Astrophysical light scattering problems

Experiments and instrumentation

Photometry, polarimetry, and ***spectroscopy***

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Why spectroscopy

- Spectroscopy is the most powerful remote sensing tool to study the composition of distant objects
    - This applies also to laboratory studies
- Spectroscopy of stars can give us chemical composition
- Redshifts in spectra can give us relative velocity
- Spectroscopy of molecular clouds in interstellar space can give us chemical composition
- Spectroscopy of atmospheres can give us chemical composition
- Spectroscopy of atmosphereless solar system bodies (planets, moons, asteroids, comets) can give us mineral composition

Atoms and molecules have specific absorption lines, i.e., sharp wavelength ranges where they absorb radiation.

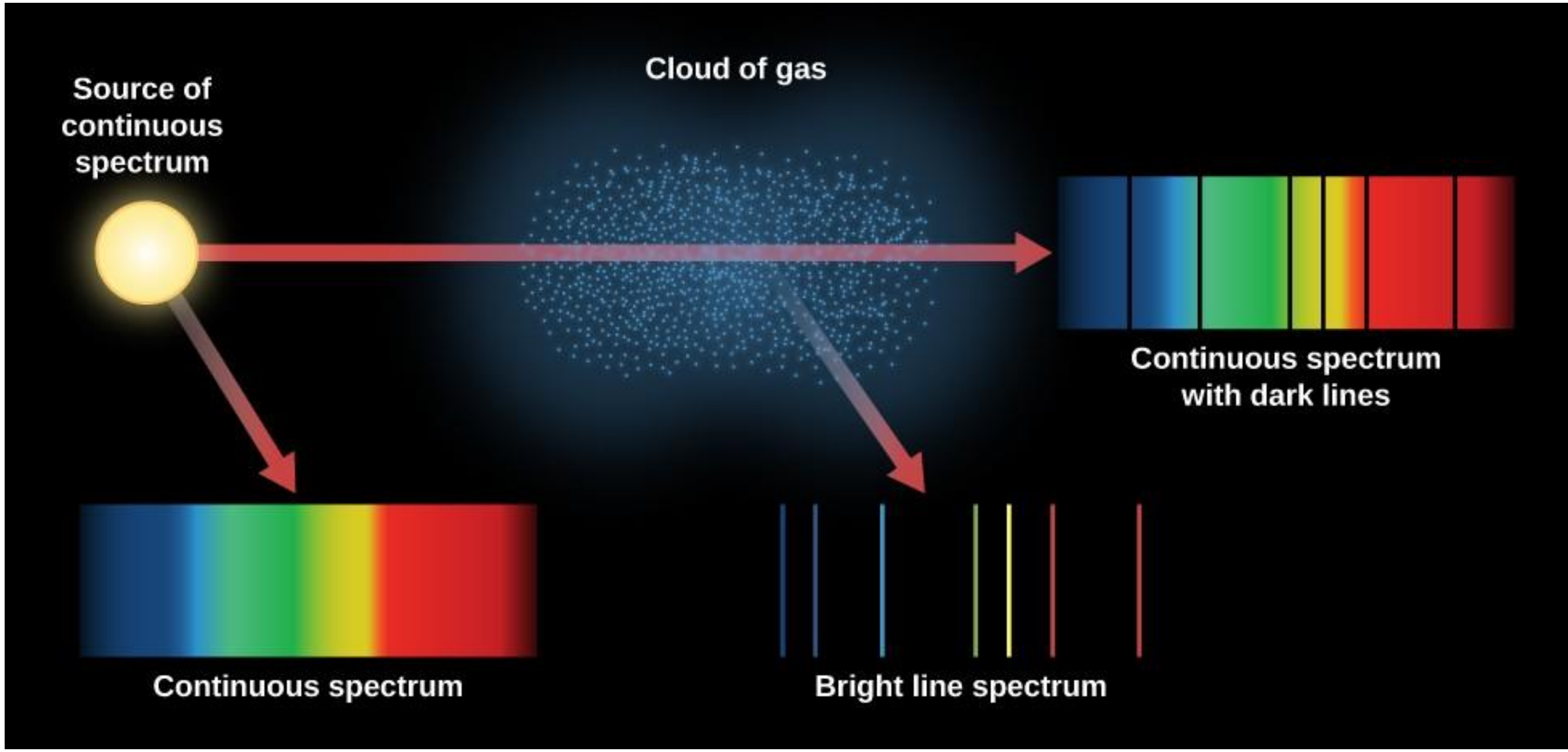


Figure source: https://courses.lumenlearning.com/astronomy/chapter/formation-of-spectral-lines/

Minerals have broader absorption bands, also the shape (absolute level, slope, etc.) of the spectrum can be diagnostic for the mineral species.

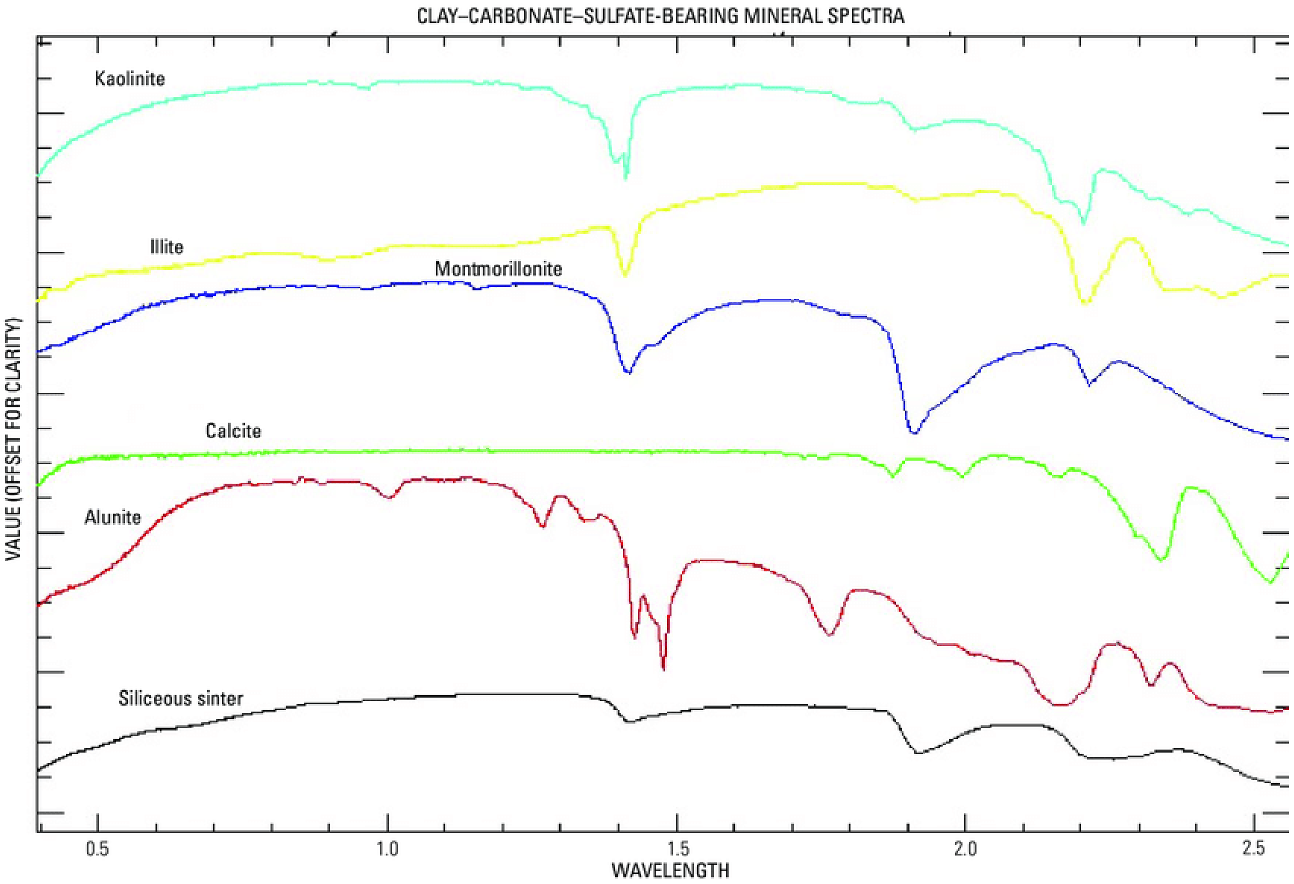


Figure source: K.E. Livo et al.

Light scattering in mineral spectroscopy

- On atomic and crystal level of the material, the spectral properties are caused by changes in the energetic states of the atoms, molecular vibrations states
- On macroscopic level, all the information about light scattering properties of a material at certain wavelength λ is packed into the complex refractive index m of the material: $m(\lambda) = n + i\,k$
  - Especially for non-metallic materials with $n \gg k$ with particle sizes $d \gg \lambda$, one can roughly say that n controls the reflection and refraction in the surface, and k controls the absorption inside the material
  - Reflected power due to reflections from surfaces (Fresnel)
  - Absorbed power due to absorption in volume
    - Beer-Lambert law, reflectance $\propto \exp(-4\pi k\, d/\lambda)$
  - This is why the strength of the spectral features change with the particle size

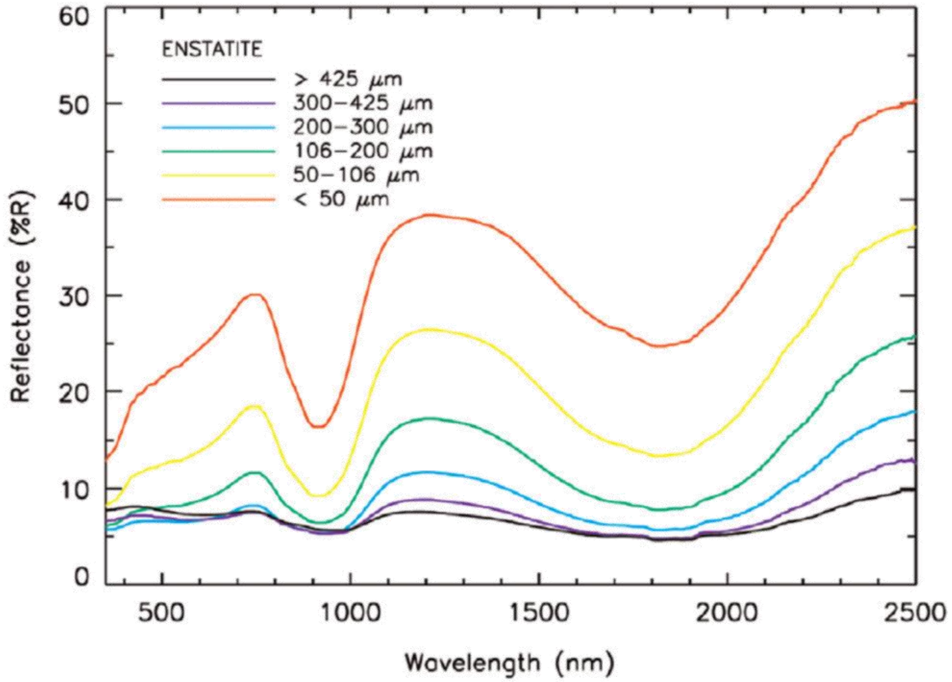
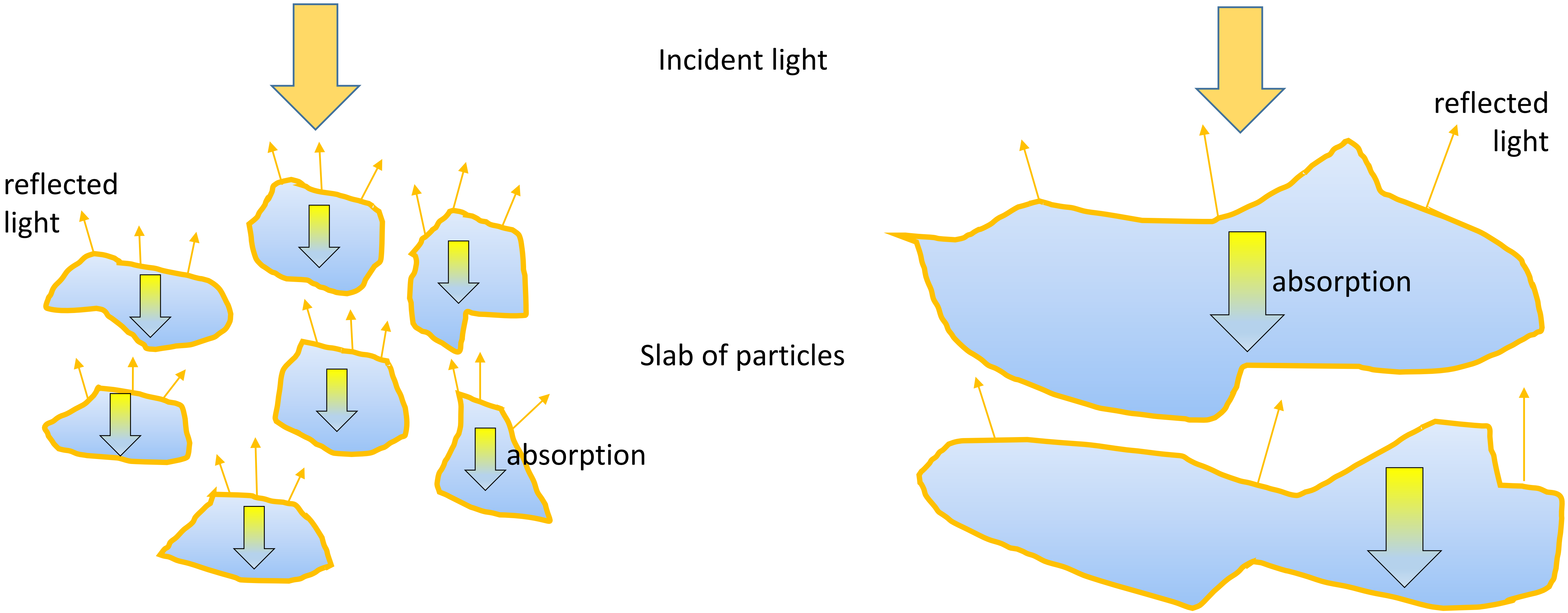


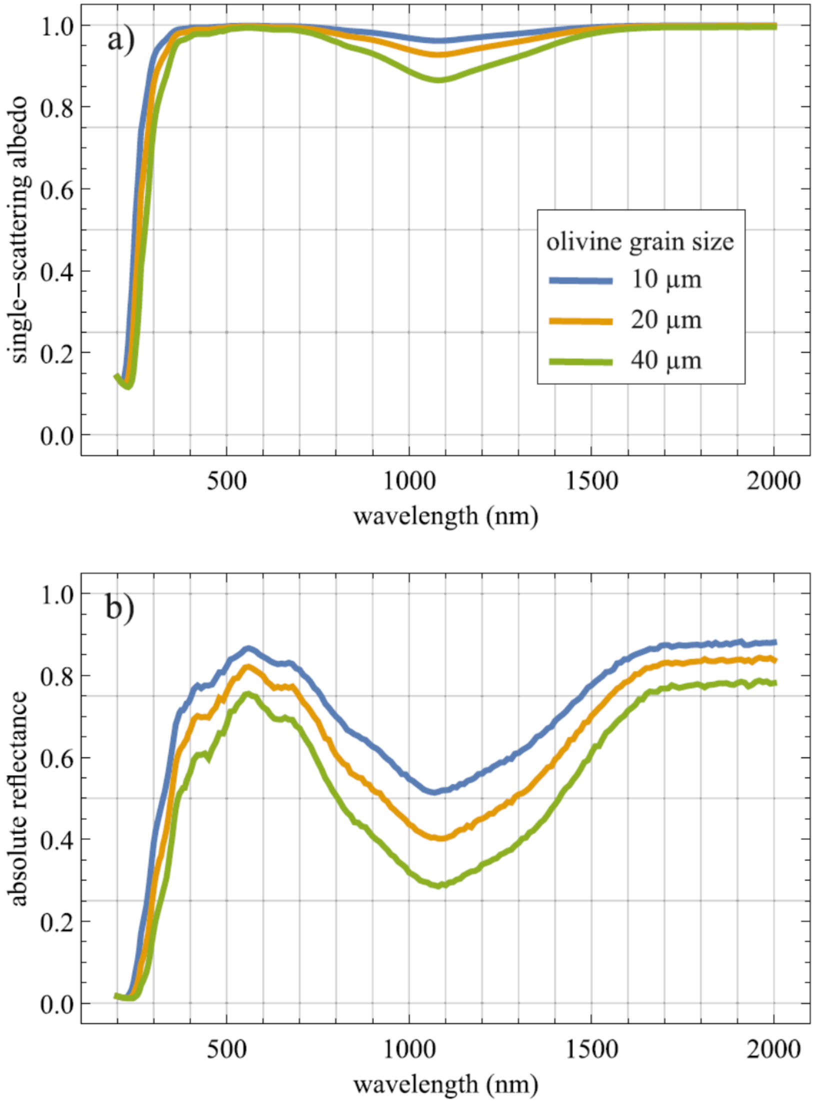
Figure source: Mancarella et al. 2015, PSS 117.

Light scattering in mineral spectroscopy

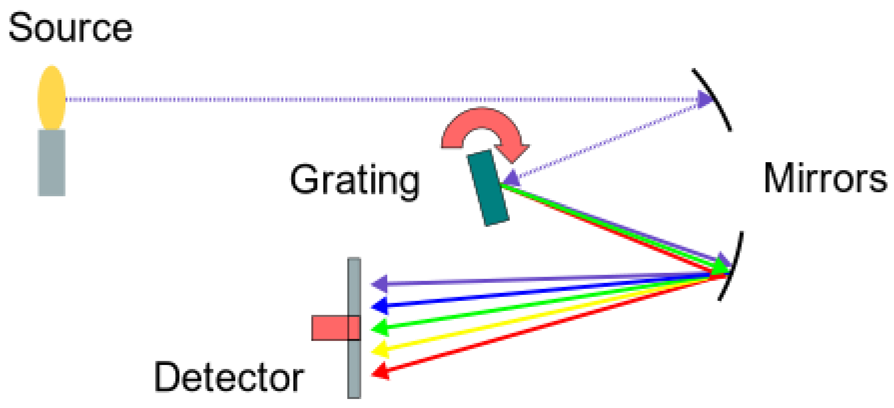


On left: smaller particles, more surface area per volume unit, more reflections. On right, larger particles, more continuous volume, less reflections

Light scattering in mineral spectroscopy



- Our simulation tools:
  - SIRIS for single grain scattering
  - RT-CB for multiple scattering by a slab of grains
- See figures on the left from Penttilä et al. 2020, Icarus 345
  - On top, single-scattering albedo of single olivine grains (SIRIS, single particle scattering)
  - On bottom, reflectance of semi-infinite slab of those olivine grains (RT-CB, multiple scattering by particles)



Grating spectrometers separate the wavelengths spatially. Detector records the signals for different wavelengths. Detector is usually a CCD or CMOS chip, but also photodiode or photomultipliers can be used.

Both reflected or refracted grating optics can be used, possibly combined with optical fibers.

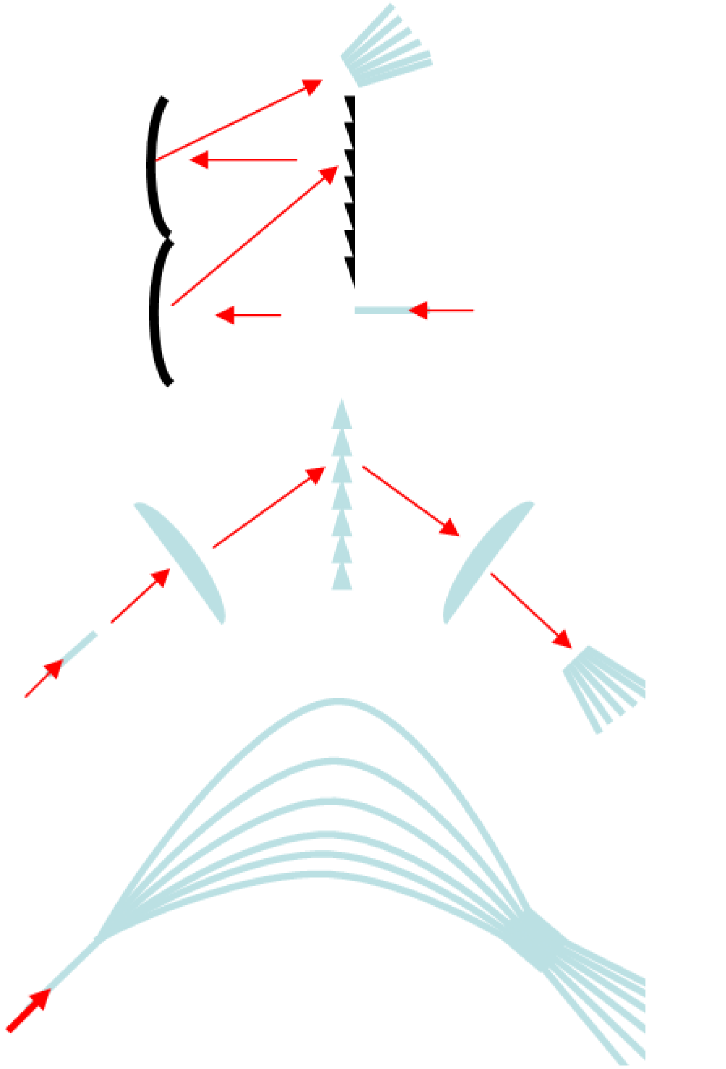


Figure credits: Wikipedia, 'Joola' and 'Myself'

Imaging spectrometers

- A 1d line can be dispersed into 2d image on a CCD chip
- If the instrument can scan these 1d strips along the other direction, one can collect a 2d spectral image or 2d spectral strip

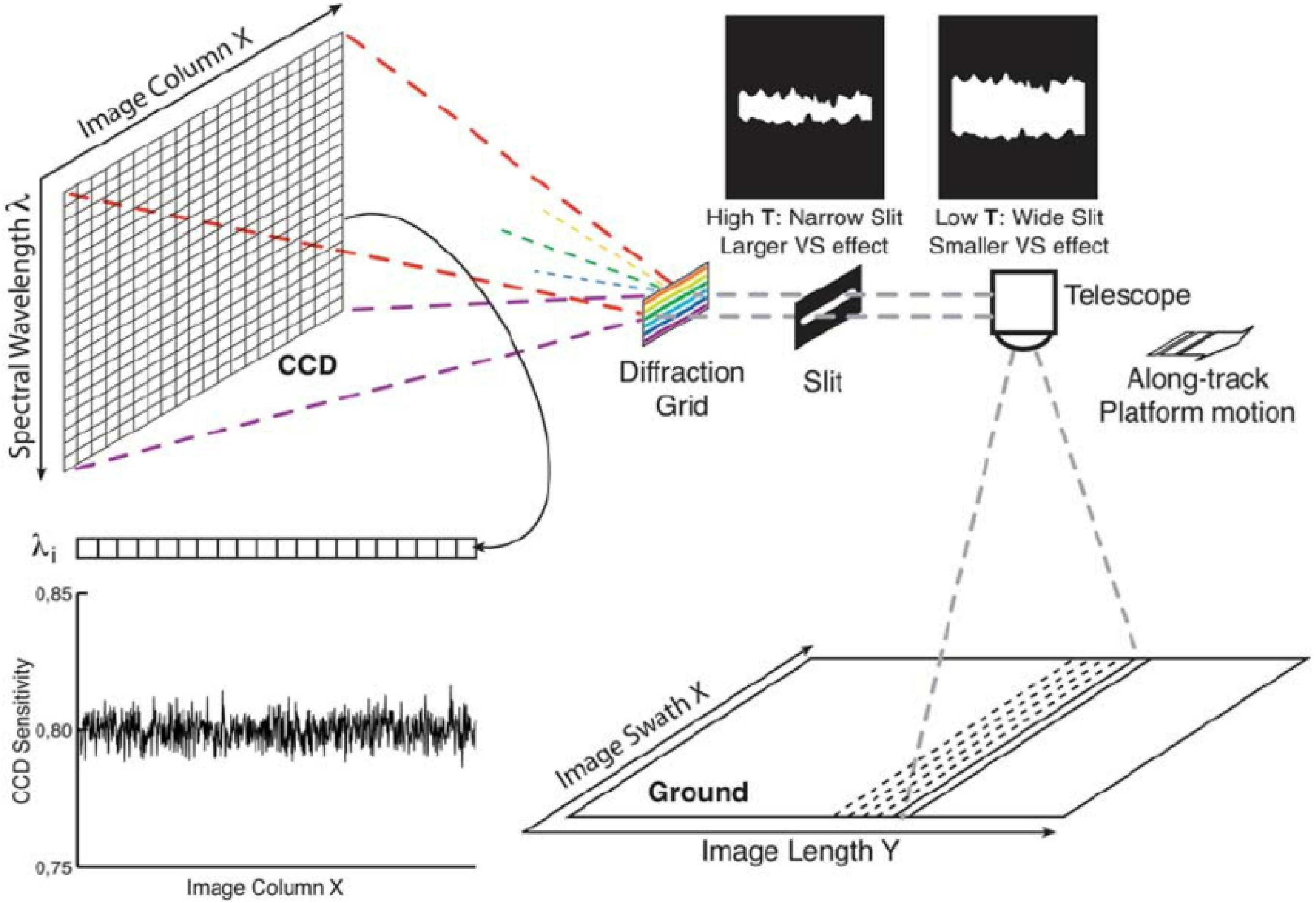


Figure credits: L. Gómez-Chova et al. 2008, Applied Optics 47

- Alternative to scanning imaging spectrometers — Fabry-Pérot interferometer (FPI)
- FPI can be used as wavelength filter in front of the CCD – instant 2d image per wavelength
- By changing the FPI gap, different wavelengths can be scanned
- VTT Finland is developing FPI cameras for space applications
    - Aalto nanosatellites
    - ESA's HERA and Comet Interceptor missions

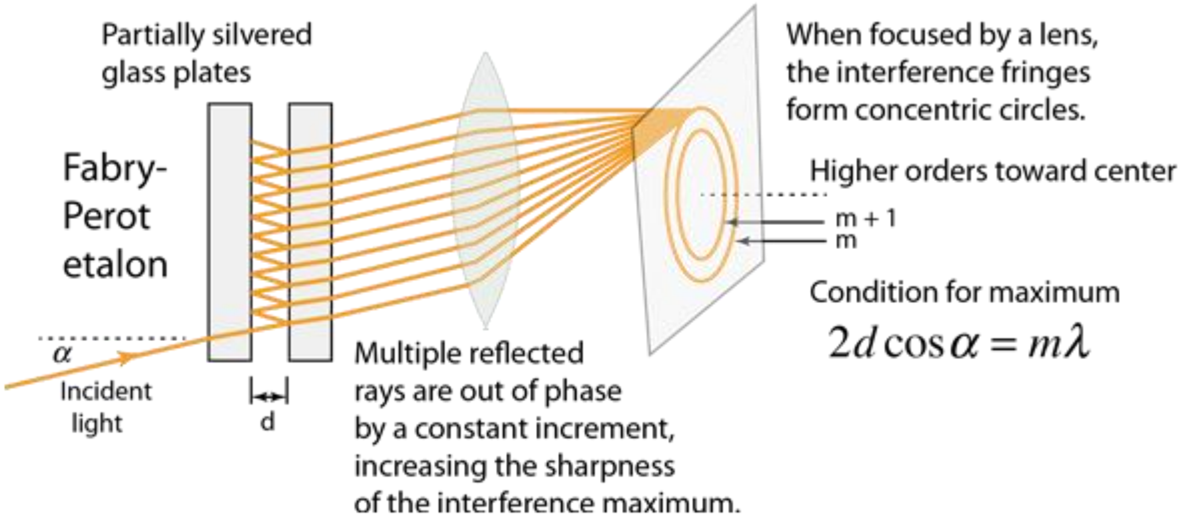


Figure source: http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/fabry.html

Additional material from reflectance spectroscopy in planetary science

- See the lecture ‘*Reflectance spectroscopy and space weathering*’ by Tomas Kohout
  - PowerPoint version for Office users, view ‘Slide show’ to hear the narration: https://helsinkifi-my.sharepoint.com/:p:/g/personal/kohout_ad_helsinki_fi/EUg_48nK2VhCmBWr5blCk4ABrCmTX-5ly8a2bWJ8seGNyA?e=Aex7RK
  - Mp4 version for non-Office users: https://helsinkifi-my.sharepoint.com/:v:/g/personal/kohout_ad_helsinki_fi/ETCnP-Ecd1hOulcQRJVkn5sBjaANCU5YGEBBYt15LsUuPQ?e=G0FBxn