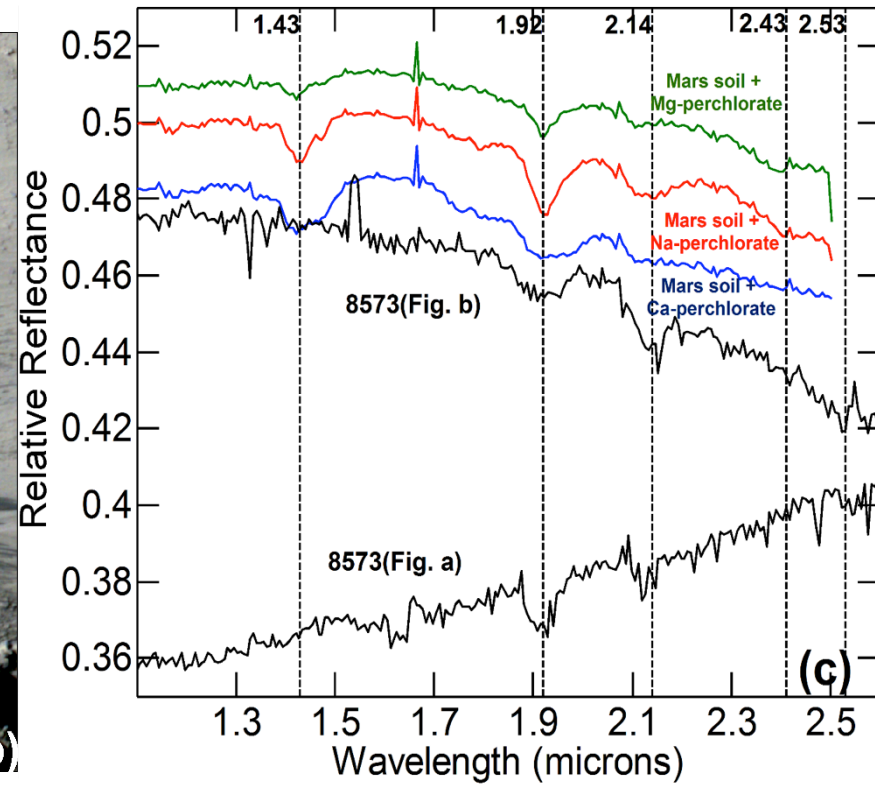
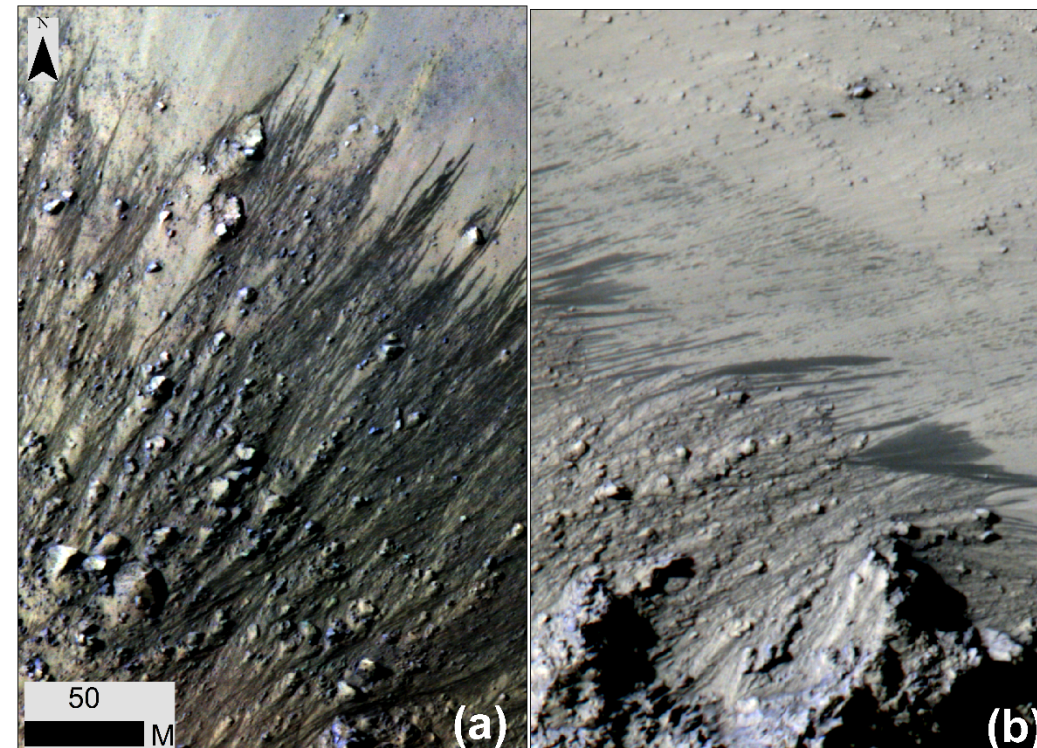
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# Hydrated salt spectra



*Essentially all features due to  $\text{H}_2\text{O}/\text{OH}$  vibrations*

# Central peaks of Horowitz Crater



# Implication for Water on Mars

## Stability of Pure Water on the Surface of Earth



## Stability of Pure Water on the Surface of Mars



## Stability of Perchlorate-brine on the Surface of Mars



# Unfilled *d* orbitals: the transition metals

## Periodic Table of the Elements

1 1 <b>H</b> Hydrogen 1.00794	2 4 <b>He</b> Helium 4.002602											13 5 <b>B</b> Boron 10.811	14 6 <b>C</b> Carbon 12.011																		
3 2 <b>Li</b> Lithium 6.941	4 2 <b>Be</b> Beryllium 9.012182											15 7 <b>N</b> Nitrogen 14.00643	16 8 <b>O</b> Oxygen 15.999																		
5 3 <b>Na</b> Sodium 22.989770	6 4 <b>Mg</b> Magnesium 24.3050	7 3 <b>Al</b> Aluminum 26.981538	8 4 <b>Si</b> Silicon 28.0855	9 5 <b>P</b> Phosphorus 30.973762	10 6 <b>S</b> Sulfur 32.06	11 7 <b>Cl</b> Chlorine 35.45	12 8 <b>Ar</b> Argon 39.948	13 9 <b>K</b> Potassium 39.0983	14 10 <b>Ca</b> Calcium 40.078	15 11 <b>Sc</b> Scandium 44.955910	16 12 <b>Ti</b> Titanium 47.867	17 13 <b>V</b> Vanadium 50.9415	18 14 <b>Cr</b> Chromium 51.9961	19 15 <b>Mn</b> Manganese 54.938049	20 16 <b>Fe</b> Iron 55.845	21 17 <b>Co</b> Cobalt 58.933200	22 18 <b>Ni</b> Nickel 58.6934	23 19 <b>Cu</b> Copper 63.546	24 20 <b>Zn</b> Zinc 65.409	25 21 <b>Ga</b> Gallium 69.723	26 22 <b>Ge</b> Germanium 72.64										
19 4 <b>K</b> Potassium 39.0983	20 4 <b>Ca</b> Calcium 40.078	21 5 <b>Sc</b> Scandium 44.955910	22 6 <b>Ti</b> Titanium 47.867	23 7 <b>V</b> Vanadium 50.9415	24 8 <b>Cr</b> Chromium 51.9961	25 9 <b>Mn</b> Manganese 54.938049	26 10 <b>Fe</b> Iron 55.845	27 11 <b>Co</b> Cobalt 58.933200	28 12 <b>Ni</b> Nickel 58.6934	29 13 <b>Cu</b> Copper 63.546	30 14 <b>Zn</b> Zinc 65.409	31 15 <b>Ga</b> Gallium 69.723	32 16 <b>Ge</b> Germanium 72.64	33 17 <b>As</b> Arsenic 74.9216	34 18 <b>Se</b> Selenium 78.96	35 19 <b>Br</b> Bromine 79.904	36 18 <b>Kr</b> Krypton 83.80	37 20 <b>Rb</b> Rubidium 85.4678	38 18 <b>Sr</b> Strontium 87.62	39 19 <b>Y</b> Yttrium 88.90585	40 20 <b>Zr</b> Zirconium 91.224	41 21 <b>Nb</b> Niobium 92.90638	42 22 <b>Mo</b> Molybdenum 95.94	43 23 <b>Tc</b> Technetium (98)	44 24 <b>Ru</b> Ruthenium 101.07	45 25 <b>Rh</b> Rhodium 102.90550	46 26 <b>Pd</b> Palladium 106.42	47 27 <b>Ag</b> Silver 107.8682	48 28 <b>Cd</b> Cadmium 112.411	49 29 <b>In</b> Indium 114.818	50 30 <b>Sn</b> Tin 118.710
55 6 <b>Cs</b> Cesium 132.90545	56 18 <b>Ba</b> Barium 137.327	57 to 71 10 <b>Lanthanide series</b>	72 18 <b>Hf</b> Hafnium 178.49	73 18 <b>Ta</b> Tantalum 180.9479	74 18 <b>W</b> Tungsten 183.84	75 18 <b>Re</b> Rhenium 186.207	76 18 <b>Os</b> Osmium 190.23	77 18 <b>Ir</b> Iridium 192.217	78 18 <b>Pt</b> Platinum 195.078	79 18 <b>Au</b> Gold 196.96655	80 18 <b>Hg</b> Mercury 200.59	81 18 <b>Tl</b> Thallium 204.3833	82 18 <b>Pb</b> Lead 207.2	83 18 <b>Bi</b> Bismuth 208.9804	84 18 <b>Po</b> Polonium (209)	85 18 <b>At</b> Astatine (210)	86 18 <b>Rn</b> Radon (222)	87 20 <b>Fr</b> Francium (223)	88 18 <b>Ra</b> Radium (226)	89 to 103 15 <b>Actinide series</b>	104 18 <b>Rf</b> Rutherfordium (261)	105 18 <b>Db</b> Dubnium (262)	106 18 <b>Sg</b> Seaborgium (266)	107 18 <b>Bh</b> Bohrium (264)	108 18 <b>Hs</b> Hassium (269)	109 18 <b>Mt</b> Meitnerium (268)	110 18 <b>Ds</b> Darmstadtium (271)	111 18 <b>Rg</b> Roentgenium (272)	112 18 <b>Uub</b> Ununbium (285)	113 18 <b>Uut</b> Ununtrium (289)	114 18 <b>Uuq</b> Ununquadium (288)

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanide series
- Actinide series
- Poor metals
- Nonmetals
- Noble gases
- Solid
- Liquid
- Gas
- Synthetic



Atomic masses in parentheses are those of the most stable or common isotope.

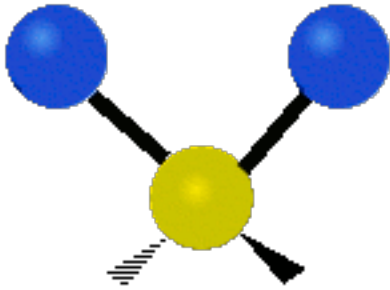
Design Copyright © 1997 Michael Dayah (michael@dayah.com) http://www.dayah.com/periodic/

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

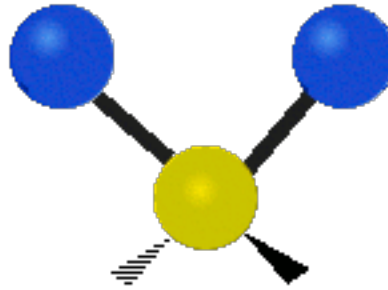
*Iron is the most geologically abundant transition metal*

# Molecular vibrations

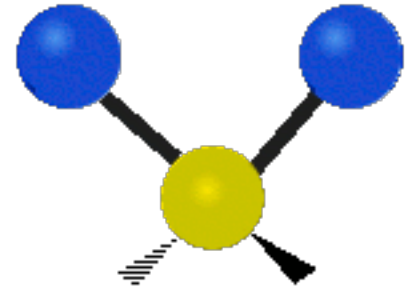
Symmetric stretch



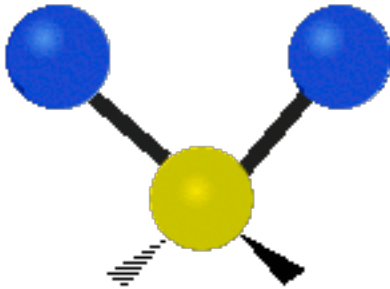
Asymmetric stretch



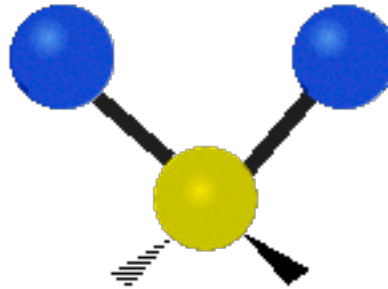
Scissor/bend



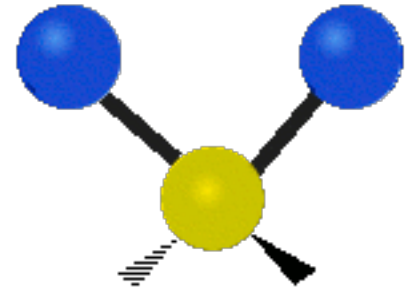
Rocking



Wagging



Twist

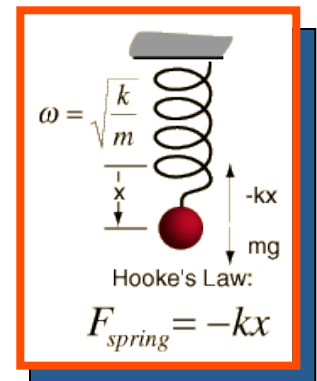




# Vibrational Processes

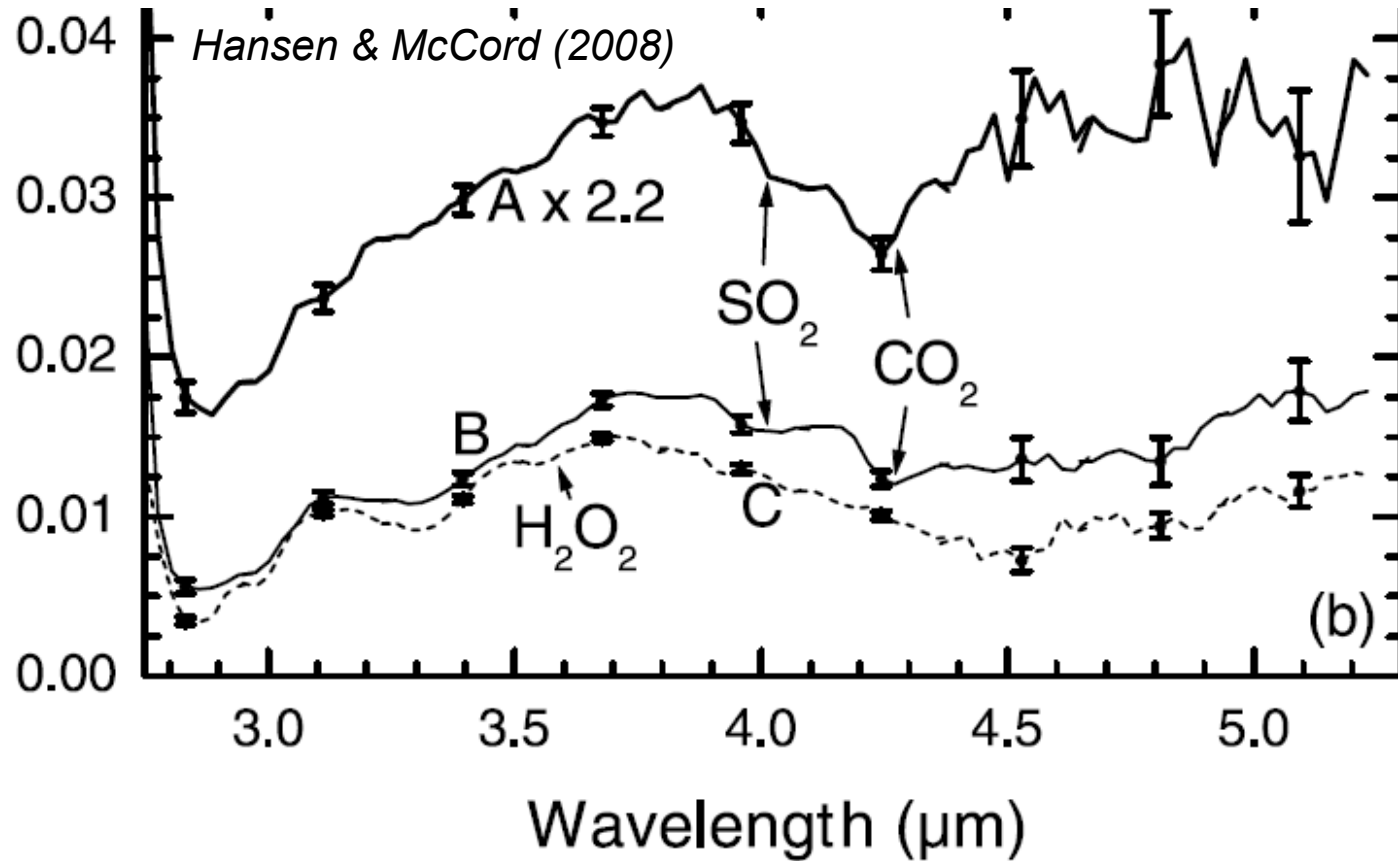
The bonds in a molecule or crystal lattice are like springs with attached weights: the whole system can vibrate. The frequency of vibration depends on the strength of each spring (the bond in a molecule) and their masses (the mass of each element in a molecule). For a molecule with  $N$  atoms, there are  $3N-6$  normal modes of vibrations called fundamentals.\* Each vibration can also occur at multiples of the original fundamental frequency (overtones) or involve different modes of vibrations (combinations).

\* In general, a molecule with  $N$  atoms has  $3N-6$  normal modes of vibration but *linear* molecules have only  $3N-5$  normal modes of vibration as rotation about its molecular axis cannot be observed.

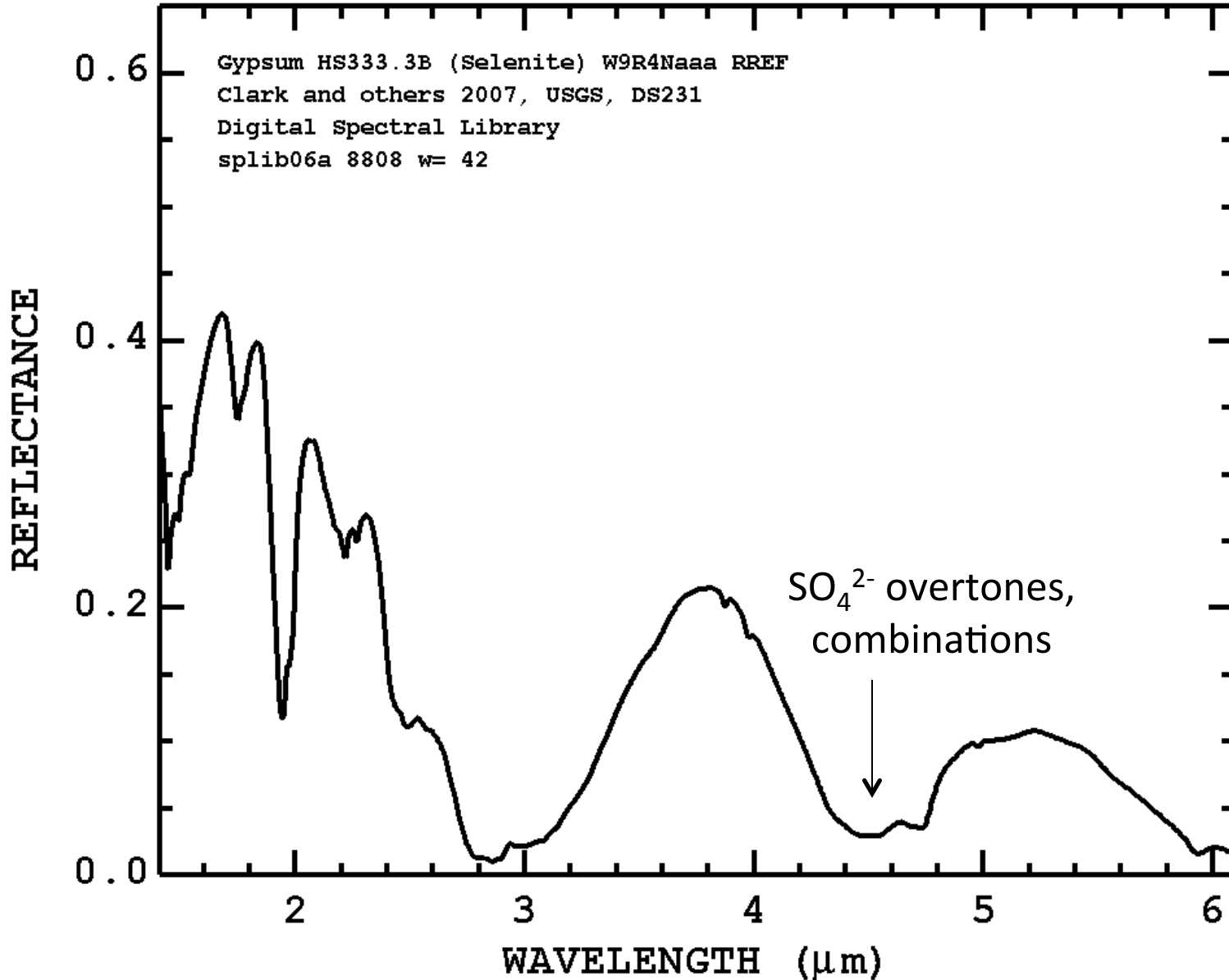


# Peroxide, CO<sub>2</sub> and more on Europa

(and Ganymede, Callisto)



# Sulfate vibrational absorptions



## Carbonate vibrational absorptions

Fundamental modes of free  $\text{CO}_3^{2-}$  ion (will vary in minerals):

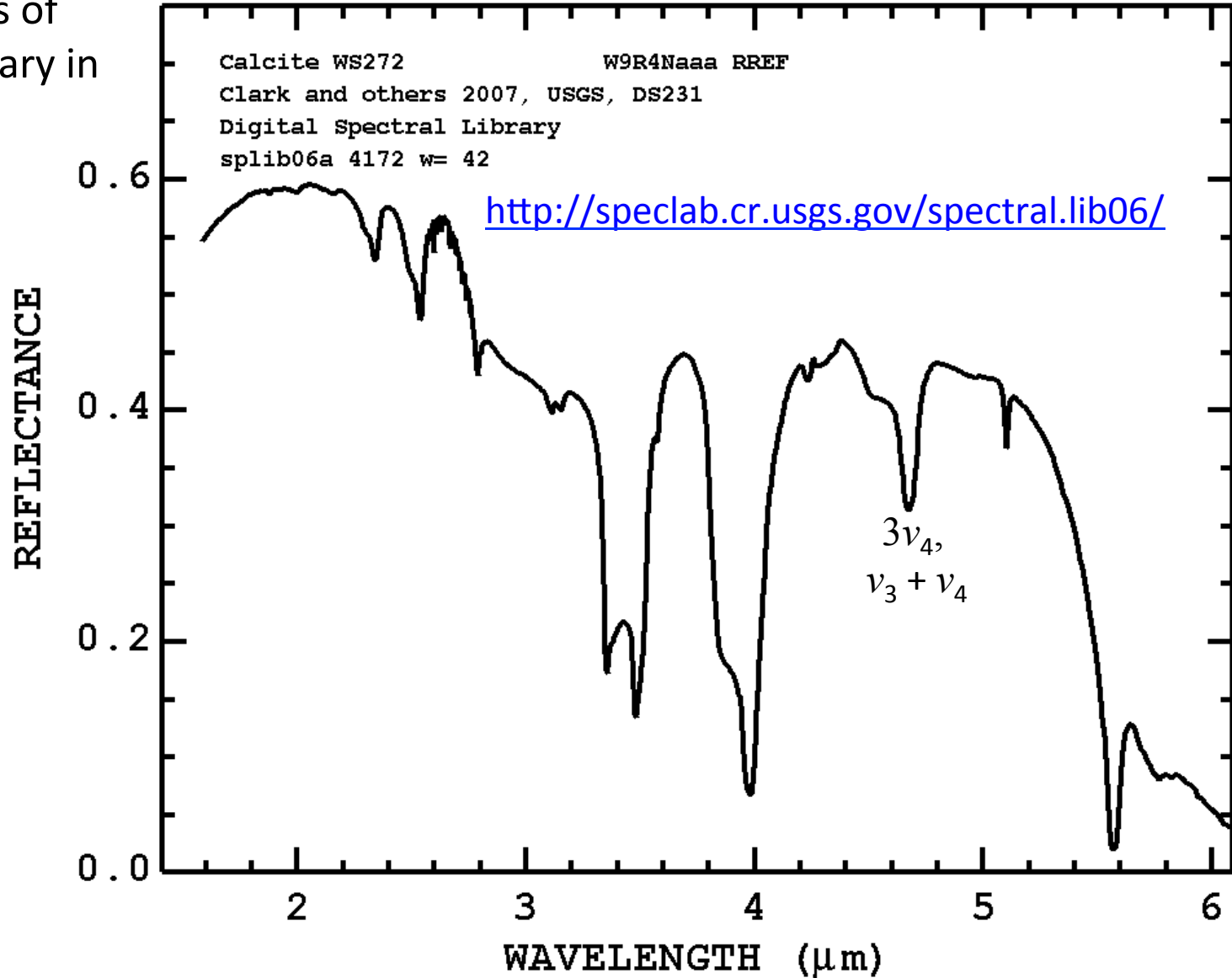
$$\nu_1 = 9.407 \mu\text{m}$$

$$\nu_2 = 11.4 \mu\text{m}$$

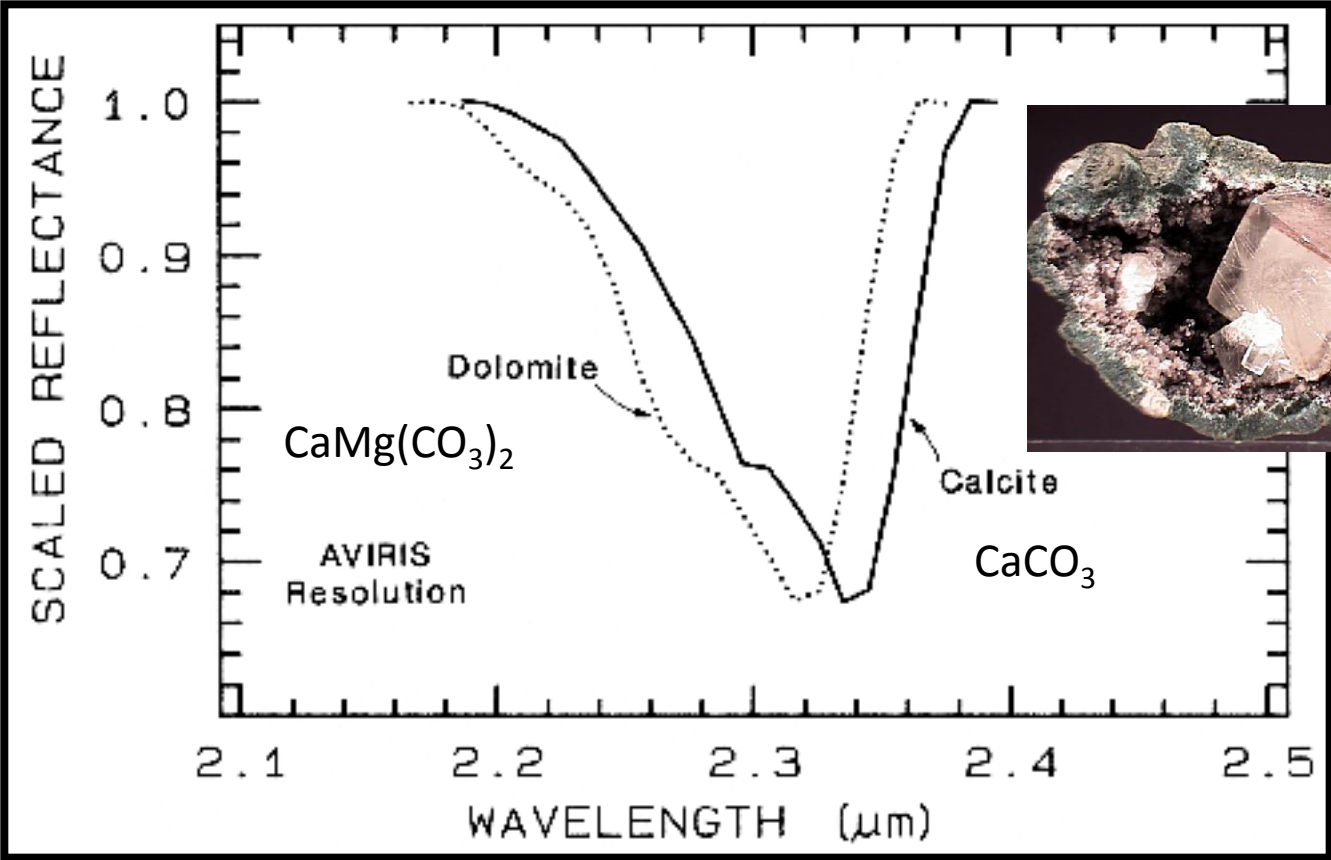
$$\nu_3 = 7.067 \mu\text{m}$$

$$\nu_4 = 14.7 \mu\text{m}$$

Combination / overtone bands are weaker

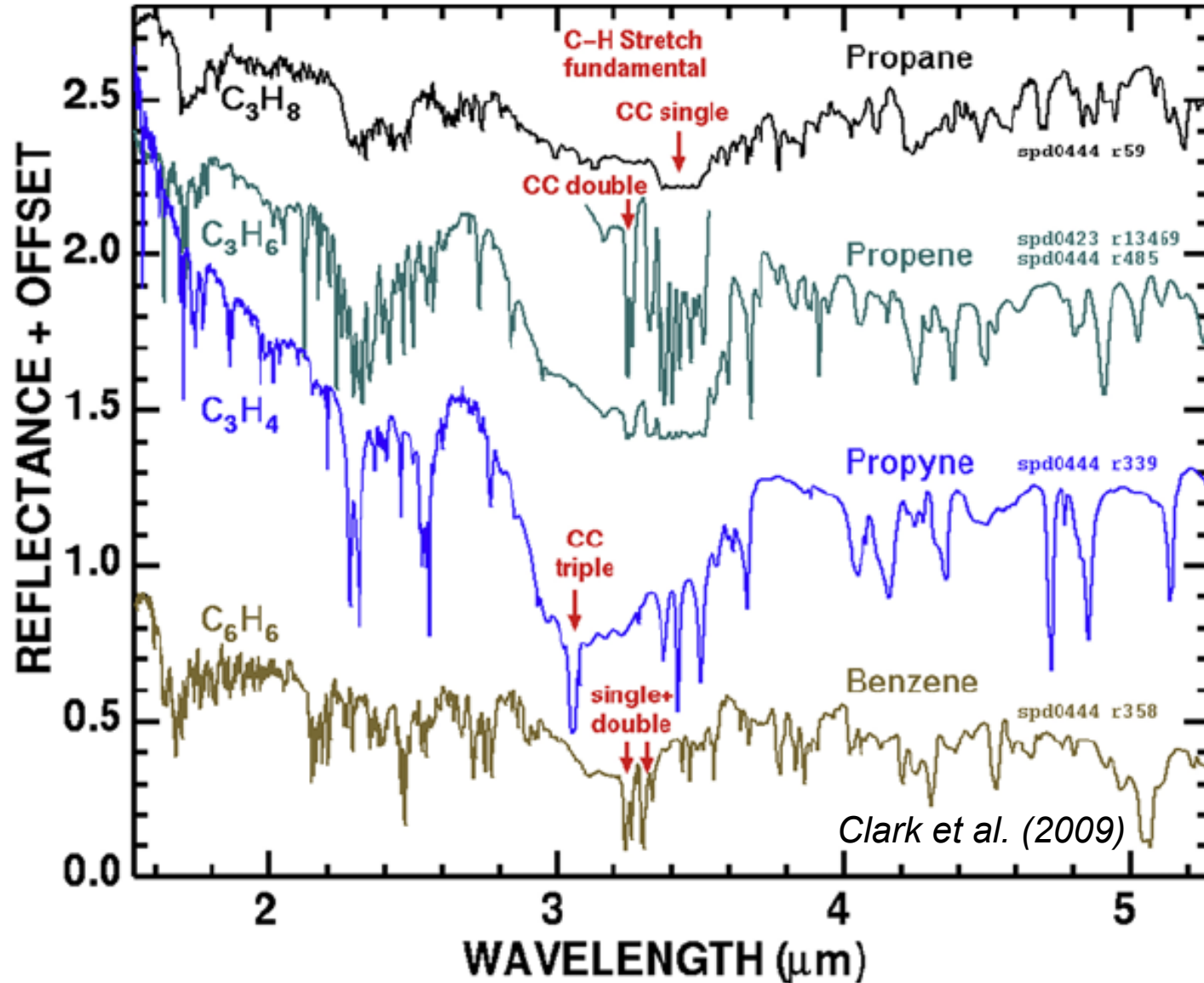


# Band position in carbonate minerals shifts with composition



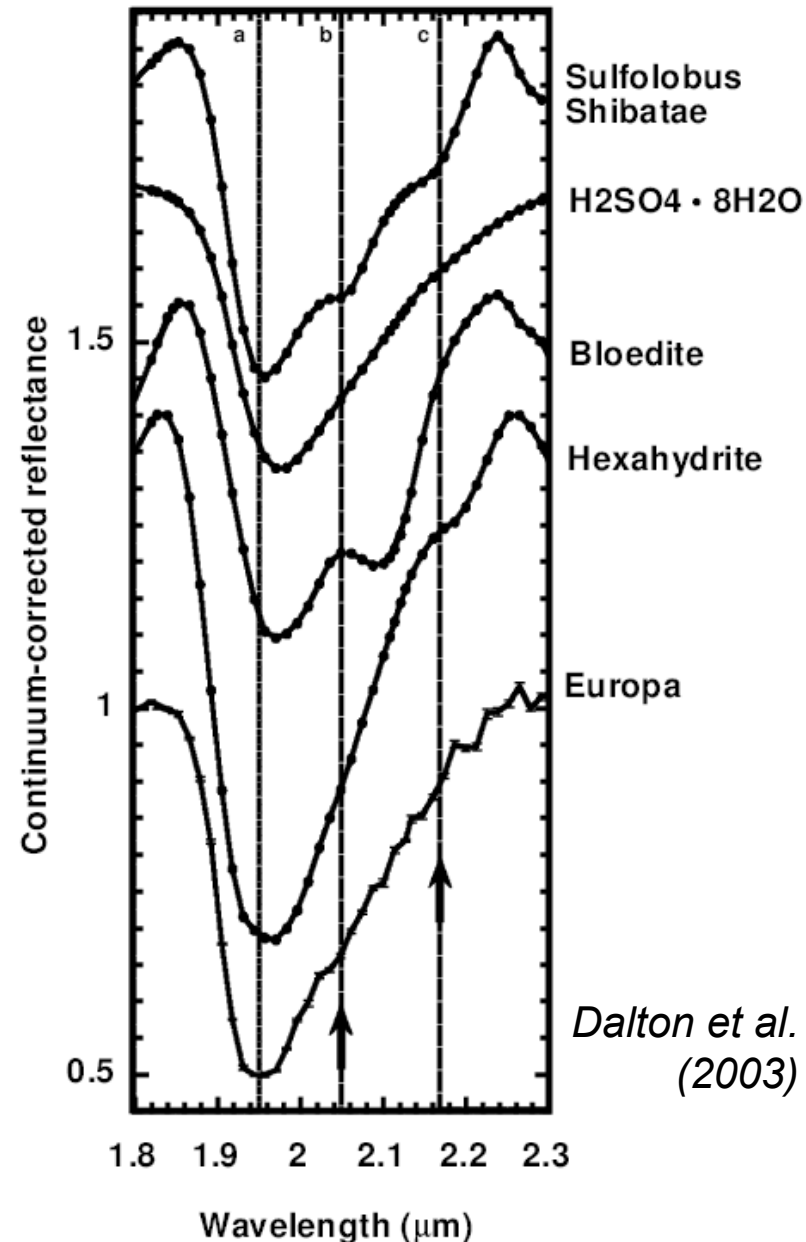
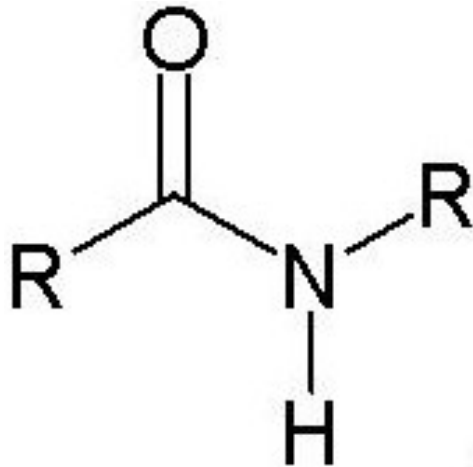
# Organic molecules

Identified on several moons of Jupiter and Saturn

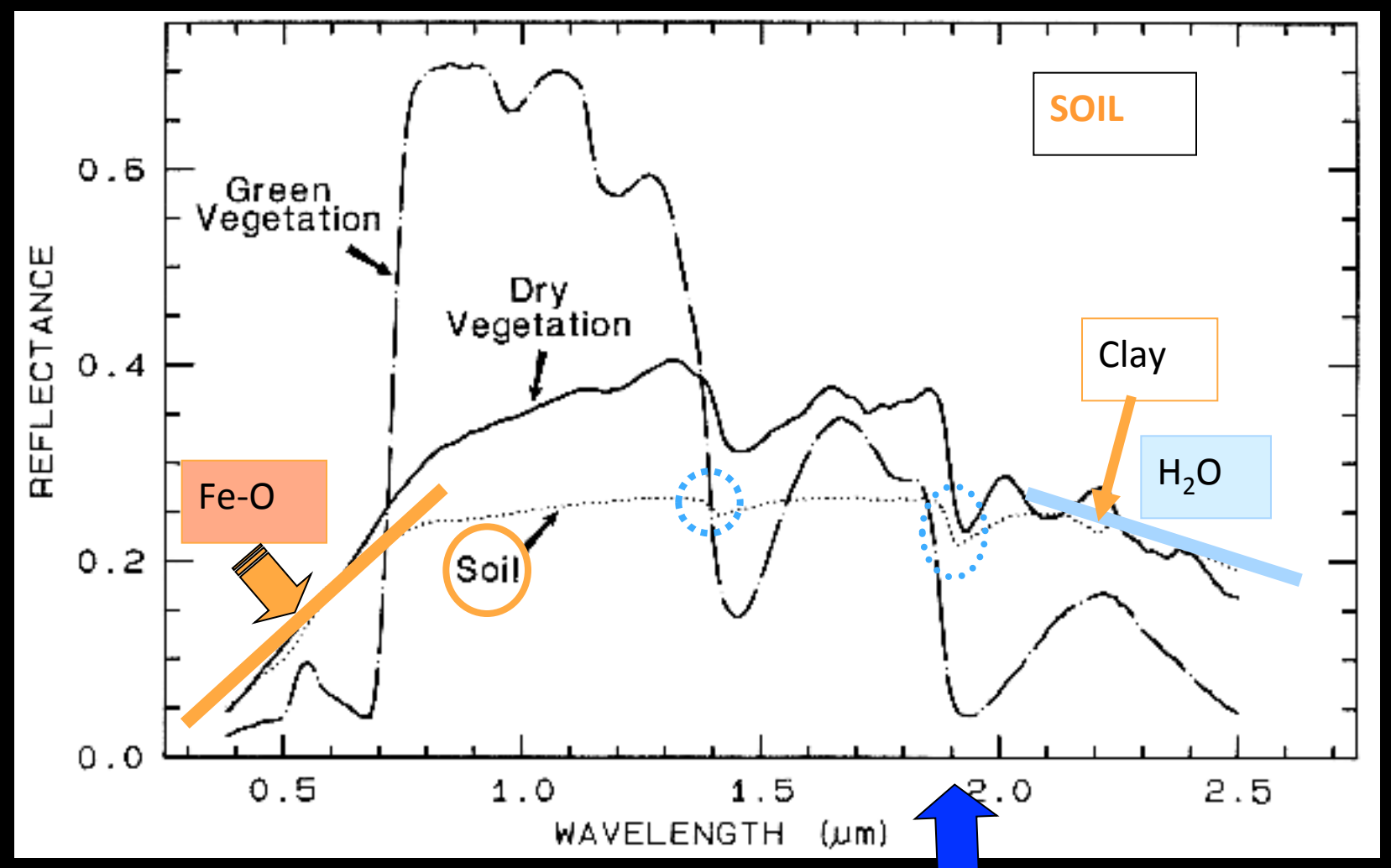


# Amides: Spectral biomarkers?

- Link amino acids in proteins, with distinct IR signature → *biomarker*
- NIR bands ambiguous; stronger fundamental bands at  $\sim 6 \mu\text{m}$



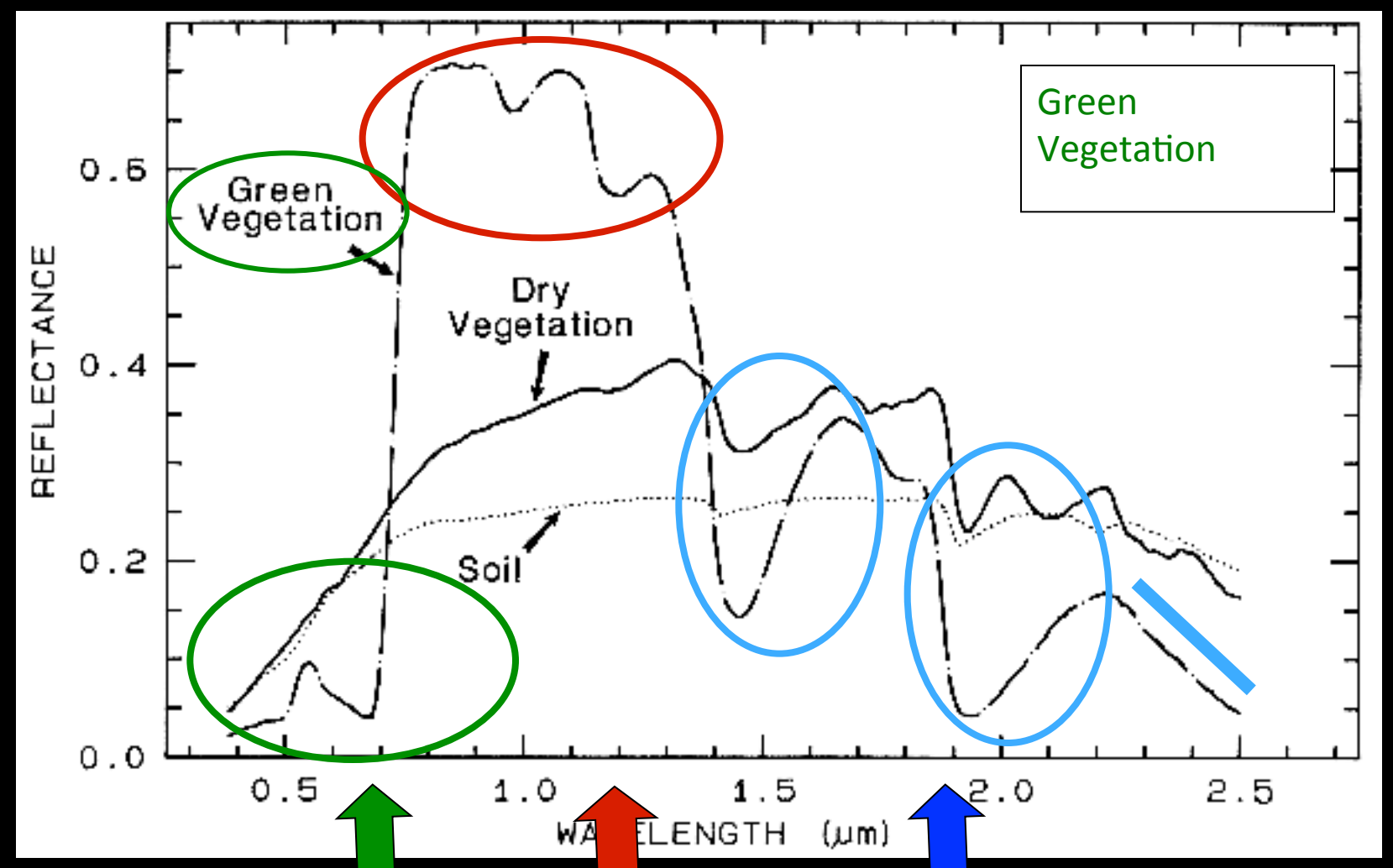
# Spectra of common Earth-surface materials



Water absorption



# Spectra of common Earth-surface materials

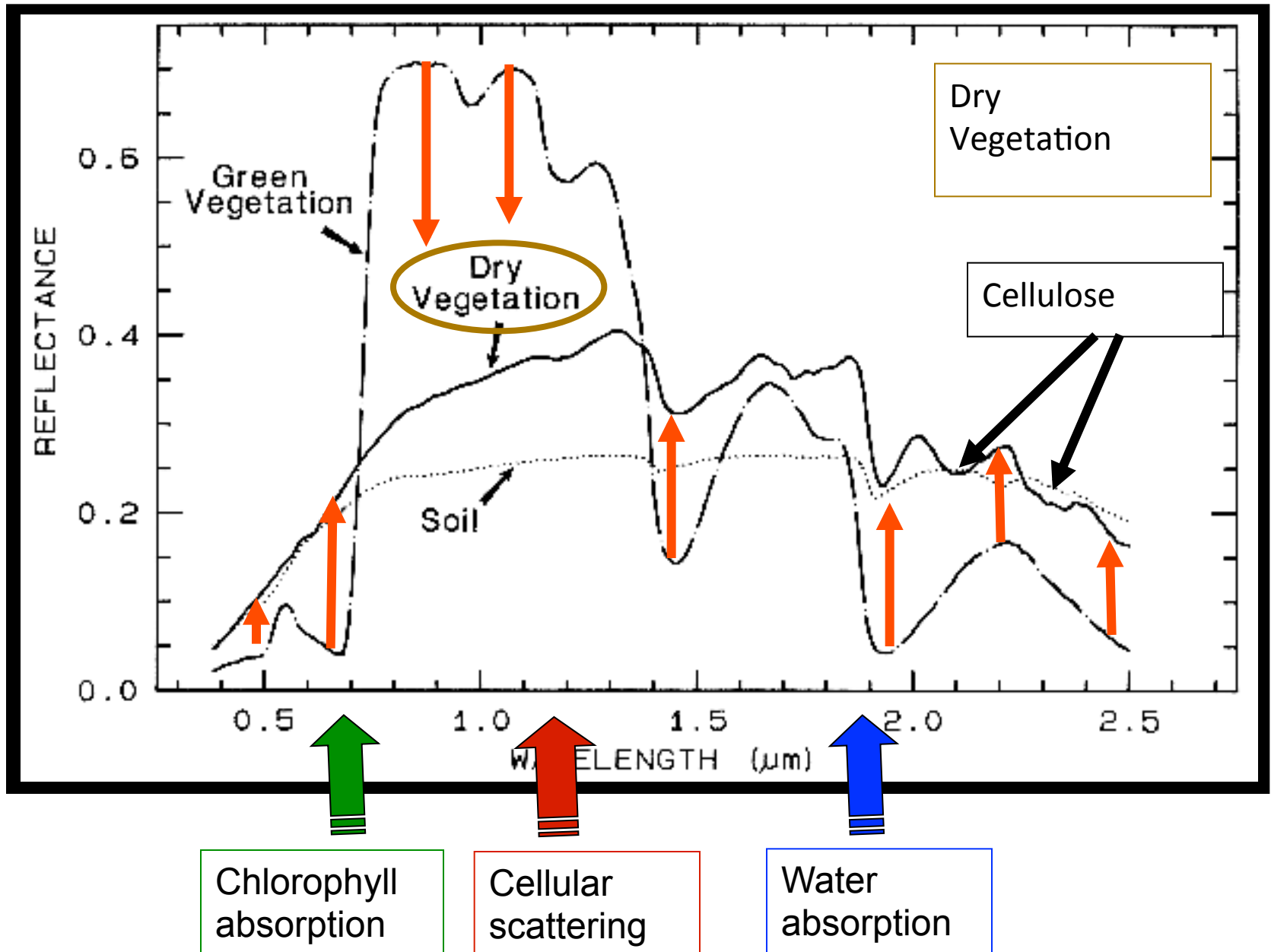


Chlorophyll absorption

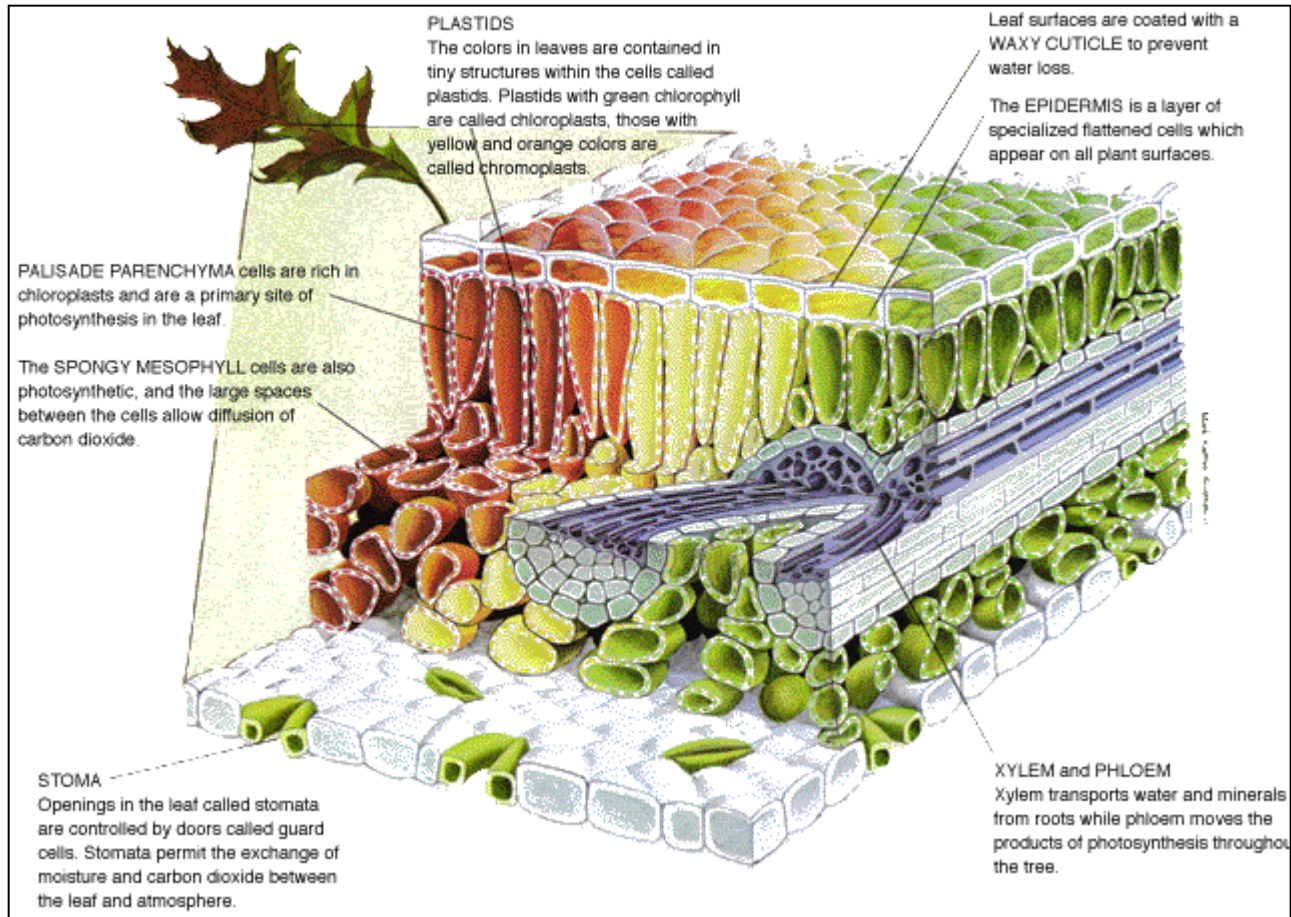
Cellular scattering

Water absorption

# Spectra of common Earth-surface materials

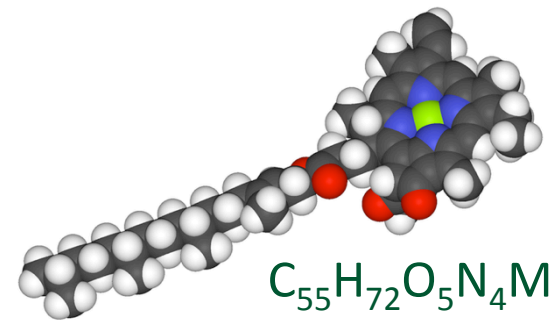
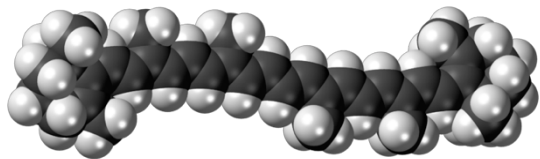
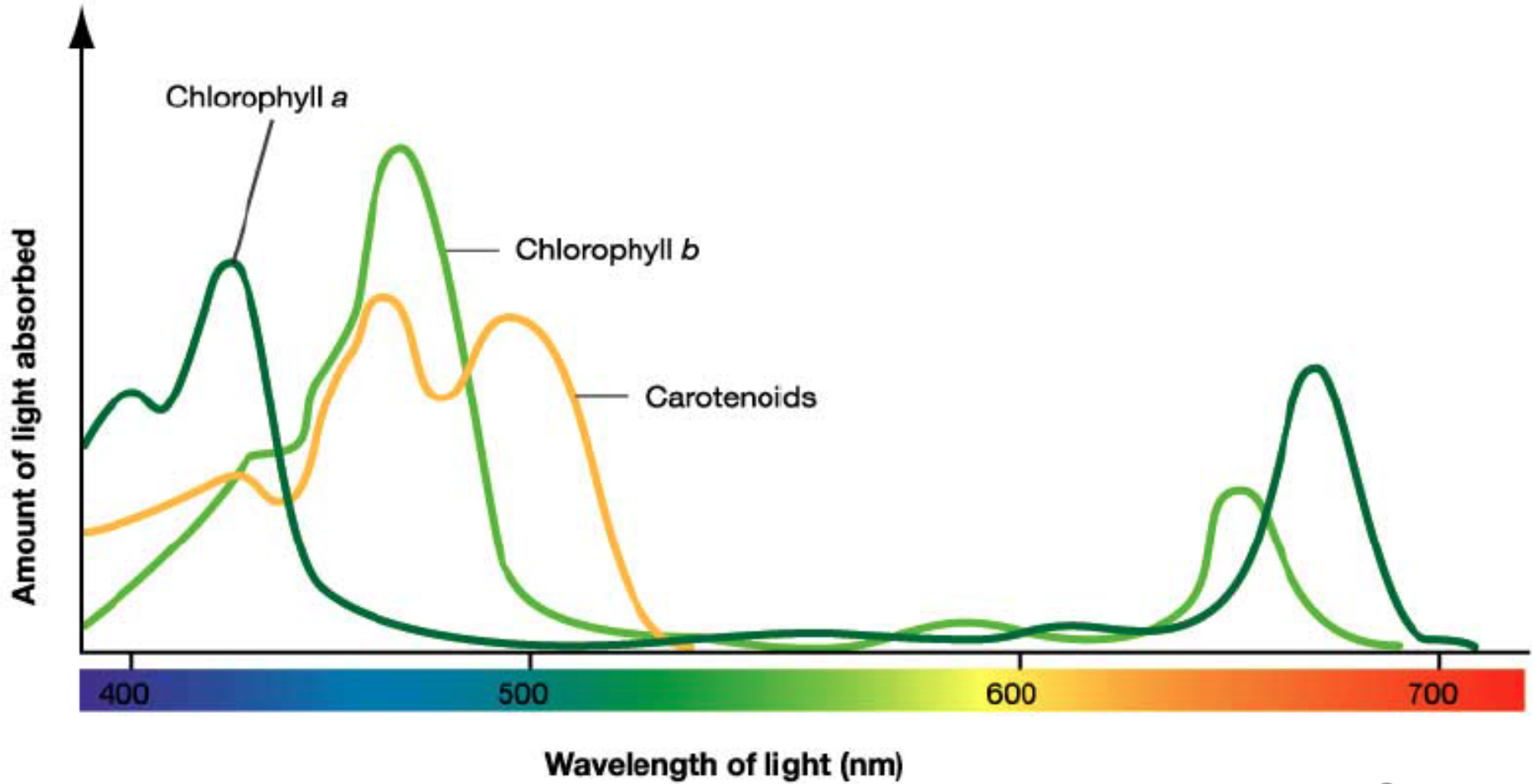


# Leaf structure and its relation to spectra

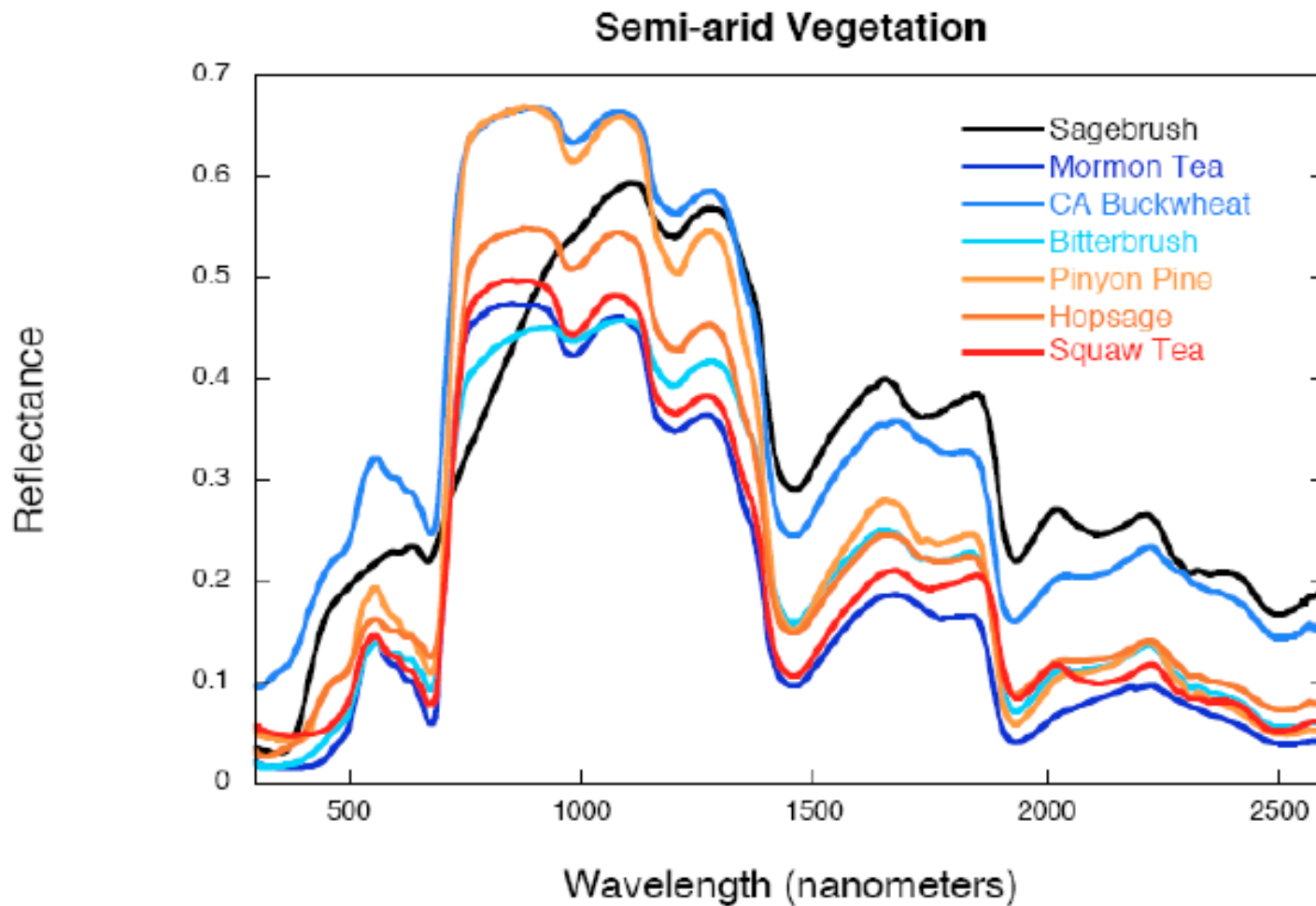


Absorption band in red: chlorophyll pigment  
Reflective NIR: scattering in the prismatic leaf cells  
SWIR absorption: absorption by leaf water

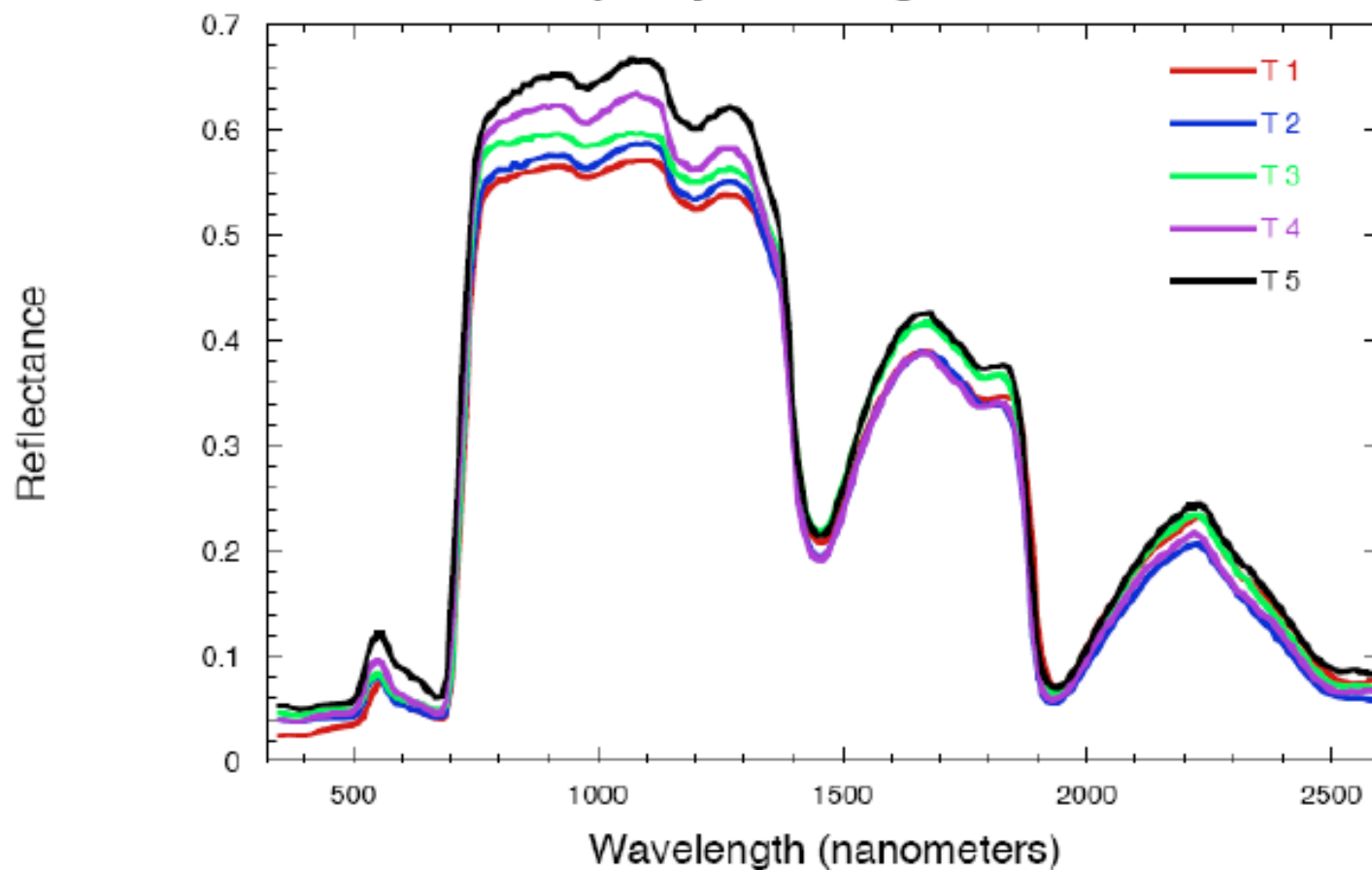
# Plant Pigments



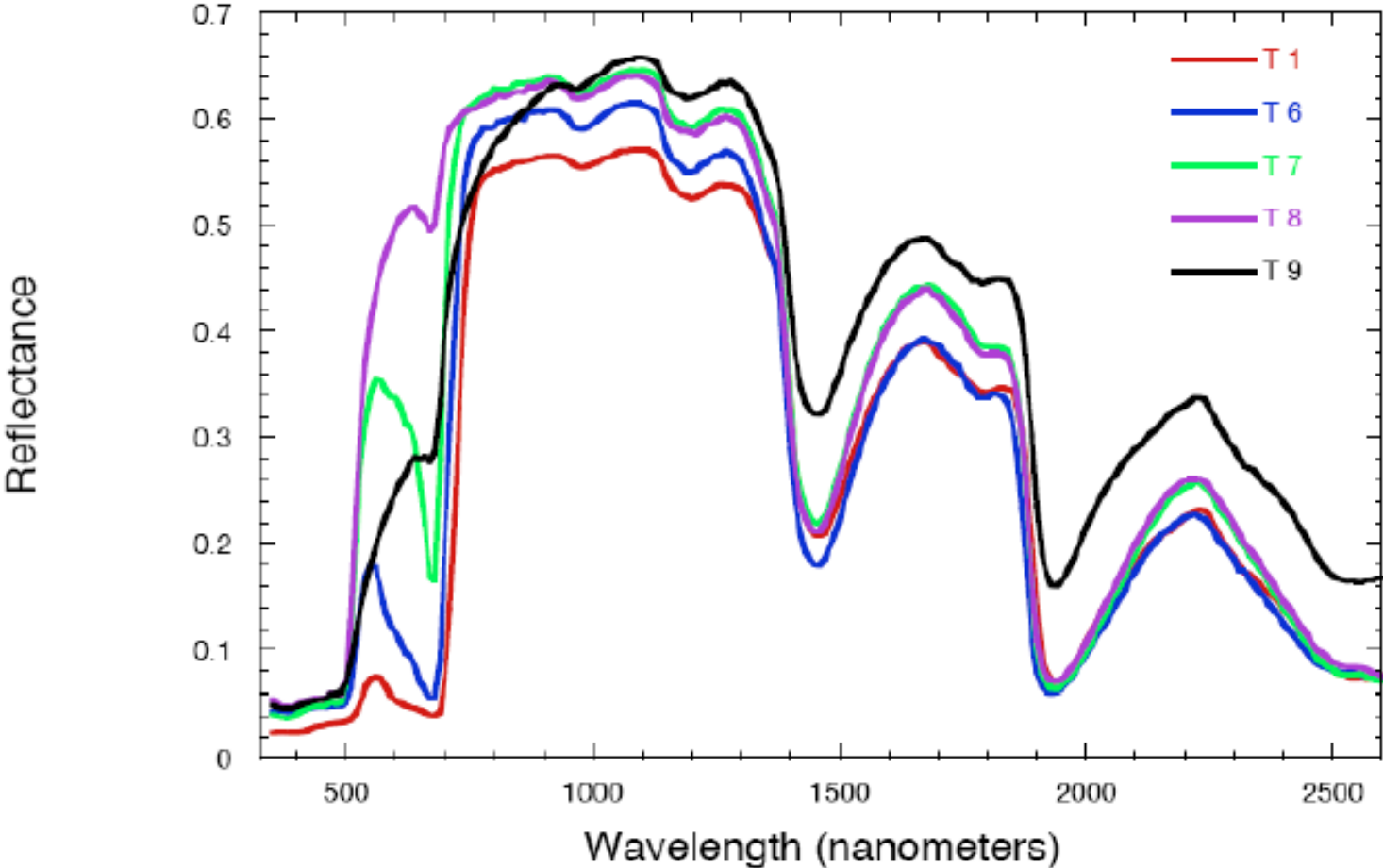
# Variations from one species to another



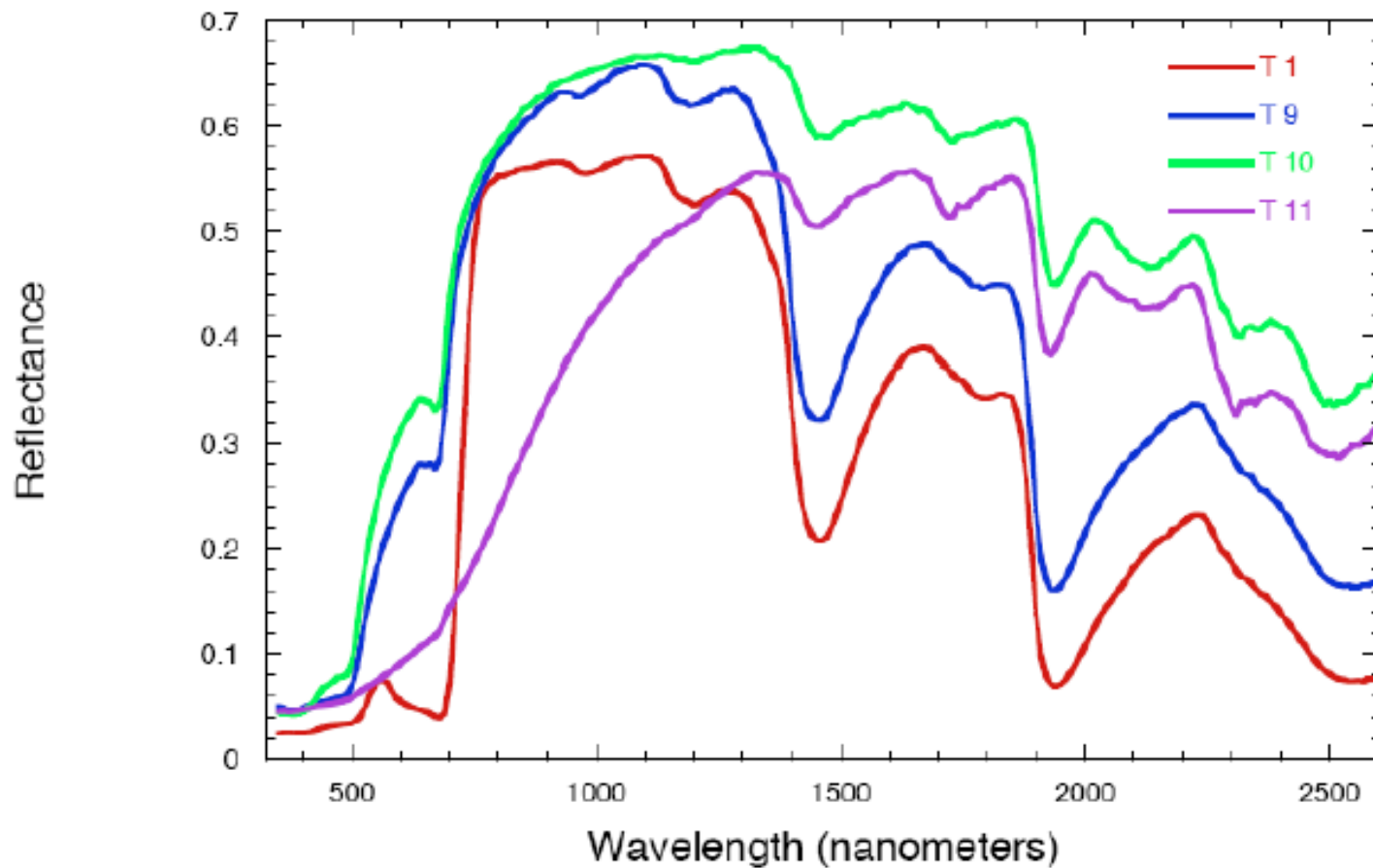
## Norway Maple During Senescence



# Norway Maple During Senescence



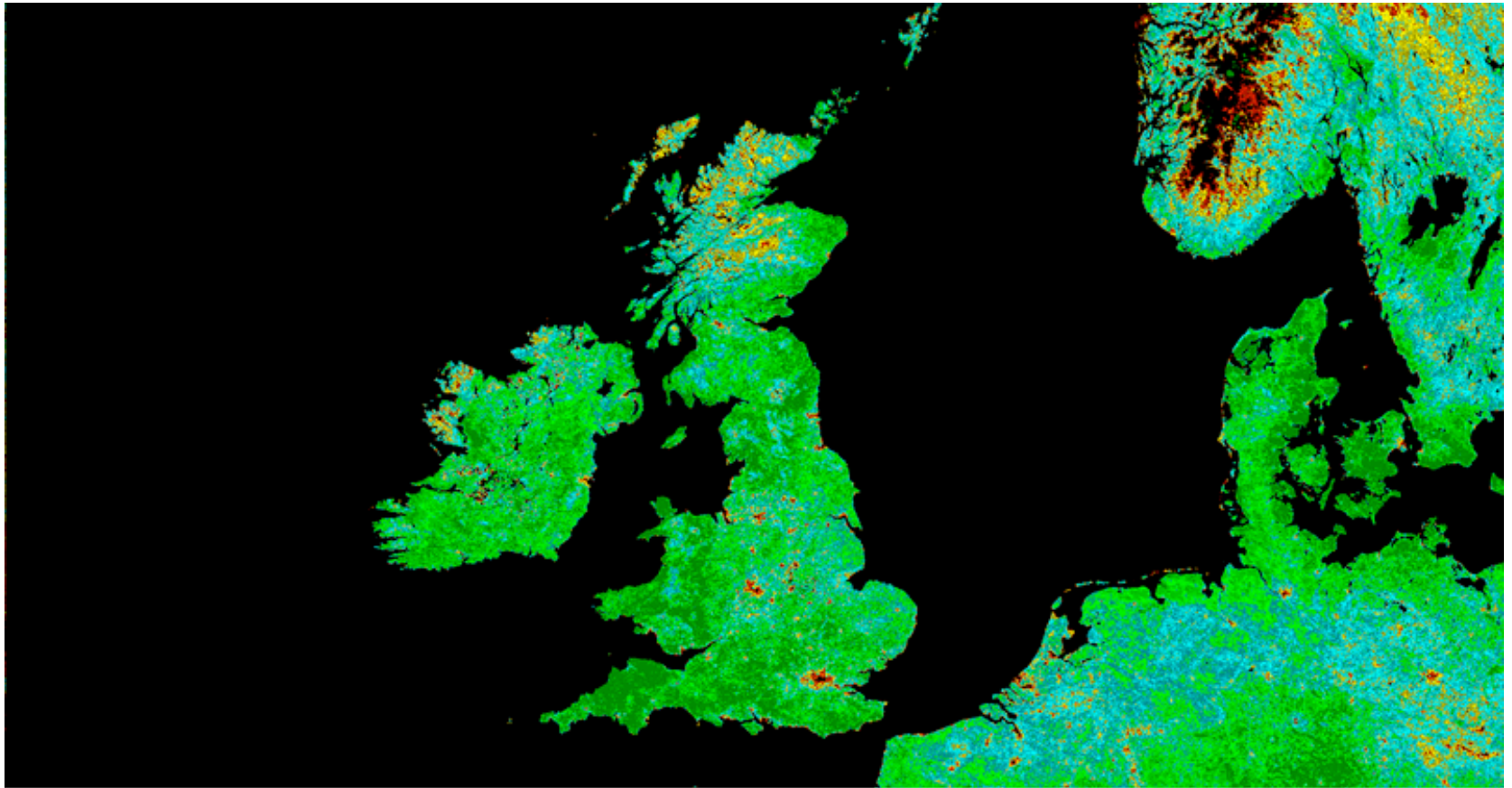
### Norway Maple During Senescence



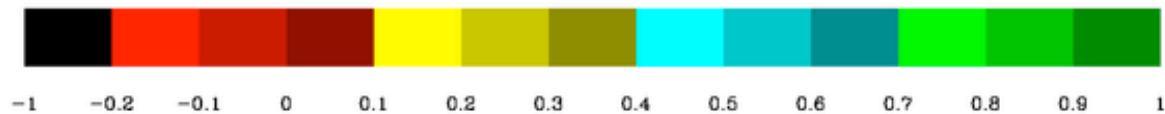


# Normalized Difference Vegetation Index

$$\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}$$

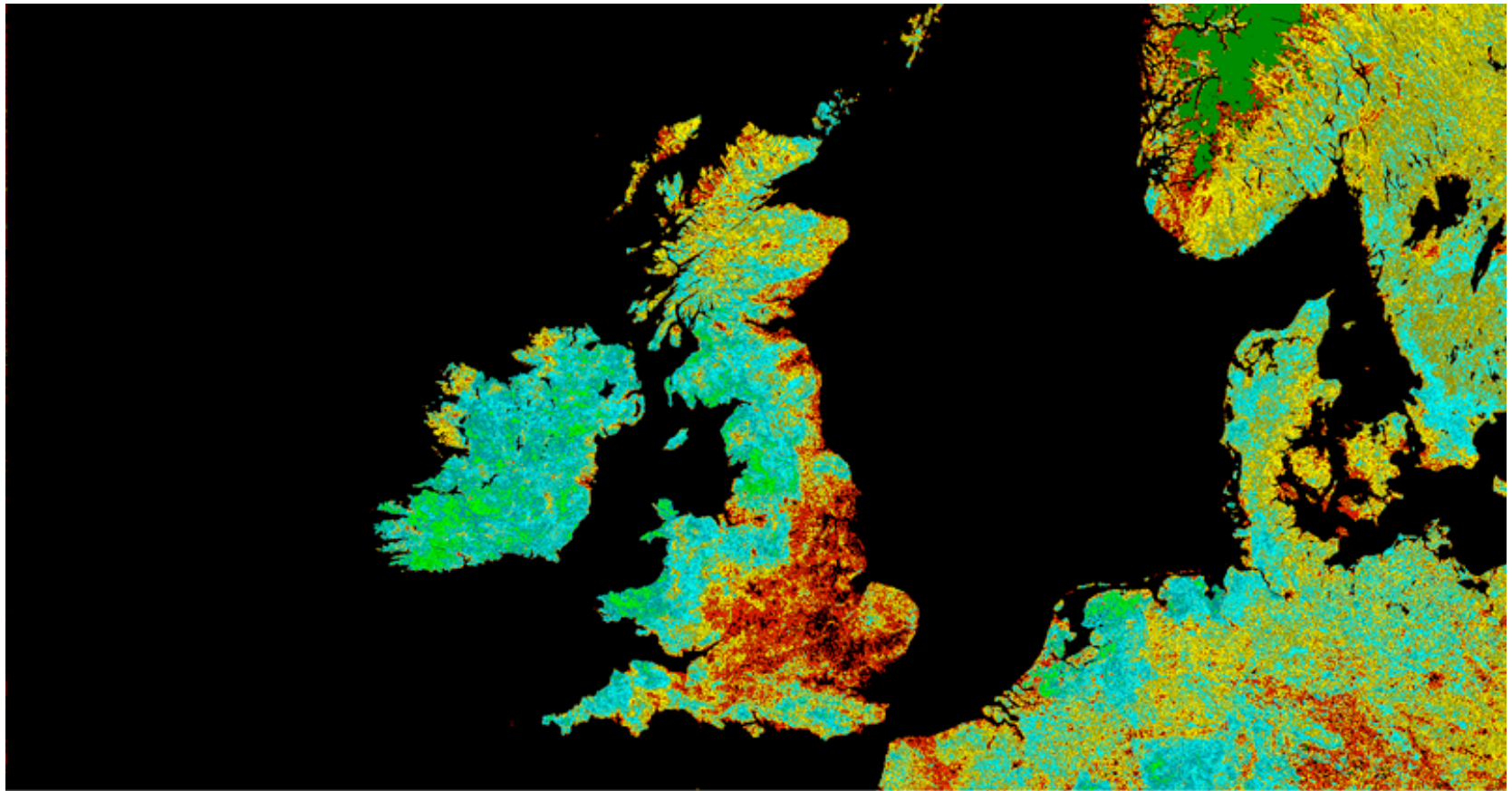


average NDVI of June 2003

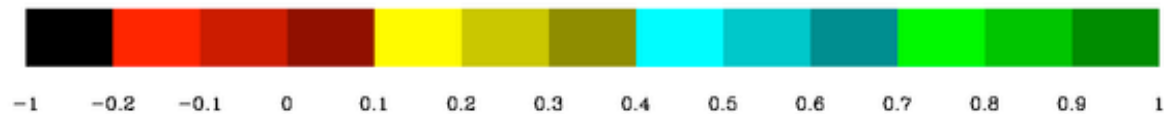


# Normalized Difference Vegetation Index

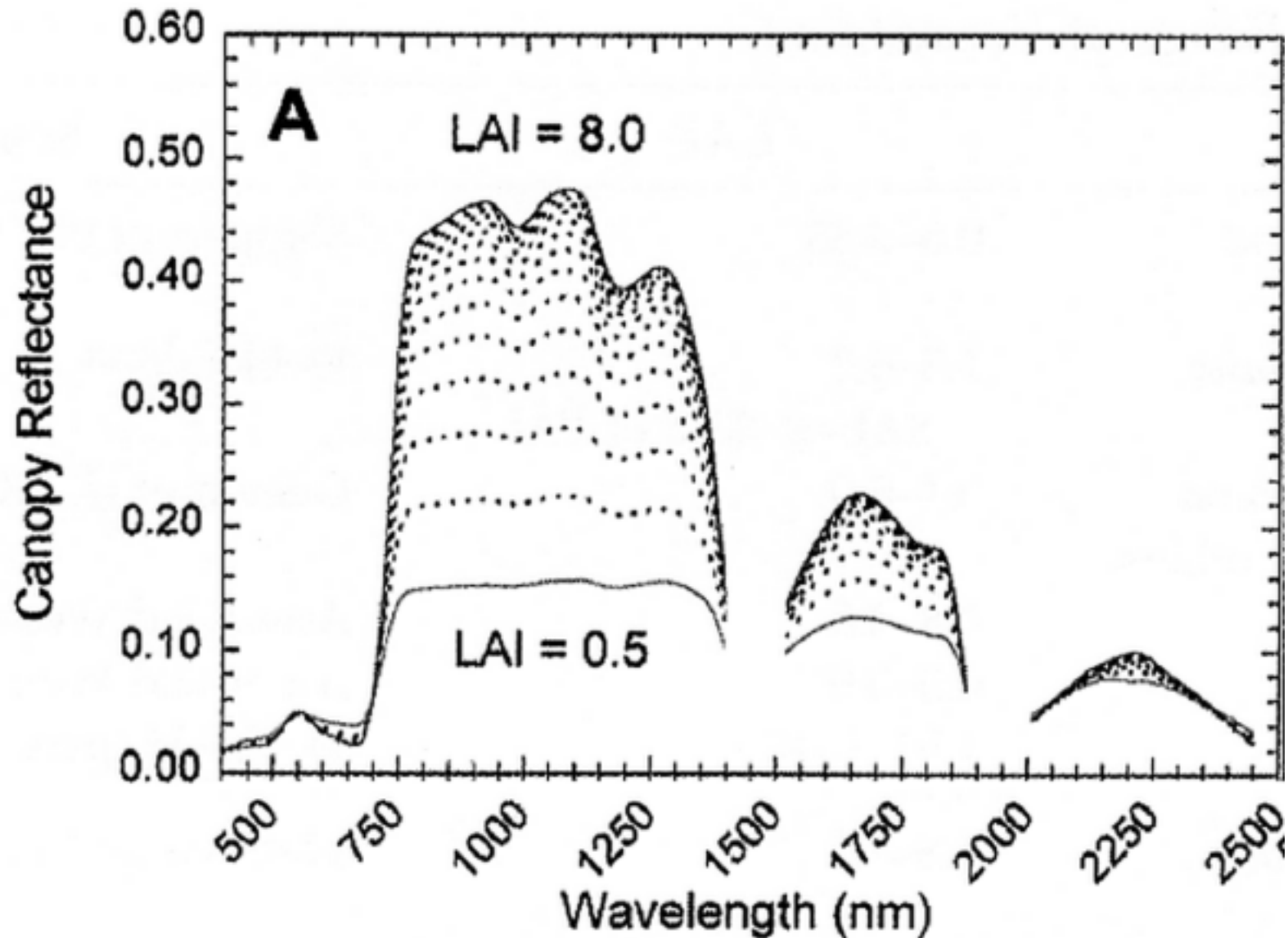
$$\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}$$



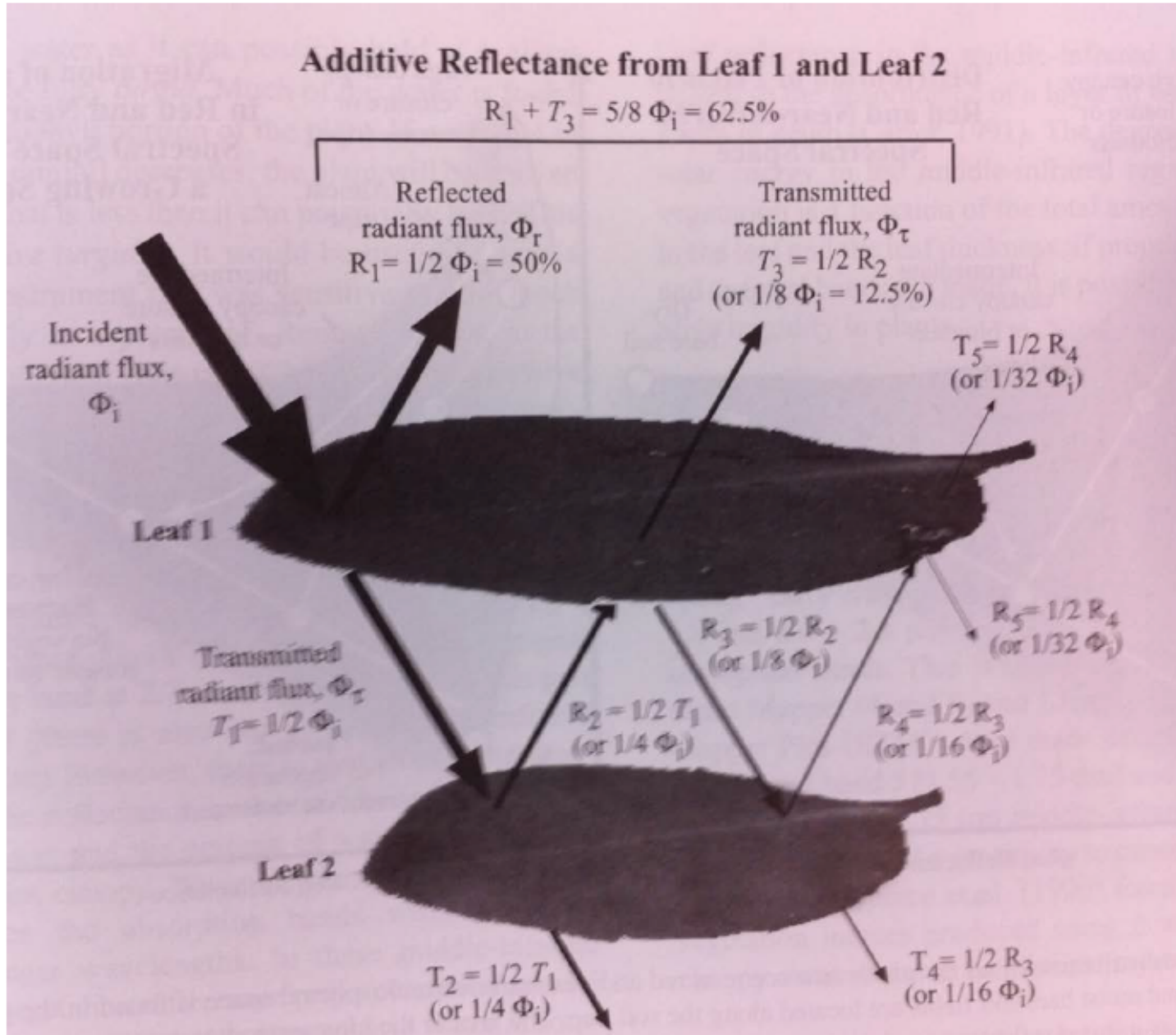
average NDVI of October 2003



Thicker canopy = *more* reflective  
(at wavelengths where absorption is minimal)

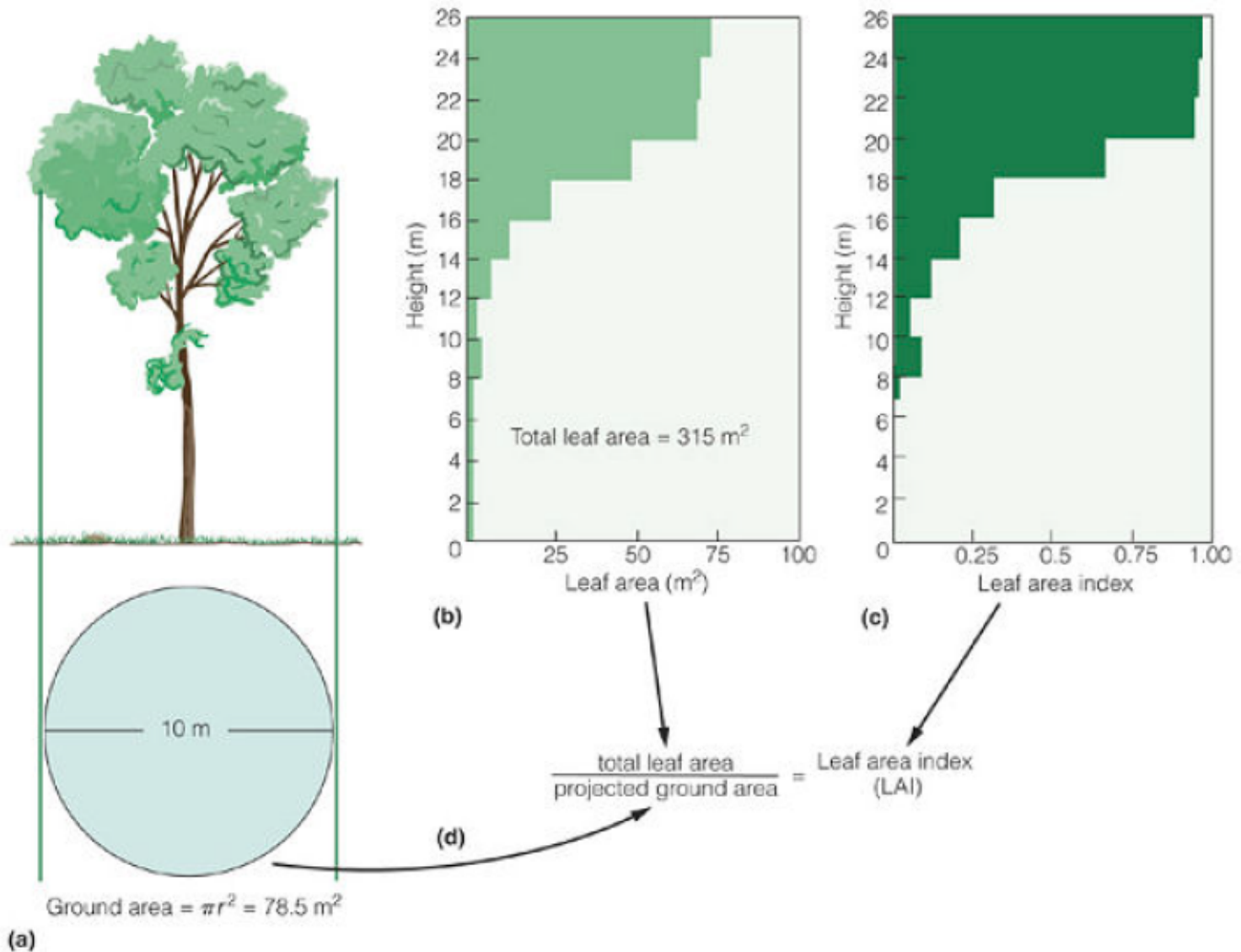


# Thicker canopy = *more* reflective (at wavelengths where absorption is minimal)



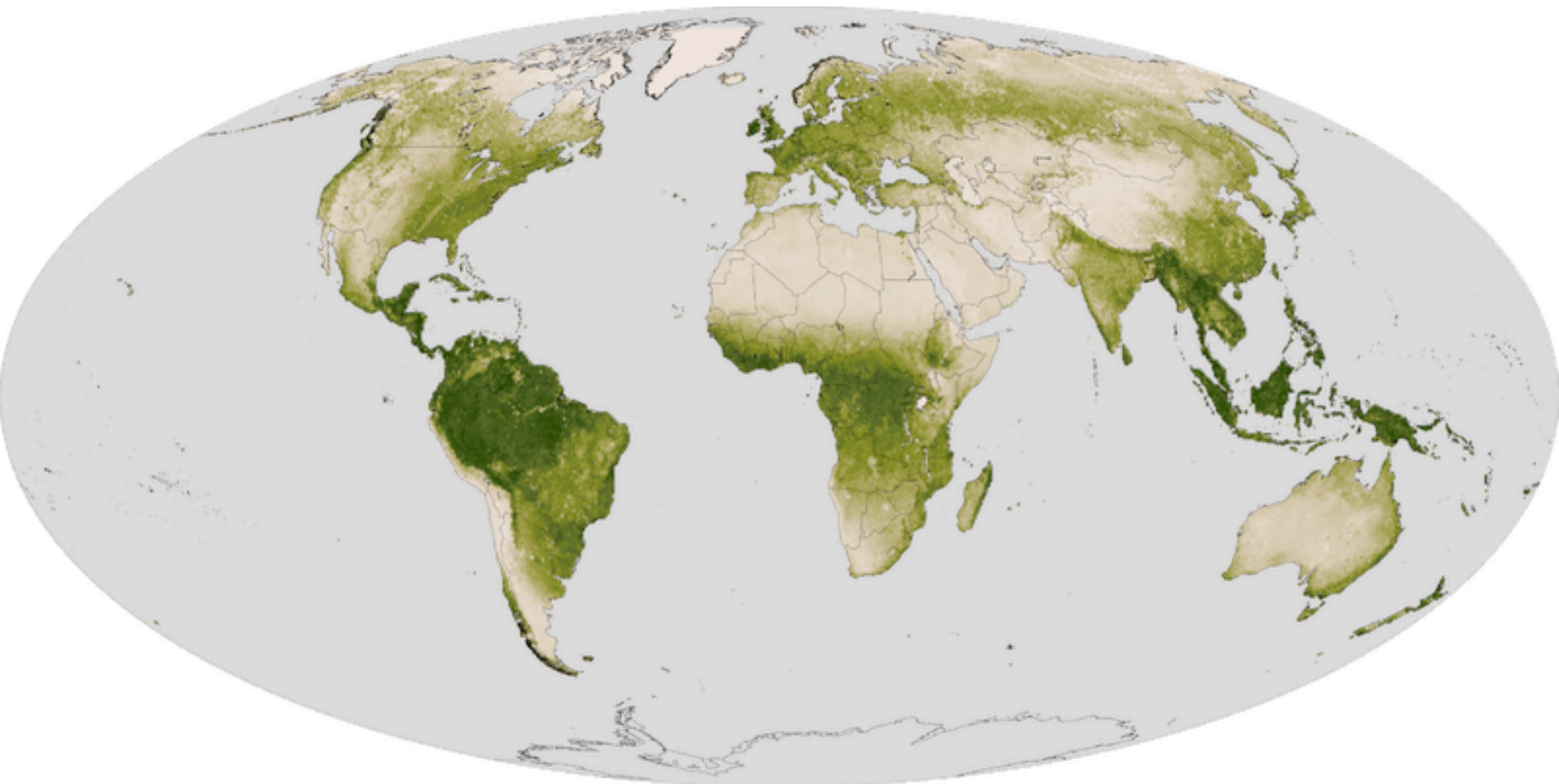
# Leaf Area Index (LAI):

*the one-sided green leaf area per unit ground surface area*





$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L)}$$



Enhanced Vegetation Index 2011

