HypsimMars : a tool for simulating hyperspectral images for Martian 3D scenes

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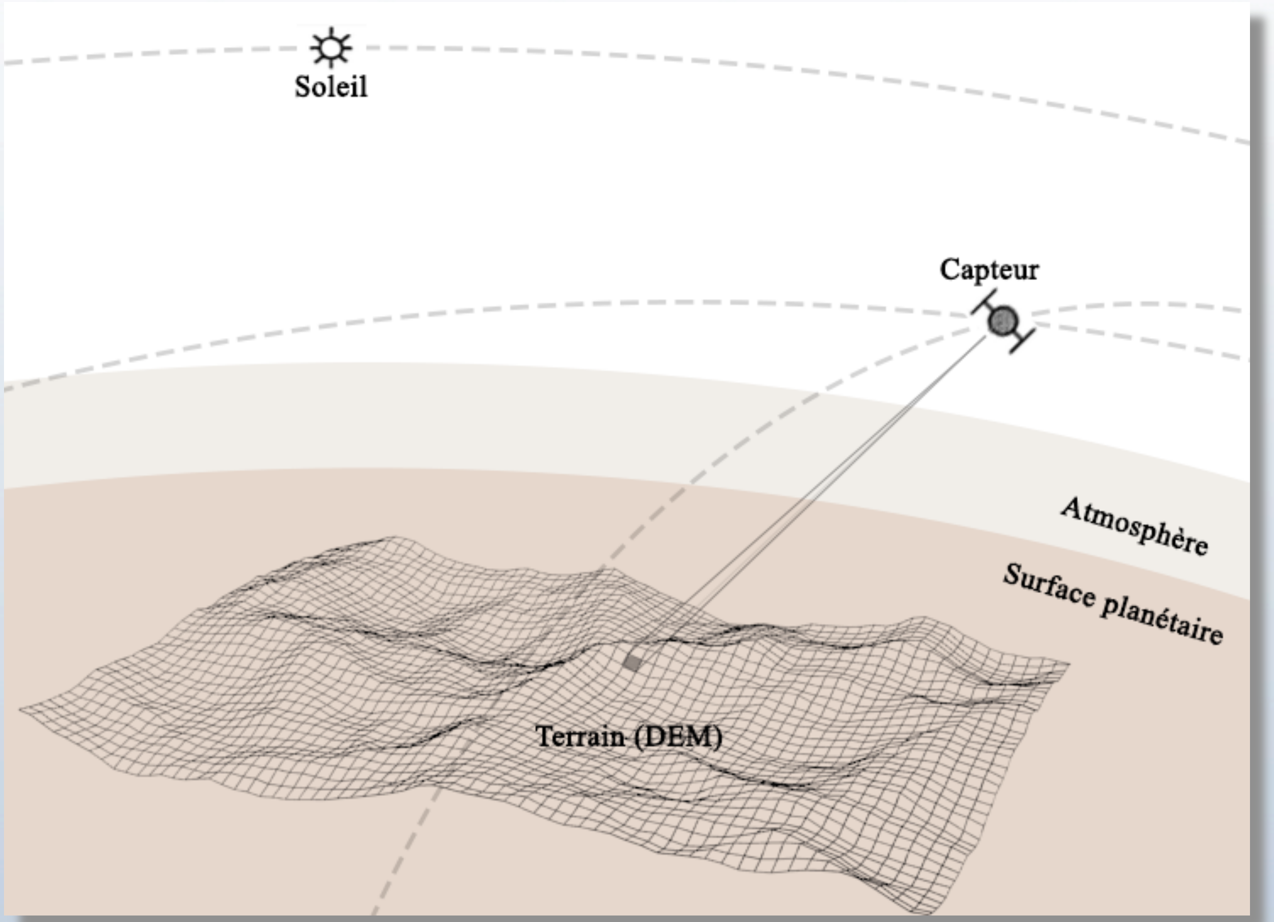
SIMULATING (HYPERSPECTRAL) IMAGES OF MARTIAN 3D SCENES

- developing and testing methods for the correction of atmospheric and photometric effects images taken by orbiter around Mars
- developing and testing methods for the linear and nonlinear spectral unmixing applied to hy-perspectral images.
- understanding the phenomenology of image formation
  - ✓ factors that control the spectrophotometric of a pixels resulting from the aggregation of physical signals at different sub-pixel scales.

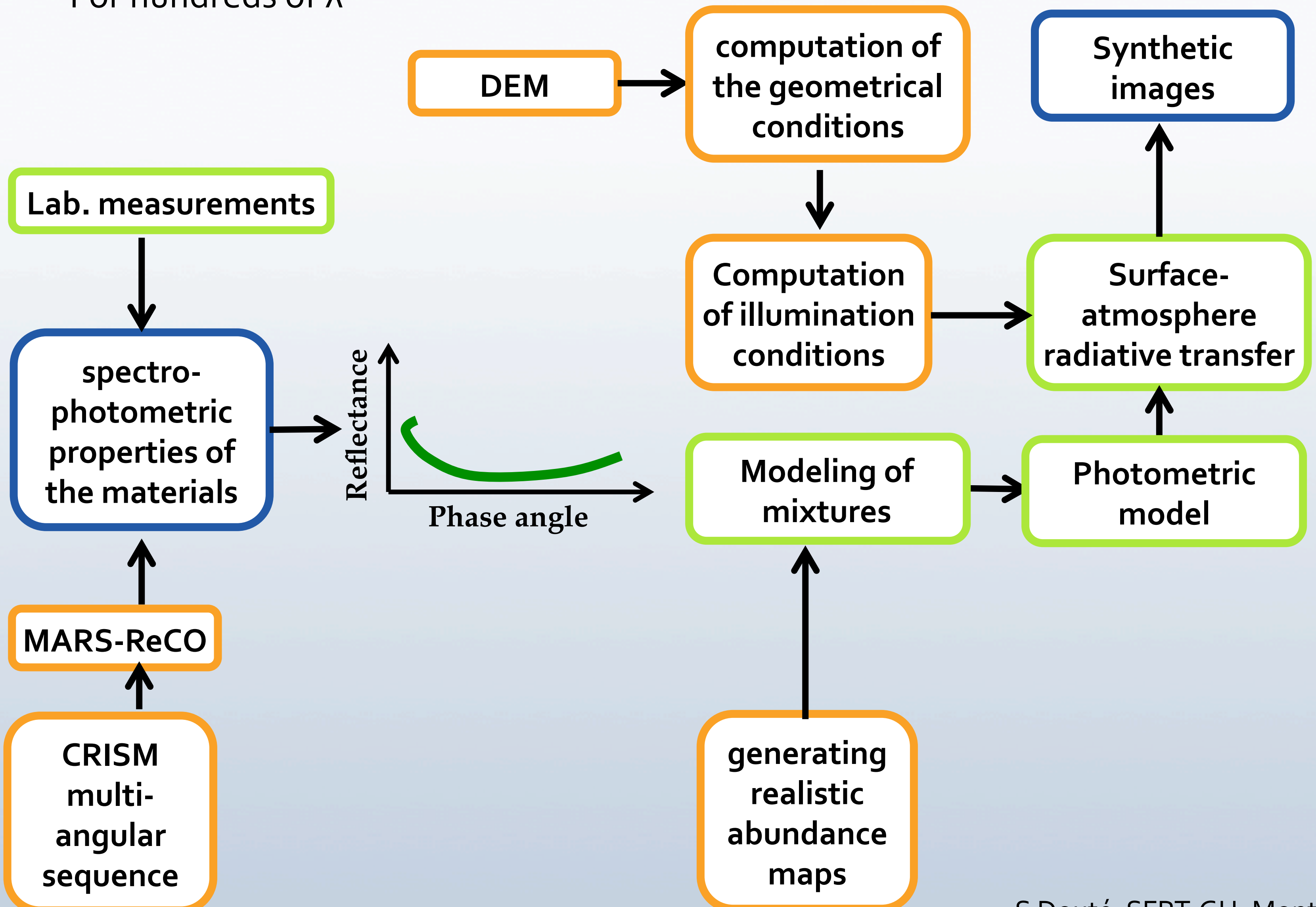
HypsimMars : a tool with a high degree of realism :

- ✓ high resolution DEM,
- ✓ description of material distribution with fractal characteristics,
- ✓ BRF measured in the laboratory for a series analogue materials, or derived from CRISM,
- ✓ mixing of spectral signatures at different scales,
- ✓ 3D radiative transfer between atmosphere and surface (fluxes and radiances).



Operational scheme of HYPSIMARS

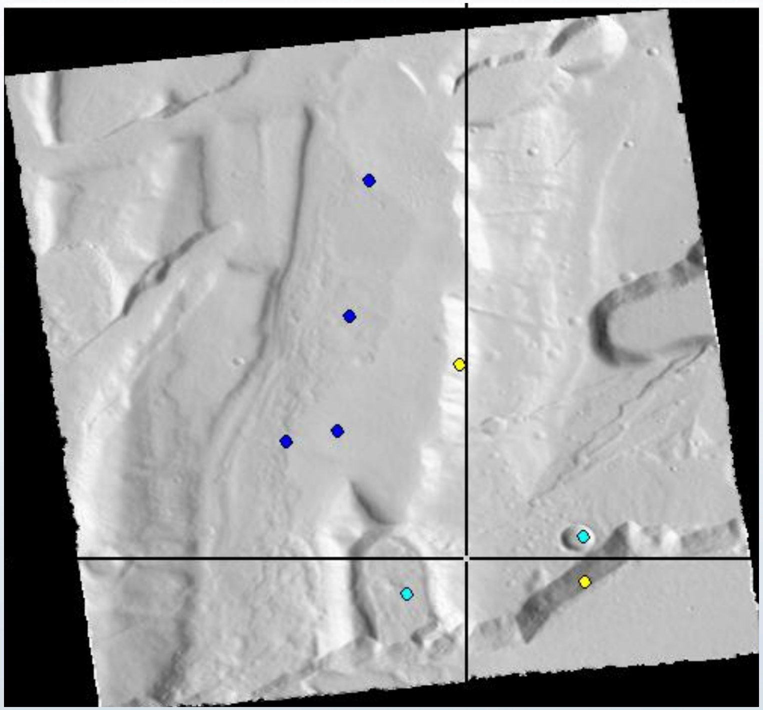
For hundreds of λ

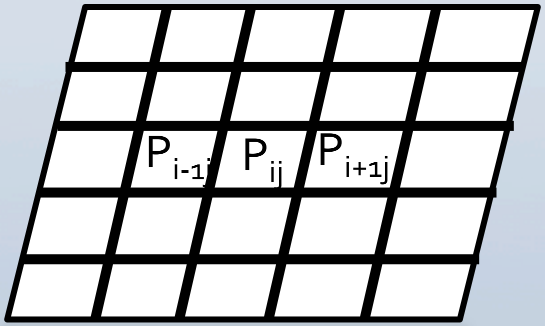


S Douté, SFPT-GH, Montpellier 2018

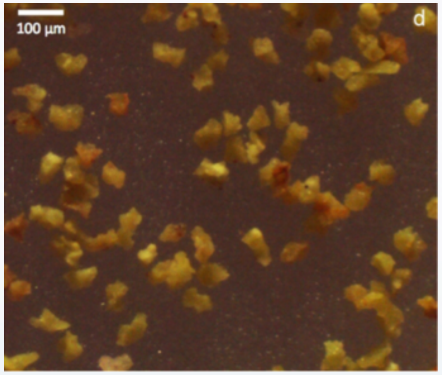
Generating realistic abundance maps using a cellular automaton

- reproducing some planetary transport and mixing processes for achieving fractal properties as expected for real scenes in nature
- iterative process starting with seeds of pure materials distributed within the scene
- probability of mixing, exchange, and no change (topographically controlled)
- distribution of the endmembers controlled by defining the seeds, the different probabilities for each action, the size of the neighborhood window, and the total number of iterations.

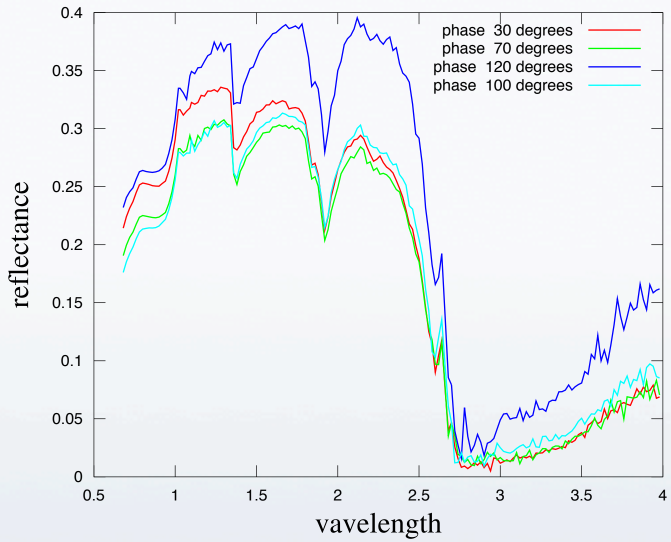


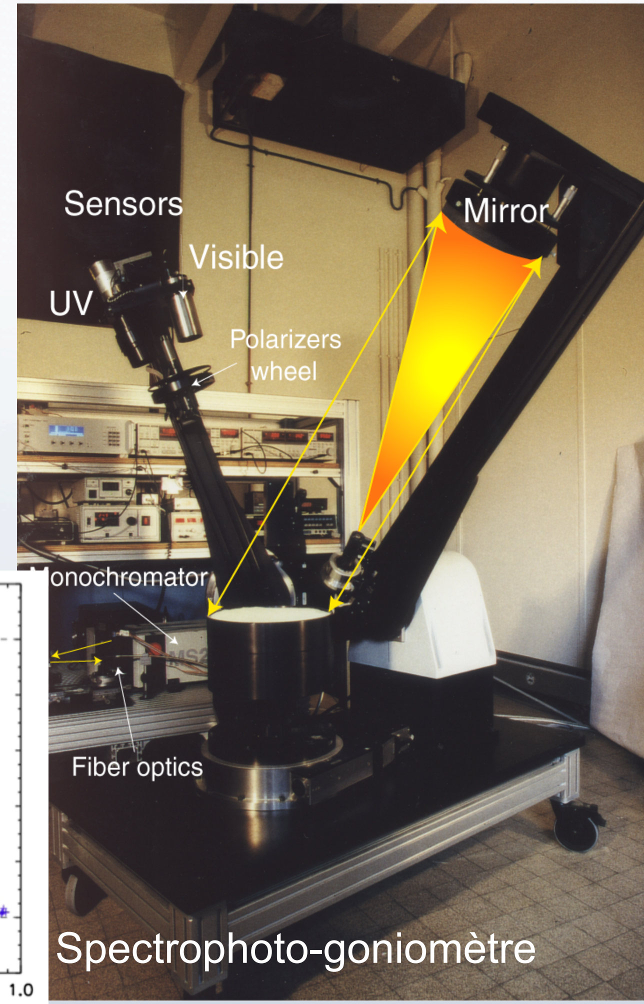


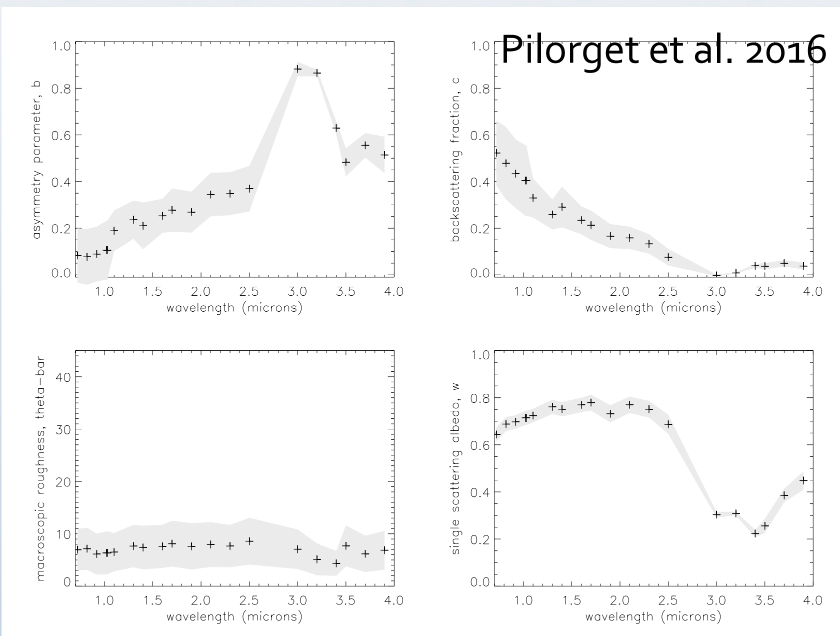
Mesures spectro-photométriques de laboratoire



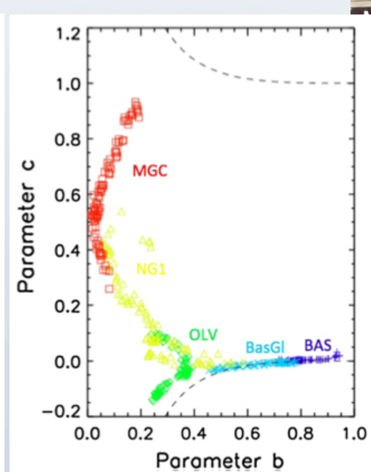
Ex: analogue martien JSC1







Pilorget et al. 2016



Paramètres photométriques Hapke évalués

8 matériaux granulaires d'intérêt planéto
incidence: 0, 30 et 60°
Emergence: -70° et 70° tous les 10°
Azimuth: plan solaire et anti-solaire

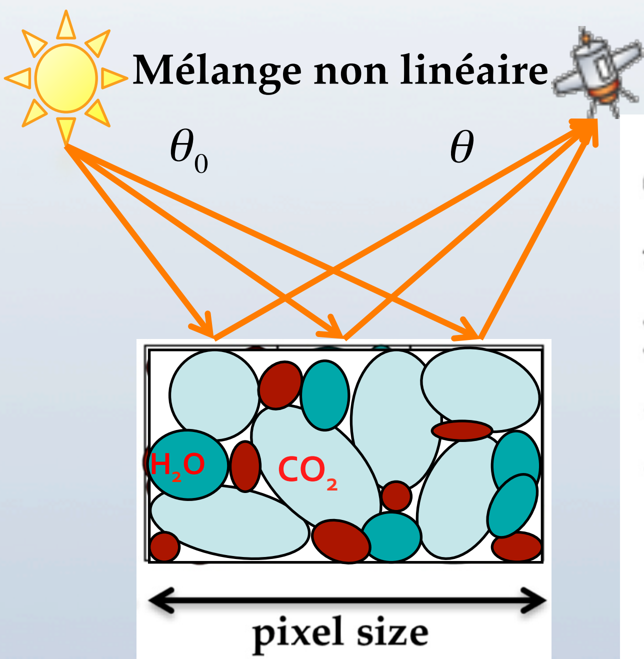
Propriétés spectro-photométriques des mélanges granulaires

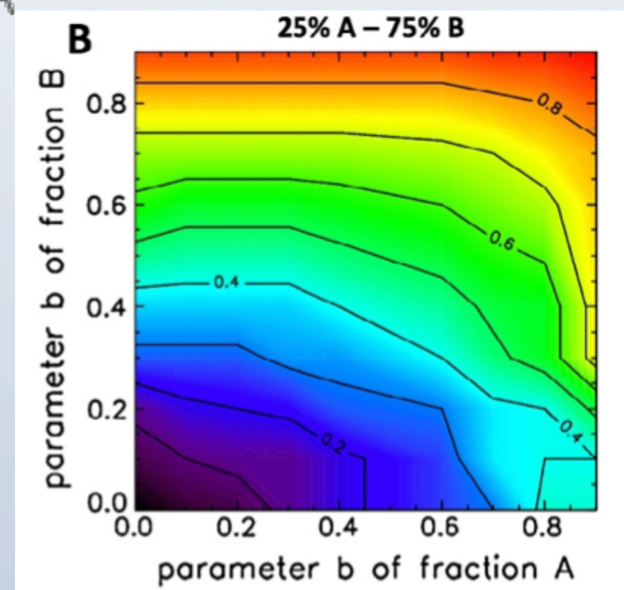
Etude des règles de mélange des paramètres photométriques $(w_r, b_r, c_r, \bar{\theta}_r)$ de chaque composant *r* de fraction f_r :

$$w = \sum_{r=1}^{R} f_r w_r \qquad c = \frac{\sum_{r=1}^{R} f_r w_r c_r}{\sum_{r=1}^{R} f_r w_r}$$

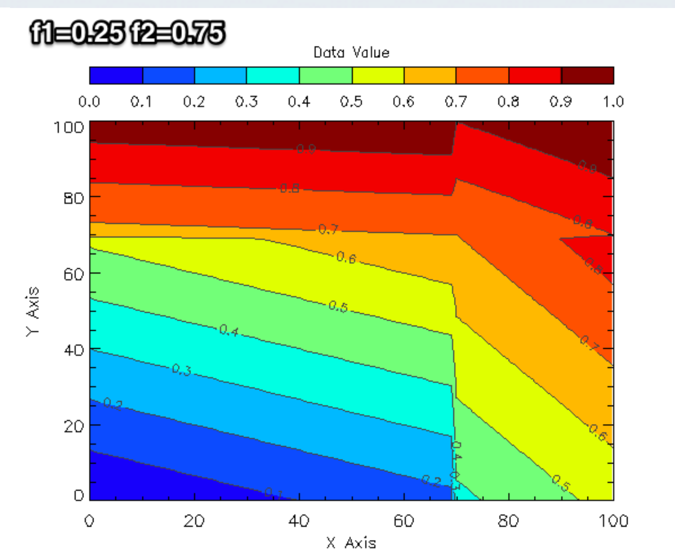
b is dominated by the higher value of b_r

Pilorget et al. 2015





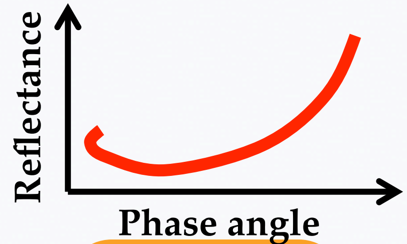
Résultats expérimentaux

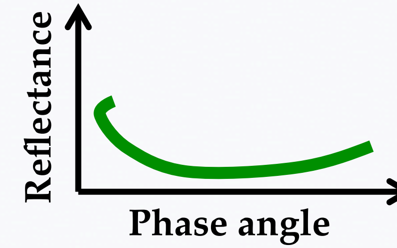


Paramétrisation mathématique

Obtention et analyse de produits spectro-photométriques CRISM

pour 544 λ





observation CRISM → fusion des 11 images → courbes spectro-photo capteur → « MARS-ReCO » schéma TR atmosphère-surface inversion → reflectance de surface en fct. de la géométrie

↓

Ajustement par modèle physique

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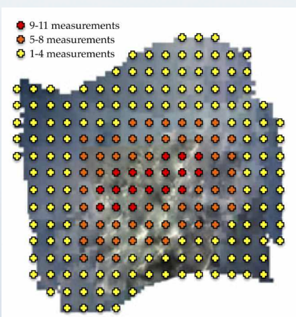
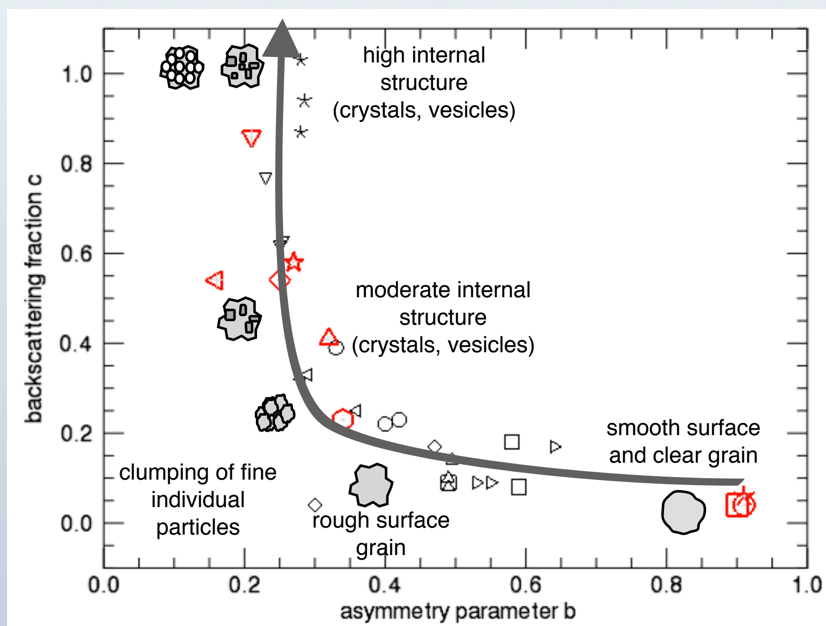
cartes de paramètres photométriques

↓

interprétation physique et planéto



données Lab. →

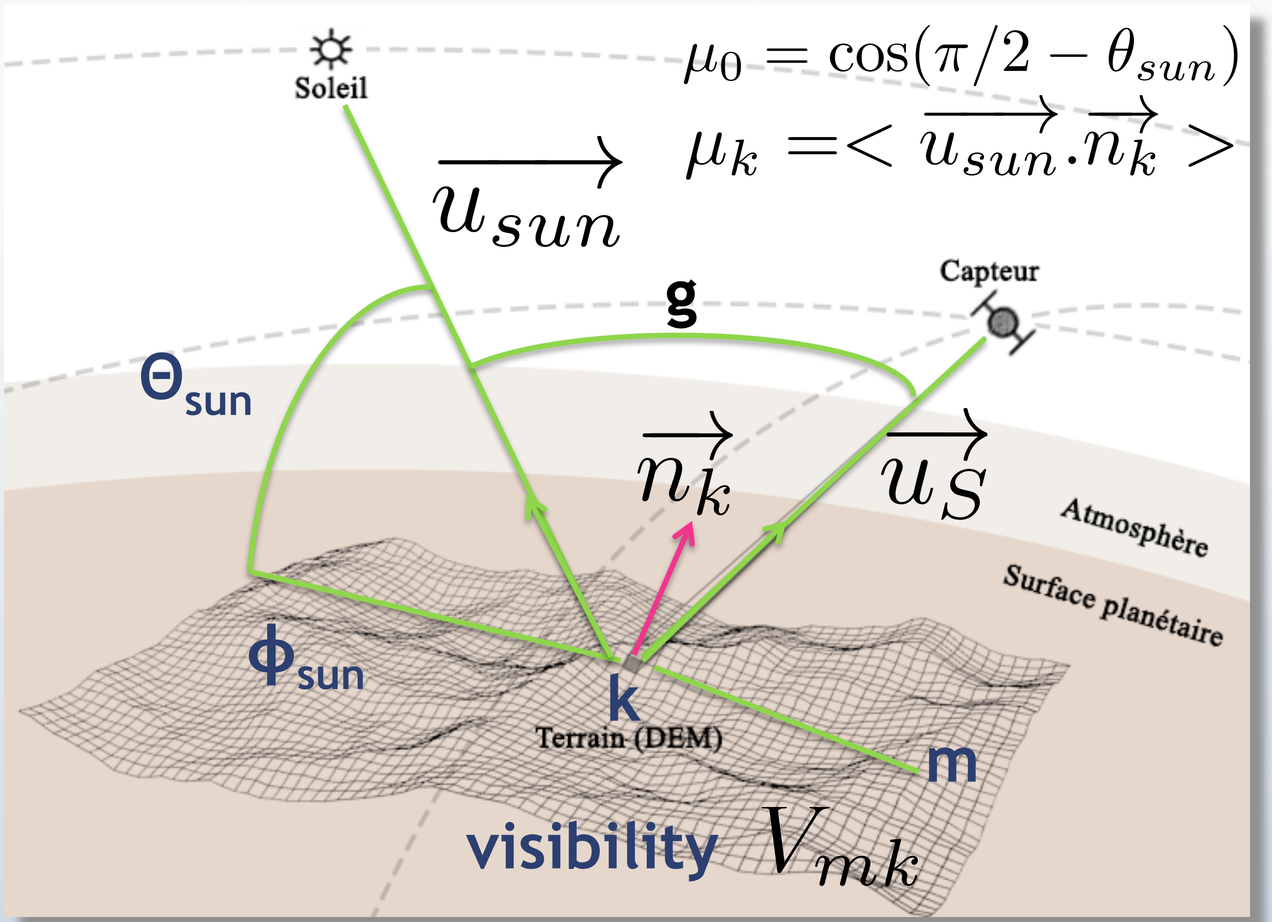


Ceamanos, Douté et al. JGR 2013

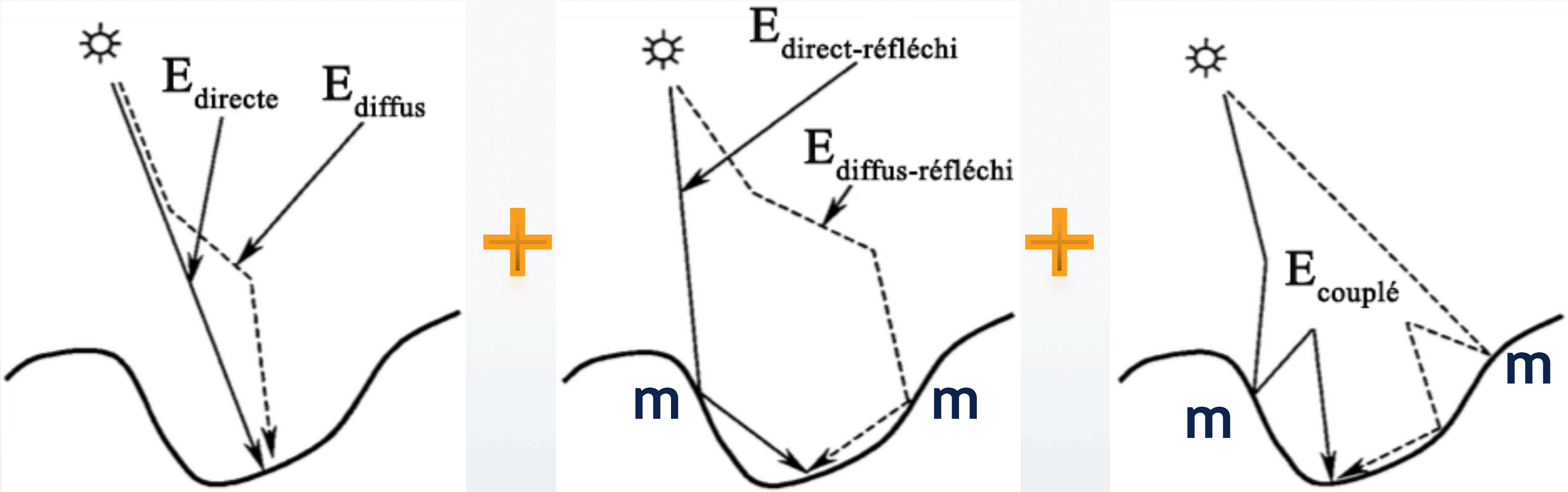
Douté et al.IEEE 2015

Computation of geometrical and illumination conditions

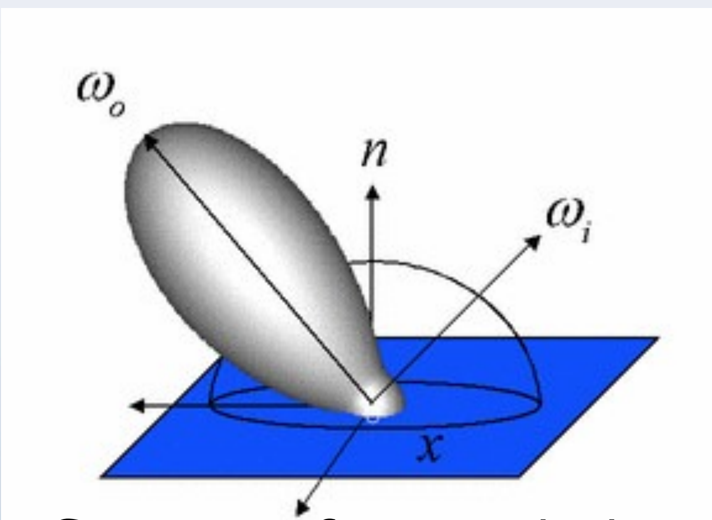
ρ_{BOA}



Geometrical conditions of the simulation.



×



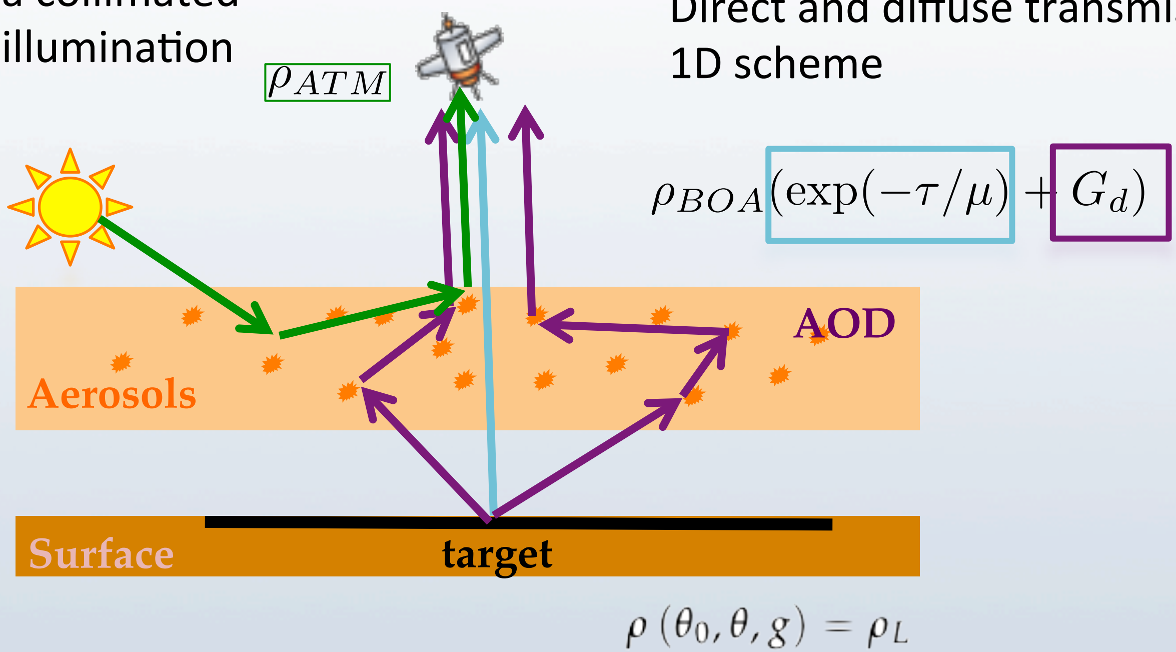
$$= \rho_{BOA}$$

Reflectance factors: bidirectional ρ^{dd}
hemispherical directional ρ^{hd}
Lambertian ρ_L

Signal measured by the sensor.

Reflectance by the atmosphere alone for a collimated illumination

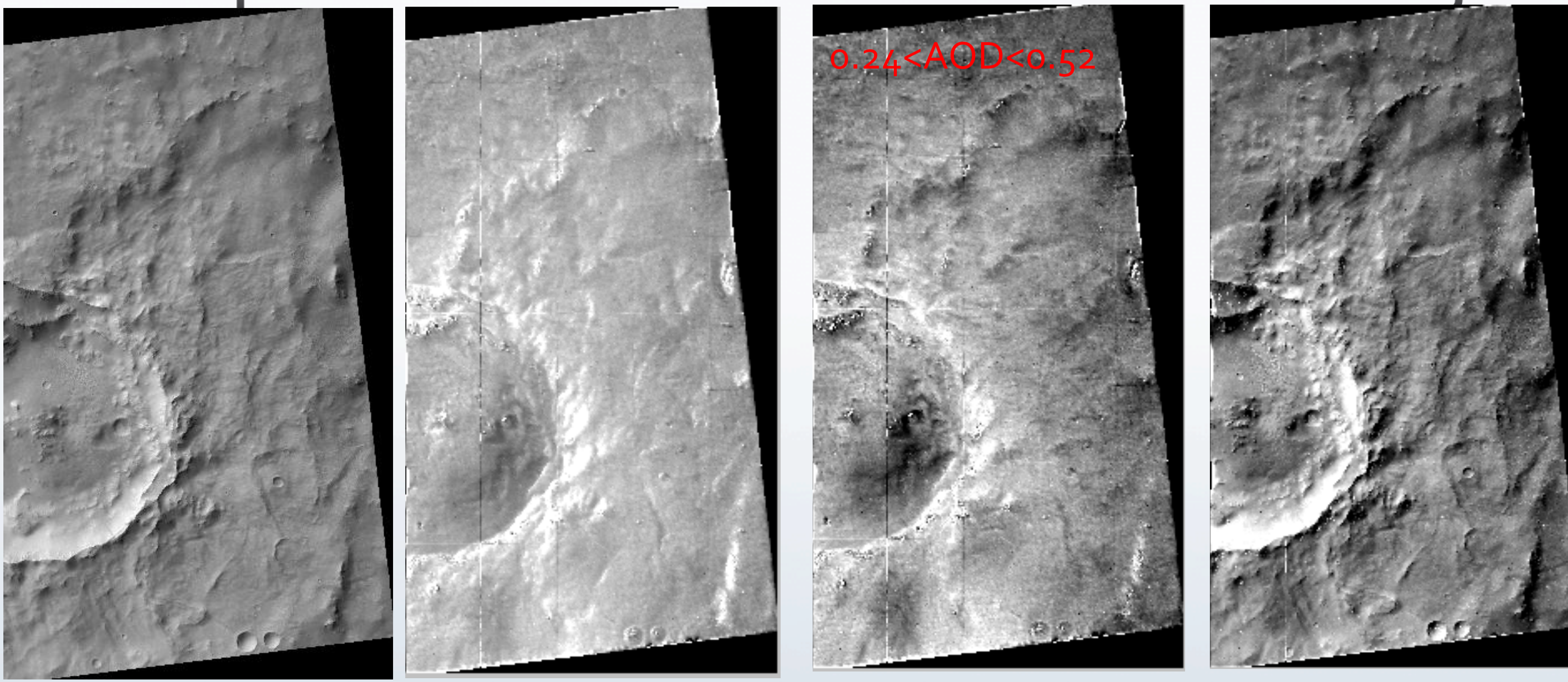
Direct and diffuse transmission through the atmosphere
1D scheme



total reflected by surface-atmosphere :

$$\rho_{TOA} = \rho_{ATM} + \rho_{BOA}(\exp(-\tau/\mu) + G_d)$$

Atmospheric and radiometric correction of real images



original image | $\tau^j = 0.1$ | $\tau^j = 0.72$ | $\tau^j = 1.5$

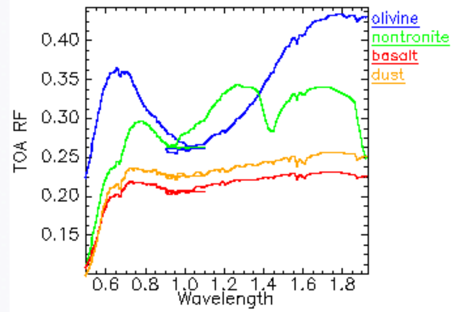
$\text{std\_dev}(\zeta^j) = 0.12$ | $\text{std\_dev}(\zeta^j) = 0.08$ | $\text{std\_dev}(\zeta^j) = 0.22$

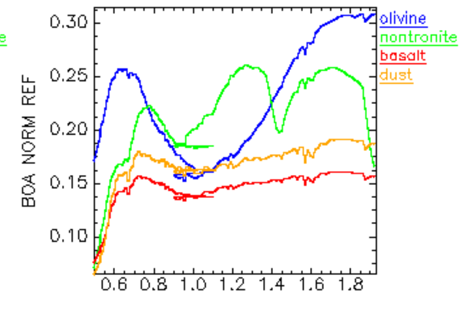
Inc : 60°
Eme : 15°
Az sun : 305°

normalized image
$$\zeta^j = \frac{S^j (I/F)_{CTX} - D_s^j}{(\exp(-\tau_j/\mu) + G_d^j)\rho_{BOA}^j}$$

The simulator generates the BOA image ρ_{BOA}^j the map of the path radiance D_s^j and the map of combined direct and diffuse transmission $(\exp(-\tau_j/\mu) + G_d^j)$ to the sensor with an AOD τ^j varying between 0.1 and 1.5.

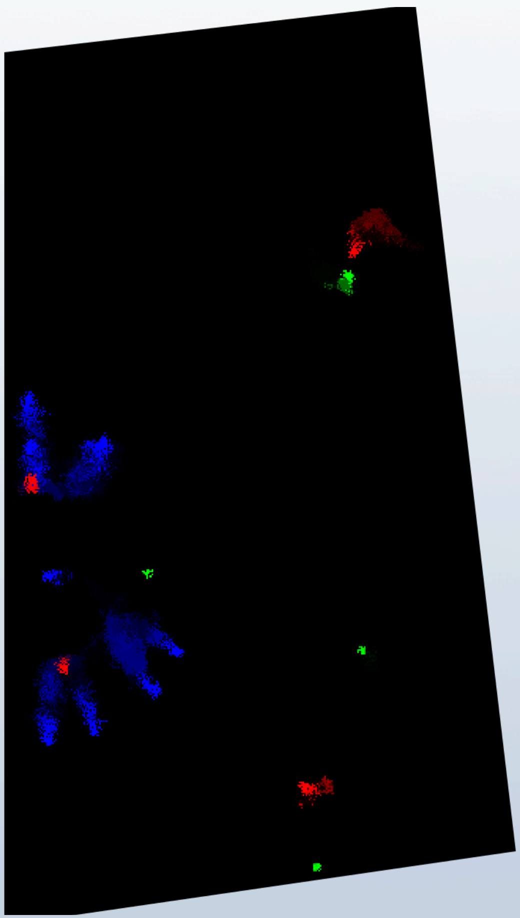
Simulating well controlled HS images for testing spectral unmixing methods



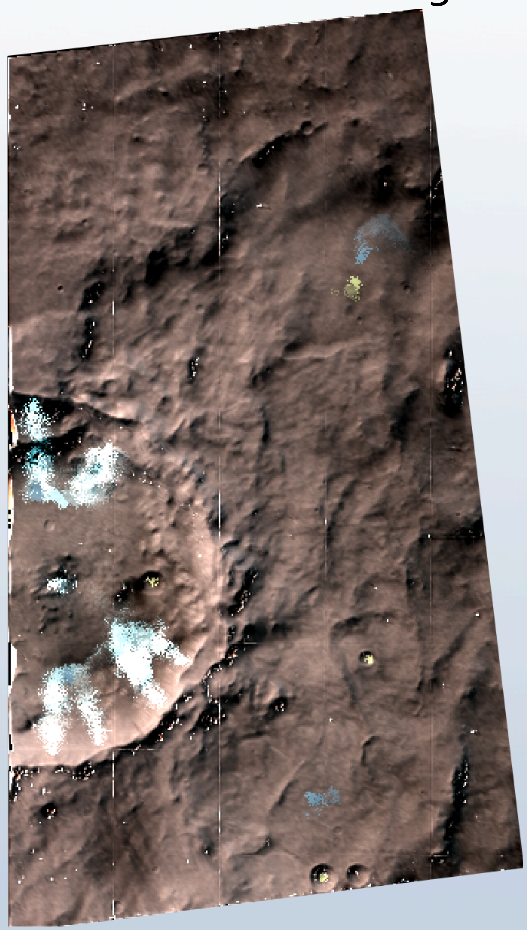


Typical Martian dust locally mixed with basalt, nontronite, and olivine

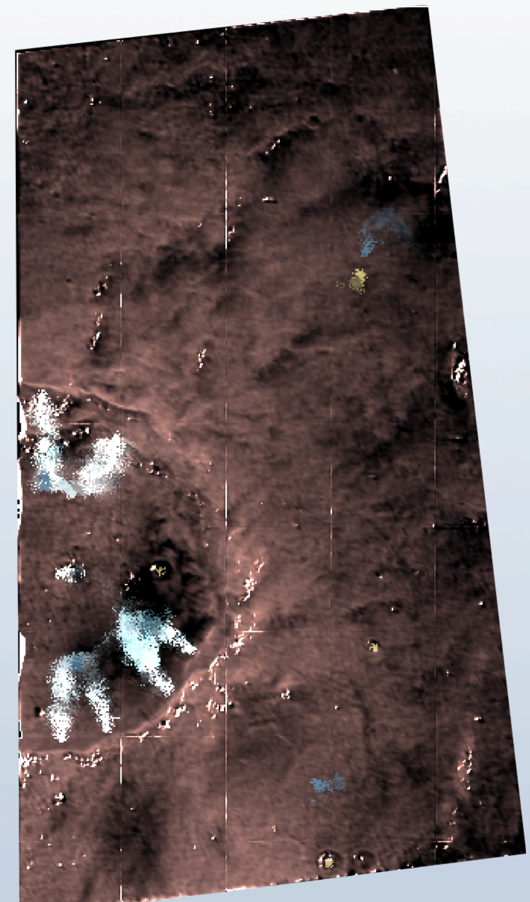
Abundance map



Simulated TOA HS image



BOA normalized reflectance HS image



S Douté, SFPT-GH, Montpellier 2018

Conclusion

Un outil pour approfondir l'exploitation des images (hyperspectrales) planétaires

- MNT haute résolution
  (horizontale 10m.pixel-1 et verticale 10m sur des aires ≈1000 km2.)
- cartes d'abondances réalistes
- cartes de propriétés spectro-photométriques
  de surface résultant de processus de mélange multi-échelle
- correction des effets photométriques et atmosphériques
- Base de données d'images hyperspectrales synthétiques
  pour tester les méthodes d'analyse.

Perspectives

- A better physics for the treatment of :
  - ✓ adjacency effects,
  - ✓ downward irradiance resulting from the multiple scattering between the atmosphere and the surface (E_coupling),
  - ✓ diffuse 3D transmission of the radiance leaving the surface to the sensor.

- A better computing for the treatment of :
  - ✓ geometrical intersections
    (k-d trees representation of DEM)

➢ **3D Monte Carlo radiative transfer model**