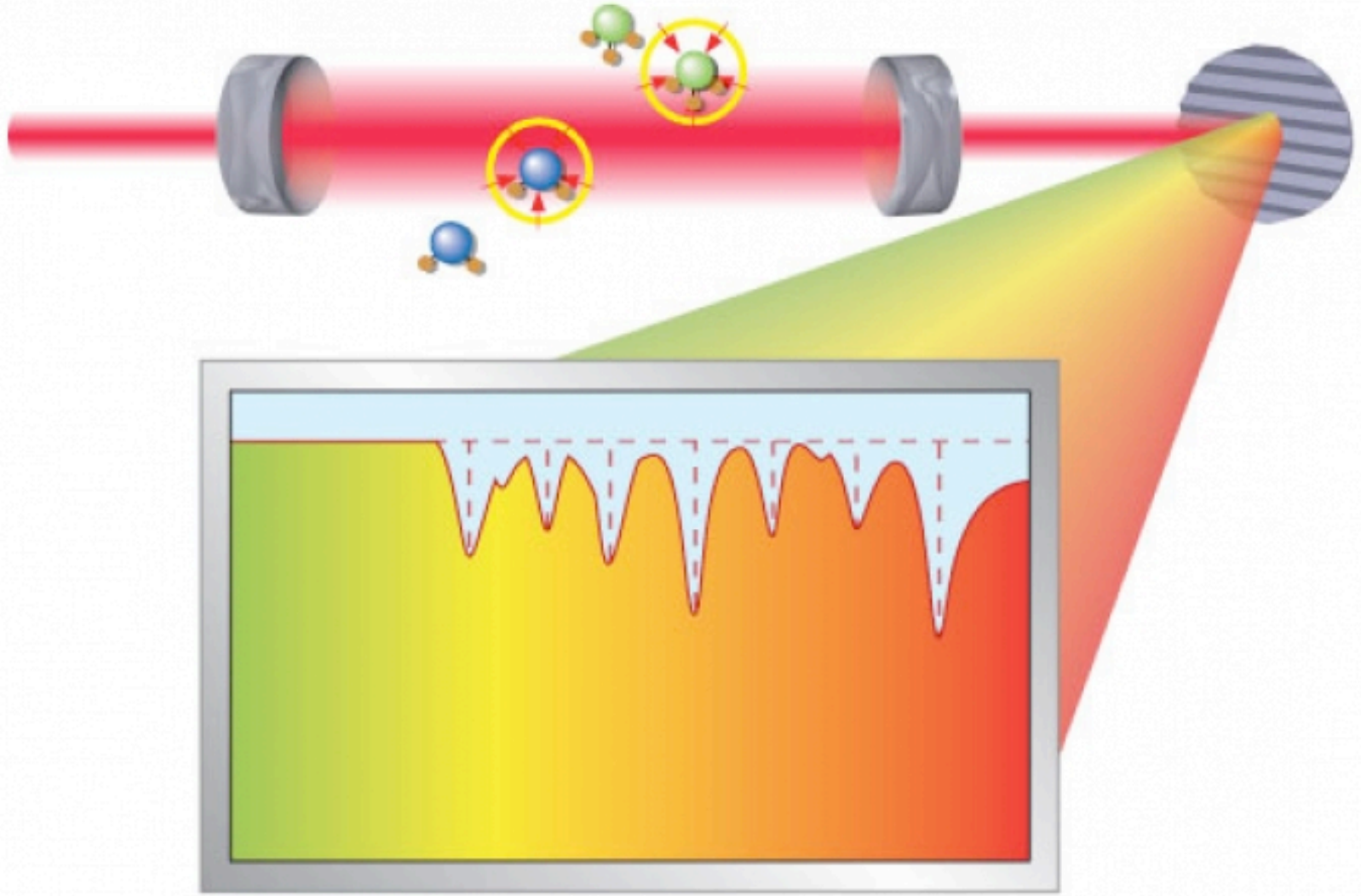
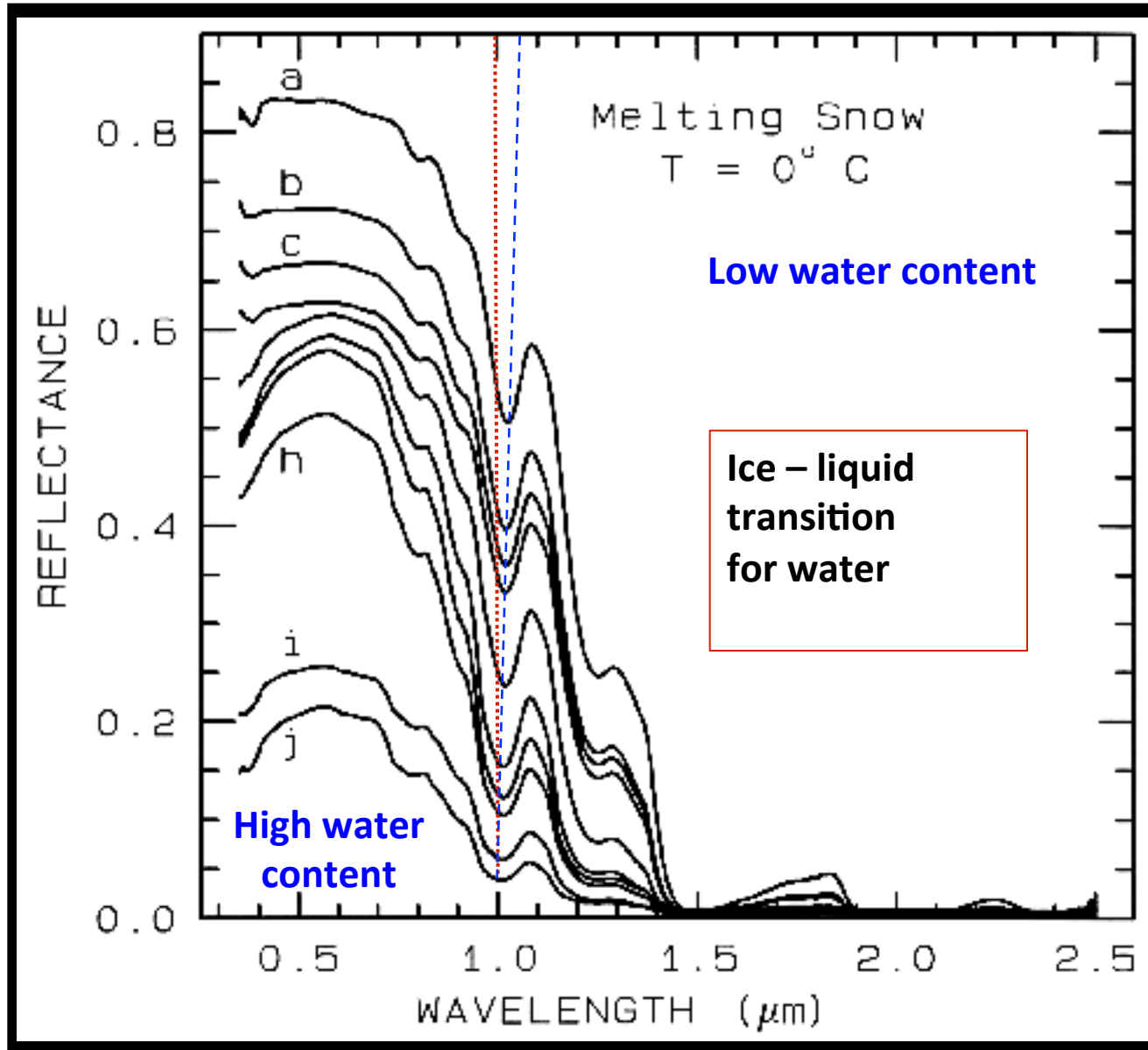


Spectroscopy: The Study of Squiggly Lines



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

Phase affects spectra



Bands don't broaden much as ice turns to water

Band centers shift subtly

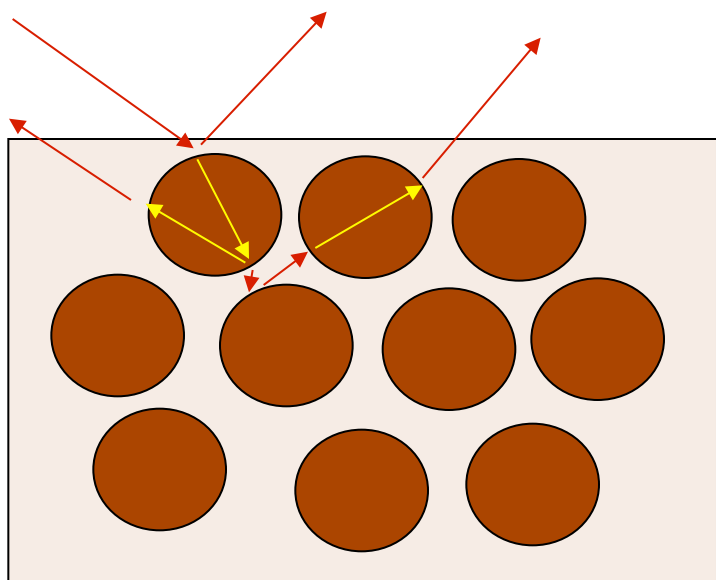
Amount of absorption increases with optical length z in Beer's law (e^{-kz}) – there are no grain interfaces in water.

This is a particle size effect

Particle size affects spectra

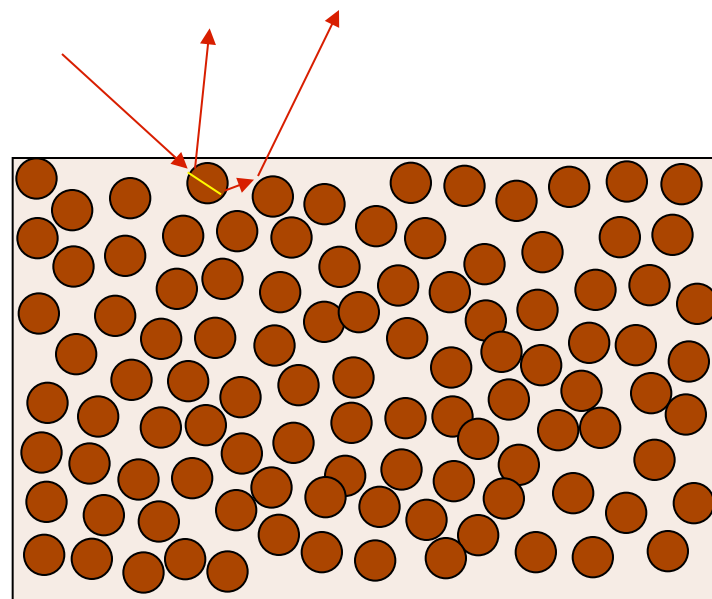
Coarse particles – spectra dominated by absorption inside grains

Fine particles – spectra dominated by surface reflection



Low surface/volume ratio

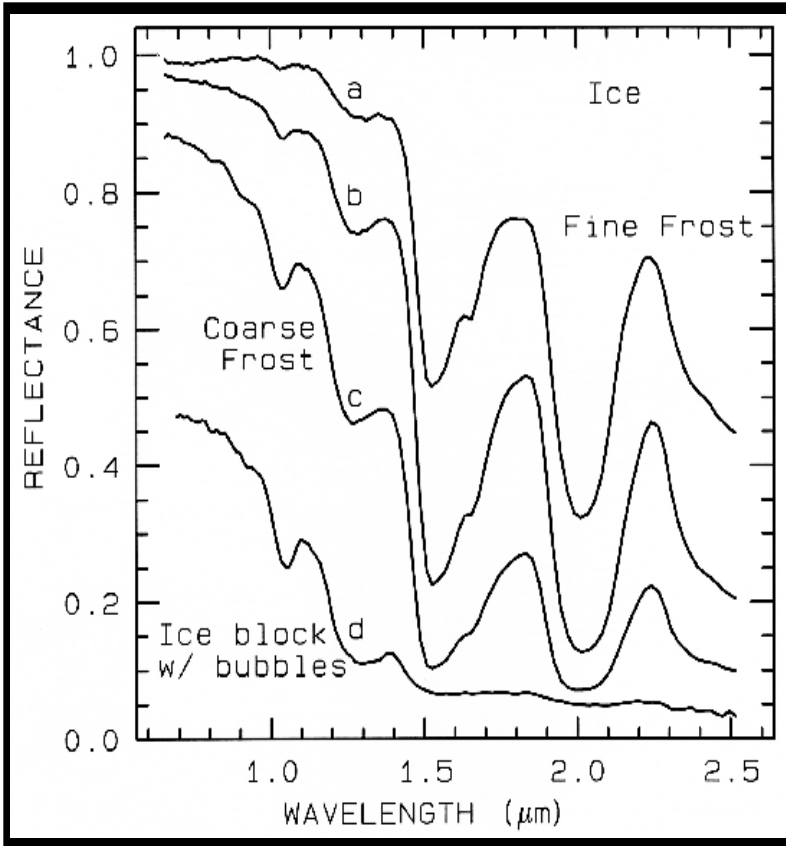
Average optical path is long



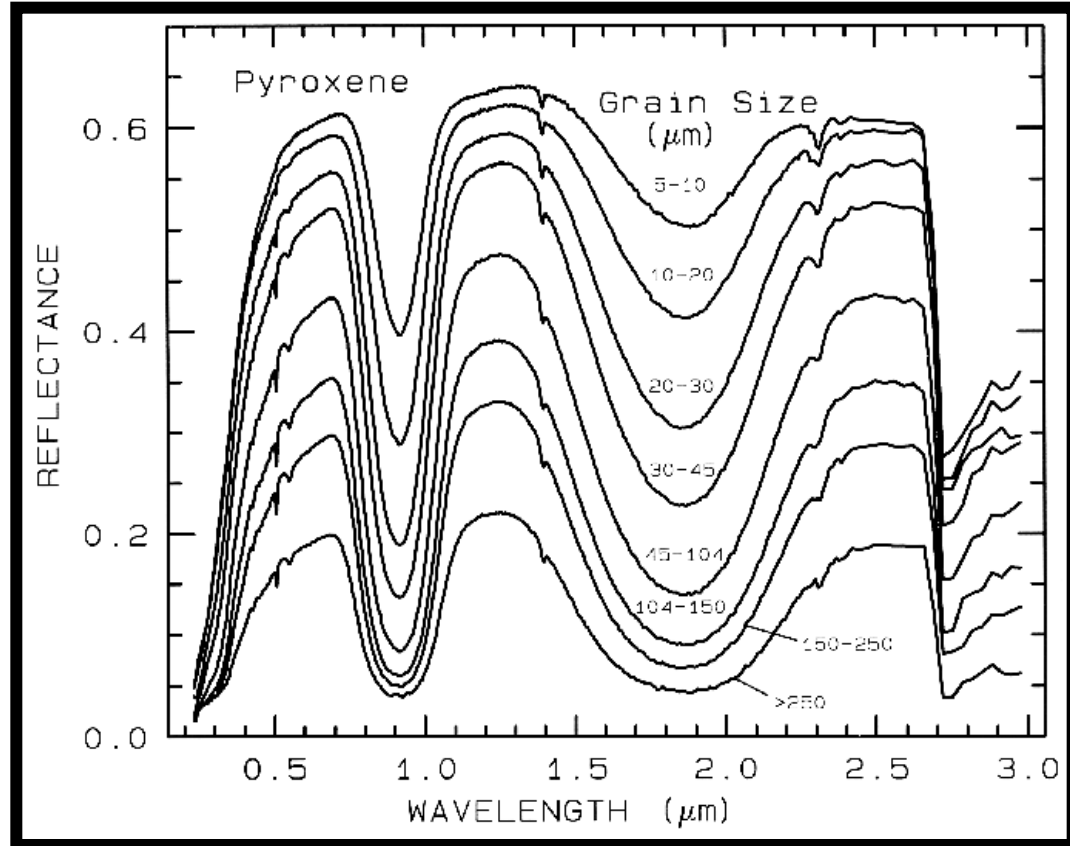
High surface/volume ratio

Path is shorter

Particle size affects spectra



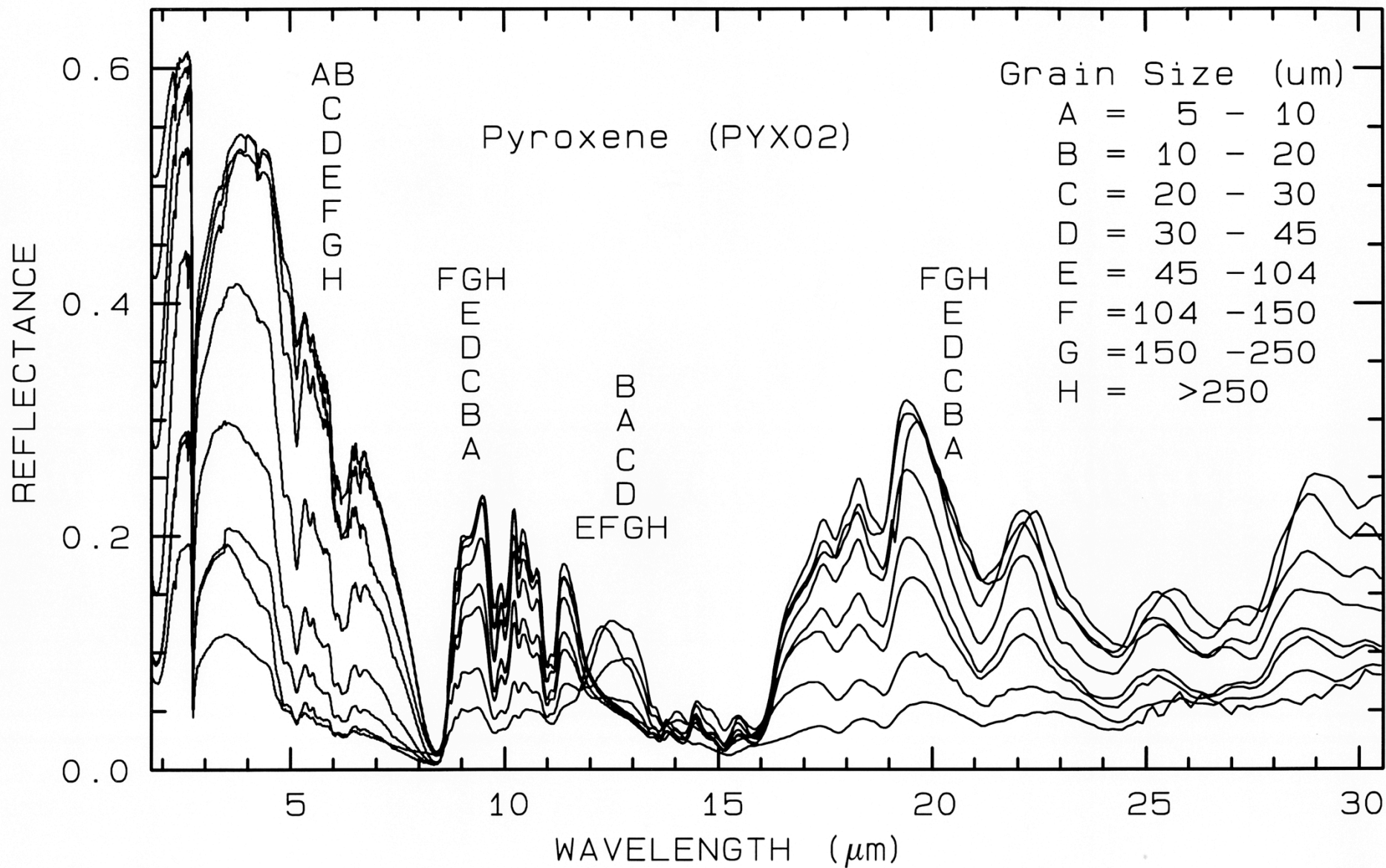
H₂O



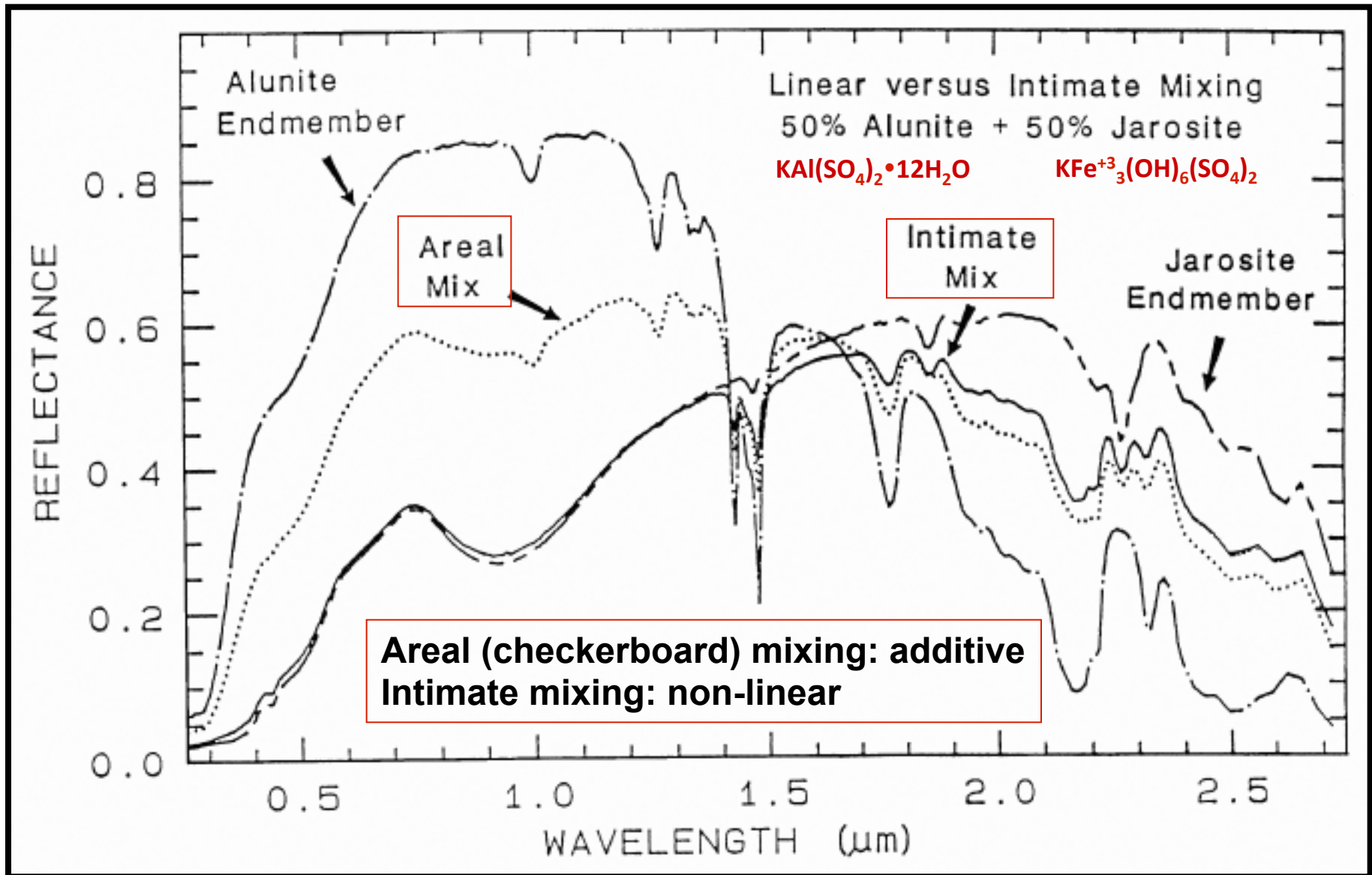
Pyroxene

$\text{XY}(\text{Si,Al})_2\text{O}_6$

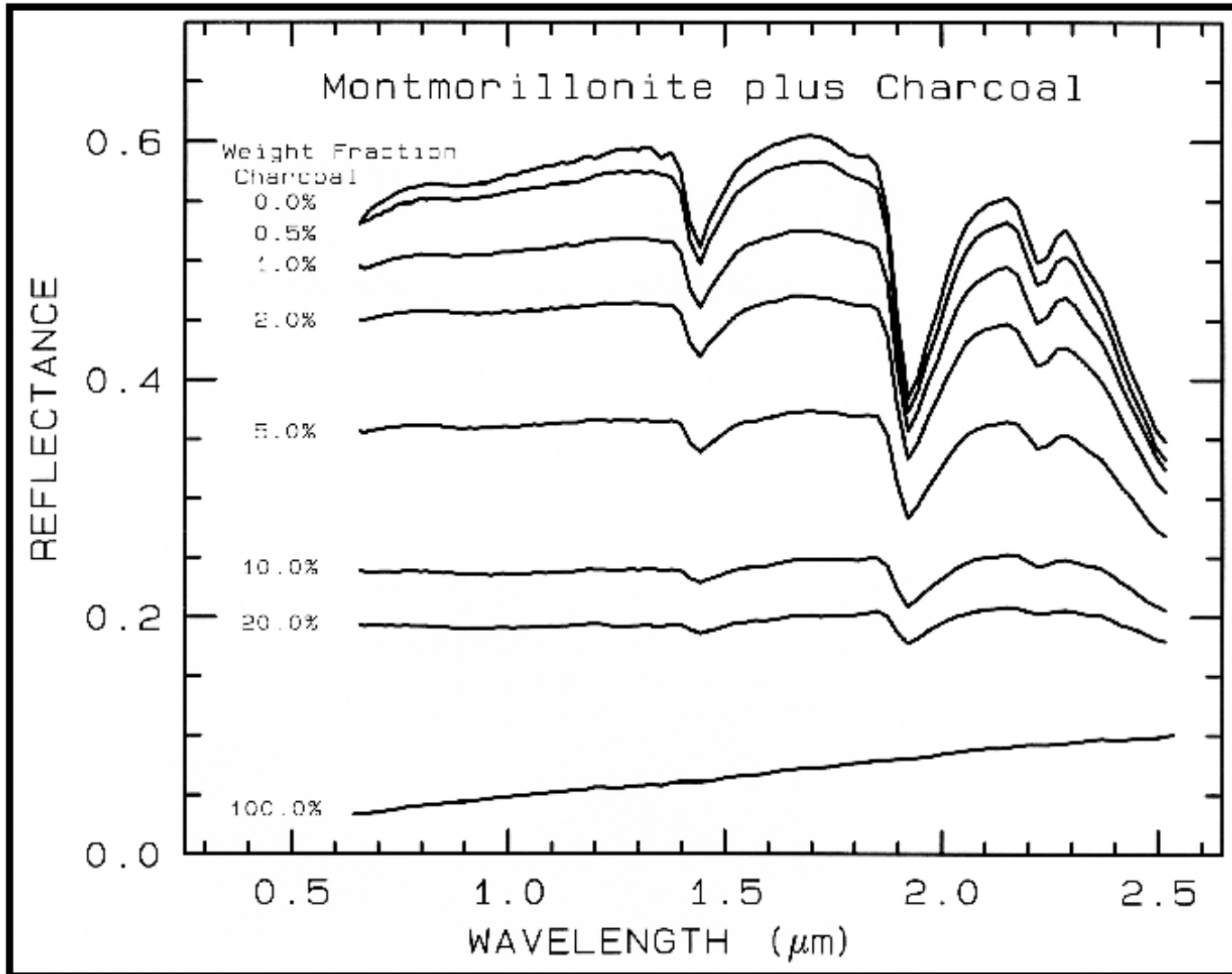
...and not always in a simple way



Spatial resolution also affects spectra (by mixing)



Intimate mixing can be highly non-linear

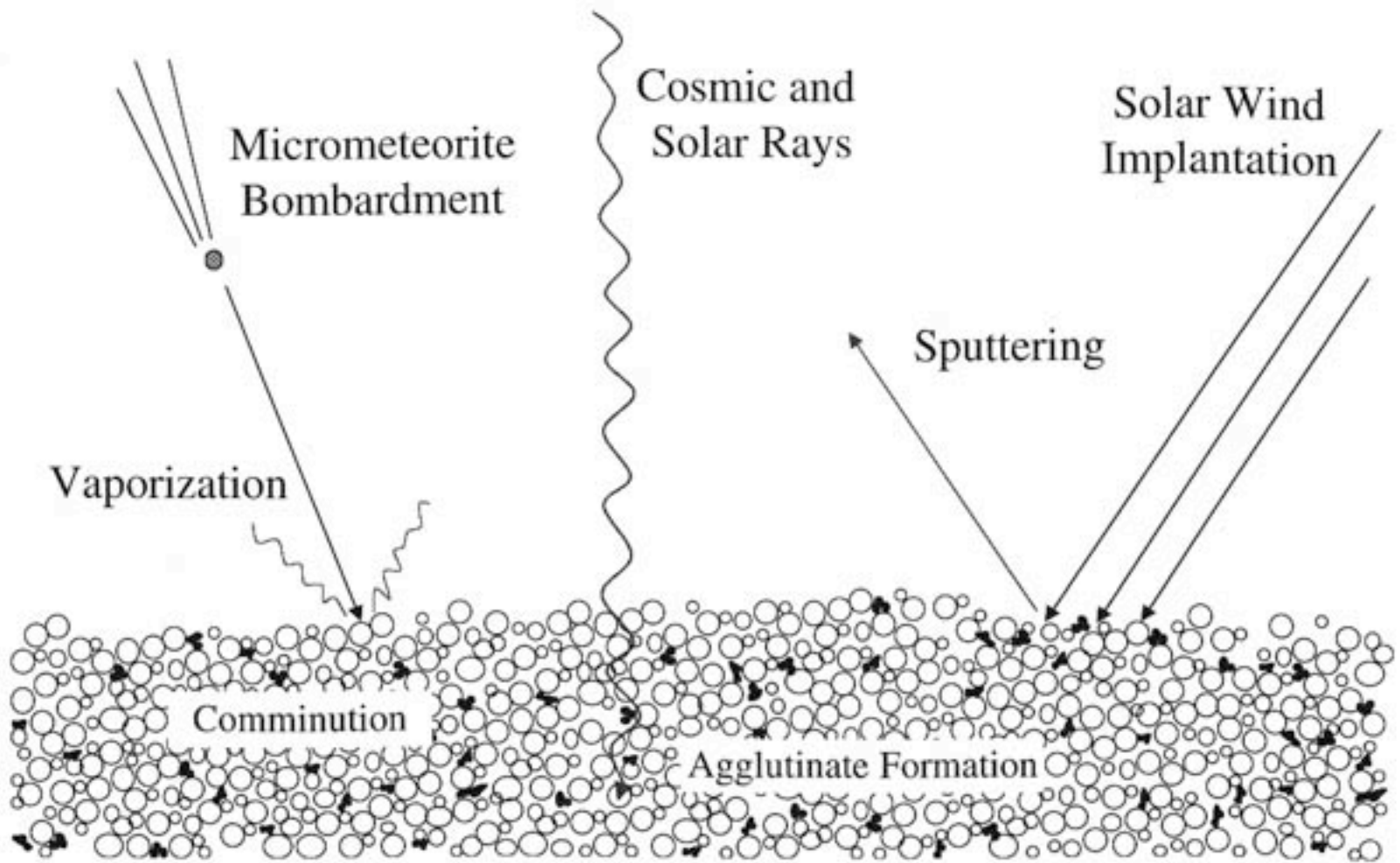


Adding highly absorptive charcoal greatly reduces the optical path length (“z” in Beer’s Law: e^{-kz})

A small amount has a large effect

Larger amounts have diminishing effect

Space weathering

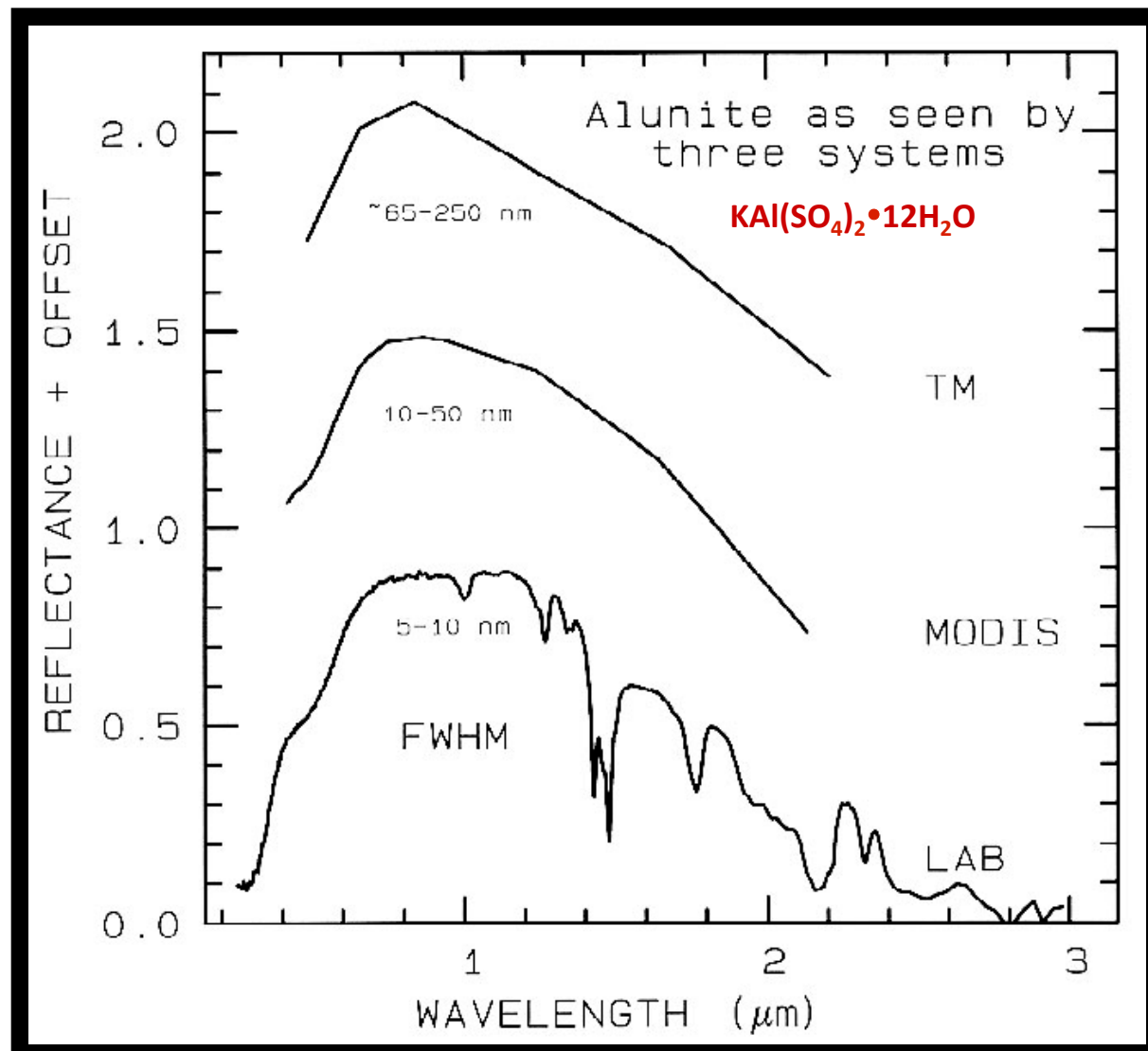


Nanophase iron reddens, darkens, weakens absorption bands

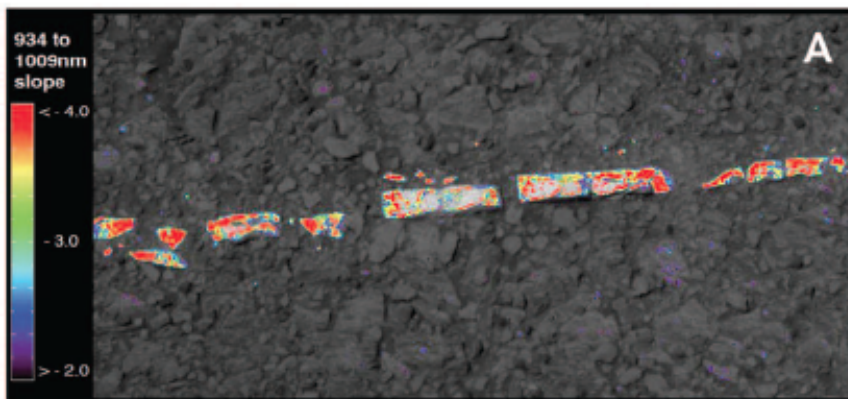
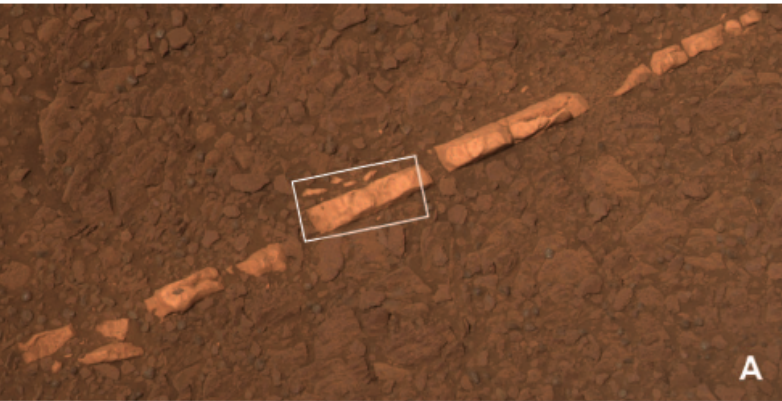
Spectral resolution:

multispectral
remote sensing vs.
imaging spectroscopy

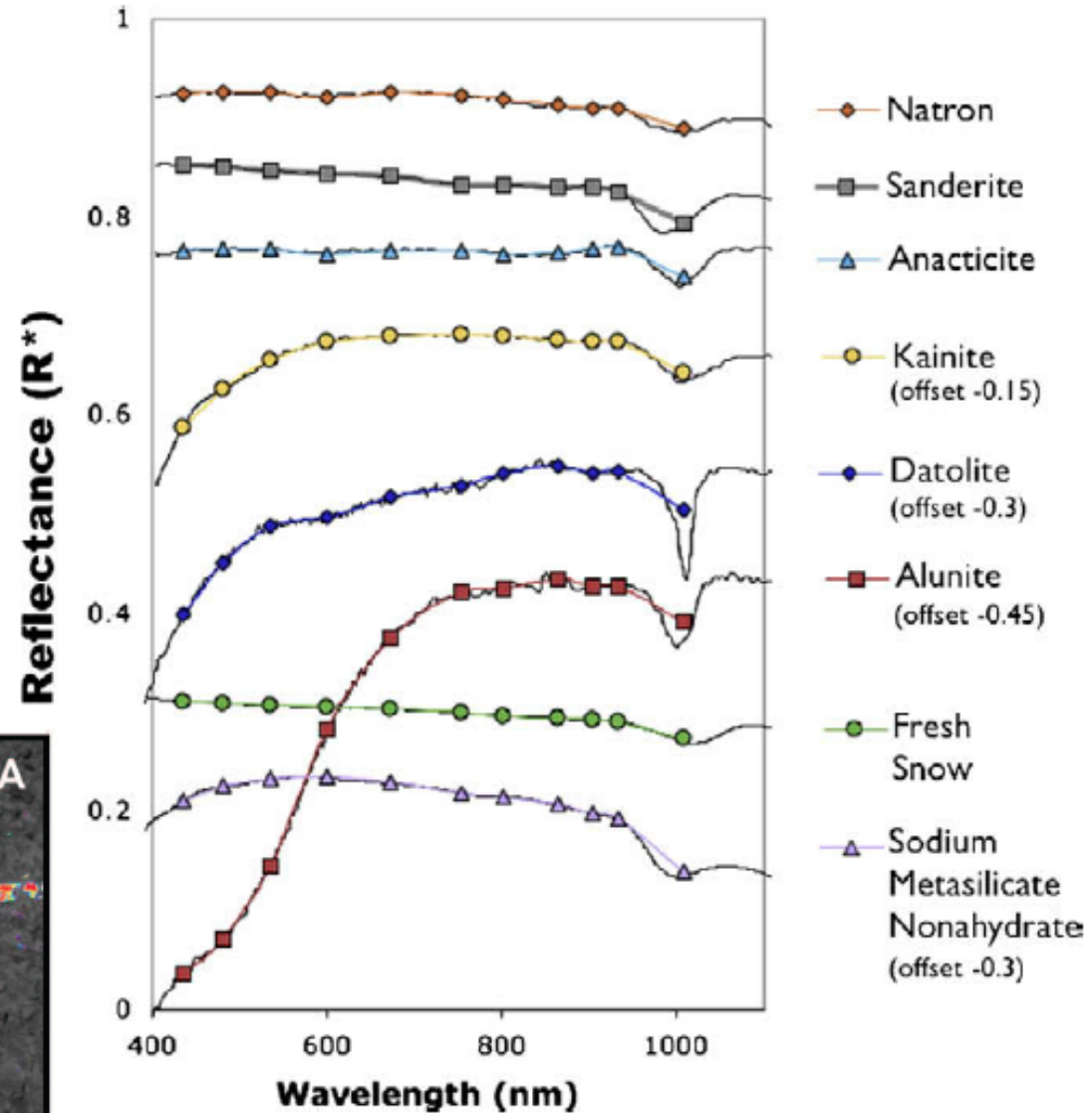
*Imaging spectroscopy
is more likely to resolve
absorption bands*



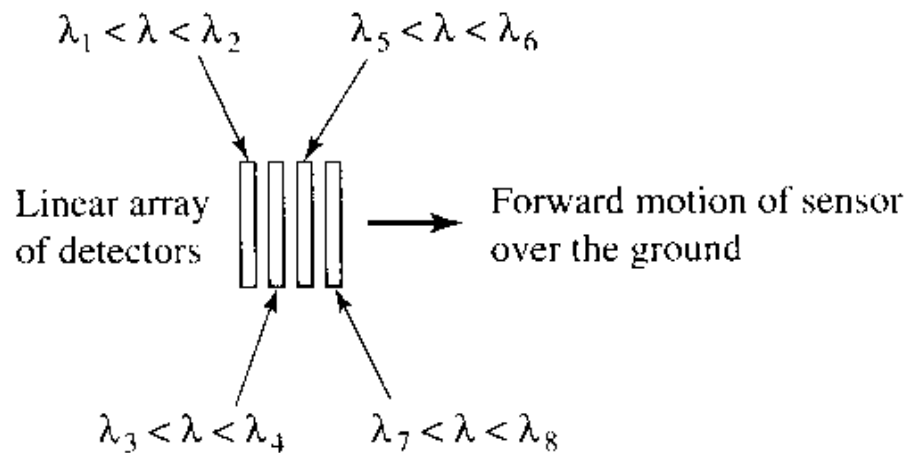
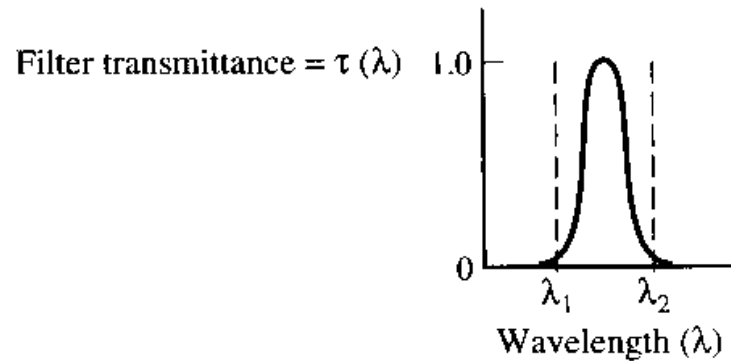
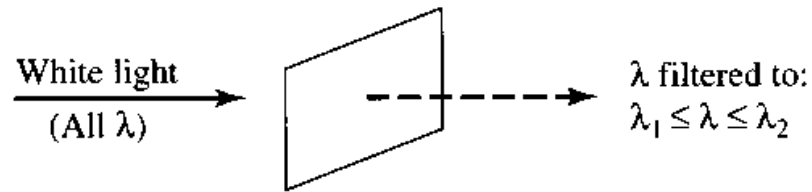
The challenge of multispectral data



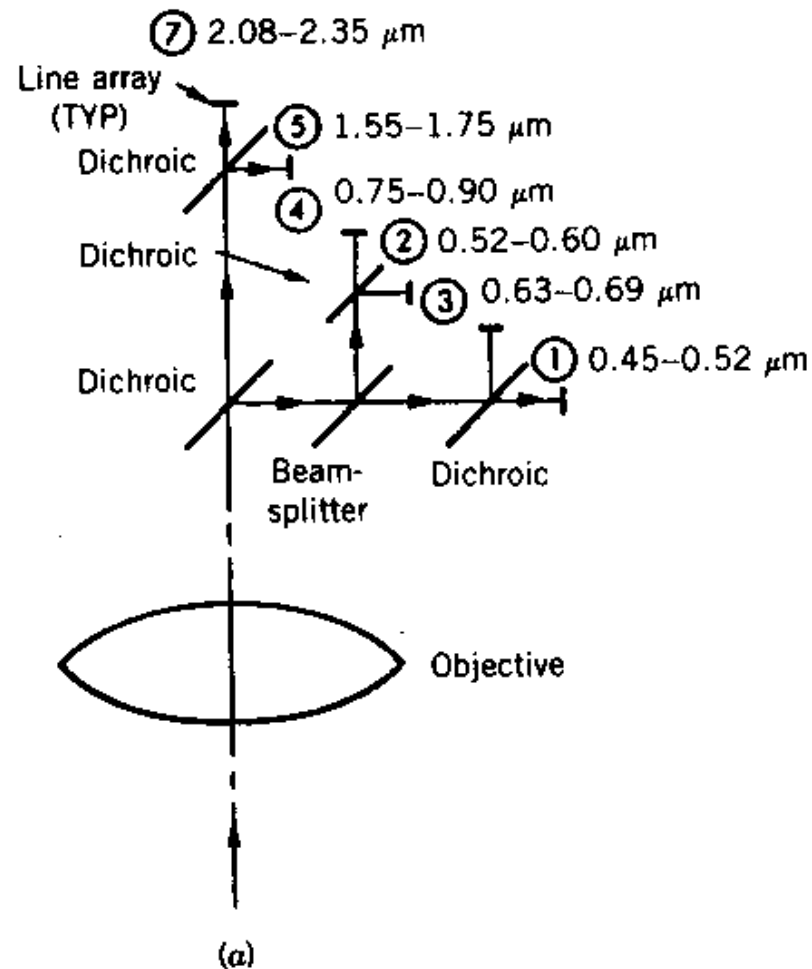
Many distinct minerals look similar!



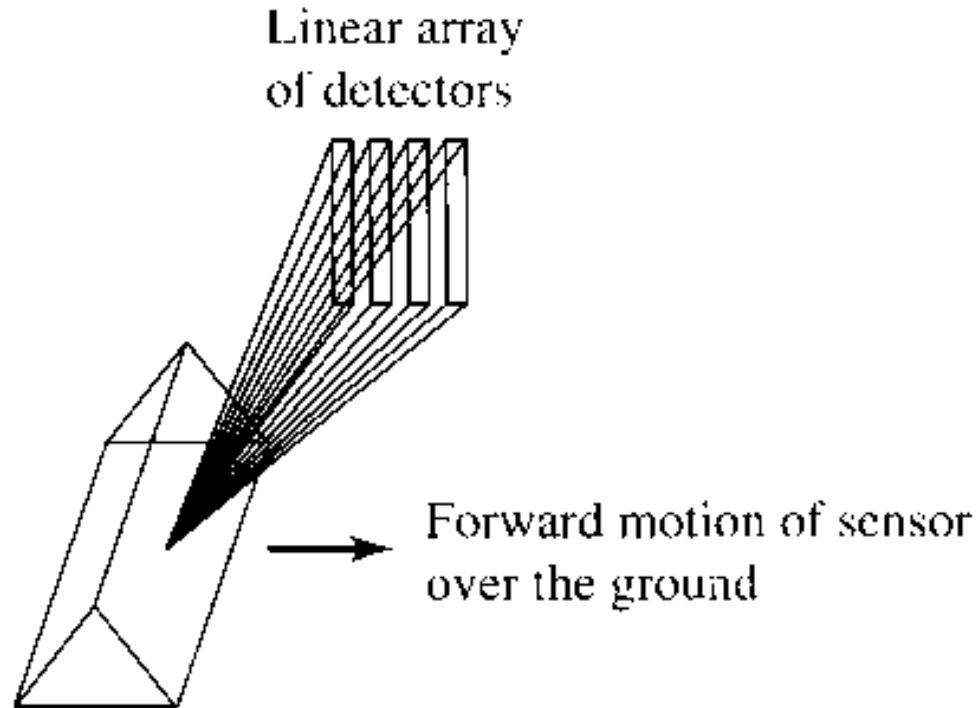
Dispersion Elements: Transmission Filters



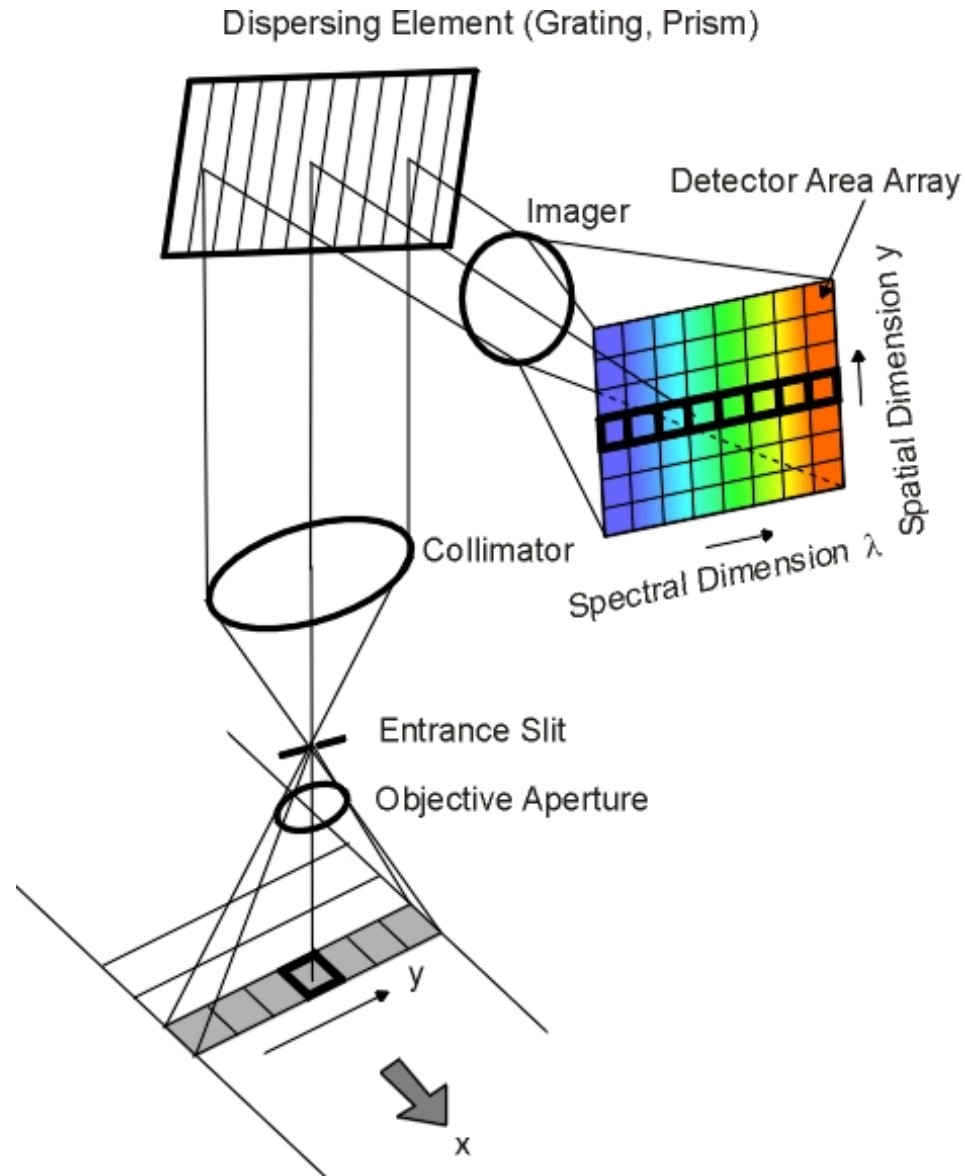
Dispersion Elements: Dichroic Mirrors



Dispersion Elements: Prisms and Diffraction Gratings



Imaging Spectrometers



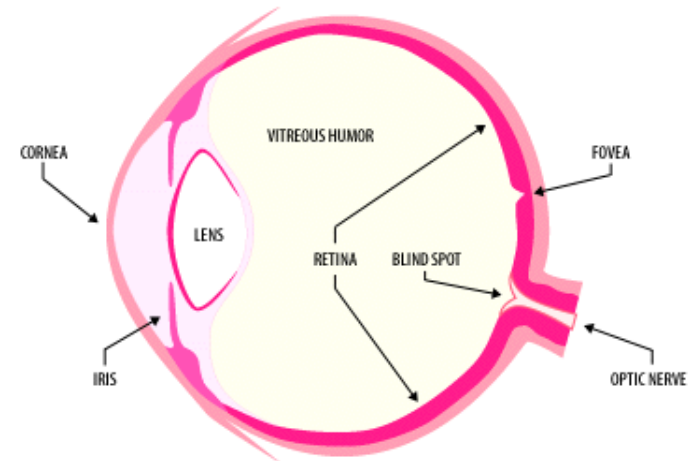
Let's start with how humans sense color:

Cone-shaped cells within the eye absorb light in 3 wavelength ranges – **RGB**

They send signals to the brain proportional to how much light is absorbed

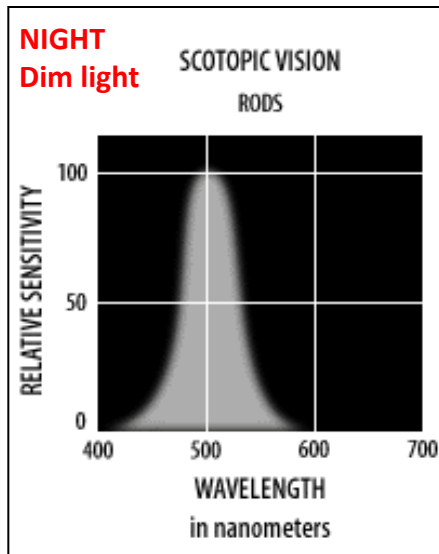
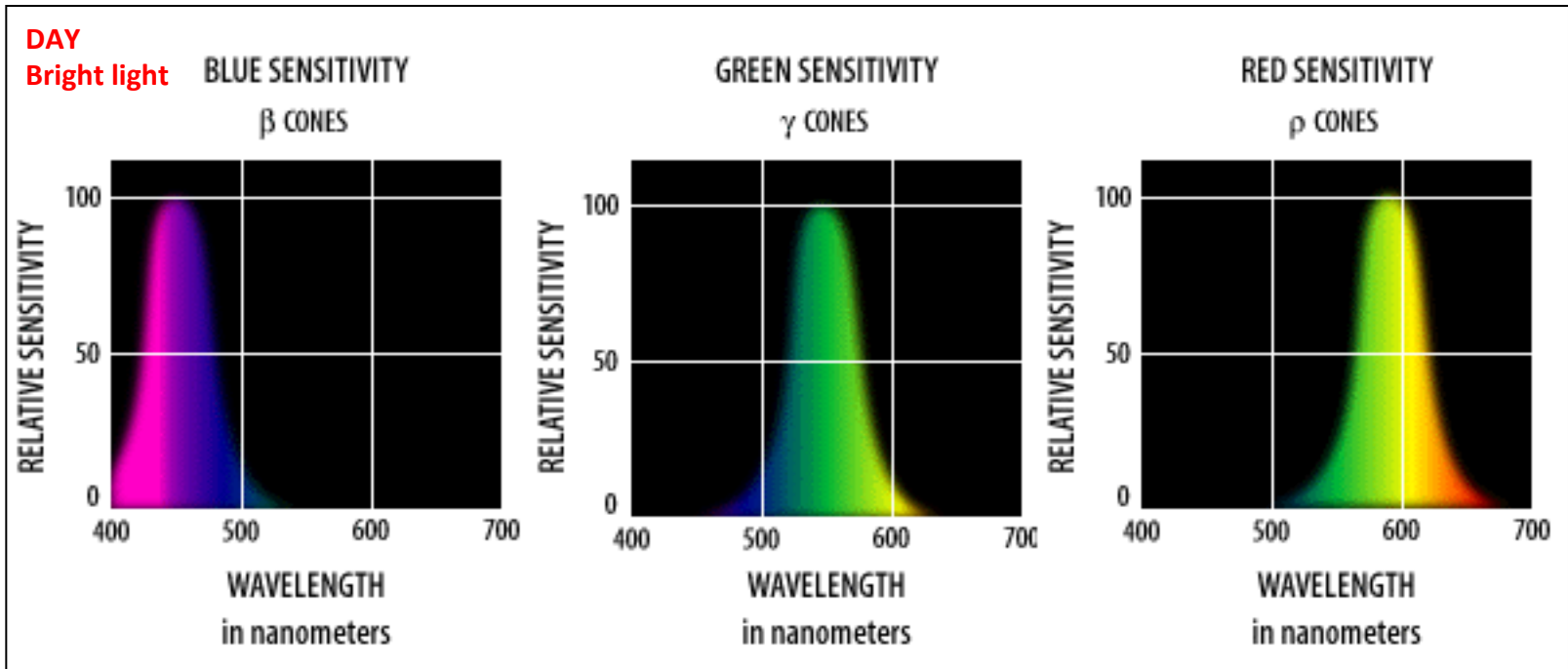
The brain turns these signals into the sensation of color

Color has three attributes – hue, saturation, and intensity or lightness



Section of the eye

color (perception) is related to radiance (physical flux)

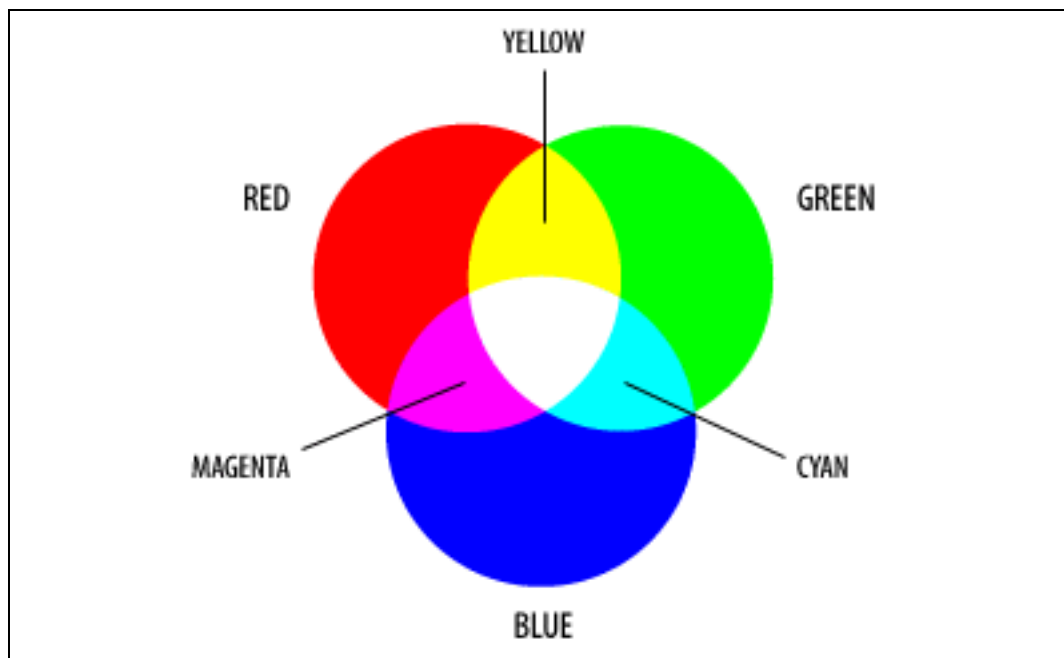


Rods are more sensitive than cones

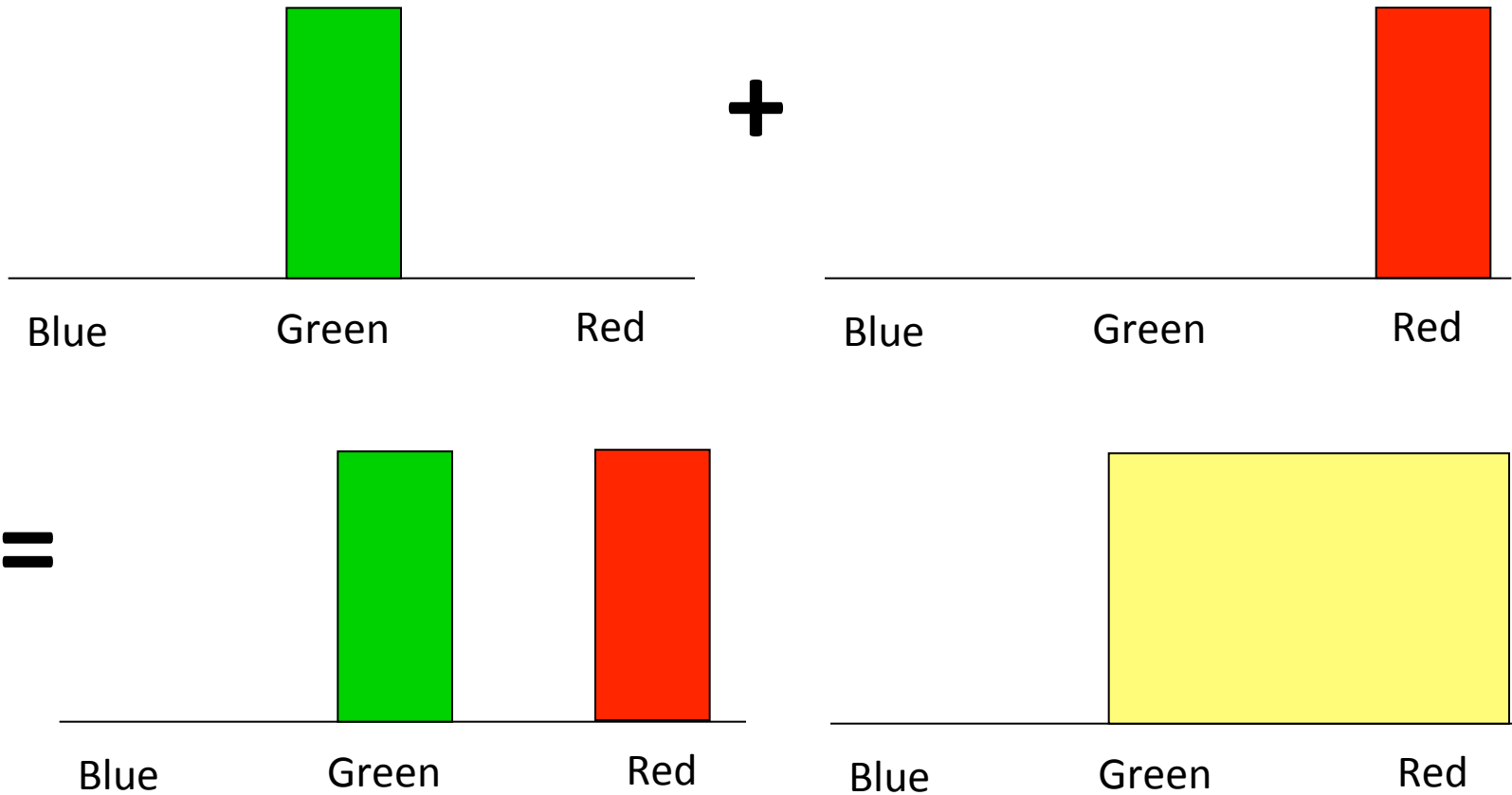
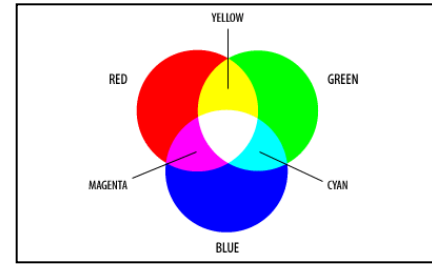
In **bright light**, the three sets of cones send strong signals to the brain that drown out the signal from the rods. The signals are interpreted as the sensation of **color**

In **dim light**, the signal from the single set of rods is dominant. It is interpreted as the sensation of black/white (**gray**)

Additive Color



Additive Color



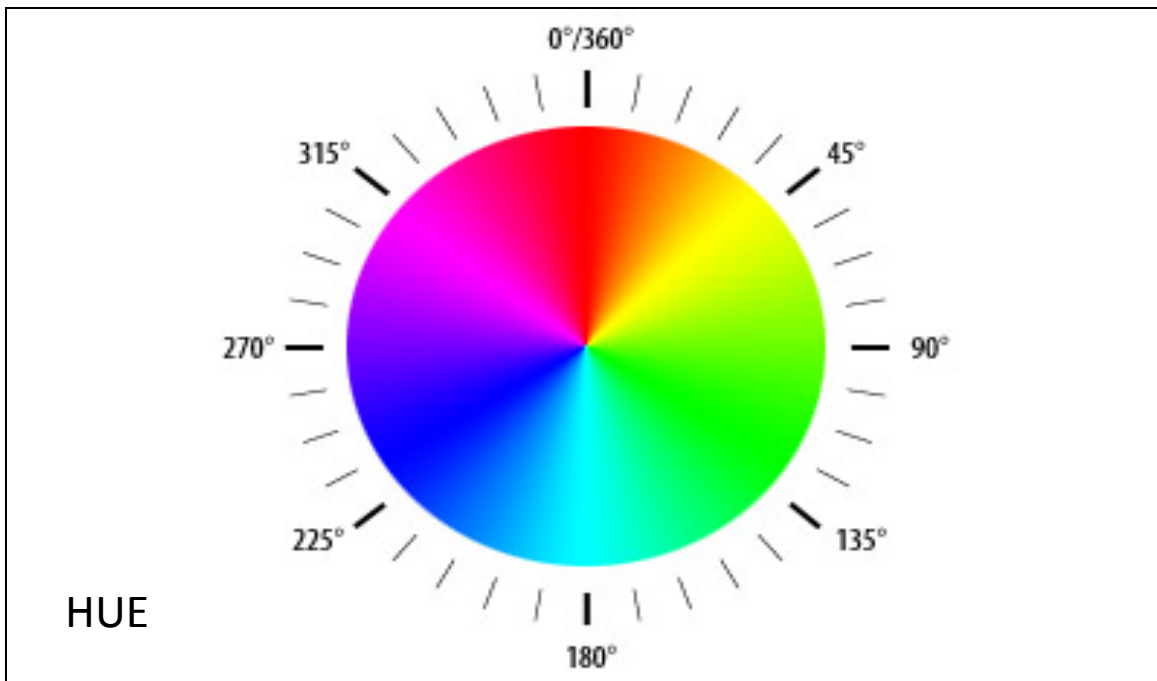
We can describe color in different **data “spaces”**, e.g.:

*Perceptual data space

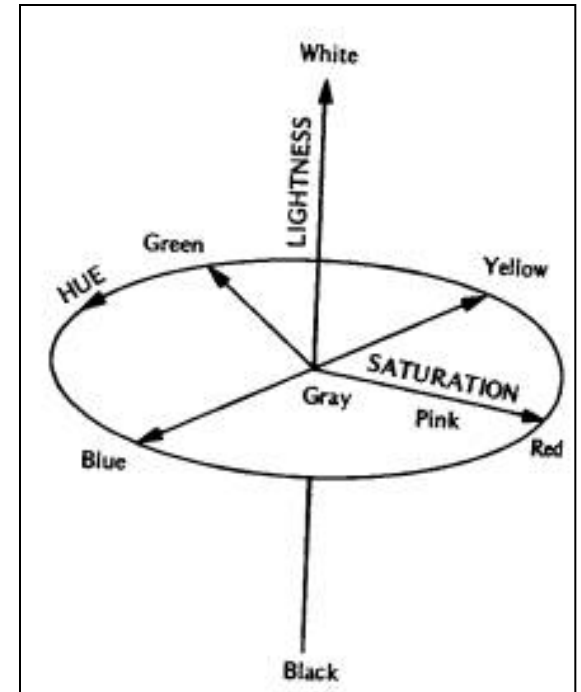
– how we sense color intuitively (Hue, saturation, intensity)

*Radiance data space

– how the color stimulus is described by the measured image data



1) A simple perceptual color space (HSI)

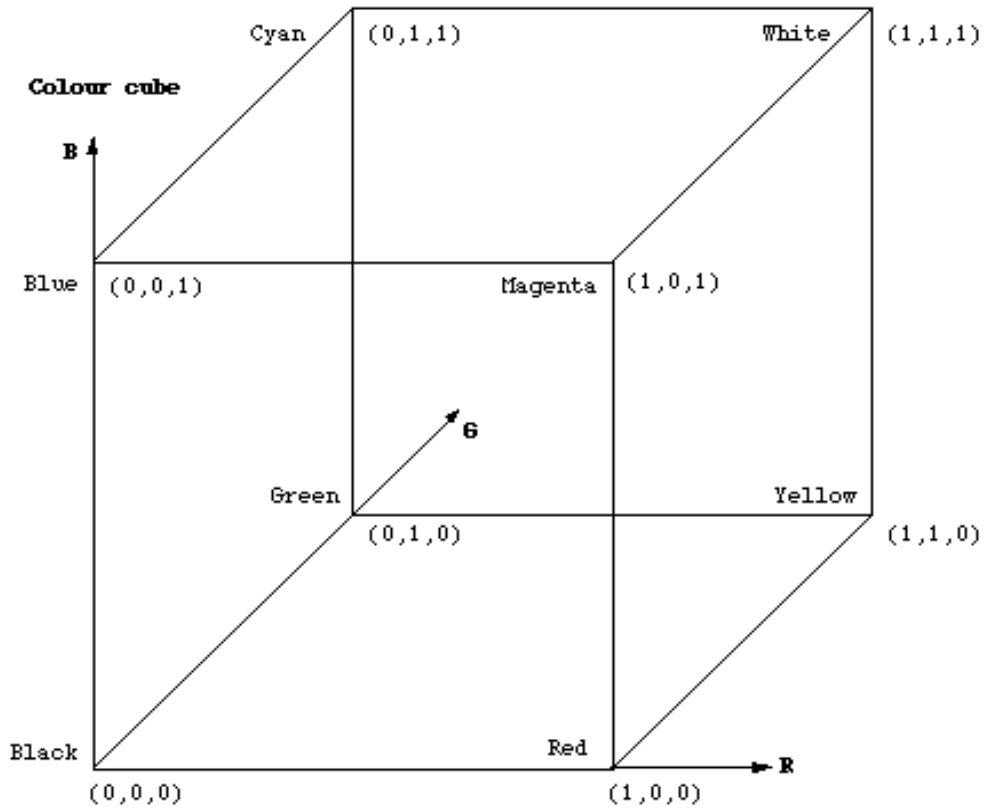


SATURATION

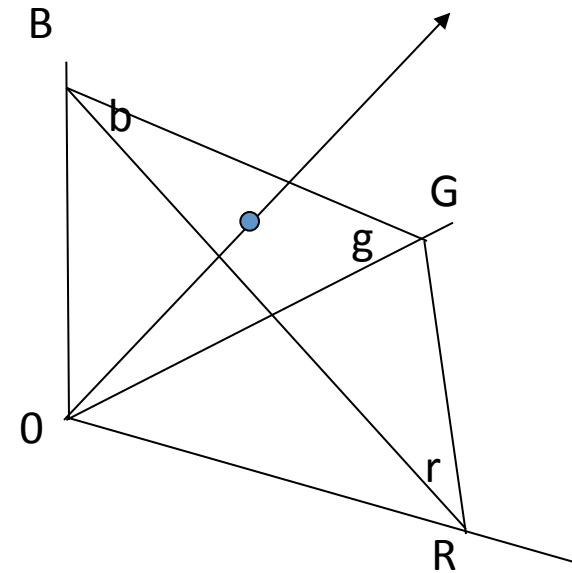


INTENSITY (LIGHTNESS)

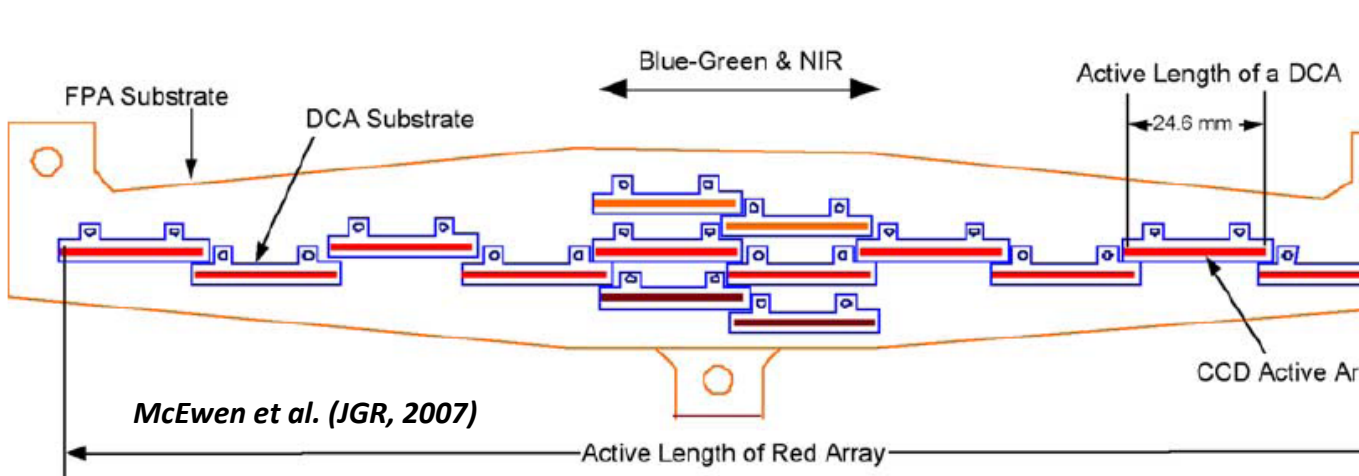
2) RGB radiance space



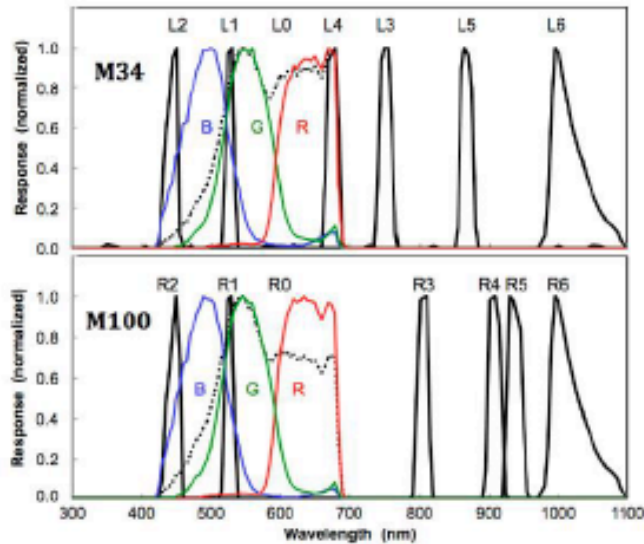
$$r = R / (R + G + B)$$
$$g = G / (R + G + B)$$
$$b = B / (R + G + B)$$



1) Use filters sequentially via spacecraft motion or filter wheel

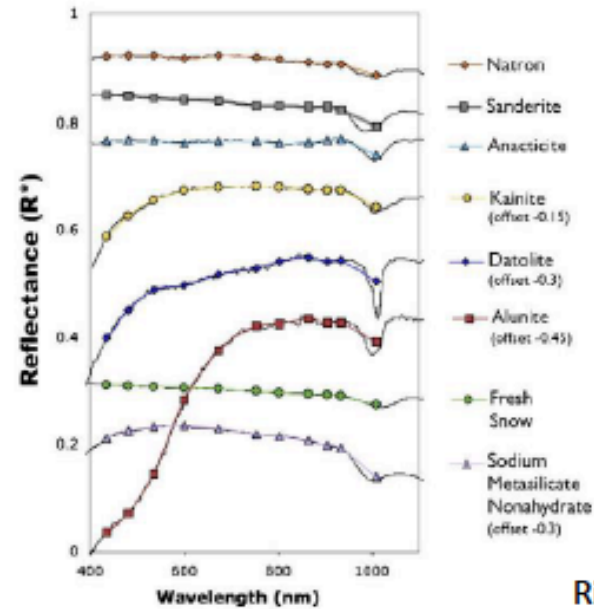


e.g. Mastcam Camera Filters



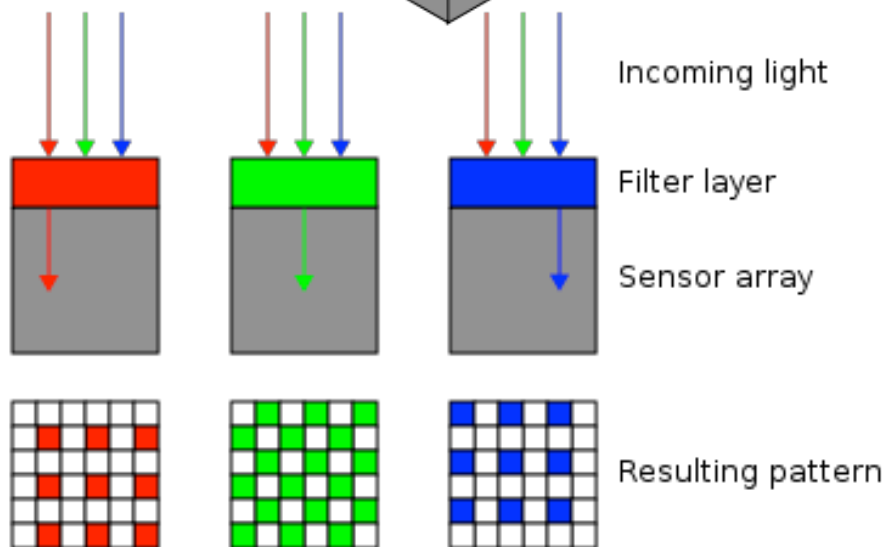
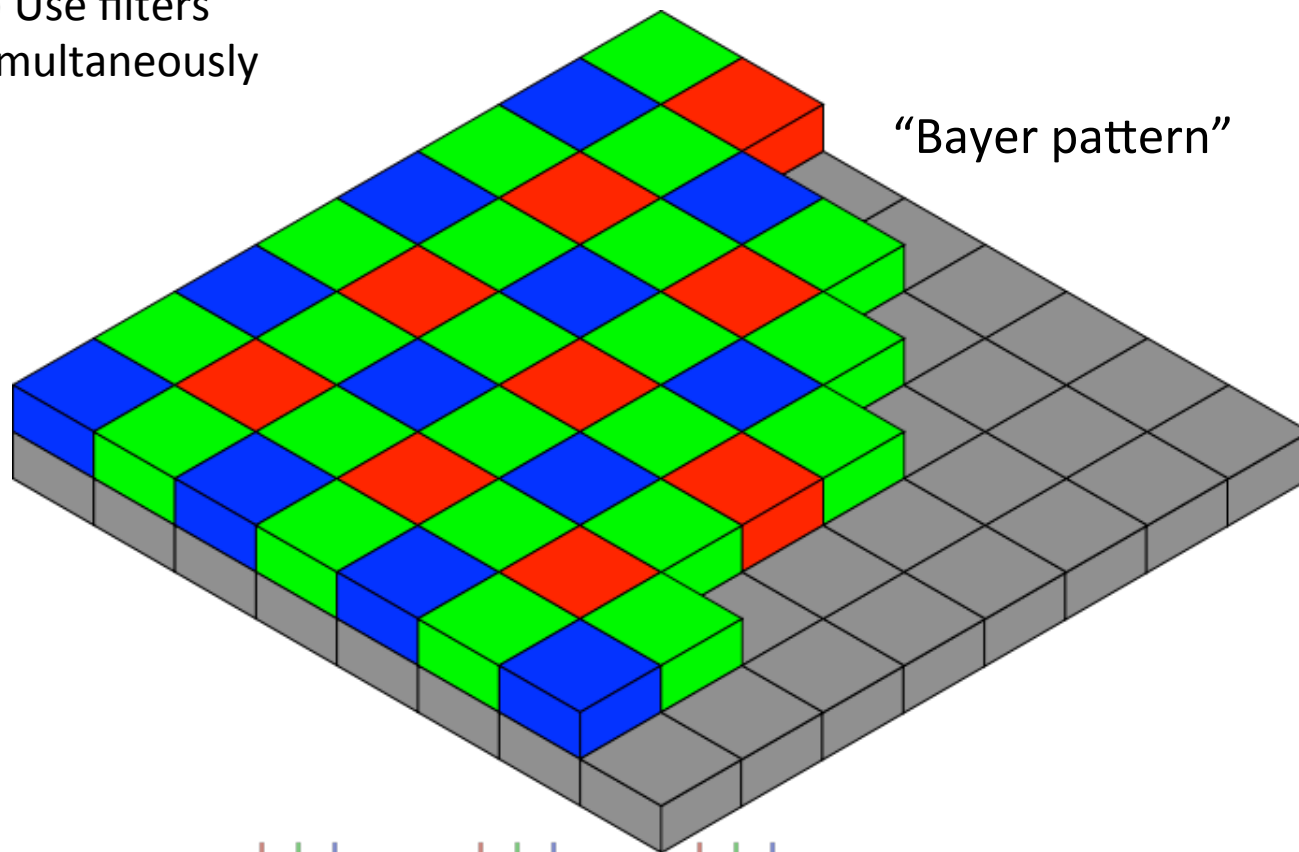
Bell et al., 2012

Hyperspectral vs. Multispectral

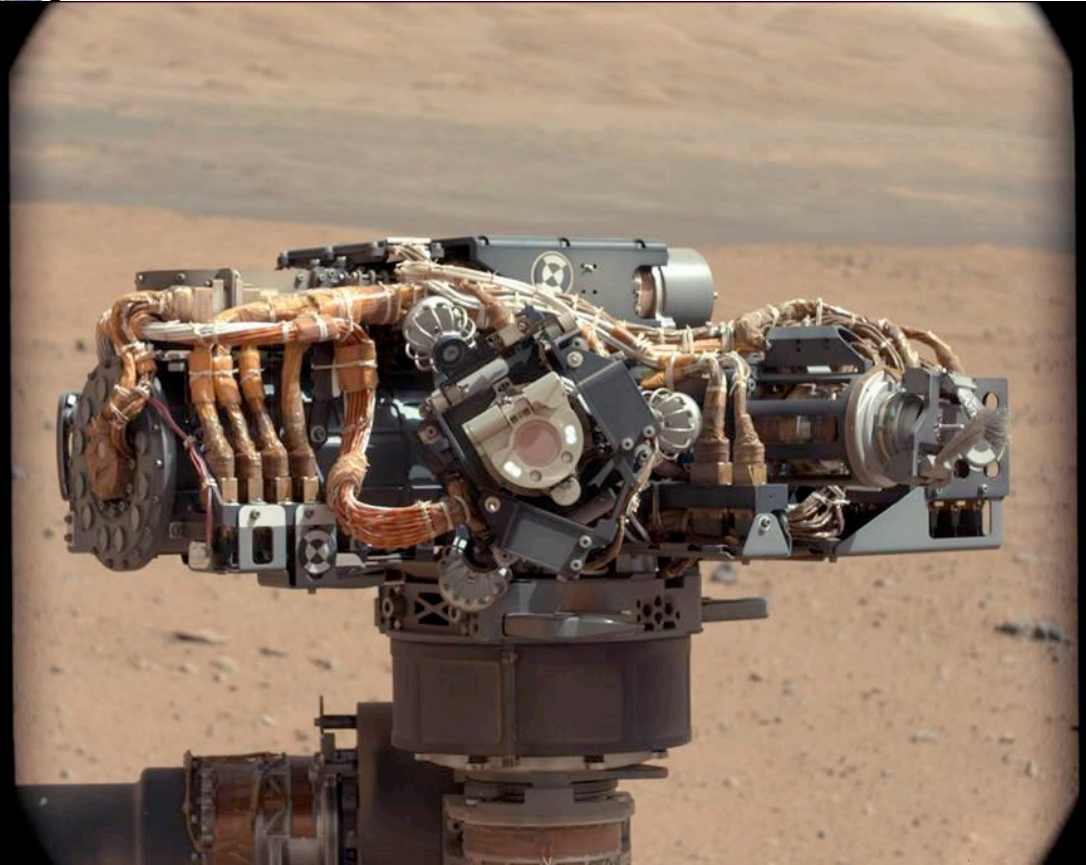
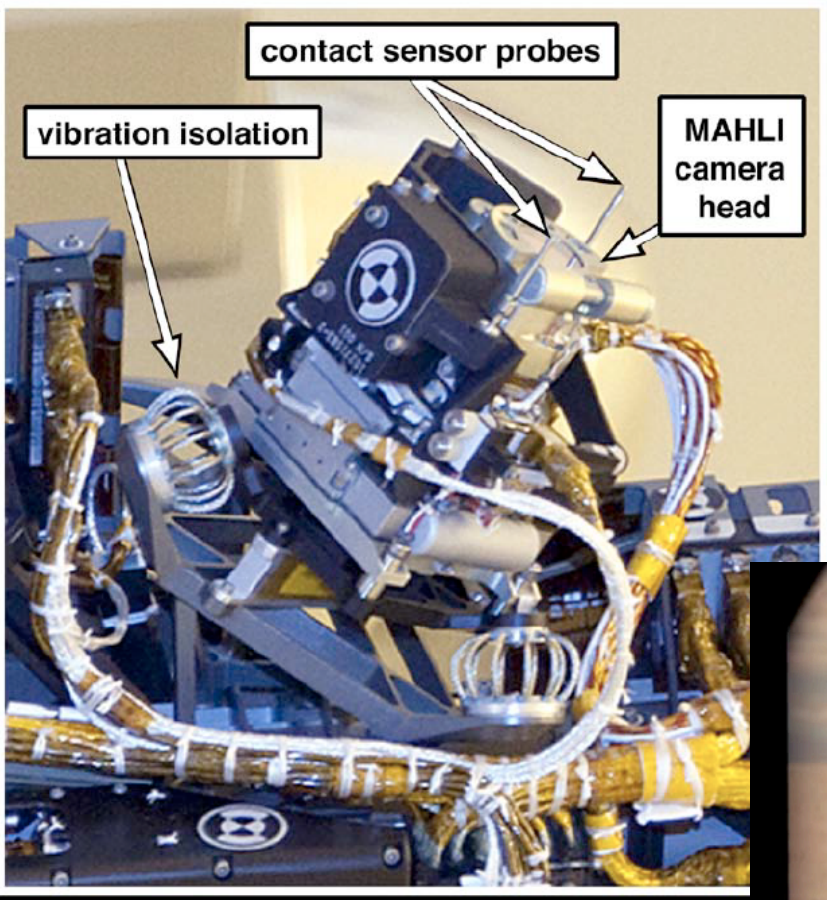


Rice et al., 2010

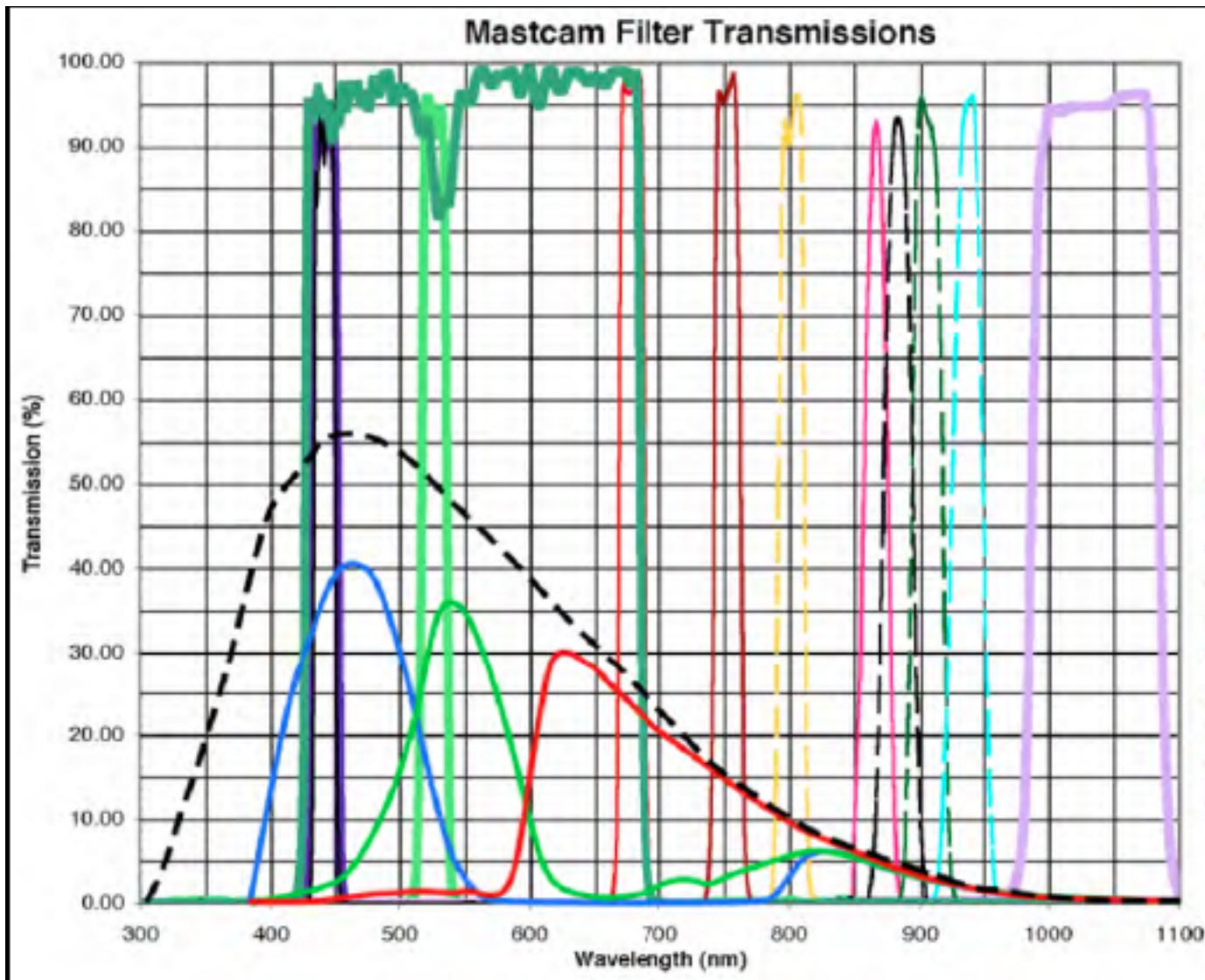
2) Use filters simultaneously



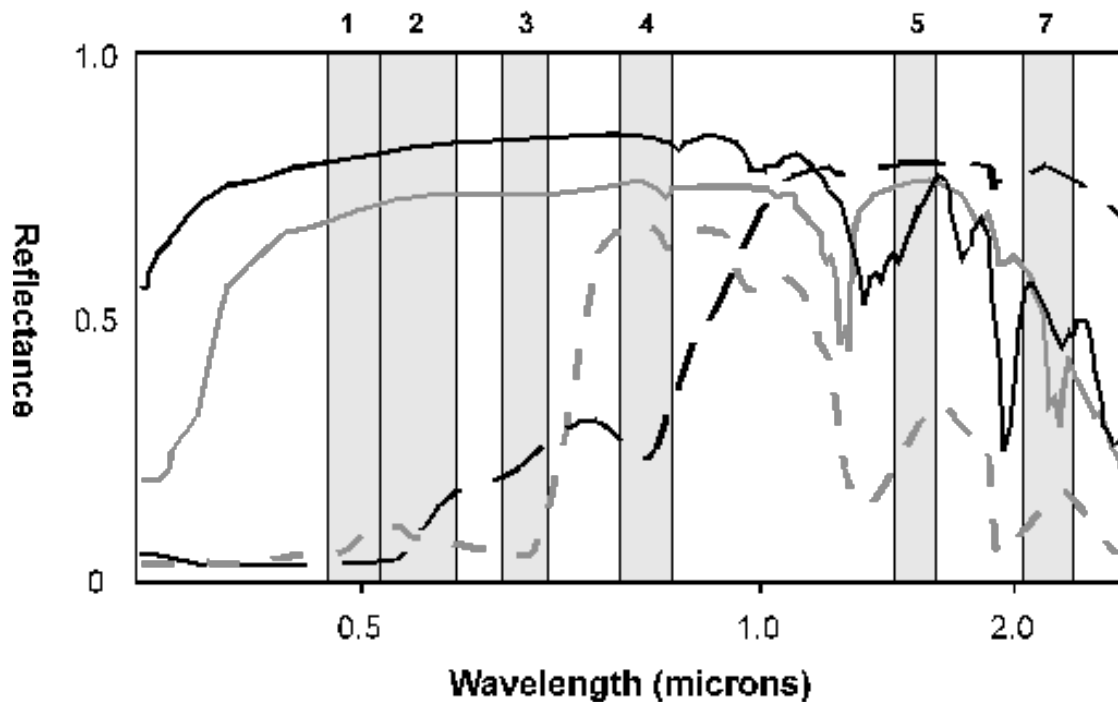
Bayer pattern user: Curiosity's Mars Hand Lens Imager (MAHLI)



Curiosity's Mastcam: Bayer pattern and filter wheel

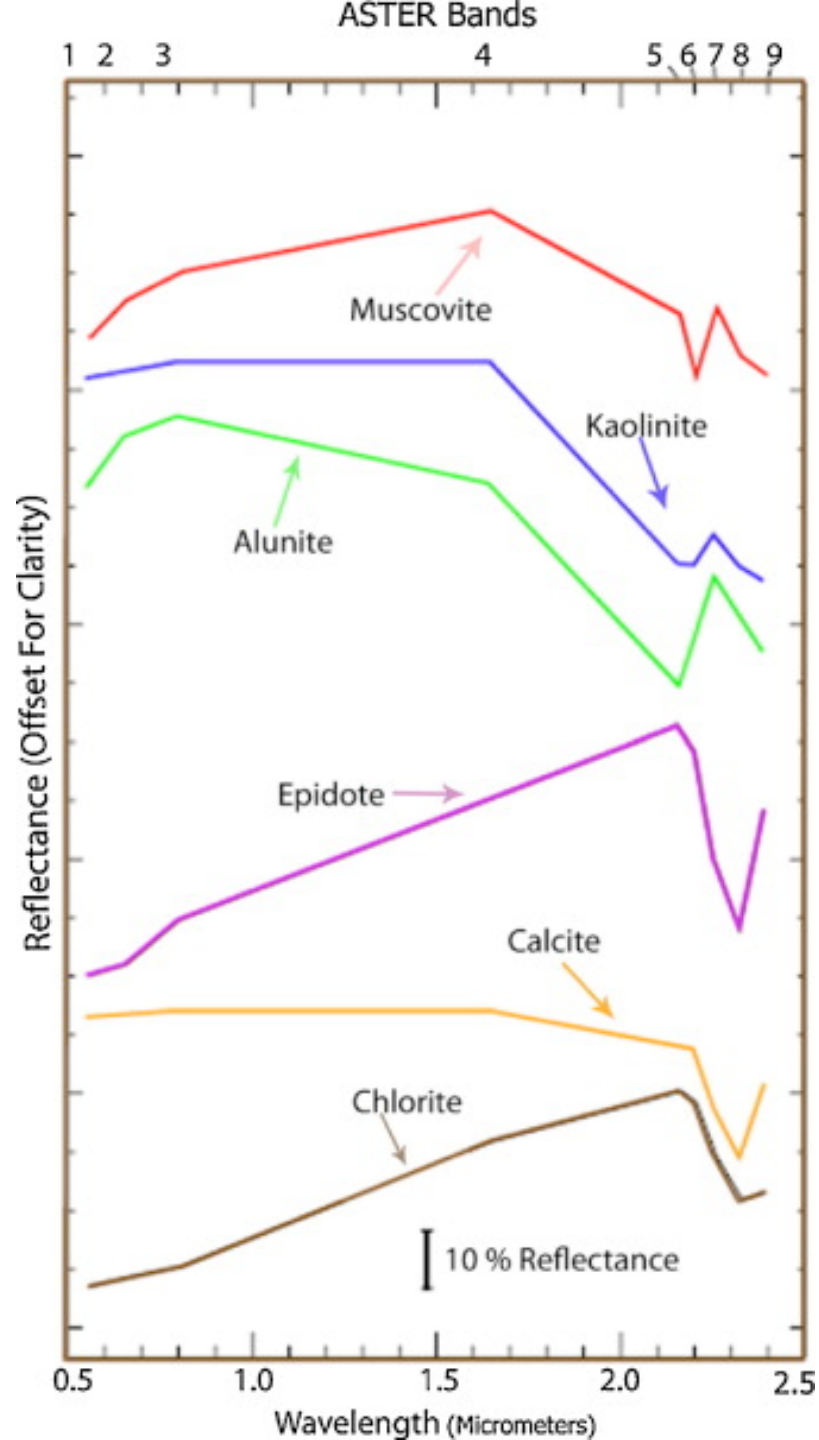


Landsat Thematic Mapper Bands



Gypsum Grassland
 Kaolinite Haematite

Band	Wavelength (μ)	Resolution (m)
1	0.450-0.515 (blue)	30
2	0.525-0.605 (green)	30
3	0.630-0.690 (red)	30
4	0.750-0.900 (near-IR)	30
5	1.55-1.75 (mid-IR)	30
6	10.4-12.5 (thermal-IR)	60
7	2.08-2.35 (long-IR)	30
Panchromatic	0.52-0.90 (green-near IR)	15



ASTER on board Terra:
 closely spaced SWIR filters to discriminate OH-bearing
 minerals

Band	Label	Wavelength (μm)	Resolution (m)	Nadir or Backward	Description
B1	VNIR_Band1	0.520–0.600	15	Nadir	Visible green/yellow
B2	VNIR_Band2	0.630–0.690	15	Nadir	Visible red
B3	VNIR_Band3N	0.760–0.860	15	Nadir	Near infrared
B4	VNIR_Band3B	0.760–0.860	15	Backward	
B5	SWIR_Band4	1.600–1.700	30	Nadir	Short-wave infrared
B6	SWIR_Band5	2.145–2.185	30	Nadir	
B7	SWIR_Band6	2.185–2.225	30	Nadir	
B8	SWIR_Band7	2.235–2.285	30	Nadir	
B9	SWIR_Band8	2.295–2.365	30	Nadir	
B10	SWIR_Band9	2.360–2.430	30	Nadir	
B11	TIR_Band10	8.125–8.475	90	Nadir	Long-wave infrared or thermal IR
B12	TIR_Band11	8.475–8.825	90	Nadir	
B13	TIR_Band12	8.925–9.275	90	Nadir	
B14	TIR_Band13	10.250–10.950	90	Nadir	
B15	TIR_Band14	10.950–11.650	90	Nadir	