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

XY(Si,Al)₂O₆
...and not always in a simple way
Spatial resolution also affects spectra (by mixing)

Areal (checkerboard) mixing: additive
Intimate mixing: non-linear

$KAl(SO_4)_2 \cdot 12H_2O$
$KFe^{+3}_3(OH)_6(SO_4)_2$
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

White light (All \( \lambda \)) \( \rightarrow \) \( \lambda \) filtered to: \( \lambda_1 \leq \lambda \leq \lambda_2 \)

Filter transmittance = \( \tau (\lambda) \)

\( \lambda_1 \leq \lambda \leq \lambda_2 \)

Wavelength (\( \lambda \))

\( \lambda_3 \leq \lambda \leq \lambda_4 \) \( \rightarrow \) Forward motion of sensor over the ground

\( \lambda_7 \leq \lambda \leq \lambda_8 \)
Dispersion Elements: Dichroic Mirrors

Diagram showing the dispersion elements with wavelength ranges:

1. 0.45–0.52 μm
2. 0.52–0.60 μm
3. 0.63–0.69 μm
4. 0.75–0.90 μm
5. 1.55–1.75 μm
6. 2.08–2.35 μm

Line array (TYP) and beam-splitter are also indicated.
Dispersion Elements:
Prisms and Diffraction Gratings

Linear array of detectors

Forward motion of sensor over the ground
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

*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

Blue  Green  Red  +  Blue  Green  Red

Blue  Green  Red  =  Blue  Green  Red

Yellow
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)
2) **RGB radiance space**

\[
\begin{align*}
    r &= \frac{R}{R + G + B} \\
    g &= \frac{G}{R + G + B} \\
    b &= \frac{B}{R + G + B}
\end{align*}
\]
1) Use filters sequentially via spacecraft motion or filter wheel.
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

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (μ)</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.450-0.515 (blue)</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>0.525-0.605 (green)</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>0.630-0.690 (red)</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>0.750-0.900 (near-IR)</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>1.55-1.75 (mid-IR)</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>10.4-12.5 (thermal-IR)</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>2.08-2.35 (long-IR)</td>
<td>30</td>
</tr>
<tr>
<td>Pan</td>
<td>0.52-0.90 (green-near IR)</td>
<td>15</td>
</tr>
</tbody>
</table>
ASTER on board Terra: closely spaced SWIR filters to discriminate OH-bearing minerals