Data Science for Planetary Science

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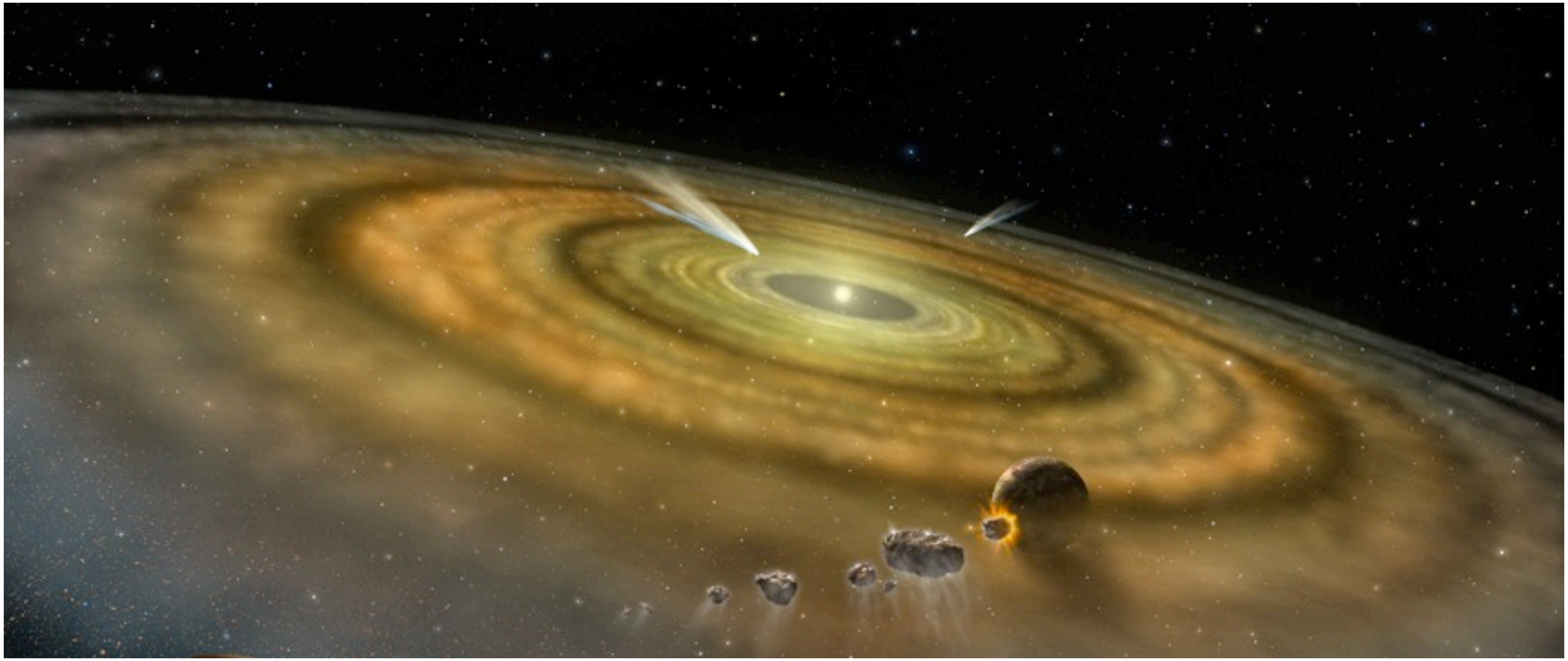
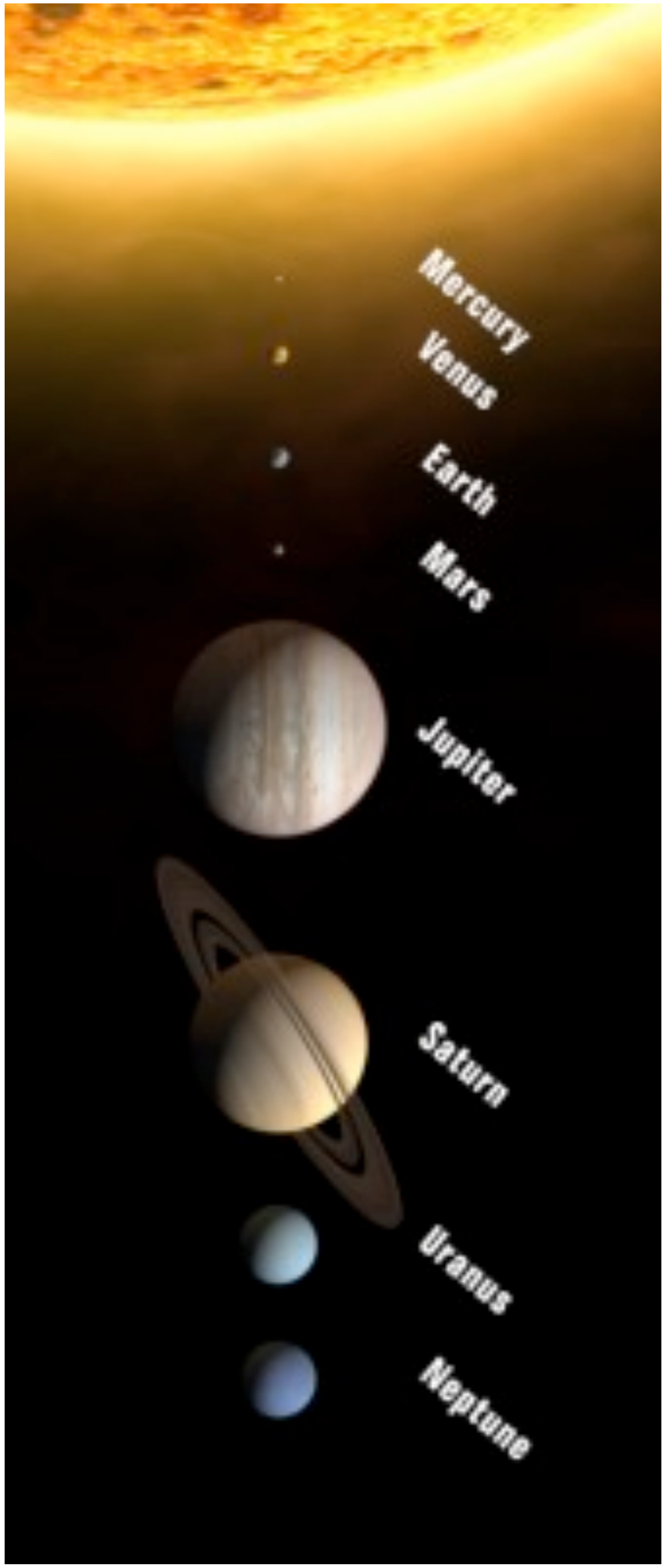
Planetary Science

- Planetary formation
  - From disk to (exo)planets
  - Meteorites, comets



Planetary Science

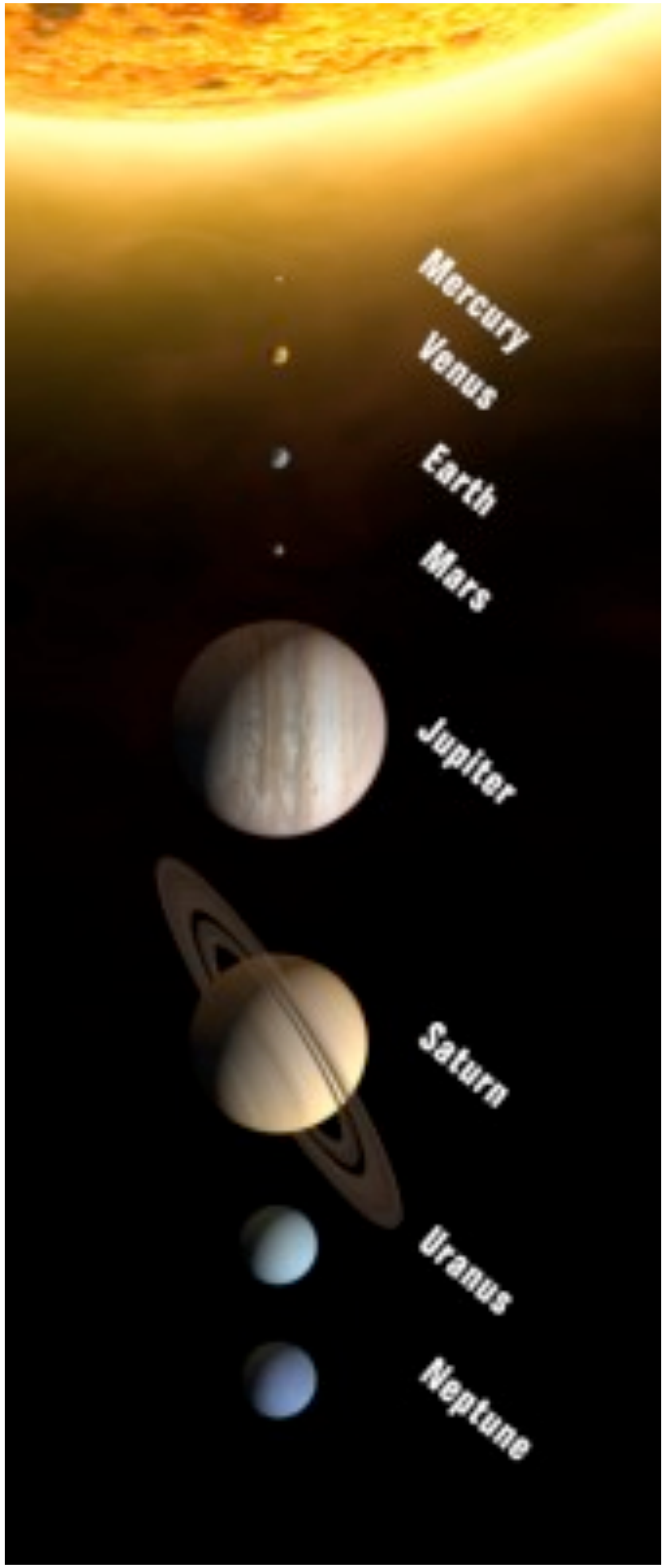
- Planetary bodies
  - Interior
  - Surface
  - Atmosphere
  - Ionosphere



Planetary Science

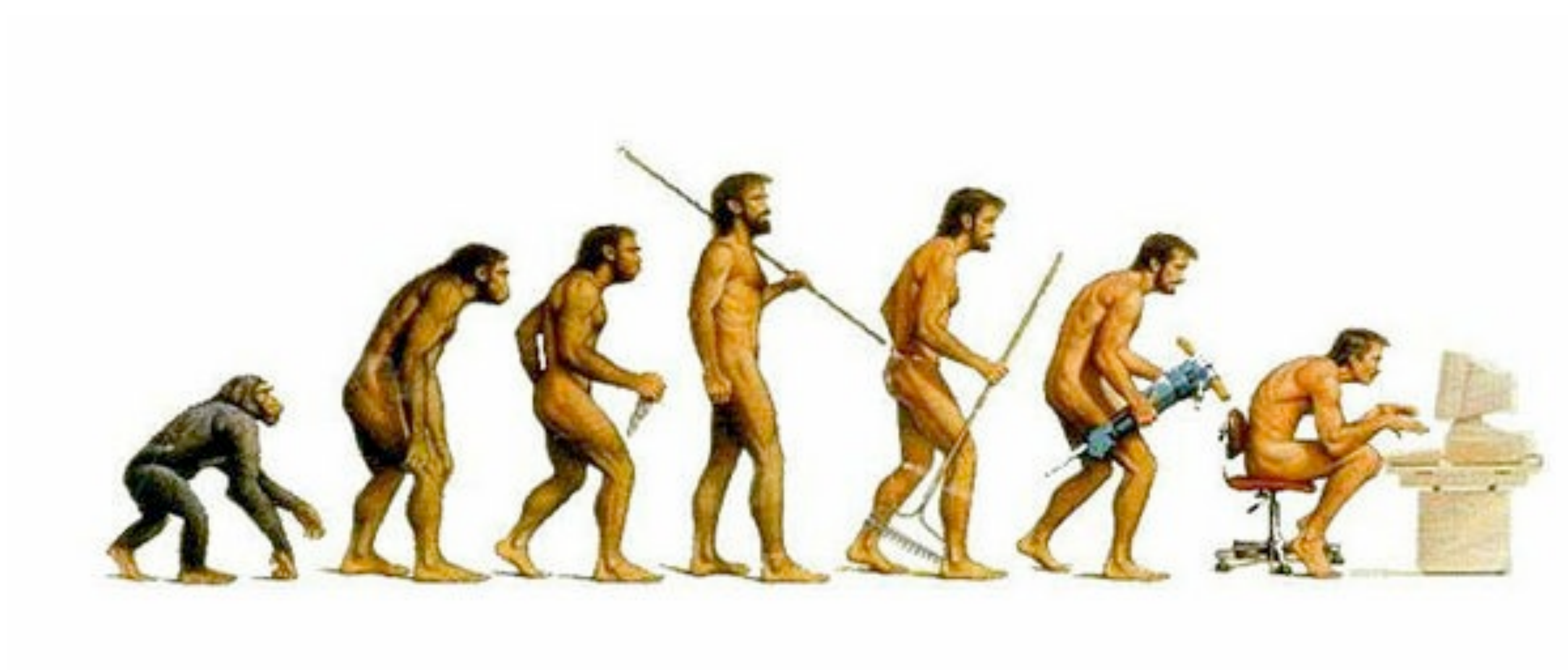
- Planetary bodies
  - Interior
  - **Surface**
  - **Atmosphere**
  - Ionosphere

Remote sensing : imagery



Big scientific questions

- Geologic evolution (tectonic, volcanic, ...)
- Climate evolution (climate change, escape, ...)
- Habitability (origin of life, human exploration)



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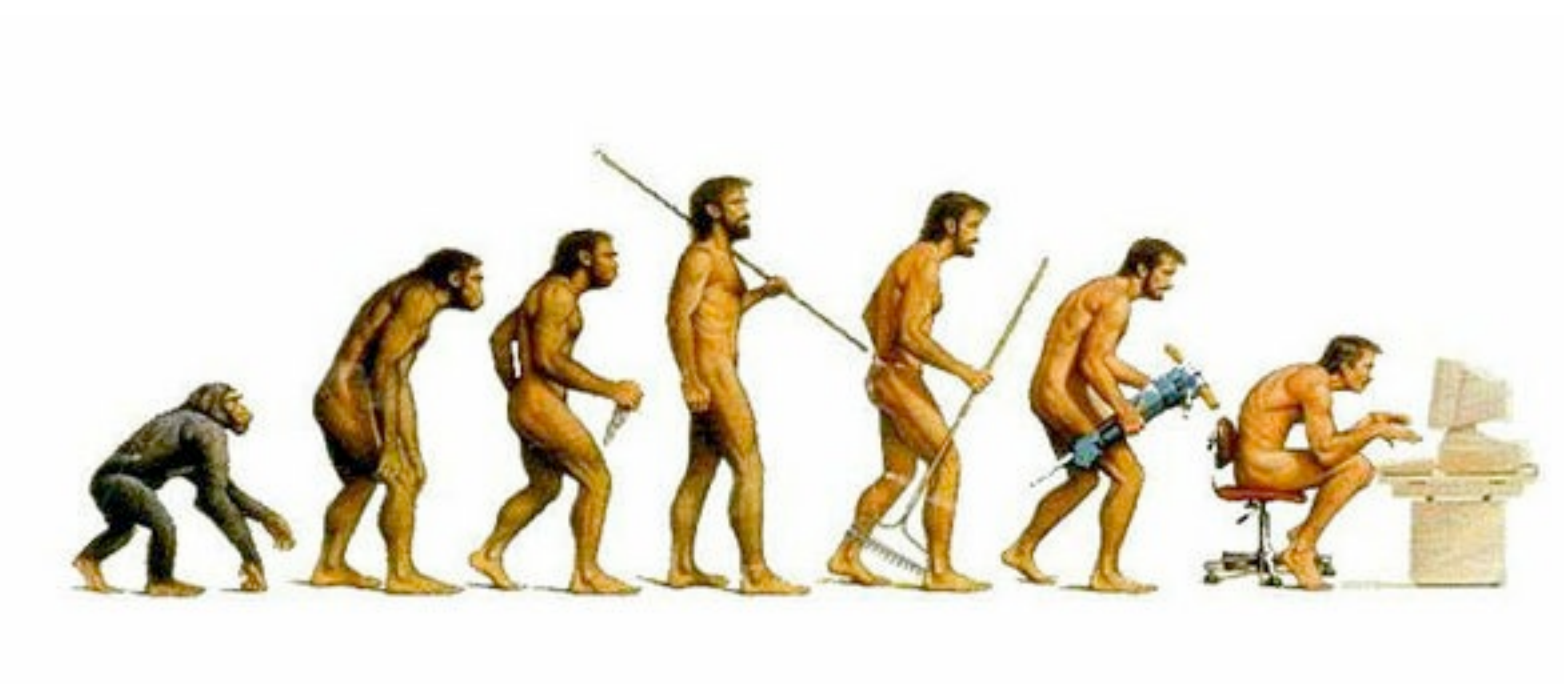
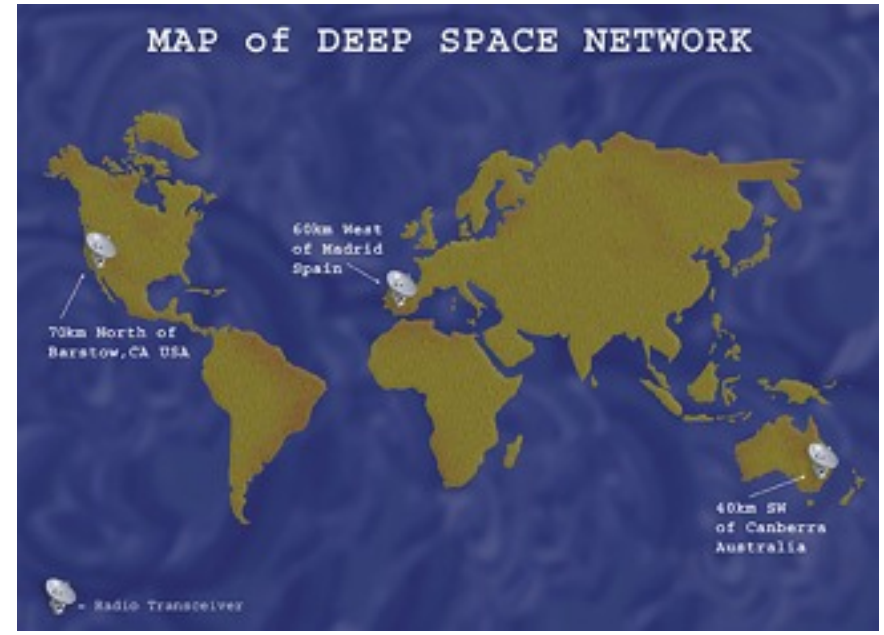
?  ?

Raw data



- Mars Express (ESA, launched in 2003) : ~50 Tb
- Mars Reconnaissance Orbiter (NASA, launched in 2005) : ~200 Tb

Calibrated data

- Increase factor : ~10

Huge amount of data

- How to treat the data ?
- How to represent the scientific results (in a global map) ?

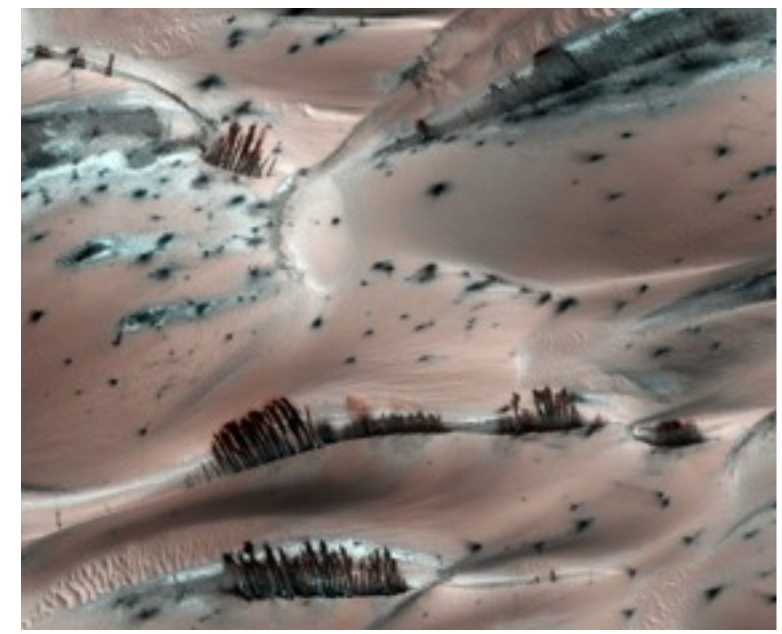
Franquin, Gaston Lagaffe

Large volume products

- High resolution spectra
- High resolution images
- Hyperpectral images
- Multi-angular hyperspectral images

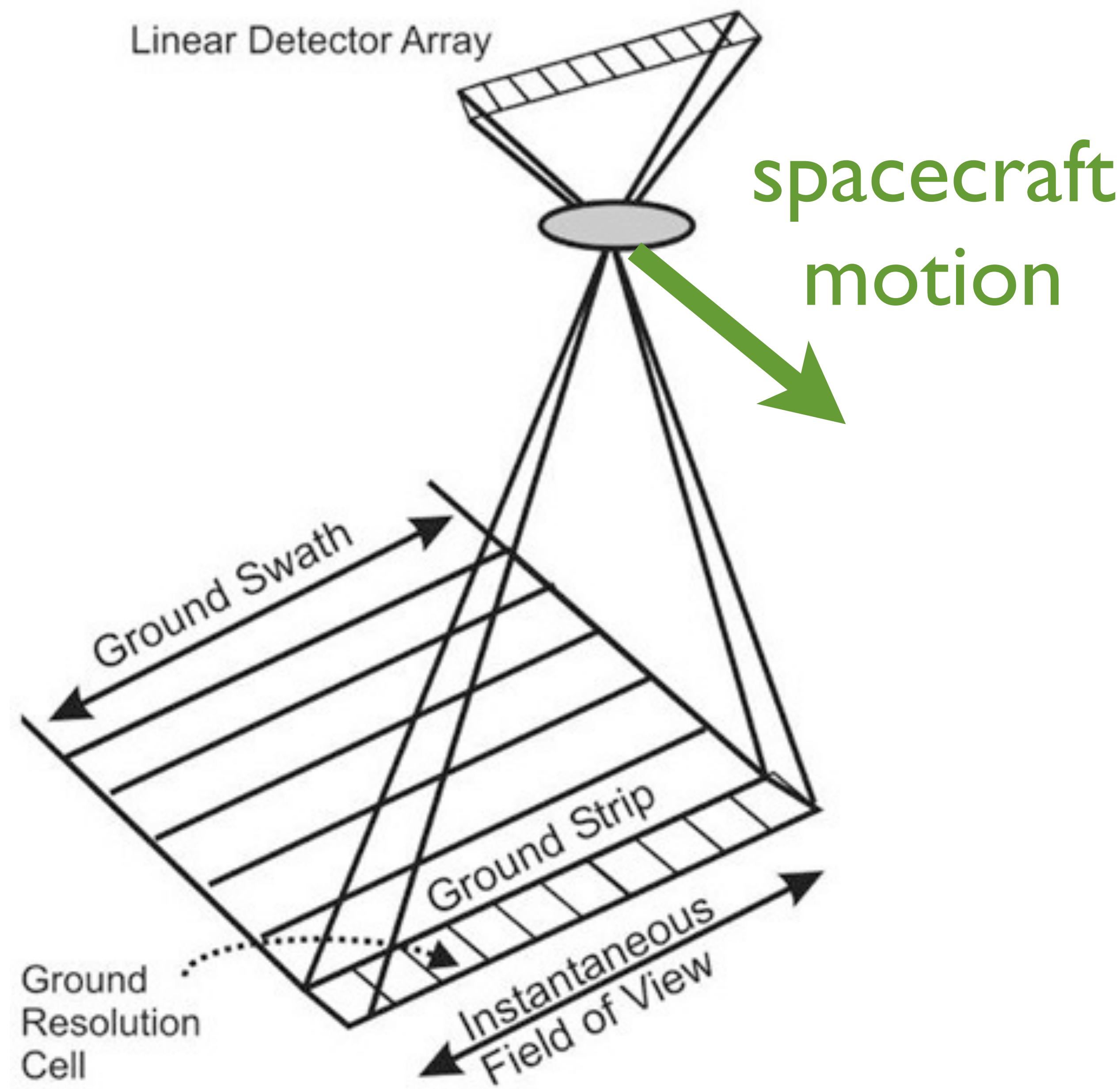
Large volume products

- High resolution spectra
- **High resolution images**
- Hyperpectral images
- Multi-angular hyperspectral images



Imaging techniques

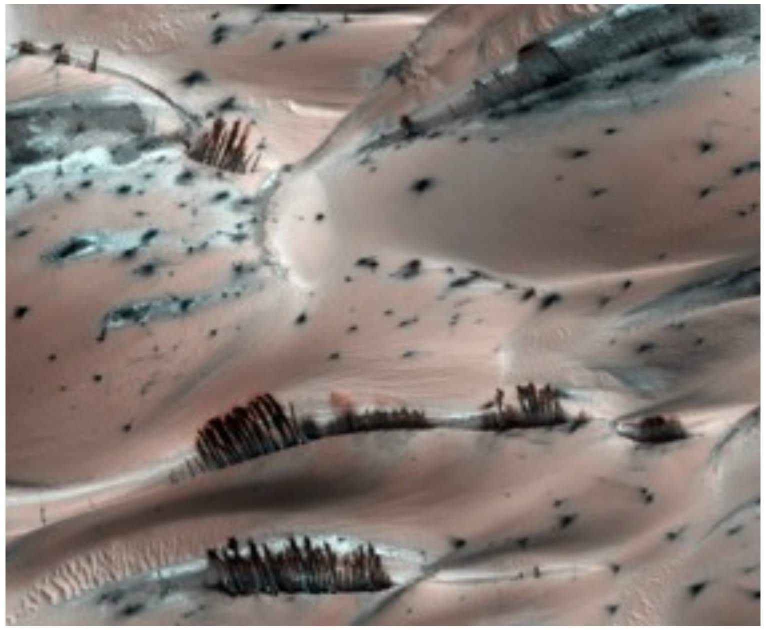
- Usual Camera
- Pushbroom system
  - up to 20 000 pixels



Examples of high resolution images datasets

- MOC (Mars Global Surveyor, NASA) Malin and Edgett, 2000
- HRSC (Mars Express, ESA) Neukum et al., 2004
- ISS (Cassini, NASA) Porco et al., 2004
- HiRISE (Mars Reconnaissance Orbiter, NASA) McEwen et al., 2007
- ...

Data Science Challenges for images

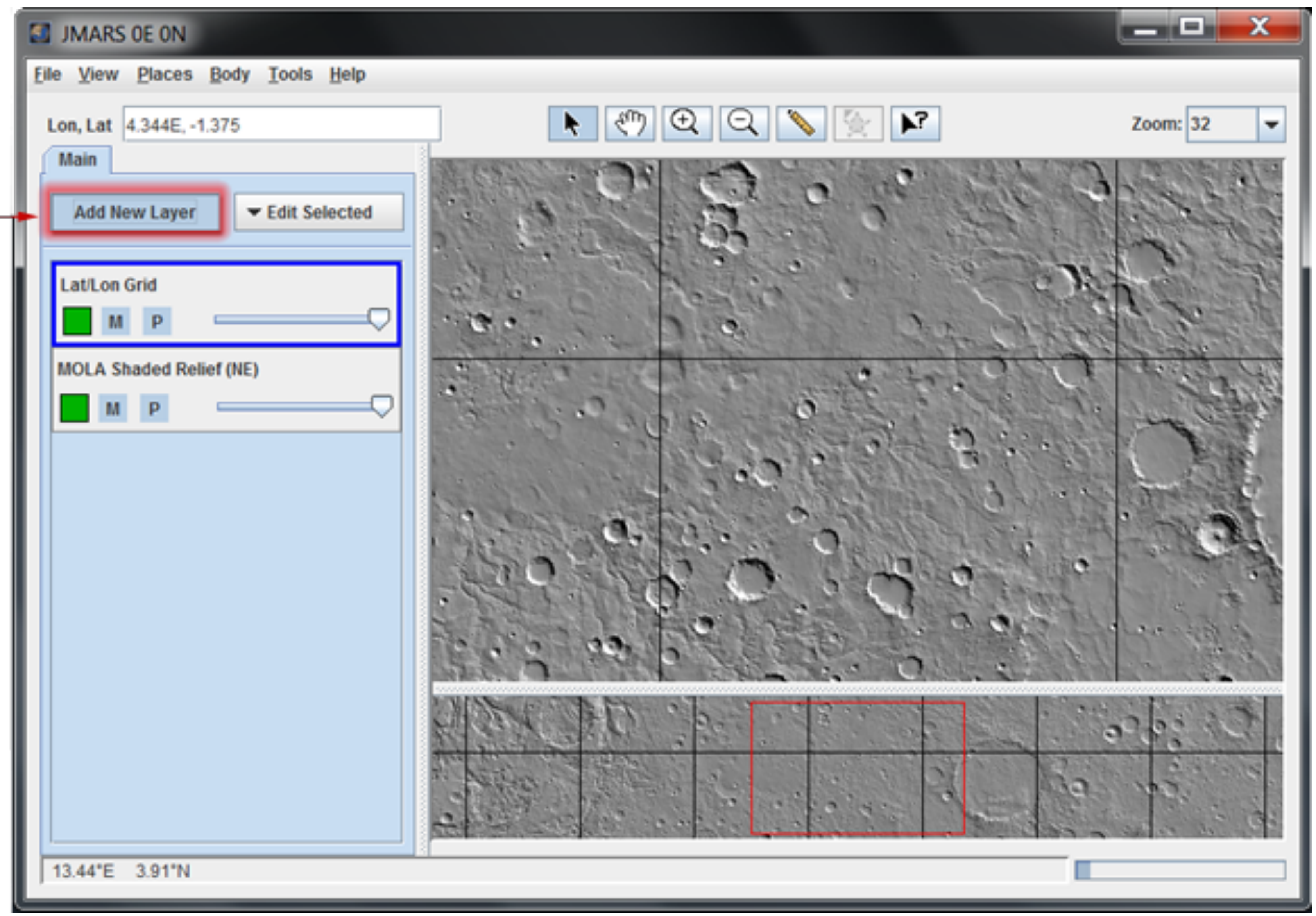


Tools for large dataset treatment:

1. global scale mosaic visualisation
2. stereoscopy to create DEM
3. change detection (crater, dust devils, dune, ...)
4. automatic feature identification

1. Scientific data visualisation

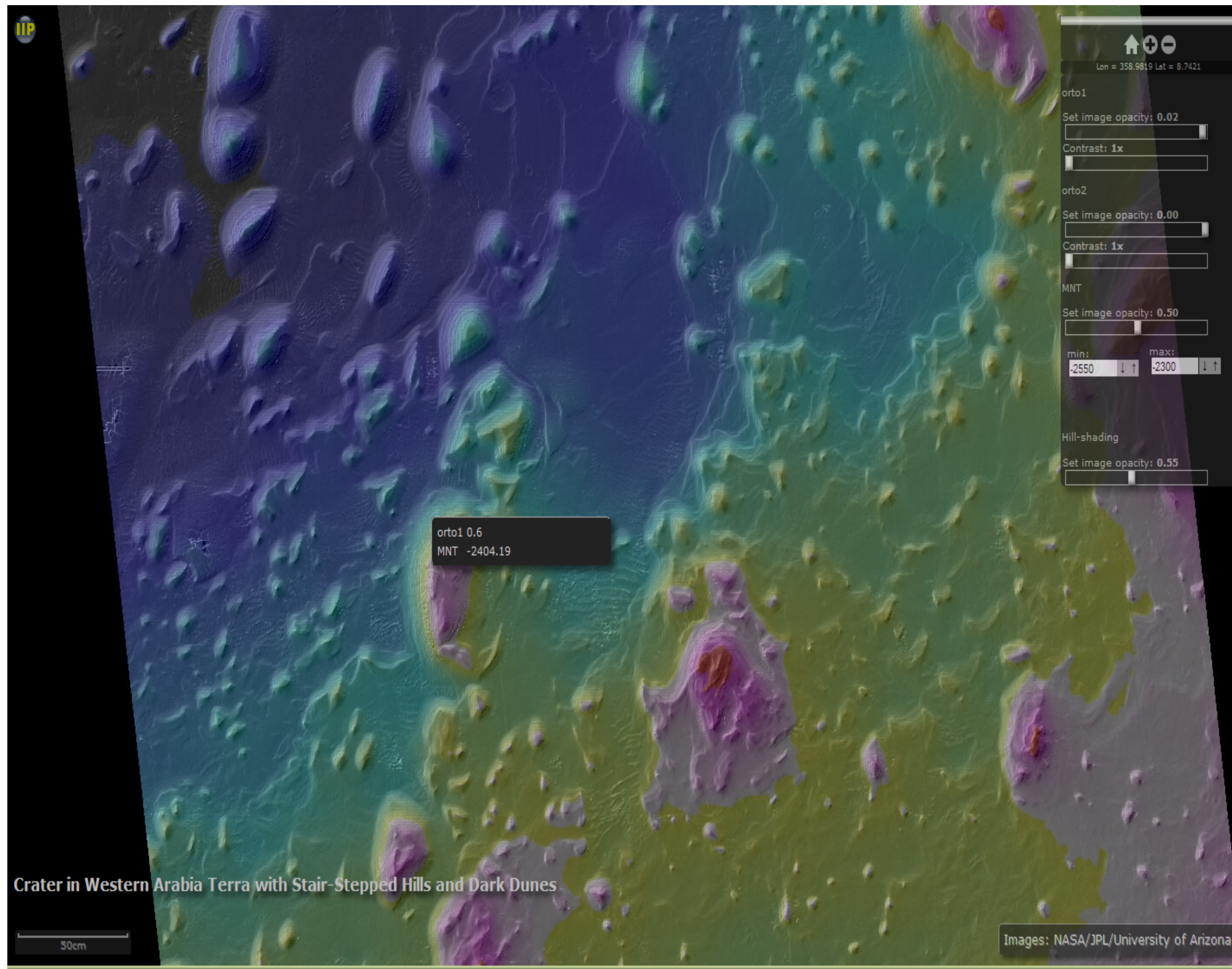
- Google Mars
  http://www.google.com/mars/
- MapAPlanet
  http://www.mapaplanet.org/
- JMars,...
  http://jmars.asu.edu/



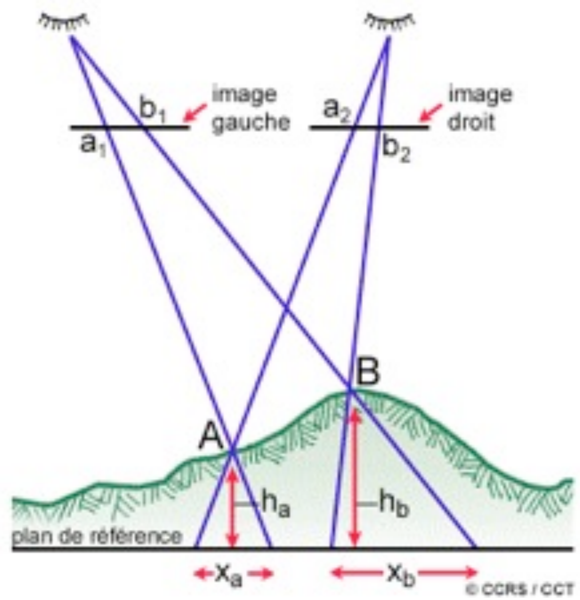
- Limitations:
  - no scientific data
  - not complete
  - Slow

1. Data visualisation project

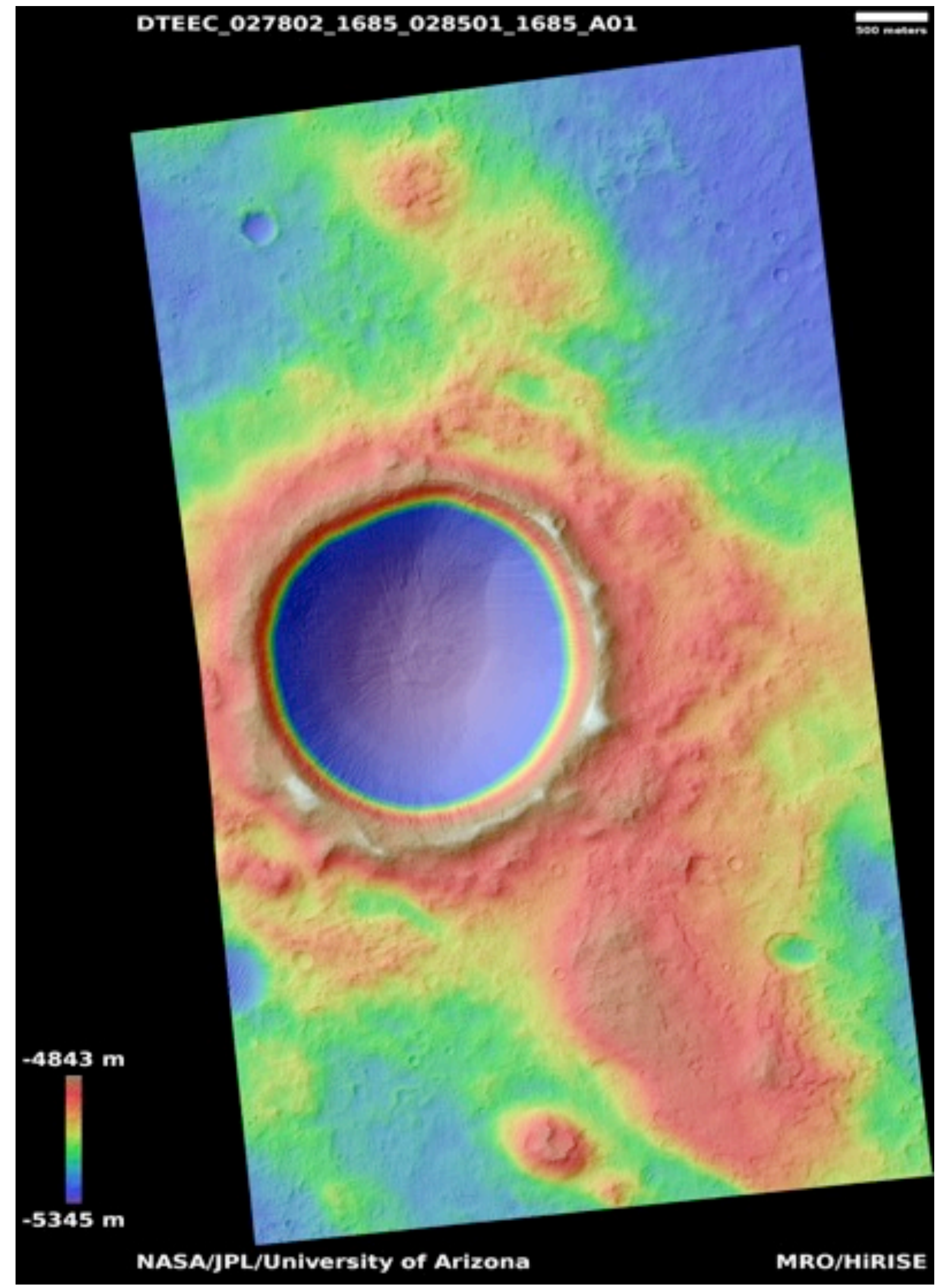
- Web based approach
- 3D and GIS oriented
- C. Marmo (GEOPS/IAS/OSUPS)



2. Digital Elevation Model

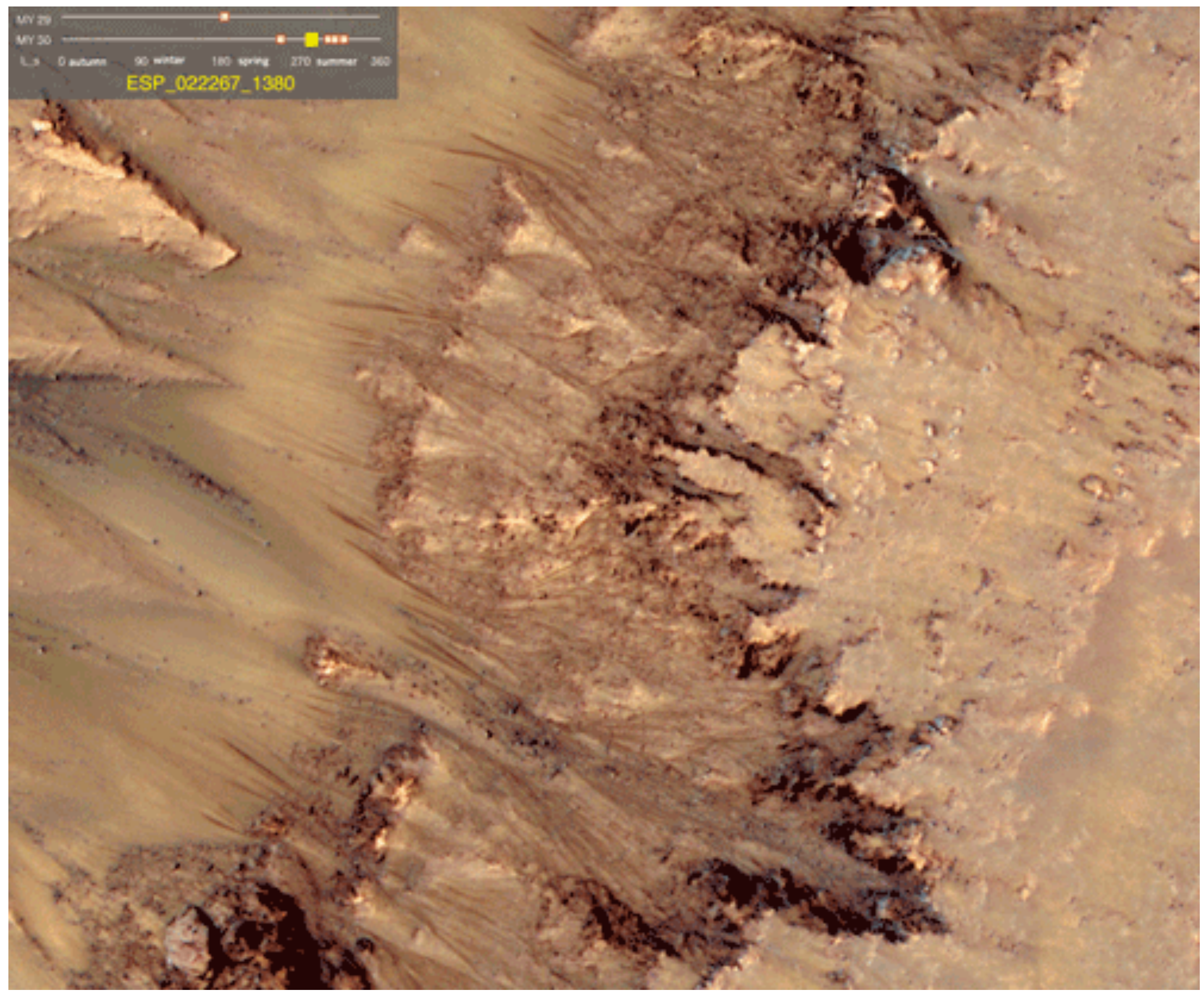


- Stereoscopy
  - based on image correlation
- Limitations:
  - Very slow
  - Uncertainties ?



3. Change detection

- HiRISE (august 2011)
- Flow
- Summer (~30°S)
- Liquid water ?



McEwen et al., 2011

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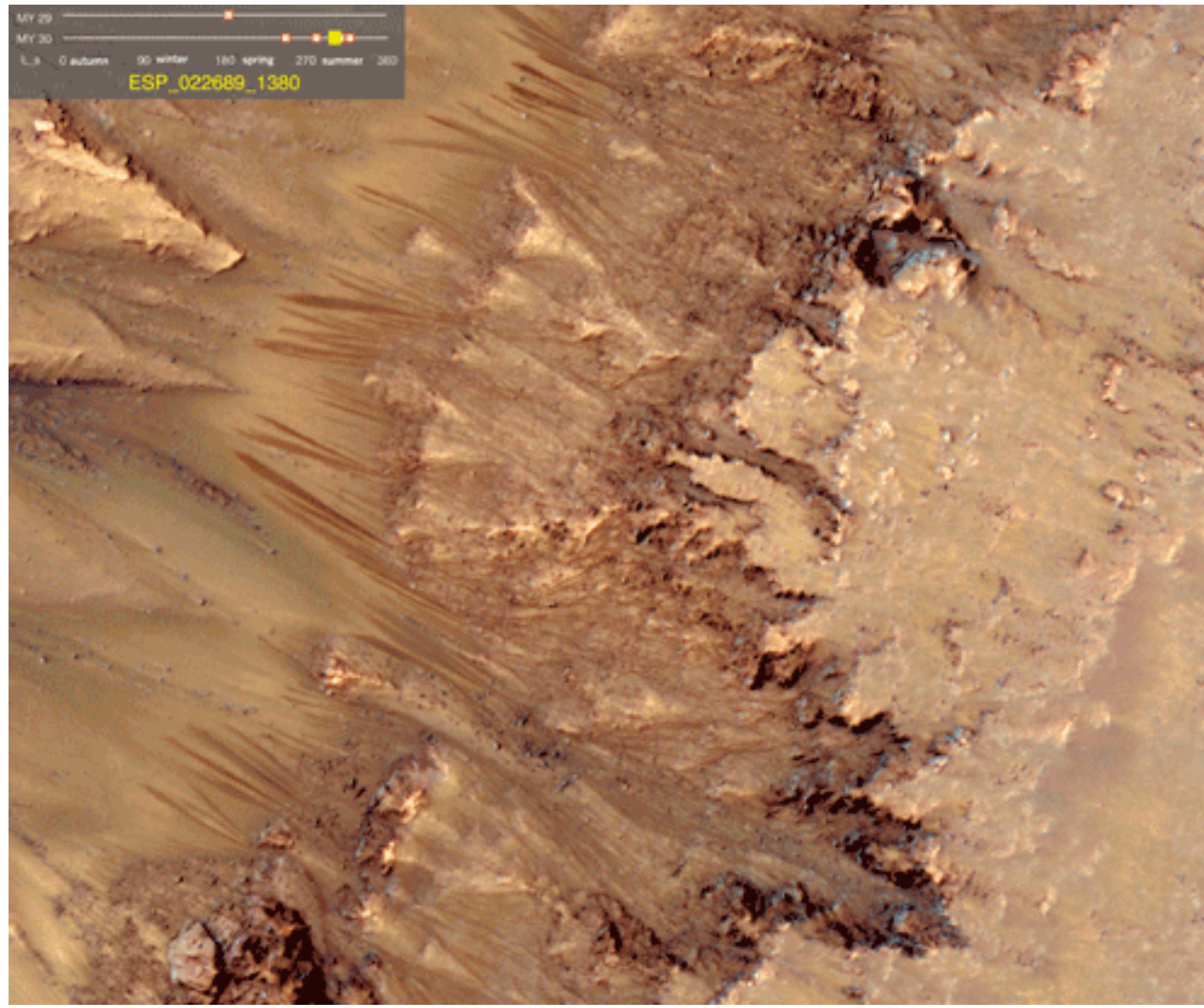
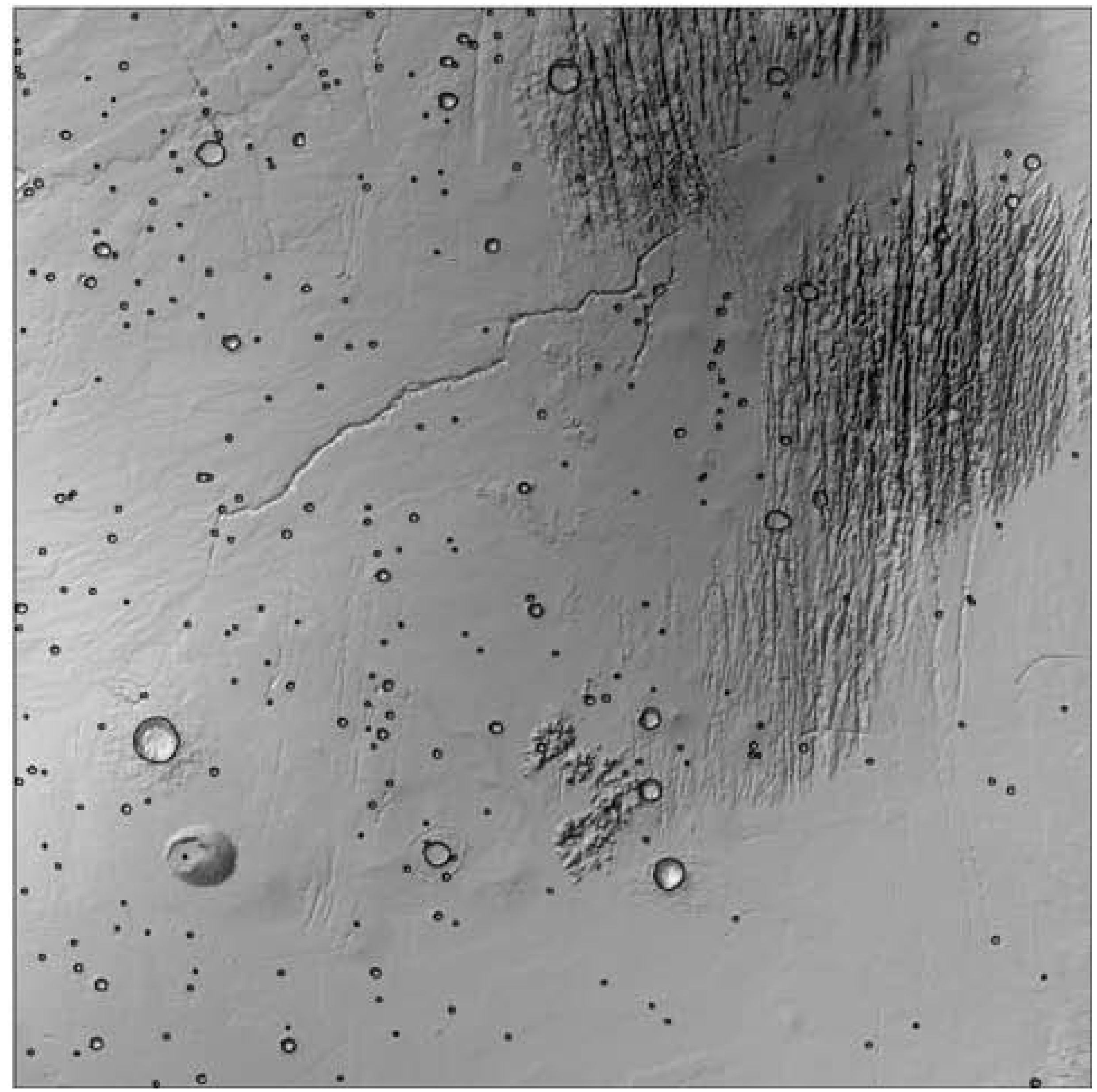


4. Feature detection

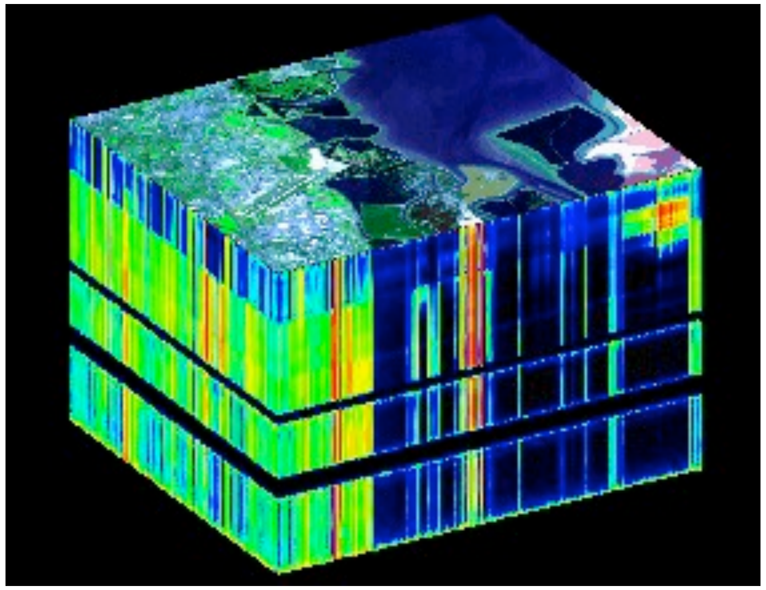
- Automatic crater counting
  - on images
    Urbach et al., 2009
  - on DEM
    Stepinski et al., 2009
- Limitations:
  - very slow
  - accuracy



Data Science Challenges for images

- Data treatment (DEM)
- Data mining (change detection, feature identification)
- How to represent the data (global map, time) ?

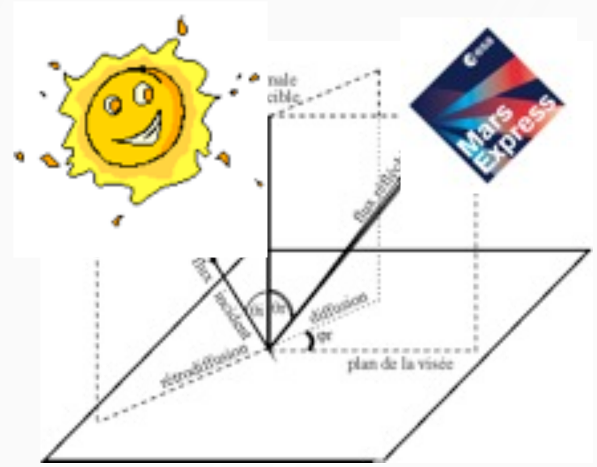
Large volume products

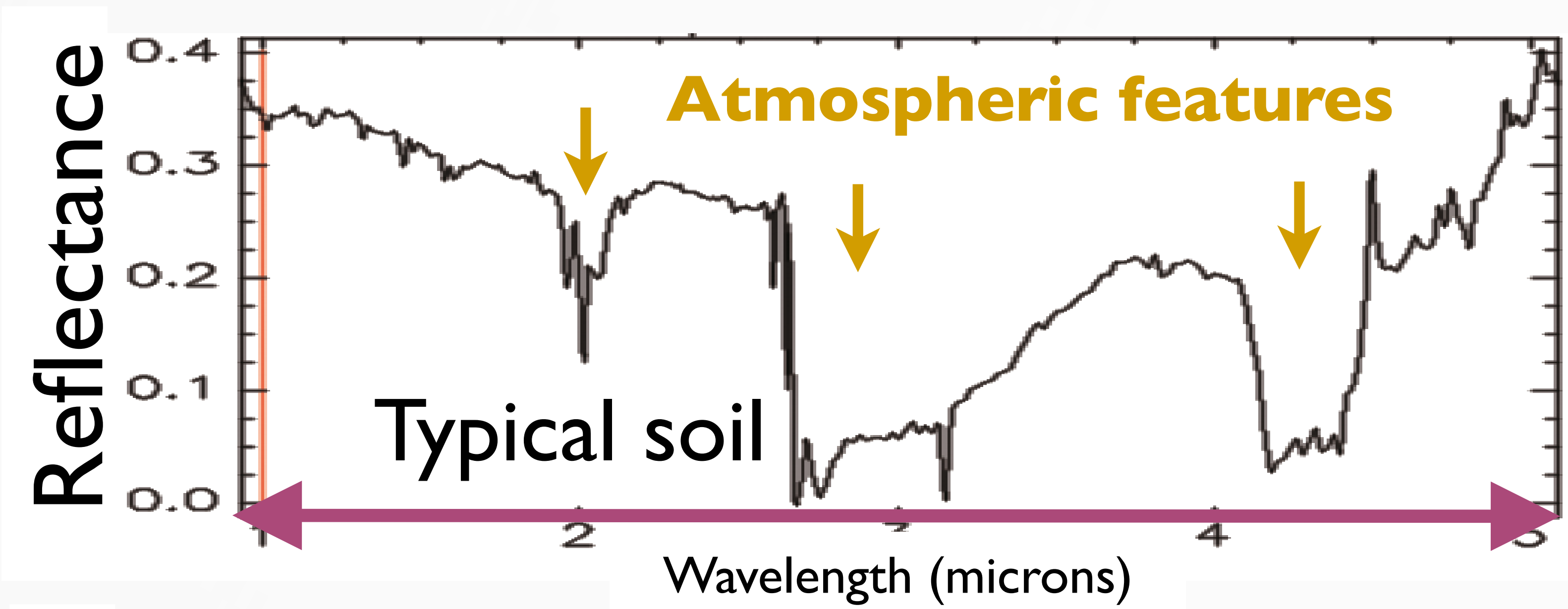


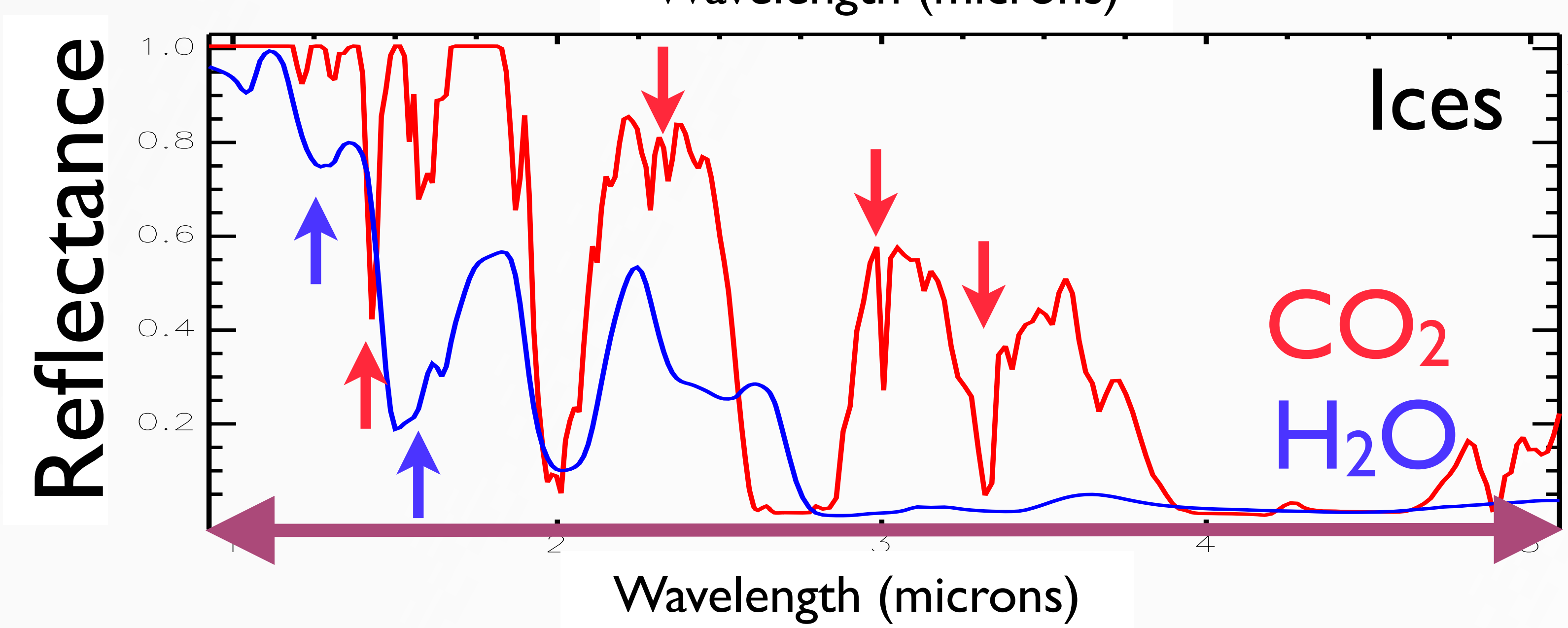
- High resolution spectra
- High resolution images
- **Hyperpectral images**
- Multi-angular hyperspectral images

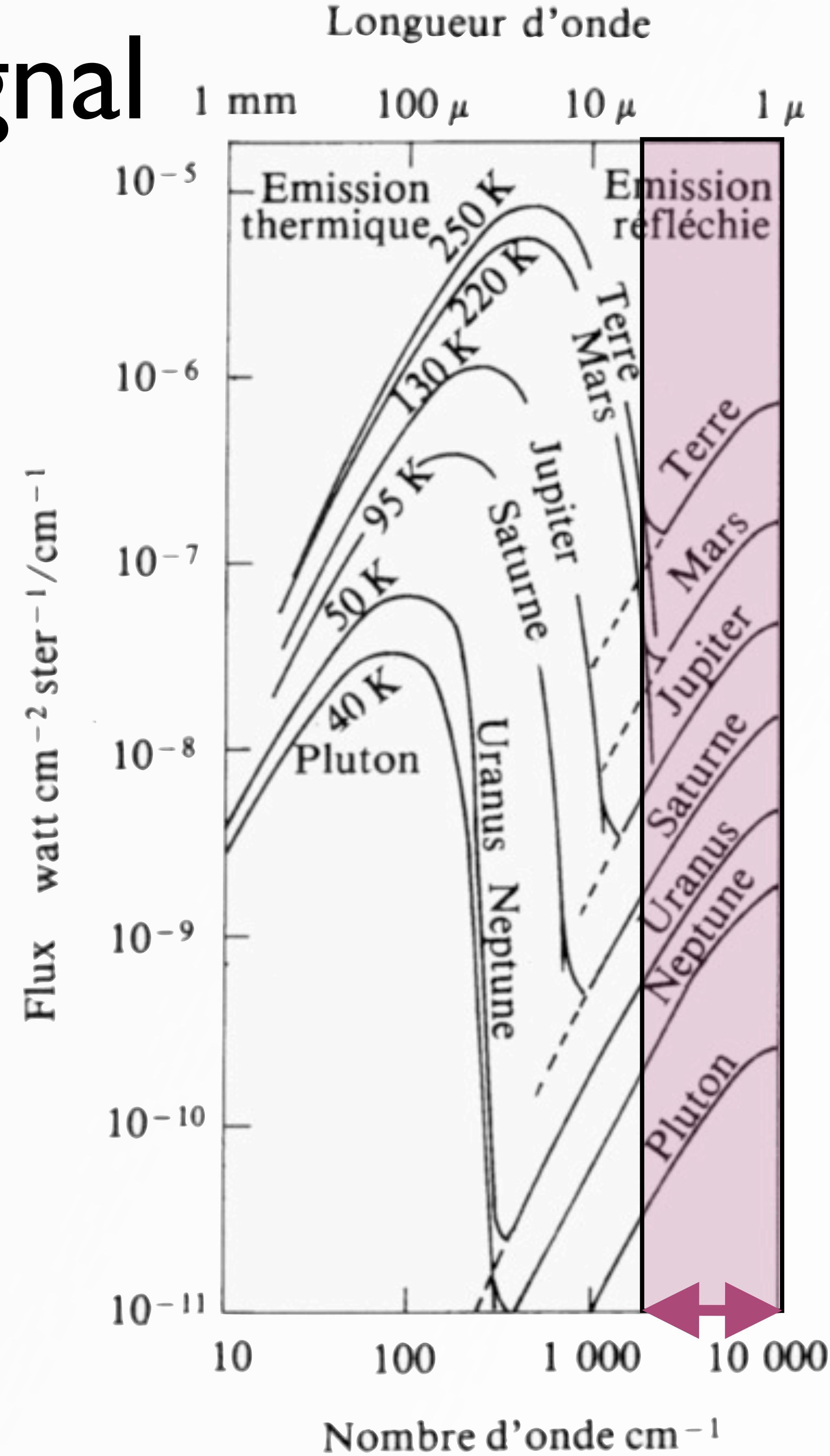
Visible and Near-IR signal

Contribution:
- atmosphere
- surface



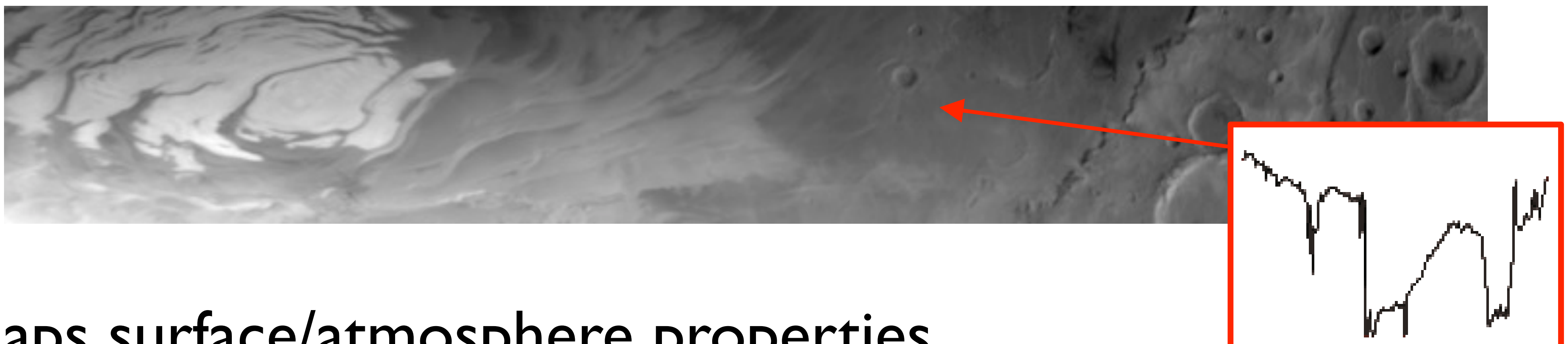






Imaging spectrometer

- Hyperspectral image



> 100 wavelengths

- Maps surface/atmosphere properties

Examples of hyperspectral datasets

- OMEGA (Mars Express, ESA) Bibring et al., 2004
- VIRTIS (Venus Express, ESA) Drossart et al., 2007
- VIMS (Cassini, NASA) Brown et al., 2004
- CRISM (Mars Reconnaissance Orbiter, NASA) Murchie et al., 2007
- ...

Data Science Challenges for hyperspectral images

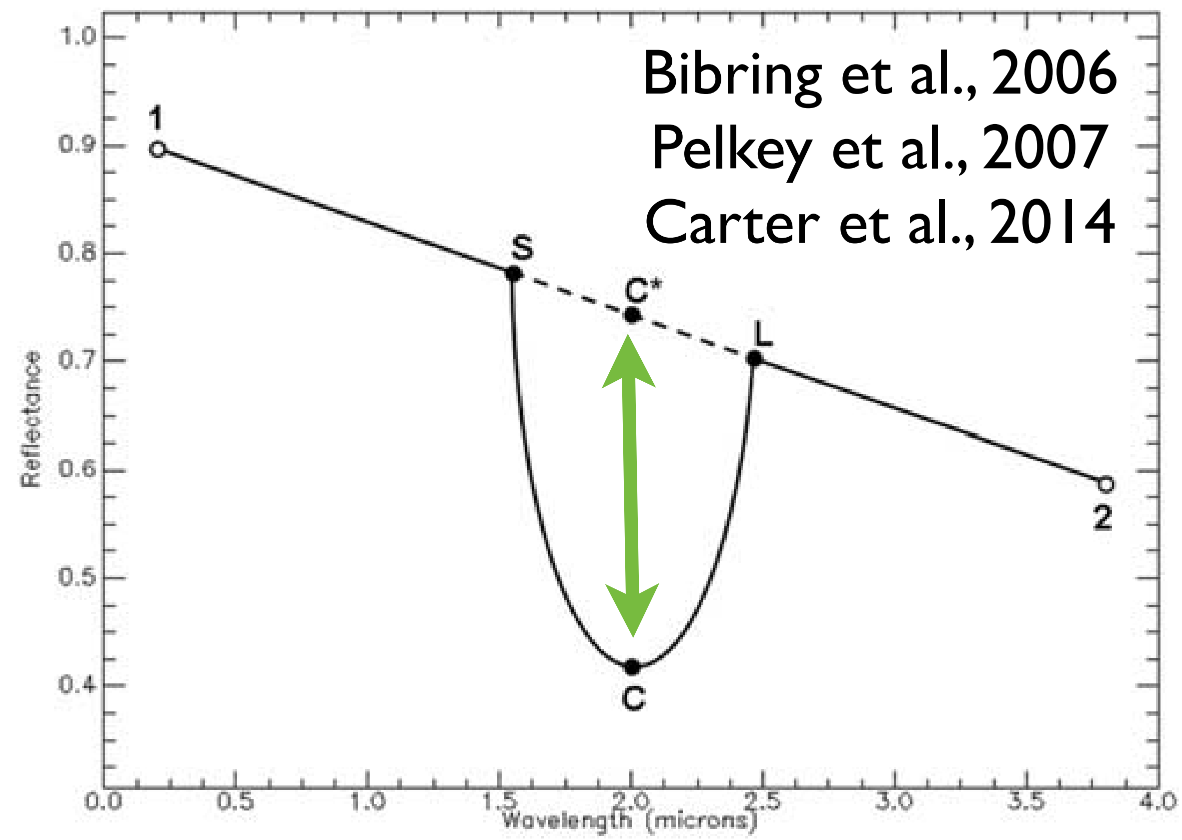
- Detection
  - band ratios, wavelets, linear unmixing
- Quantification
  - radiative transfer inversion

Data Science Challenges for hyperspectral images

- **Detection**
  - band ratios, wavelets, linear unmixing
- Quantification
  - radiative transfer inversion

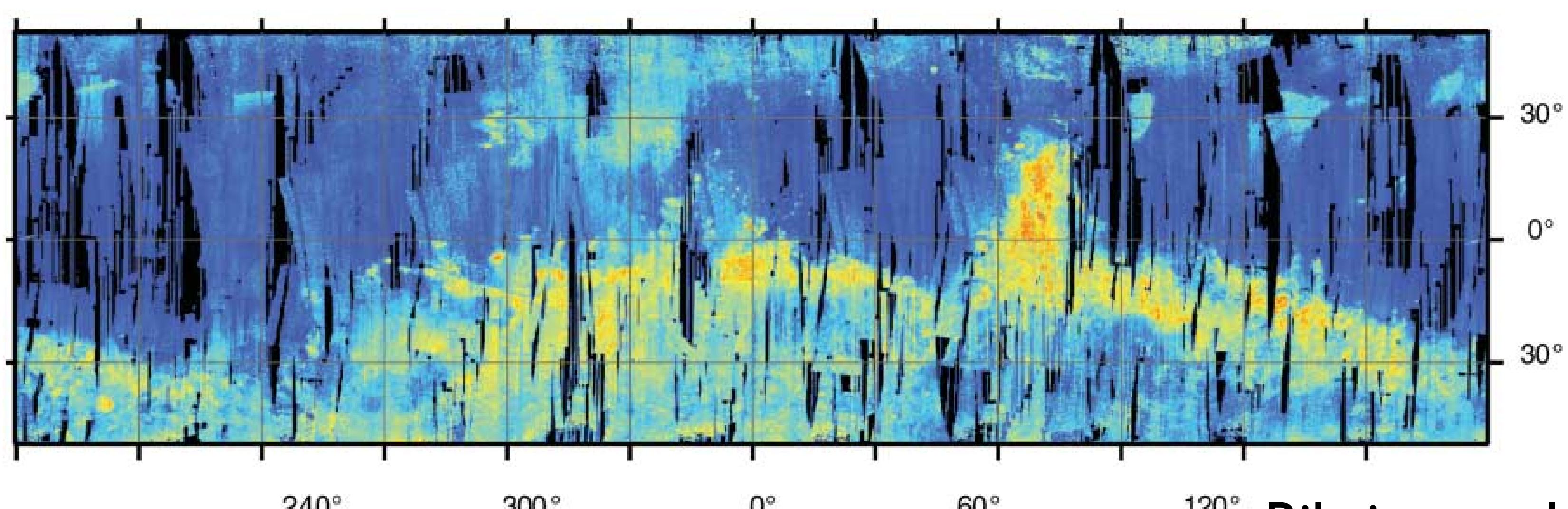
Detection using Band ratio

- Very Fast
- Limitations:
  - superposition of bands
  - angular effects



Absorption depth

Pyroxene global map



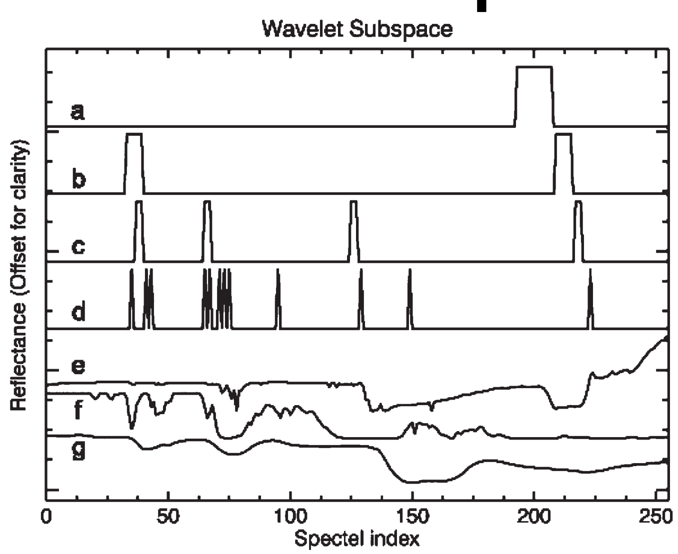
Bibring et al., 2006

Detection using Wavelets

- WAVANGLET

Schmidt et al., IEEE TGRS 2007

  - correlation in a wavelet coefficient subspace



- Fast and efficient to remove angular effect
- Limitations:
  - ~10 endmembers

Schmidt et al., Icarus 2009

Detection using Wavelets

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  Schmidt et al., IEEE TGRS 2007

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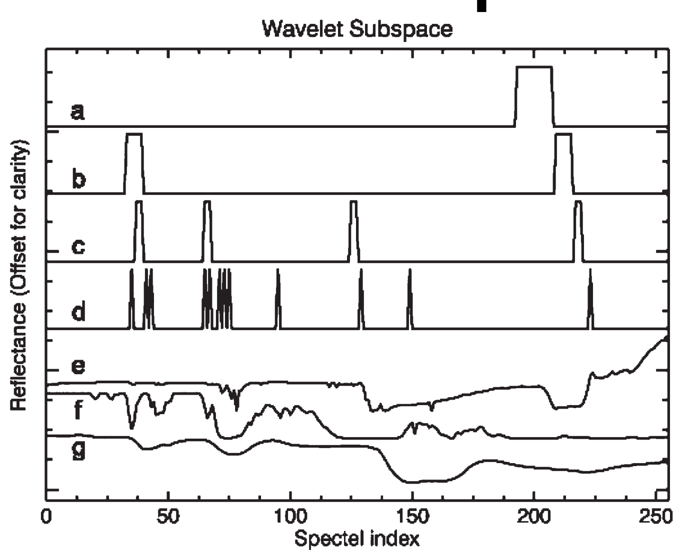

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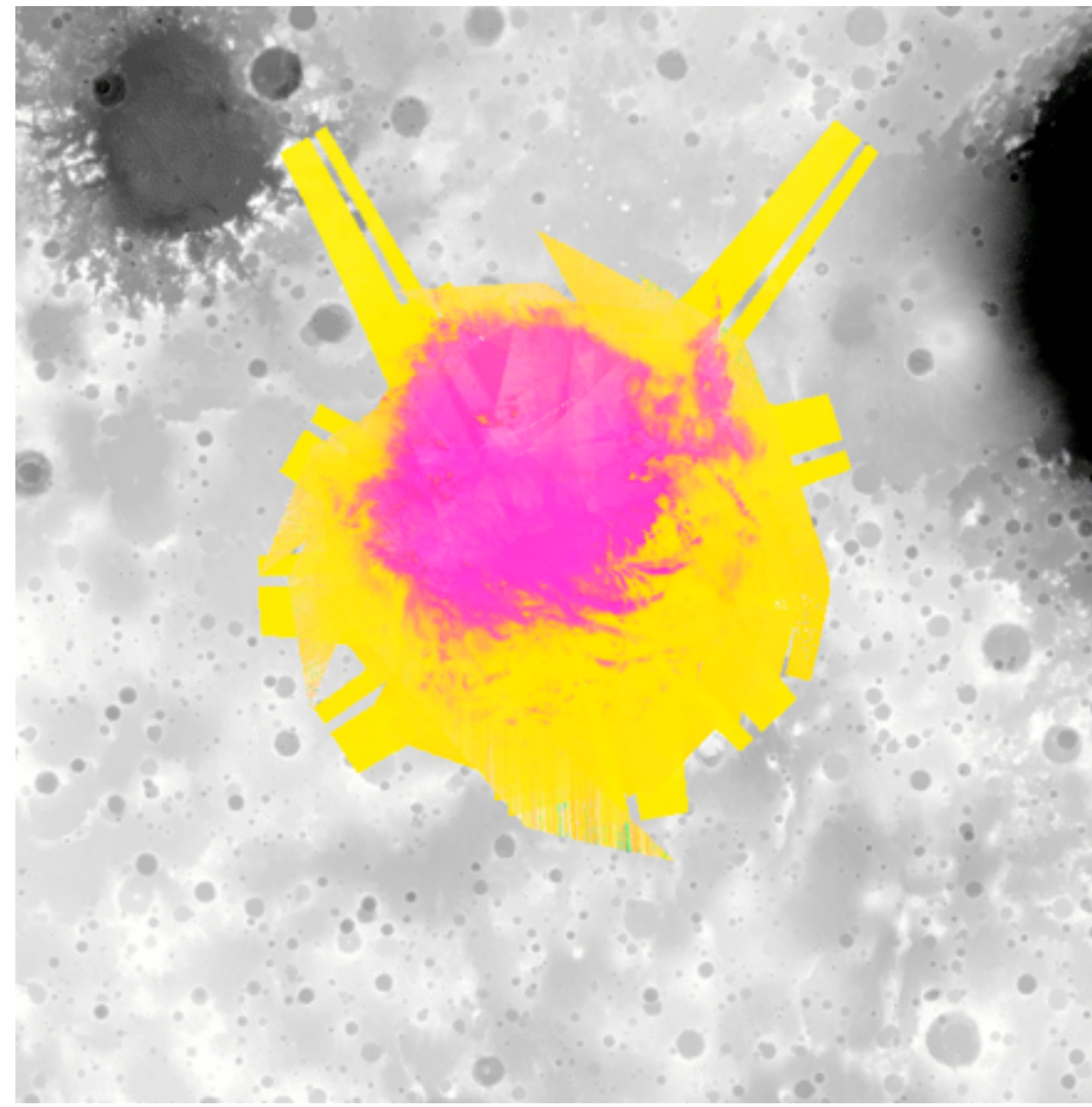


Schmidt et al., Icarus 2009

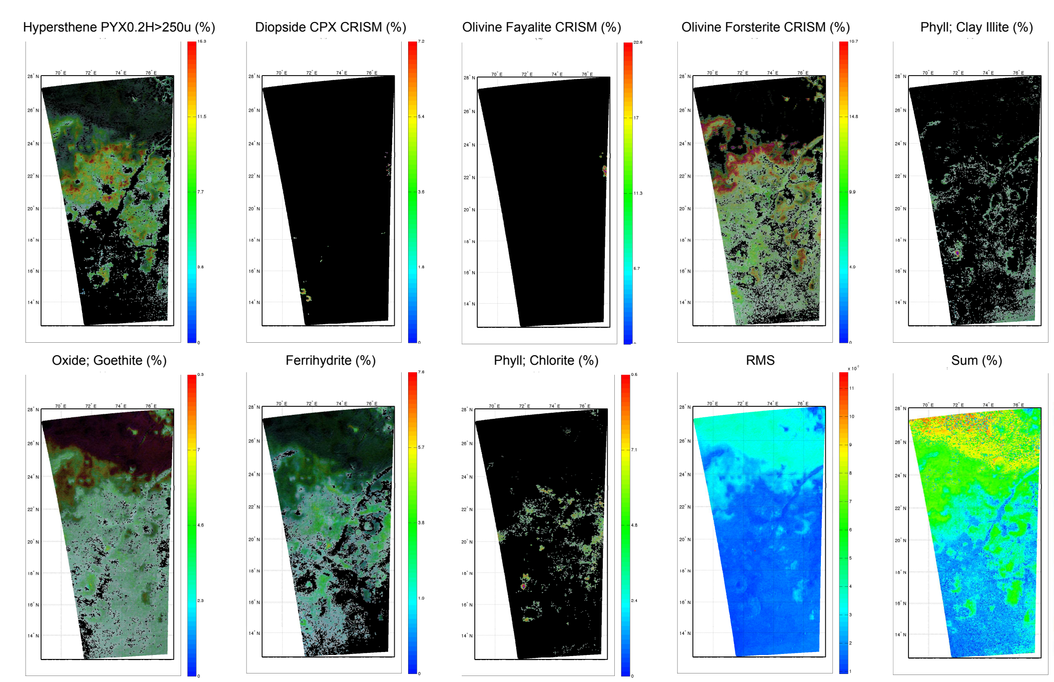
Detection using Linear unmixing

- Linear unmixing
  Combe et al., 2008
  - under constraints
    Legendre et al., 2013
  - compensate non linearities
    Schmidt et al., 2014

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

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

- Highly parallel algorithm (GPU)
- Limitations:
  - ~50 endmembers



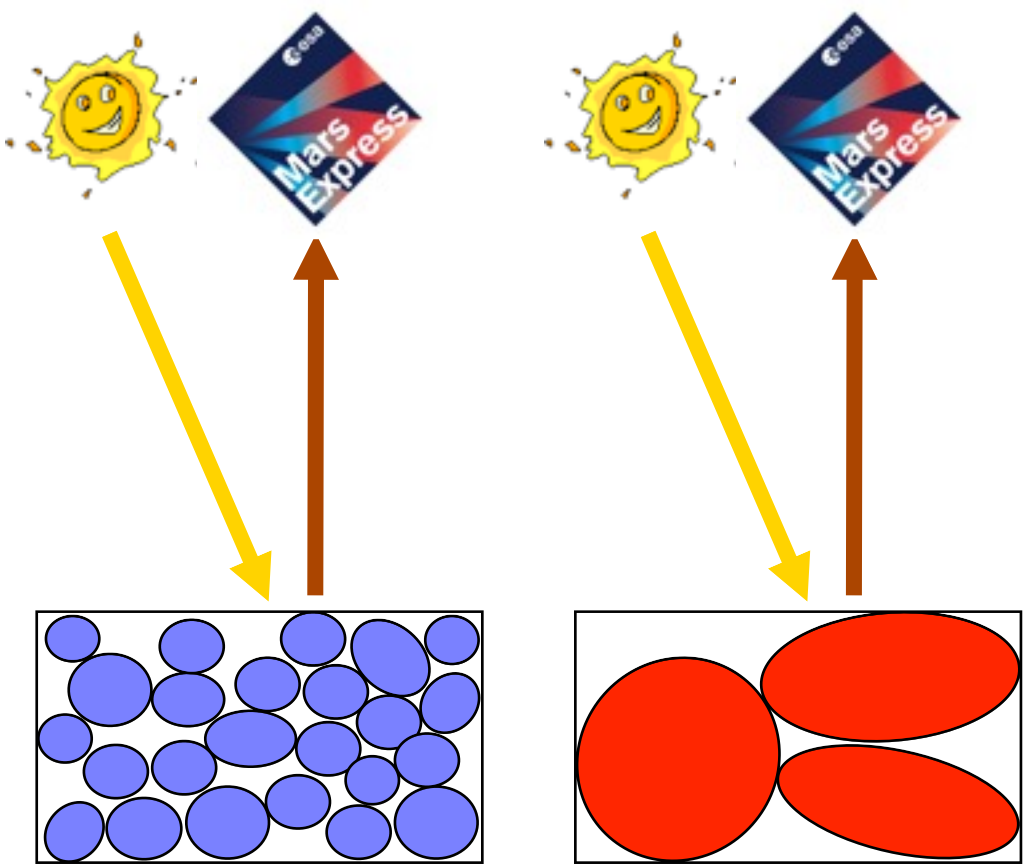
Data Science Challenges for hyperspectral images

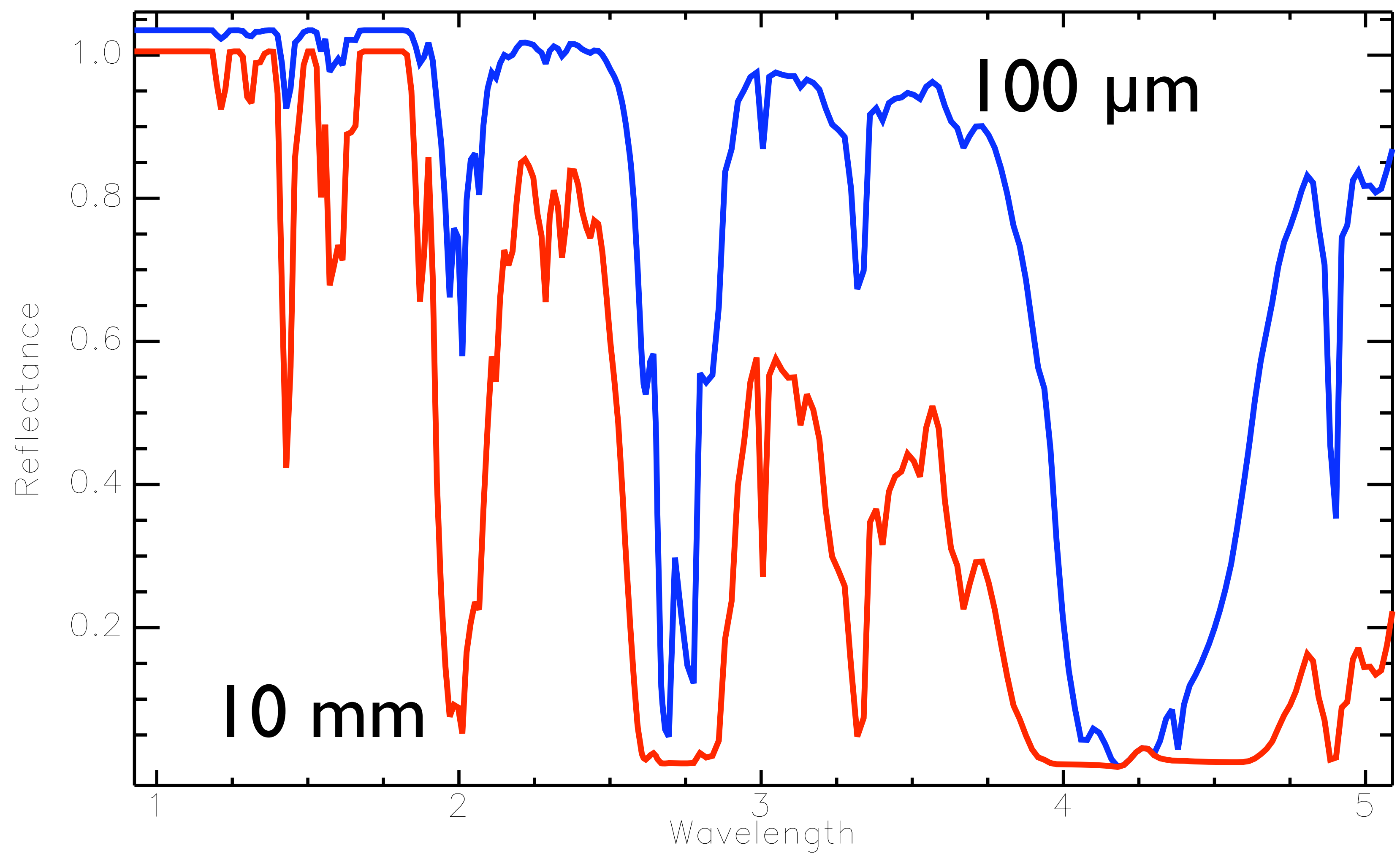
- Detection
  - band ratios, wavelets, linear unmixing
- **Quantification**
  - radiative transfer inversion

Spectral shape = physical state

Grain size

Free mean path





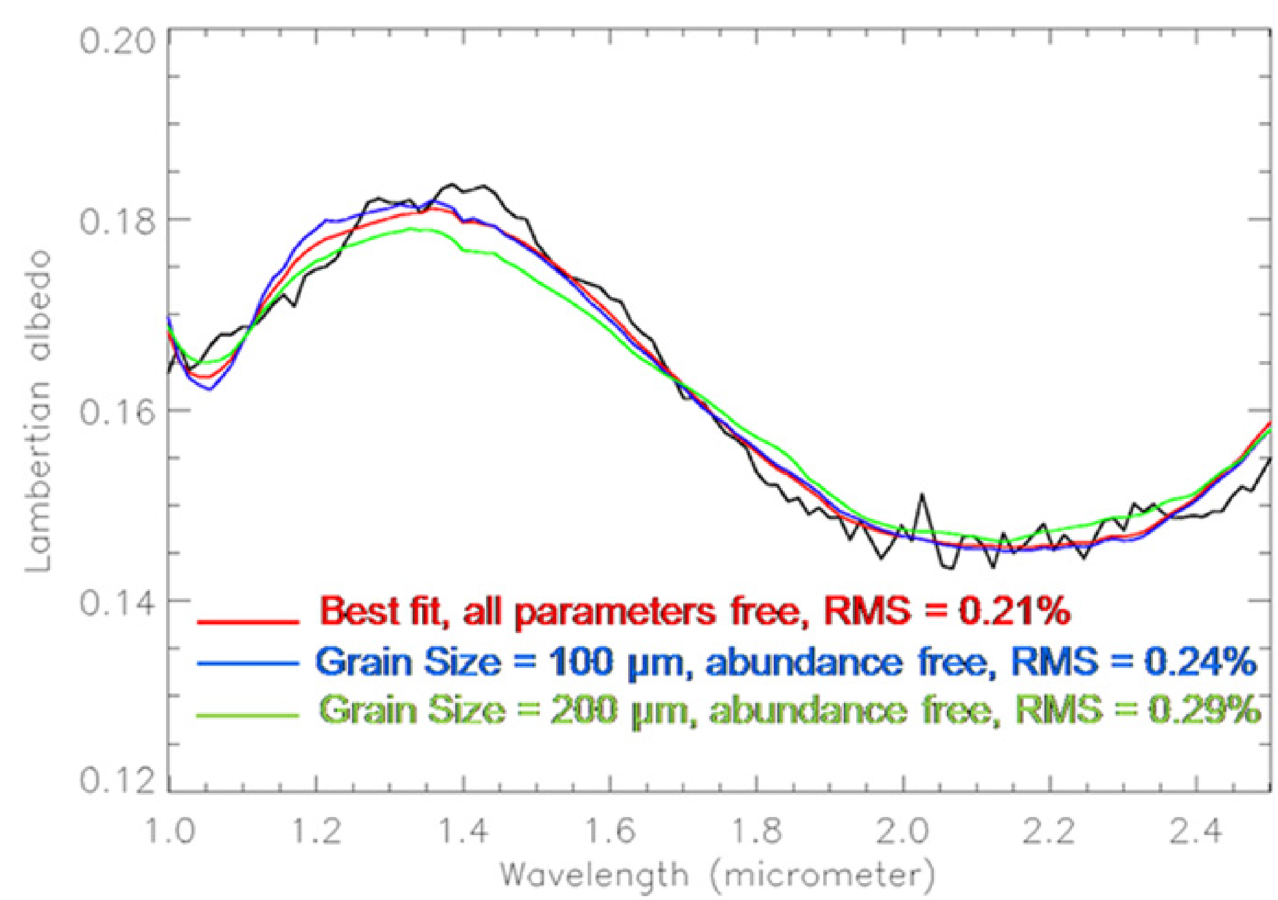
Douté, et al, *JGR*, 1998

Schmitt, et al, *Solar System Ice*, 1998

Inversion using Least square

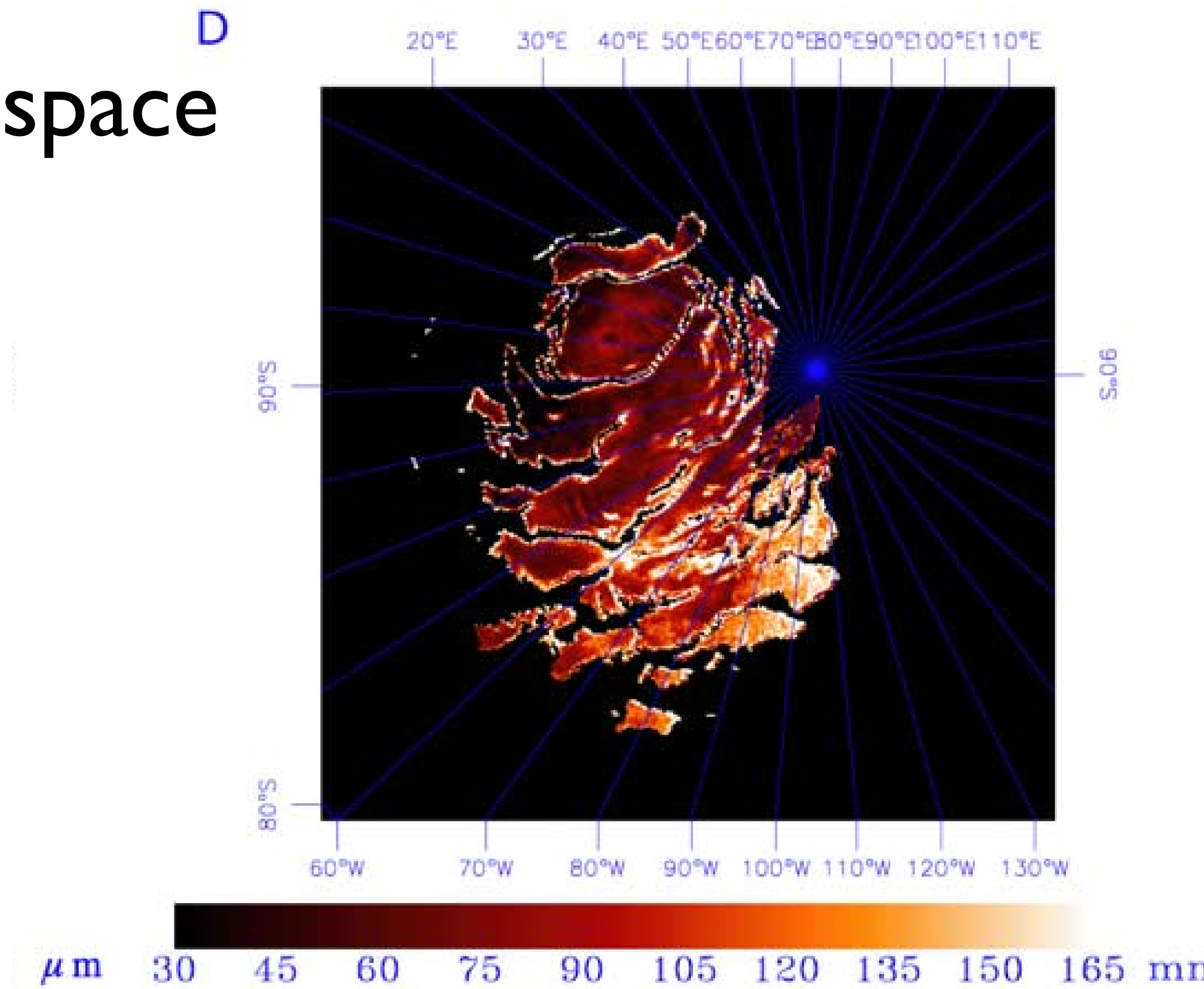
- Minimisation technique
  - Surface
    Poulet et al., 2009
  - Atmosphere
    Wolff et al., 2009

- Limitations
  - Slow
  - Multiples solutions



Inversion using Linear Subspace

- Look up table
  Douté et al., *LPSC*, 2007
- GRSIR Bernard-Michel et al., *Statistic and computing*, 2009
  Bernard-Michel et al., *JGR*, 2009
  - Projection into a linear subspace
- Very fast
- Limitations:
  - Non linearities
  - Multiple solutions

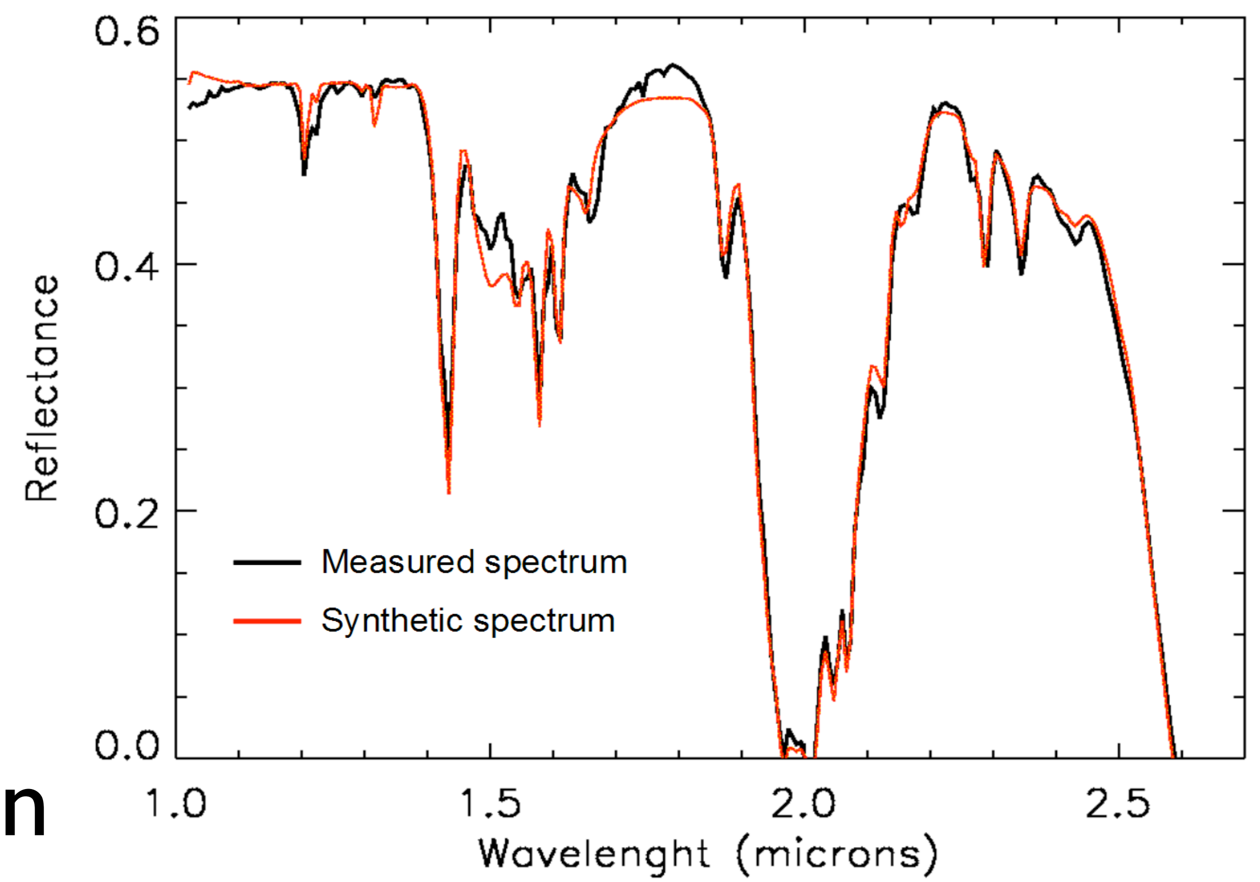


CO_2 ice grain size

Bayesian Inversion

- Monte Carlo inversion on photometry
  - Limitations:
    - Computation time

Ceamanos et al., 2013
Fernando, J. et al., 2013



- Maximum likelihood inversion

Andrieu, F. et al., in preparation

Data Science Challenges for hyperspectral images

- Radiative transfer inversion (bayesian technique)
  - estimation of surface/atmospheric properties

- How to represent the data (global map, wavelength, time) ?

Conclusion

- Planetary Science (and Geoscience) needs Data Science revolution
  - Data Mining
  - Data visualisation
  - Massive data treatment
- Virtual Observatory

Europlanet
European Planetology Network