Imaging spectroscopy storage in planetary science

(and beyond)

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Imaging spectrometry

Basic observational measurements for planetary surfaces and atmospheres.
The main source form mineralogical composition of planetary surfaces - mostly in the visible/near-IR range

Relatively new (first dedicated instrument flown on Galileo)
Also used in Earth Observation

3D data, different from filter cameras:
- lower spatial resolution, much larger spectral resolution
- acquisition process is different (spectral dimension acquired in one shot)

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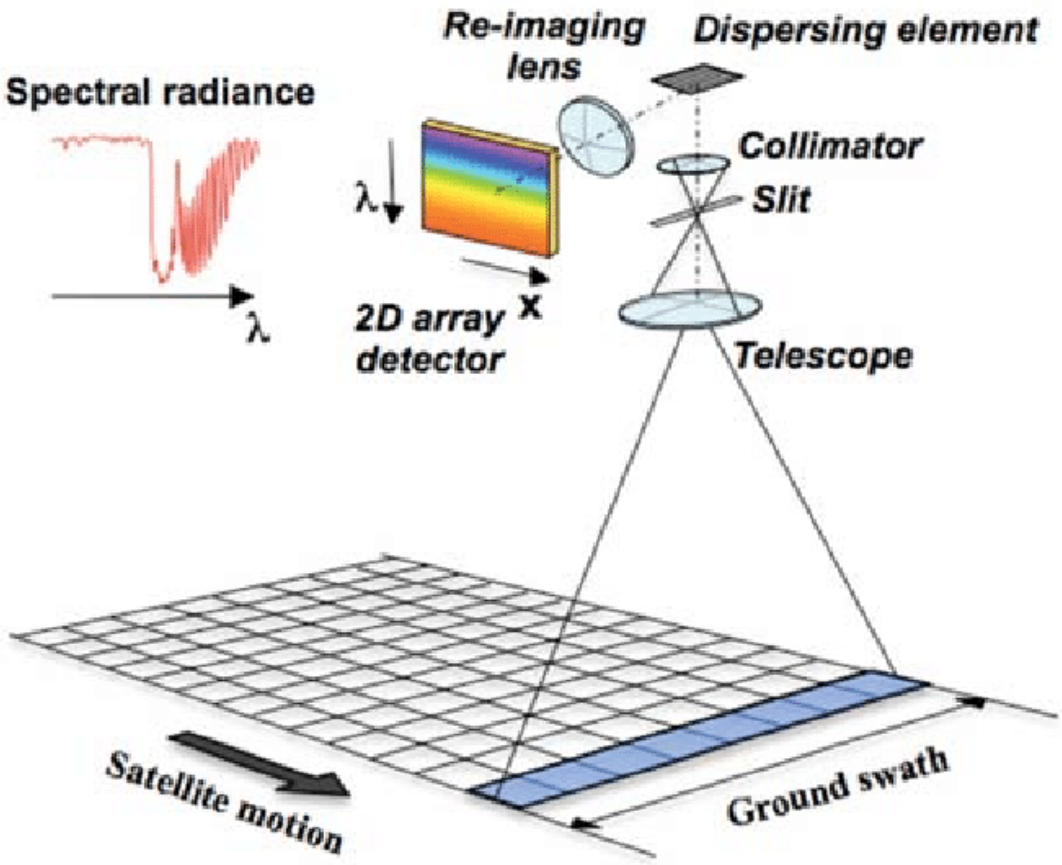
Measurement principle:
the main one is pushbroom
- 2D data at each time step:
  1 spatial dim & 1 spectral dim
- 2nd spatial dim acquired through time

Alternative modes:
- 1 spectrum / time step
- 2 spatial dim acquired through time
(either with 1D detectors or échelle spectrometers: 2D used for spectral dim)



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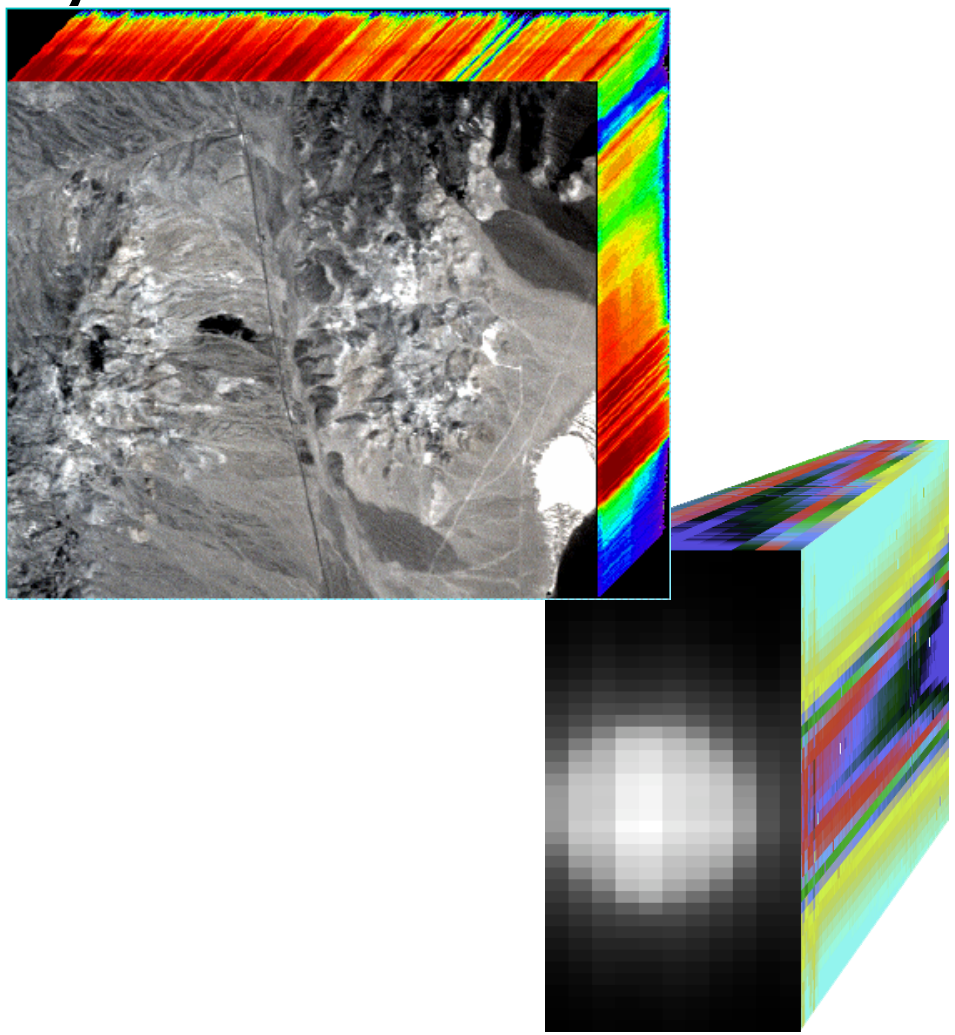
Final data format:

3D spectral cubes

- With significant spatial resolution from orbit

- Also usable with only a few points on the target (telescopic observations, flybys…)

- Echelle spectrometers can also produce spectral cubes (VIRTIS-H / VEx & Rosetta)



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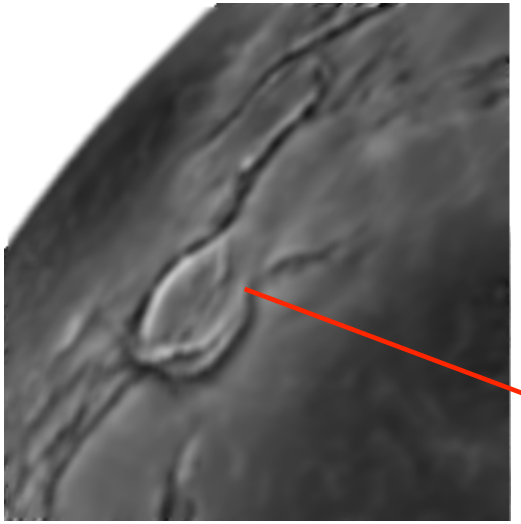
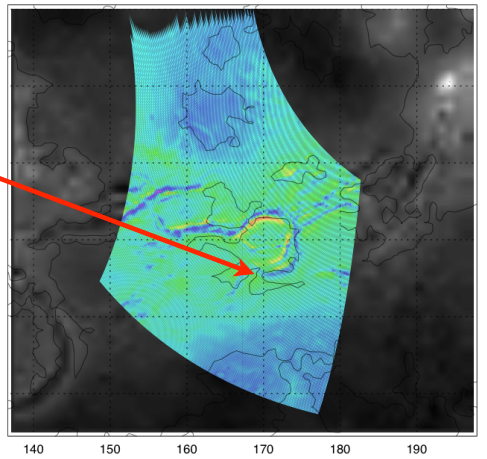
Coordinates - projection on body

Extra info required *for each pixel*:
- Coordinates + wvl vector (to plot data)
- Illumination angles (to analyse data)
- each pixel has an extended footprint (for comparison with HR imaging)

VIRTIS-M VenusExpress



Cube slice: spatial dimensions (~ single wavelength image)



Projected image on surface (~ map)

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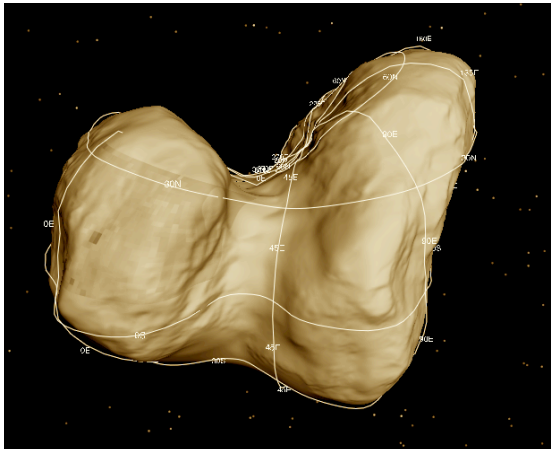
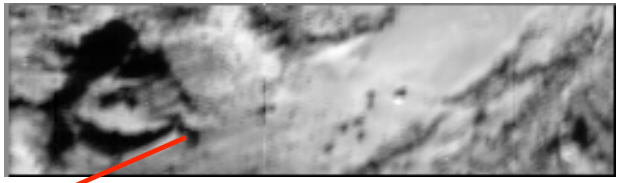
Coordinates - projection on body

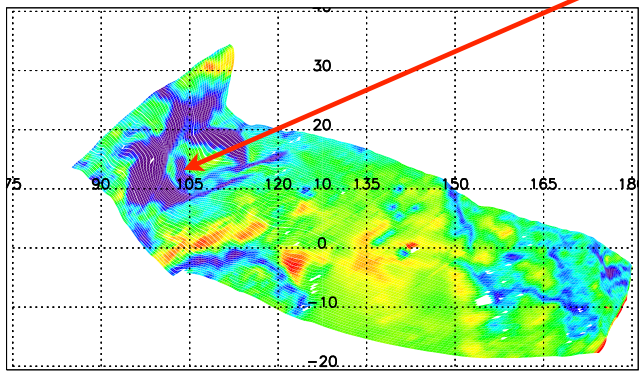
Particularly important for irregular small bodies…



VIRTIS-M Rosetta



Cube slice: spatial dimensions (~ single wavelength image)



Projected image on shape model (~ map)

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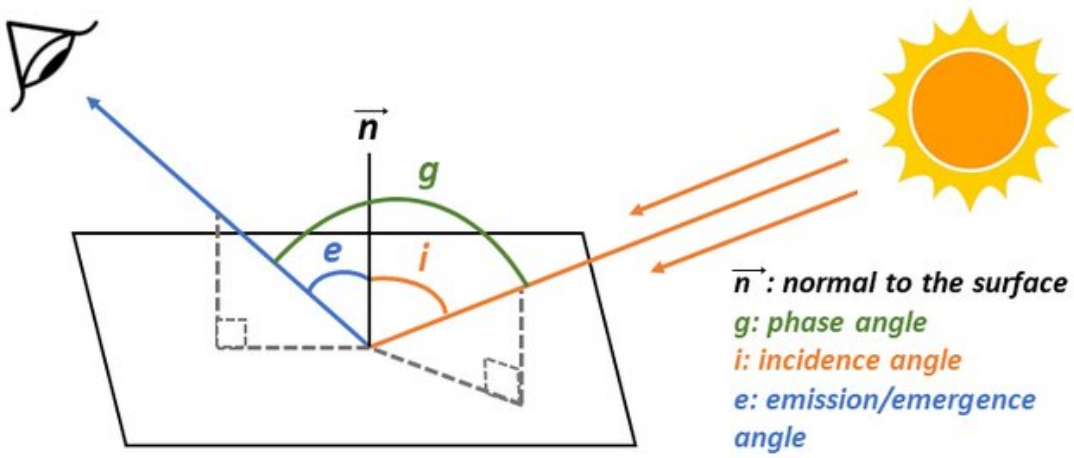
Illumination angles on body

3 angles: incidence, emergence, phase
Affect the spectra (level, slope, absorption depth)
=> required for analysis, provided at spectrum level



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Data format requirements

- 3D organisation related to acquisition sequence => direct plots make sense

For each pixel, provide:

- Complete spectrum
- Spatial coordinates for exact visu and comparison with HR images (typically coord of footprint corners + center)
- Illumination angles (i, e, phi) for analysis / correction (maybe on several reference surfaces)
- Acquisition time (interpolation, etc) + other metadata (airmass, altitude…)

- (assumed common to all spectra): spectral vector + other metadata

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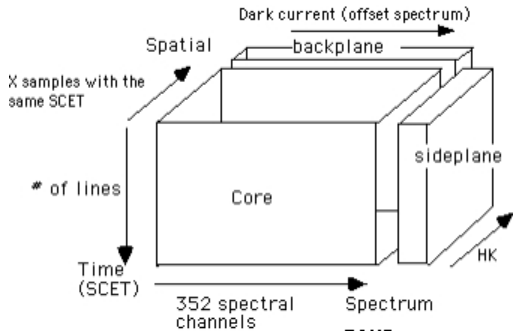
Space archives

- Extremely diverse
- In PDS3, dedicated data objects: Qube, Spectral_cube + ISIS cube (USGS)
  - but other data objects often used
  - may be different for raw and calibrated data
  - every single experiment uses specific variations on Qube
- No generic software reading (or writing) everything correctly
  => major blocking point to handle these observations
  => incredible loss of time for new experiments
- PDS4 guidelines: a 3D variation of array for data, separated geometry
- Fits: limited support for planetary coordinates (but coming)



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Main space archives

- Family of ISM, OMEGA, VIRTIS / VEx, VIRTIS Rosetta:
  Data = Qube, geometry in separated Qube files with px/px correspondence
- NIMS / Galileo: object = Table (1 / scan ?)
- VIMS / Cassini (2018 version) = Spectral_cube
- THEMIS - object = Spectral_cube & Image
- CRISM / MRO - object = Images in 3D (with bands)
- HRII / DeepImpact : 2D fits files with 2 images — successive planes in separated files, difficult to recombine and get spatial dimension
- NIS / NEAR - ?
- VIR / Dawn - Qubes - geometry not included in archive
- M3 / Chandrayaan - Tables
- MASCS / MESSENGER - Binary Table
- JIRAM / Juno - Tables and Images — successive planes in separated files, difficult to recombine and get spatial dimension

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Software?

- Typically home brewed libraries, often IDL
- Generic PDS libraries from PDS SBN
  - IDL PDS3 does not support every archive
  - python PDS3: TBC
  - python PDS4: TBC
- Generic IDL library from VIRTIS / VESPA (LecturePDS)
  - access to (several) historical datasets
- ENVI: OK plot/analysis tool, needs IDL input routines, expensive
- Aladin + CASSIS plugin (sky only currently) for visu
  - requires fits format + WCS

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Improvements?

1) programming approach — python / IDL / whatever
- Fixed data / files organization
- Fixed keywords to identify info
- Small bodies are difficult to handle (refer to a given shape model)

2) VO (or non-VO) tools
- Data + geometry in a single file?
- Fits is handy, provided:
  - support for planetary reference frames => Marmo et al 2018 - 10.1029/2018EA000388
  - support for illumination angles - TBD

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Improvements in fits may help

- Support for planetary reference frames => Marmo et al 2018 / WCSlib 8.0

OK for images, supported in DS9

Issue with longitudes in Aladin?

- WCS adapted for cubes => fits TAB projection (allowing interpolation)

Assessment with DS9 on historical datasets, should be compliant with PDS4

Marmo et al 2019 4th Planetary Data Workshop, held 18-20 June, 2019 in Flagstaff, Arizona, abstract 7094

- Other solutions from ground observatories / astronomy ?