Investigations of planetary atmospheres: methods and results

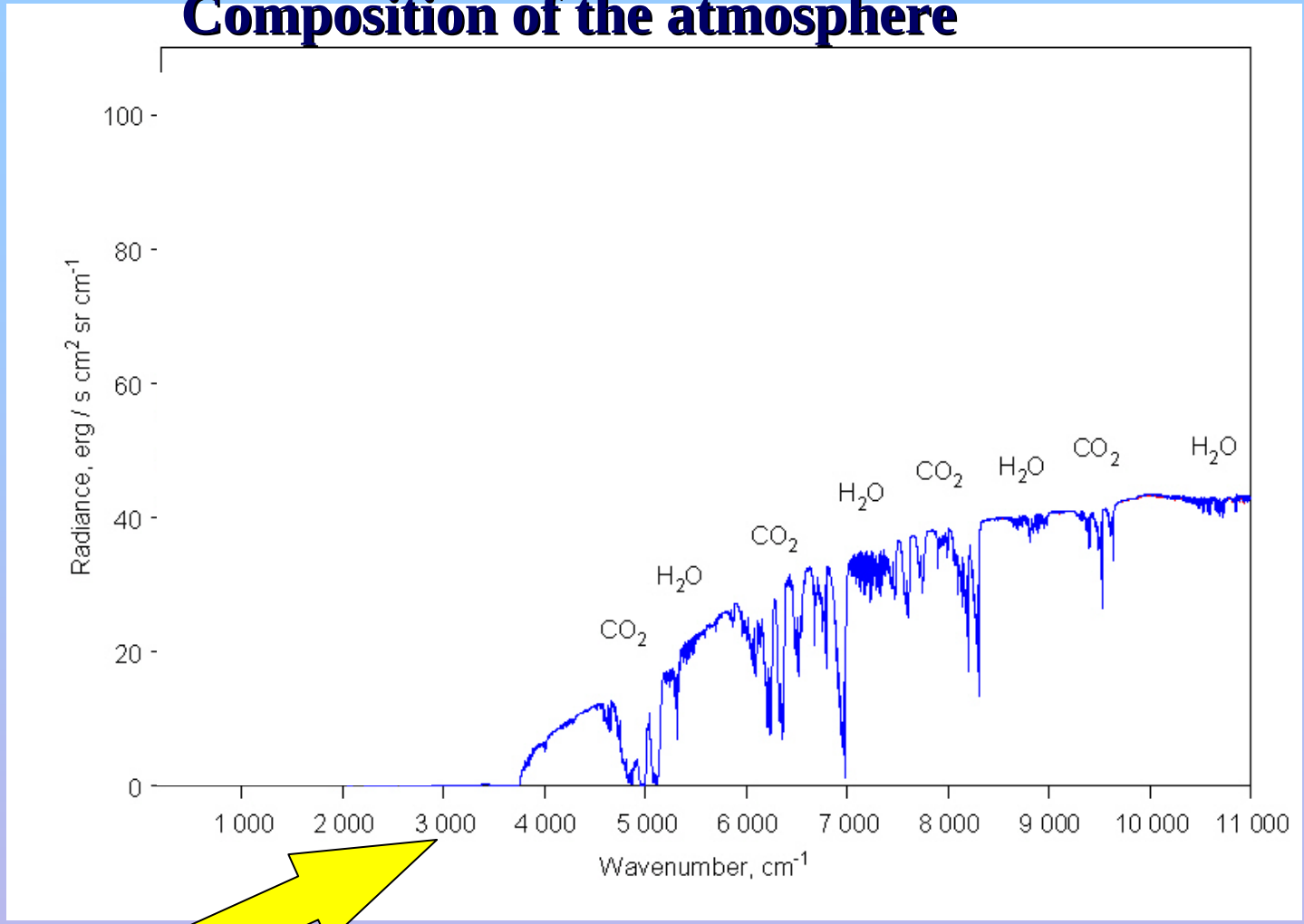
Remote sensing

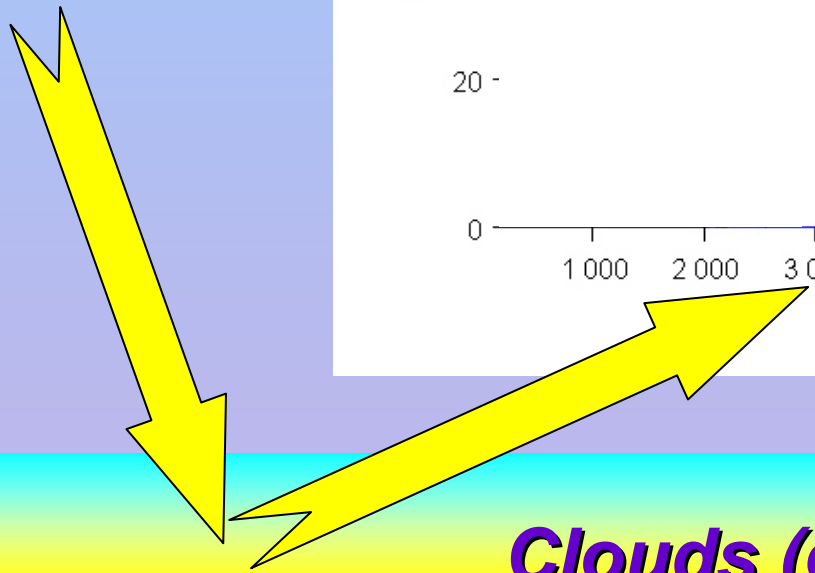
- Imaging
- Spectrometry
- Polarimetry
- Limb sounding
- Occultation methods
- Radar sounding
- Thermal sounding
- Microwave investigations

Spectrometry of reflected solar radiation

- **Wavelength range UV – Near-IR *(0.3 … ~ 3μm)***
- **Good sensitivity to the *total number of molecules* on the line of sight**
- **Low sensitivity to the atmospheric temperature**
- **Day side observations**
- **Multiple scattering needs to be taken into account**

Composition of the atmosphere

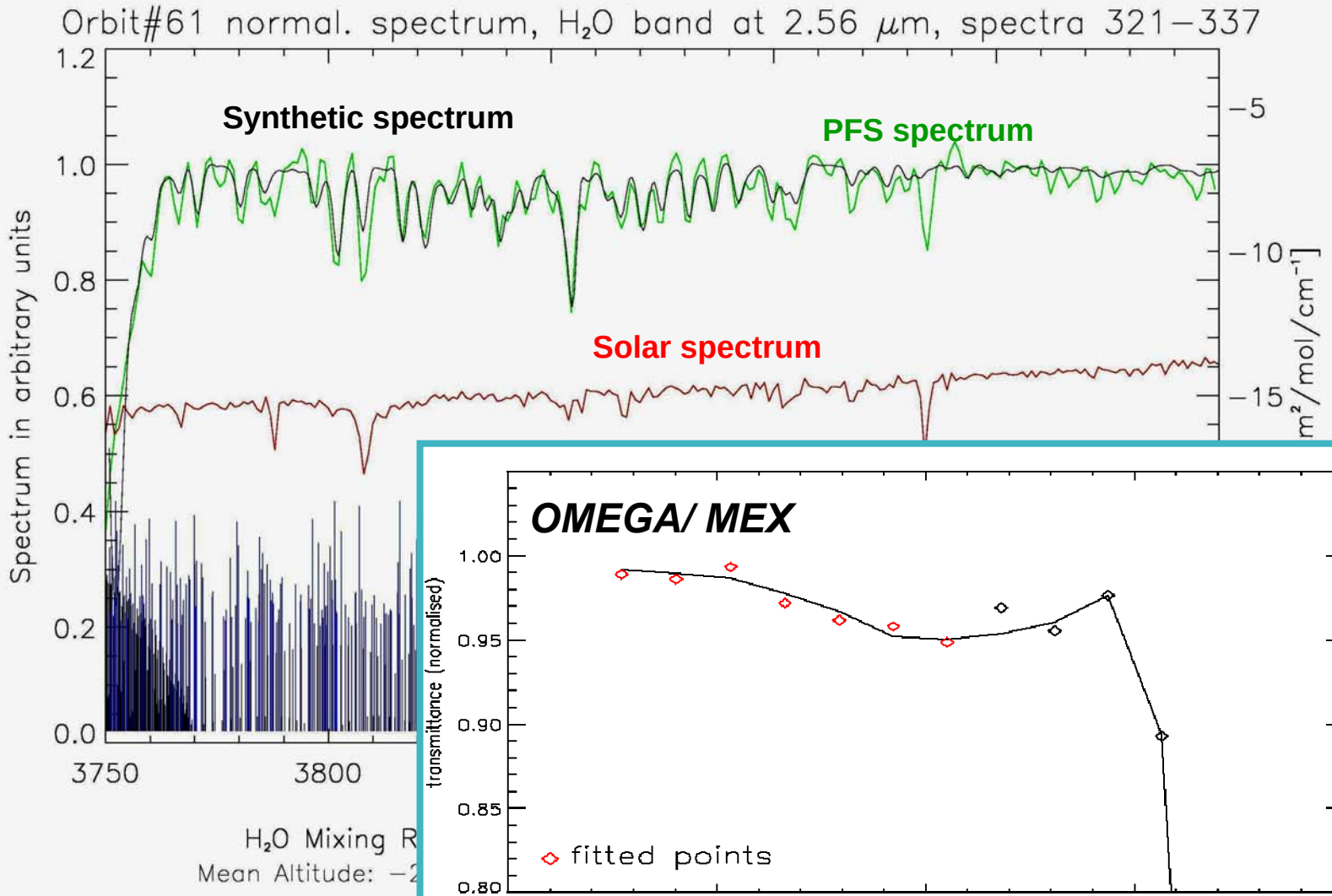




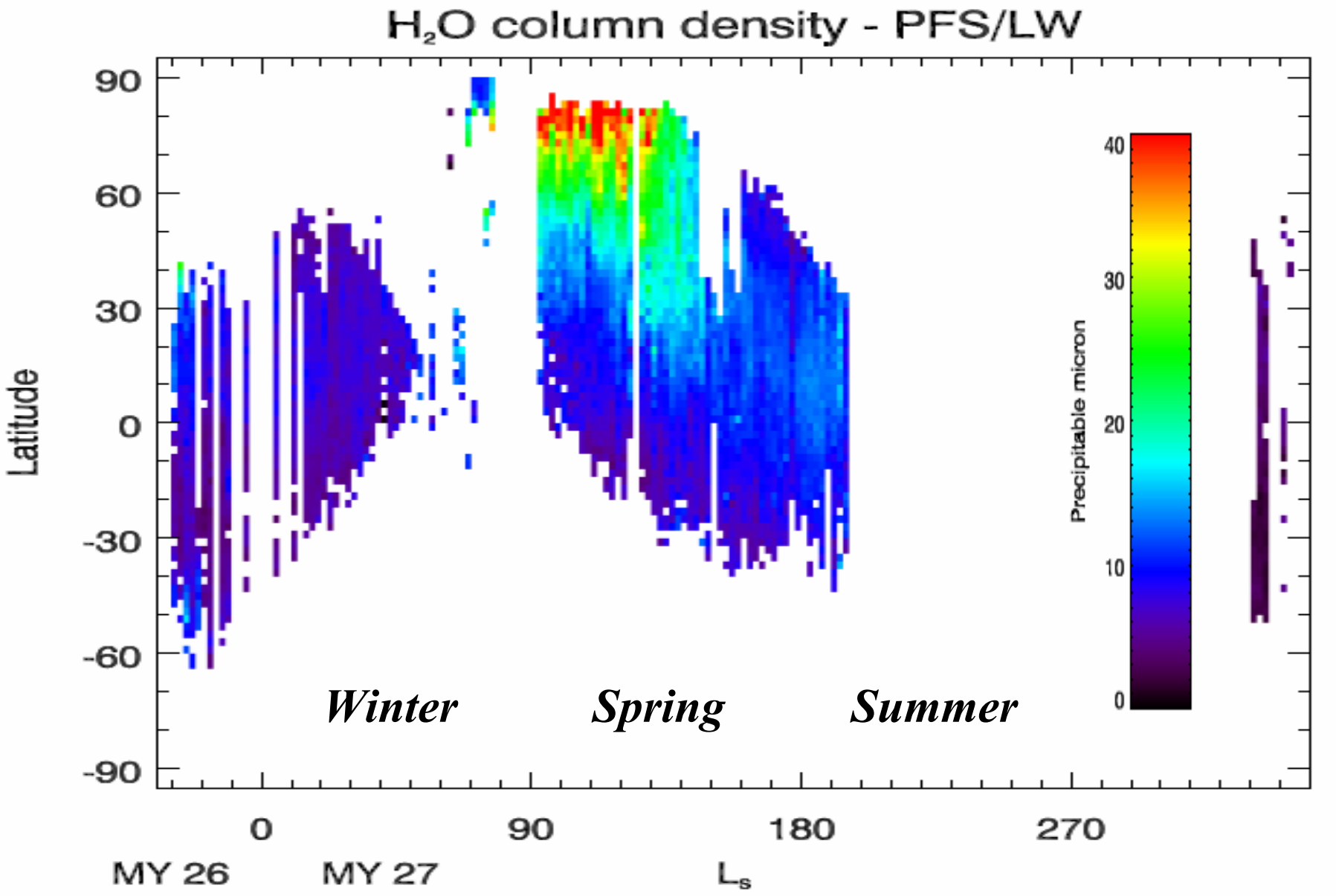
Clouds (or surface)

Monitoring the atmospheric water on Mars

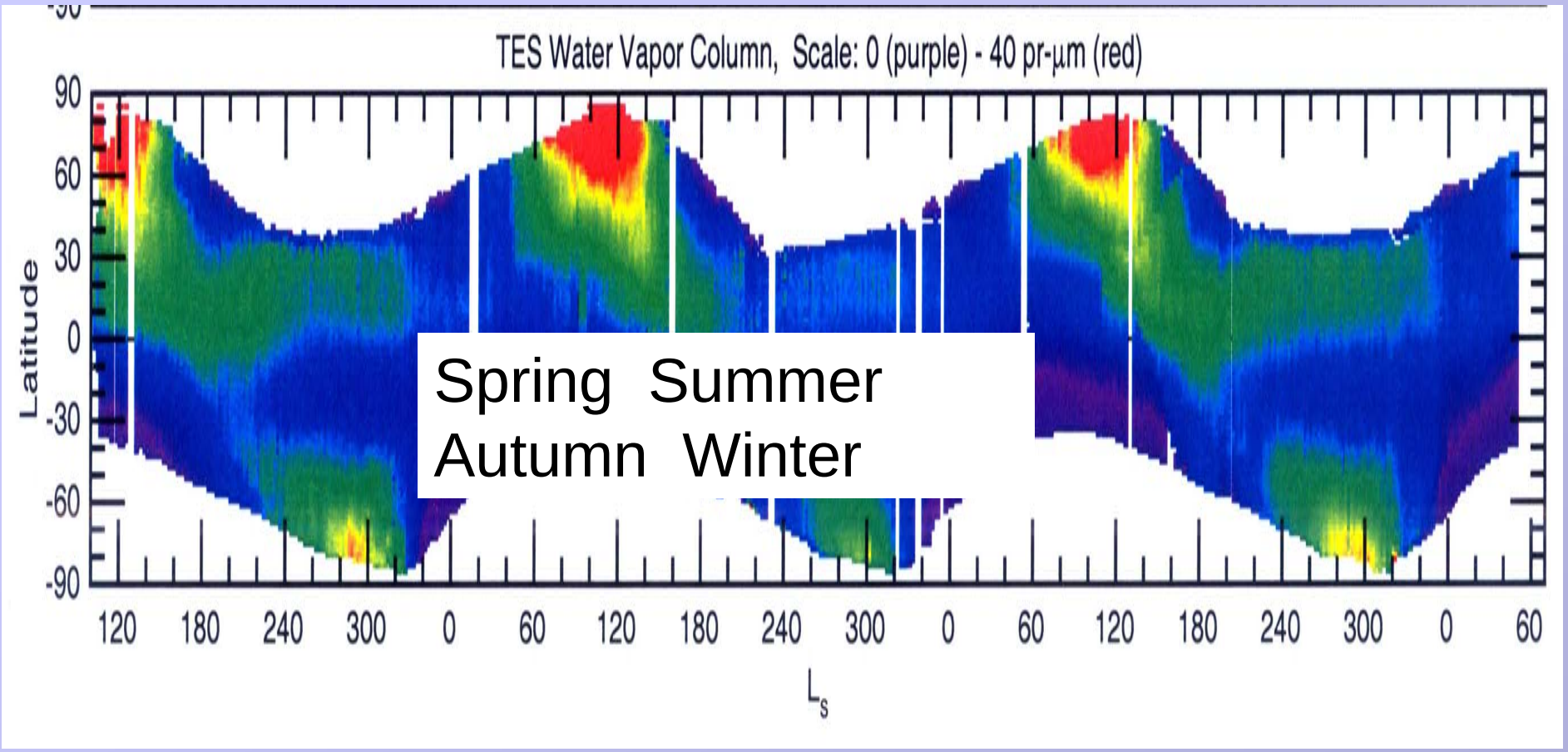
PFS/MEX spectrum in the 2.56 μm H_2O band



Seasonal cycle of water on Mars

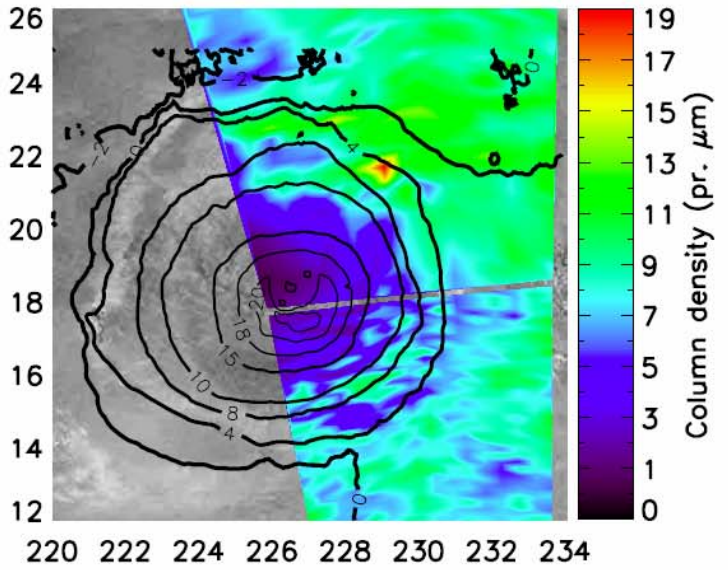


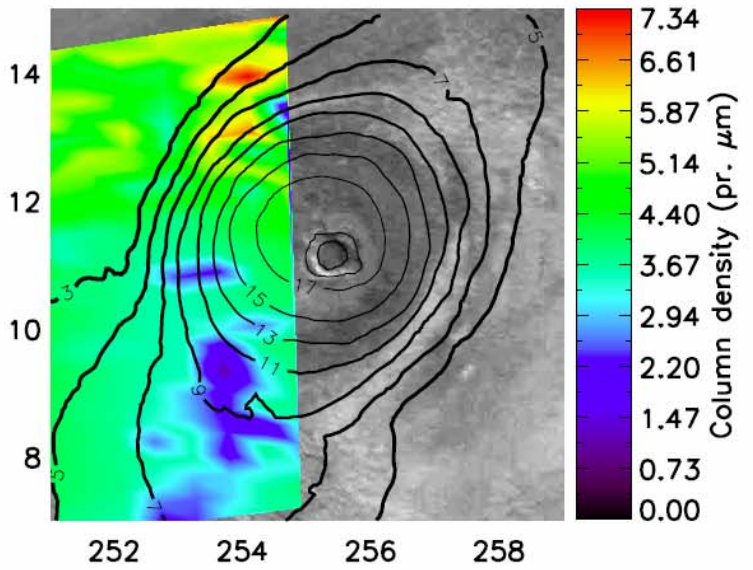
Seasonal water cycle on Mars

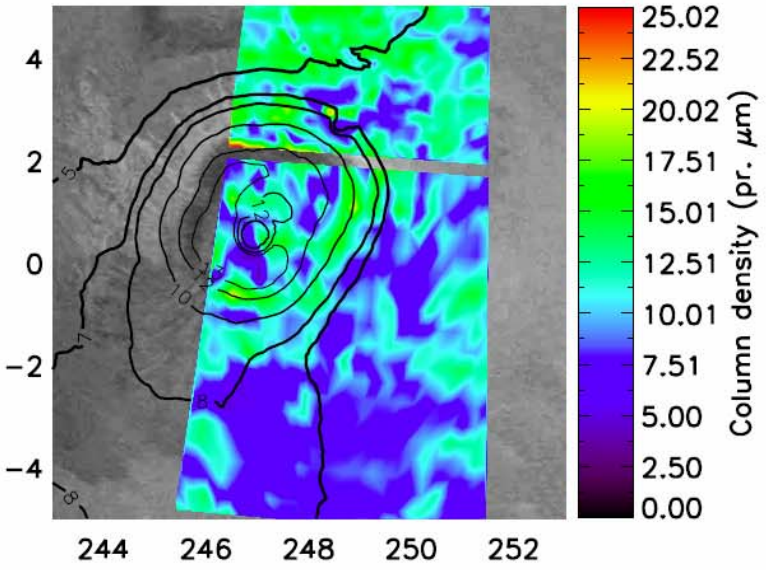


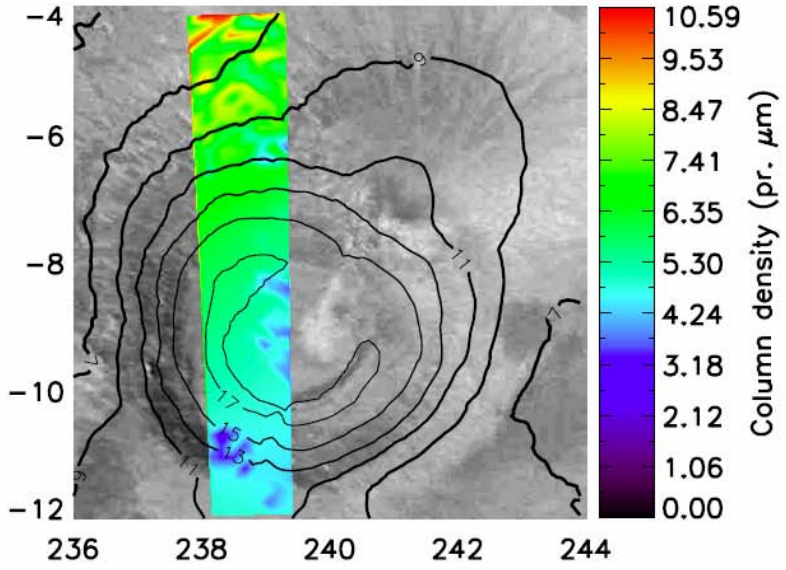
- **Seasonal variability 100 – 1000 ppm**
- **Advective transport**
- **Non-atmospheric reservoirs (polar caps, regolith)**

Atmospheric water above Tharsis volcanoes



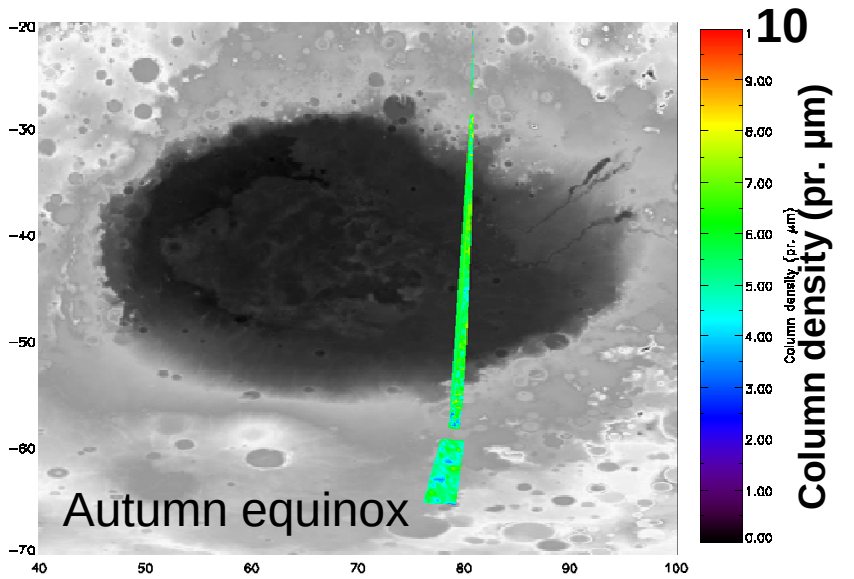


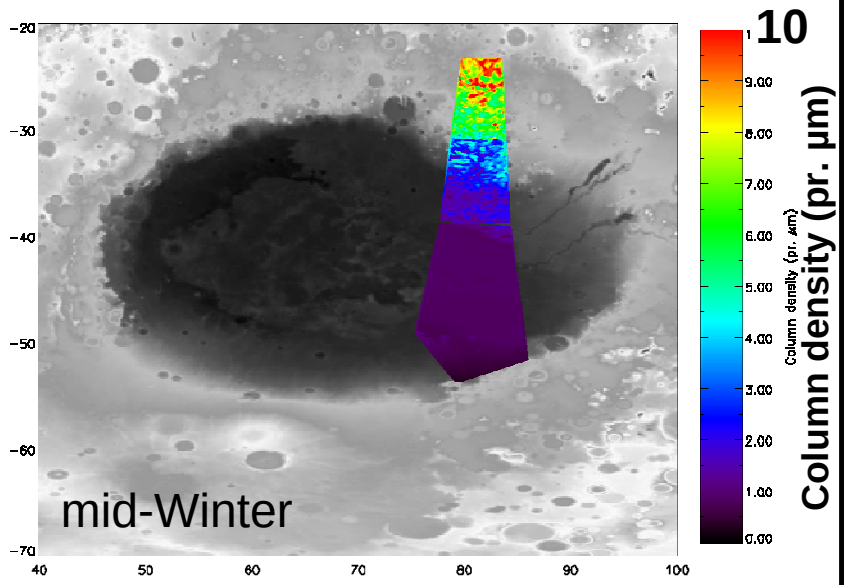


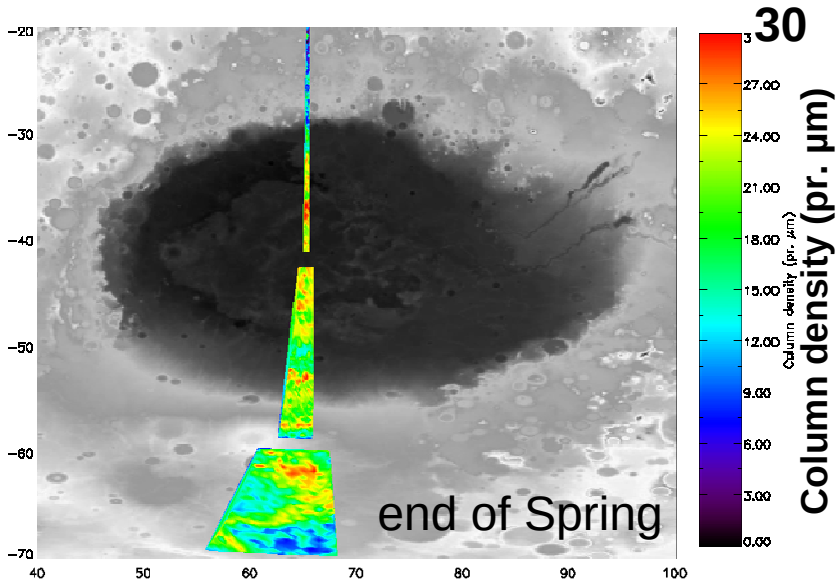


Maltagliati, Titov & OMEGA Team

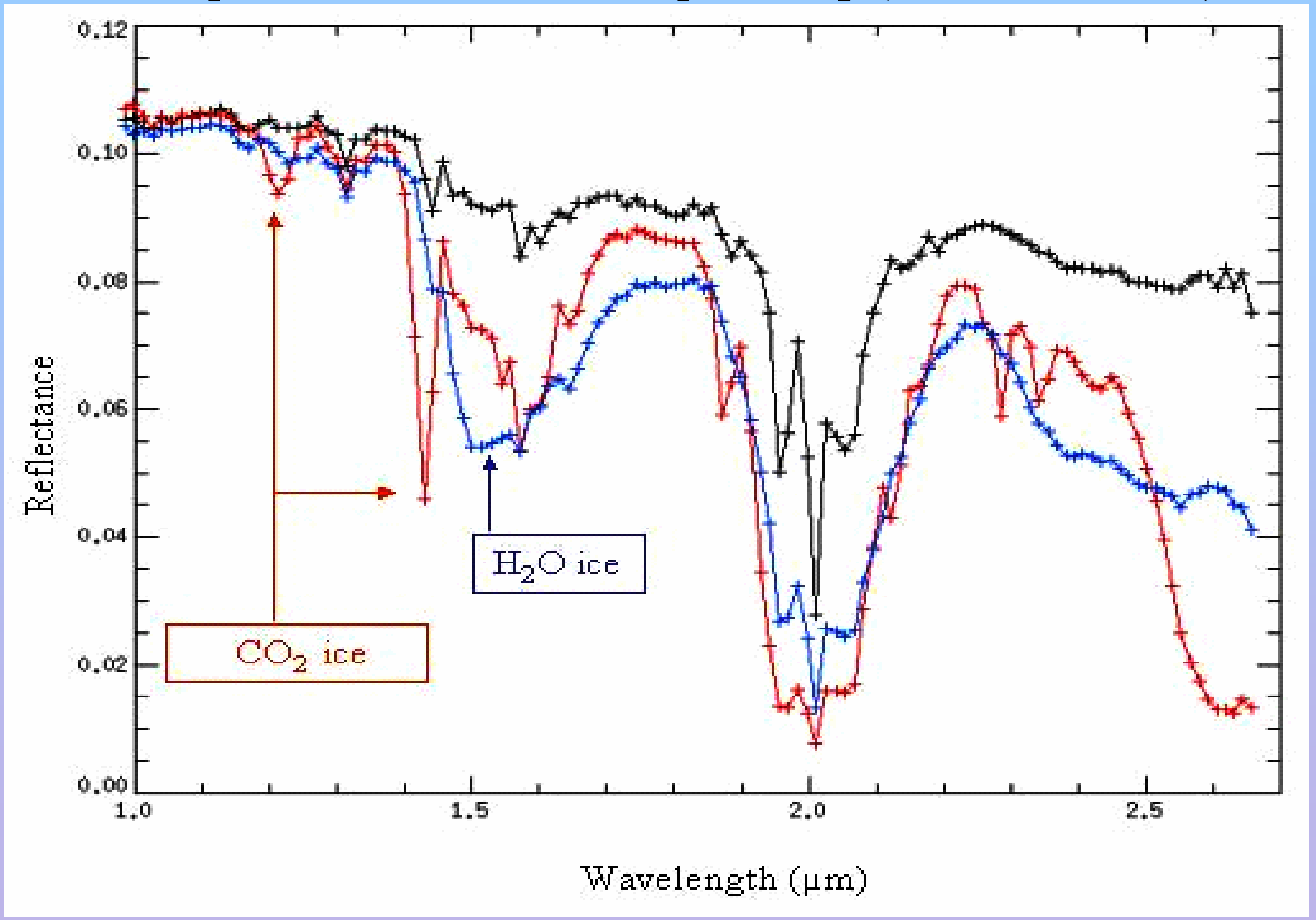
Atmospheric water above Hellas Basin



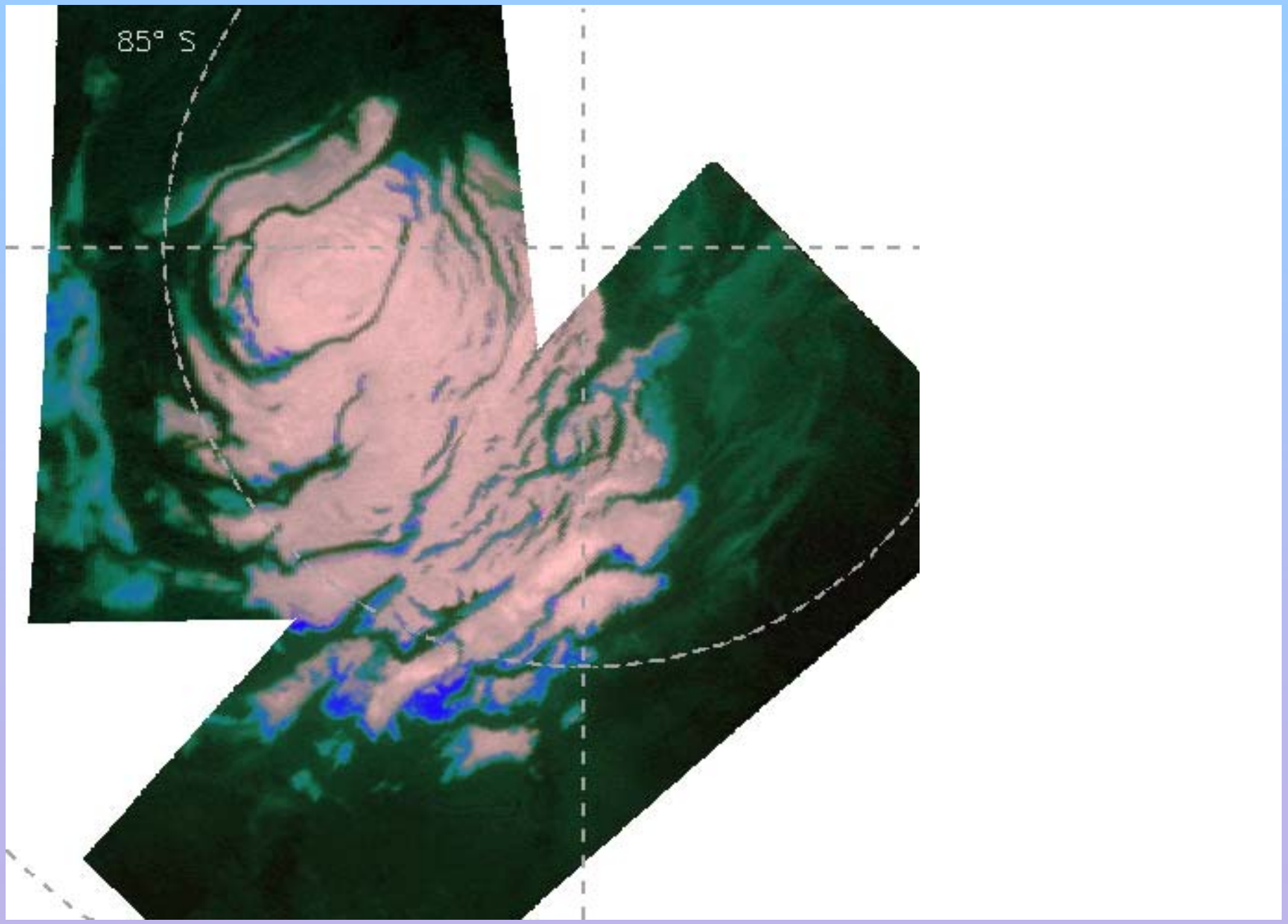




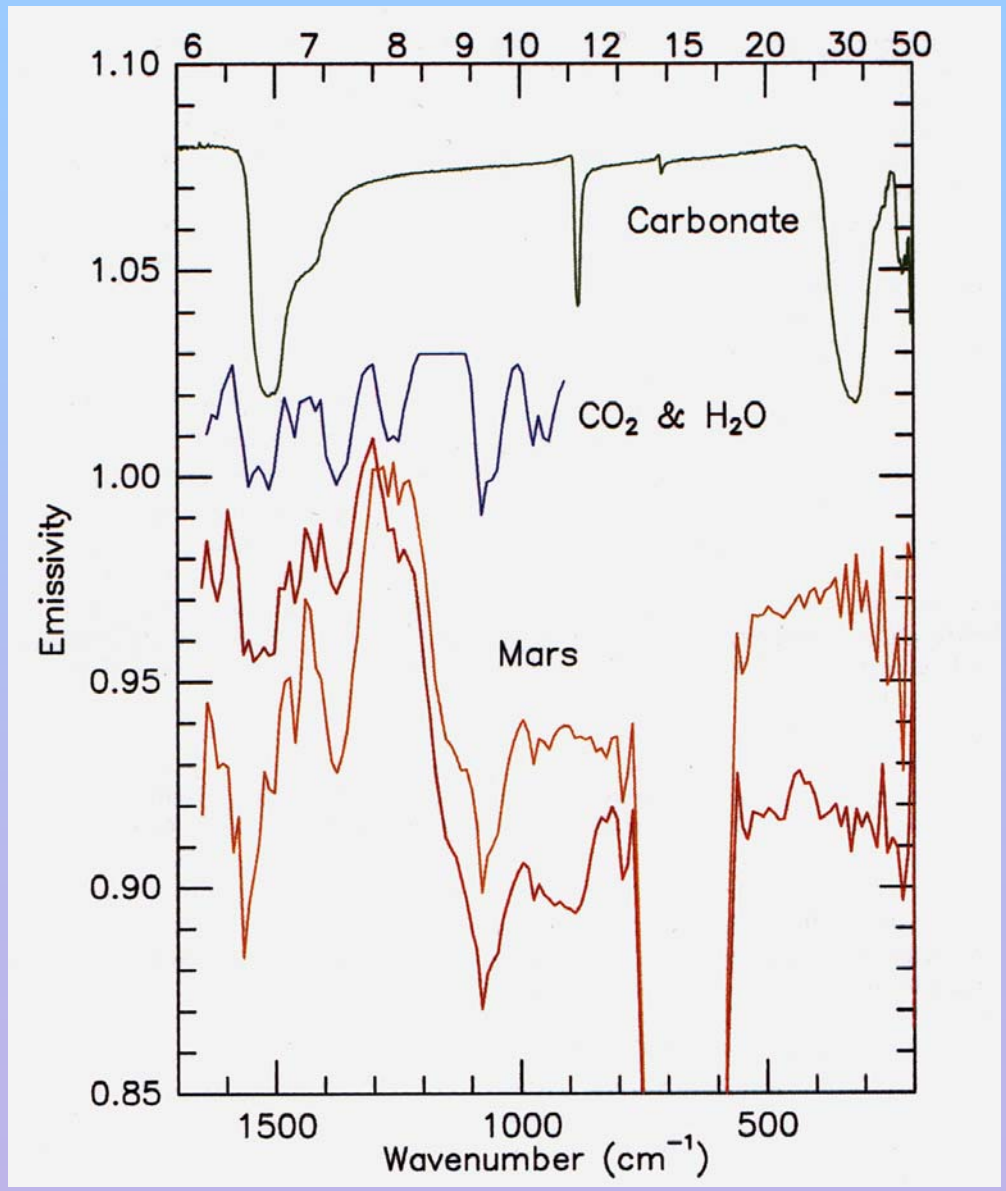
Composition of the Martian polar cap (OMEGA/ MEX)



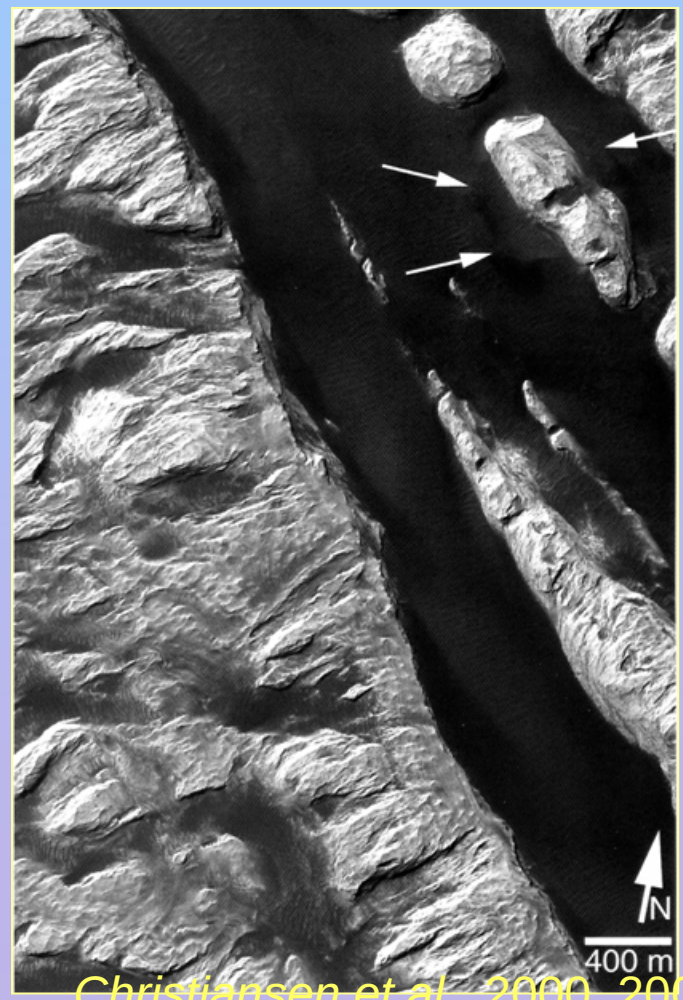
Detection of perennial water ice on the South pole of Mars (OMEGA/ MEX)



TES: Surface mineralogy
Carbonates and weathering products

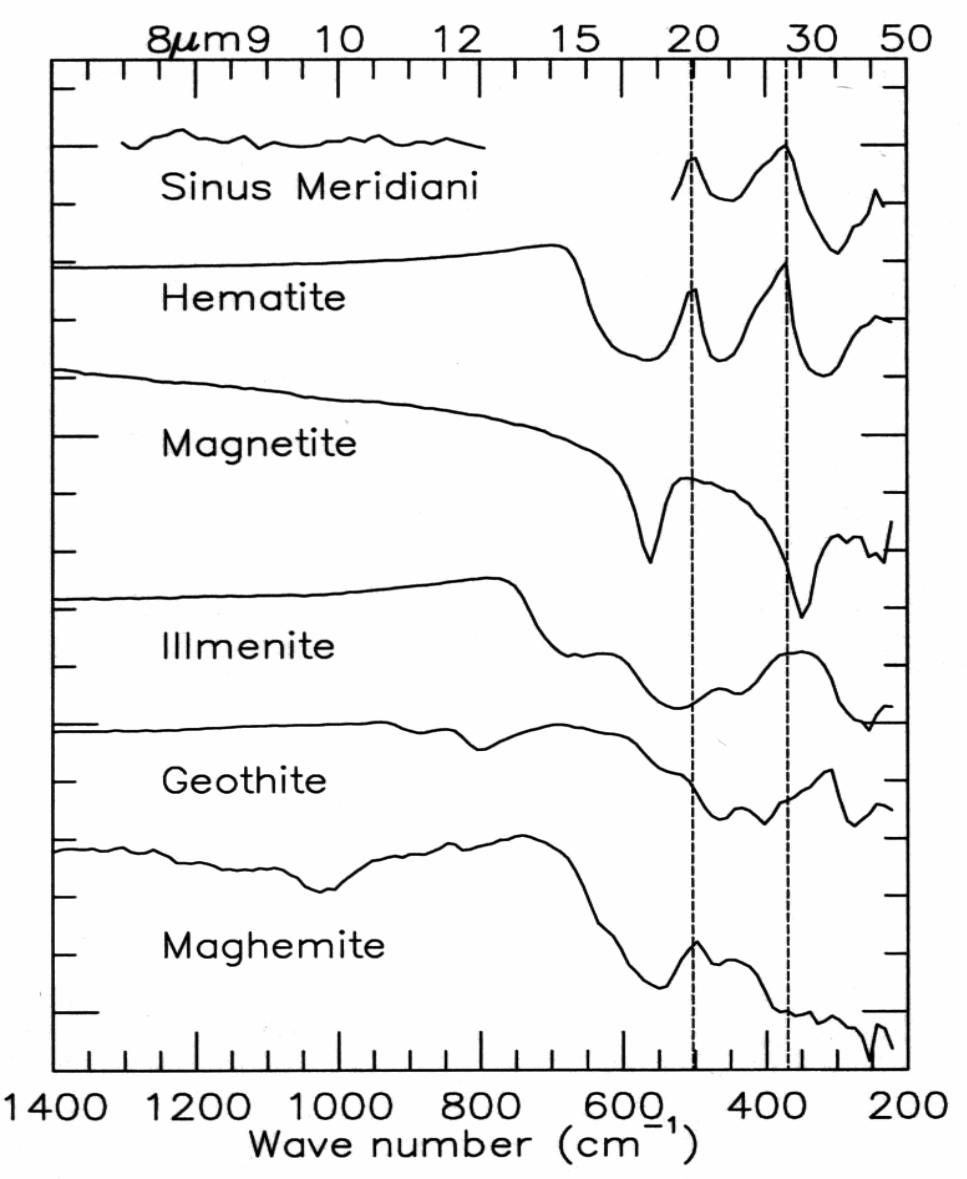


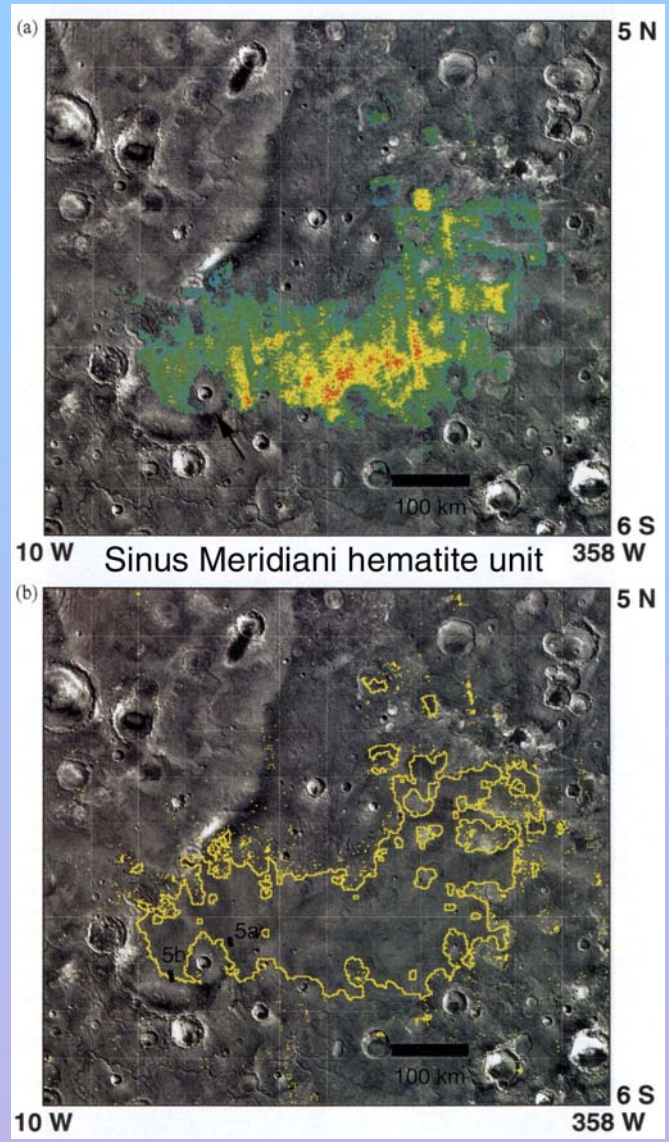
Carbonates, quartz and sulfates have not been identified at detection limit of 5, 5, and 10% respectively and 3 km spatial resolution.



Christiansen et al., 2000, 2001

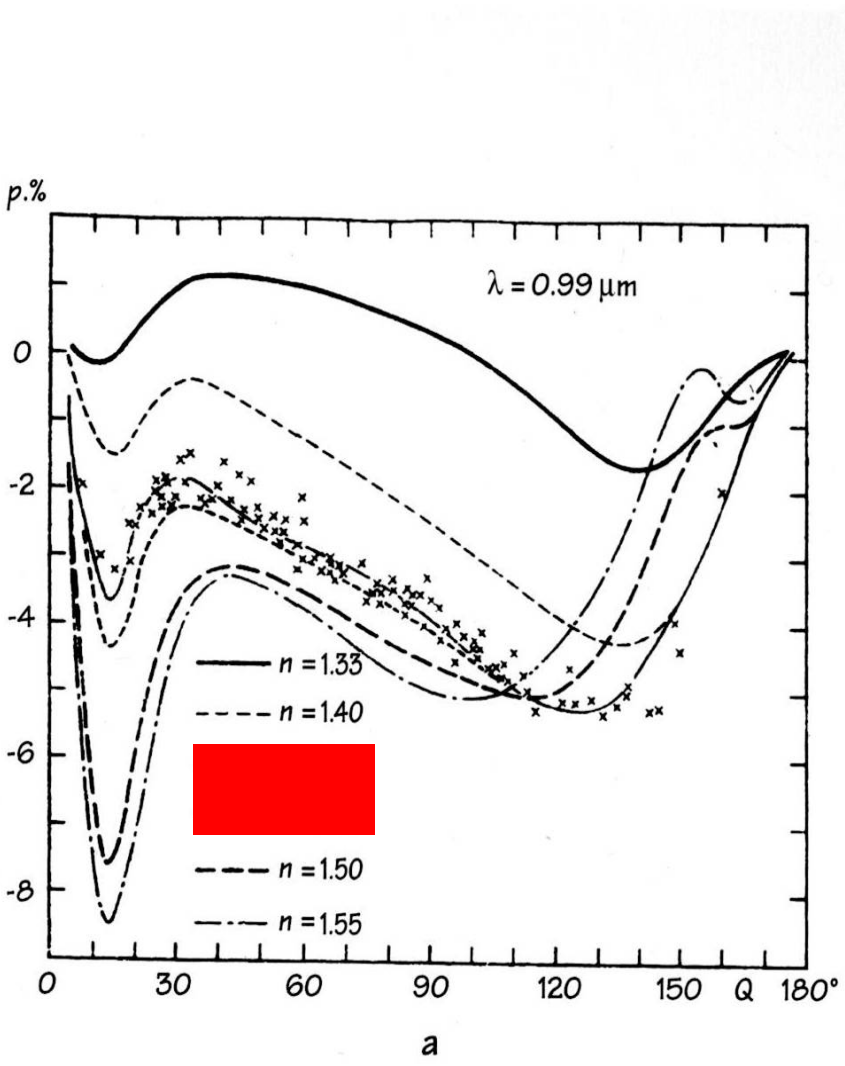
TES: detection of hematite

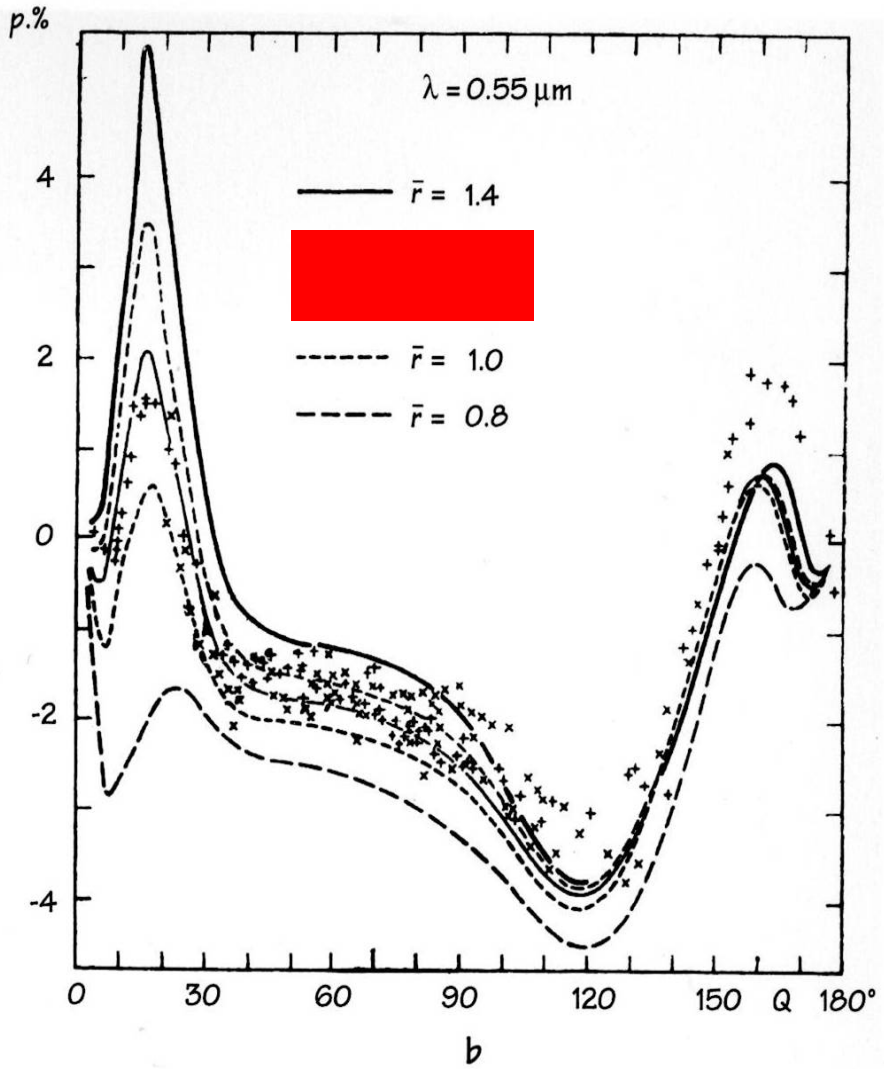




Three localities of crystalline gray hematite: Sinus Meridiani, Aram Chaos, Ophir/Candor small deposits.

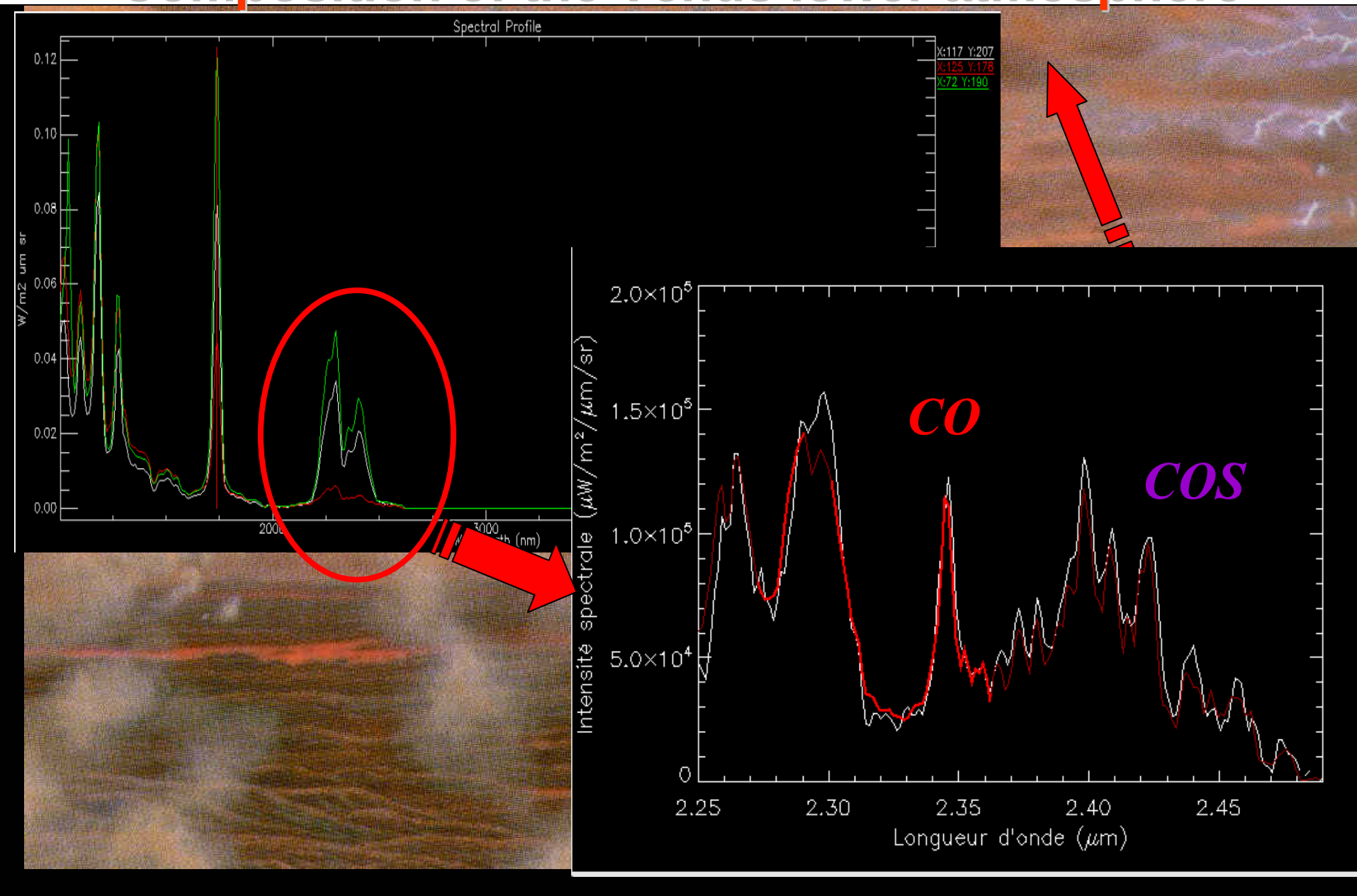
Polarimetry of Venus: discovery of sulfuric acid clouds



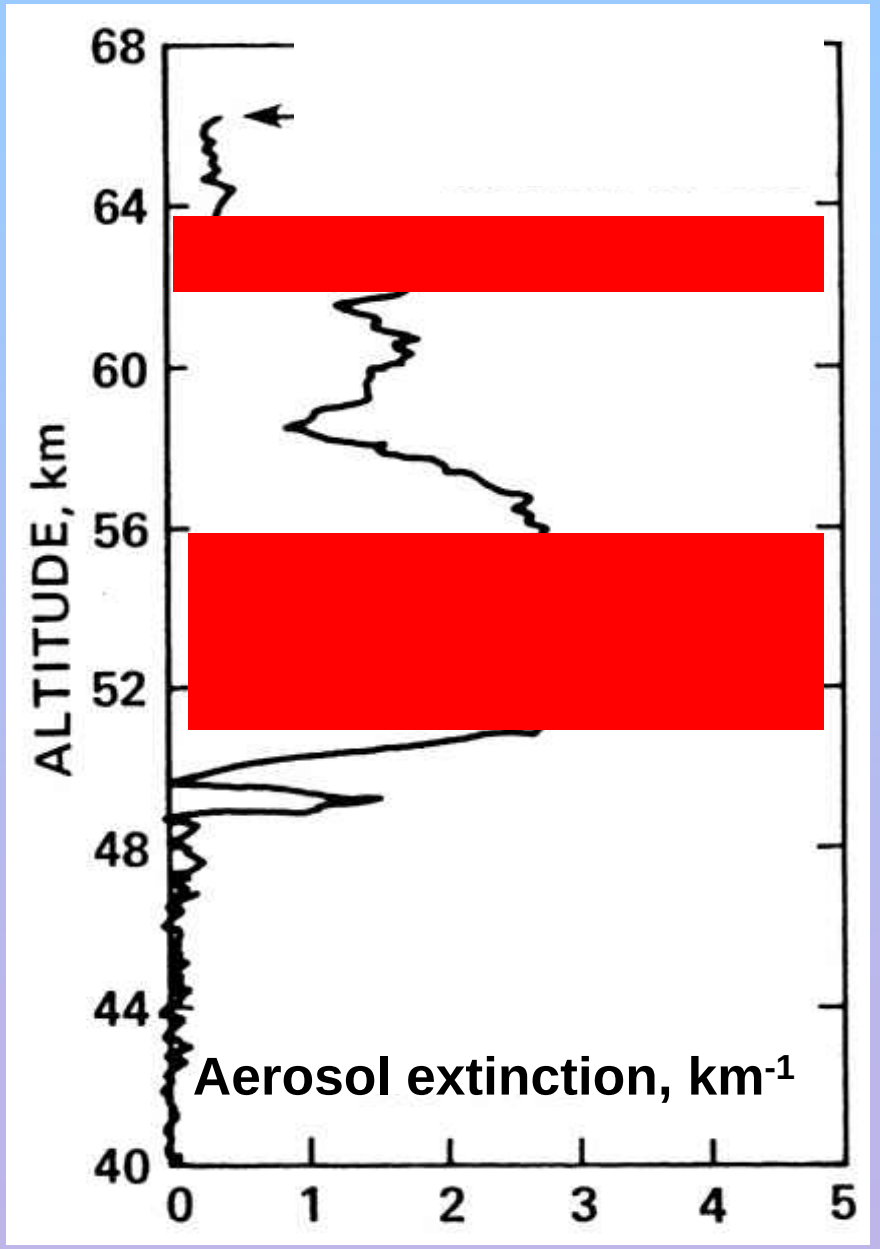


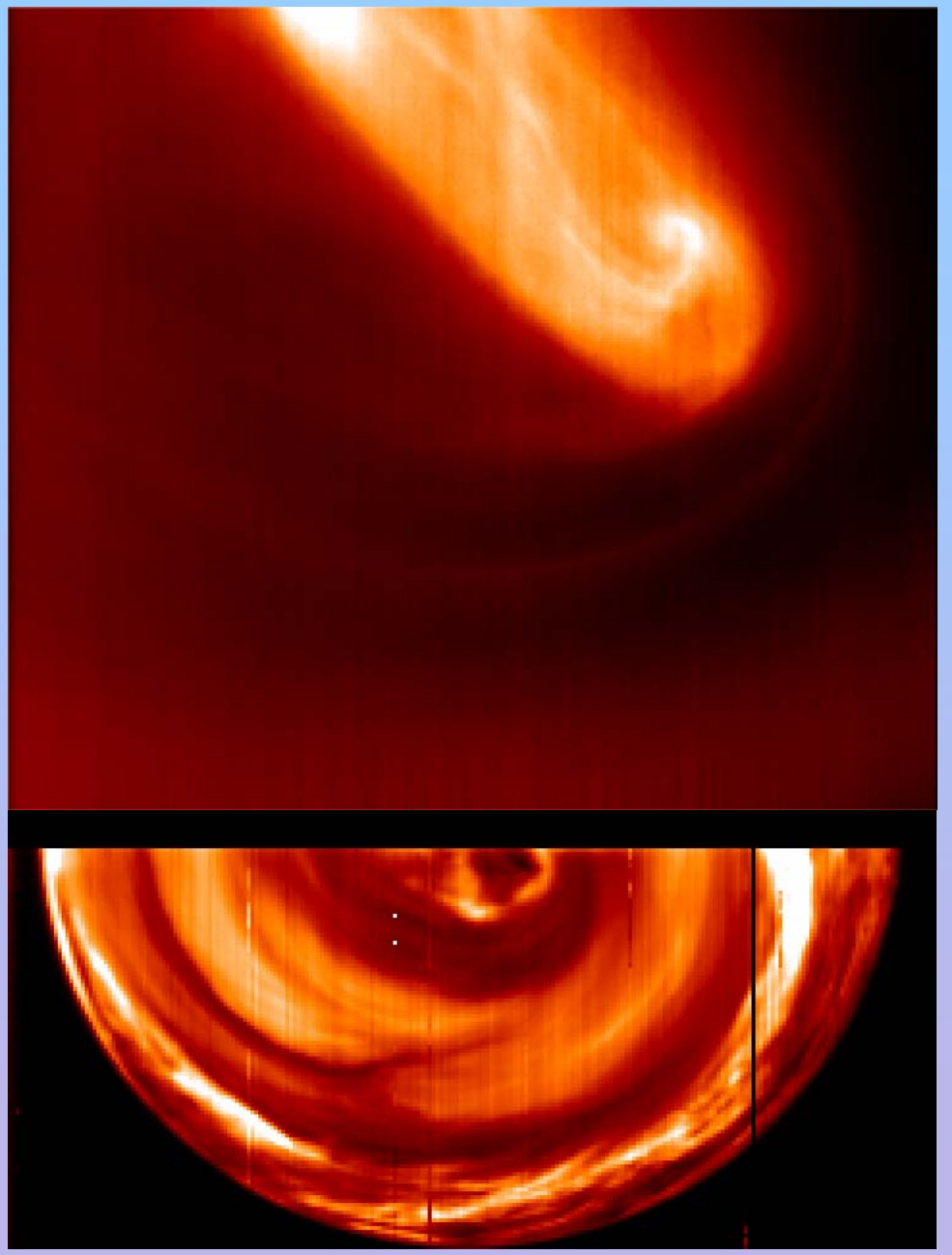
- Sensitivity to aerosol optical properties and size distribution

Spectroscopy in transparency “windows”: Composition of the Venus lower atmosphere

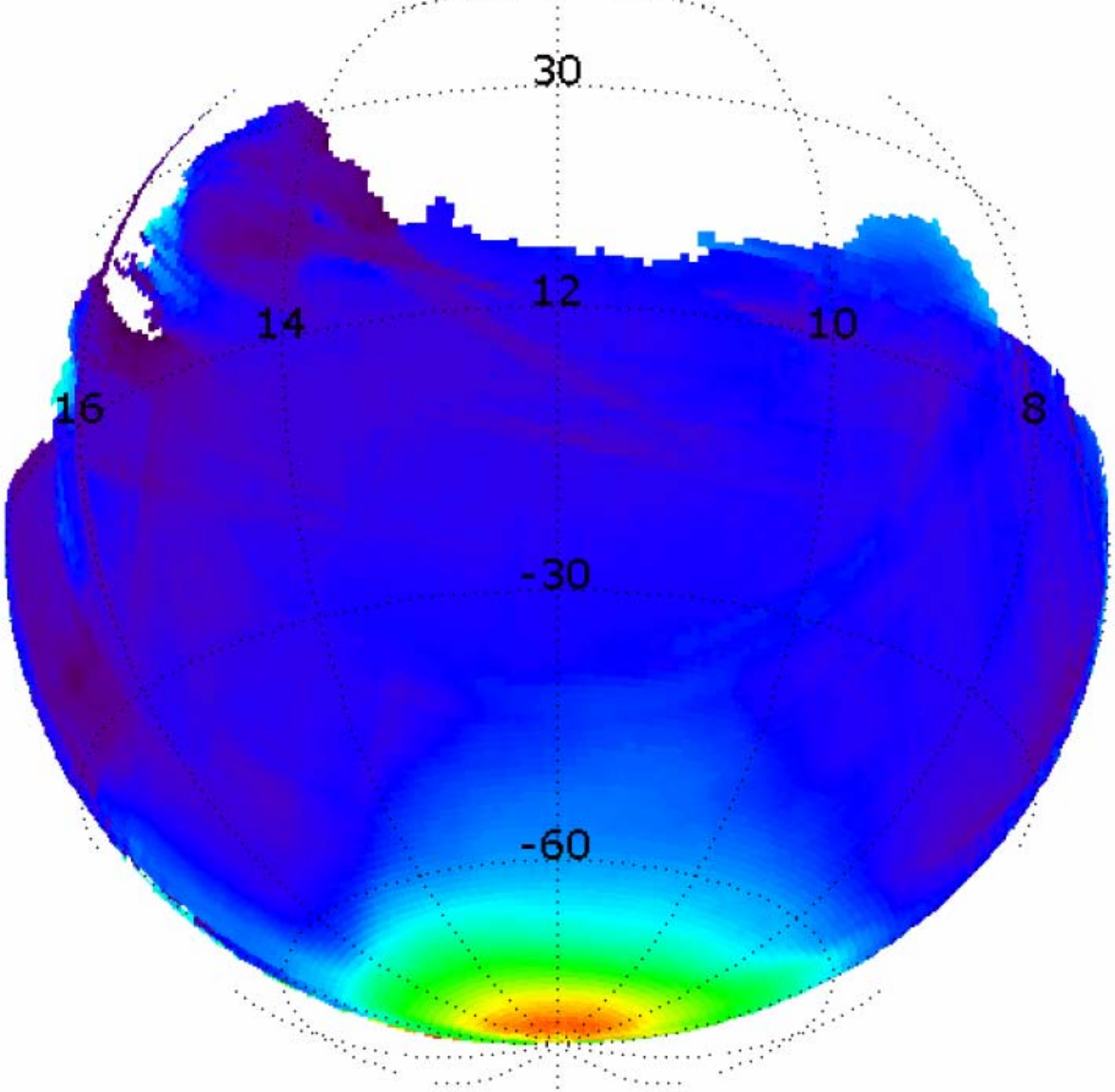


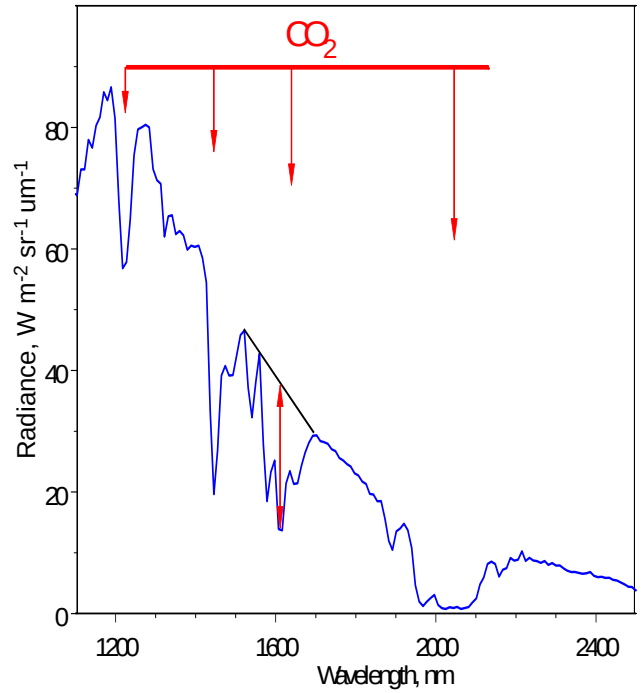
Imaging at different wavelengths





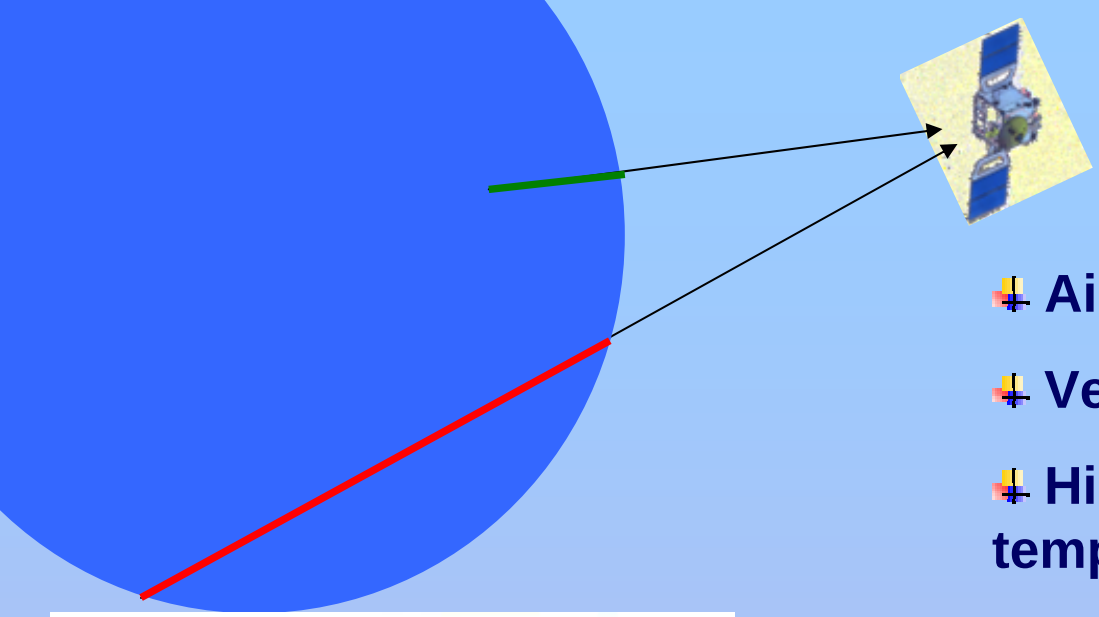
Cloud top altitude



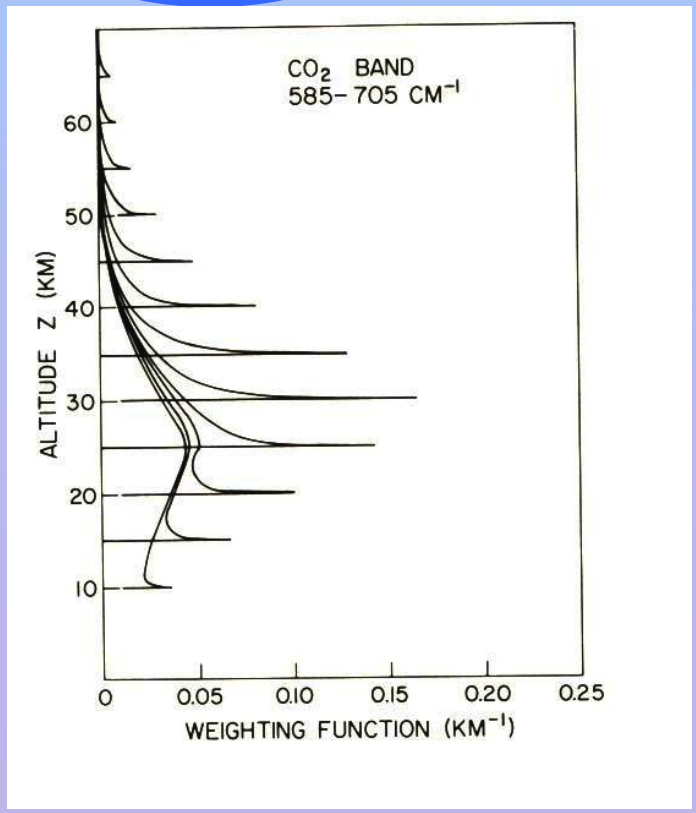


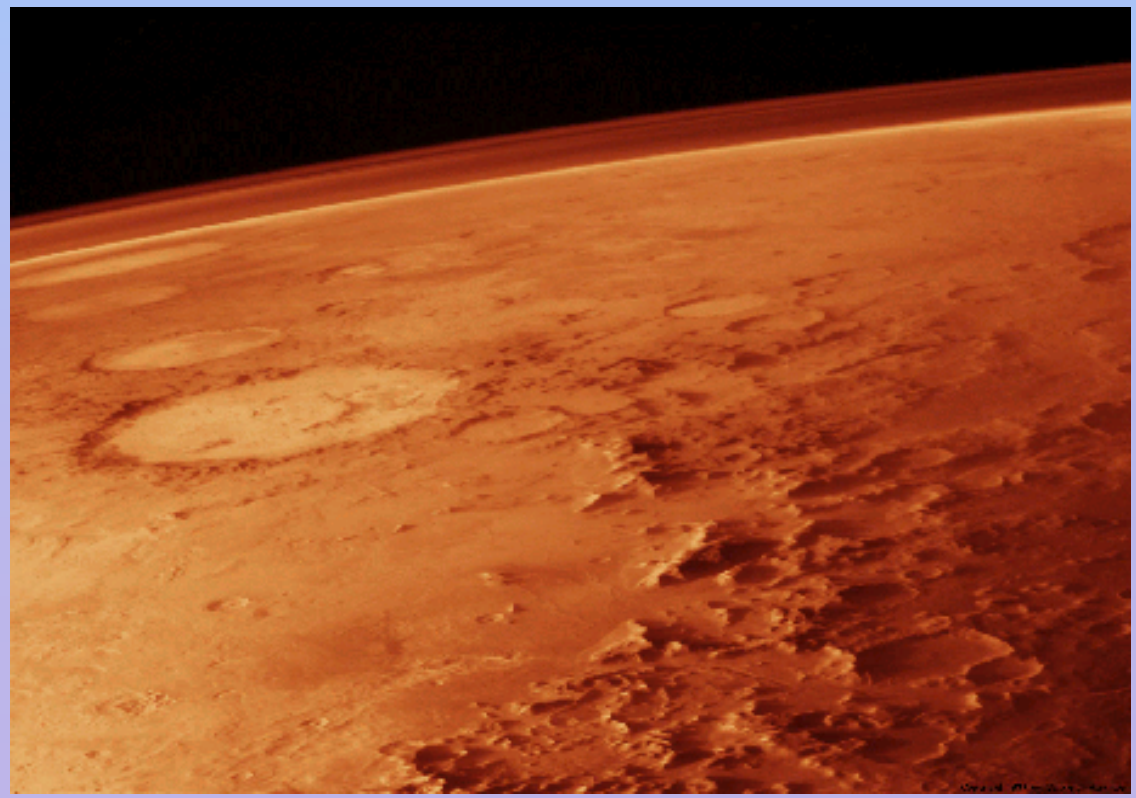
Ignatiev et al.

Limb sounding

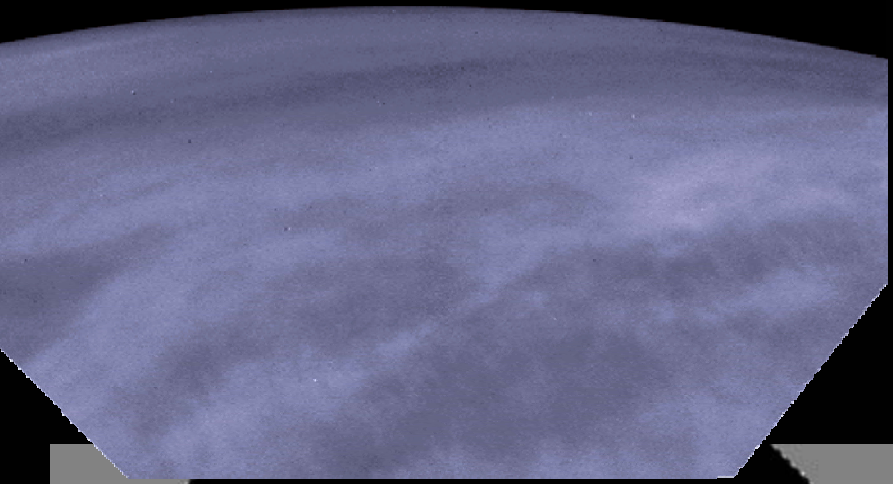


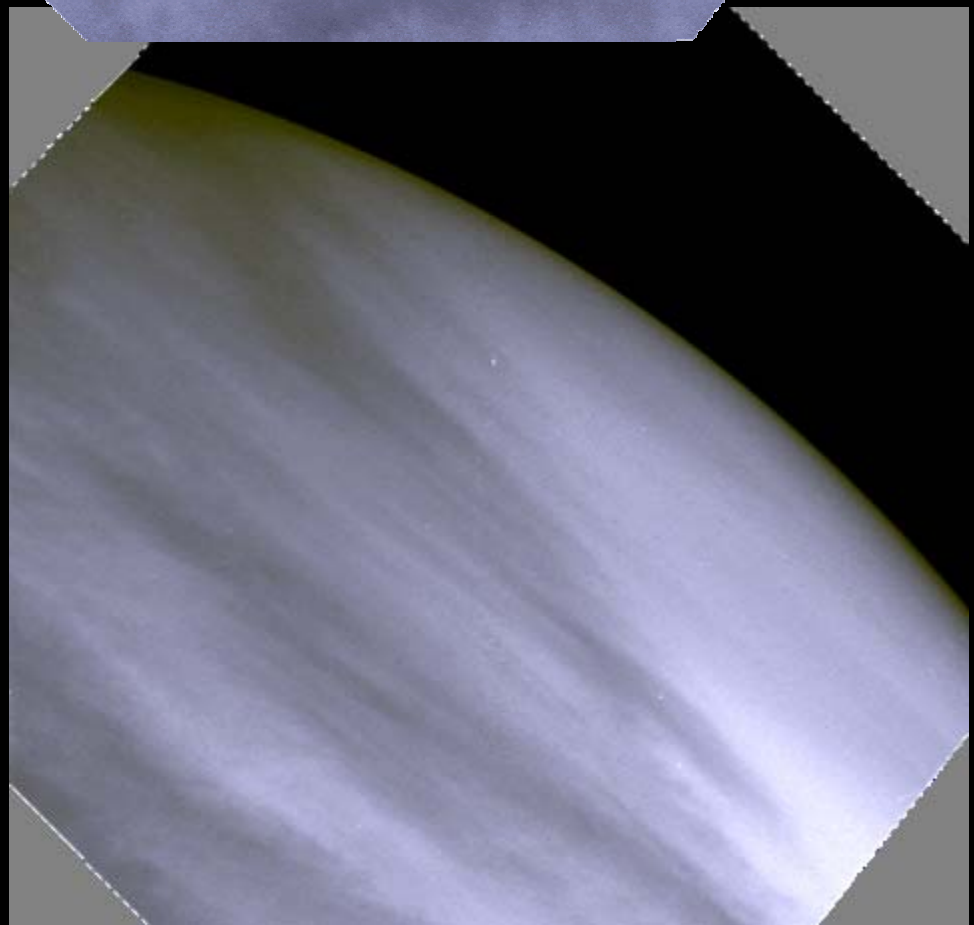
- Air mass advantage
- Vertical sounding
- Higher altitude resolution in temperature sounding

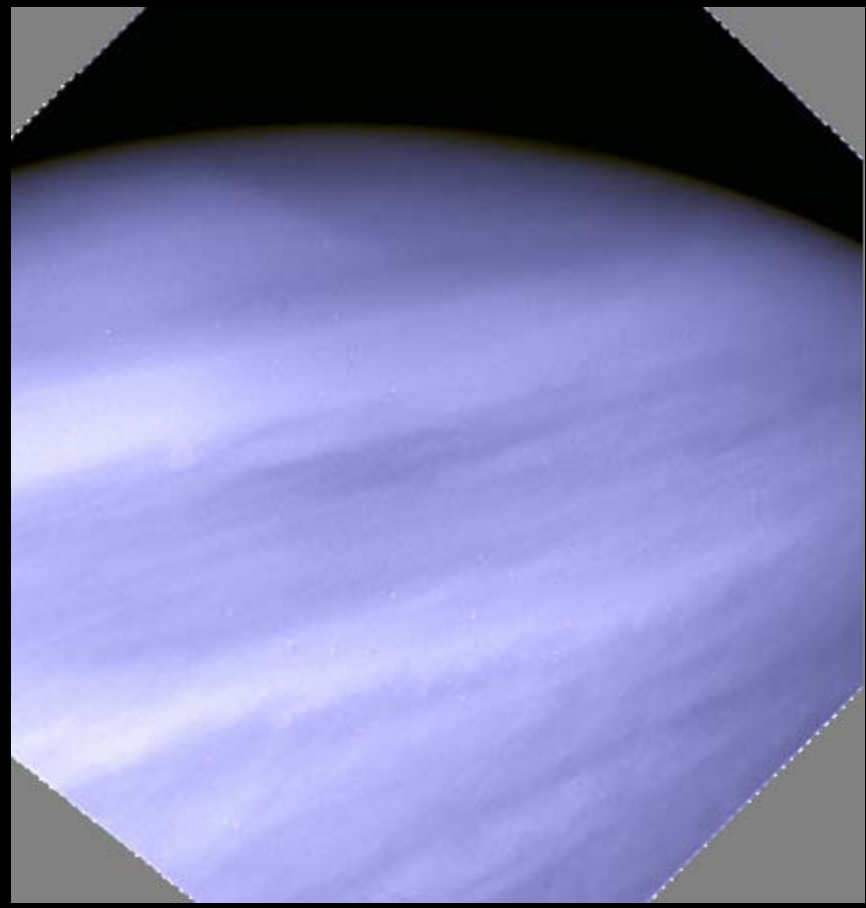




Venus limbs by Venus Express Monitoring Camera

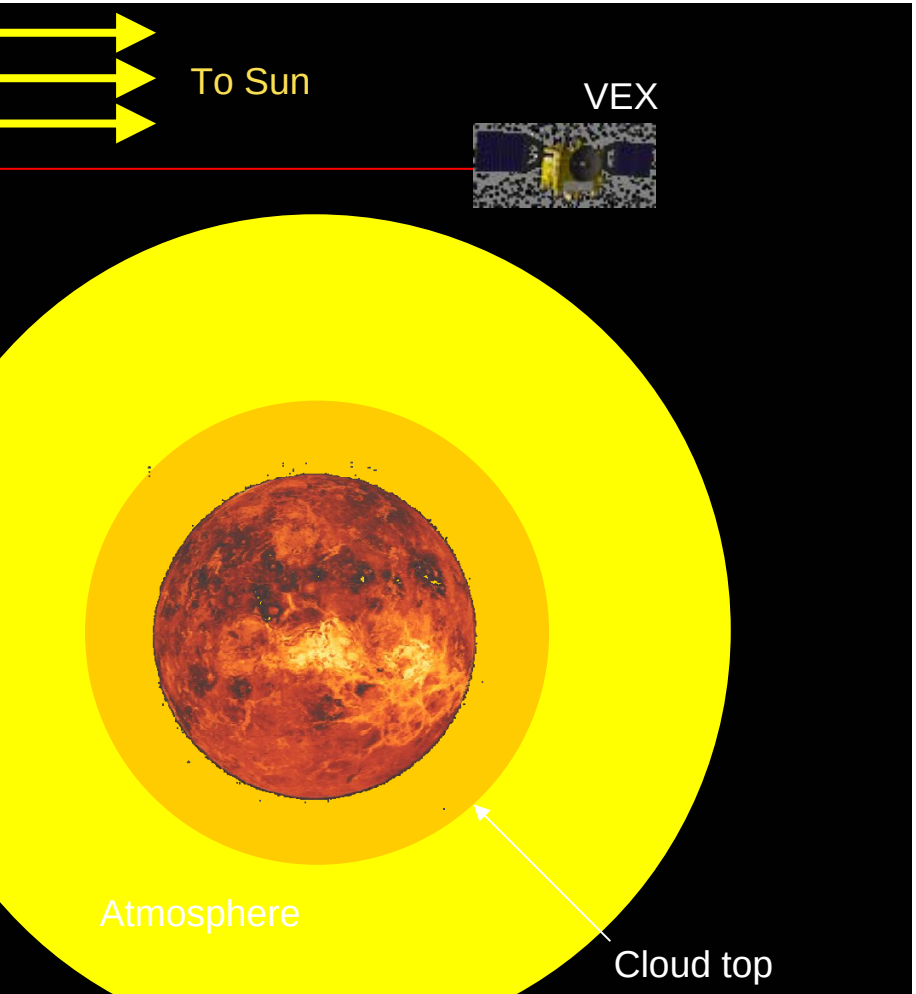




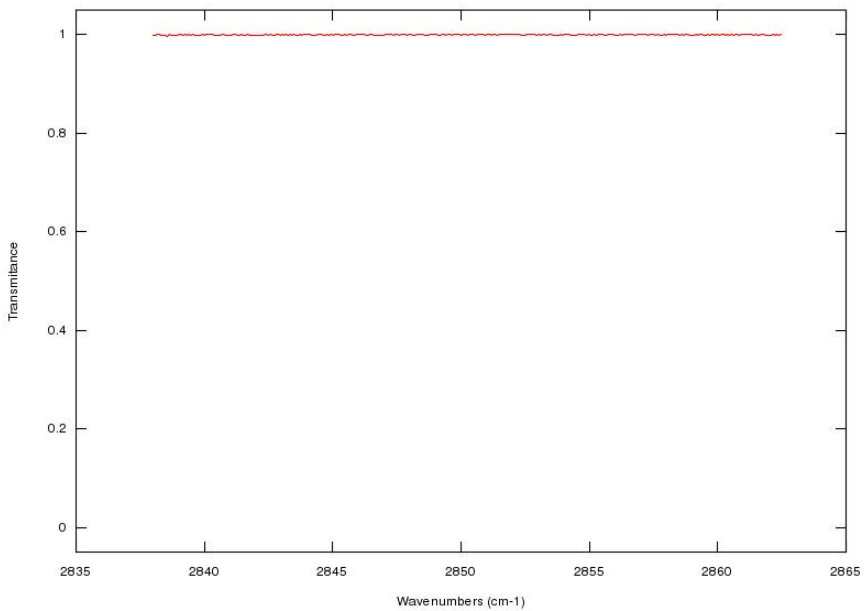


Solar occultation sounding

SPICAV/SOIR solar occultation



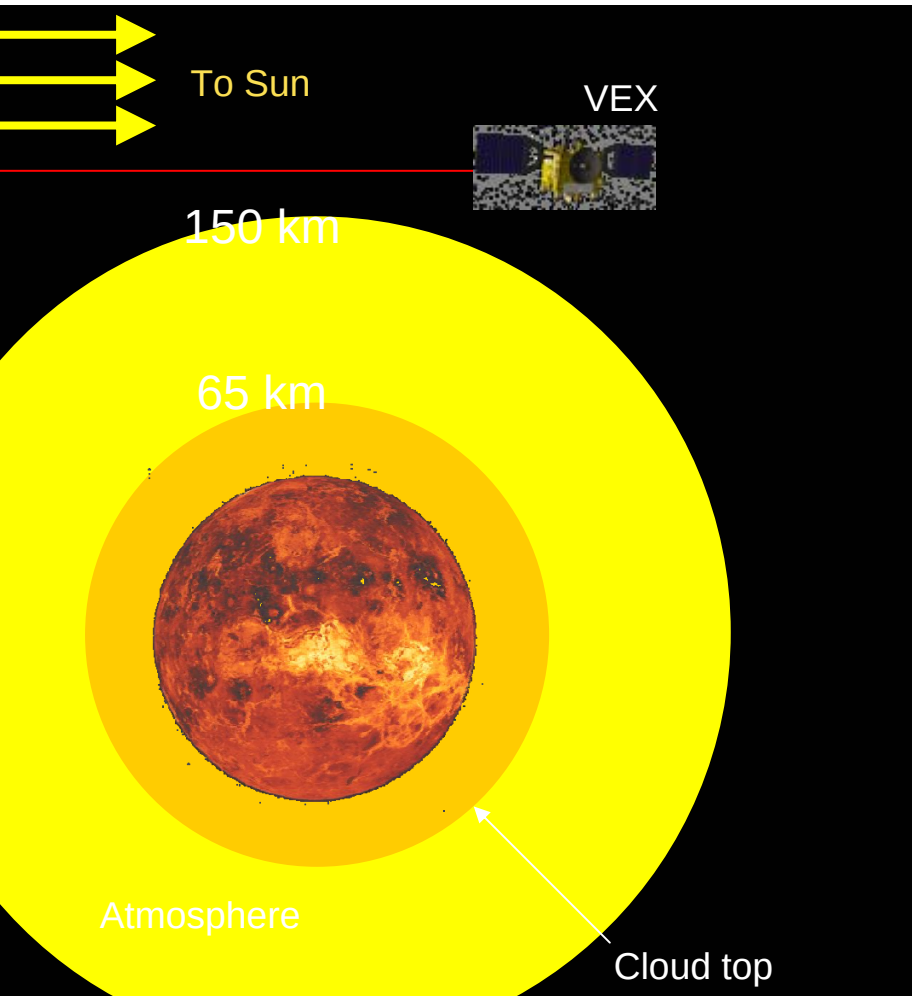
Orbit 232 – Order 129



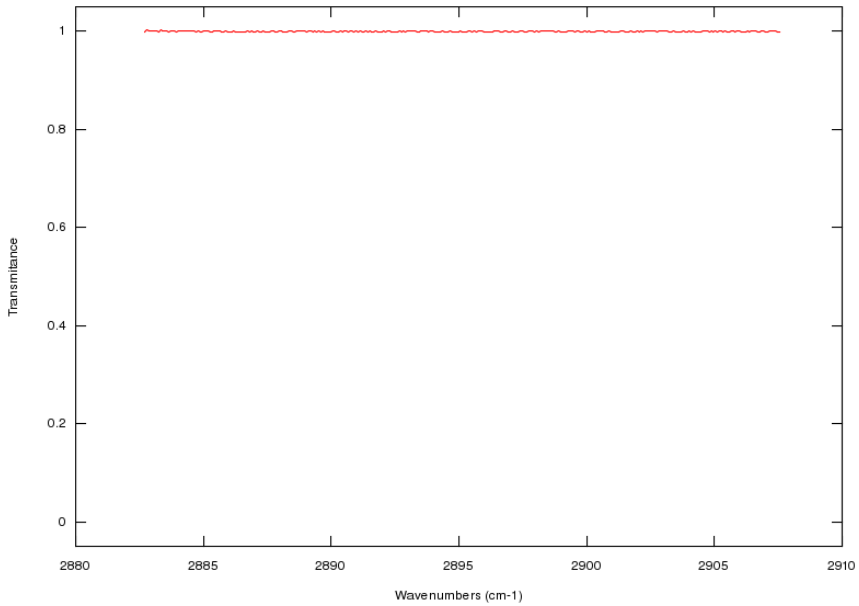
SPICAV/SOIR solar occultation

Detected molecules:

CO_2, H_2O, HDO, CO, HCl, SO_2

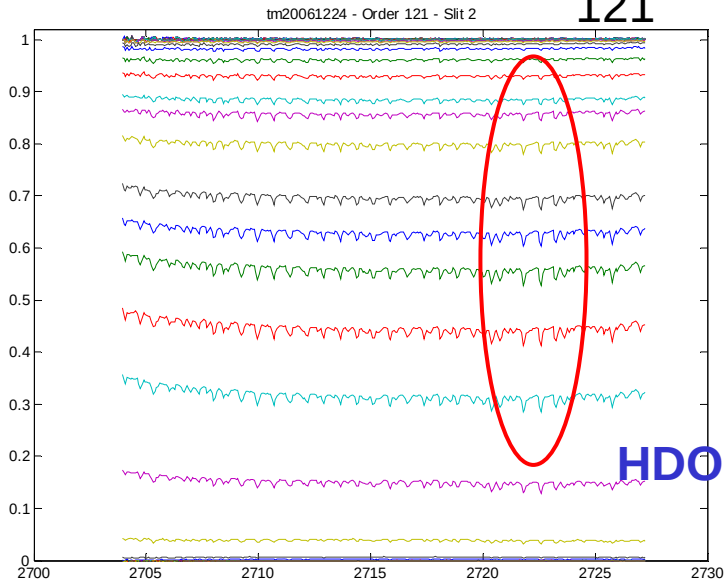


Orbit 232 – Order 129

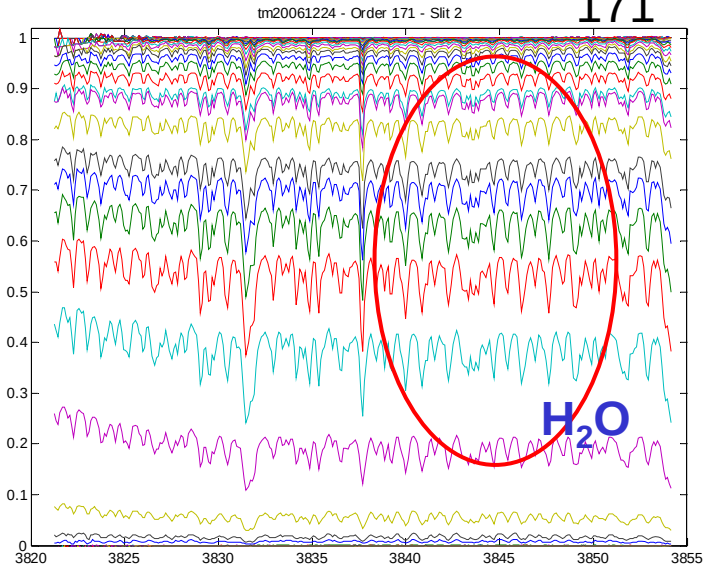


Examples of SOIR Venus Express spectra

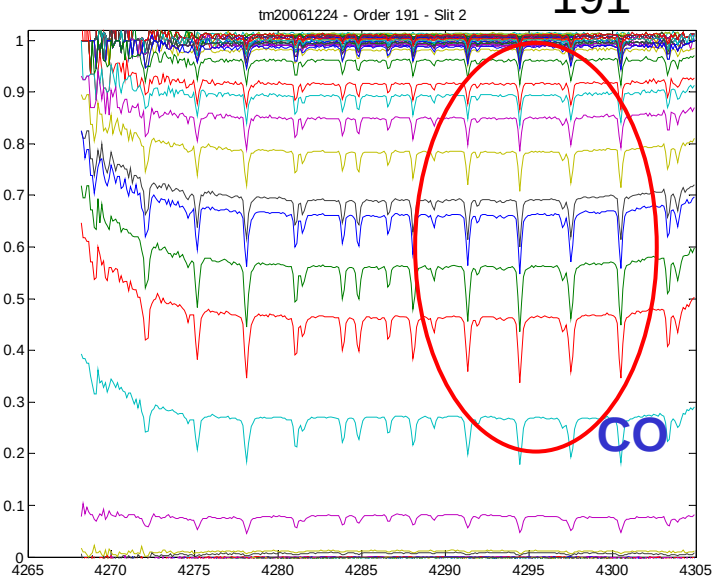
121



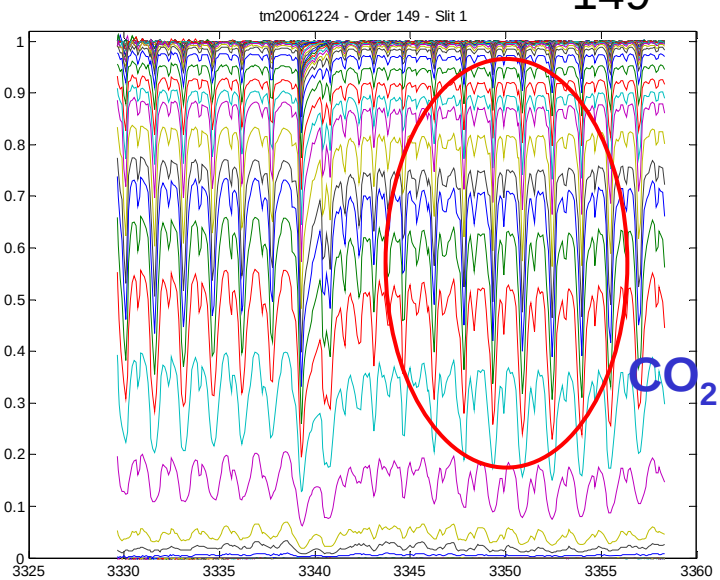
171



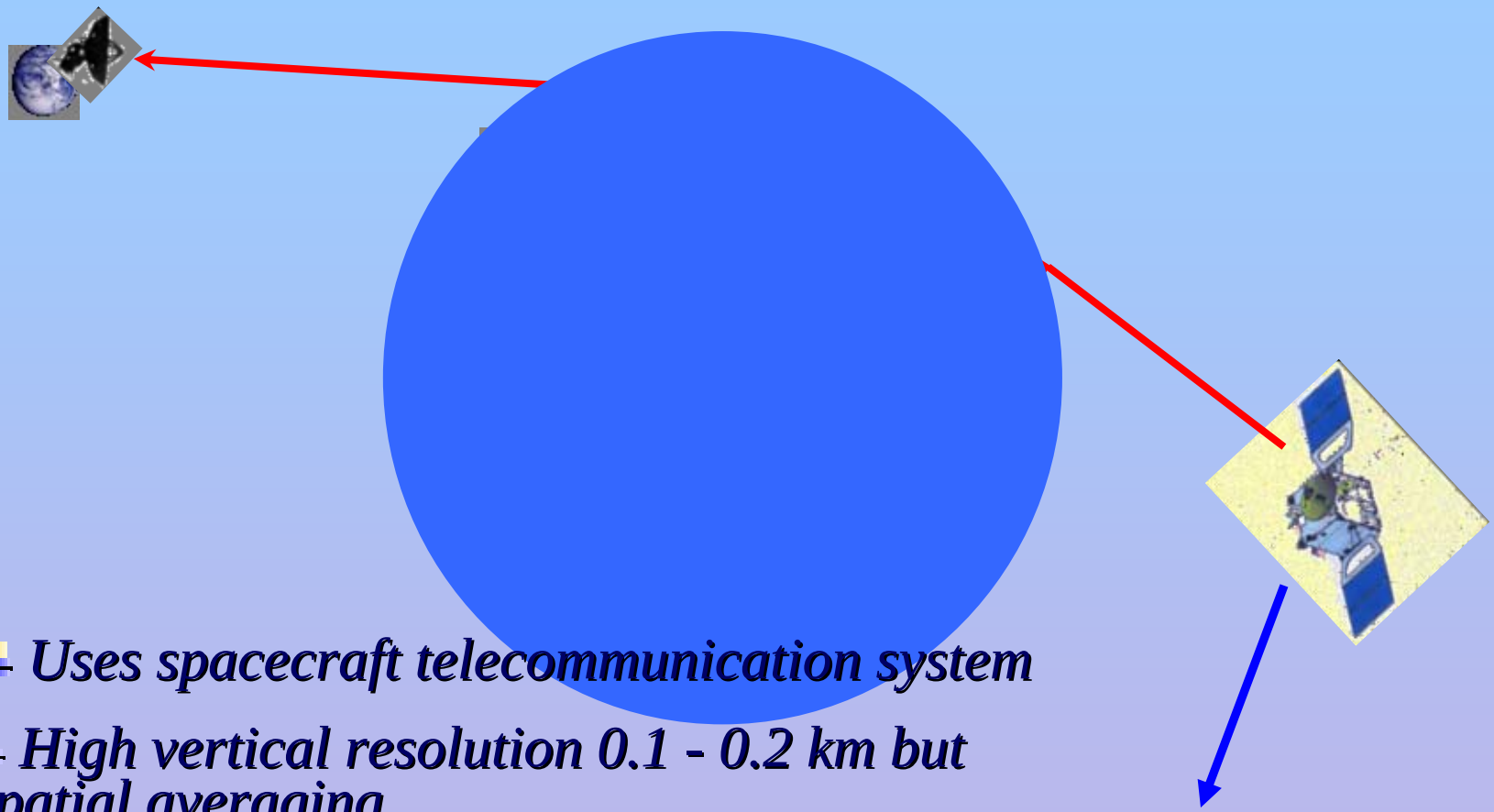
191



149

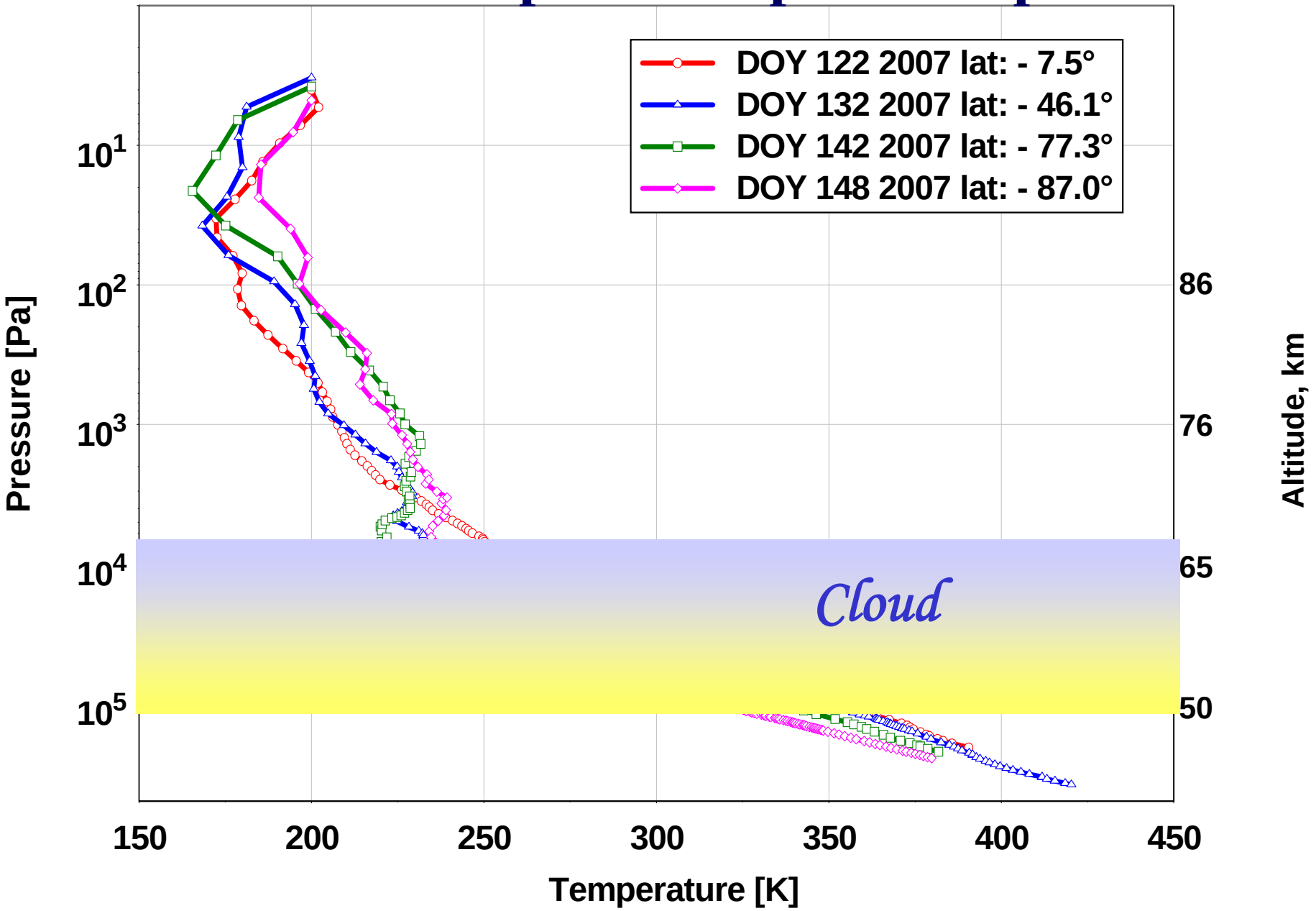


Earth radio occultation



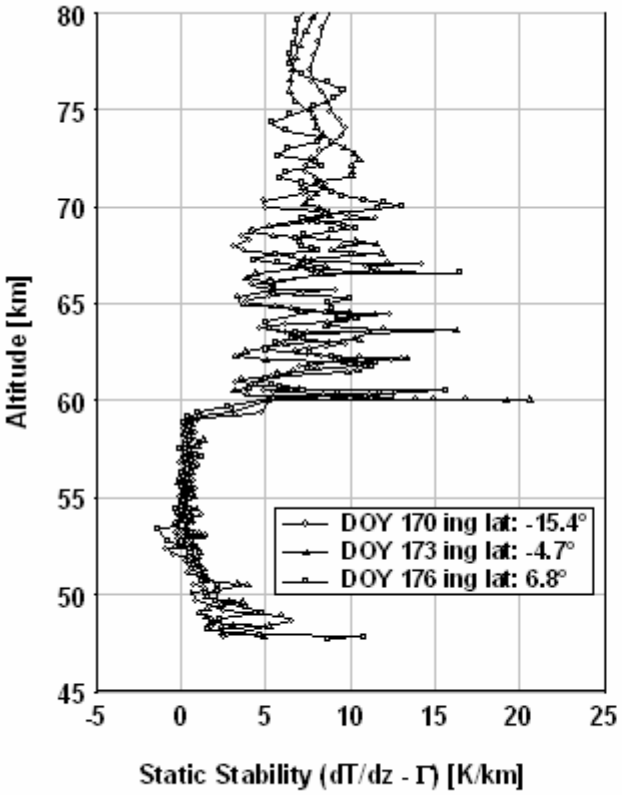
- *Uses spacecraft telecommunication system*
- *High vertical resolution 0.1 - 0.2 km but spatial averaging*
- *Deep penetration in the atmosphere*
- *Complete latitude coverage*
- *Occultations occur in seasons*

VeRa/Venus Express temperature profiles

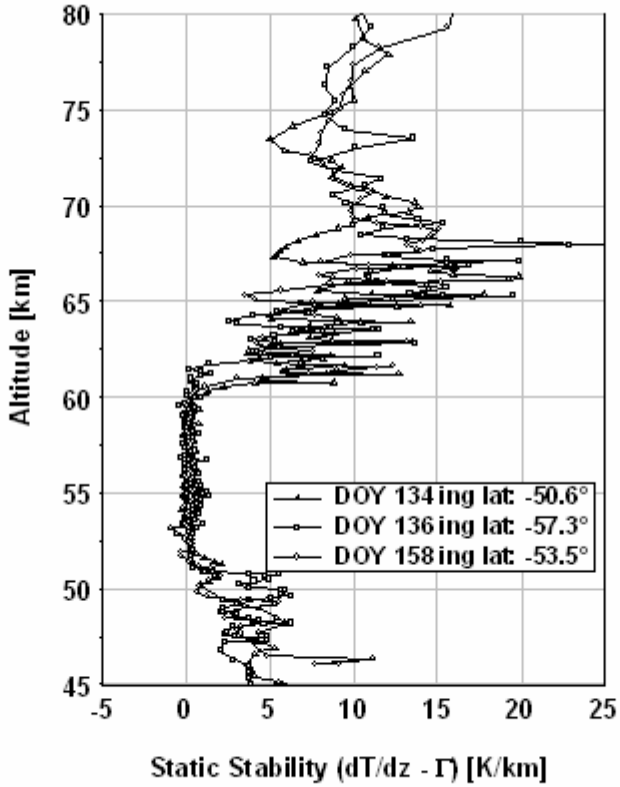


Atmosphere static stability from radio-occultations by Venus Express

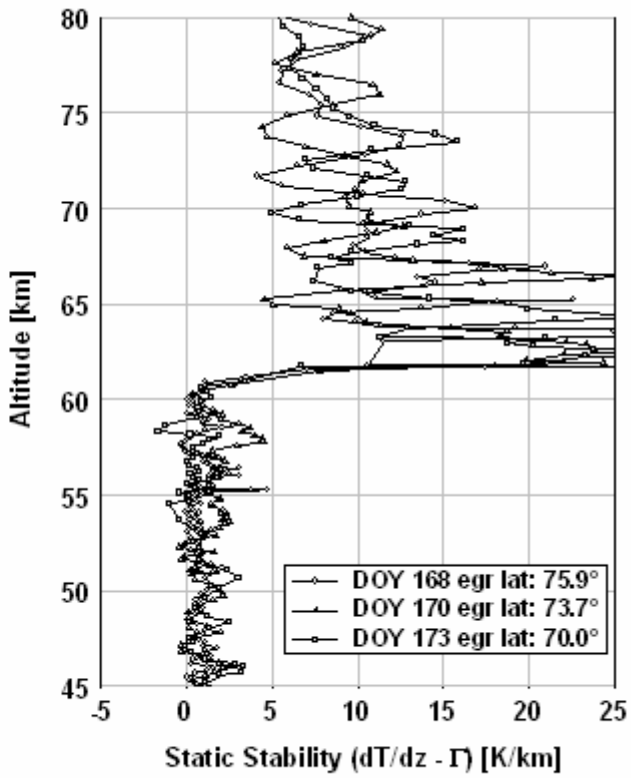
low latitudes



middle latitudes



high latitudes

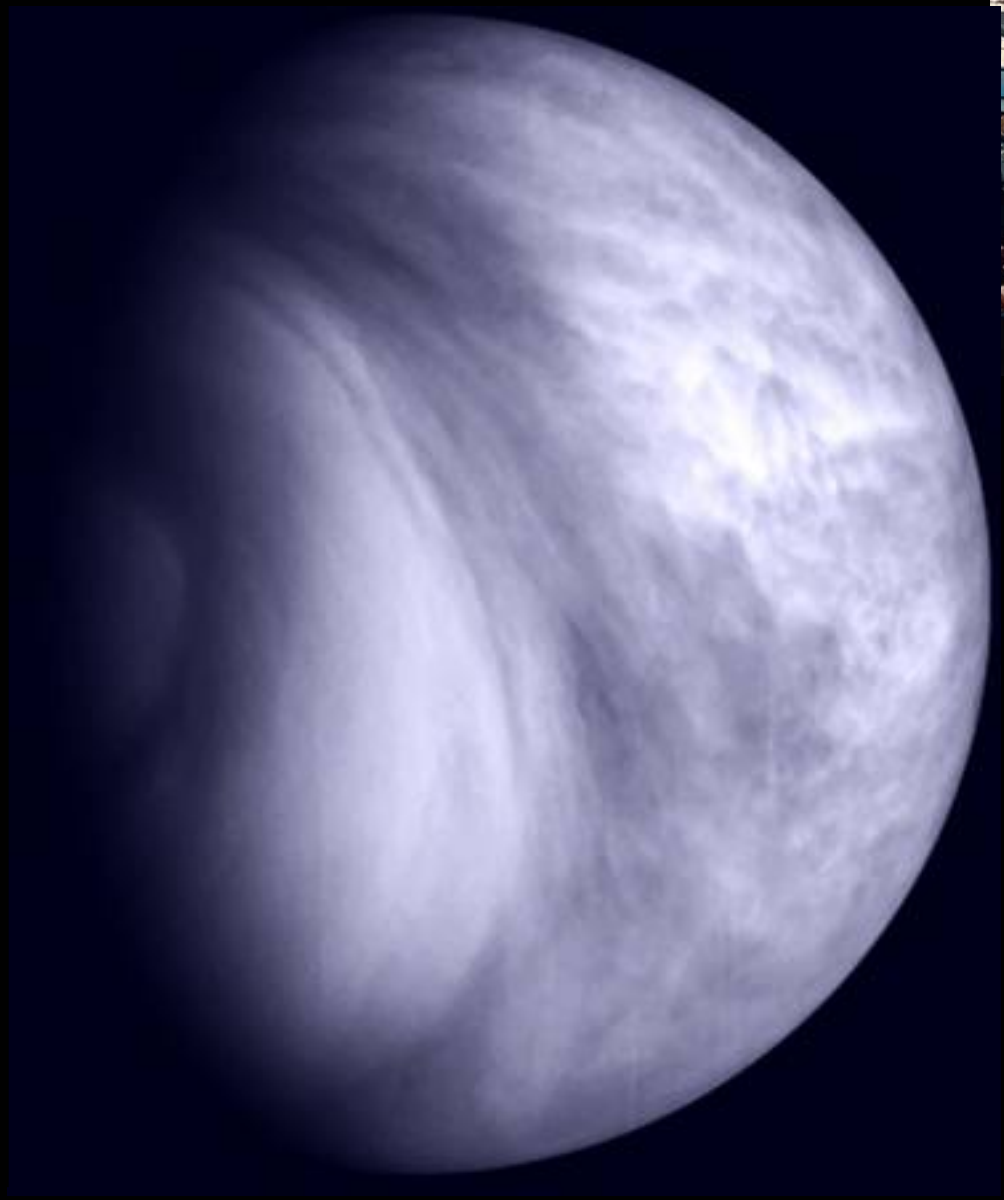


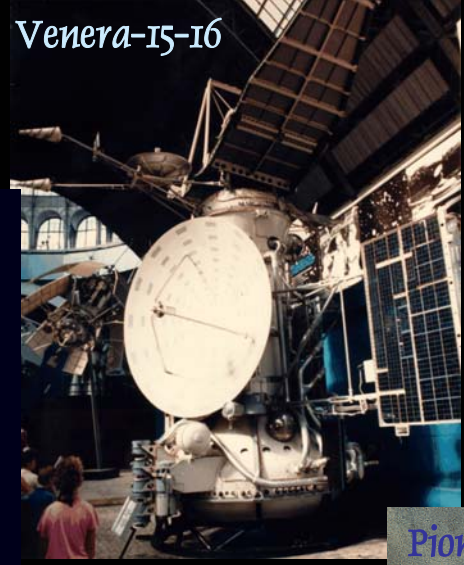
Universität München

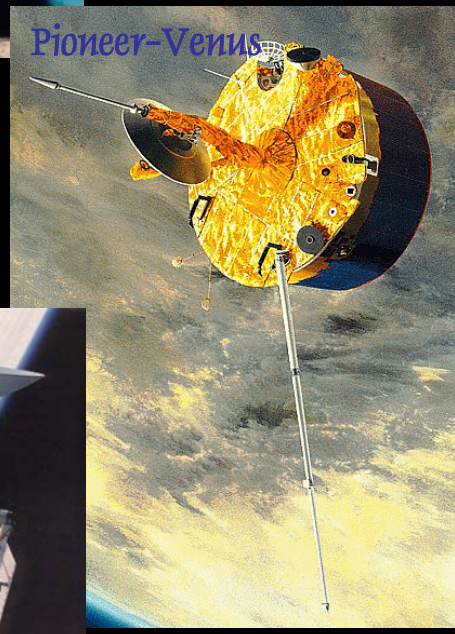
Argelander-Institut für Astronomie

Planetary Research

Venus unveiled…





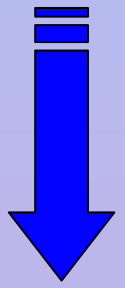


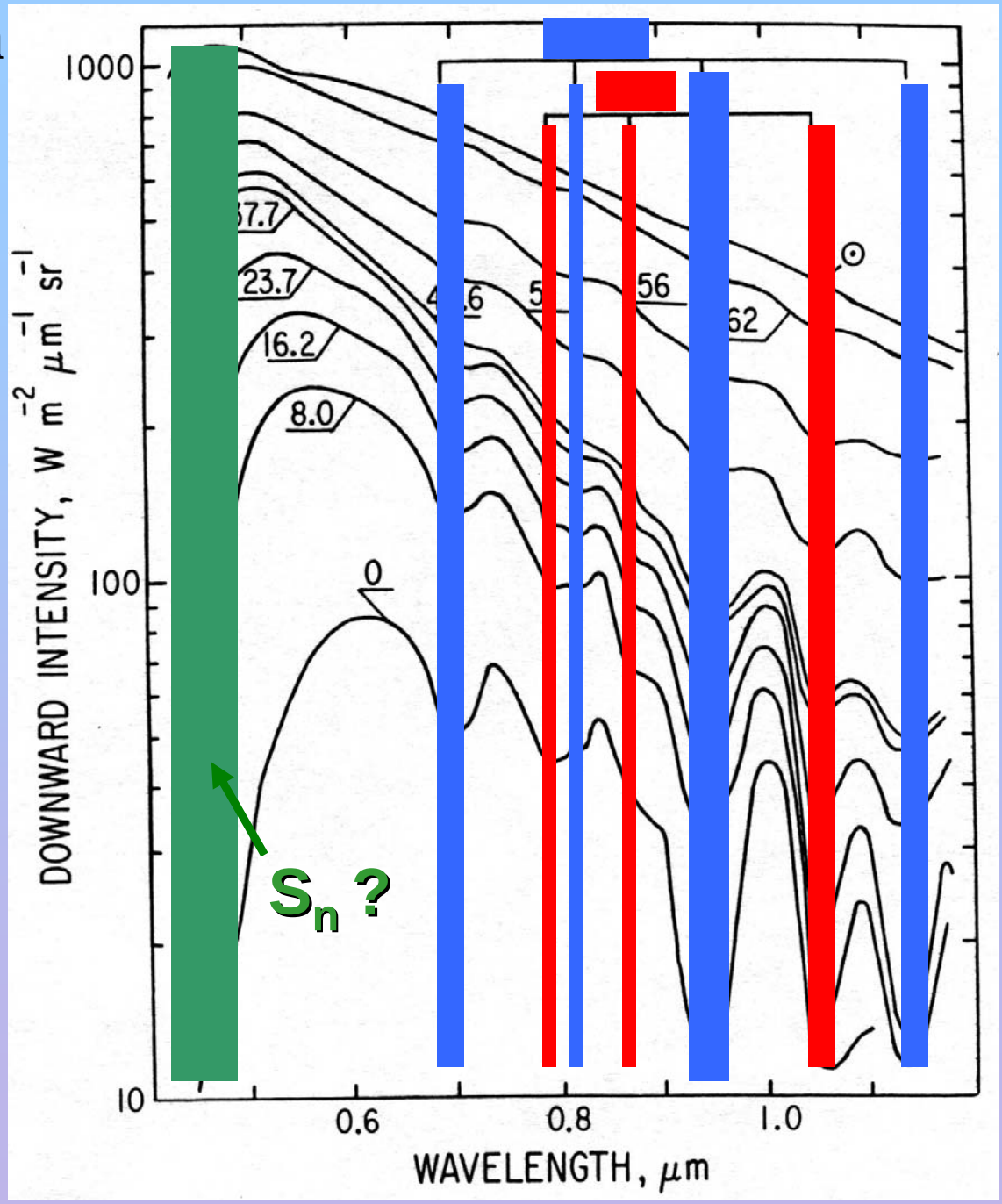
In-situ investigations

- Descent probes
  - *Pressure/ temperature sensors*
  - *Optical studies*
  - *In-situ analysis of gases, aerosols, and rocks*
- Balloons
- Rovers

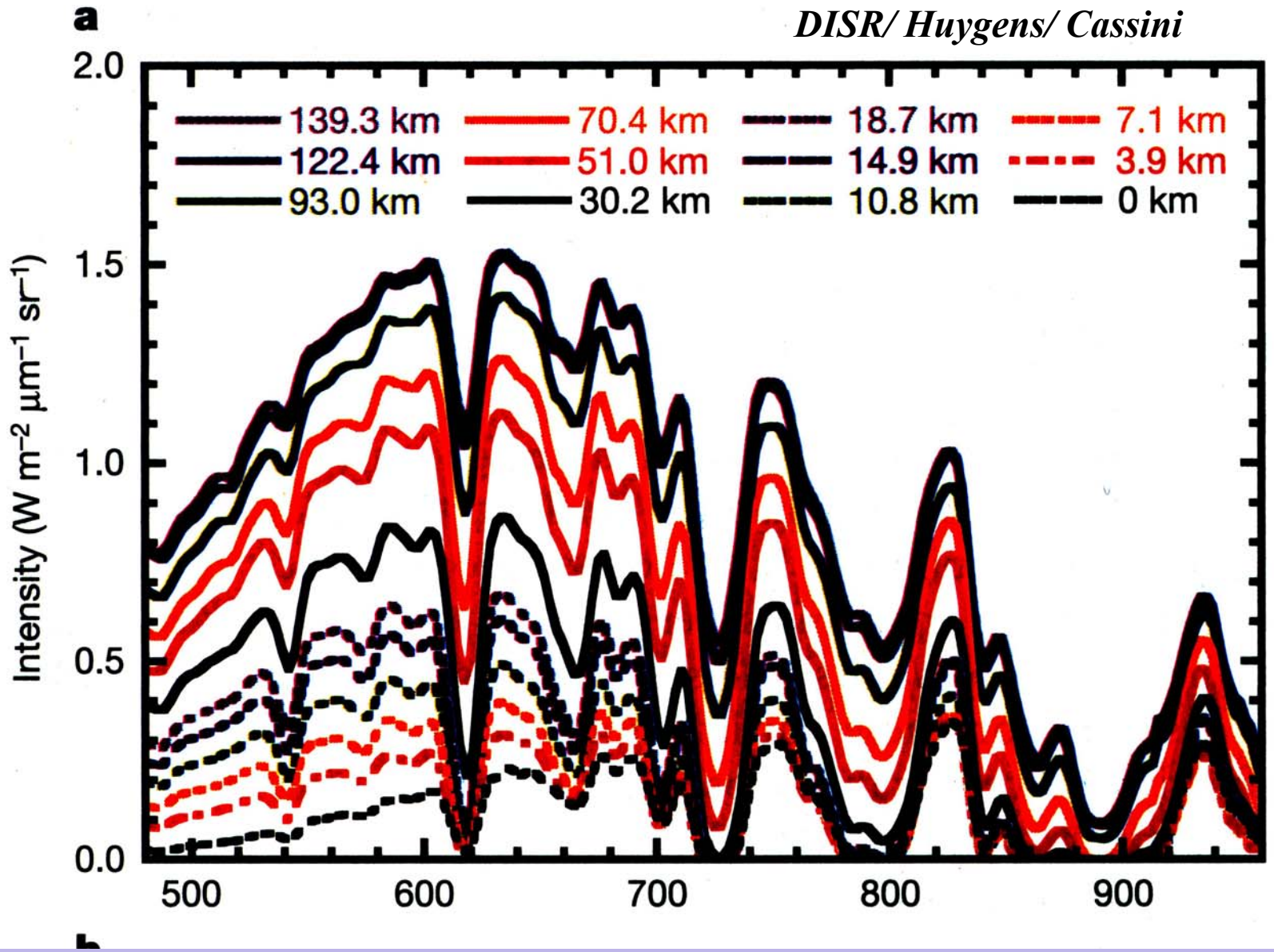
Spectrophotometry on descent probes

Venera-11





Spectra of the Titan atmosphere

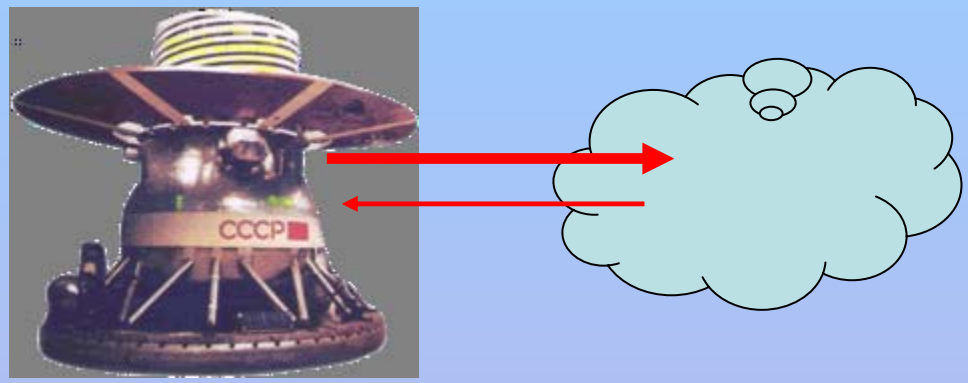


Titan atmosphere: Let´s dive in !

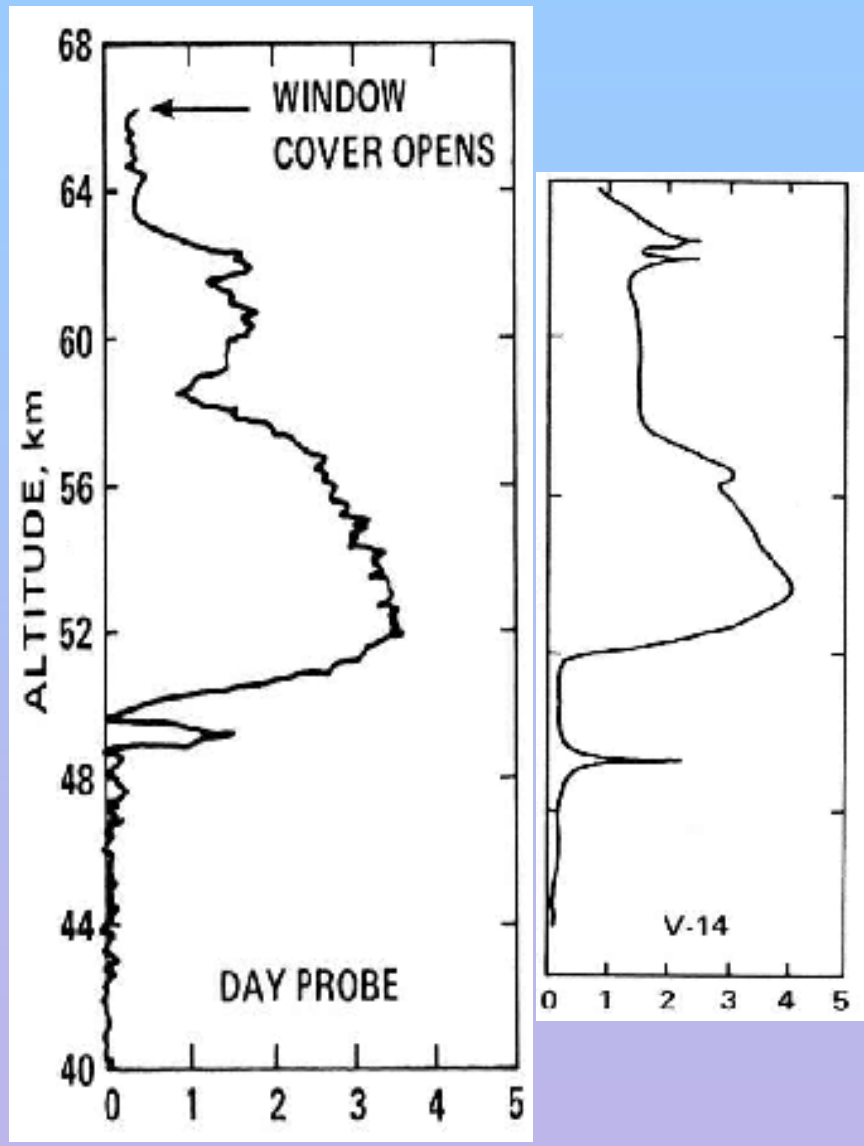
Descent on Titan.mpeg

Huygens descent on Titan
Simulations by B. Grieger

Nephelometry on descent probes

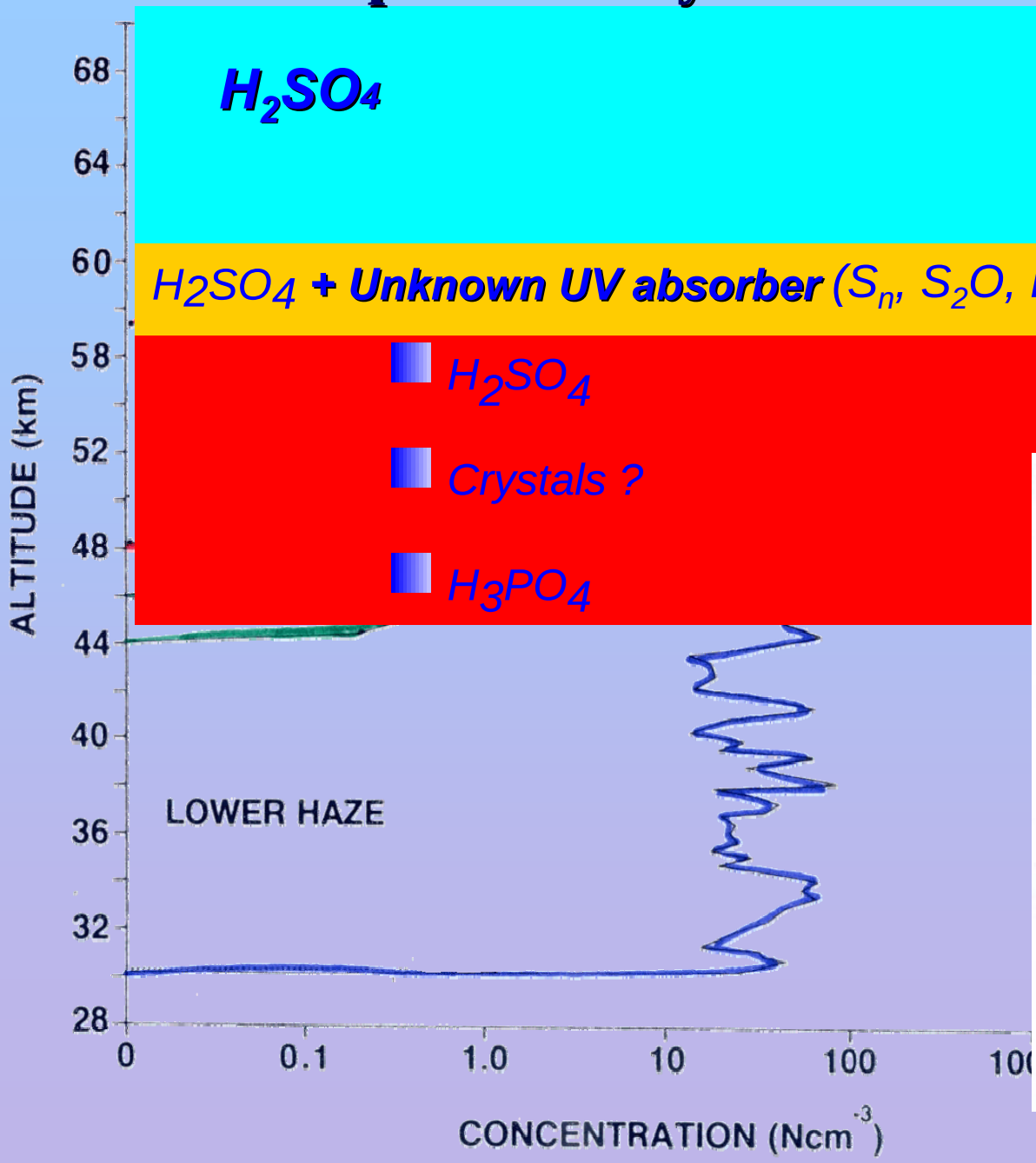


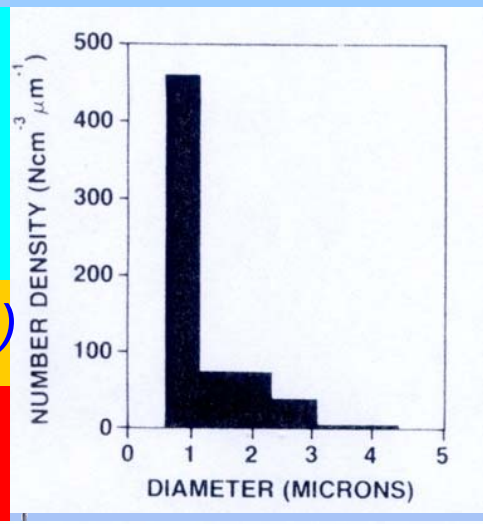
- Vertical profile of aerosol extinction
- Optical properties of cloud particles

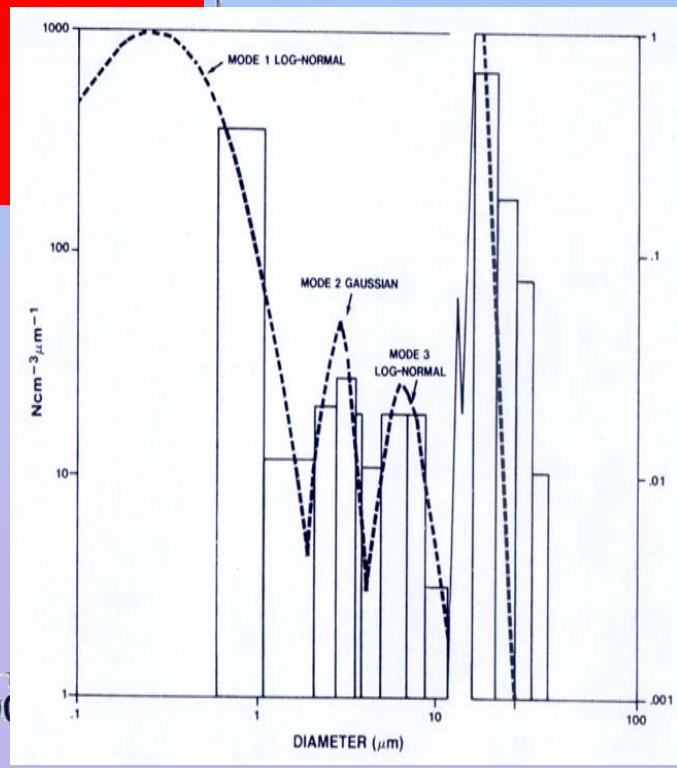


Extinction coefficient, km^{-1}

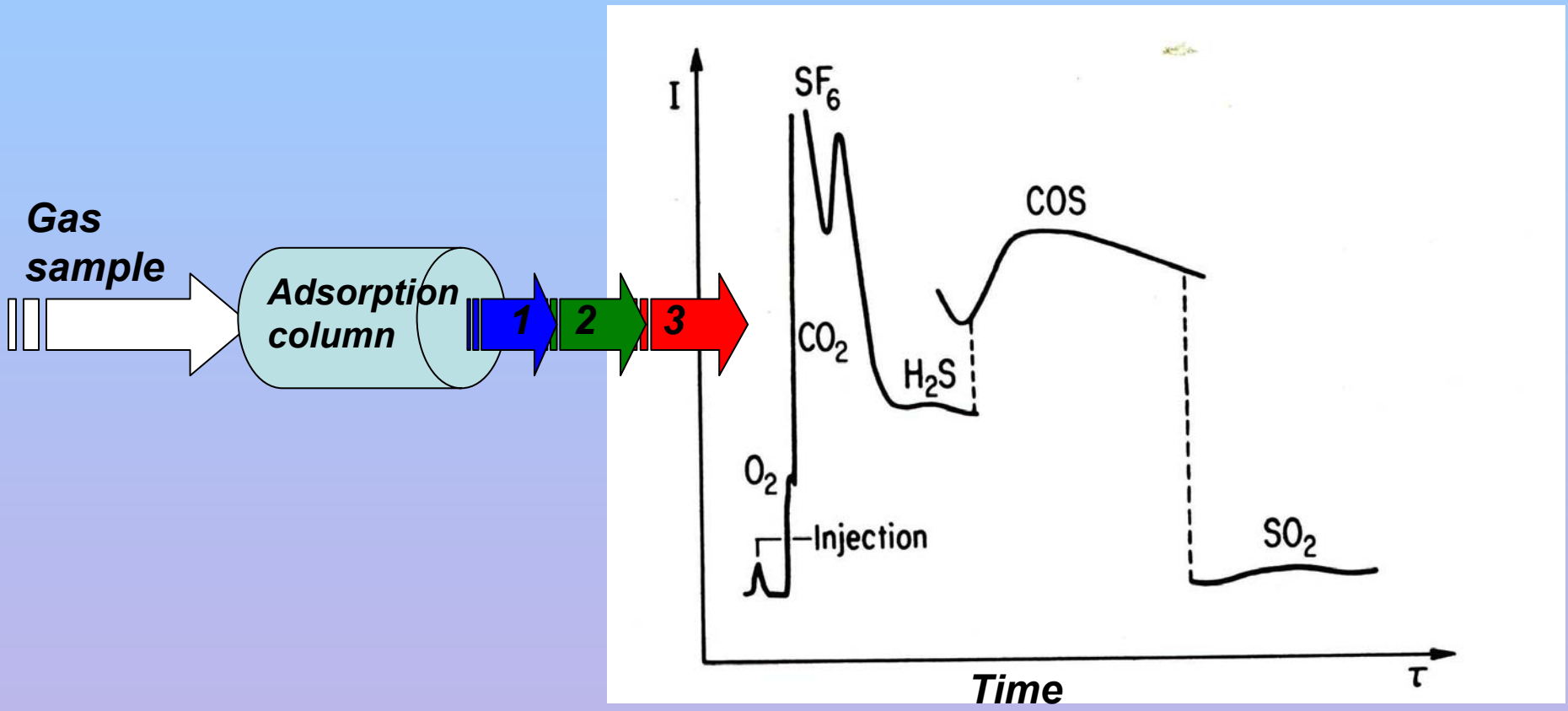
Spectrometry of the aerosol particle sizes



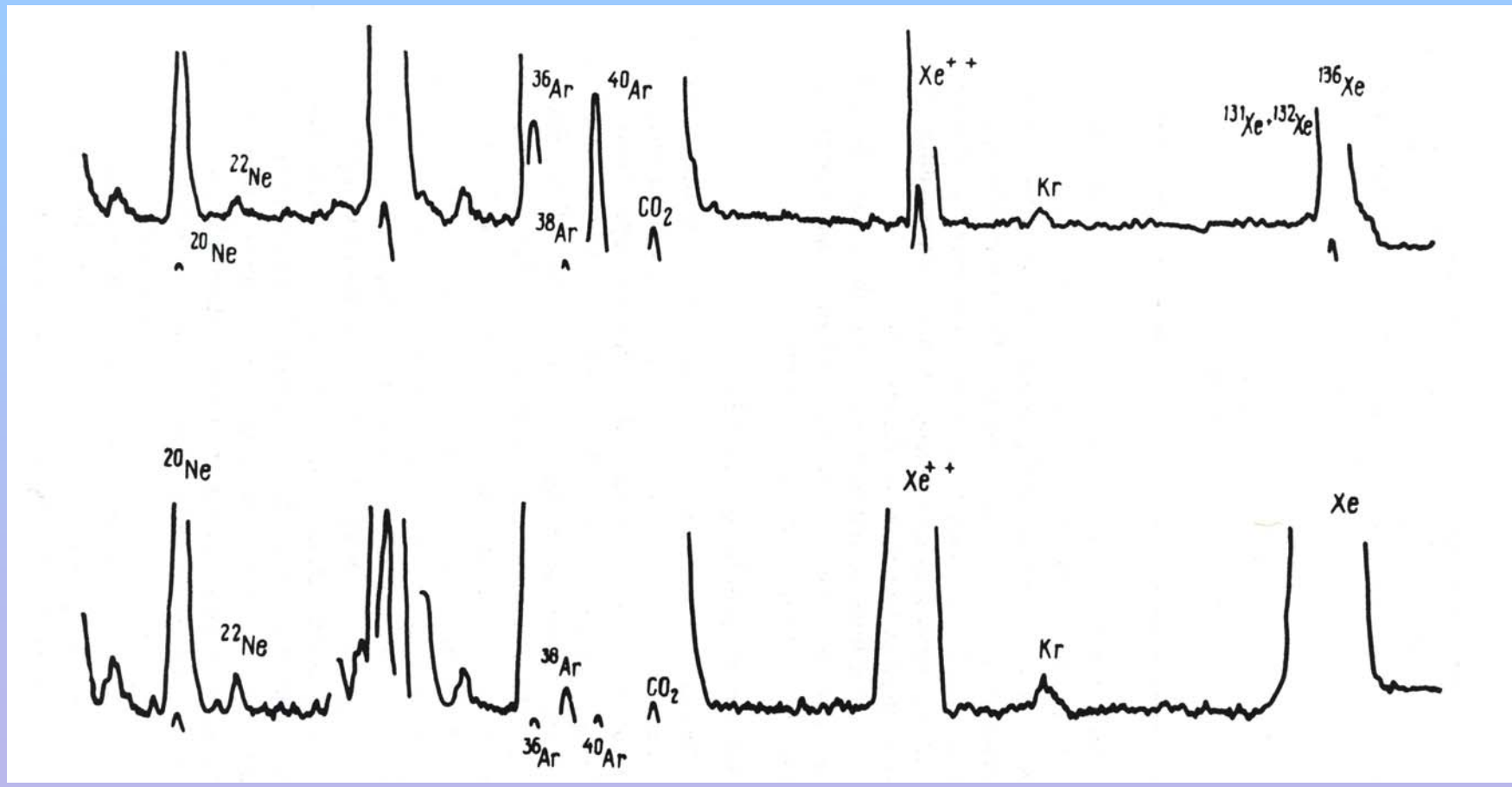




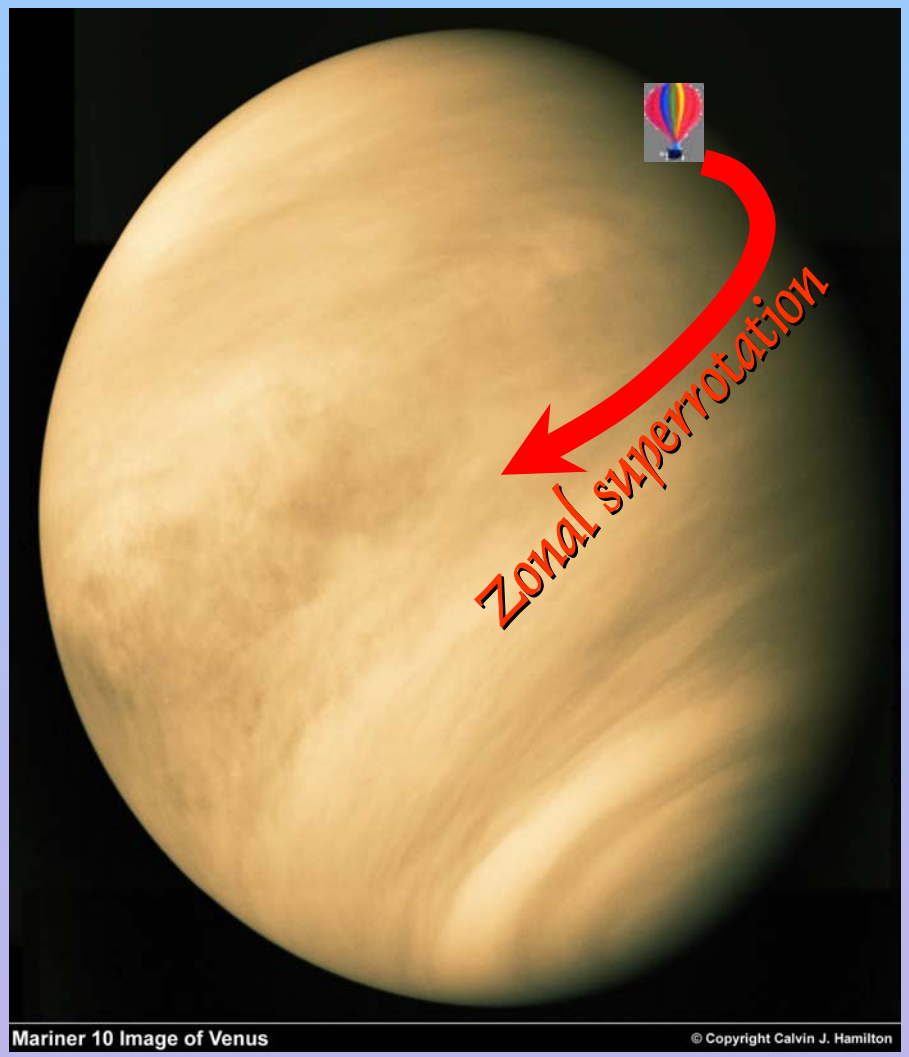
In-situ composition analysis: gas chromatography



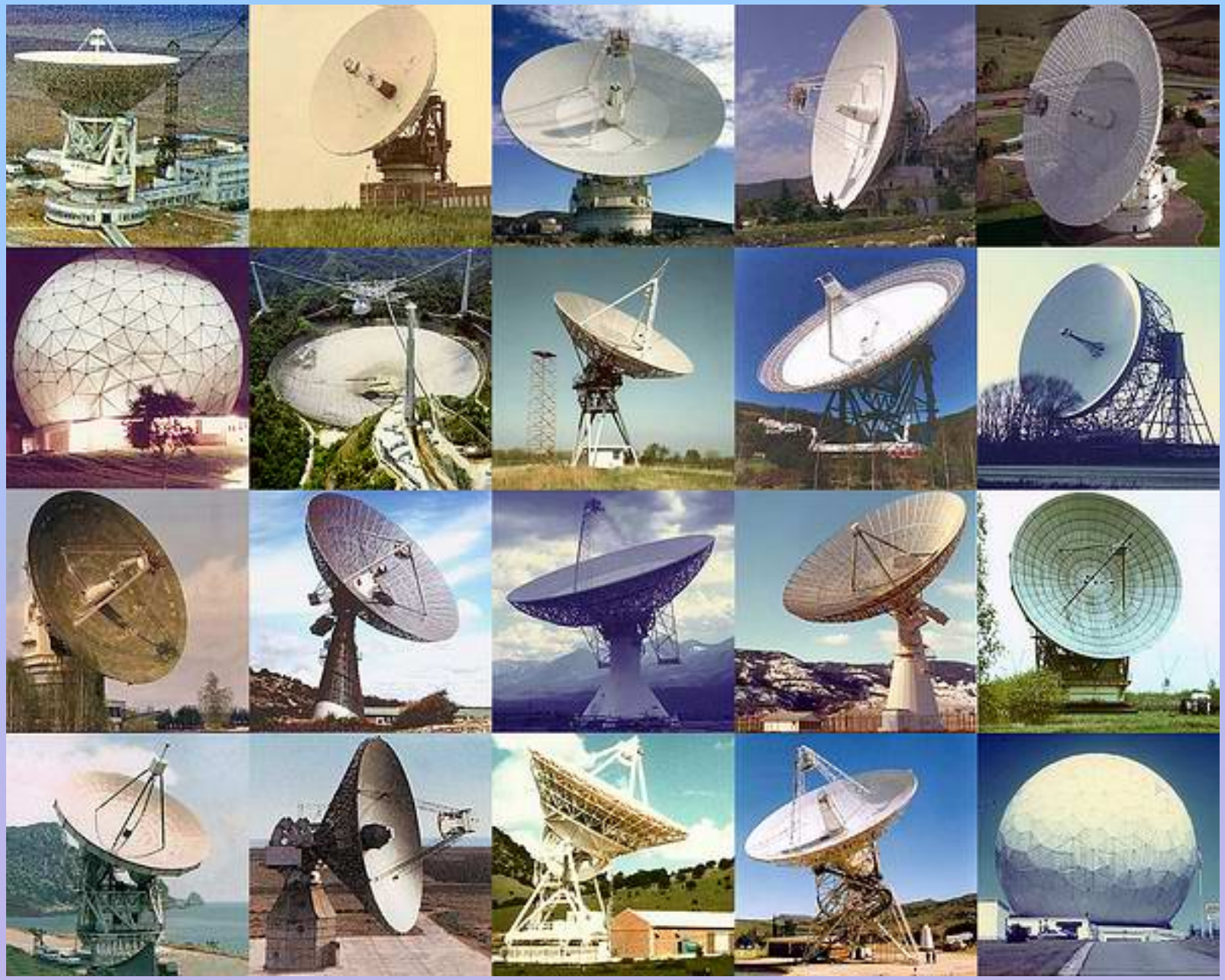
In-situ composition analysis: mass-spectrometry



VEGA -1, -2 Balloon Experiment (1984)



Global network of tracking stations

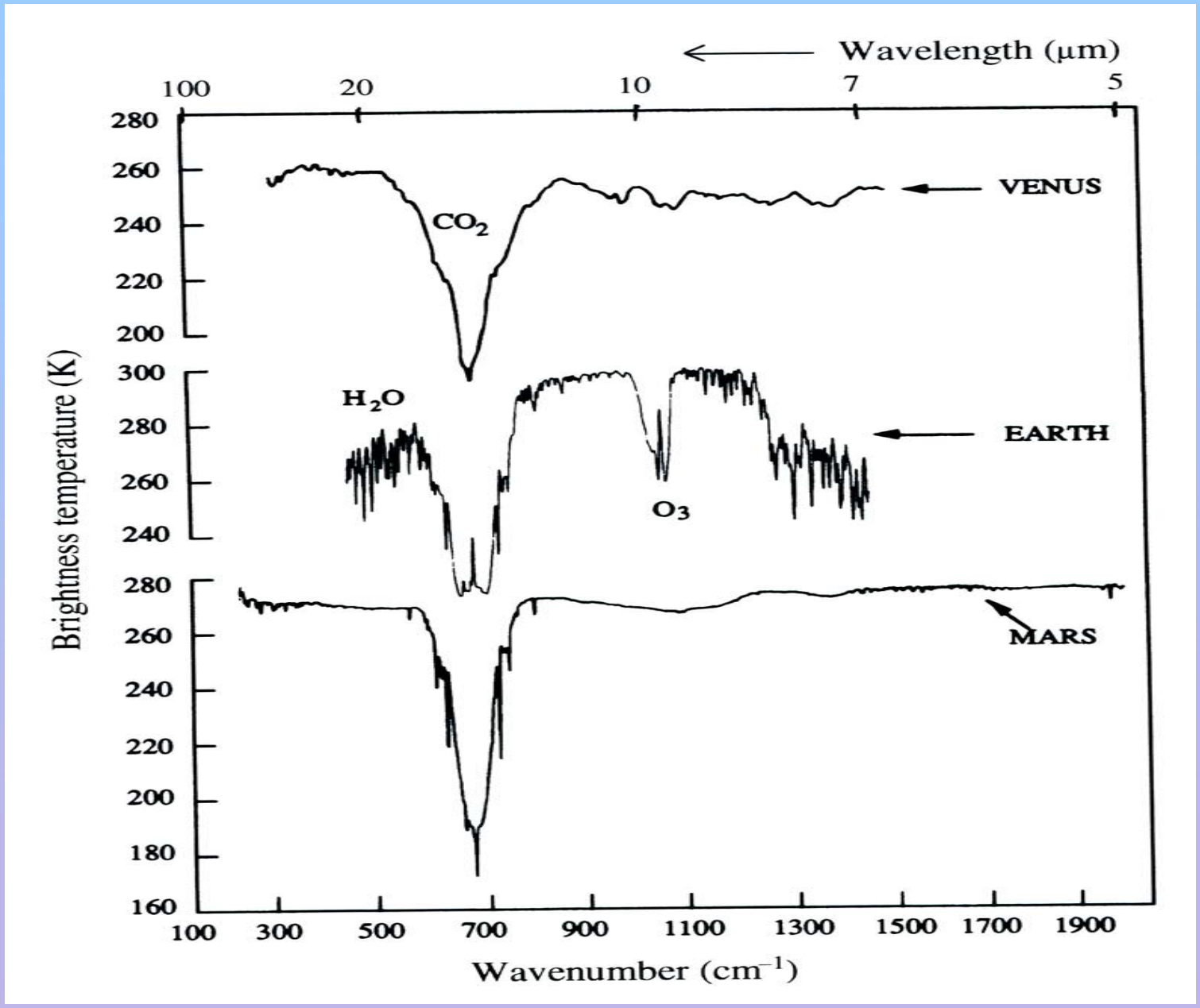


Spectrometry of thermal radiation

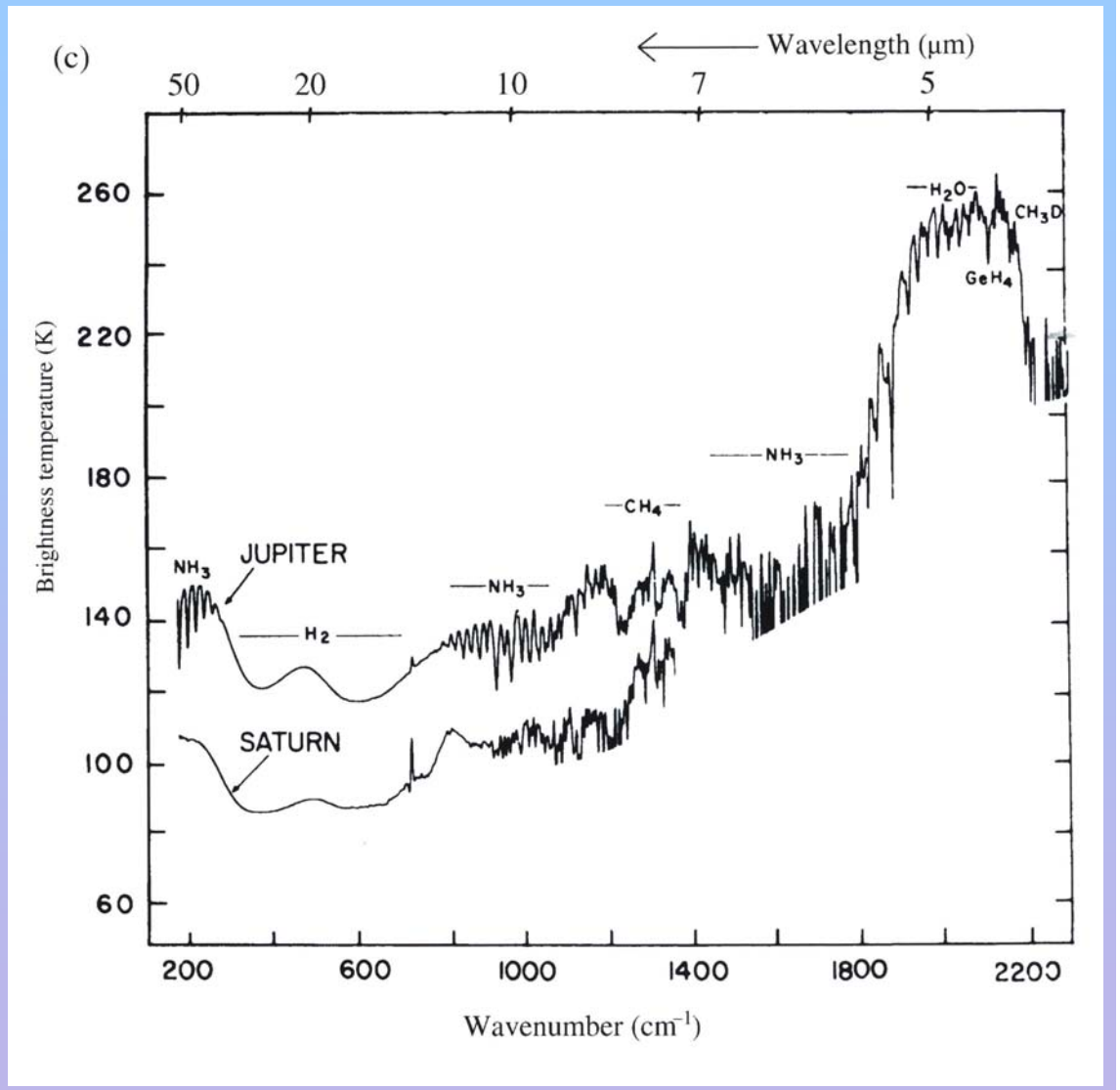
Spectrometry of thermal radiation

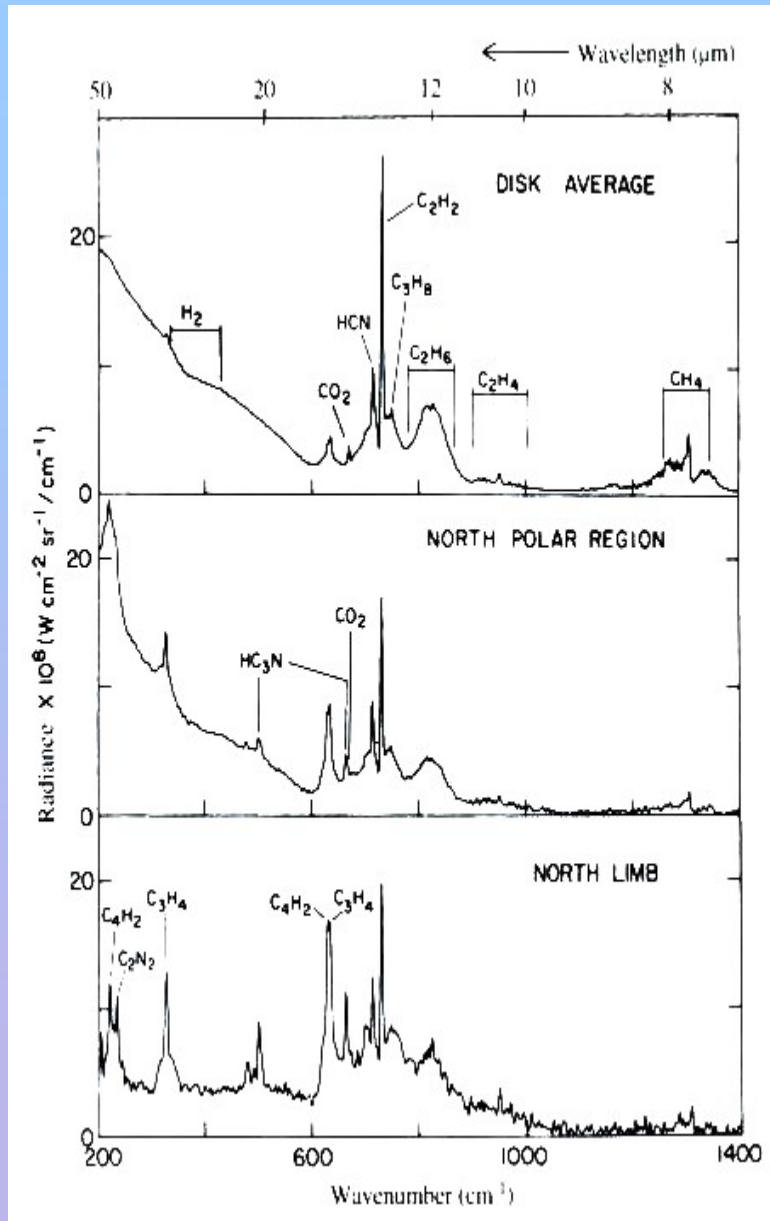
- Wavelength range mid – far-IR *(3 – 1000 μm)*
- Good sensitivity to
  - *1. atmospheric temperature and*
  - *2. total number of molecules*
- Both day and night side observations
- Multiple scattering is usually of minor importance

Thermal emissions spectra of terrestrial planets



Thermal emission spectra of Giants and Titan





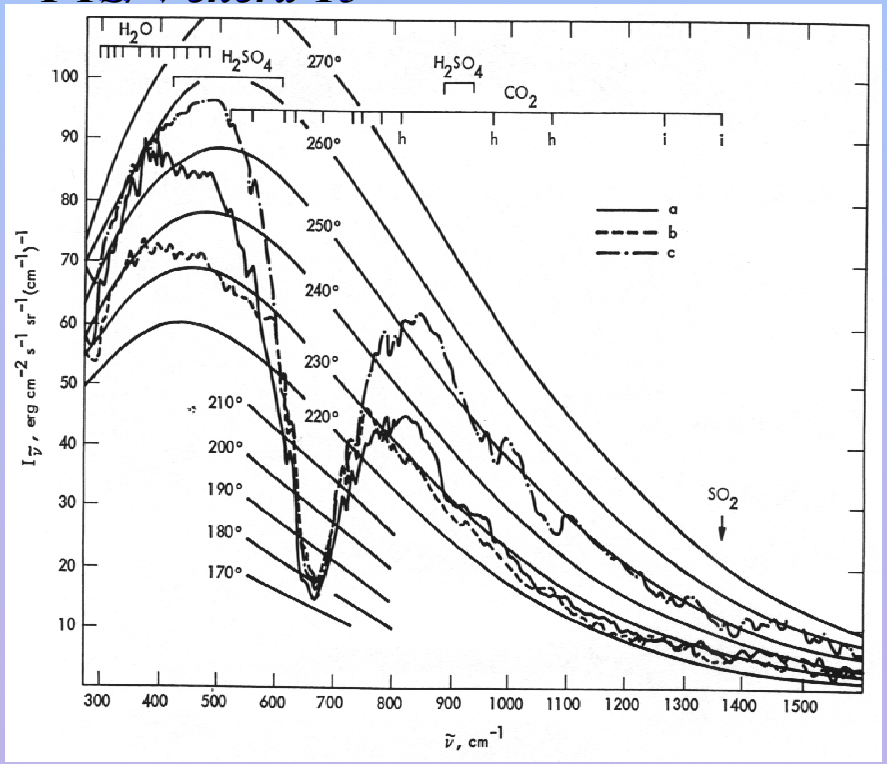
Temperature sounding

$$I(\nu) = \varepsilon_s B_\nu(T_s)t + \int_{Surface}^{Space} B_\nu[T(\xi)] \cdot K_\nu(\xi) d\xi \qquad \xi = \lg p$$

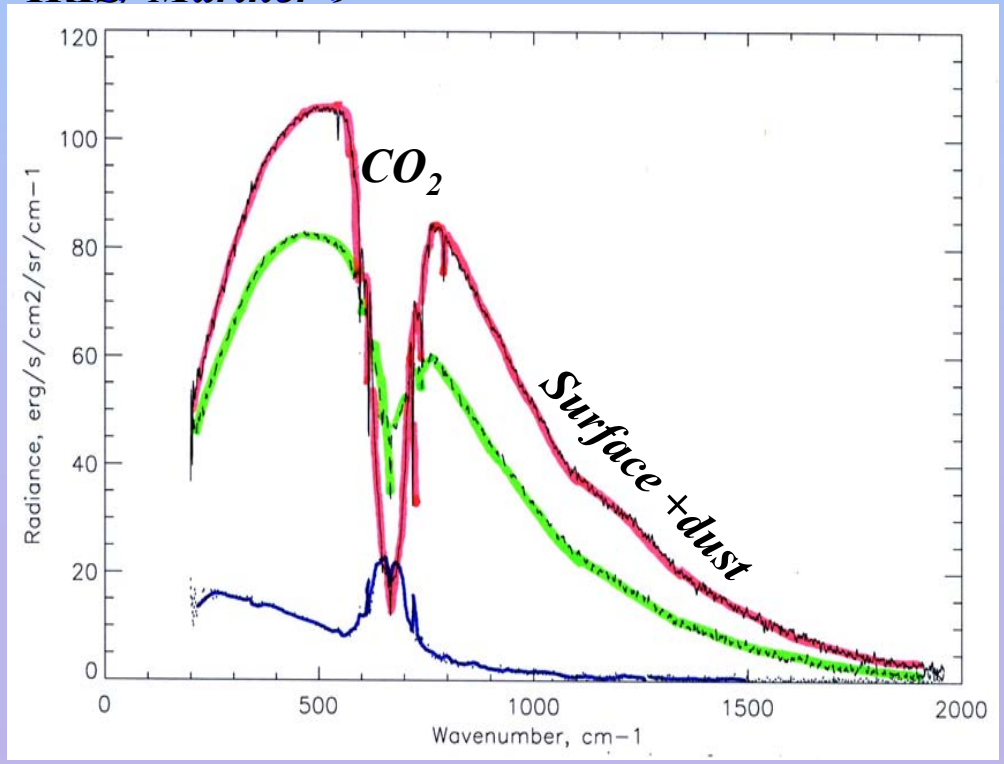
$$K_\nu(\xi) = -\frac{\partial t_\nu}{\partial \xi}$$ - weighting function

No scattering!

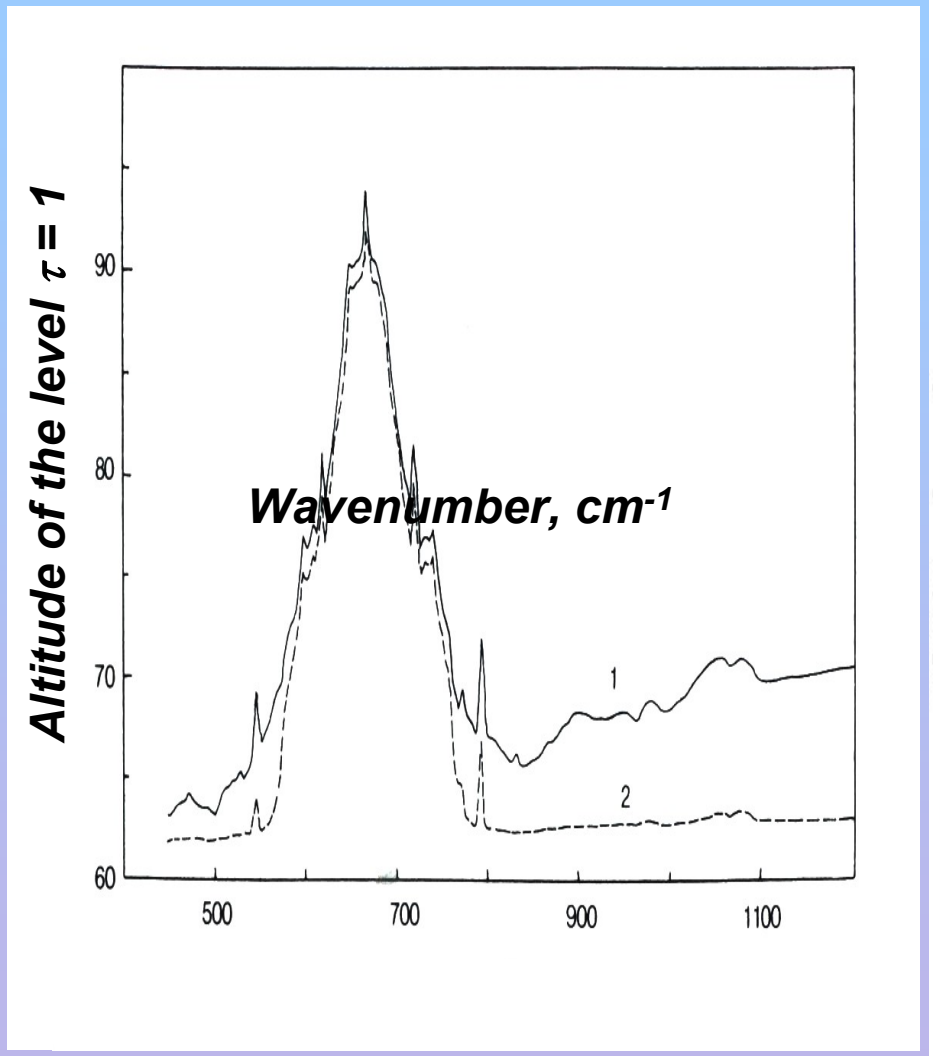
FTS/ Venera-15

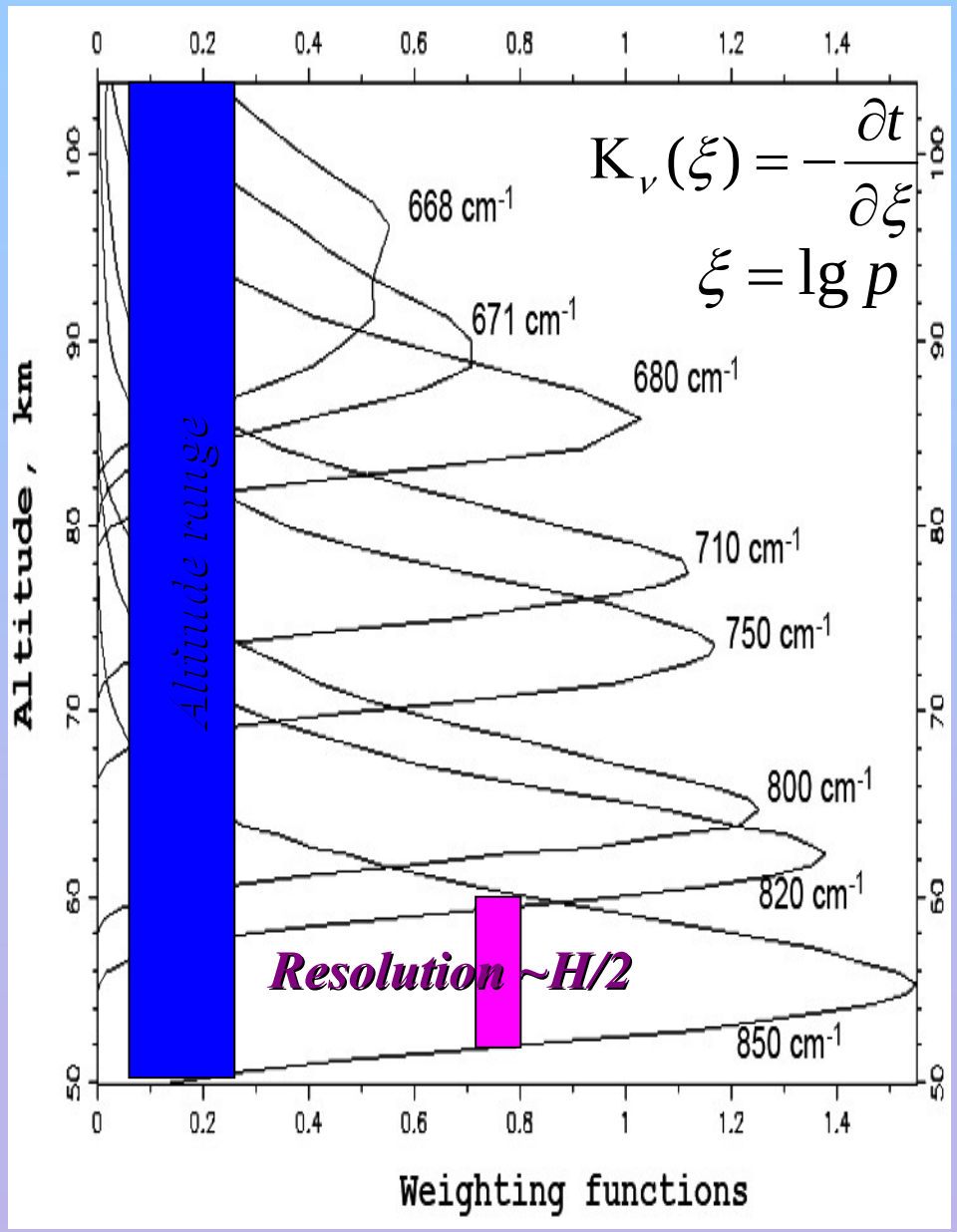


IRIS/ Mariner-9



Vertical sounding of the temperature structure





τ ~ 1 rule

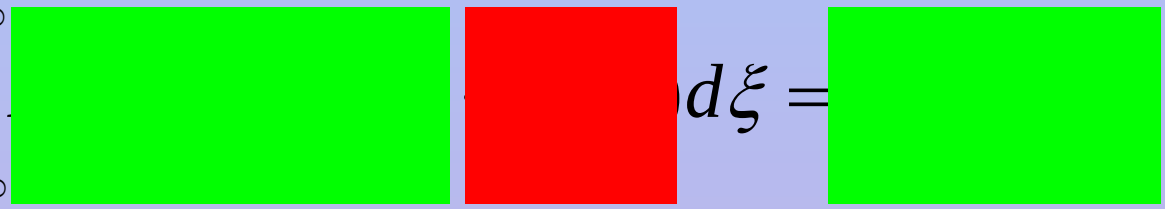
Principles of the temperature remote sensing

- In strong bands thermal radiation forms at different altitudes depending on wavelength (***τ ~ 1 rule***)
- Gas should be well mixed, not variable, with known abundance
- Local thermodynamic equilibrium (LTE)
- Vertical resolution ~ half a scale height

$$\int_{+\infty}^{-\infty} B_\nu[T(\xi)] \cdot K_\nu(\xi) d\xi = \mathrm{I}(\nu)$$

$$B_\nu[T] = B_\nu[T_0] + \frac{\partial B}{\partial T} \Delta T(\xi)$$

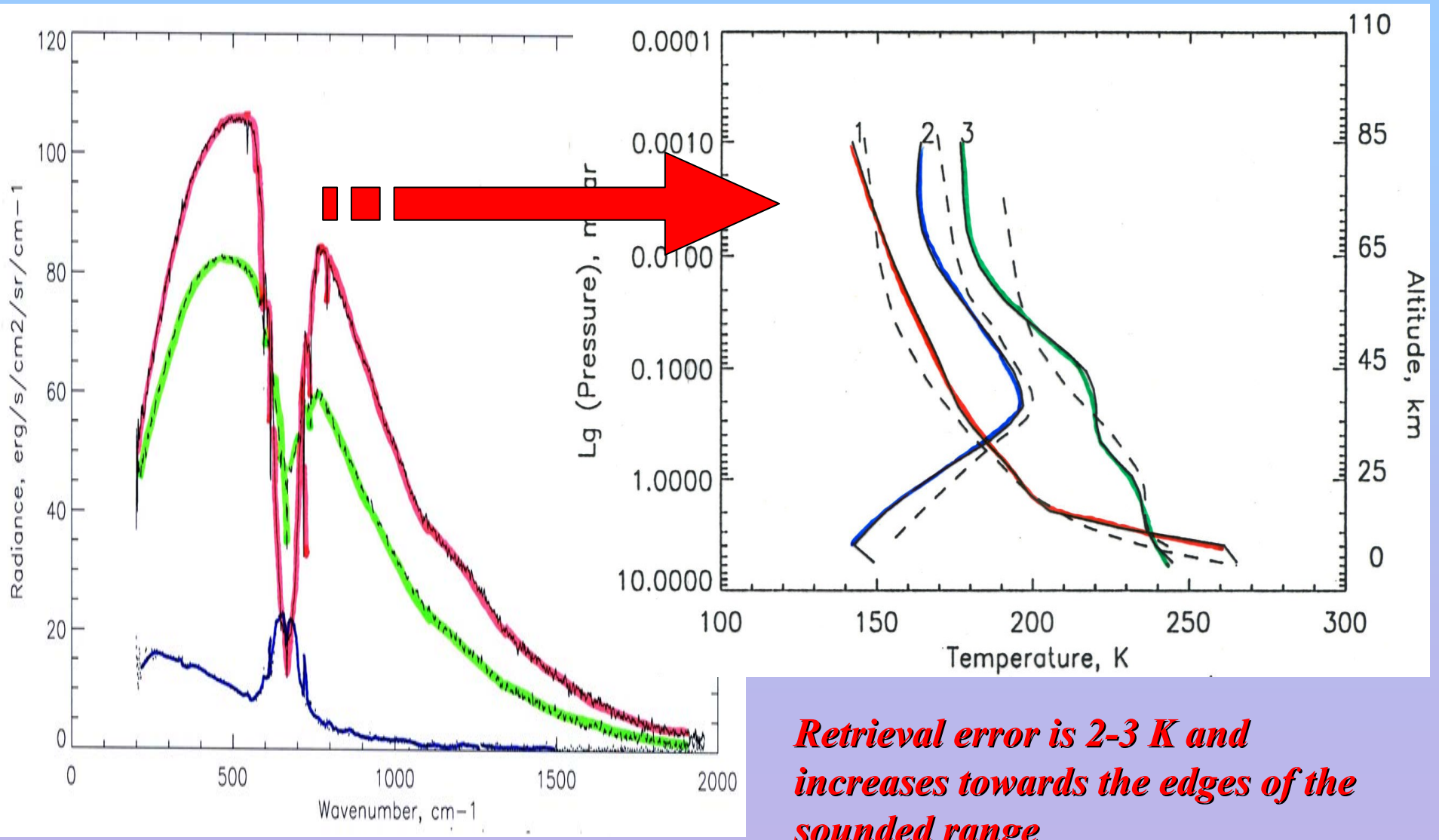
$$\int_{+\infty}^{-\infty} \quad d\xi =$$



Temperature retrieval is an ill-posed problem.

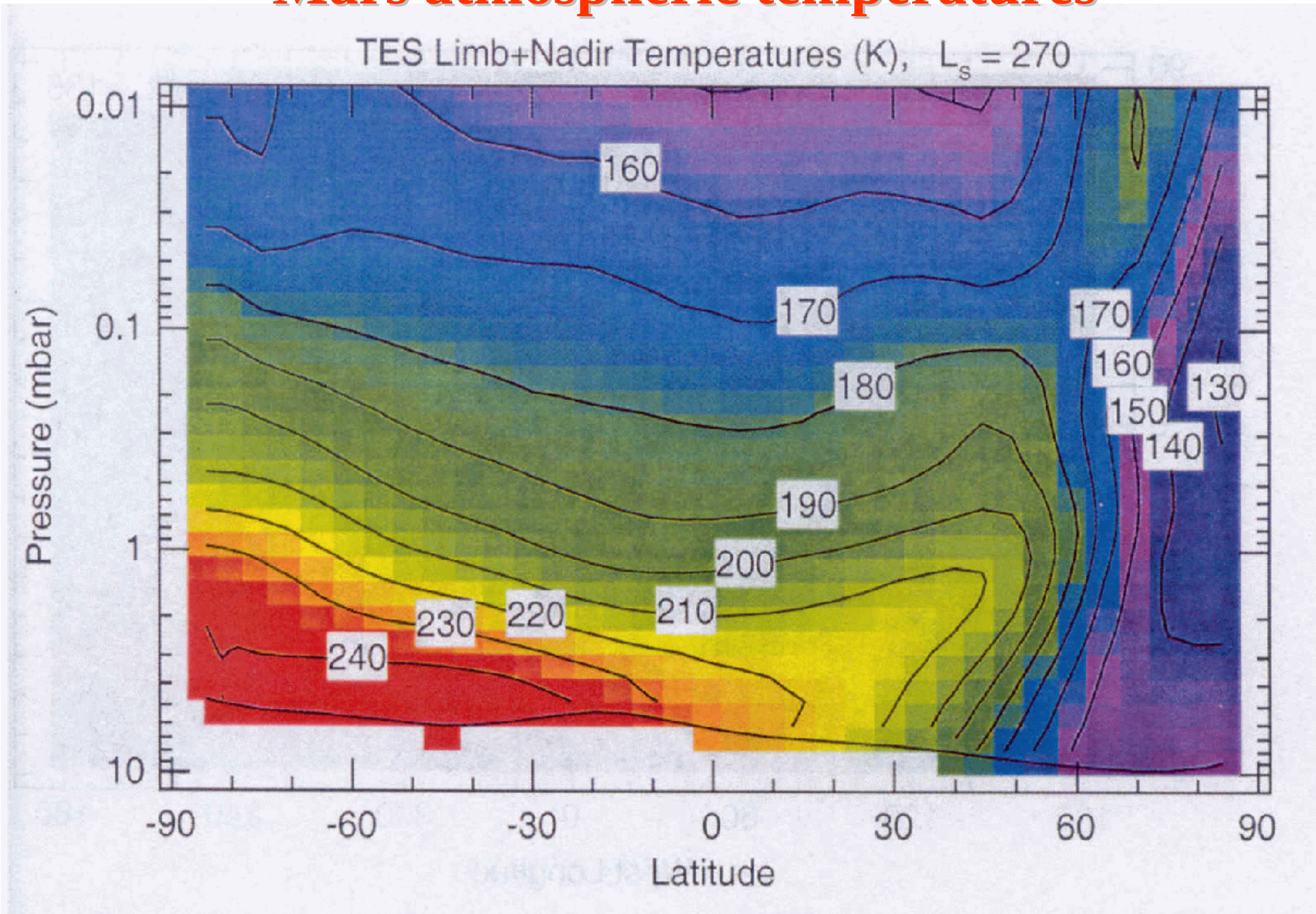
Special stabilization (regularization) methods are required

Temperature sounding of the Martian atmosphere

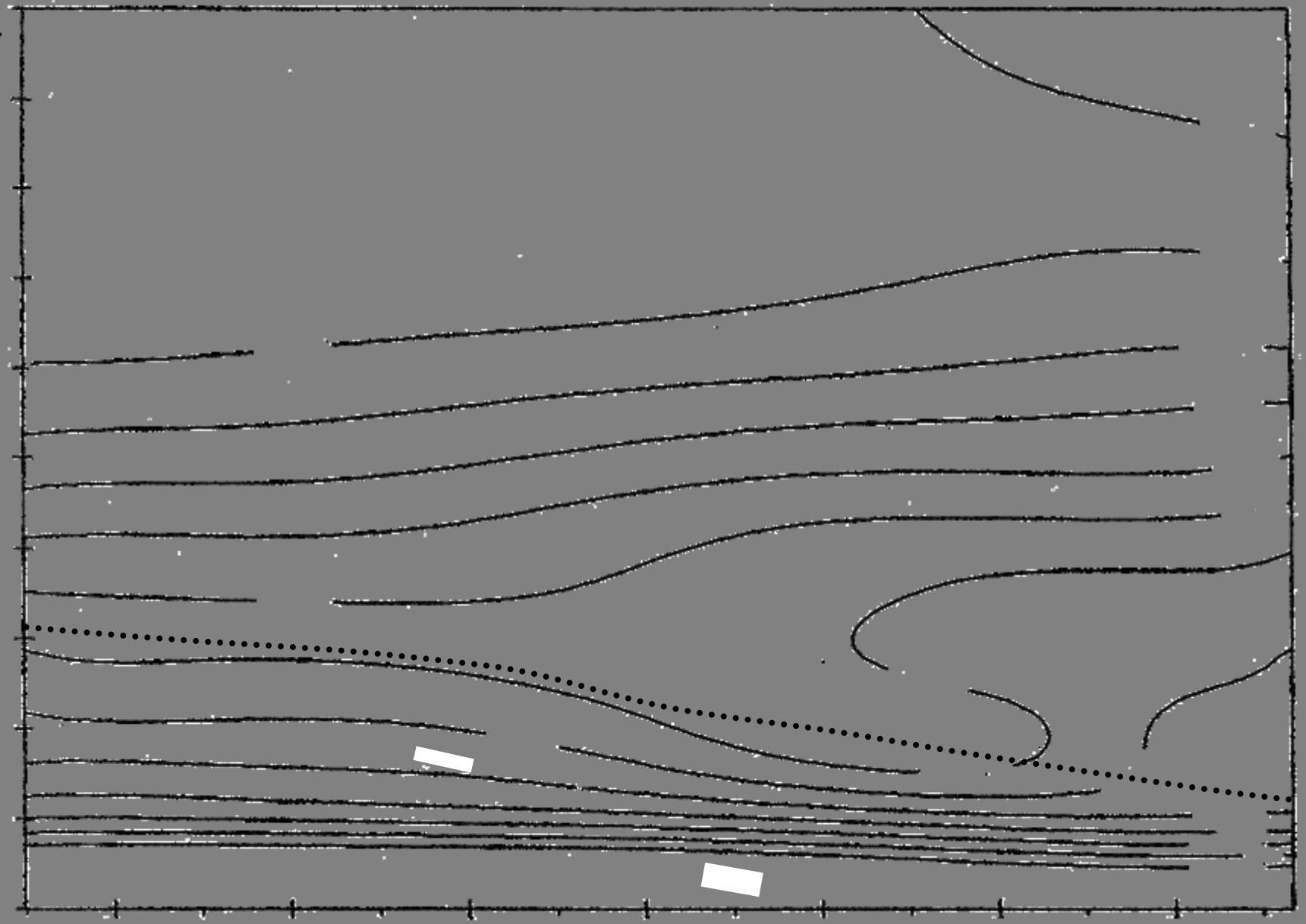


Retrieval error is 2-3 K and increases towards the edges of the sounded range

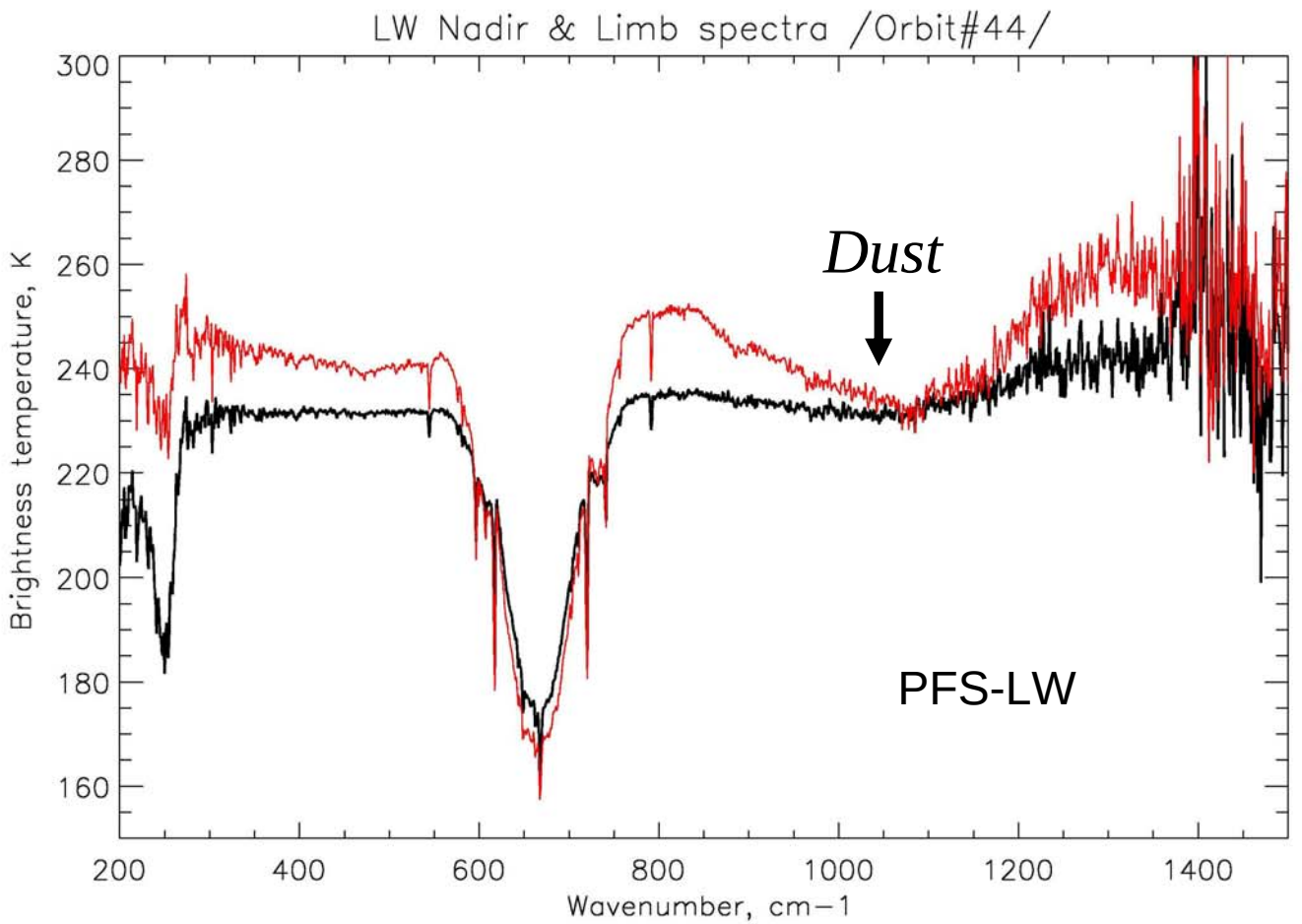
Mars atmospheric temperatures



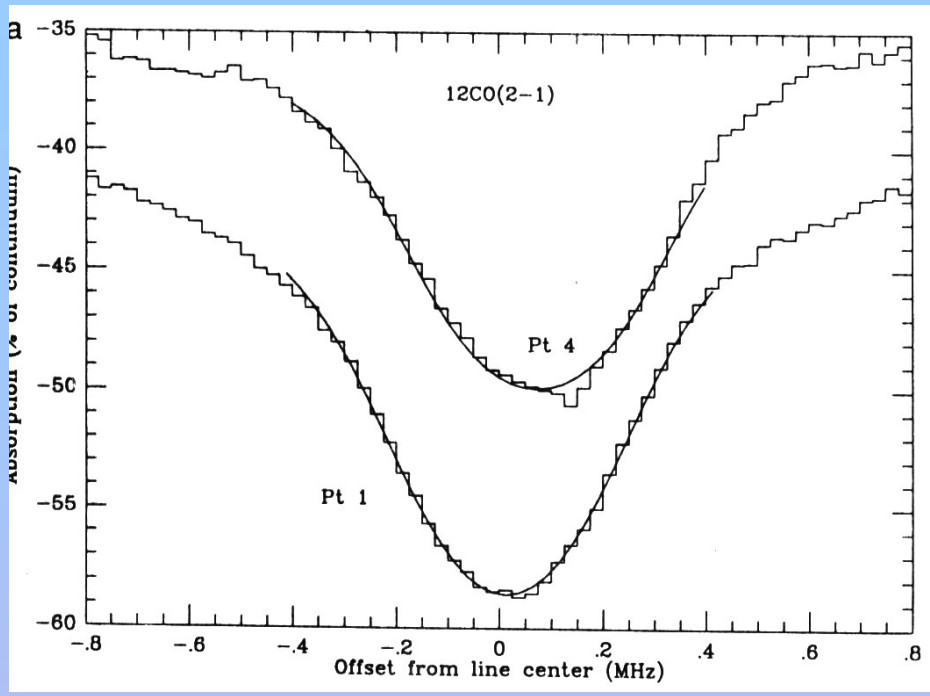
Temperature sounding of the Venus mesosphere

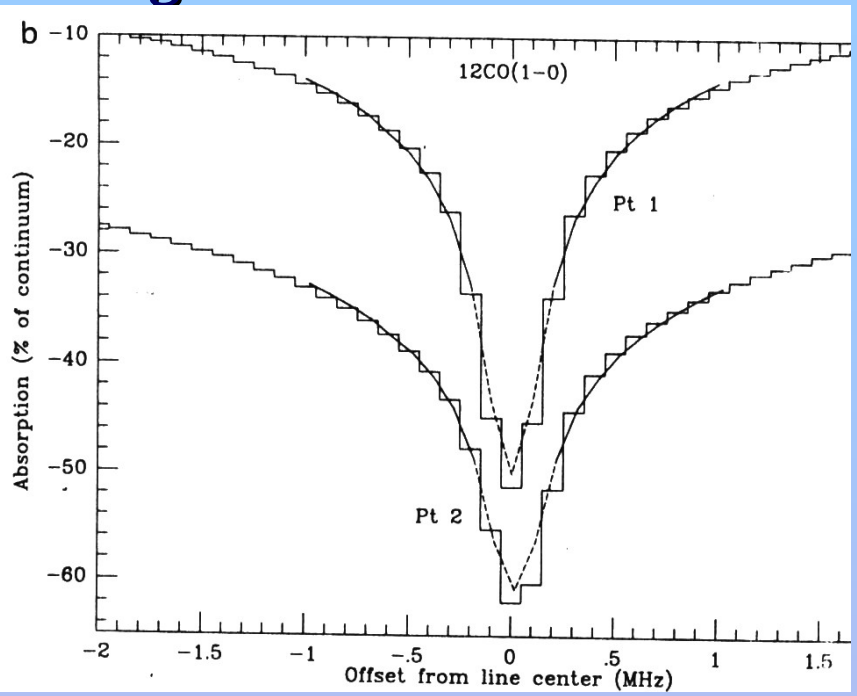


Sounding of the Martian atmospheric dust



Microwave investigations





- ***Very high spectral resolution 10^{-3} – 10^{-4} cm^{-1}***
- ***Temperature sounding***
- ***Trace gases sounding***
  - ***Very high sensitivity***
  - ***Vertical profile***
- ***Doppler wind measurements***