CRISM-derived mineral abundances at the MSL landing sites

Hapke modeling with DISORT- and volcano scan-corrected data cubes

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5th MSL landing site workshop

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Washington University in St. Louis

IAS orsay

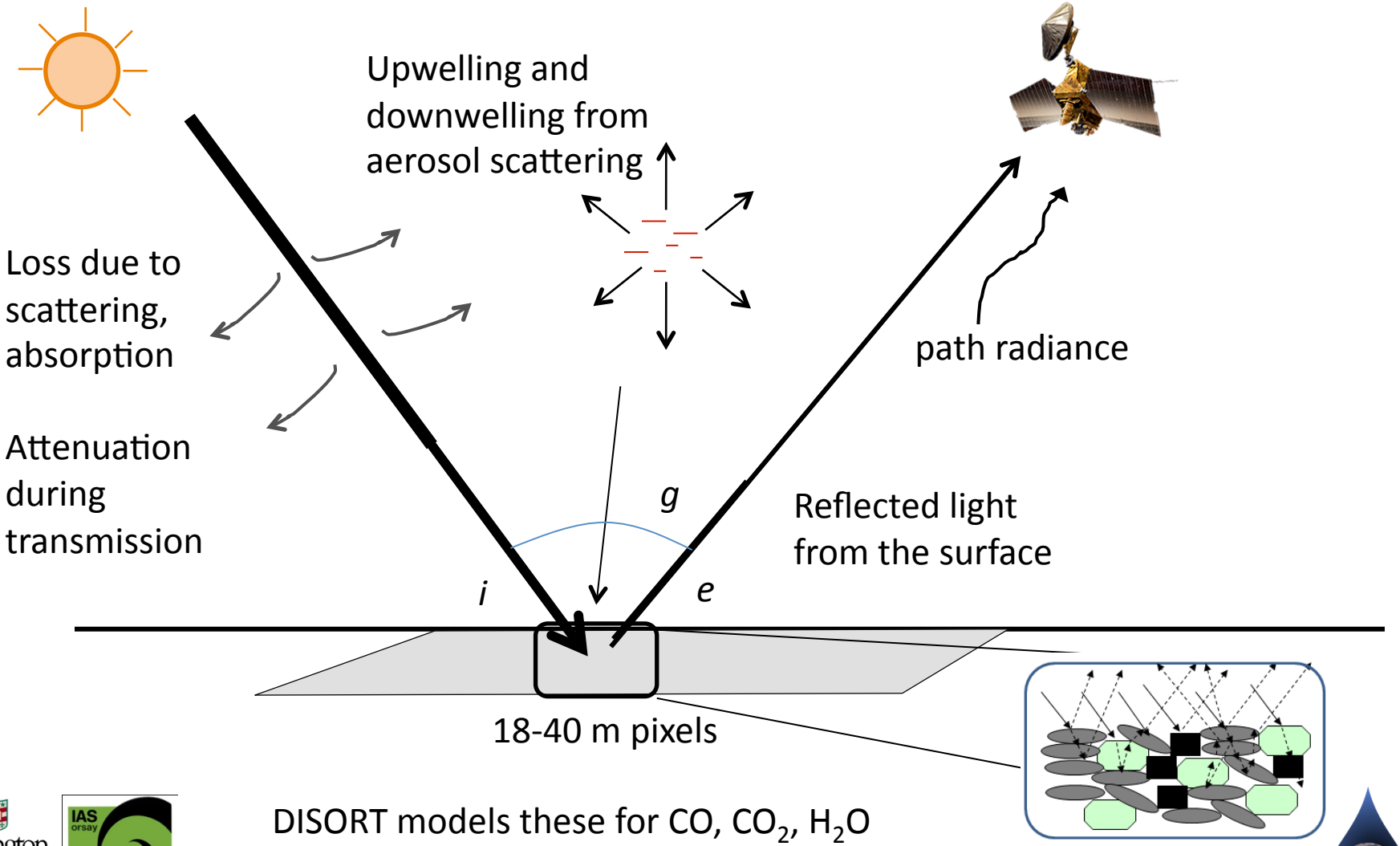
CRISM

Motivation

- Provide **quantitative mineralogic data** for candidate sites
  - Emphasize **clay-bearing materials** (signs of habitability, potential repositories of organic matter)
  - Estimate/predict **mineral endmembers, abundance, grain size**
- We utilize **Hapke theory** to model multiple scattering at near-infrared wavelengths (***Shkuratov theory, Poulet presentation***)
- Demonstrate result dependencies (or not) due to **atmospheric effects** and **data reduction methods**
  - For both **quantitative modal mineralogy** and **qualitative indicators like band depth**
- We test
  - **Inter-observation variability**
  - **Effects of assumed phase behavior**
  - **DISORT radiative transfer vs. empirical volcano scan atmospheric correction**

Physical processes (atmospheric)

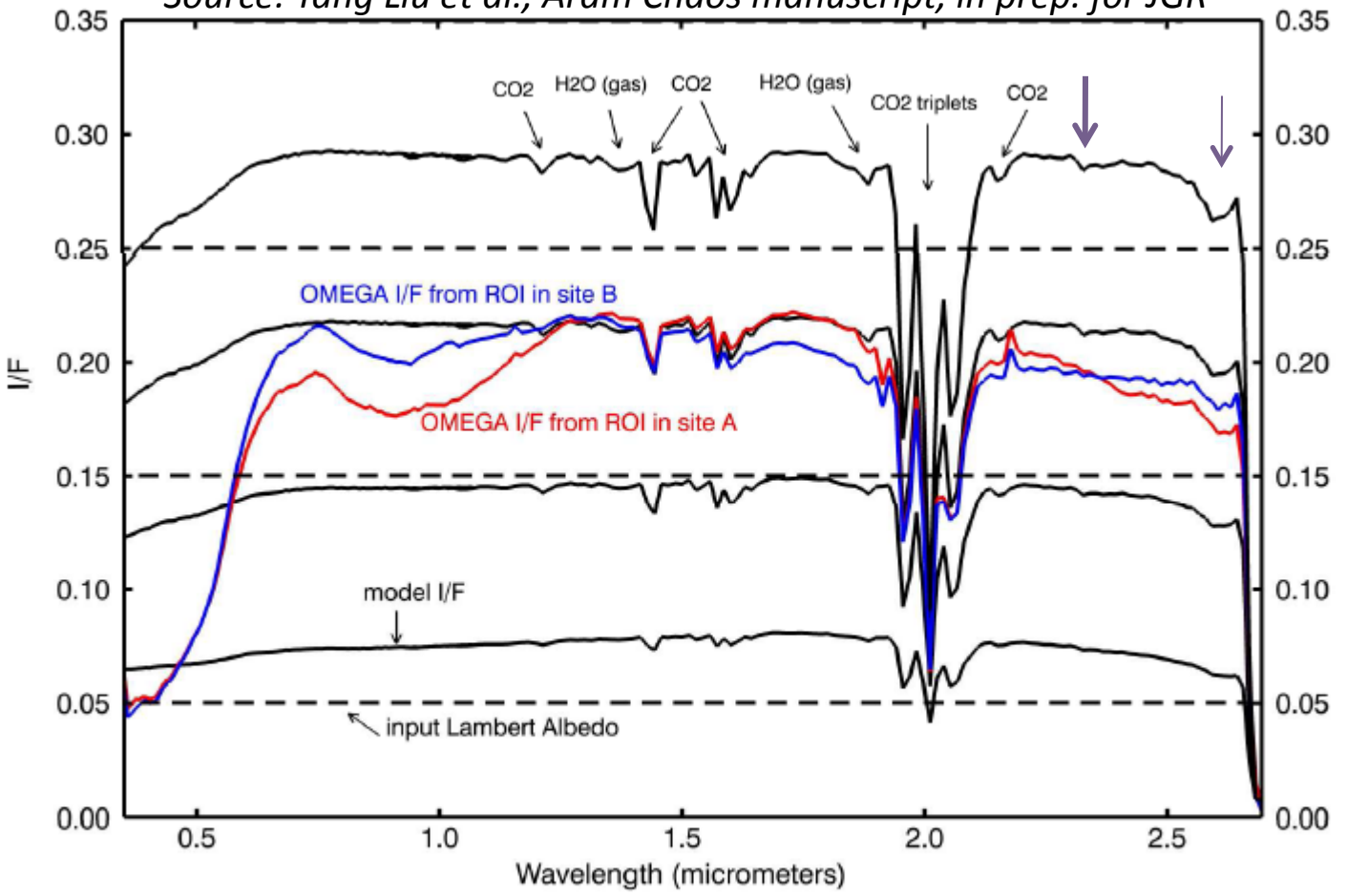
- Atmospheric absorption → absorption features, contrastreduction
- Scattering due to aerosols (dust ice opacity)→ changes spectral shape, contrast reduction



DISORT models these for CO, CO_2, H_2O

DISORT Modeling Atmospheric Effects on Input Flat Spectra

Source: Yang Liu et al., Aram Chaos manuscript, in prep. for JGR

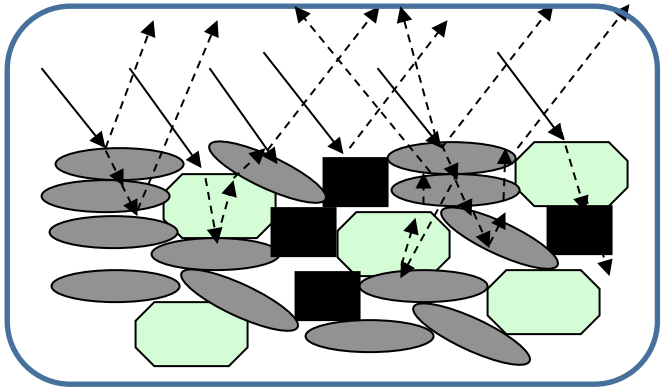


decrease due to loss during transmission (~multipli-cative)

brightening from path radiance (~additive)

Physical processes (surface)

Photometric effects, multiple-scattering, grain size and composition affect scattering in VNIR spectra→ Non-linear problem



Assume Gusev-like scattering behavior (Johnson et al., 2006)

For a given incidence(i), emission (e), and phase (g) angle (neglecting the opposition effect and coherent backscatter)

$$r(\mu_0,\mu,g)=\frac{w}{4\pi}\frac{\mu_0}{\mu_0+\mu}[P(g)+H(\mu)H(\mu_0)-1]$$

$$\mu_0=\cos(i),\mu=\cos(e)$$

Key parameter: single scattering albedo

$$H(x)=\left[1-wx\left(r_0+\frac{1-2r_0x}{2}\ln\frac{1+x}{x}\right)\right]^{-1}$$

$$r_0=\frac{1-\sqrt{1-w}}{1+\sqrt{1-w}}$$

Hapke Modeling for a Particulate Medium

Optical constants (from lab data for each endmember)

$$w_{mix} = \sum_{i=1}^{n} \frac{v_i}{D_i} w_i$$

$$w = S_e + (1 - S_e)\frac{(1 - S_i)}{(1 - S_i\Theta)}\Theta$$

(modeled for each endmember) **volumetric abundance**

(modeled for each endmember) **particle diameter**

$$S_e = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} + 0.05$$

reflected, externally incident light

$$S_i = 1.014 - \frac{4}{n(n+1)^2}$$

reflected, internally incident light; adjusted leading coefficient to 1.014 from 1.0 on the basis of empirical data (Lucey, 1998)

$$\Theta = \frac{r_i + \exp\left(-\sqrt{\alpha(\alpha+s)}\langle D\rangle\right)}{1 + r_i \exp\left(-\sqrt{\alpha(\alpha+s)}\langle D\rangle\right)}$$

particle internal transmission coefficient

$$\langle D\rangle = 0.9D$$

average distance of ray path, assuming spherical particles of diameter, D

$$r_i = \frac{1 - \sqrt{\alpha/(\alpha+s)}}{1 + \sqrt{\alpha/(\alpha+s)}}$$

internal, diffusive reflectance inside particle

$$\alpha = 4\pi k / \lambda$$

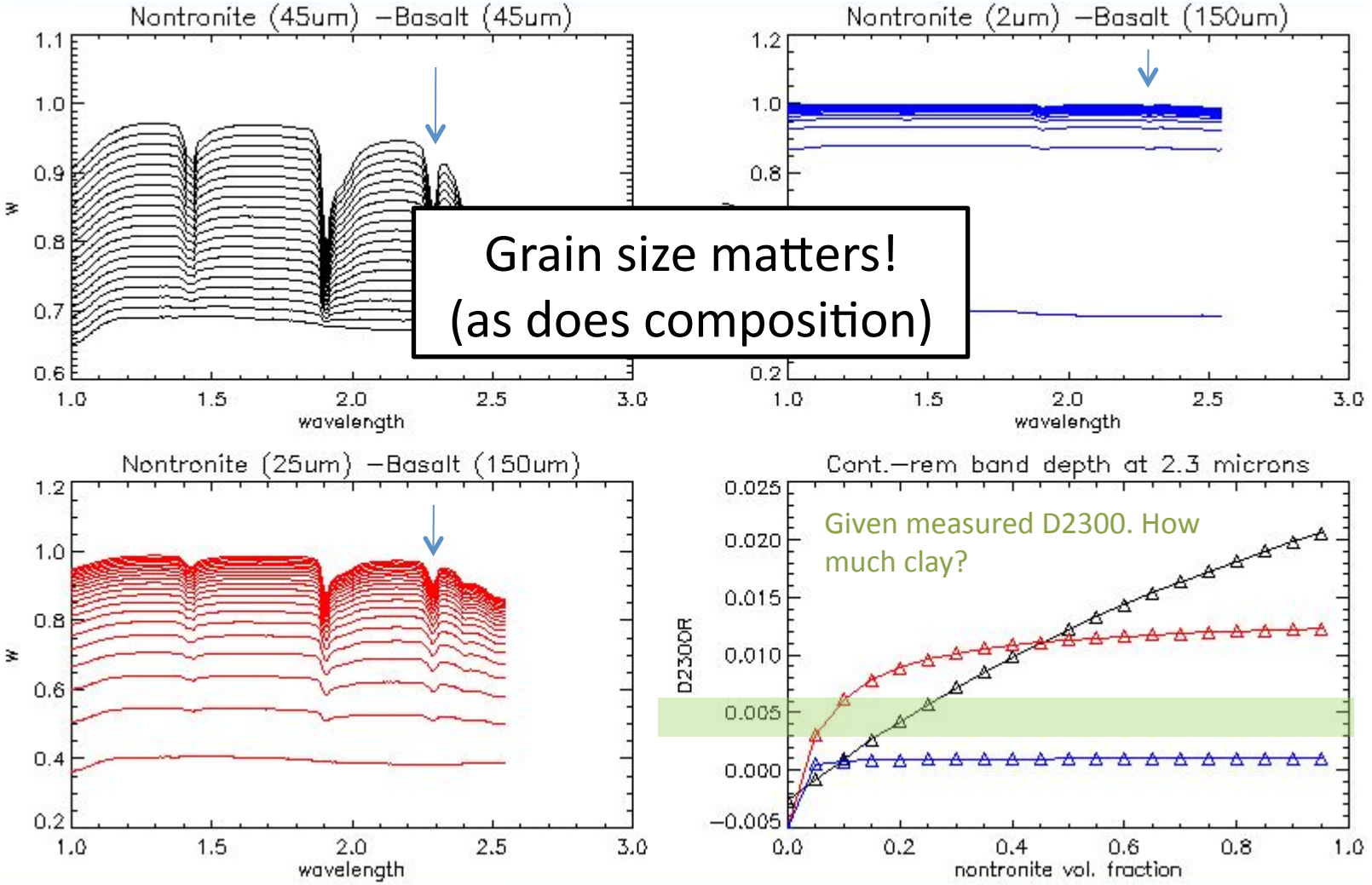
coefficient for internal attenuation by absorption (by e^{-1} after 1/a distance)

assumed **coeff. internal scattering** s

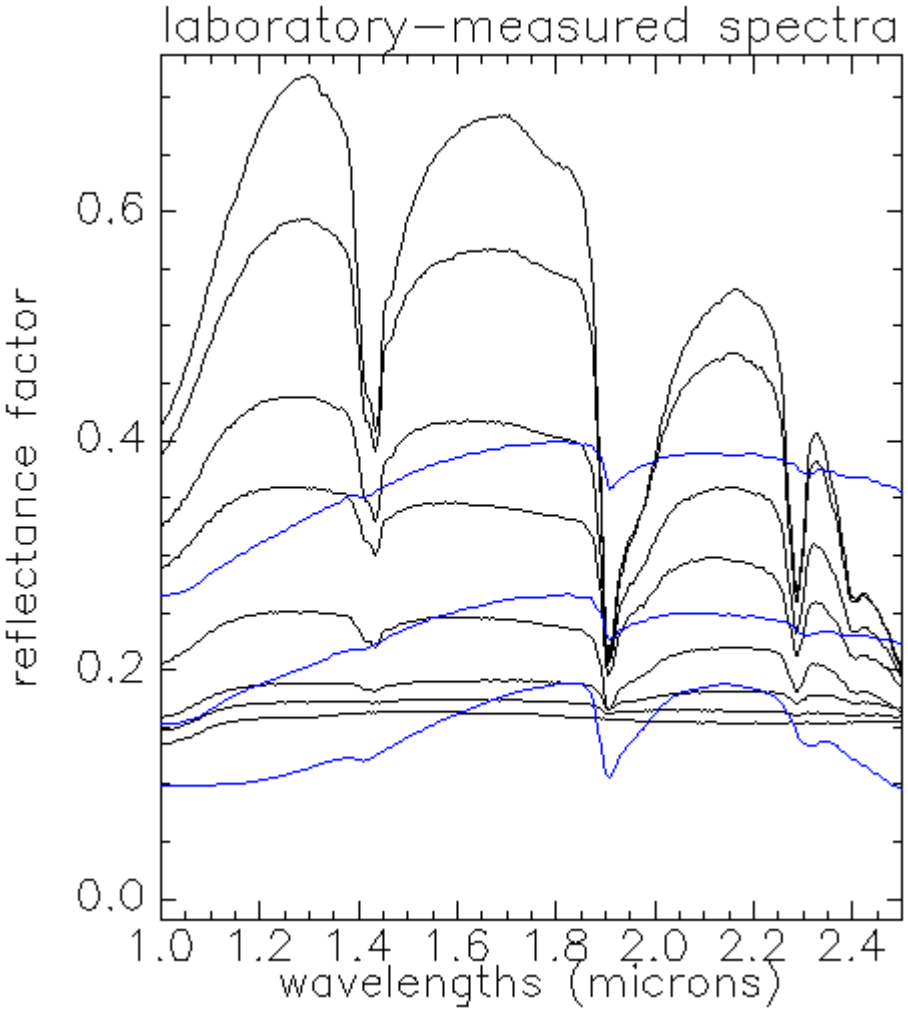
coefficient for internal attenuation by scattering (by e^{-1} after 1/a distance)

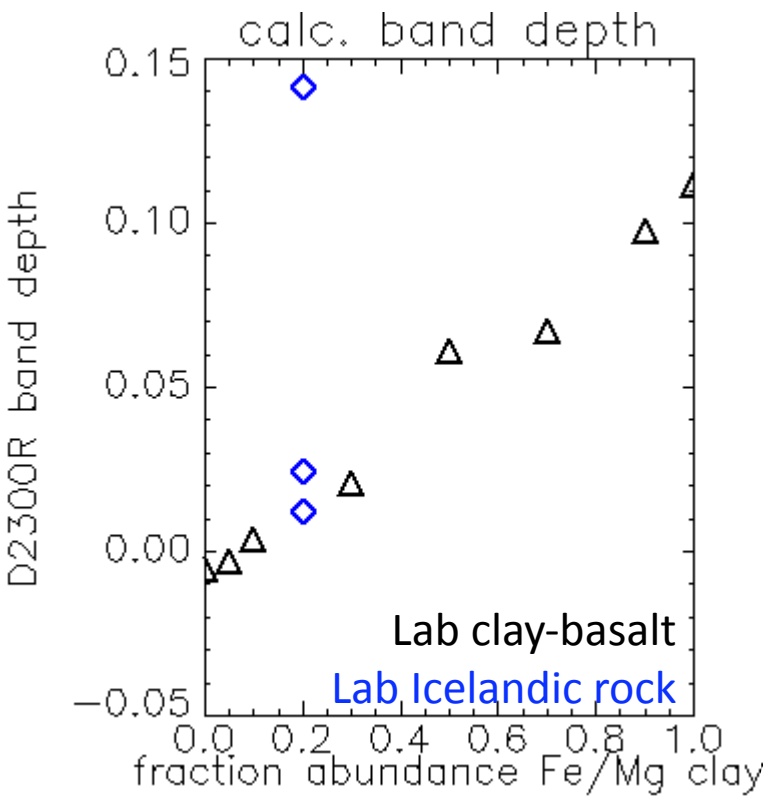
Found to b 0.06um for ground silicate glass (Hapke & Wells, 1981) but **Lucey (1998) found that 0 better fit data from particulate mineral samples**

Why go through all this? Can't we just look at D2300 for Fe/ Mg clay abundance? (No. Example)



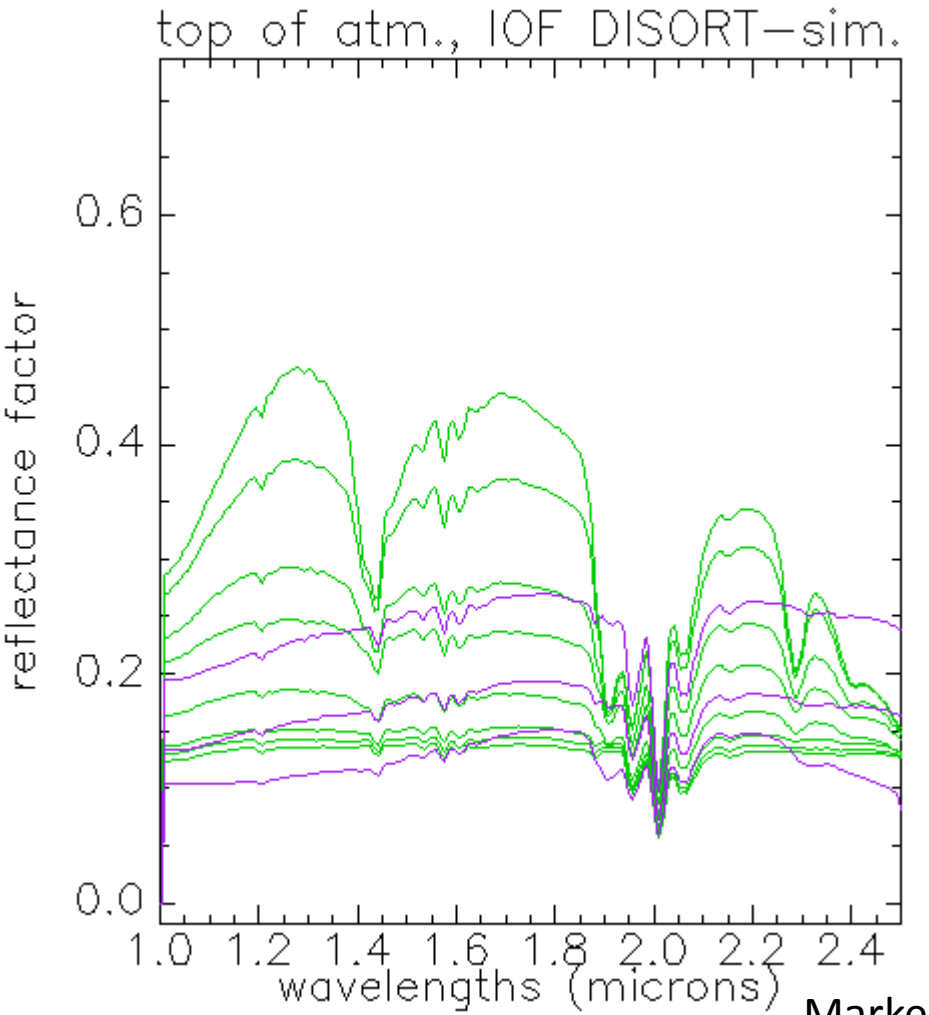
Even if know particle size and endmembers, can't go directly from lab to Mars band depth

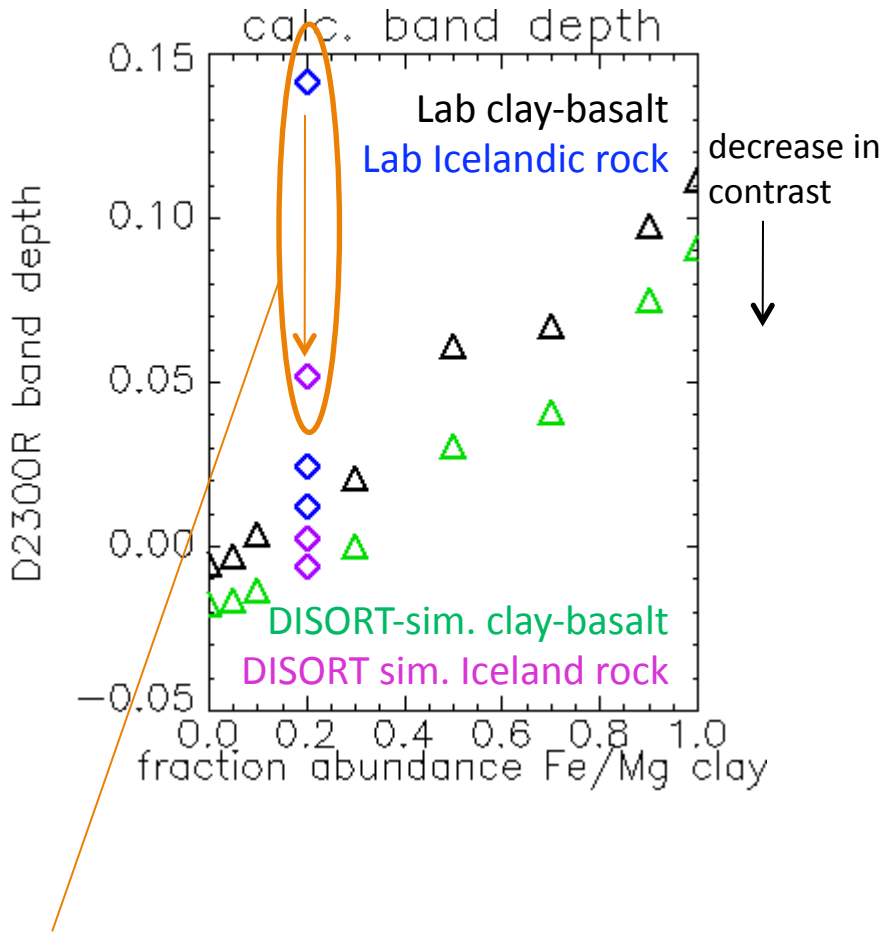




Natural sample
28% augite, 49% plagioclase,
3% ilmenite, 20% smectite
<25µm, <150µm, rock

IOF, top of atmosphere, DISORT forward modeling

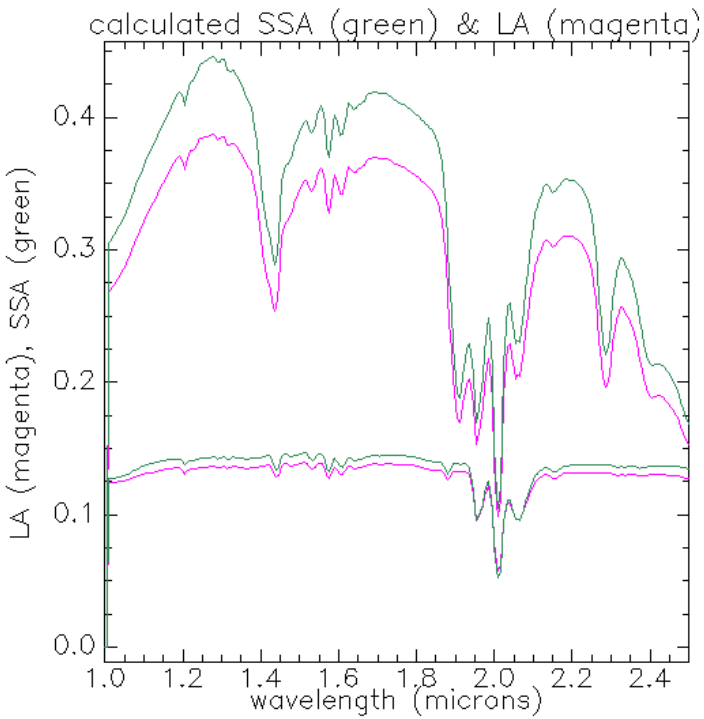


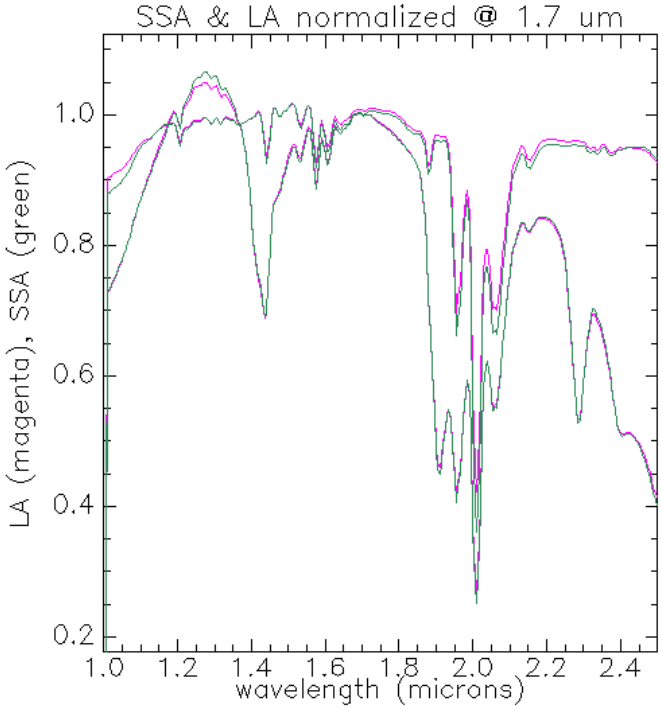


Marked decrease in band depth for dark surfaces

Effects of phase function?

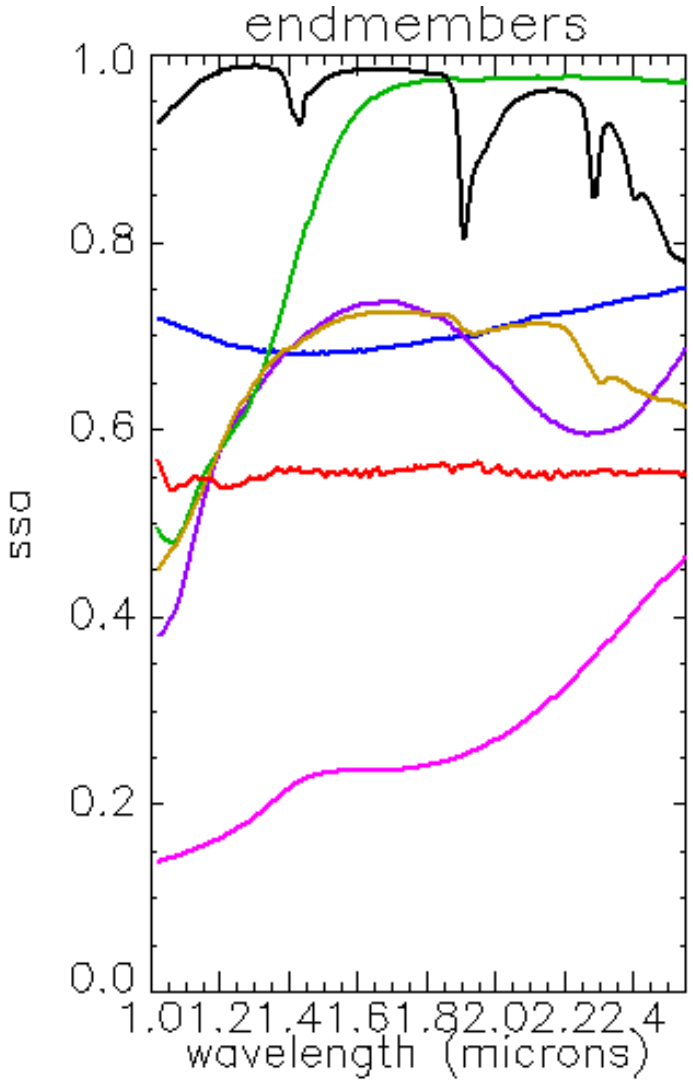
- Slight albedo, shape differences -- but not very important
- Can usually approximate surface as a Lambert Albedo (equal probability of scattering in all directions)
  - Surface is weakly backscattering (Johnson et al., 2006



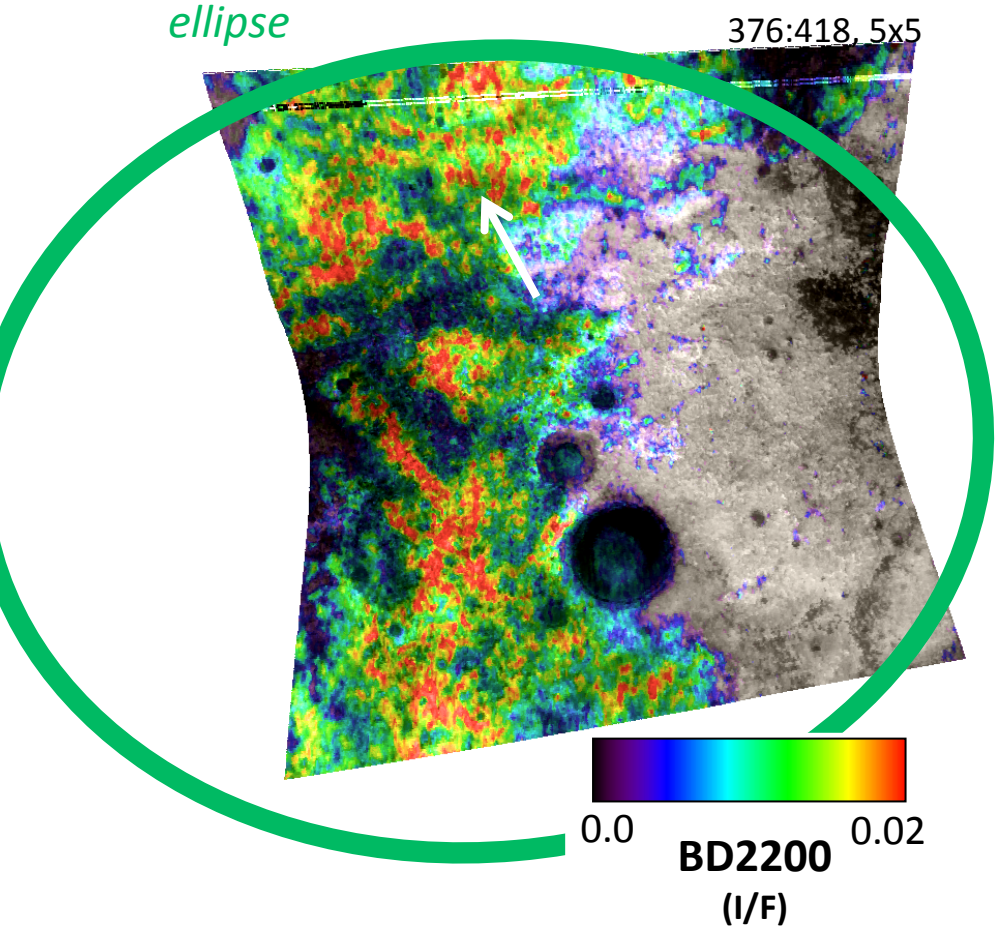


Endmembers, determining the best-fit solution for mineralogy, grain size

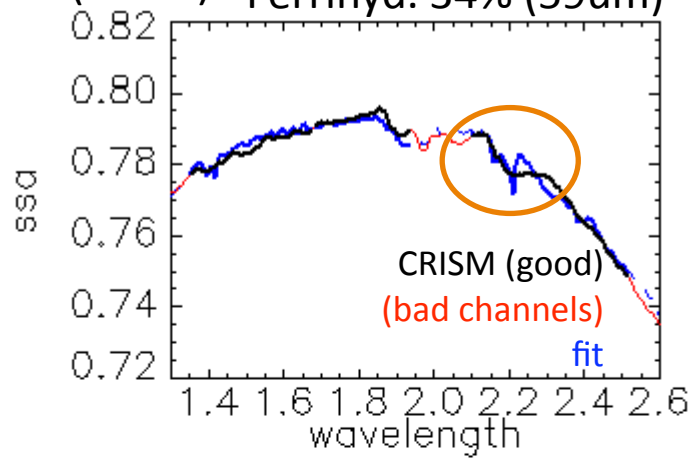
- Simulated annealing downhill simplex method, mimizing error between measured and calculated
- Up to 7 endmembers
  - Nontronite
  - HCP
  - LCP
  - Olivine
  - Ferrihydrite
  - Dust (*Arabia Terra, Poulet et al., 2008*)
- For Fe-smectite bearing terrains, 11 scenarios run with different numbers and combinations of endmemembers
  - Nont.+dust, Nont.+dust+ferrihydrite, Nont.+dust+LCP+HCP, etc
  - **When RMS was approx. equivalent, most parsimonious (fewest EM) solution that fit the data was chosen**

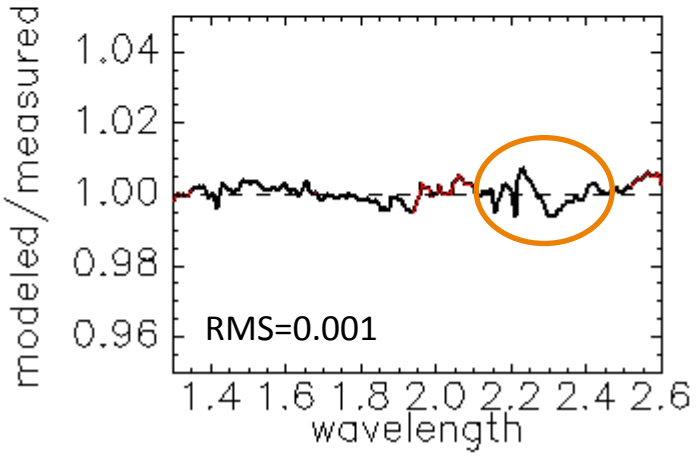


Mawrth Vallis: units with Al-phyllosilicate/silica



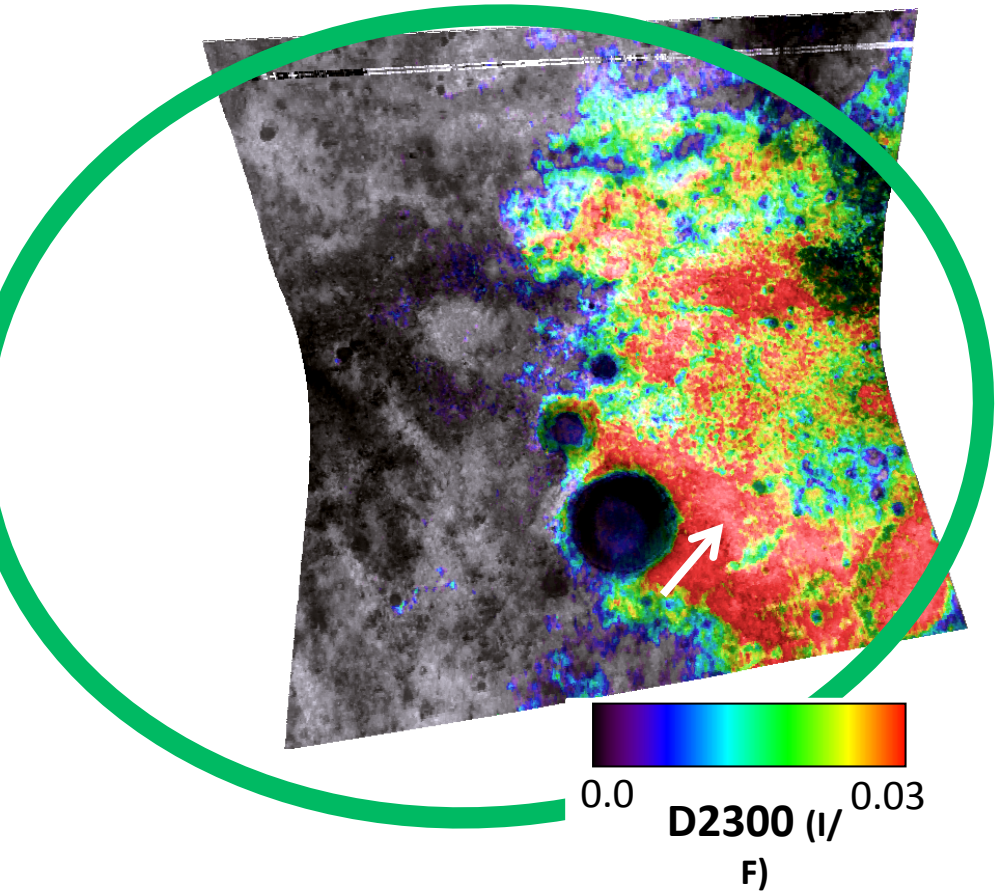
Plag. 30% (34um)
Dust 9% (13um)
Kaol. 20% (41um)
Mont. 4% (42um)
Ferrihyd. 34% (59um)



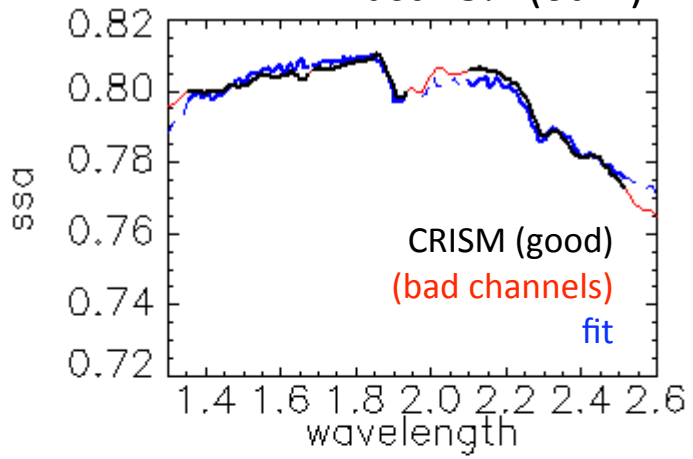


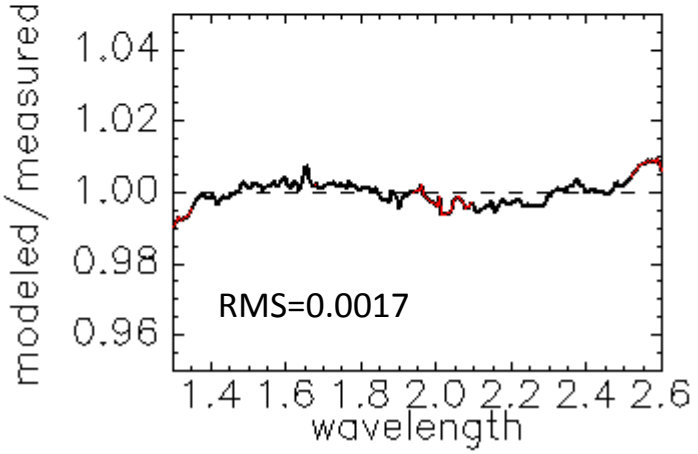
Good fit. Also needs EM with broader absorption near 2.2 µm (less sharp than kaolinite)

Mawrth Vallis: units with Fe-smectite clay (Set 1)



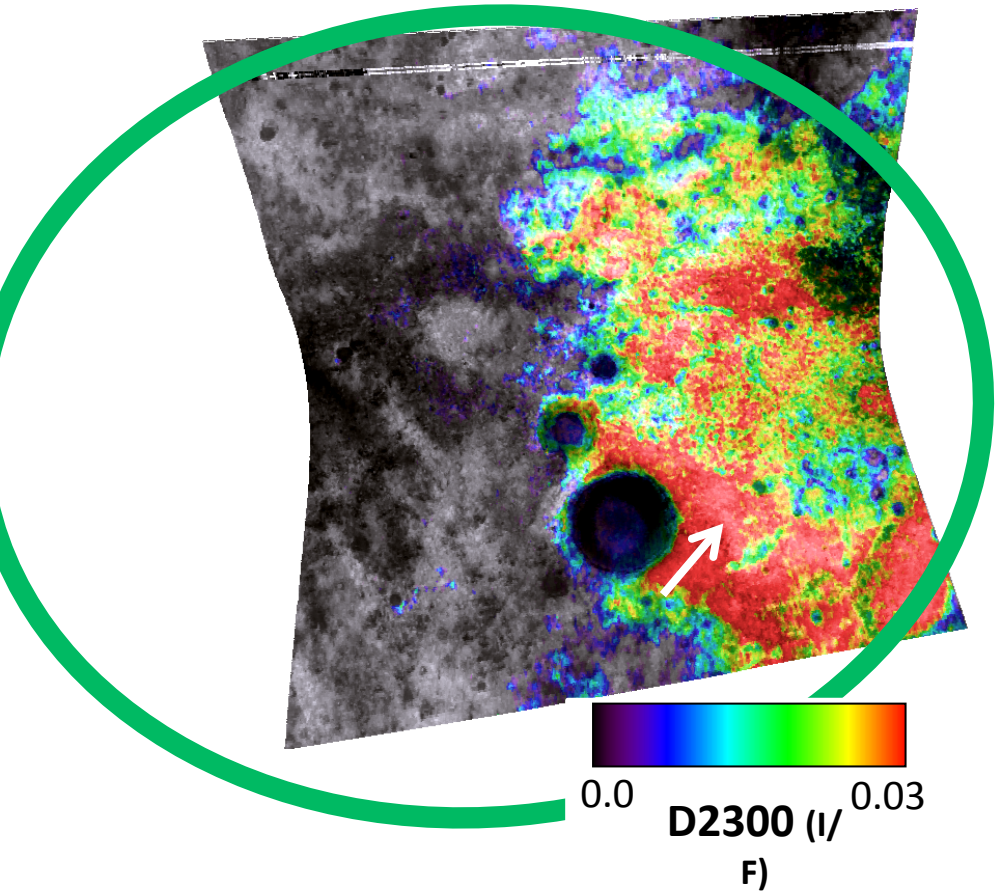
Nont. 10% (5um)
Ferrihyd. 74% (74 um)
Dust 15% (6um)



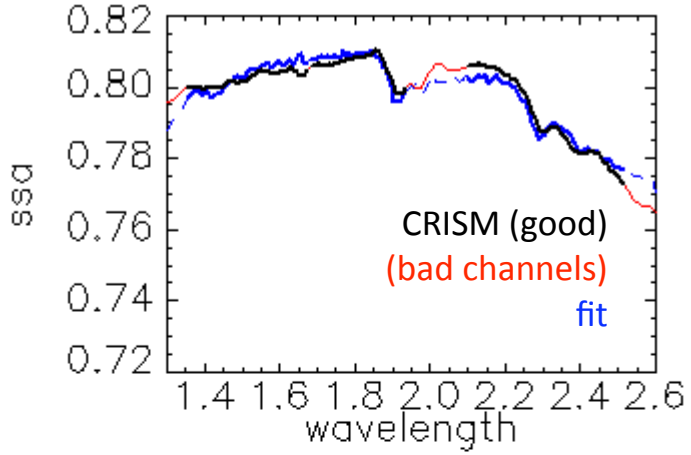


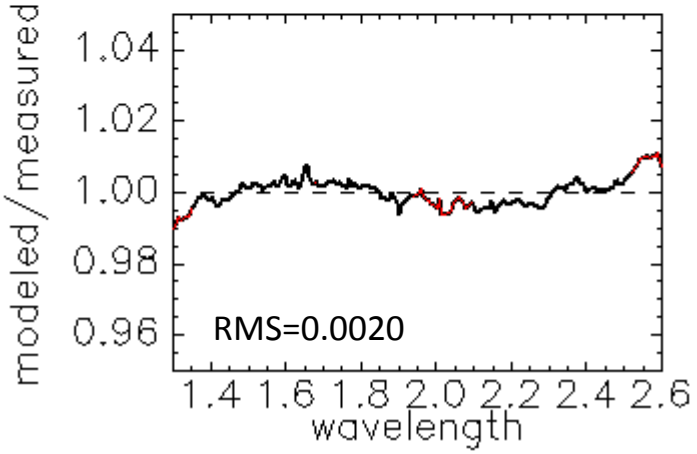
Good fit. *NOTE: B/c of similar ~ 2.3um abs., ferrihydrite likely includes some nontronite

Mawrth Vallis: units with Fe-smectite clay (Set 2)



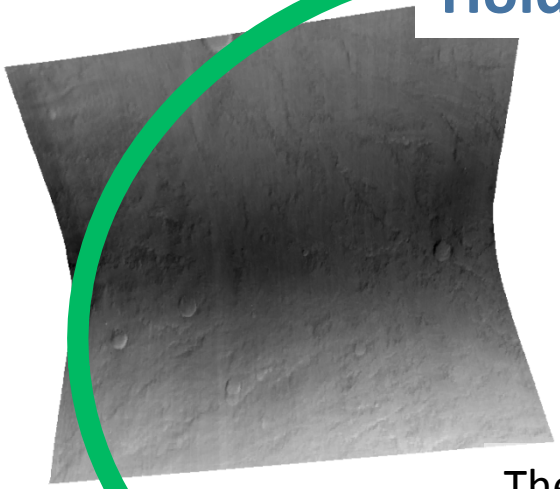
Nont. 10% (12um)
Plag. 19% (39um) Ferrihyd. 31% (19 um)
HCP 22% (299 um) Dust 16% (16um)





Good fit. Also works with relatively more plag. and more nontronite (but coarser grained)

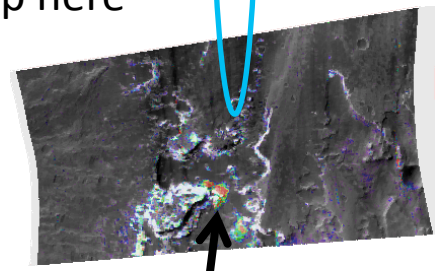
Holden: units with Fe/Mg phyllosilicate



<No clays modeled in 9DF7>

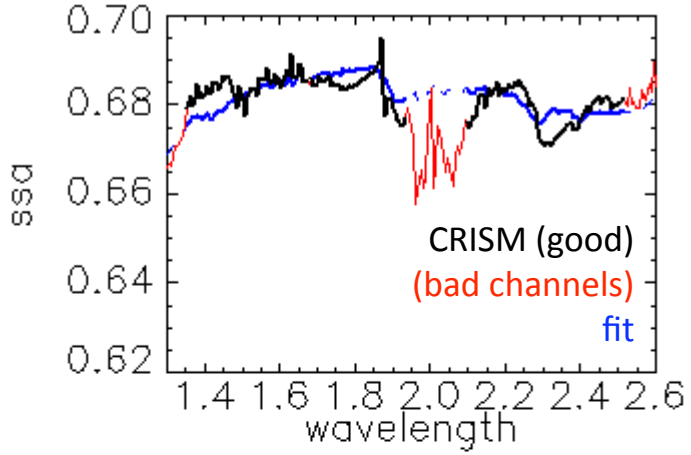
-0.002 **D2300 (I/F)** 0.02

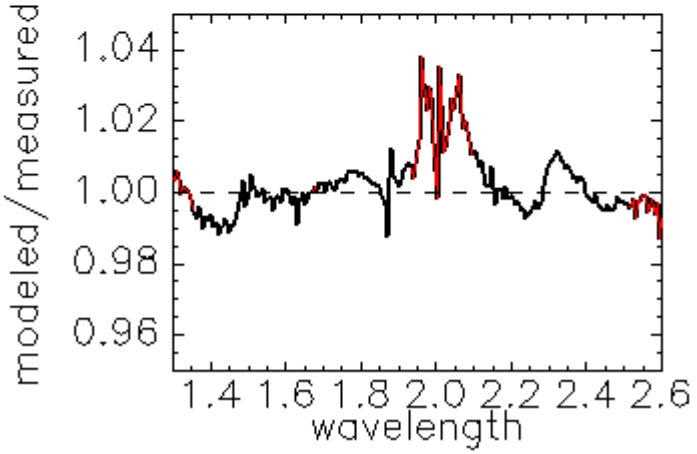
There are in-ellipse clays, but C1D1 not modeled in time for workshop. Continuation of outcrop here



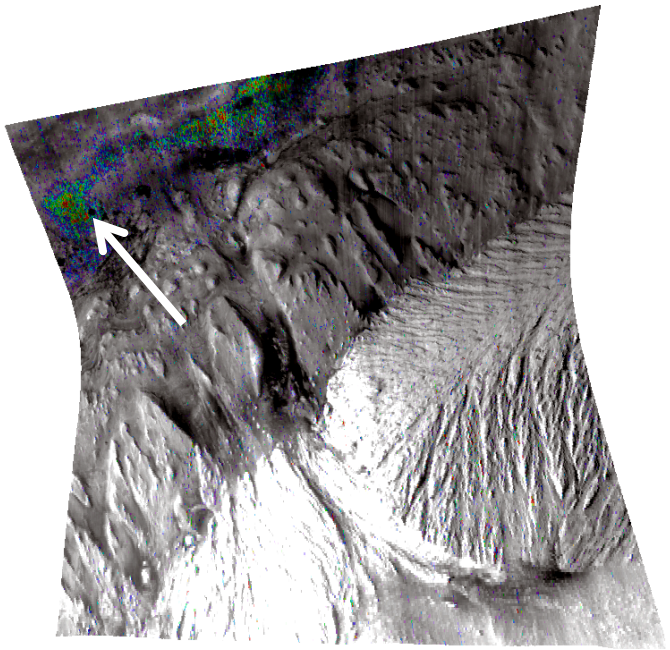
Very poor fit. Notronite not the clay-endmember

<poorly moded with this EM suite>

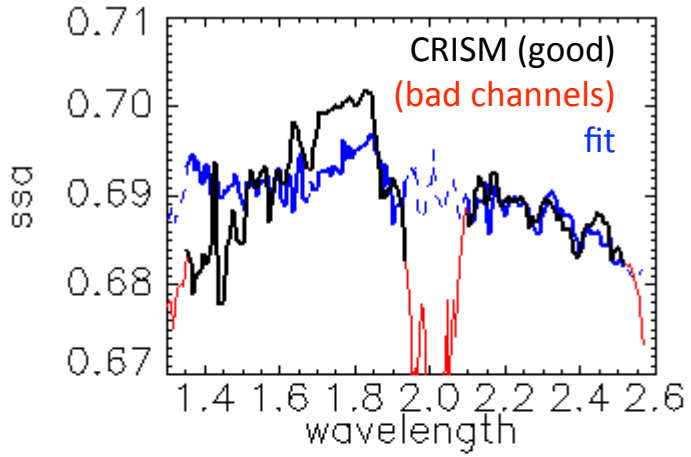


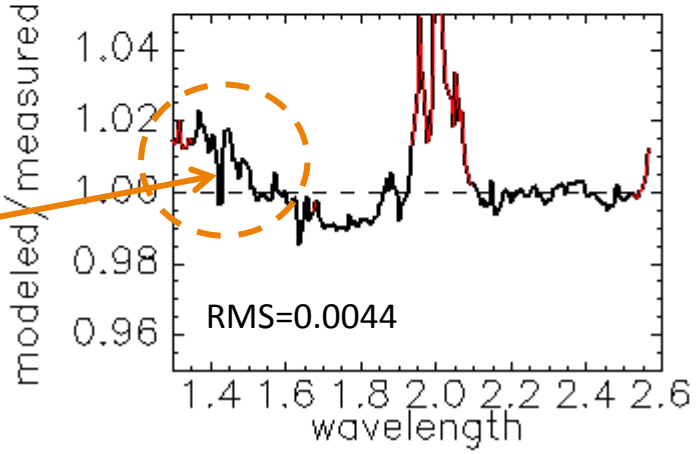


Gale: unit with Fe-smectite clay



12% Nont. (4µm)
87% Dust (18%)

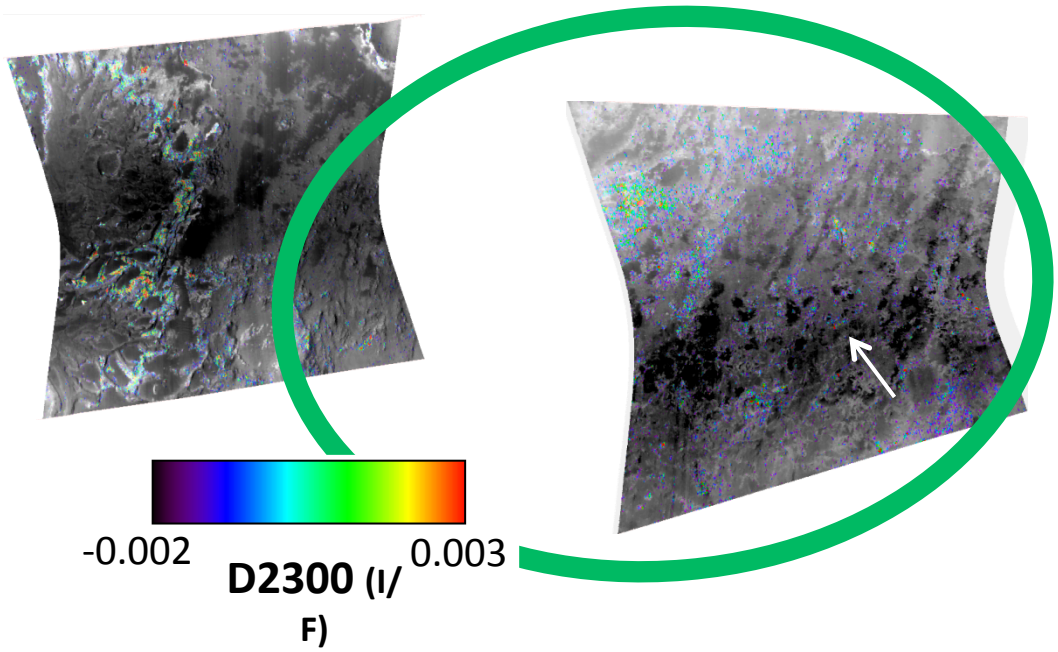




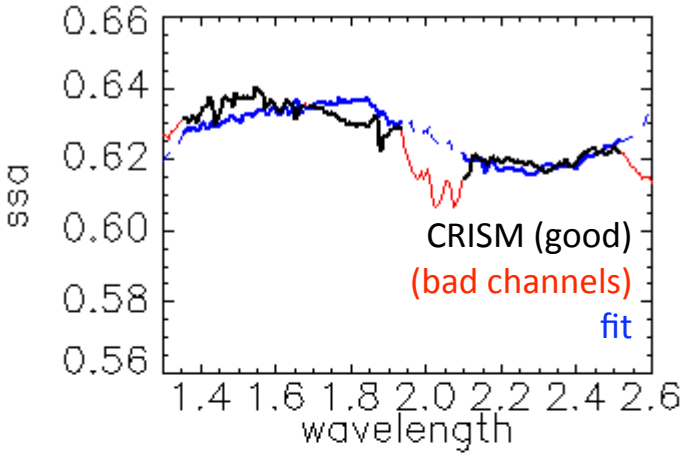
D2300 (I/F)

OK fit. Low contrast spectra. Residual may be due to ferrous component OR a more dehydrated Fe-smectite than measured in terrestrial labs (not OLV)

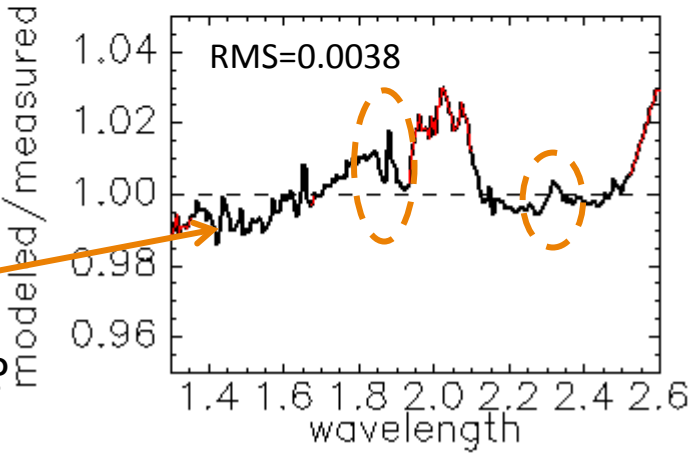
Eberswalde: units with Fe/Mg phyllosilicate (Volc Scan corr.)



Plag. 18% (133um) Nont. 2% (8um)
HCP 28% (29 um) Dust 49% (38um)

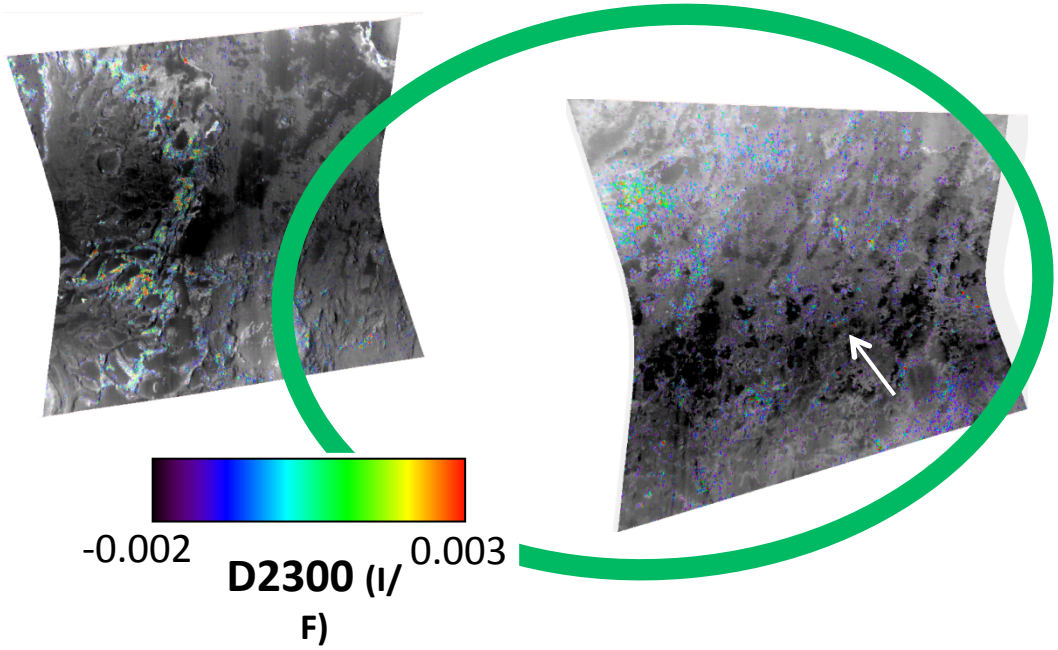


OK fit. Other similar RMS solutions yield nontronite between 0-8%

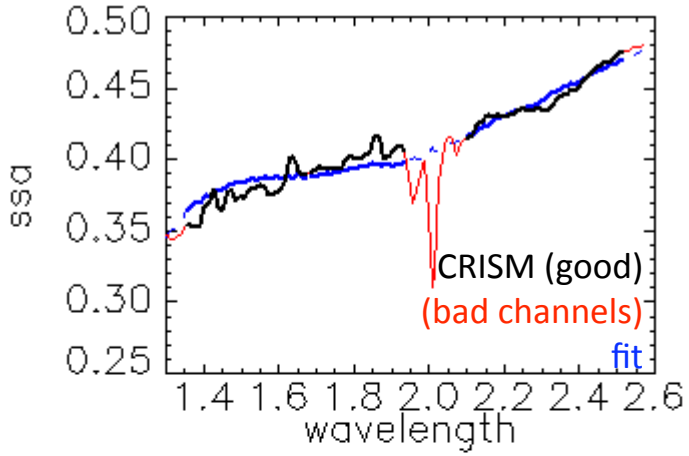


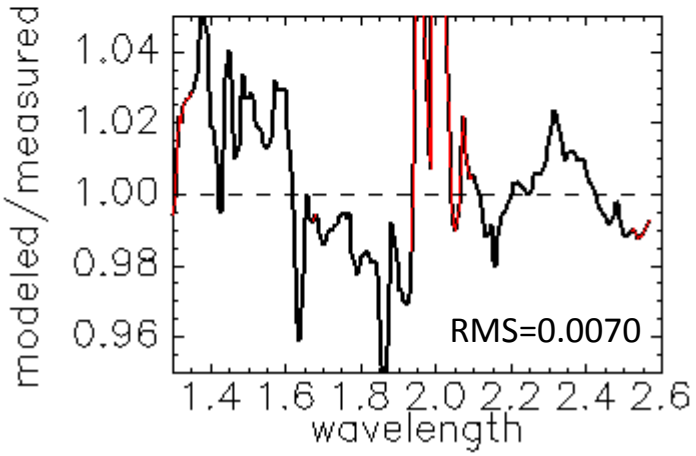
Residual due to differences in a ferrous component or hydration? (not OLV). Like Holden, clay ill-fit by endmember.

Eberswalde: units with Fe/Mg phyllosilicate (DISORT corr.)



<DOES NOT CONVERGE TO A SATISFACTORY SOLUTION>





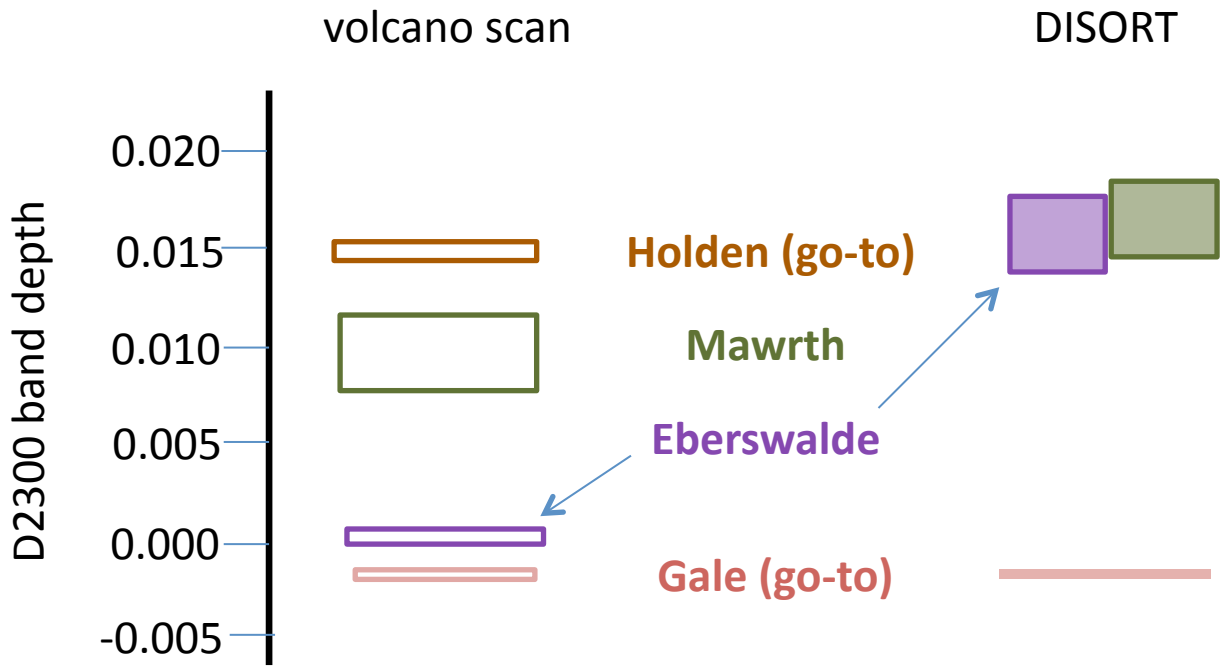
Does not converge. Substantially different spectral shape, lower albedo than VS. Highlights affects of path radiance in Eberswalde. Very dark surface with different phase function behavior

Conclusions

- Site-by-site retrievals and confidence level (work-in-progress):
  - **Mawrth**: There will be clay: >25% Al-clay unit, >10% nont. unit, few primary minerals (<50%)
  - **Holden**: Clays in extreme SE of the ellipse and go-to clays may have abundances comparable to Mawrth. No other clays are modeled for ellipse-data. Ill-fit of model indicates alteration phase is not Fe-smectite alone. (also primary minerals present)
  - **Gale**: Nontronite is not volumetrically large component (<25%) but is present. Dust is dominant, few/no primary minerals required in best fit.
  - **Eberswalde**: Not sure. Surface is very dark; confounds retrivals due to different scattering behavrior and additive effects of path radiance (not corrected for with volcano scan). Only slight evidence for clays from modeling of volcano scan data. Data modeled from DISORT have larger band depths, but do not converage to a satisfactory solution.
- Sensitivity analyses testing multiple methods/assumptions lends confidence in overall results, including approximate clay abundance
- Abundances are successfully predicted for lab spectra with well-characterized endmembers. Estimates for Mars models can be better constrained by further study with synergistic use of multiple datasets (TI for particle size; TES for mineralogy)

EXTRAS

Maximum D2300 Band Depths: DISORT vs. Volcano Scan

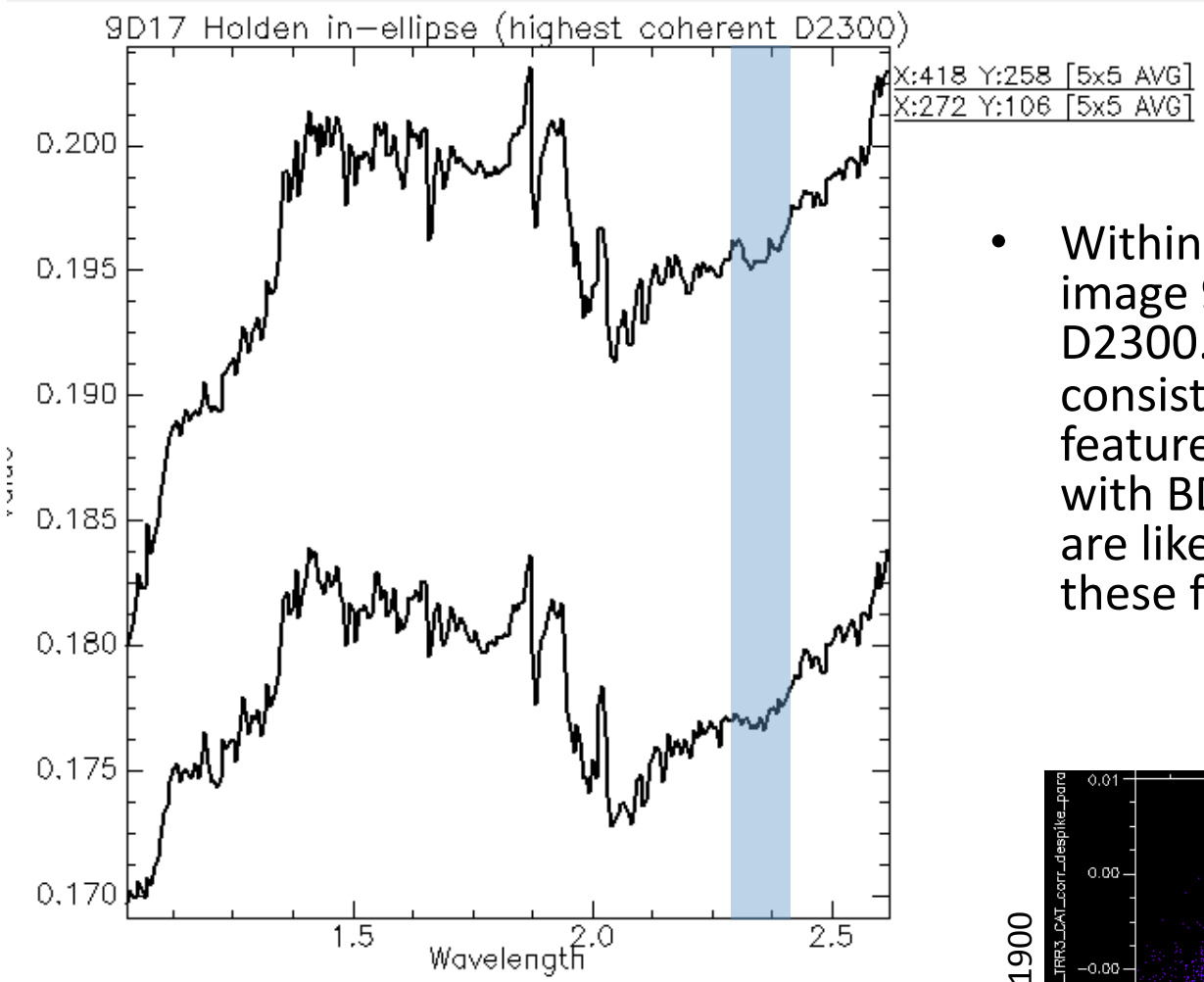


- Change in relative ordering due to how Eberswalde dark surface is corrected for

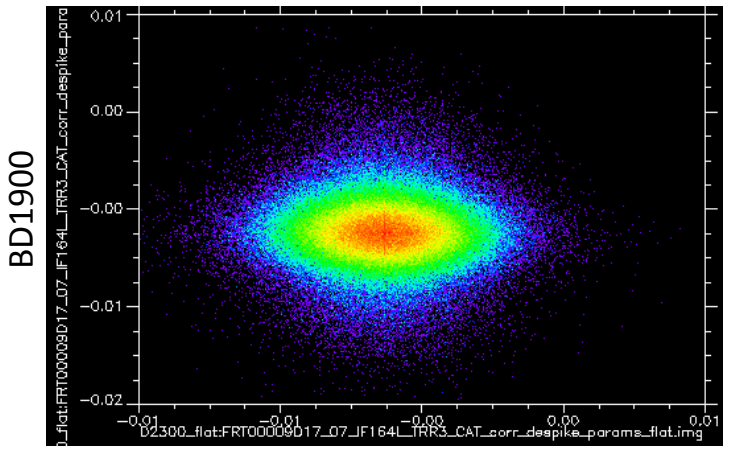
Summary of % Mineral Abundances

Site	Al smect. + Kaol	Ferrih yd.	Plag	HCP	LCP	OLV	Dust	Other
Mawrth	4 + 20	34	30	<no>	<no>	<no>	9	silica, alloph. palag.? (needs broad abs. ~2.2µm)

Site	Fe smect.	Ferri hyd.	Plag.	HCP	LCP	OLV	Dust	Other
Mawrth	>10	74 (31)	(19)	(22)	<no>		15	
Holden	*band depth comparable to Mawrth. Ill-fit because lacking correct clay EM*							
Gale	12				<no>		87	Needs more dehyd. endmember or Fe(II) component
Ebers.	2-8%	(8)	18	28 (20)	12	<no>	49 (31)	also needs less hydrated Fe/Mg-OH species



- Within the NW Holden ellipse image 9D17, elevated values of D2300. But the positions are consistent with atmospheric features and not correlated with BD1900. Smectite clays are likely not responsible for these features



Volcano-scan correction of simulated DISORT spectrum