GEOL 1460/2461 Ramsey
Introduction/Advanced Remote Sensing Fall, 2023

Atmospheric interactions; aerial photography; imaging systems; introduction to spectroscopy

Week #2: September 6, 2023

I. Quick Review from Last Lecture

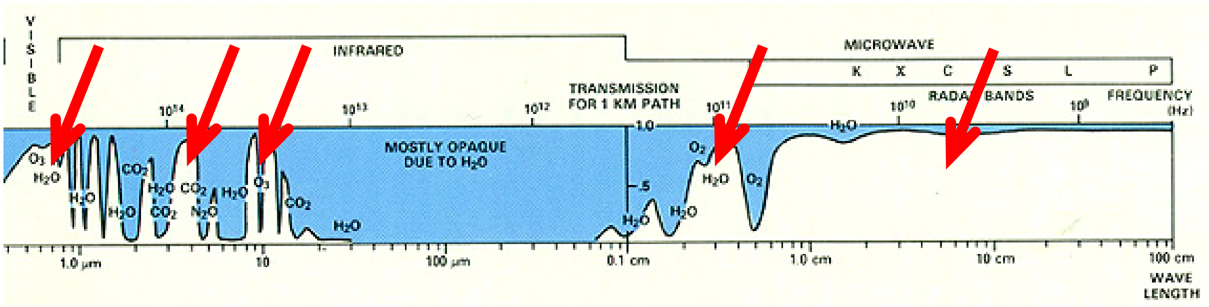
- summarize the five main points that you took away from lecture 1:
  - ○
  - ○
  - ○
  - ○
  - ○

- we will start this lecture with a focus on the material quickly covered (or not covered) in the last ~ 20 minutes of the first lecture *(basic image processing techniques)*
  - this would be the last 3 pages of last week's notes
  - so have those with you for this lecture

- there will be time for any other questions before starting the new material

II. New Material: The Atmosphere

- atmospheric window: regions that are ***not*** blocked by the Earth's atmospheric gases so we can see the surface from space (*denoted by red arrows in the figure below)*
  - have high atmospheric transmission and low absorption
  - H_2O, CO_2 and O_3 are the main gas species that absorb photons in the VIS – TIR and block our view
  - even within the atmospheric windows, the energy is interacting with gases and particulates, so no region is 100% clear!



- *general stages of image processing:* you start with DN values and want to convert those to radiance and then calibrated radiance and then finally to the physical properties of the surface (reflection, emissivity, temperature, etc.)

  - DN (in an image) converted to “radiance (energy) at sensor”
    - generally, a linear function: gain and offsets applied for every instrument

  - “radiance at sensor” to “radiance at surface”
    - removal of atmospheric terms (path radiance)

- <u>radiance at sensor:</u> path radiance + ground radiance
  - atmospheric “correction” algorithms in remote sensing are designed to remove or lessen the contribution of the path radiance to get at the absolute ground radiance

- <u>path radiance:</u> any energy contributed by interactions with the atmosphere over the path-length prior to detection

- <u>path-length:</u> distance traveled through the atmosphere by a photon
  - function of the location of the energy source, location of the sensor and the wavelength
  - <u>example:</u> reflected solar energy travels through the atmosphere twice before detection, but emitted thermal wavelengths only travel through it one time

- <u>transmissivity (τ):</u> measure of the fraction of energy that passes through the atmosphere unattenuated (varies between 0 and 1)
    - τ = 1 (perfectly clear atmosphere)

- scattering of surface radiance from particles in the atmosphere
  - 3 types:

1. selective scattering (aka, Rayleigh scattering)
    - caused by particles **much less** than the size of the scattered wavelengths
      - <u>example:</u> atmospheric gases (N_2, O_2, O_3)

    - effects VIS shorter wavelengths more (UV - VIS blue)
      - <u>example:</u> that is why the sky is blue on Earth

    - none of these gases present in significant quantities on Mars for example
      - <u>example:</u> Martian atmosphere scatters the longer red wavelengths due mostly to dust (see type #2)

2. selective scattering (aka, Mie scattering)
    - caused by particles **about equal** to the wavelength
      - <u>example:</u> dust, smoke, aerosols

    - longer VIS wavelengths are affected more (reddish coloration)
      - <u>example:</u> pollution or volcanic eruptions cause very red sunsets

3. non-selective scattering
    - caused by particles **much larger** than the wavelength
      - <u>example:</u> water vapor, ice crystals

        - all wavelengths are effected (white coloration)
            - <u>example:</u> clouds, haze, etc.

low amount of non-selective scattering

much higher amount of non-selective scattering

III. Cameras/Aerial Photography

- cameras are photon detectors *(different from imaging scanners)*
    - <u>examples:</u> film, vidicons, charged-couple devices (CCDs)
    - absorption of a photon breaks an electron free from its binding atom
    - this change in energy state can be measured electrically
    - different detector material for different wavelength regions
        - <u>examples:</u> Ag-halide (film), Si (VIS), KBr (SWIR - TIR), HgCdTe (TIR)

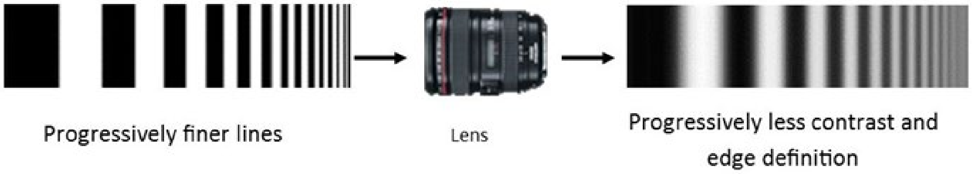
  - these detectors are just one part of a remote sensing instrument:
    1. foreoptics (primary and secondary mirrors/telescope)
    2. beam splitter
    3. detector
    4. electronics
    5. storage

- framing camera using digital imaging or directly on <u>film</u> *(more rare these days!)*
  - with film, a 2-D image is acquired instantly
    - <u>positives:</u> high spatial resolution, low costs, large amount of data captured
    - <u>negatives:</u> limited spectral range, non-digital, higher amounts of geometric distortion away from image center *(known as relief displacement)*

  - <u>ground resolution</u> = ability to resolve ground features (expressed as the number of line pairs per m)

$$\mathbf{R_g = (R_s\, f)/H}$$

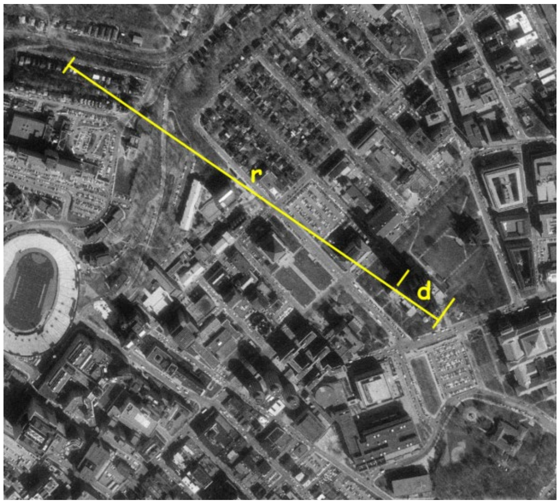
    - where, R_s = system resolution (mm); f = focal length of camera (mm); H = camera height above ground (m)
    - whereas, the width of an individually-resolved line pair = $R_g{}^{-1}$



    - <u>scale</u> = f/H
      - commonly written as 1:20,000
      - 1 mm on the photograph = 20,000 mm (20m) on the ground

  - <u>relief displacement</u>
    - geometric distortion at image edges giving the effect that taller objects are "leaning" away from the optical center of the photo
    - distortion amount is related to:

      1. vertical height of the object
      2. distance from the principal point
      3. inversely proportional to the camera height



h = (H d) / r

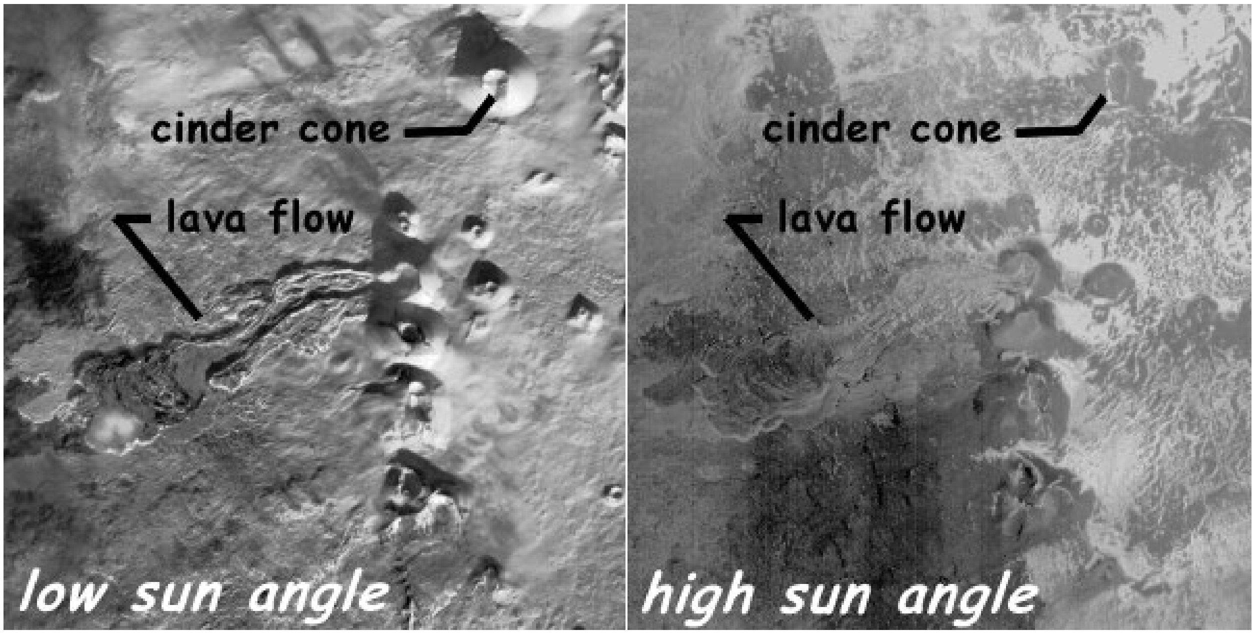
  - where, h = actual height of the object (m) ; H = camera height above ground (m); r = distance from image center to the **top** of the object (m); d = relief displacement

  - removal of *large-scale* relief displacement produces an "orthophotograph"

  - stereo-pairs = successive overlapping air photos
    - because each photograph images each point on the ground from a slightly different angle, the offsets can be used to reproduce the vertical dimension
    - known as a DEM (digital elevation model)
    - what are used to produce the USGS topographic maps

- sun angle
  - low sun angle: images taken generally early morning, late afternoon, or at high latitudes, where the sun is < 15° above the horizon
    - produces pronounced shadows if object is perpendicular to sun
    - excellent for interpretation of subtle topographic features

  - high sun angle:
    - *what benefits could you see in the following images?*



IV. Imaging Systems: Scanners

- systems used to build up electronic images line by line/row by row
  - most common form of orbital sensors

- dwell time
  - **dwell time = scan time per line / number of cells per line**
  - in other words, the amount of time a scanner has to collect photons from a ground resolution cell

  - translates to:

$$\frac{\textbf{(down-track pixel size / orbital velocity)}}{\textbf{(cross-track line width / cross-track pixel size)}}$$

  - for the Landsat Thematic Mapper (TM) instrument
    - dwell time = [(30 m / 7500 m/s) / (185,000 m / 30m)]
    - dwell time = 6.5×10^{-7} sec for each pixel

  - very short time per pixel leads to a low signal to noise ratio
  - need to find ways to increase the dwell time for better data

- General classes: **cross-track scanners**
  - rotation or "back and forth" motion of the foreoptics (mirror)
  - scans each ground resolution cell (pixel) one by one

- General classes: **along-track scanners**
  - multiple cross-track detectors (no scanning motion)
  - positives: dwell time increases. *Why?*
    - in the dwell time equation, the denominator = 1.0 because the line width is in effect the cross track width of the pixel
    - equation reduces to:
      - dwell time = (down-track pixel size / orbital velocity)
      - dwell time = 4.0×10^{-3} sec/pixel *(for the above example)*

  - negatives: large arrays are more difficult to fabricate *(TM would require 6200 elements)*, failure of one element produces a loss/calibration error of an entire column of data *(see images on next page)*

- Types: **whisk-broom scanners**
  - combination of a cross-track scanner and a push-broom scanner
  - scan with a small line array of detectors
  - positives: longer dwell time (several lines per scan motion)
    - *only if all detectors are the same wavelength!*
    - reverts to the same dwell time as the cross-track scanner *if each detector was tuned to a different wavelength*
      - why?

  - <u>negatives</u>: different response sensitivities in each detector can cause striping in the image *(see above)*

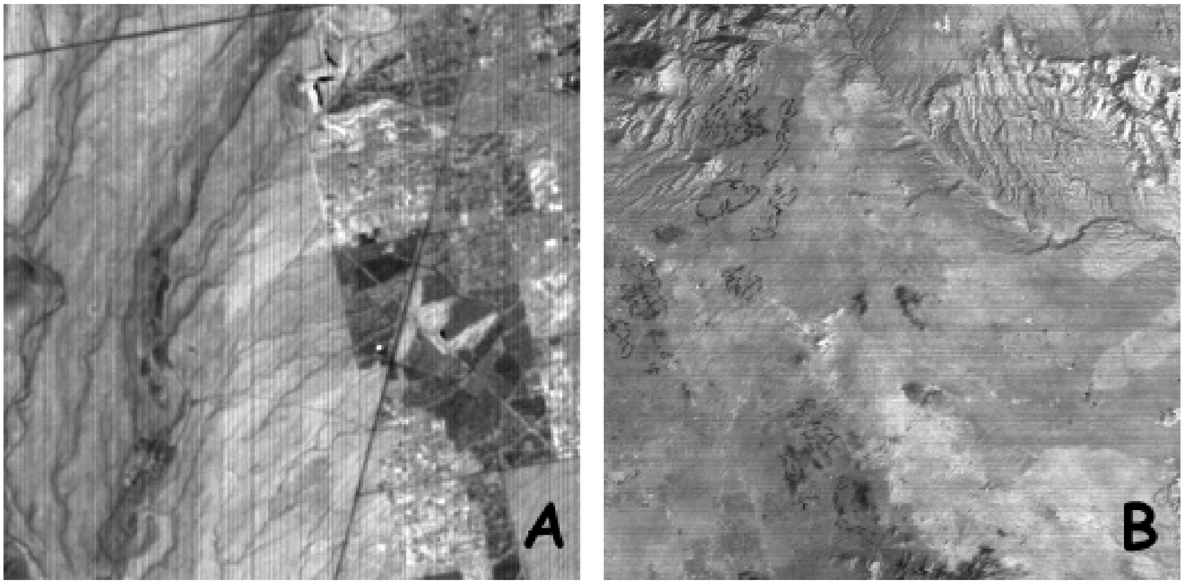
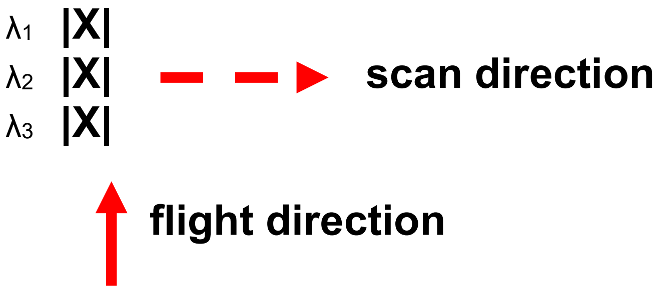
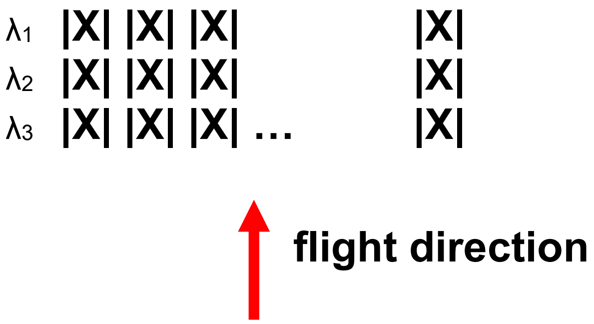


Image A is an example of push-broom line array errors in band 4 of the ASTER sensor; image B is an example of cross-scanner array errors in band 10 of ASTER.

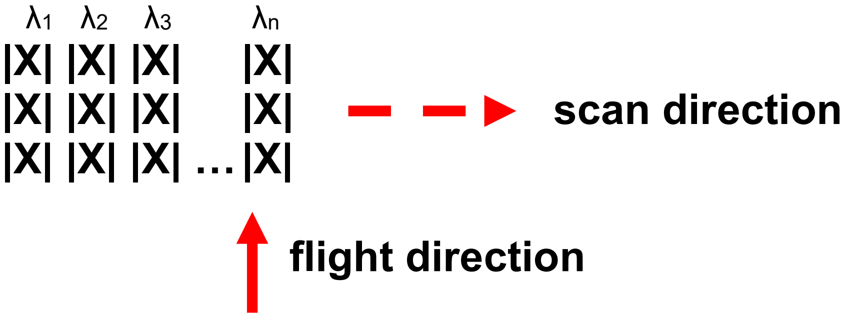
- Types: **push-whisk scanners**
  - thus far, we have looked at scanners with just one spectral band
  - how do we add multiple wavelength observations?
  - add cross-track scanning with a line array
  - *different than a whisk-broom*
    - there, the scanning is done with a line array of the same wavelength
    - here, the scanning is performed with a line array of detectors at different wavelengths
    - <u>negatives</u>: short dwell time again, spacecraft movement, planet rotation causes imprecise alignment



        - 2 solutions:
            1. push-broom scanning with a 2-D array



            2. whisk-broom scanning with a 2-D array *(TM scanner)*



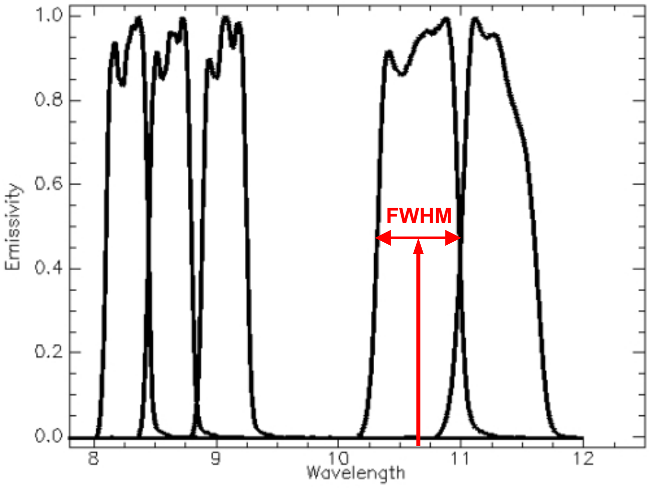
V. Imaging Systems: Spectral Resolution

- information interpretation
    - what is ***spectral*** resolution?
        - spectrum for each pixel over the number of instrument channels

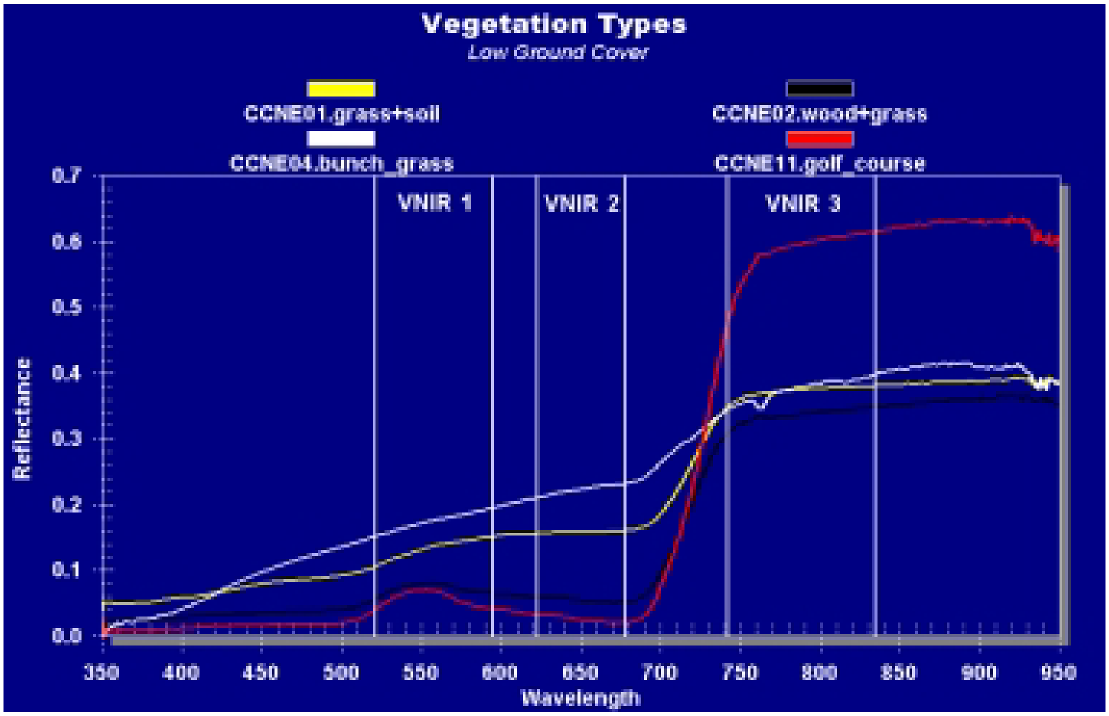
        - multi-spectral vs. hyper-spectral data
            - energy returned from the surface and detected by the sensor is quantized over some wavelength region
            - broken down into some number of discrete instrument channels

- how?
    - band pass filters
        - subdivide the EM spectrum of the pixel into discrete wavelength channels
            - each pixel in the image is one wavelength channel
            - each image comprises one channel of all the pixels a multi-channel image
            - each channel can be placed in either the red, green or blue color of a remote sensing software package

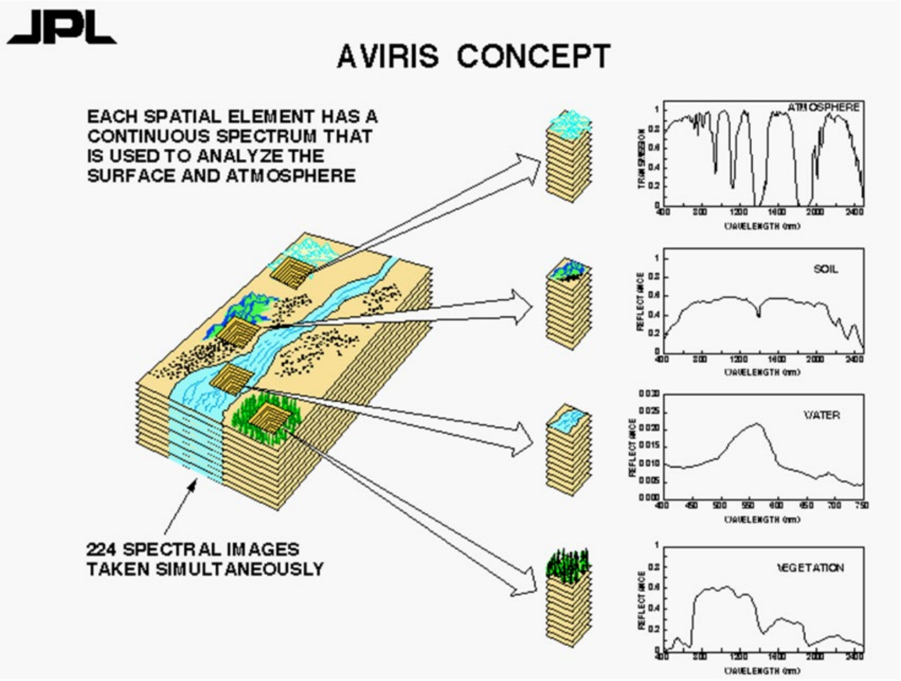
    - channel width: width of the filter (band) at 50% of the peak response
    - FWHM: “full width/half max”
            - measure of the spectral width of each wavelength channel



- example: going back to sunlight reflected off a green leaf
  - ➢ produces a spectrum that contains info on the amount and type of chlorophyll pigments
  - ➢ spectrum is continuous (many points)
  - ➢ but a multispectral sensor will only detect energy over the number of wavelength regions corresponding to the number of band pass filters
  - ➢ example: a 3-point spectrum *(multi-spectral instrument)*
  - ➢ another instrument may have hundreds of channels in this wavelength region *(hyper-spectral instrument)*



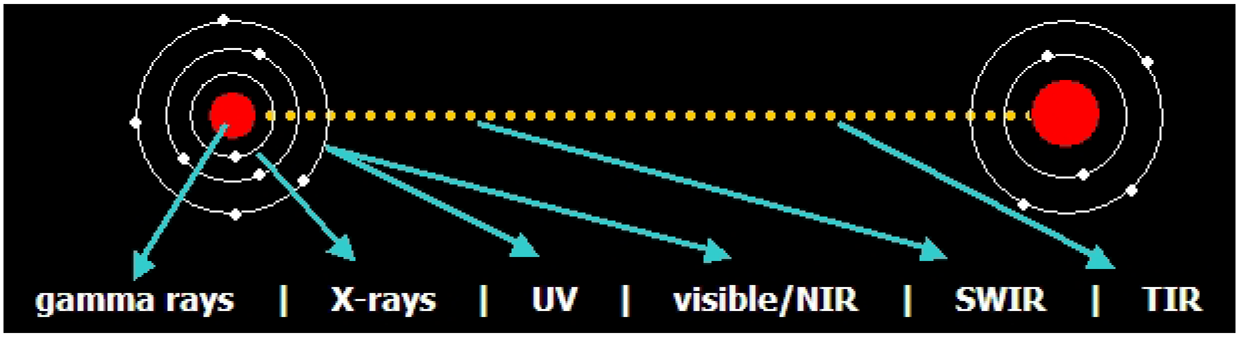
Visible/near infrared (VNIR) spectra of common desert vegetation showing three wavelength bands (VNIR 1, VNIR 2, VNIR 3) of a multi-spectral instrument. However, the VNIR spectra are 1000's of points.



VI. Spectroscopy

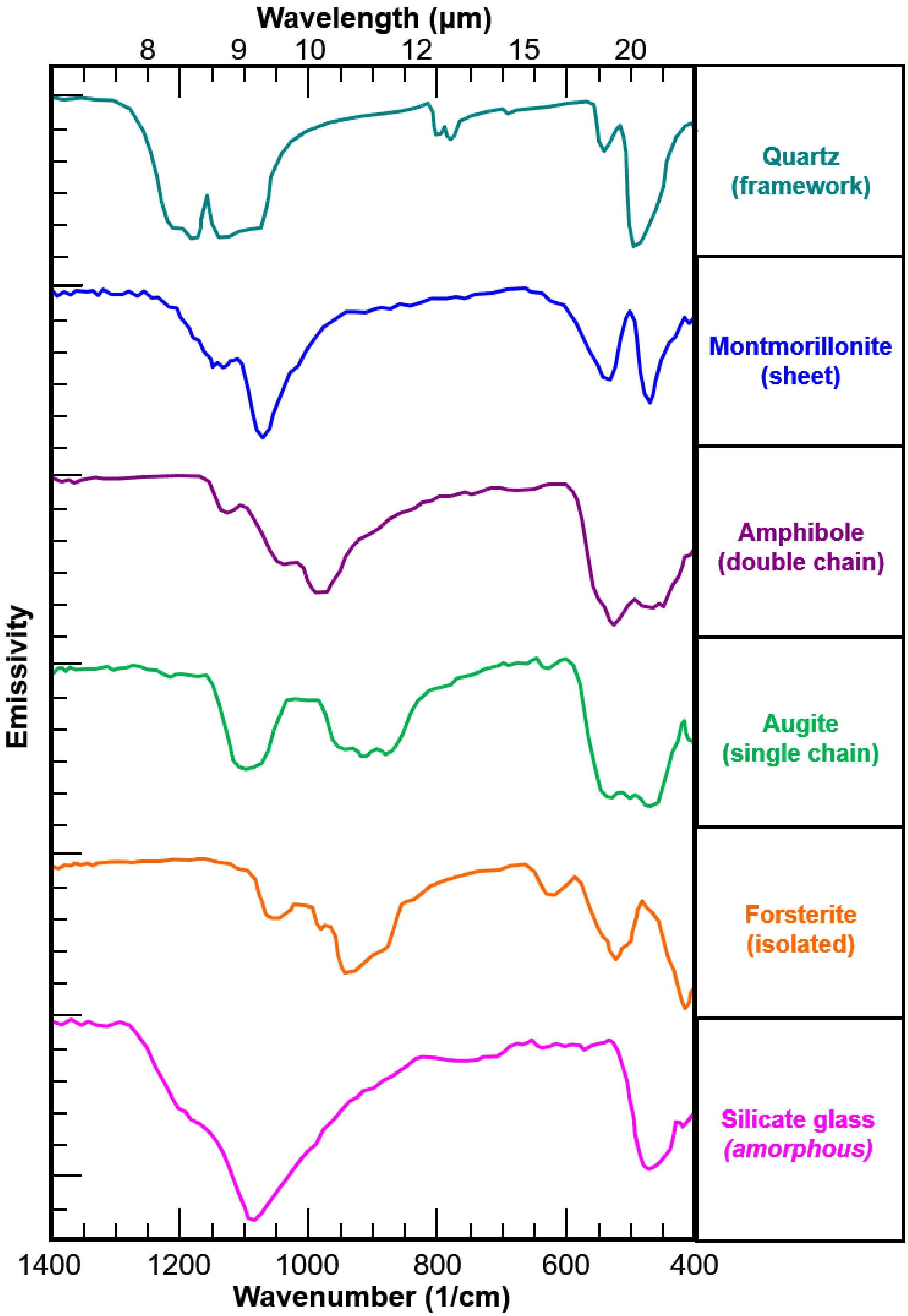
- spectroscopy: science and analysis of the EM spectra of materials
  - type of spectroscopy is a function of the wavelength region under study
    - gamma ray spectroscopy, TIR spectroscopy, etc.

  - the analysis of the spectrum tells you something about the surface material
    - talked some about this last week
    - spectral features caused by electronic processes within atoms and vibrational processes between atoms



    - example *(next page)*: thermal infrared (TIR) emissivity spectra
      - emissivity lows indicate regions of fundamental vibrations of the bonds between the Si -- O atoms

  - ***much more detail on all this in the coming weeks!***


Wavelength (μm)
8
9
10
12
15
20
Emissivity
Quartz (framework)
Montmorillonite (sheet)
Amphibole (double chain)
Augite (single chain)
Forsterite (isolated)
Silicate glass *(amorphous)*
1400
1200
1000
800
600
400
Wavenumber (1/cm)