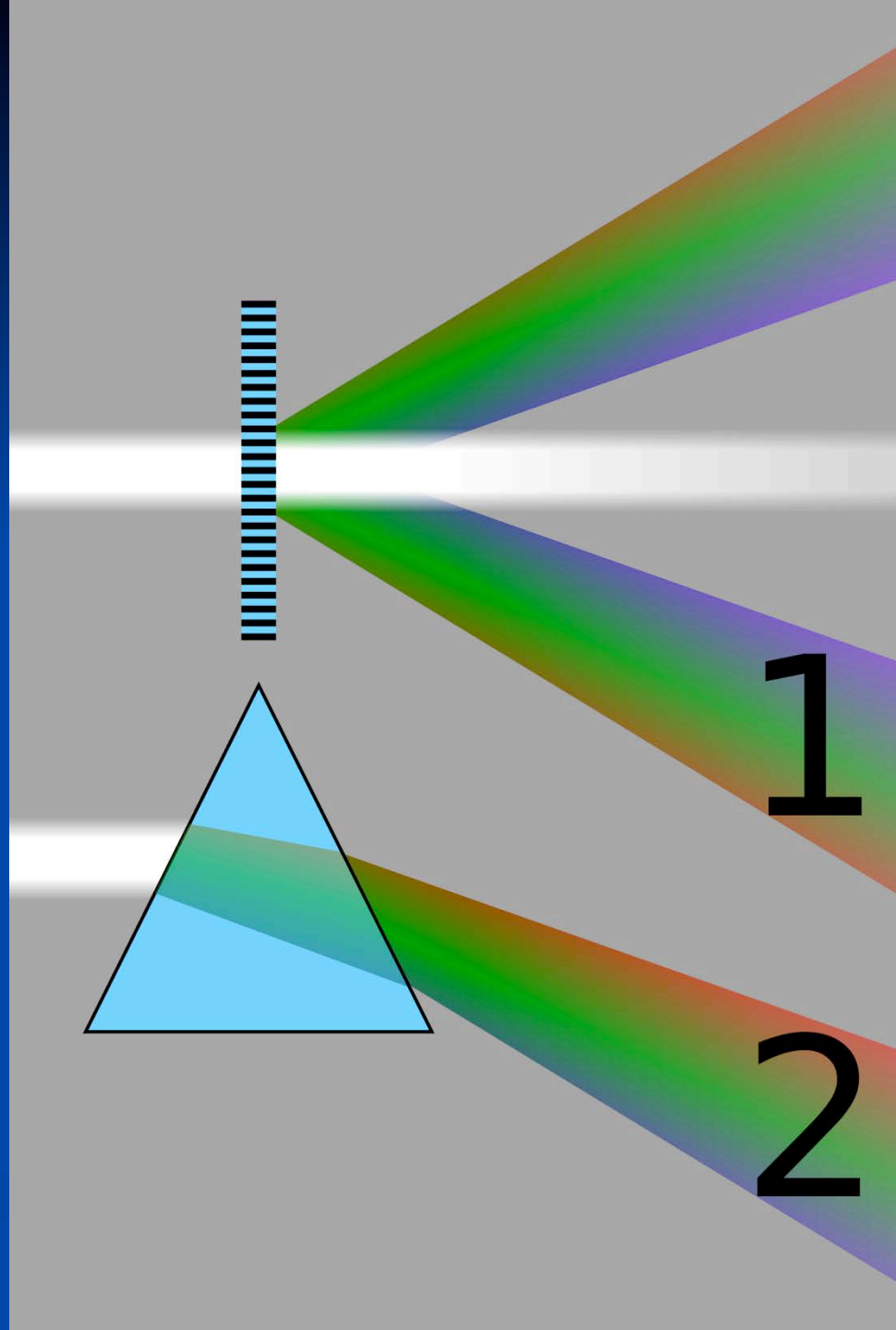
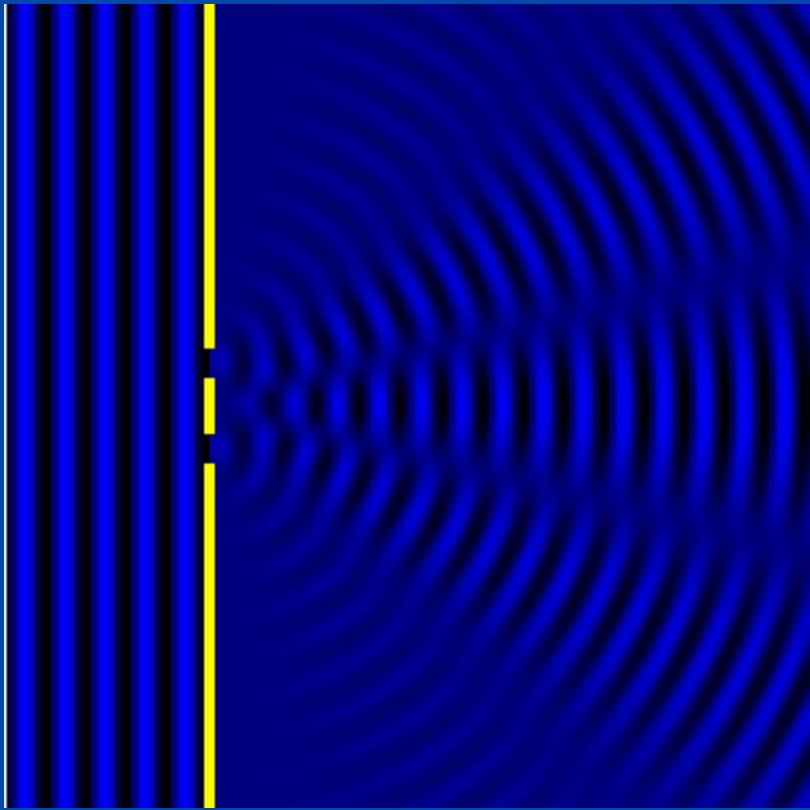
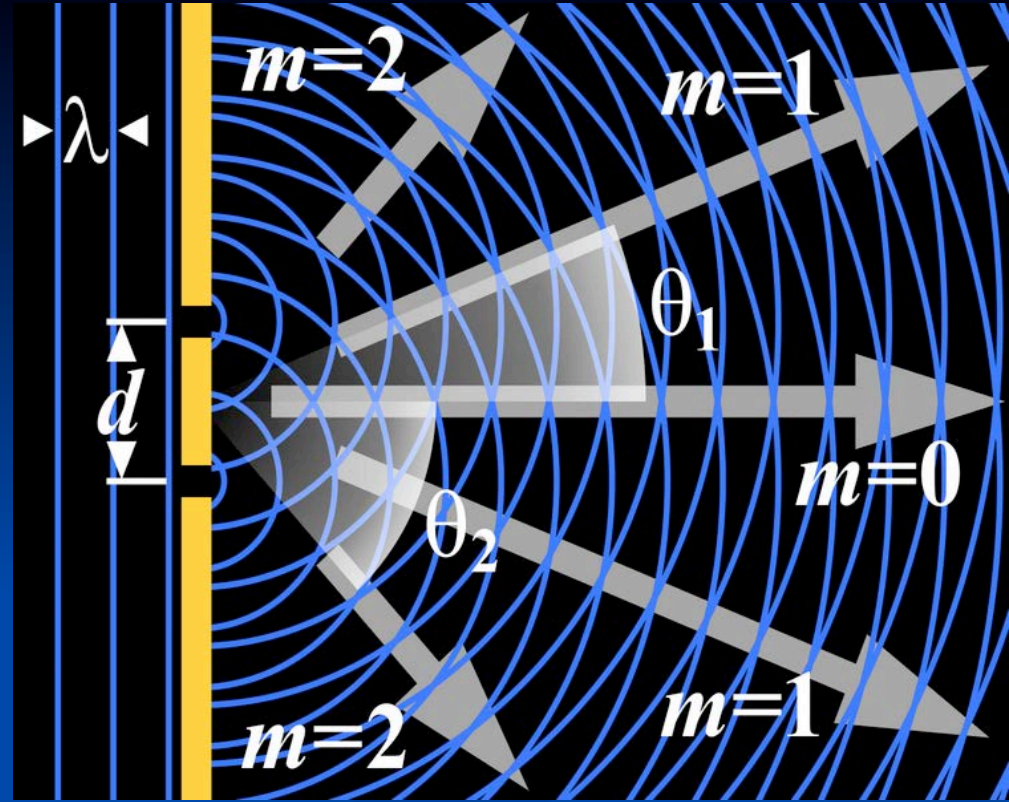
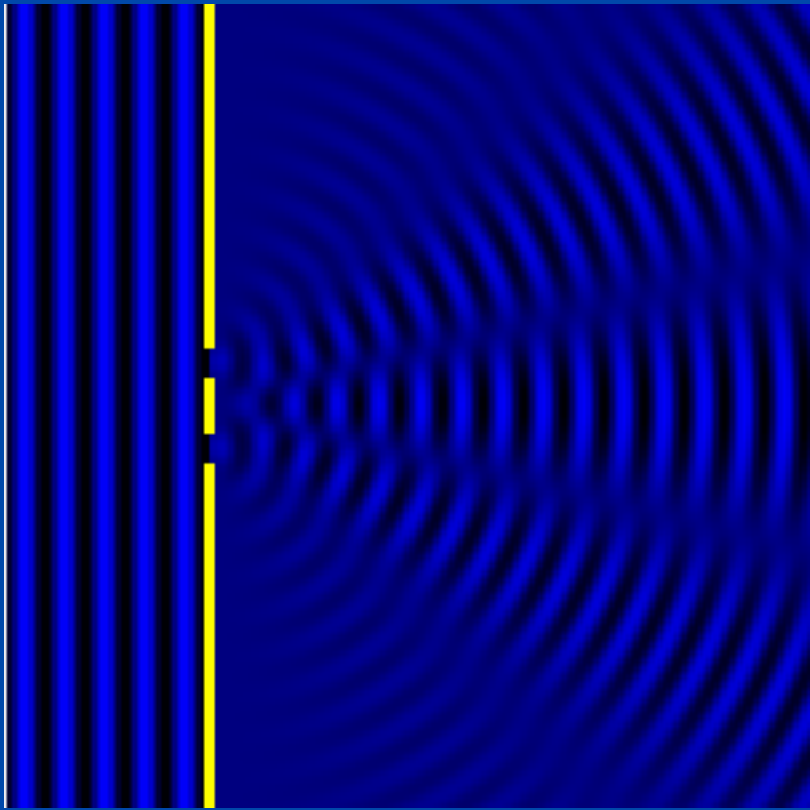


Diffraction gratings

e.g., CDs and DVDs



Diffraction gratings

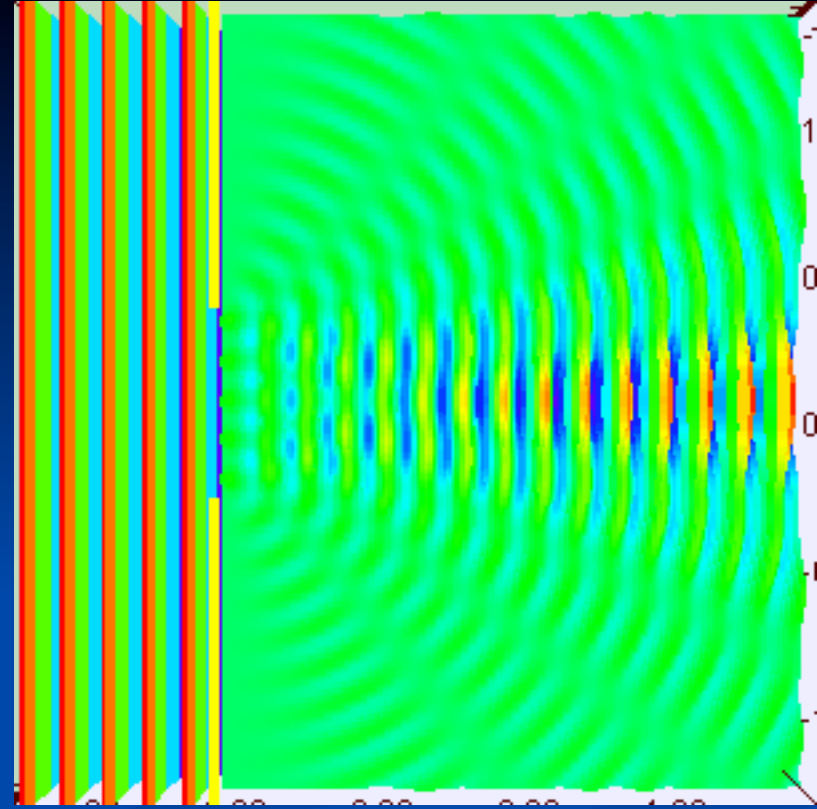
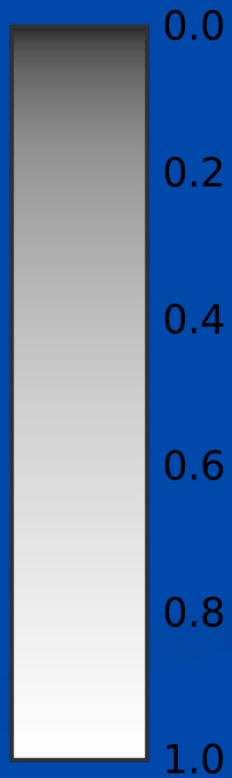
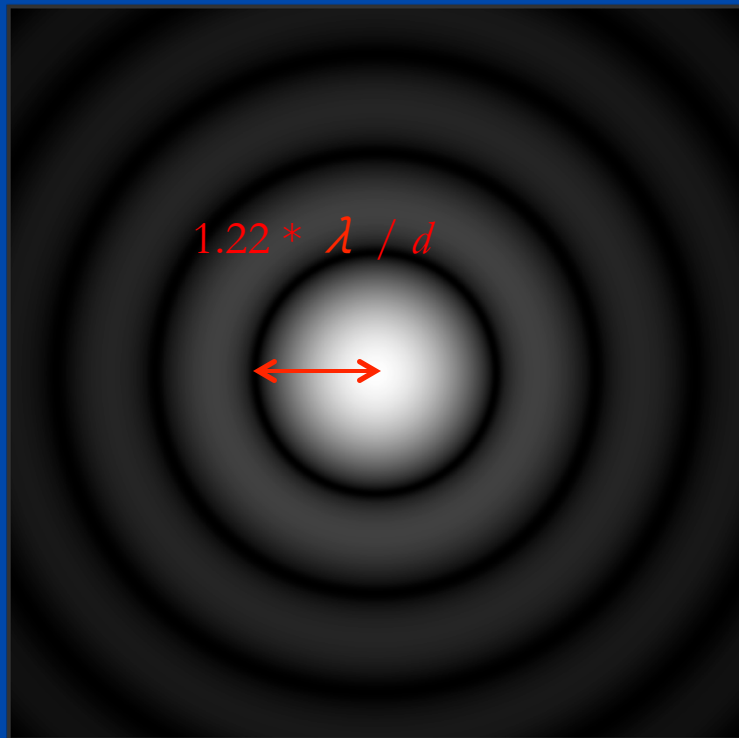


Constructive interference where:

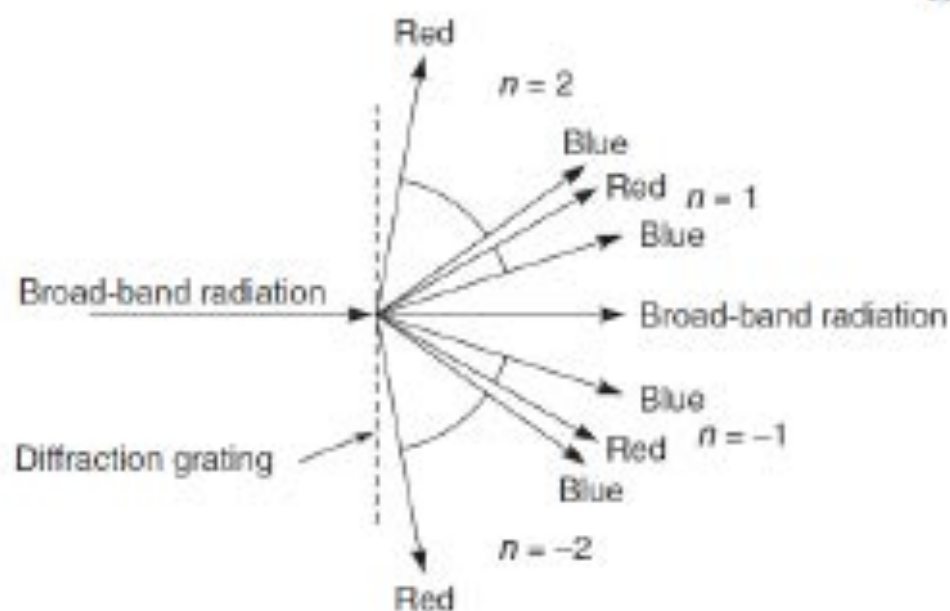
$$\sin \theta = m \cdot \lambda / d$$

(If $d > \lambda$)

Single-slit diffraction



$$\sin \theta = \frac{n\lambda}{d}$$



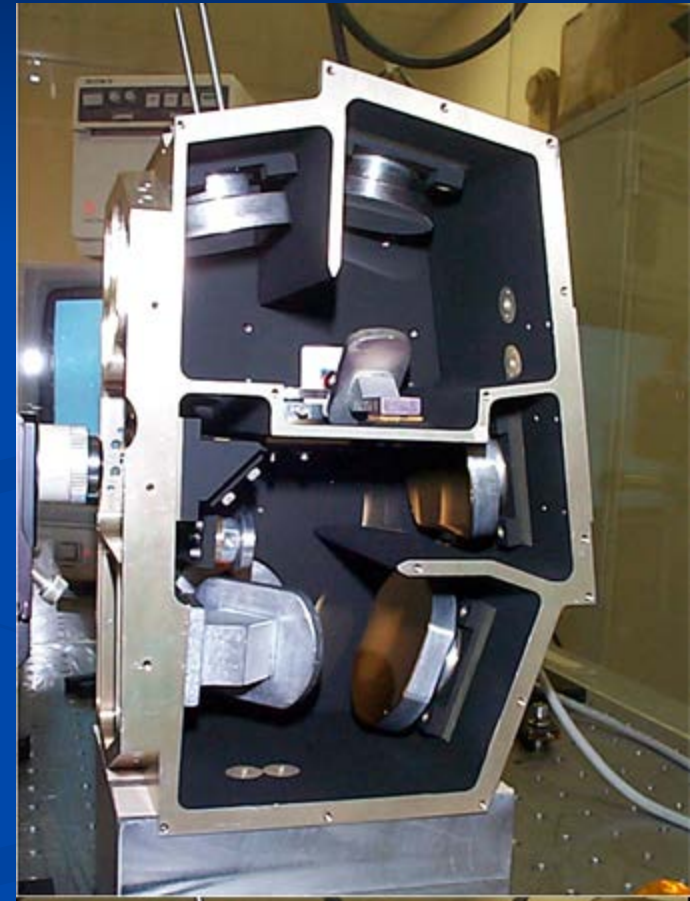
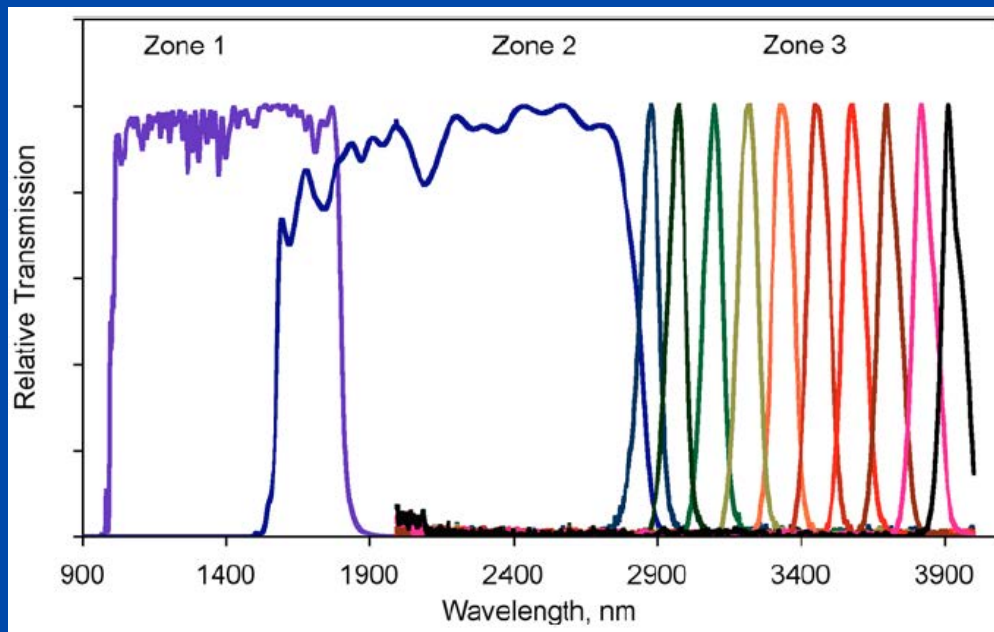
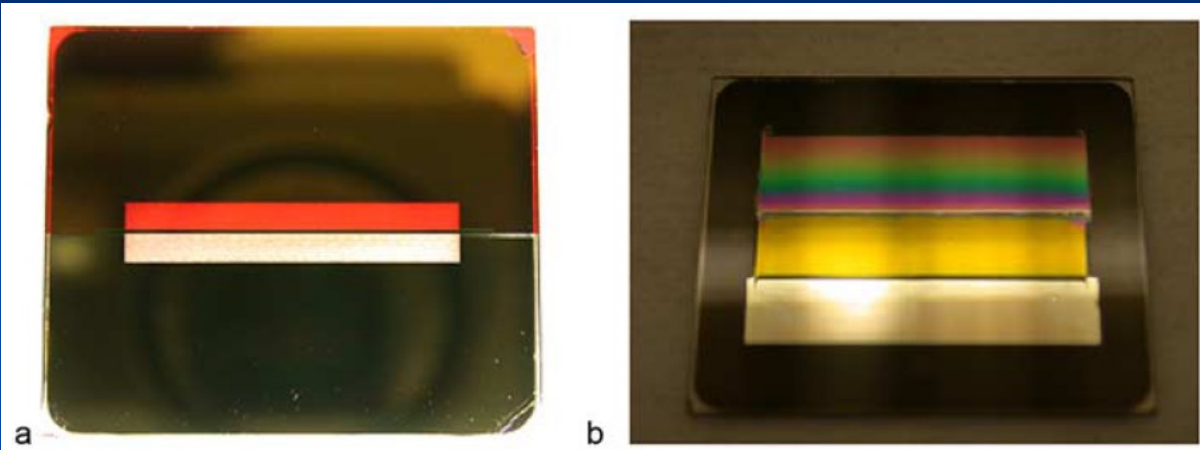
Gratings allow hyperspectral wavelength spacing. But beware of "parasitic" light contributions from higher orders to a given channel

Figure 6.8. Dispersion of broad-band radiation by a diffraction grating. The values of n are the orders of the spectra.

Grating, plus “order-sorting filters” on detector

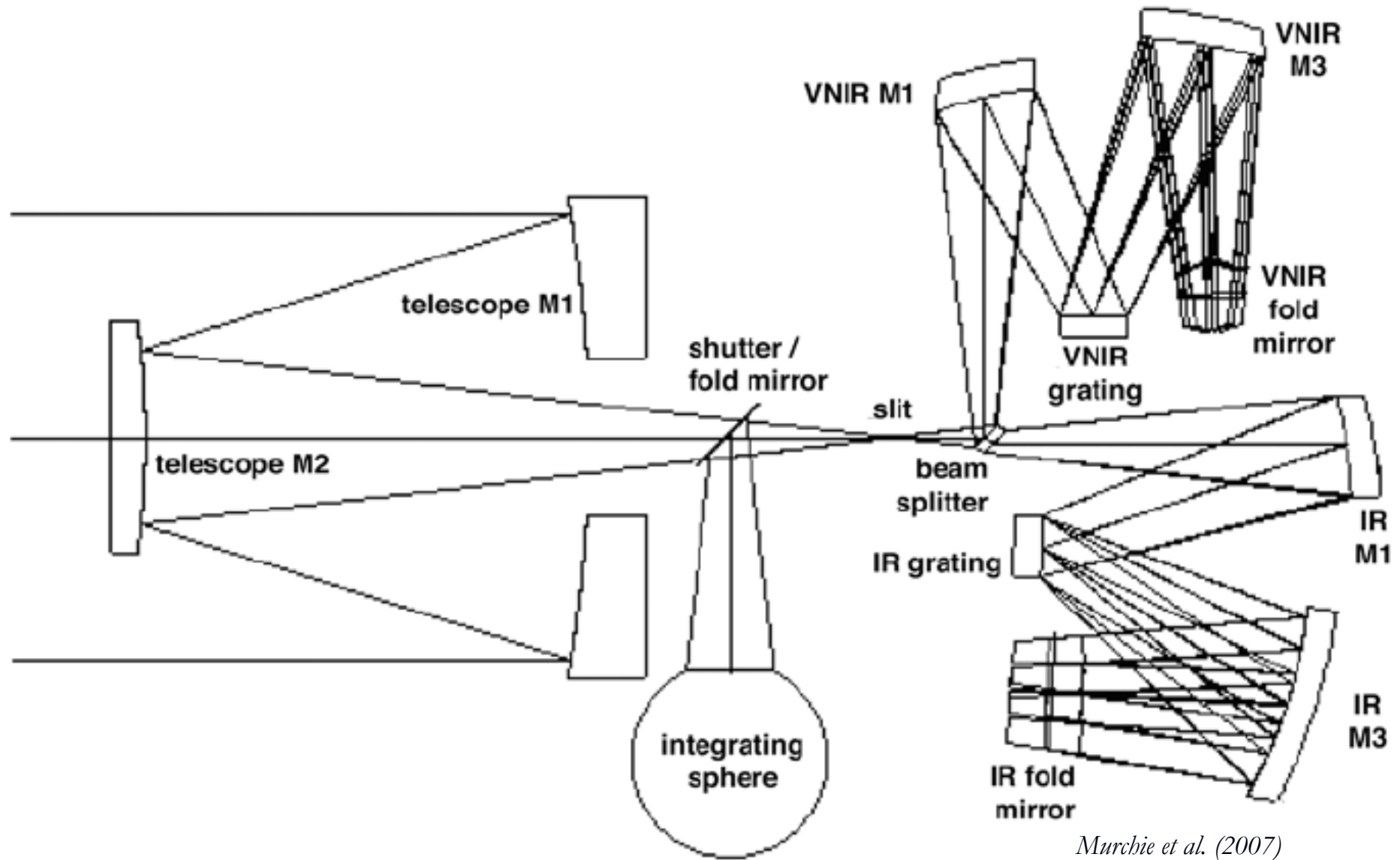
VNIR (Si)

IR (HgCdTe)



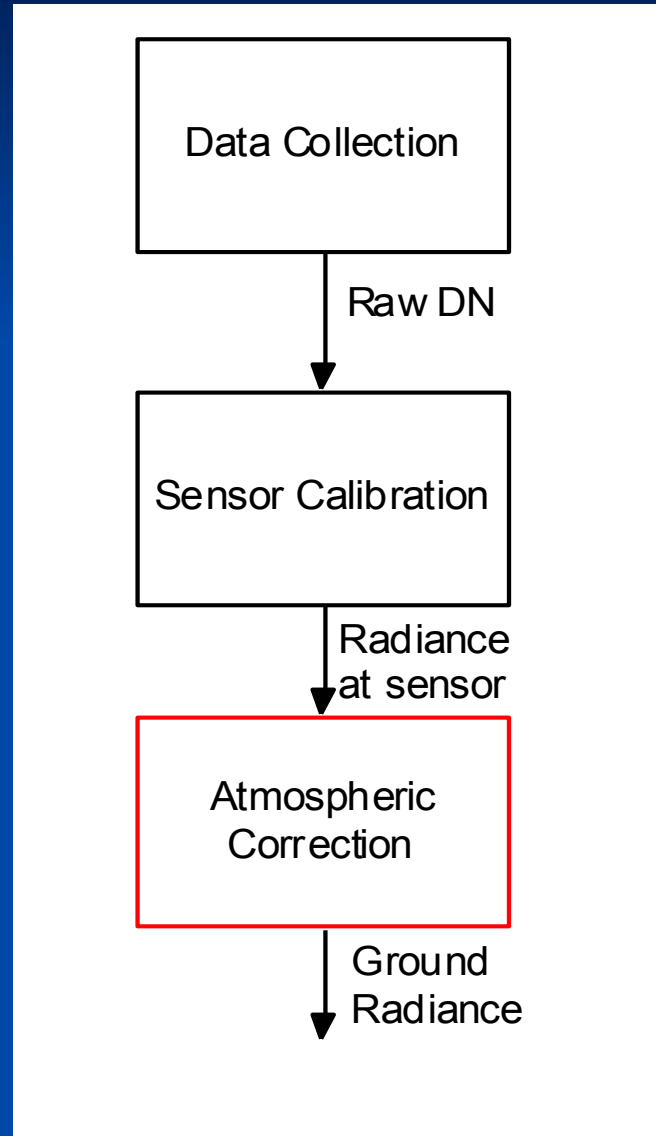
Murchie et al. (JGR, 2007)

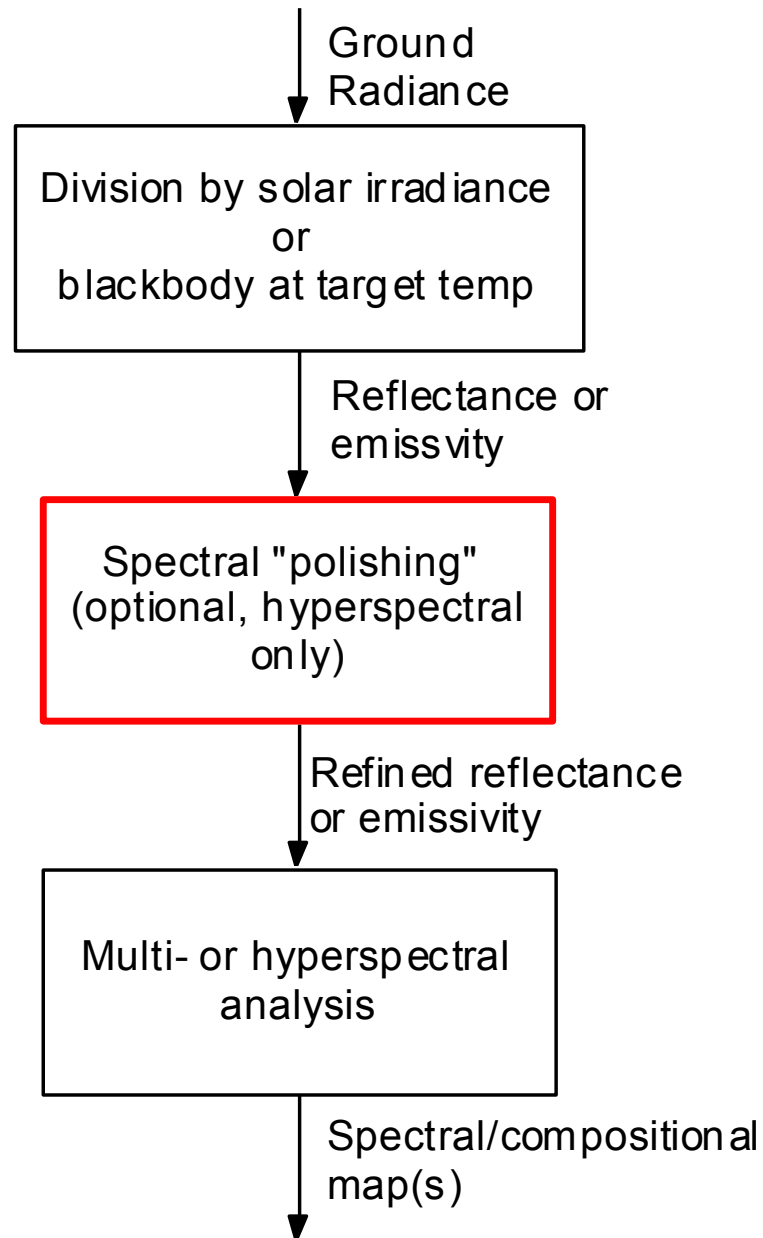
Diffraction gratings: an example
(compare to AVIRIS,
most planetary reflectance spectrometers)

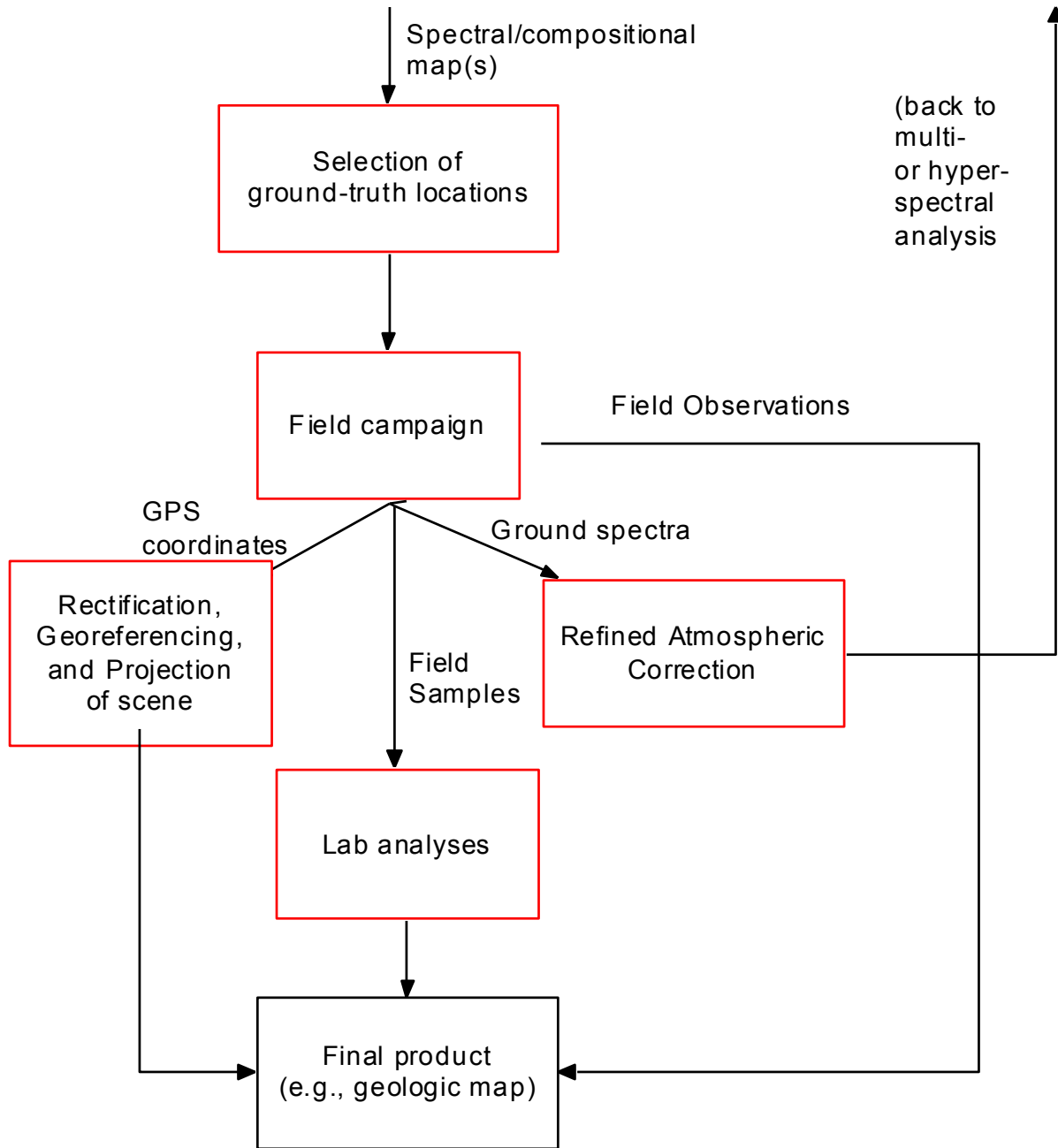


Murchie et al. (2007)

Putting It All Together: A Typical Flowchart for Remote Sensing Projects



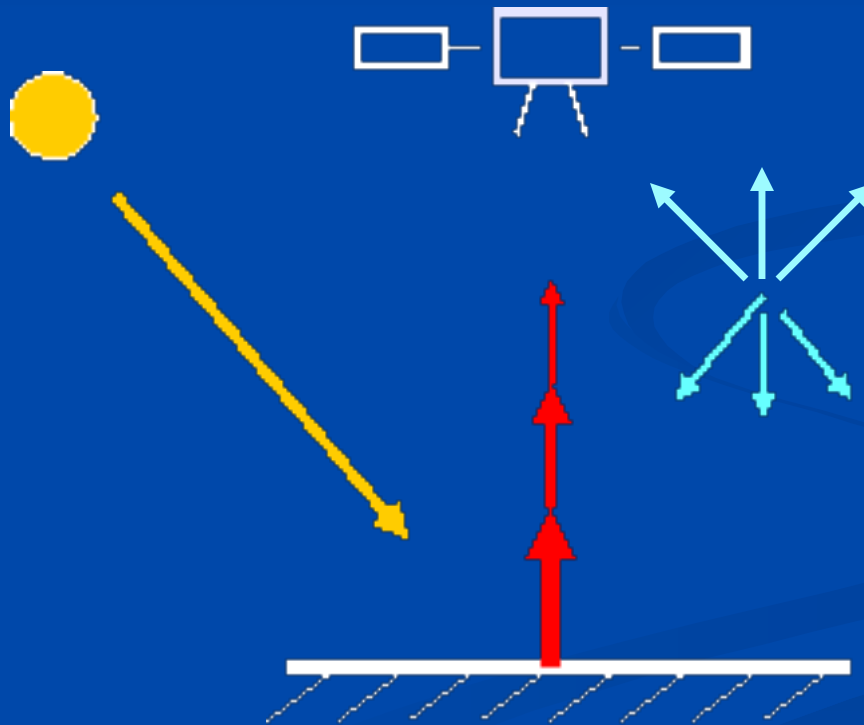




Atmospheric Effects

For measurements of reflected sunlight (Vis/NIR):

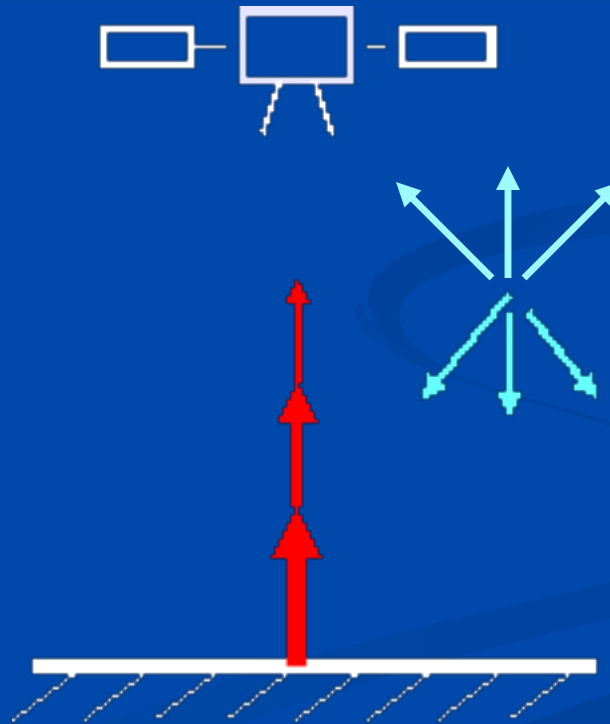
$$I_{sensor} = [RJ_{sun} + RL_{atm_down}] (1 - 2\tau_{atm}) + L_{atm_up}$$



Atmospheric Effects

For measurements of self-emitted light (TIR):

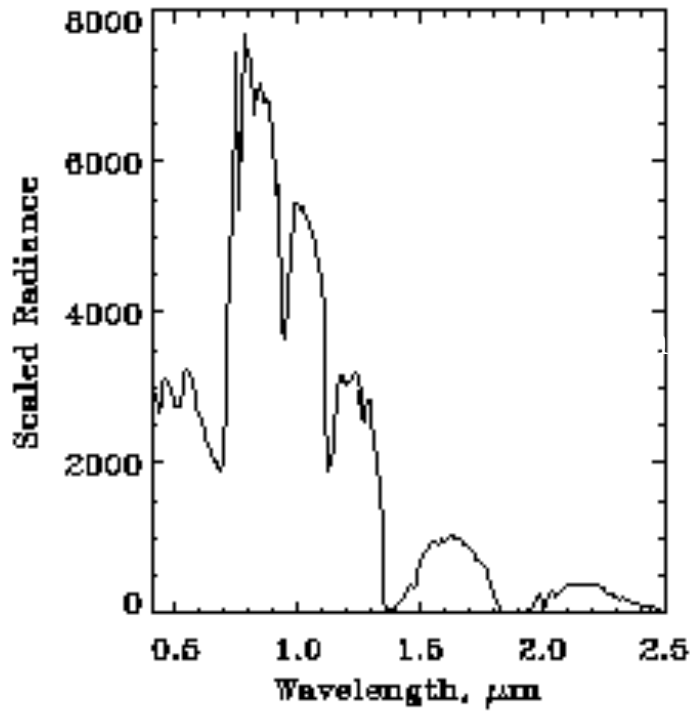
$$I_{sensor} = [\epsilon B_{surface} + RL_{atm_down}] (1 - \tau_{atm}) + L_{atm_up}$$



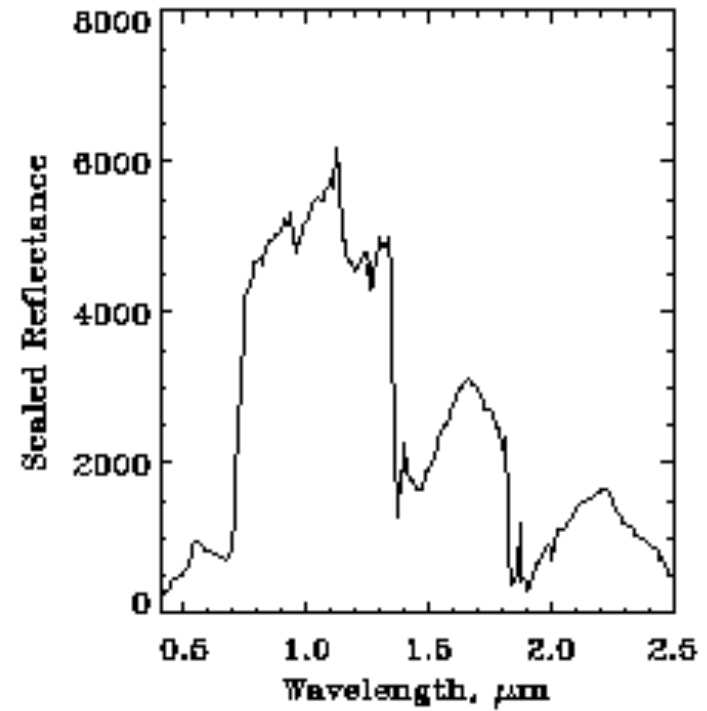
Atmospheric Correction

Model-based corrections:

- Goal is to remove effects of absorption, emission, and scattering of photons by the atmosphere
- For the geologic remote sensing analyst, typically involves use of one of several “black boxes”, e.g. MODTRAN or ATREM.

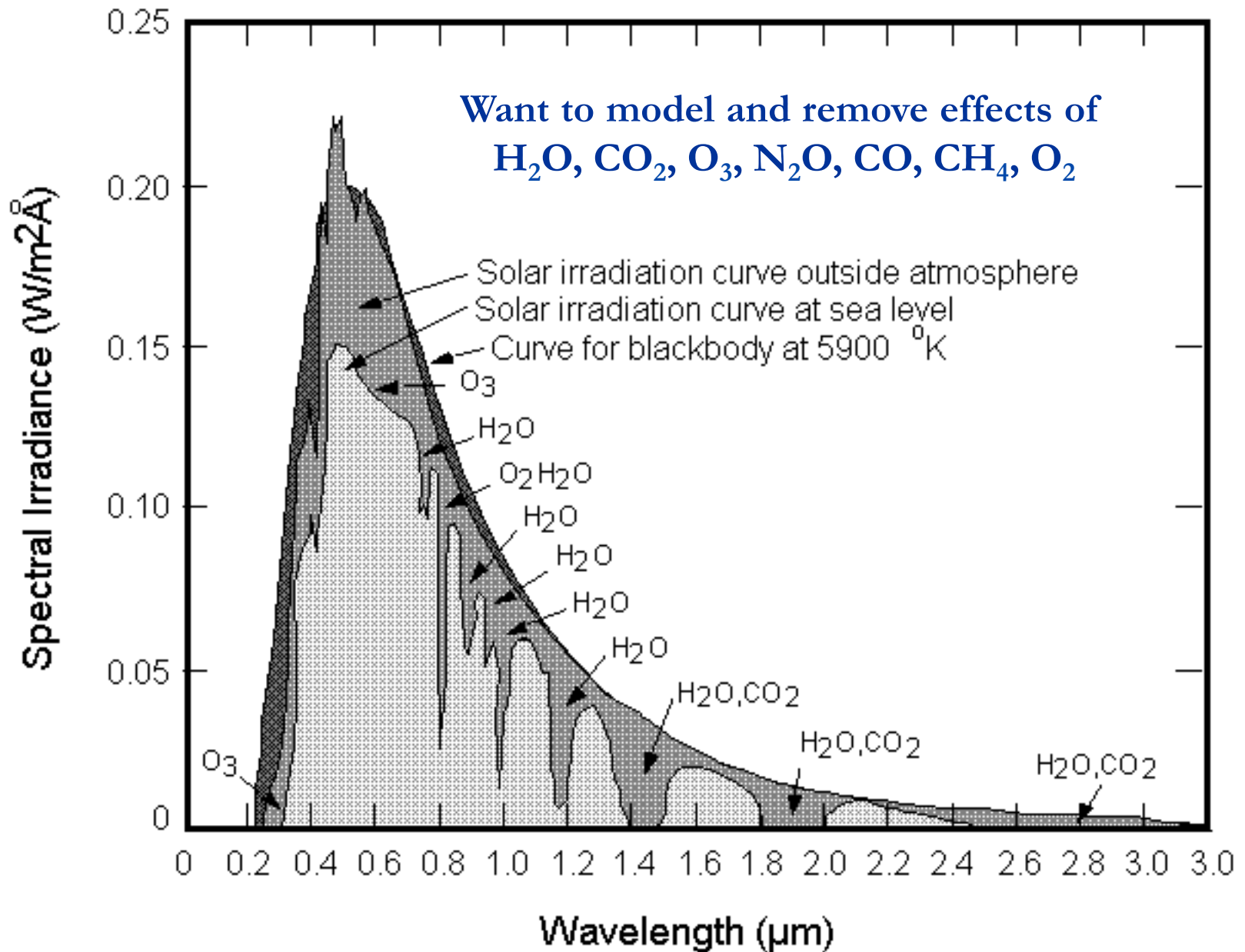


ATREM input



ATREM output

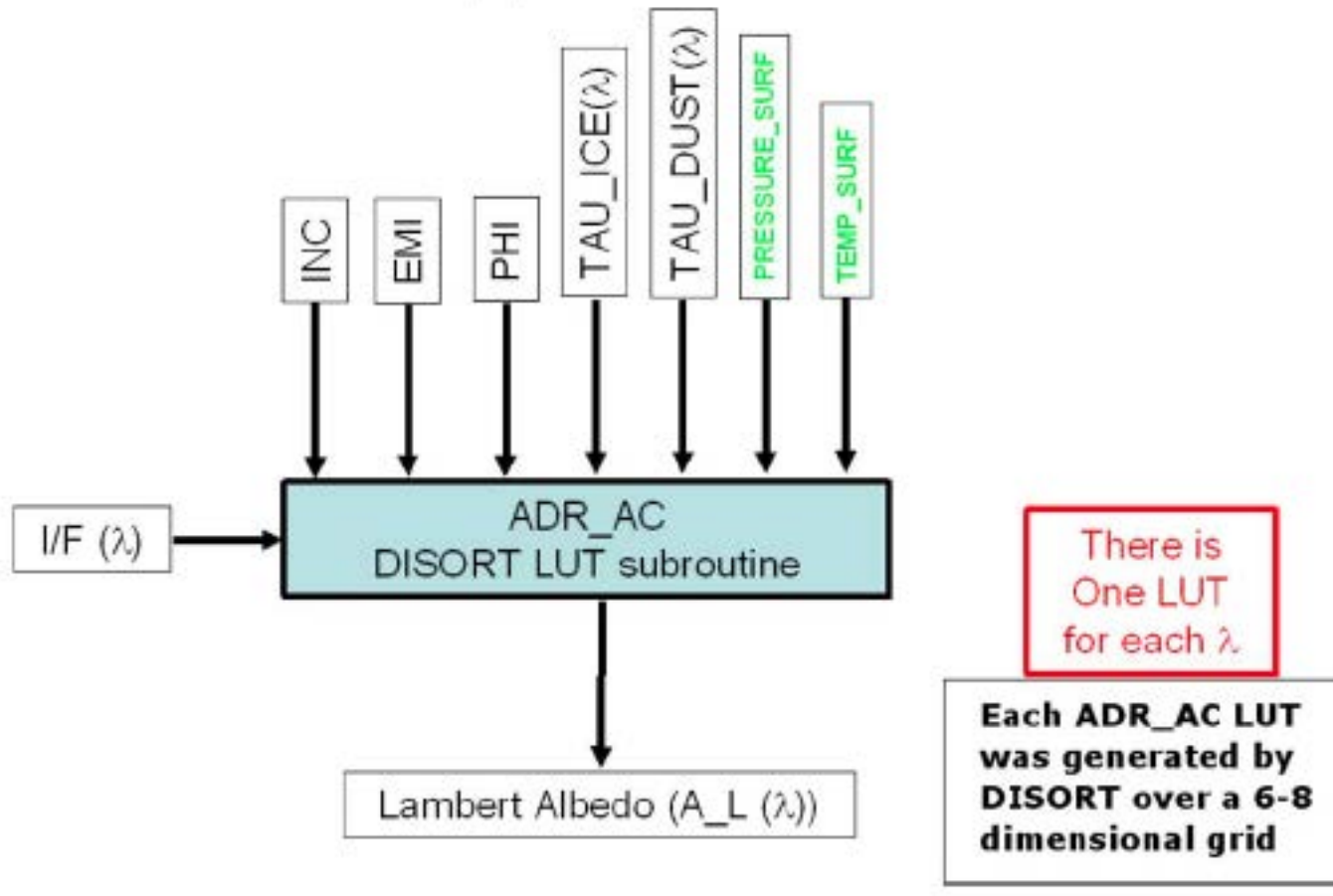
Want to model and remove effects of
 H_2O , CO_2 , O_3 , N_2O , CO , CH_4 , O_2



Solar Spectrum with Atmospheric Absorptions

DIScrete Ordinates Radiative Transfer (DISORT)

Detail of inputs/outputs to the
ADR_AC subroutine



Other types of atmospheric correction:

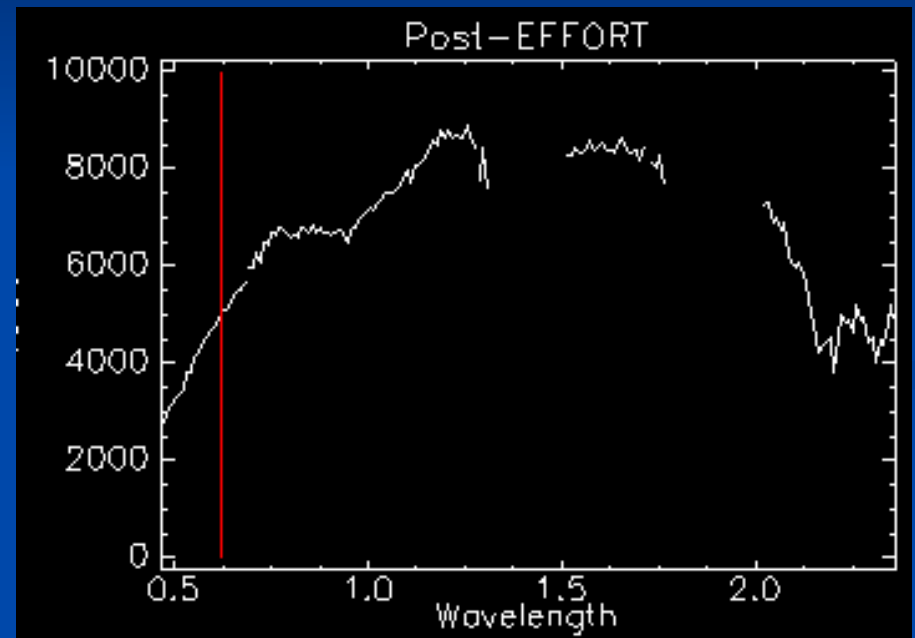
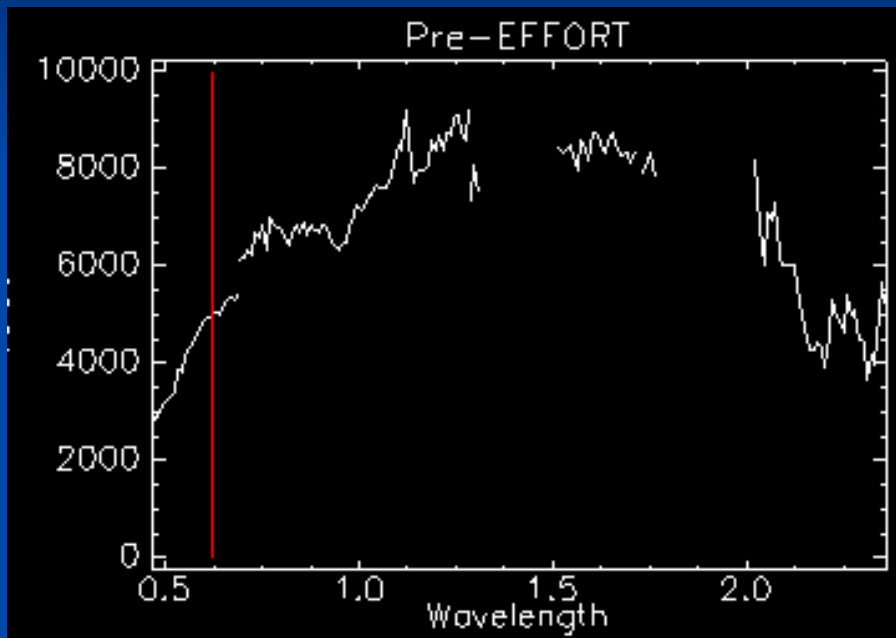
- IARR (Internal Average Relative Reflectance): Calculates the reflectance of every pixel in the scene relative to the average of all pixels in the scene averaged together.
 - Works best when there are a wide variety of mineralogies in scene, but not great with vegetation.
 - Useful when nothing is known about the scene – e.g., no ground truth spectra, and no model-based atmospheric correction available.
 - Will mute the spectral contrast of components present in a large fraction of the scene.

Other types of atmospheric correction:

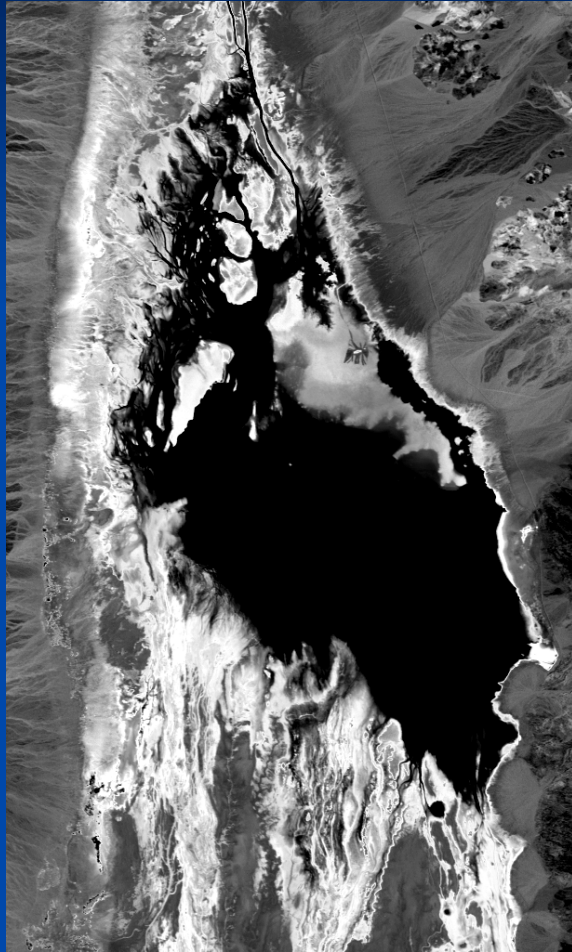
- Empirical Line Calibration
 - Employs spectra collected on the ground from known locations in the scene.
 - By comparing pre-correction remote spectrum to ground spectrum from same location, correction values are derived for each wavelength.
 - Works best when multiple locations used, especially if some have low overall reflectance and others have high overall reflectance.
 - Similar in some ways to *volcano scan* technique used on Mars (divide by “atmospheric spectrum” derived from comparing summit and flank of dusty Olympus Mons)

Spectral Polishing

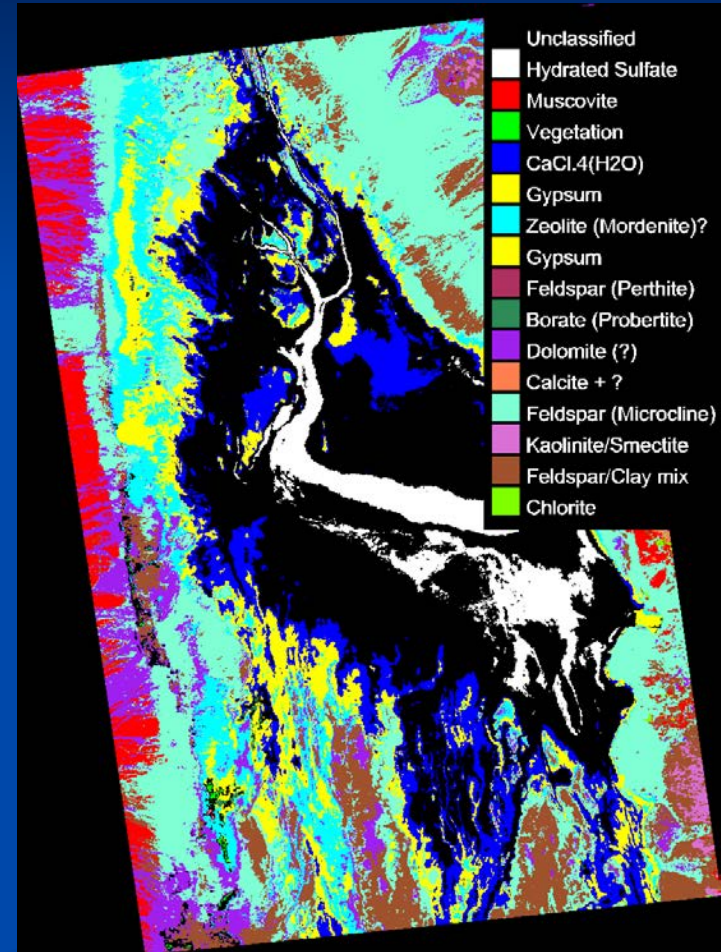
- Goal is to remove any residual atmospheric effects in the spectra
- EFFORT: Empirical Flat Field Optimized Reflectance Transformation:
 - A purely mathematical technique – no physics or geology used.
 - Takes advantage of fact that residual atmospheric effects are usually narrow spectral features, whereas mineralogic features are usually somewhat wider.
 - Fits n-degree polynomial model to spectra from all pixels. For each channel, calculate linear regression of correction factor between data and model. Average correction factors from all pixels



“Continuous” vs. “Discrete” Spectral Mapping

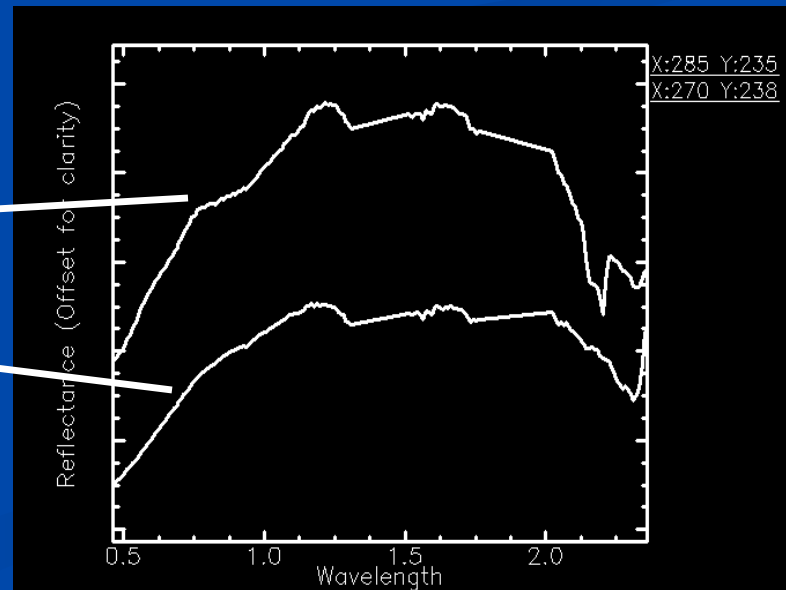
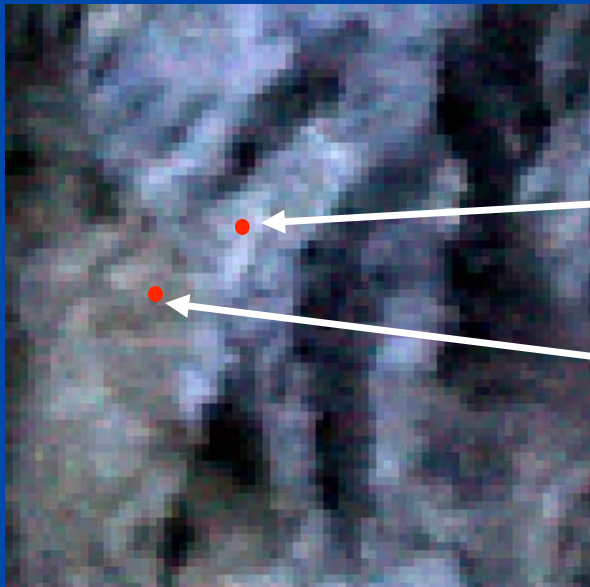
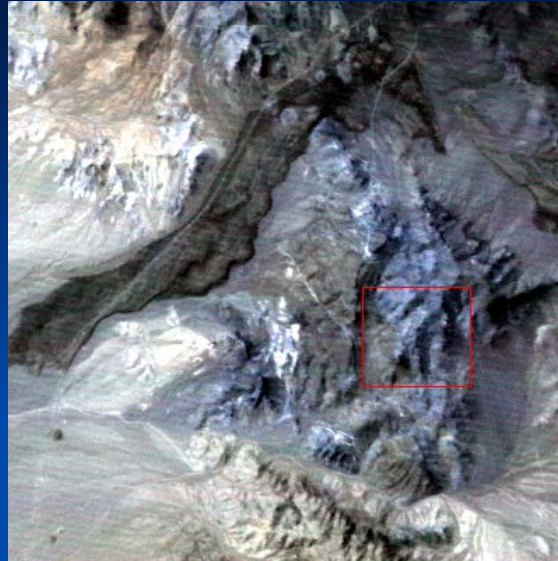


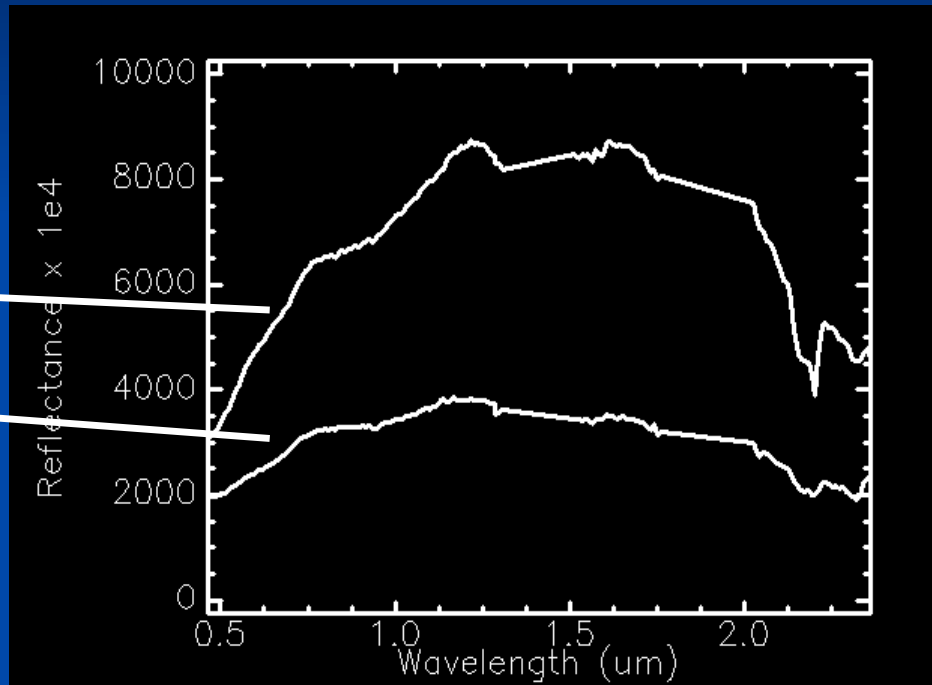
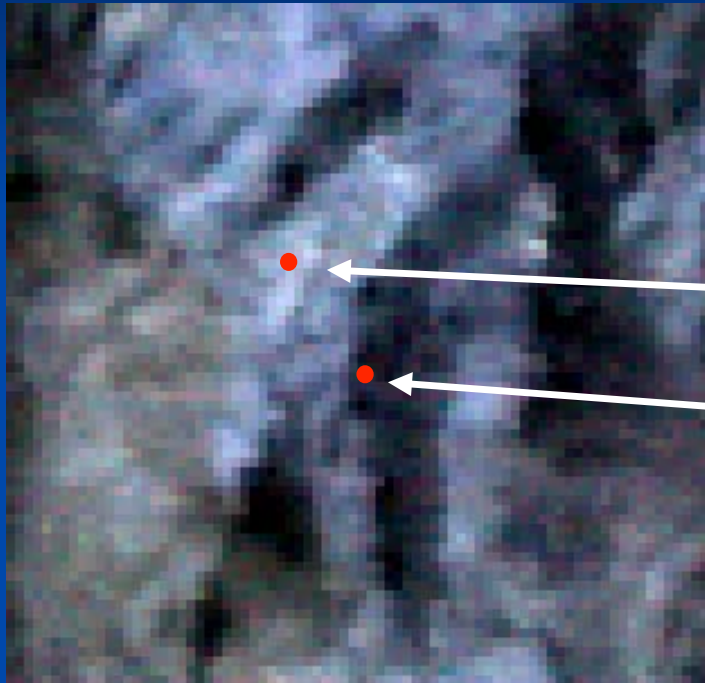
Map that highlights a particular composition

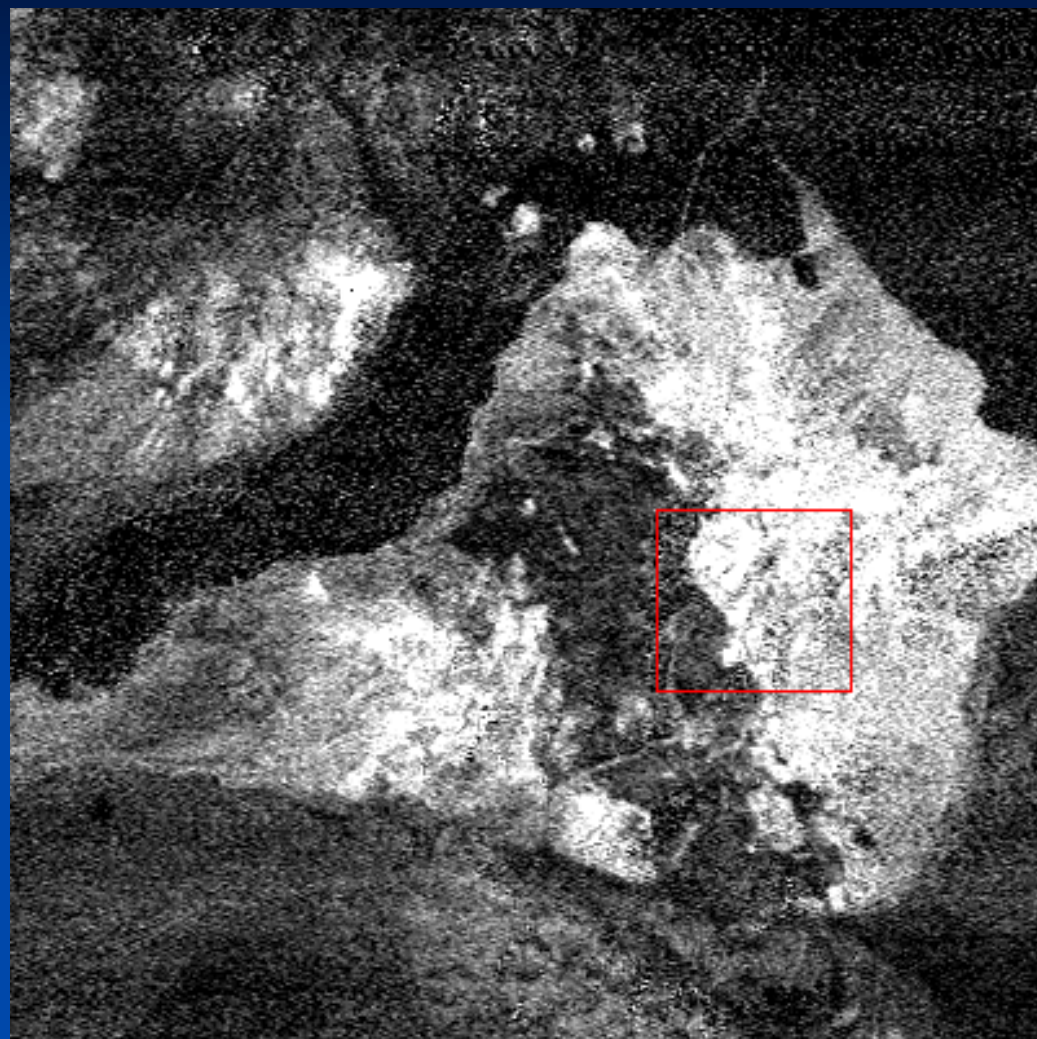


Map that attempts to classify every pixel in the scene

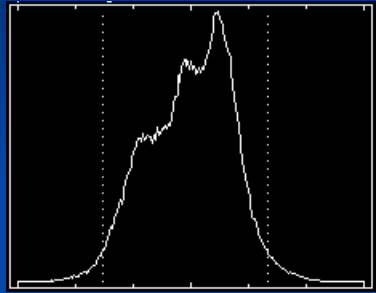
Band Ratios and Color



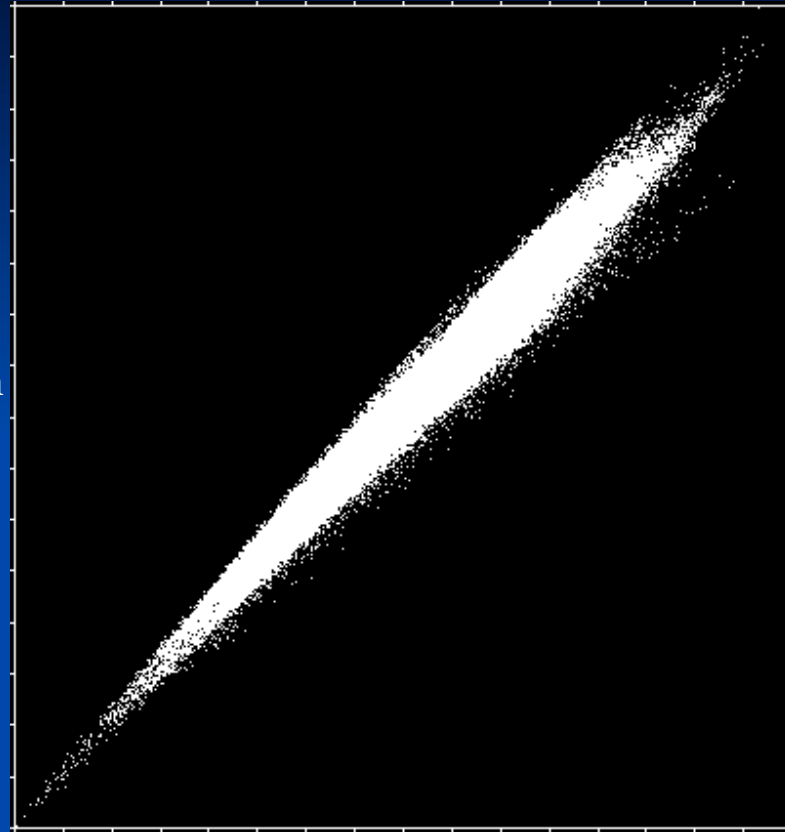




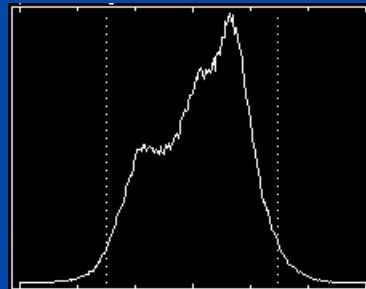
Band Ratio $2.10\mu\text{m} / 2.22\mu\text{m}$



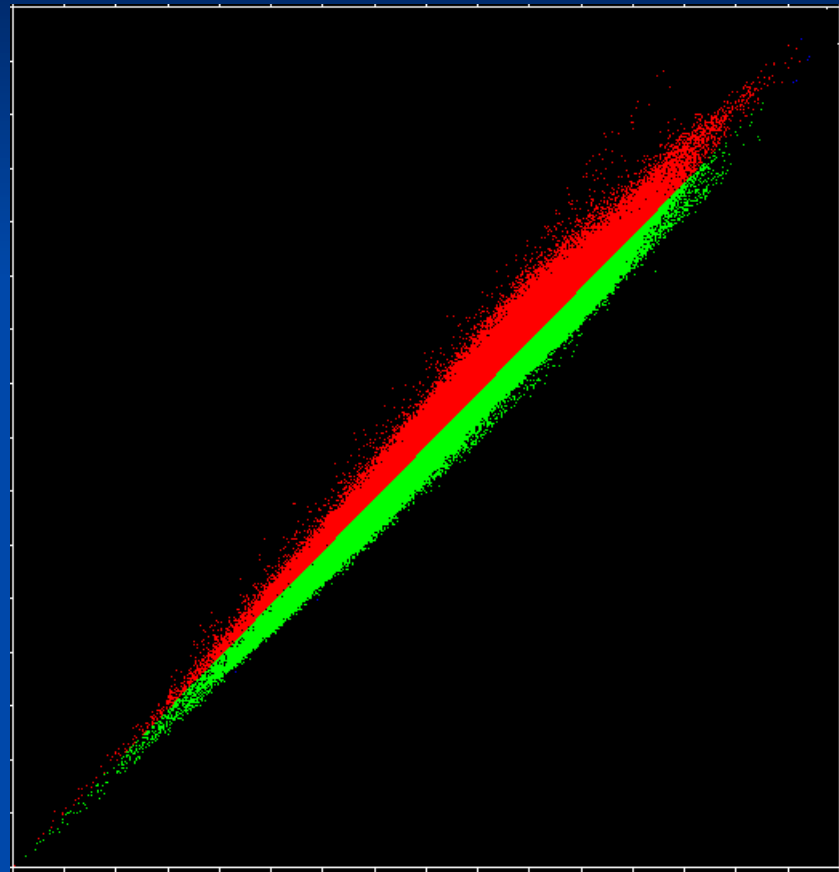
2.10 μm



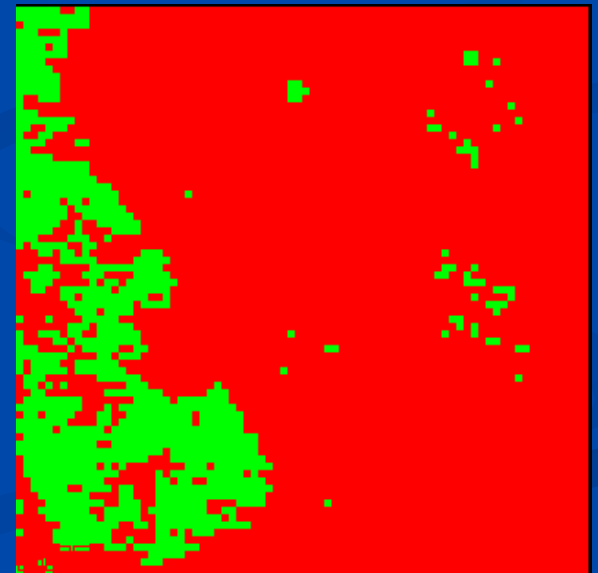
2.22 μm



2.10 μm



2.22 μm



Can go beyond simple band ratios to band depths...

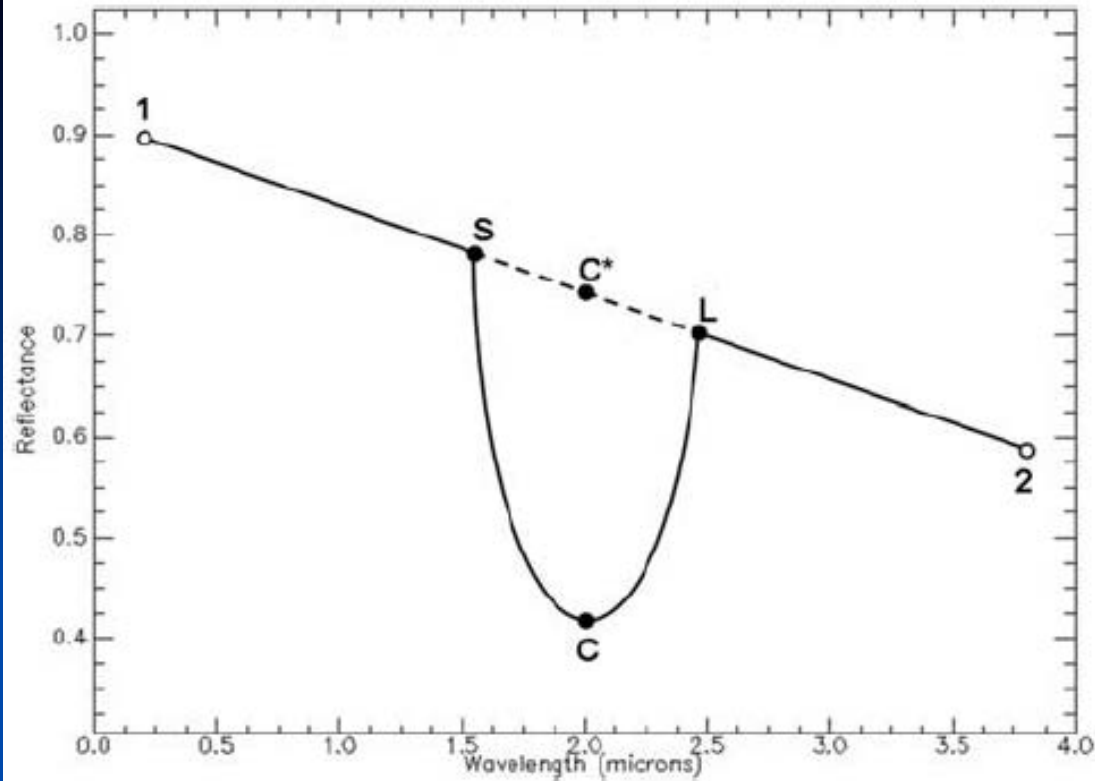


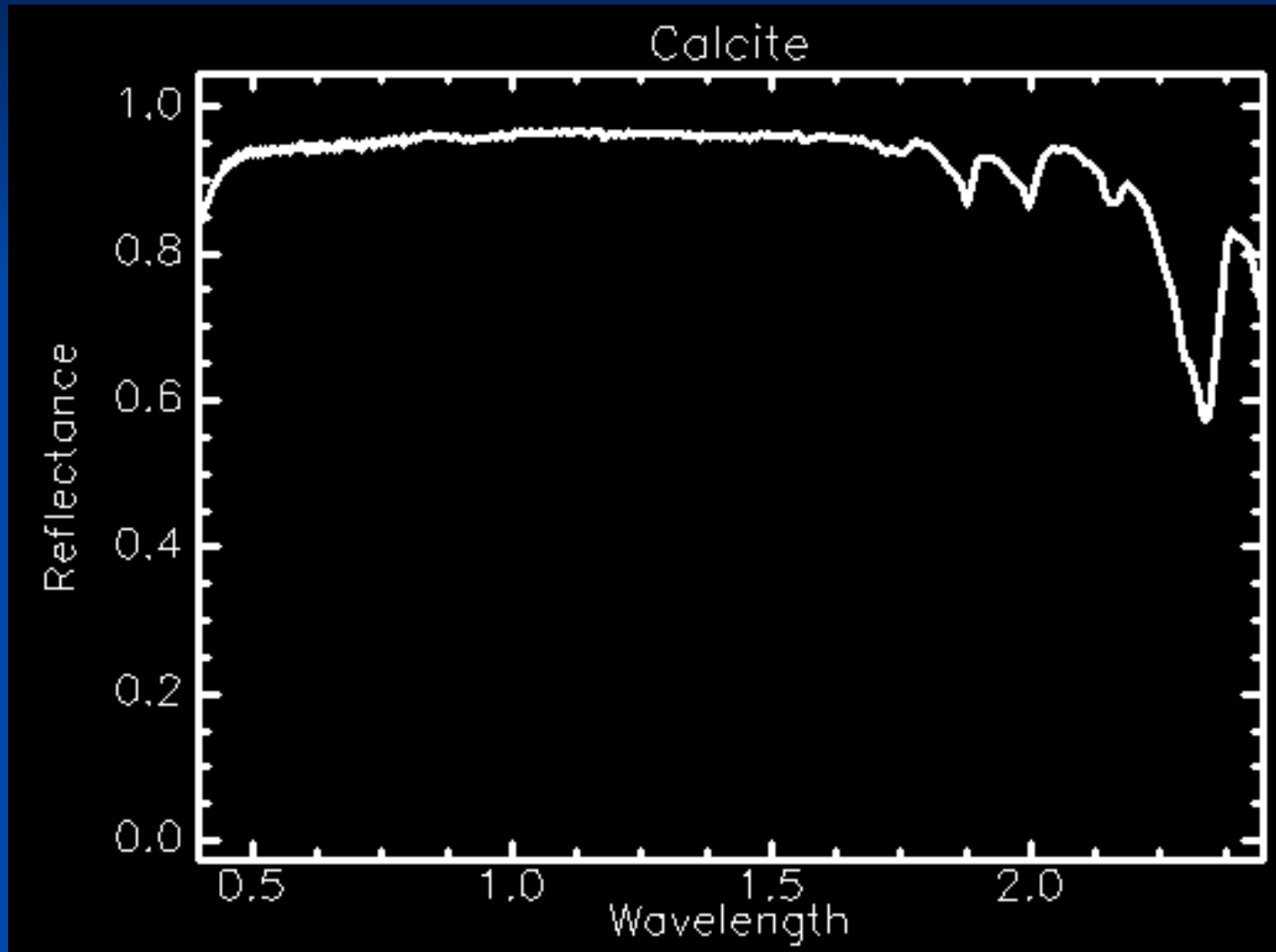
Figure 1. An explanation of some of the most common spectral parameters using an idealized spectrum. The solid line is an idealized spectrum with an absorption band superimposed on a sloped continuum. In the above example, the reflectance at the wavelength indicated by the point labeled 1 (i.e., at λ_1) is represented as R_1 . Spectral slope is found by $(R_1 - R_2)/(\lambda_1 - \lambda_2)$. Band depth is found by $1 - R_C/R_{C^*}$, where the point labeled C indicates the center of the absorption at λ_C , R_C is the reflectance at that wavelength, and R_{C^*} is derived from the continuum fit along the dashed line and is equal to $(a \cdot R_S + b \cdot R_L)$, where $a = 1 - b$ and $b = (\lambda_C - \lambda_S)/(\lambda_L - \lambda_S)$.

Table 1. CRISM Spectral Parameter Summary Products^a

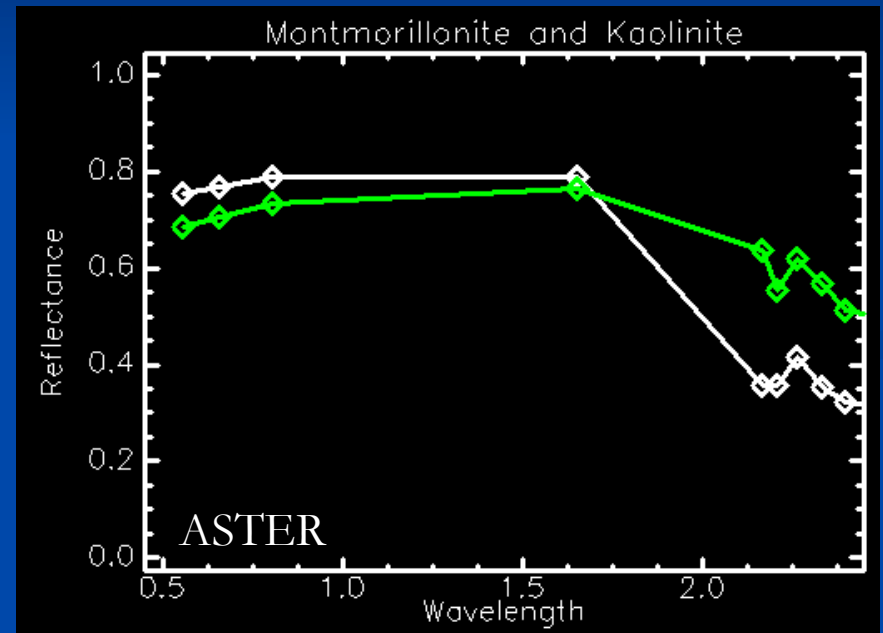
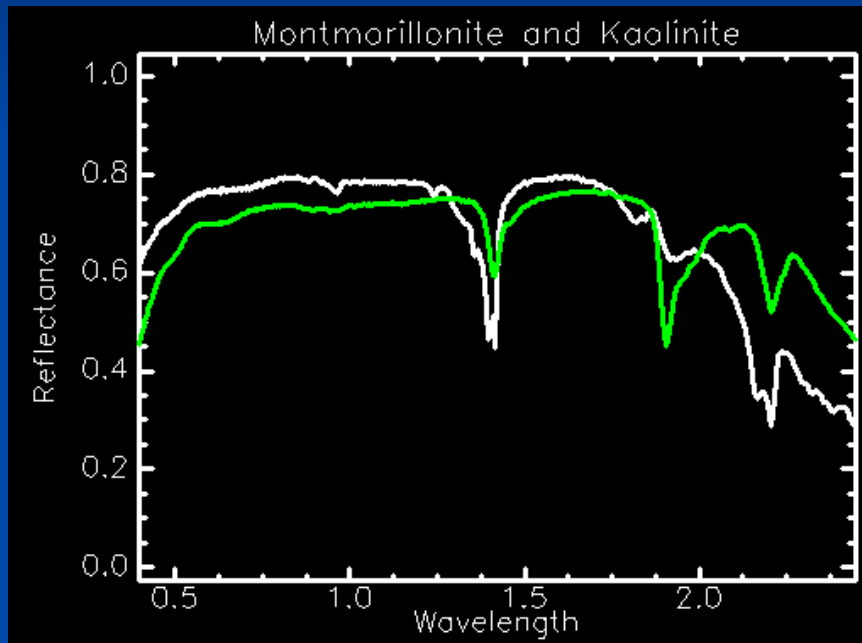
Name	Parameter	Formulation ^b	Rationale
<i>Surface Parameters^c</i>			
R770	0.77 μm reflectance	R770	rock/dust
RBR	red/blue ratio	R770/R440	rock/dust
BD530	0.53 μm band depth	$1 - (R530/(a*R648 + b*R440))$	crystalline ferric minerals
SH600	0.60 μm shoulder height	$R600/(a*R530 + b*R680)$	select ferric minerals
BD640	0.64 μm band depth	$1 - (R648/(a*R600 + b*R680))$	select ferric minerals
BD860	0.86 μm band depth	$1 - (R860/(a*R800 + b*R920))$	select ferric minerals
RPEAK1	reflectance peak 1	wavelength where 1st derivative = 0 of 5th order polynomial fit to R600, R648, R680, R710, R740, R770, R800, R830	Fe mineralogy
BDI1000VIS	1 μm integrated band depth; VIS wavelengths	divide R830, R860, R890, R920 by RPEAK1 then integrate over (1 - normalized reflectances)	Fe mineralogy
BDI1000IR	1 μm integrated band depth; IR wavelengths	divide R950, R980, R1020, R1050, R1080, R1150 by linear fit from peak R between 1.3-1.87 μm to R2530 extrapolated backward to remove continuum, then integrate over (1 - continuum-corrected reflectances)	Fe mineralogy
IRA	1.3 μm reflectance	R1330	IR albedo
OLINDEX	Olivine index	$(R1695/(0.1*R1050 + 0.1*R1210 + 0.4*R1330 + 0.4*R1470)) - 1$	olivine will be strongly positive; based on fayalite
LCPINDEX	pyroxene index	$((R1330-R1050)/(R1330 + R1050)) * ((R1330-R1815)/(R1330 + R1815))$	pyroxene will be strongly positive; favors LCP
HCPINDEX	pyroxene index	$((R1470-R1050)/(R1470 + R1050)) * ((R1470-R2067)/(R1470 + R2067))$	pyroxene will be strongly positive; favors HCP
VAR	spectral variance	variance of observed data from a line fit from 1.0-2.3 μm	olivine and pyroxene will have high values
ISLOPE1	-1 * spectral slope1	$(R1815-R2530)/(2530-1815)$	ferric coating on dark rock
BD1435	1.435 μm band depth	$1 - (R1430/(a*R1370 + b*R1470))$	CO ₂ ice
BD1500	1.5 μm band depth	$1 - (R1510/(a*R1330 + b*R1695))$	H ₂ O ice
ICER1	1.5 μm and 1.43 μm band ratio	R1510/R1430	CO ₂ , H ₂ O ice mixtures
BD1750	1.75 μm band depth	$1 - (R1750/(a*R1660 + b*R1815))$	gypsum
BD1900	1.9 μm band depth	$1 - (((R1930 + R1985)*0.5)/(a*R1857 + b*R2067))$	H ₂ O
BDI2000	2 μm integrated band depth	divide R1660, R1815, R2140, R2210, R2250, R2290, R2330, R2350, R2390, R2430, R2460 by linear fit from peak R between 1.3-1.87 μm to R2530, to remove continuum, then integrate over (1 - continuum-corrected reflectances)	Fe mineralogy
BD2100	2.1 μm band depth	$1 - (((R2120 + R2140)*0.5)/(a*R1930 + b*R2250))$	Monohydrated minerals
BD2210	2.21 μm band depth	$1 - (R2210/(a*R2140 + b*R2250))$	Al-OH minerals
BD2290	2.29 μm band depth	$1 - (R2290/(a*R2250 + b*R2350))$	Mg,Fe-OH minerals (@ 2.3); ALSO CO ₂ ice (@ 2.292)
D2300	2.3 μm drop	$1 - ((CR2290 + CR2320 + CR2330)/(CR2140 + CR2170 + CR2210))$ (CR values are observed R values divided by values fit along the slope as determined between 1.8-2.53 μm (essentially continuum corrected))	hydrated min; particularly phyllosilicates
D2400	2.4 μm drop	$1 - ((CR2390 + CR2430)/(CR2290 + CR2320))$ (CR values are observed R values divided by values fit along the slope as determined between 1.8-2.53 μm (essentially continuum corrected))	hydrated min; particularly sulfates
ICER2	gauge 2.7 μm band	R2530/R2600	CO ₂ ice will be $\gg 1$; H ₂ O ice and soil will be ~ 1
BDCARB	2.33 & 2.53 μm band depth	$1 - (\text{sqrt} [(R2330/(a*R2230 + b*R2390)) * (R2530/(c*R2390 + d*R2600))])$	carbonate overtones
BD3000	3 μm band depth	$1 - (R3000/(R2530*(R2530/R2210)))$	H ₂ O
BD3100	3.1 μm band depth	$1 - (R3120/(a*R3000 + b*R3250))$	H ₂ O ice
BD3200	3.2 μm band depth	$1 - (R3320/(a*R3250 + b*R3390))$	CO ₂ ice
BD3400	3.4 μm band depth	$1 - ((a*R3390 + b*R3500)/(c*R3250 + d*R3630))$	carbonates; organics
CINDEX	gauge 3.9 μm band	$(R3750 + (R3750-R3630)/(3750-3630)) * (3950-3750)/R3950 - 1$	carbonates

...or even more complex
band math

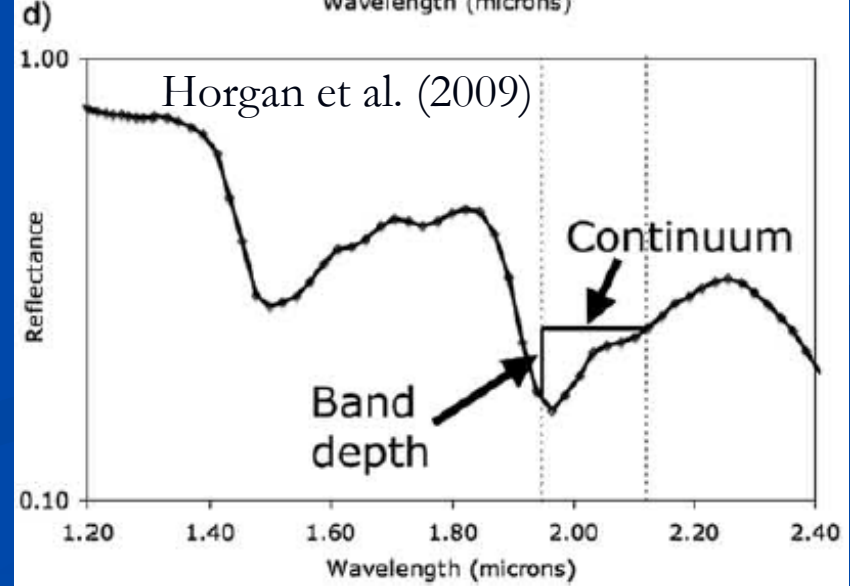
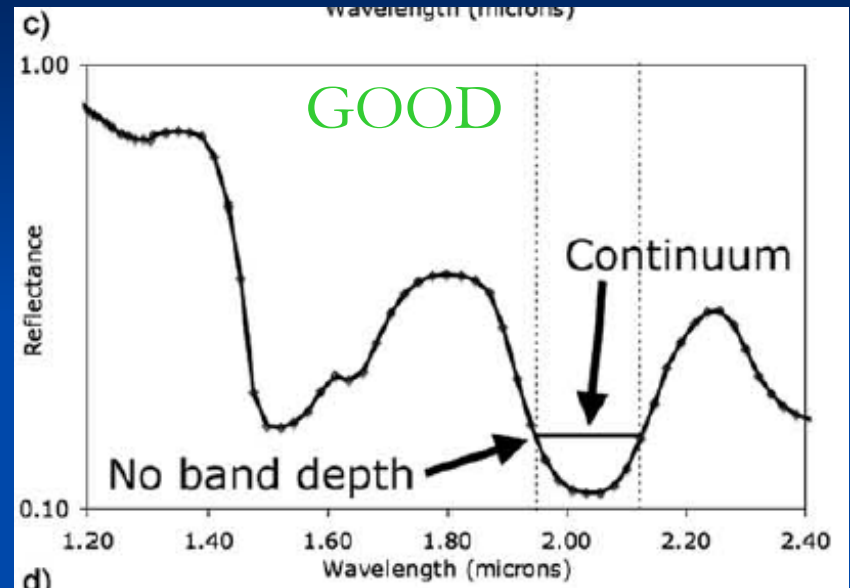
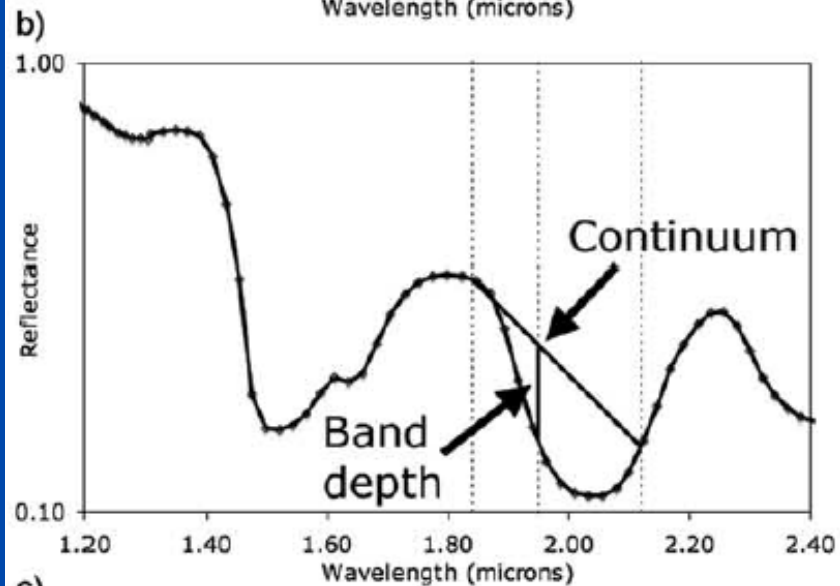
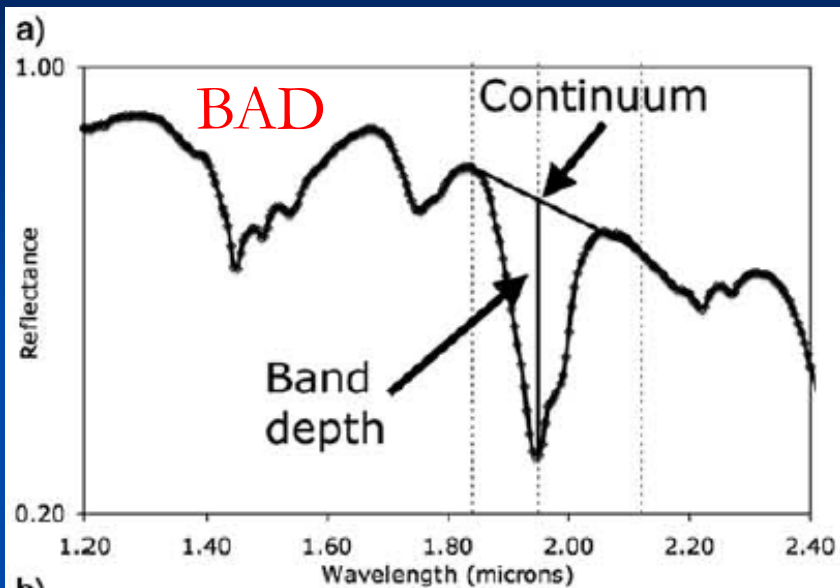
Which bands would you ratio?



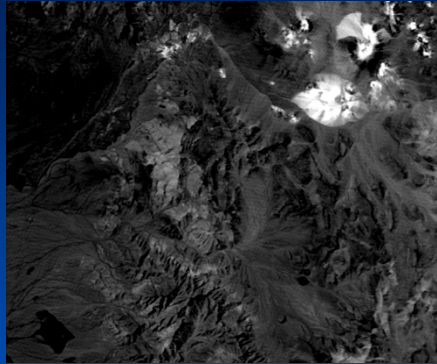
Which bands would you ratio?



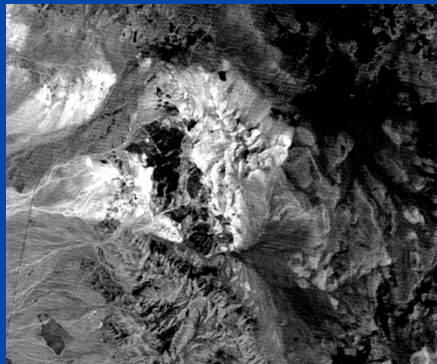
Distinguishing H₂O ice from hydrous minerals



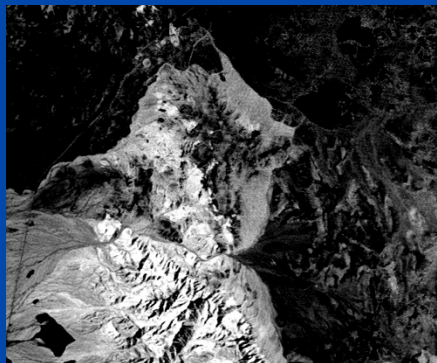
Color Composites from Continuous Images



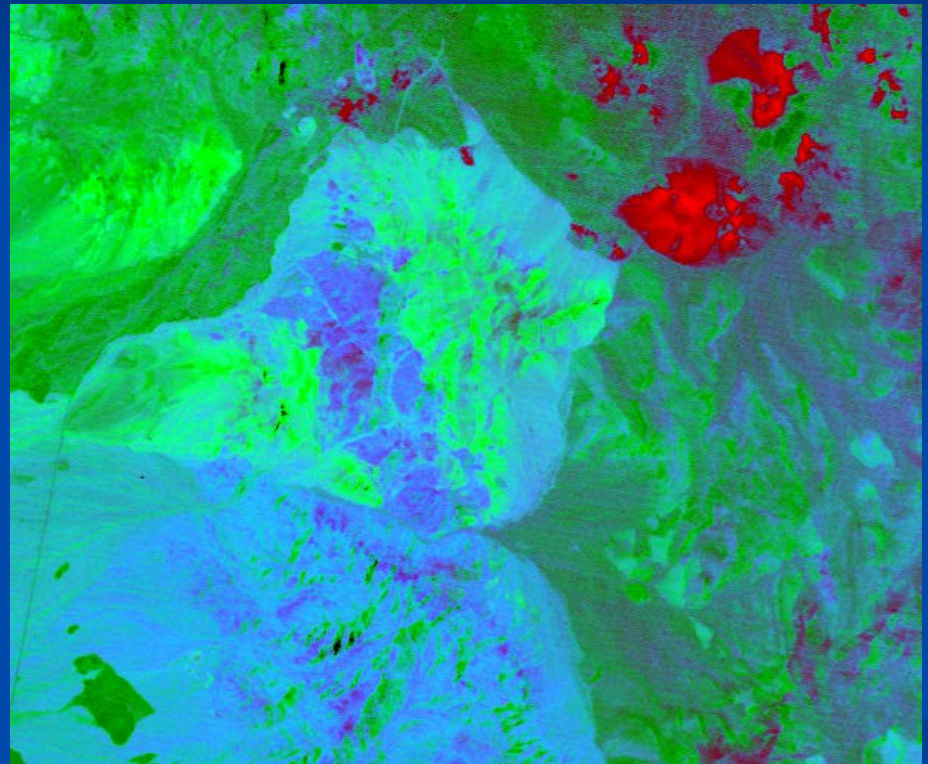
Hematite



Kaolinite



Dolomite



Only three compositions can be displayed at once (R,G,B)