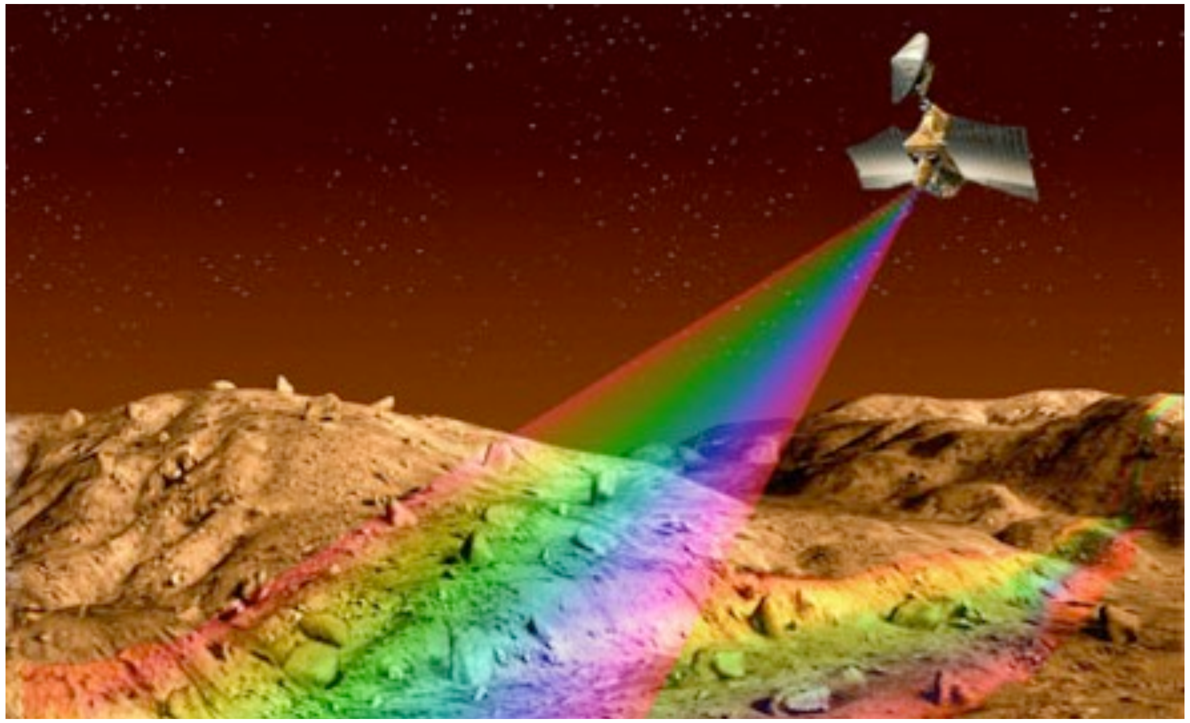
Compositional mapping of shear zones in northern Valles Marineris, Mars



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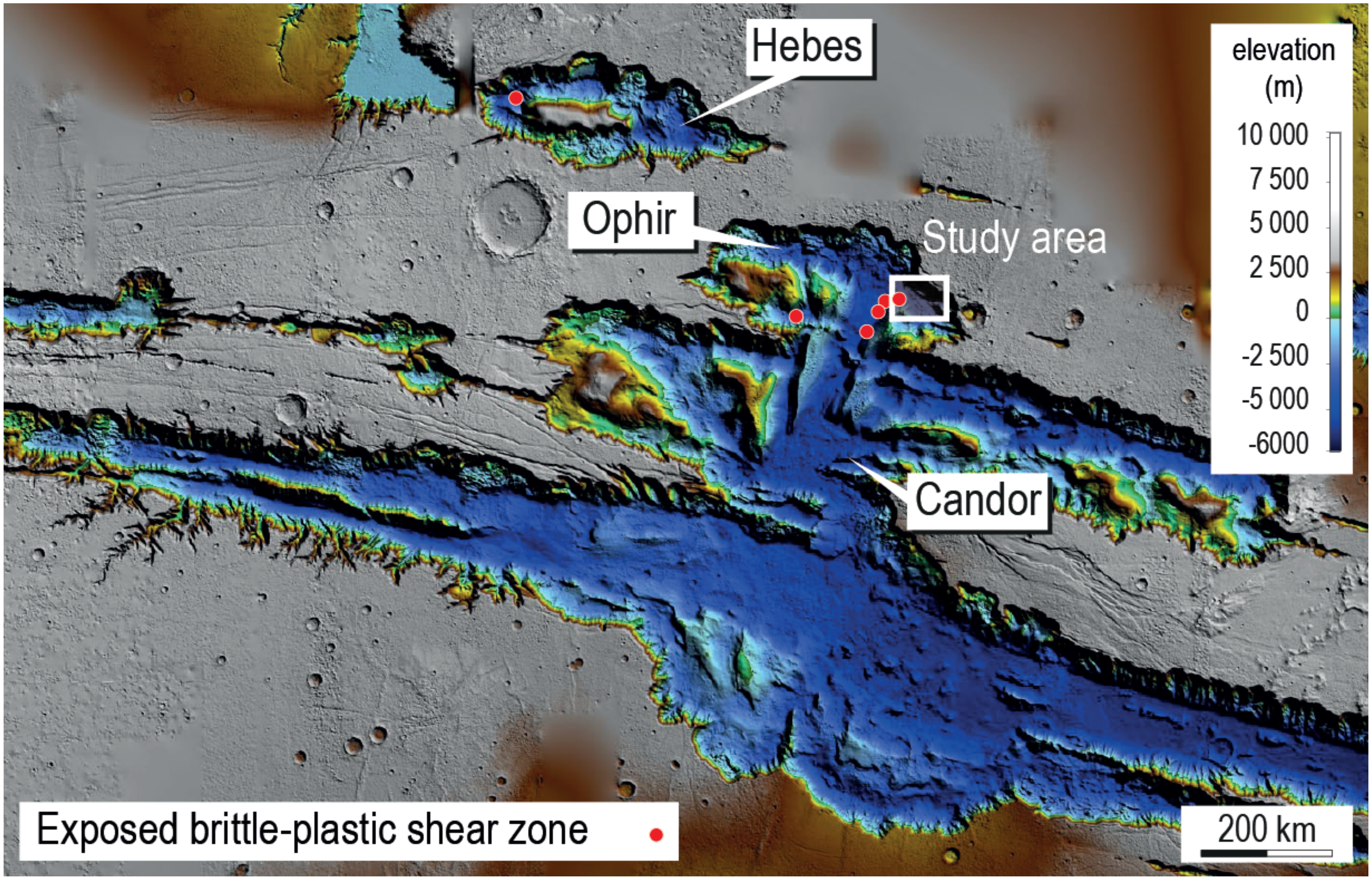
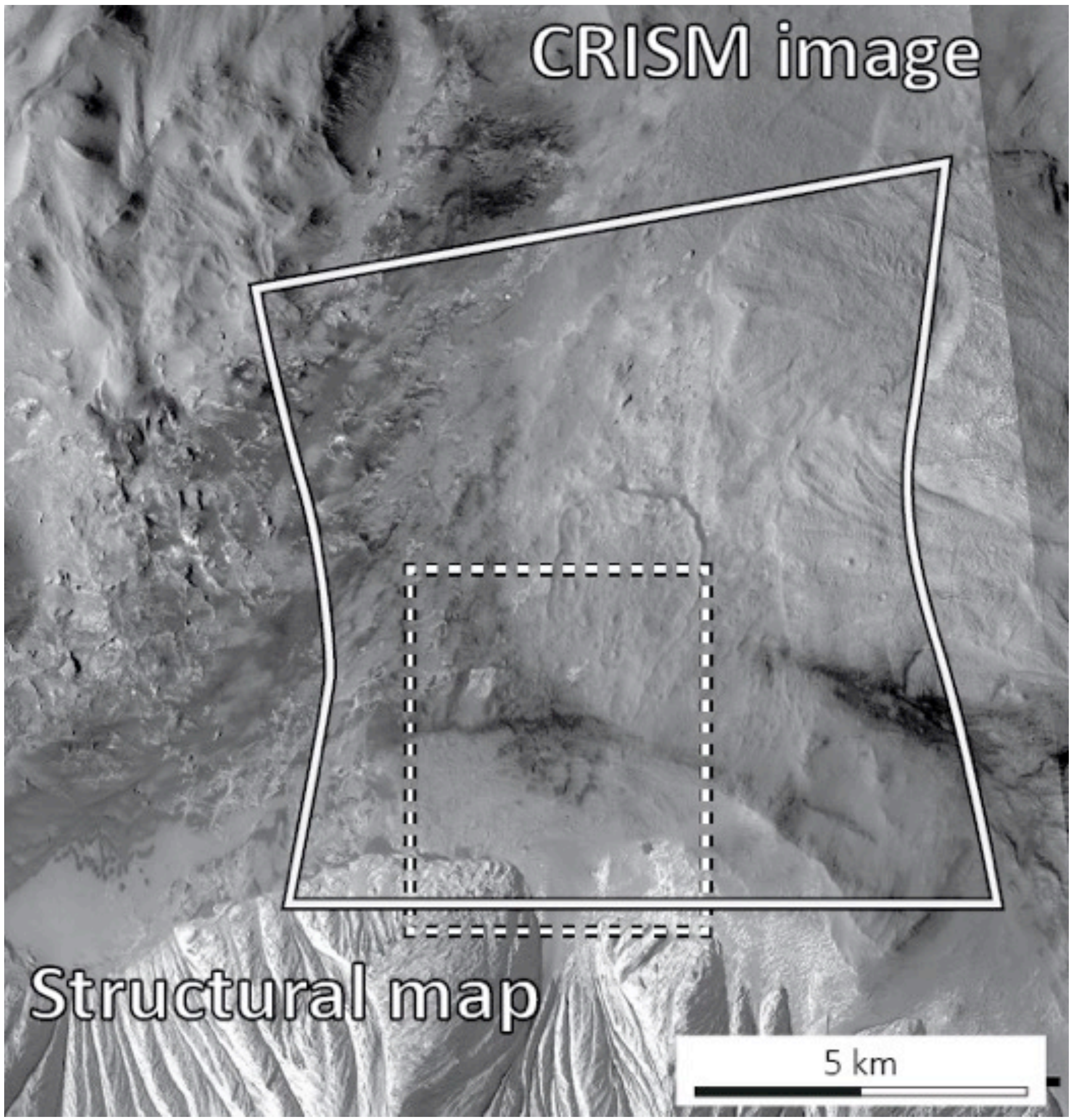
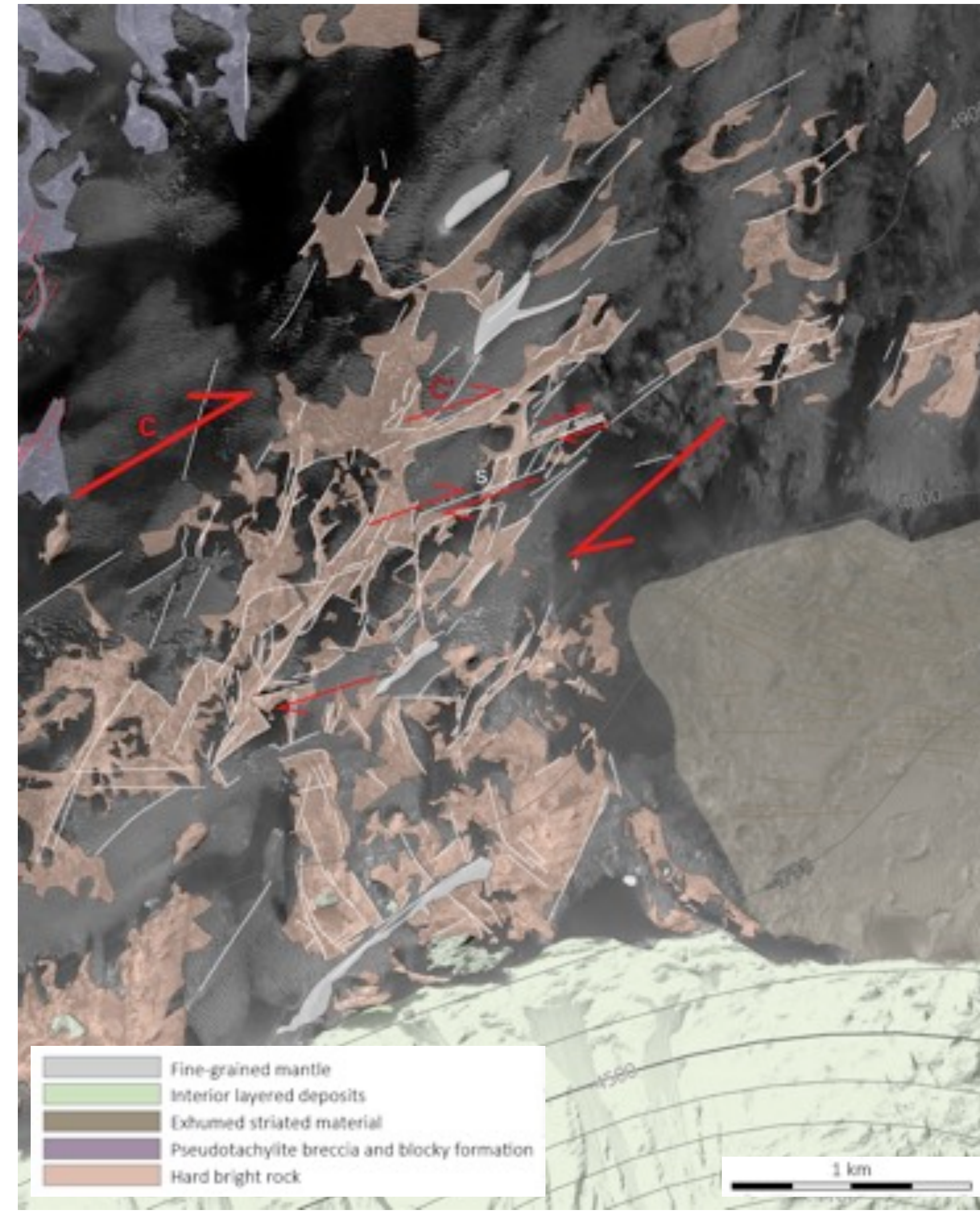
Valles Marineris

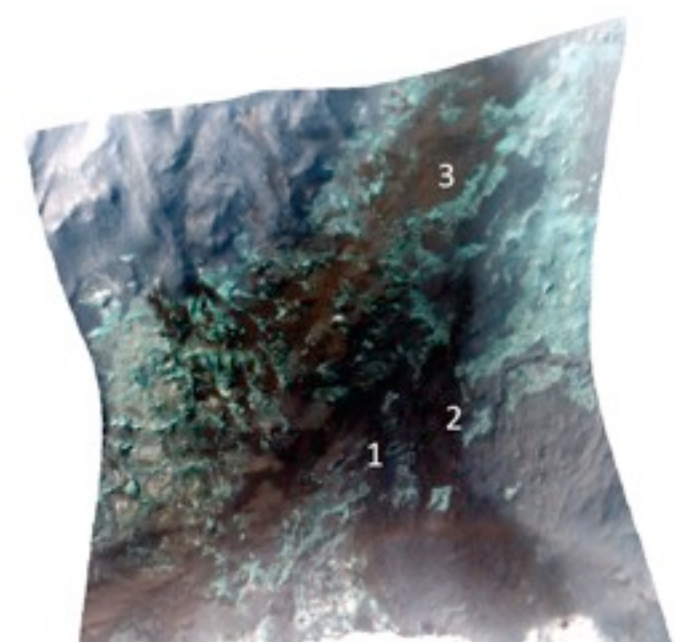


- One of the largest fault in the Solar System

Ophir Chasma

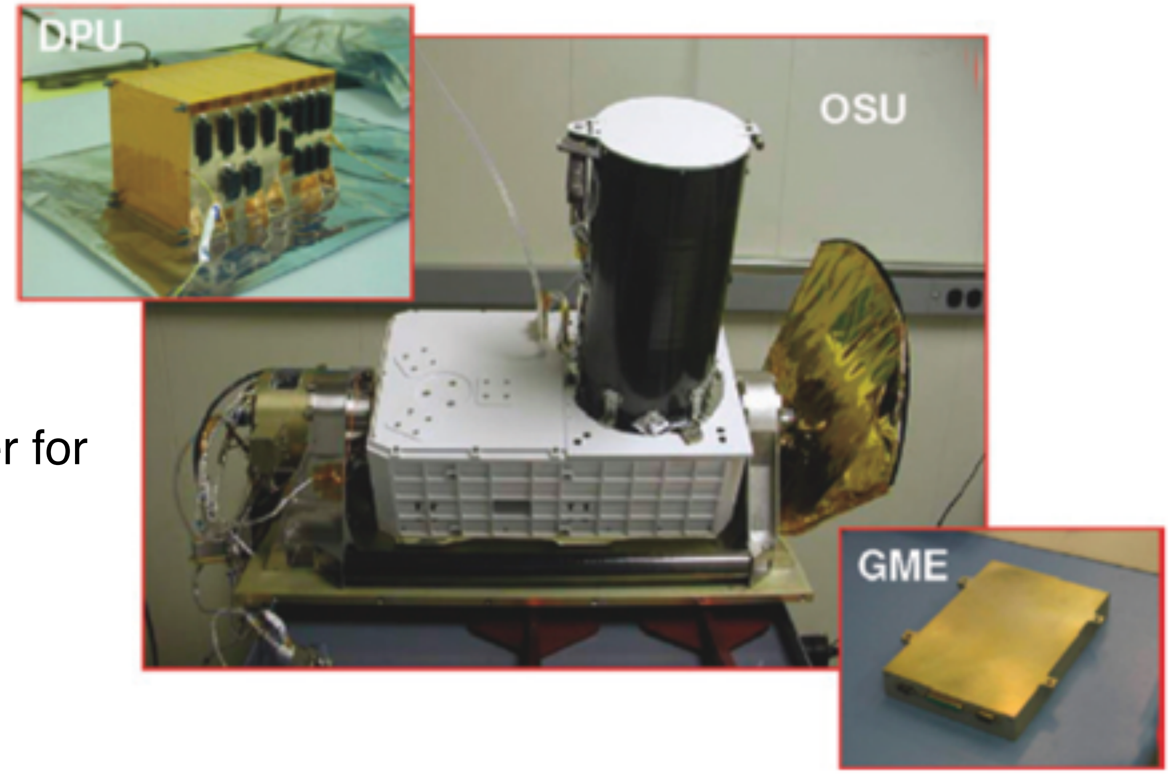






CRISM data: frt00018b55_07_if165l_trr3, bands: R: 233, G: 78, B: 13

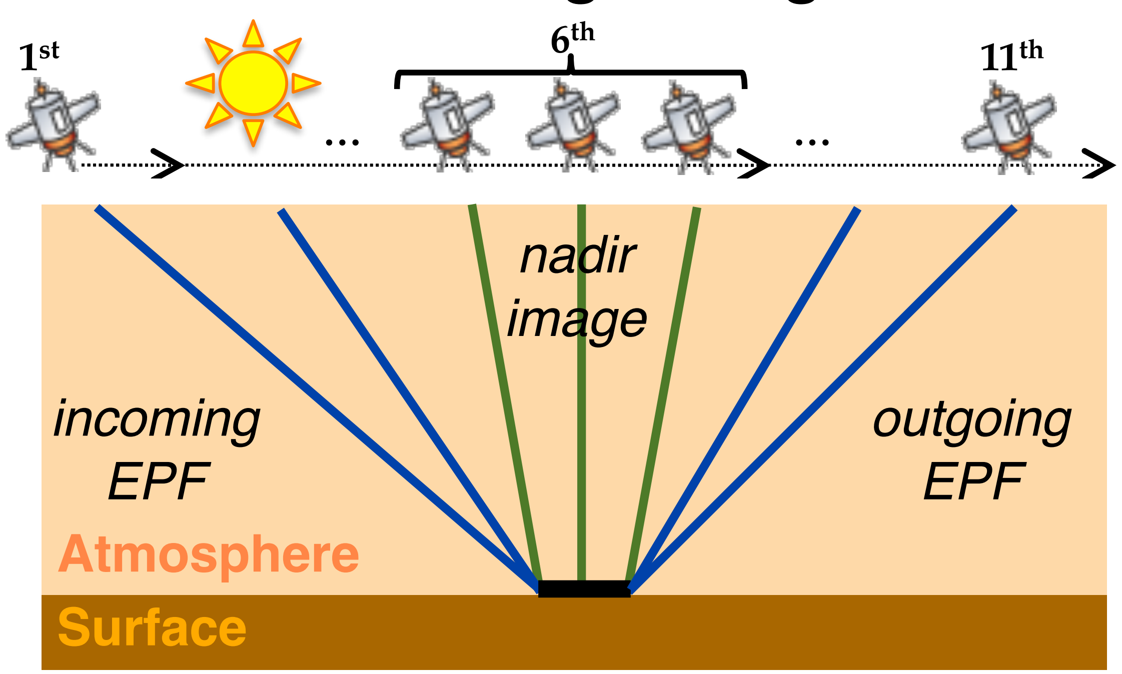
Instrument



CRISM (Compact Reconnaissance Imaging Spectrometer for Mars in Mars Reconnaissance Orbiter spacecraft)

Murchie et al., JGR, 2007

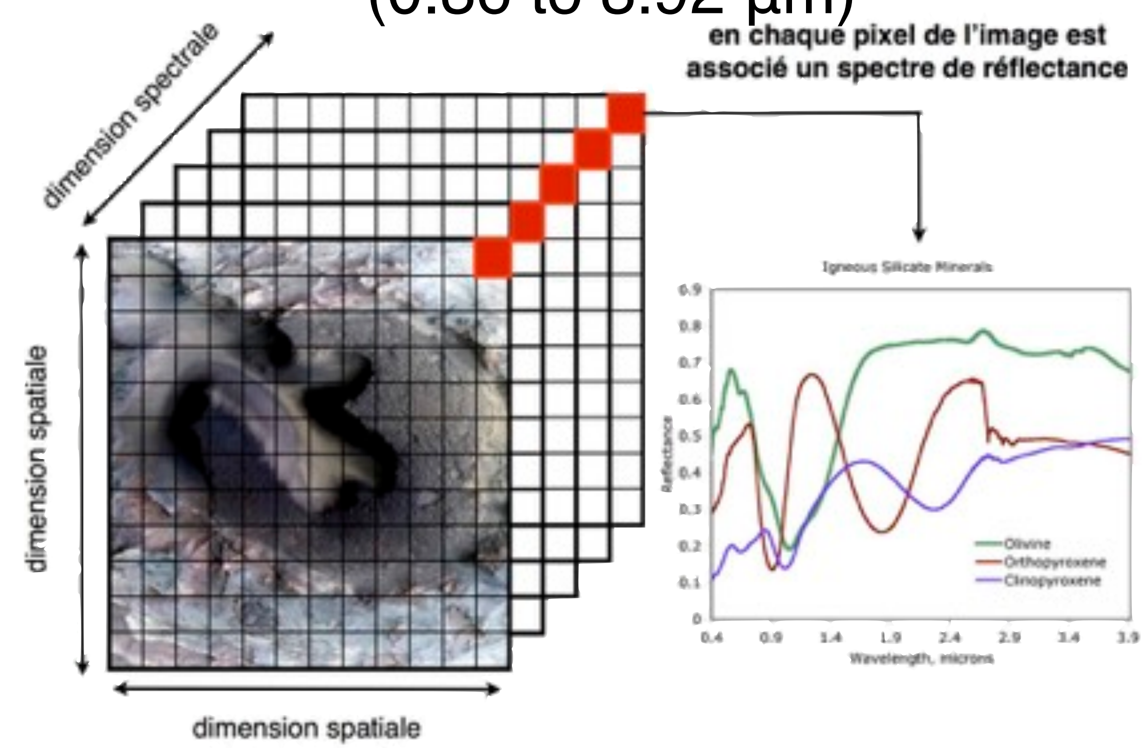
Targeted observations
11 multi-angle images



10 off-nadir images (180 m/pxl)
eme±70°, constant inc
1 nadir image (20 m/pxl)

+

Hyperspectral image
438+107 bands
(0.36 to 3.92 µm)



credit: http://crism.jhuapl.edu

Spectral analysis

1. **Classification**
    - **Supervised:** knowing laboratory spectra
        - GOAL: Where are the reference spectra ?
2. **Radiative transfer inversion**
    - Quantitative estimation of surface properties

Mathematical problem

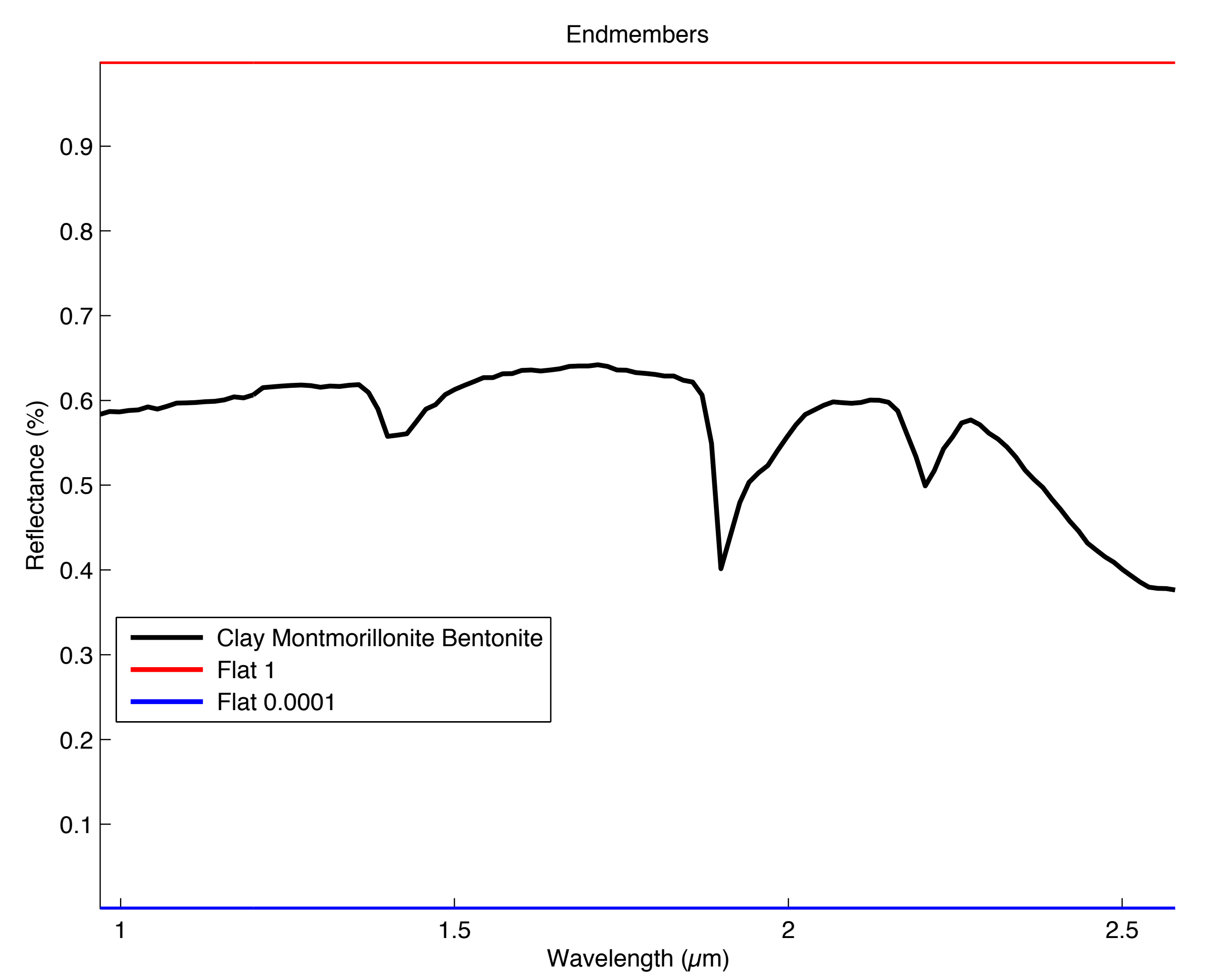
- Estimation of abundances, under constraints

$$L(x, y, \lambda) = \sum_{p=1}^{P} \alpha_p(x, y)\, \rho_p(\lambda)$$

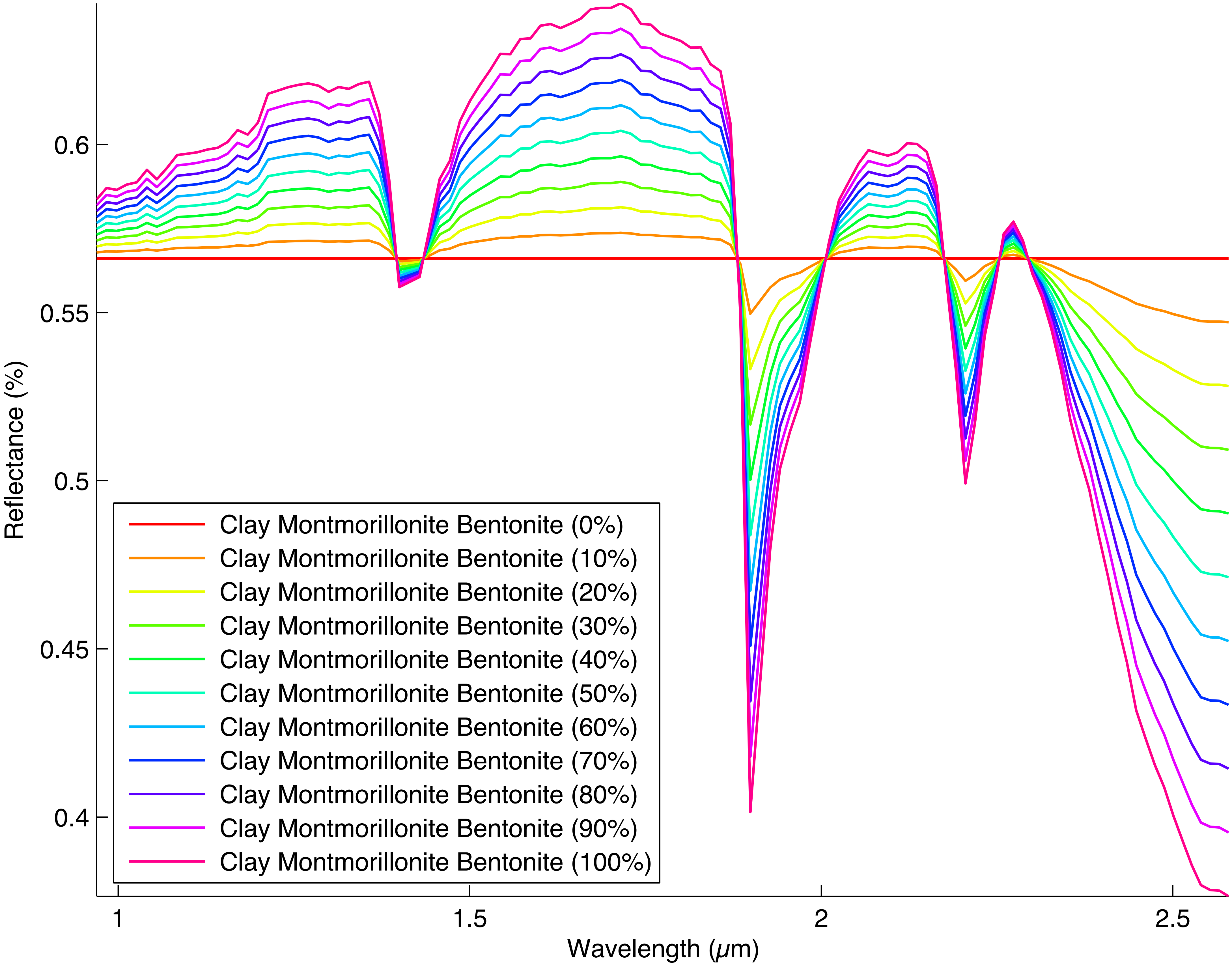
$$\min\ ||\alpha_p.\rho_p - L||,\ \alpha_p > 0,\ \sum \alpha_p = 1$$

Positivity, sum-to-one

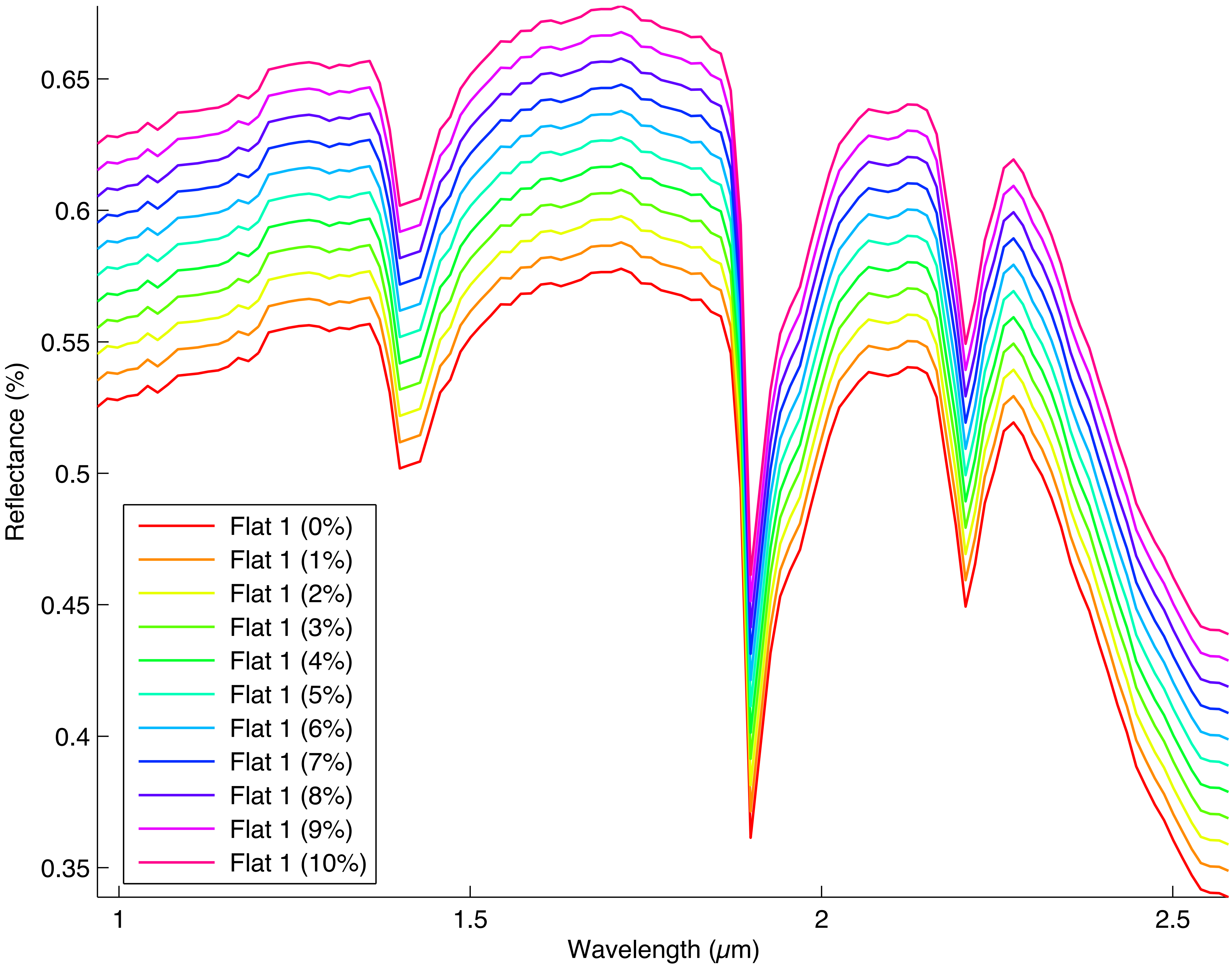
- **Property : linearly dependent spectra in the database give one single solution !**



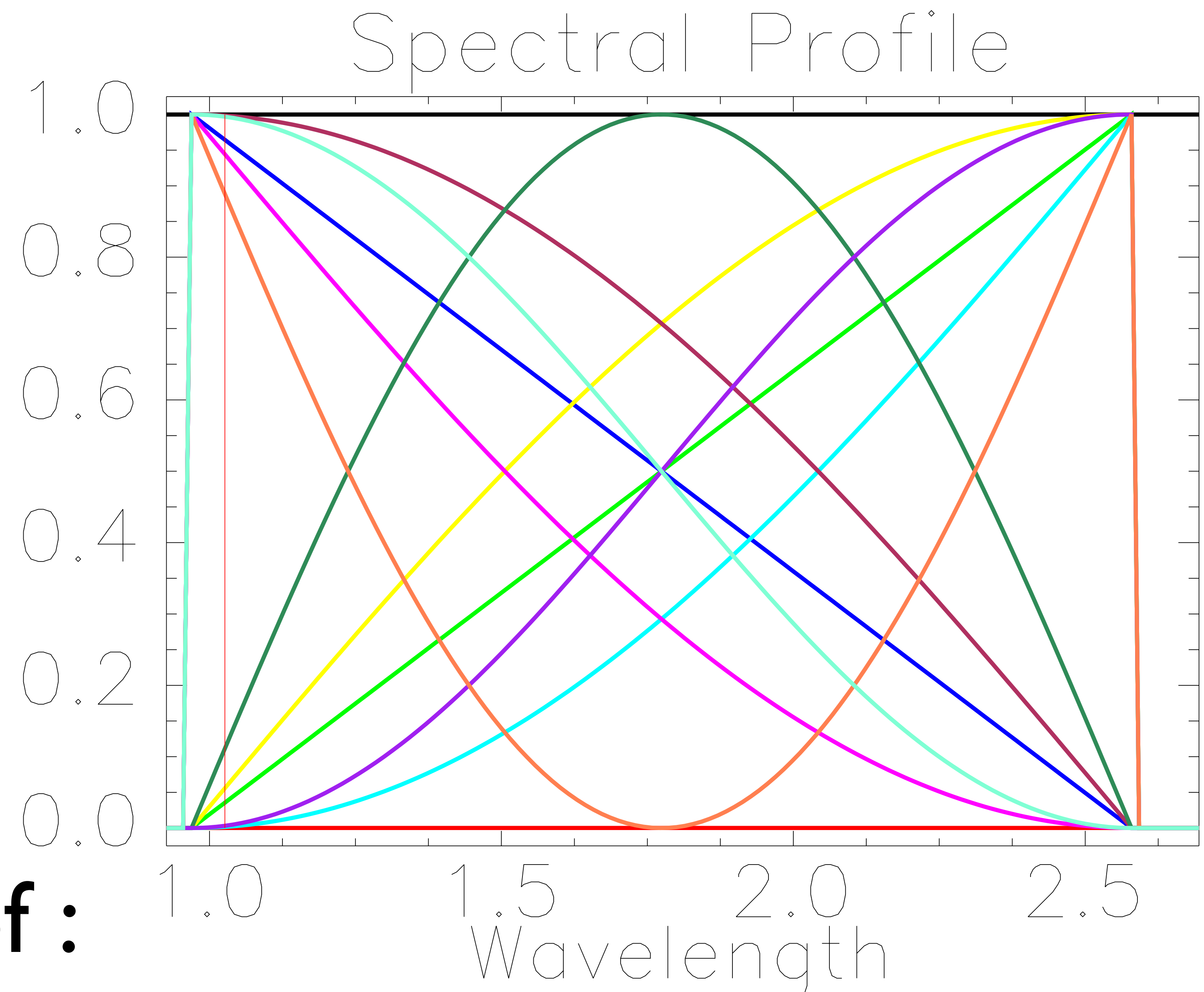
Absorption band depth



Continuum shift



Adding other spectra ?

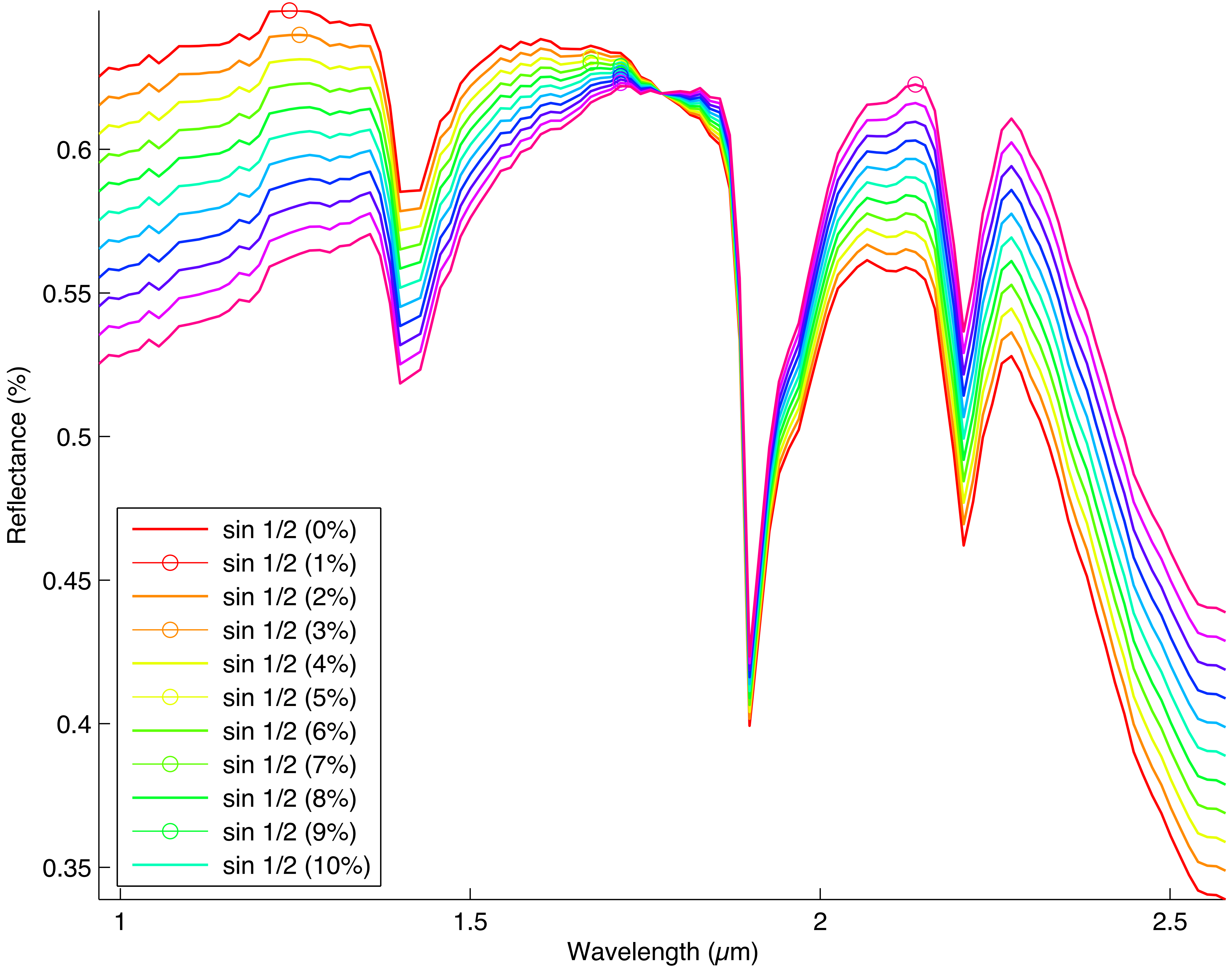


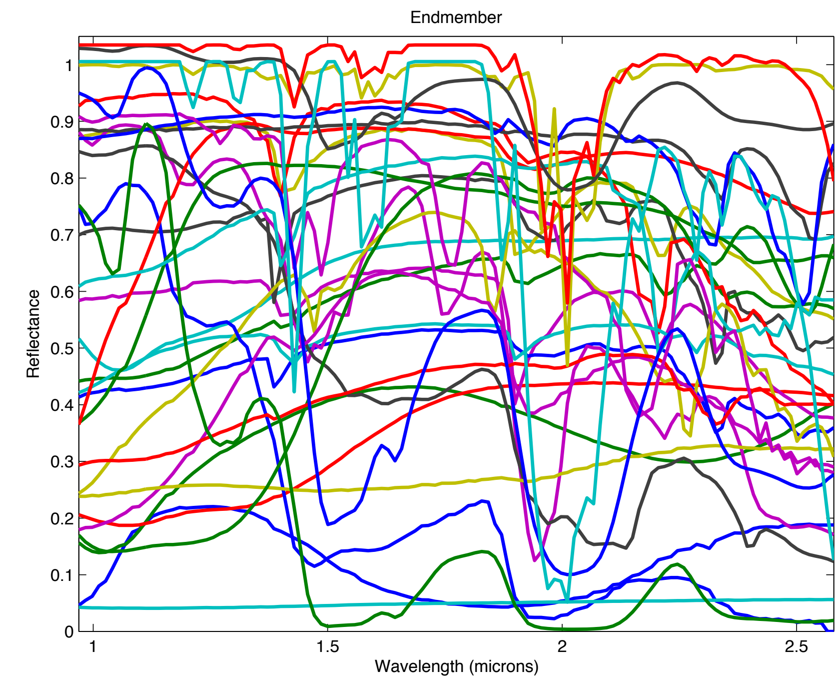
To model the effect of :

- aerosols
- continuum
  - surface roughness of the regolith
  - grain size, shape roughness
- mixture (opaque, feldspar, ...)

Remove discrepancies between observed spectra and database

Maximum shift ?





Spectral database

- Selection of spectra for Mars

Name of the 32 spectra:

1 Inosilicate (Hypersthene OPX PYX02.h >250u)	12 Sulfate; Gypsum	23 Carbonate; Siderite
2 Inosilicate (Diopside CPX CRISM)	13 Sulfate; Jarosite	24 Phyllosilicate (Chlorite)
3 Olivine Fayalite CRISM	14 Sulfate; Kieserite	25 Muscovite GDS116 Tanzania
4 Olivine Forsterite CRISM	15 Epsomite USGS GDS149	26 Alunite GDS83 Na63
5 Phyllosilicate (Clay Montmorillonite Bentonite)	16 Oxide; Goethite	27 Atmospheric Transmission
6 Phyllosilicate (Clay Illite Smectite)	17 Oxide; Hematite	28 H2O grain 1
7 Phyllosilicate (Serpentine Chrysotile Clinochry.)	18 Oxide; Magnetite	29 H2O grain 100
8 Phyllosilicate (Serpentine Lizardite)	19 Ferrihydrite USGS GDS75 Sy F6	30 H2O grain 1000
9 Phyllosilicate (Clay Illite)	20 Maghemite USGS GDS81 Sy (M-3)	31 CO2 grain 100
10 Phyllosilicate (Clay Kaolinite)	21 Carbonate; Calcite	32 CO2 grain 10 000
11 Phyllosilicate (Nontronite)	22 Carbonate; Dolomite	

Schmidt, F.; Legendre, M. & Le Mouëlic, S. Minerals detection for hyperspectral images using adapted linear unmixing: LinMin *Icarus,* **2014**, *237*, 61-74, http://dx.doi.org/10.1016/j.icarus.2014.03.044

Algorithm

$$L(x, y, \lambda) = \sum_{p=1}^{P} \alpha_p(x, y)\, \rho_p(\lambda)$$

$$\min \; ||\alpha_p.\rho_p - L||, \; \alpha_p > 0, \; \sum \alpha_p = 1$$

- Primal-dual interior-point

  Chouzenoux, E.; Legendre, M.; Moussaoui, S. & Idier, J. Fast Constrained Least Squares Spectral Unmixing Using Primal-Dual Interior-Point Optimization *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of,* **2014***, 7*, 59-69, http://dx.doi.org/10.1109/JSTARS.2013.2266732

- GPU implementation

  Legendre, M.; Capriotti, L.; Schmidt, F.; Moussaoui, S. & Schmidt, A. GPU implementation issues for fast unmixing of hyperspectral images *EGU General Assembly Conference Abstracts,* **2013***, 15*, 11686,

Schmidt, F.; Legendre, M. & Le Mouëlic, S. Minerals detection for hyperspectral images using adapted linear unmixing: LinMin *Icarus,* **2014***, 237*, 61-74, http://dx.doi.org/10.1016/j.icarus.2014.03.044

Synthetic test 1

Schmidt, F.; Legendre, M. & Le Mouëlic, S. Minerals detection for hyperspectral images using adapted linear unmixing: LinMin *Icarus,* **2014***, 237*, 61-74, http://dx.doi.org/10.1016/j.icarus.2014.03.044

- Synthetic spectra of:
  - 90% Flat at 0.35 (average Mars)
  - 10% random mixture of one/two components

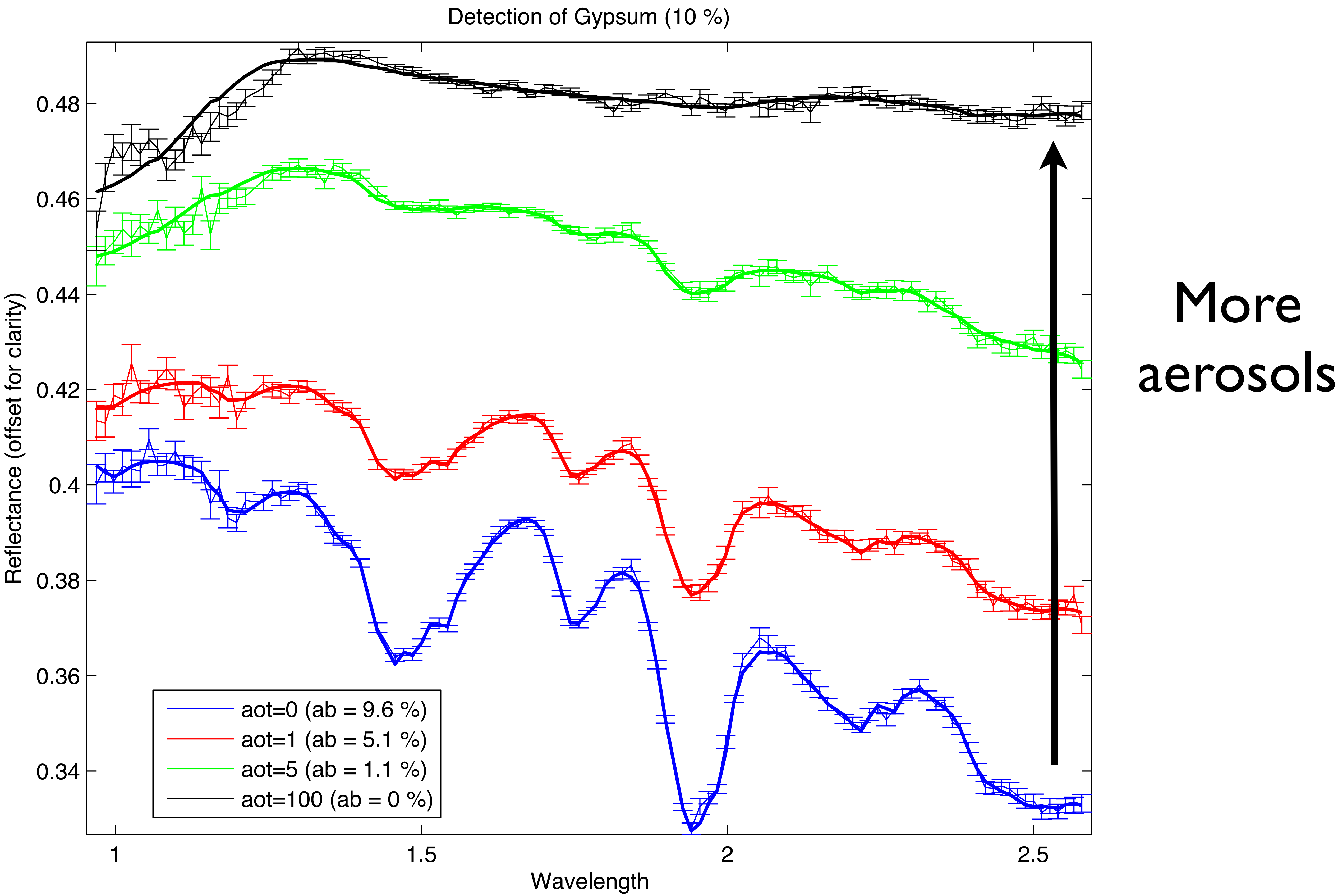
- Radiative transfer :
  - DISORT : non-linear

Lin, Z.; et al.,Improved discrete ordinate solutions in the presence of an anisotropically reflecting lower boundary: Upgrades of the DISORT computational tool *Journal of Quantitative Spectroscopy and Radiative Transfer,* **2015***, 157*, 119 - 134, http://dx.doi.org/http://dx.doi.org/10.1016/j.jqsrt.2015.02.014

  - Martian aerosols from AOT=0 to AOT=100

Wolff, M. et al., Wavelength dependence of dust aerosol single scattering albedo as observed by the Compact Reconnaissance Imaging Spectrometer *J. Geophys. Res.,* **2009***, 114*, E00D04-, http://dx.doi.org/10.1029/2009JE003350

- Adding instrumental noise from dark current



Detection of Gypsum (10 %)
Reflectance (offset for clarity)
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
1
1.5
2
2.5
Wavelength
aot=0 (ab = 9.6 %)
aot=1 (ab = 5.1 %)
aot=5 (ab = 1.1 %)
aot=100 (ab = 0 %)
More aerosols

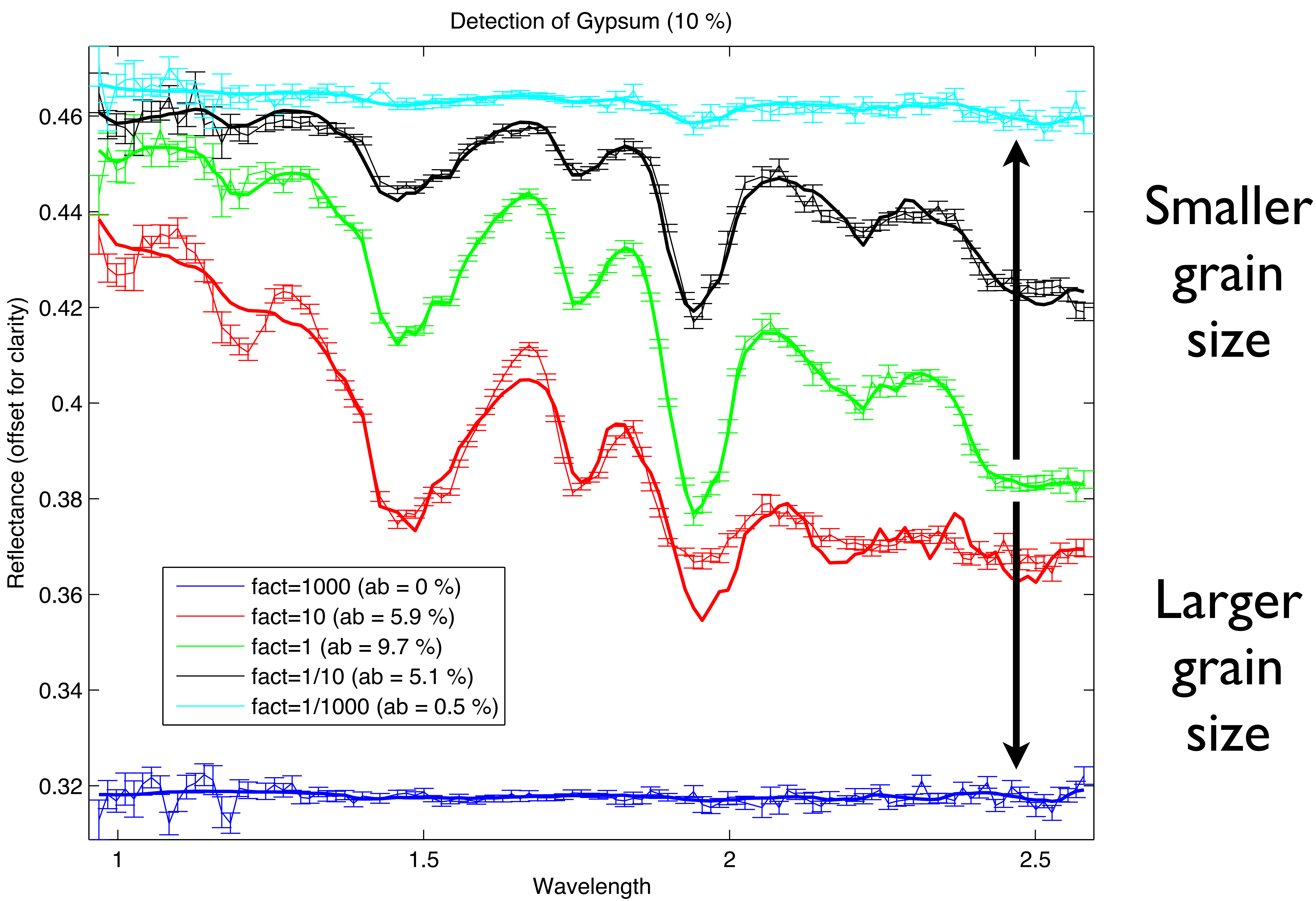
Synthetic test 2

Schmidt, F.; Legendre, M. & Le Mouëlic, S. Minerals detection for hyperspectral images using adapted linear unmixing: LinMin *Icarus,* **2014**, *237*, 61-74, http://dx.doi.org/10.1016/j.icarus.2014.03.044

- Pure mineral spectra :
  - Grain size factor using Shkuratov theory from x1/1000 to x1000

Shkuratov, Y.; Starukhina, L.; Hoffmann, H. & Arnold, G. A Model of Spectral Albedo of Particulate Surfaces: Implications for Optical Properties of the Moon *Icarus,* **1999**, *137*, 235-246, http://www.sciencedirect.com/science/article/B6WGF-45GMFKB-5T/2/2b056567d27e74edbaf976c01f89d10f

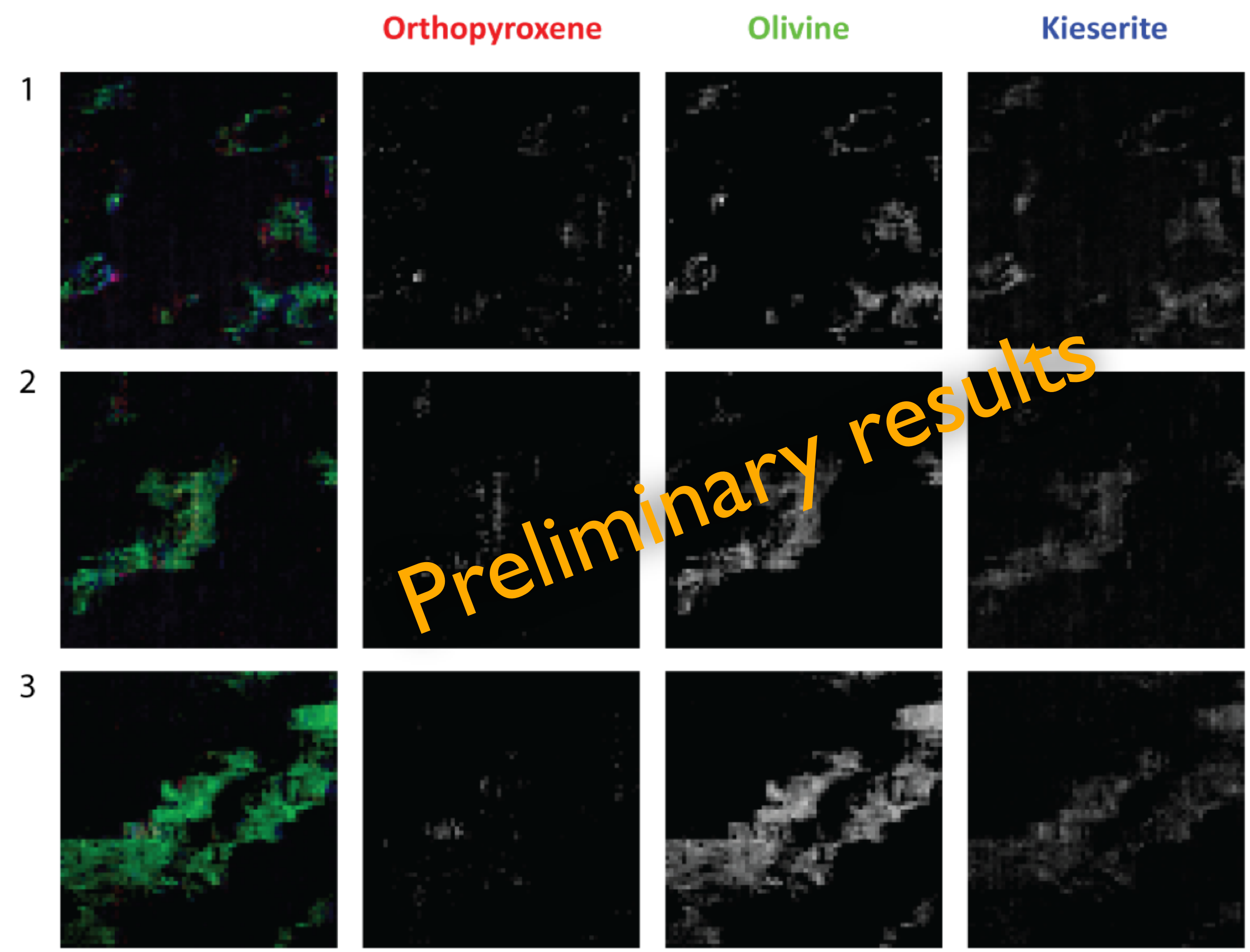
- Adding instrumental noise from dark current



Detection of Gypsum (10 %)
Reflectance (offset for clarity)
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
1
1.5
2
2.5
Wavelength
fact=1000 (ab = 0 %)
fact=10 (ab = 5.9 %)
fact=1 (ab = 9.7 %)
fact=1/10 (ab = 5.1 %)
fact=1/1000 (ab = 0.5 %)
Smaller grain size
Larger grain size

Results on Ophir, Valles Marineris

- Indurated rocks made of :
  - Orthopyroxene
  - Olivine
  - Kieserite
- ultramafic rock, altered by aqueous processes




Thank you !