SPICAM on Mars Express: an overview of near IR spectrometer of SPICAM and its results.

MEX Science Conference at ESTEC, February 23, 2005

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SPICAM Light / MEX

IR: 1-1.7 µm
AOTF
spectrometer
Two pixels

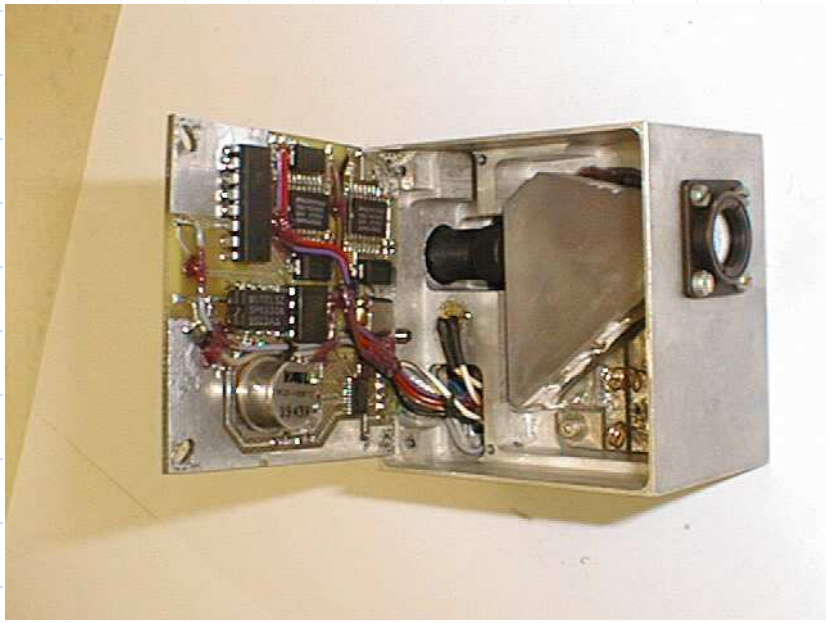
UV:
110-310 nm
spherical
grating
imaging
spectrometer
with slit
mechanism

History of the AOTF on MEX

- SPICAM/Mars 96 originally consisted of stellar par (15 kg at the platform) and solar part (19 kg). It was not in the model payload of Mars Express
- 1997 AO: proposed UV spectrometer and IR solar occultation/nadir channel (~10 kg total); after peer review only UV was chosen (5 kg)
- Descoped IR reproposed for solar occultation only (~2.5 kg) without success.
- A concept of AOTF Nadir channel (1 kg) proposed
- 1999: prototype Nadir channel demonstrated and accepted by ESA an add-on to the UV optical block with **no additional mass allowed**

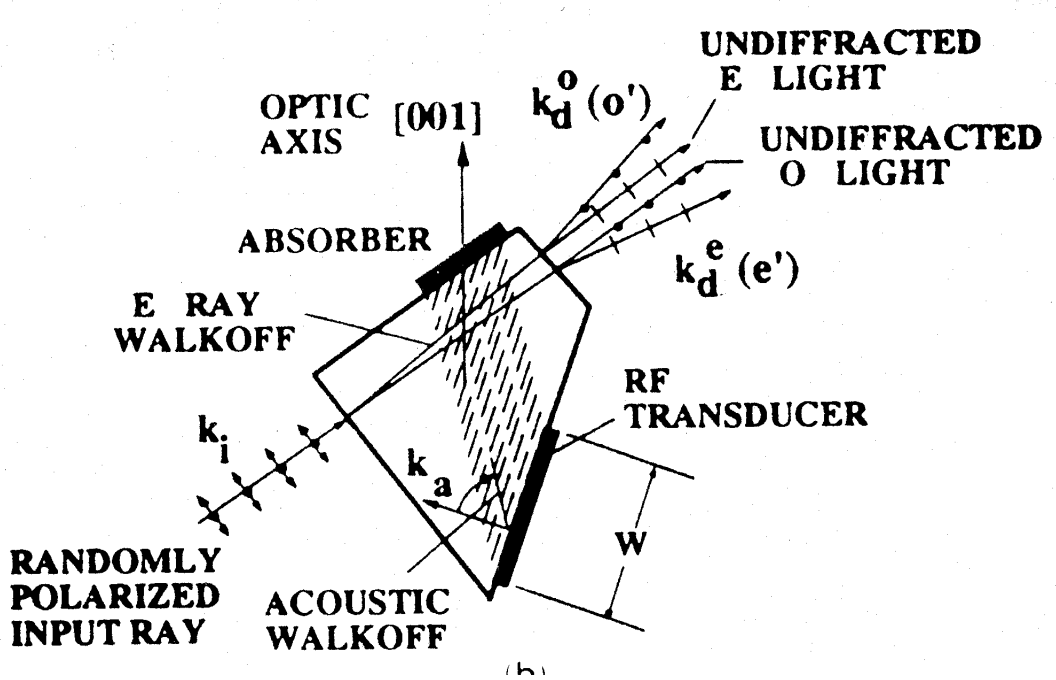
First Acousto Optic Tuneable Filter (AOTF) ever flown in civil space

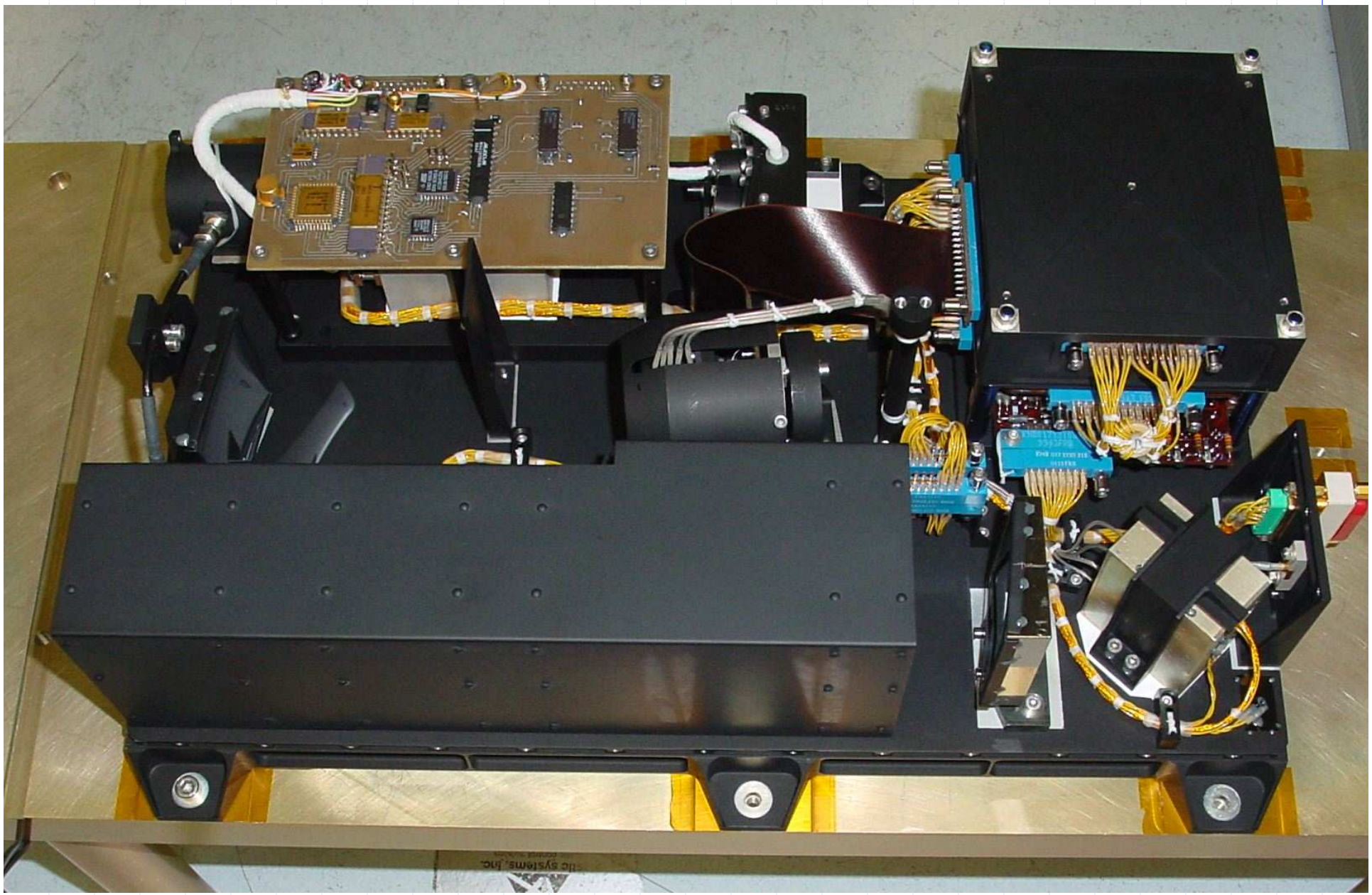
- Mass inferior to 1 kg (700 g, DC/DC and Solar entry not included)
- Spectral resolution specified as 3.5 cm^{-1} ($\lambda/\Delta\lambda>1300$)
- Capable of measuring H_2O in Mars atmosphere similar to MAWD



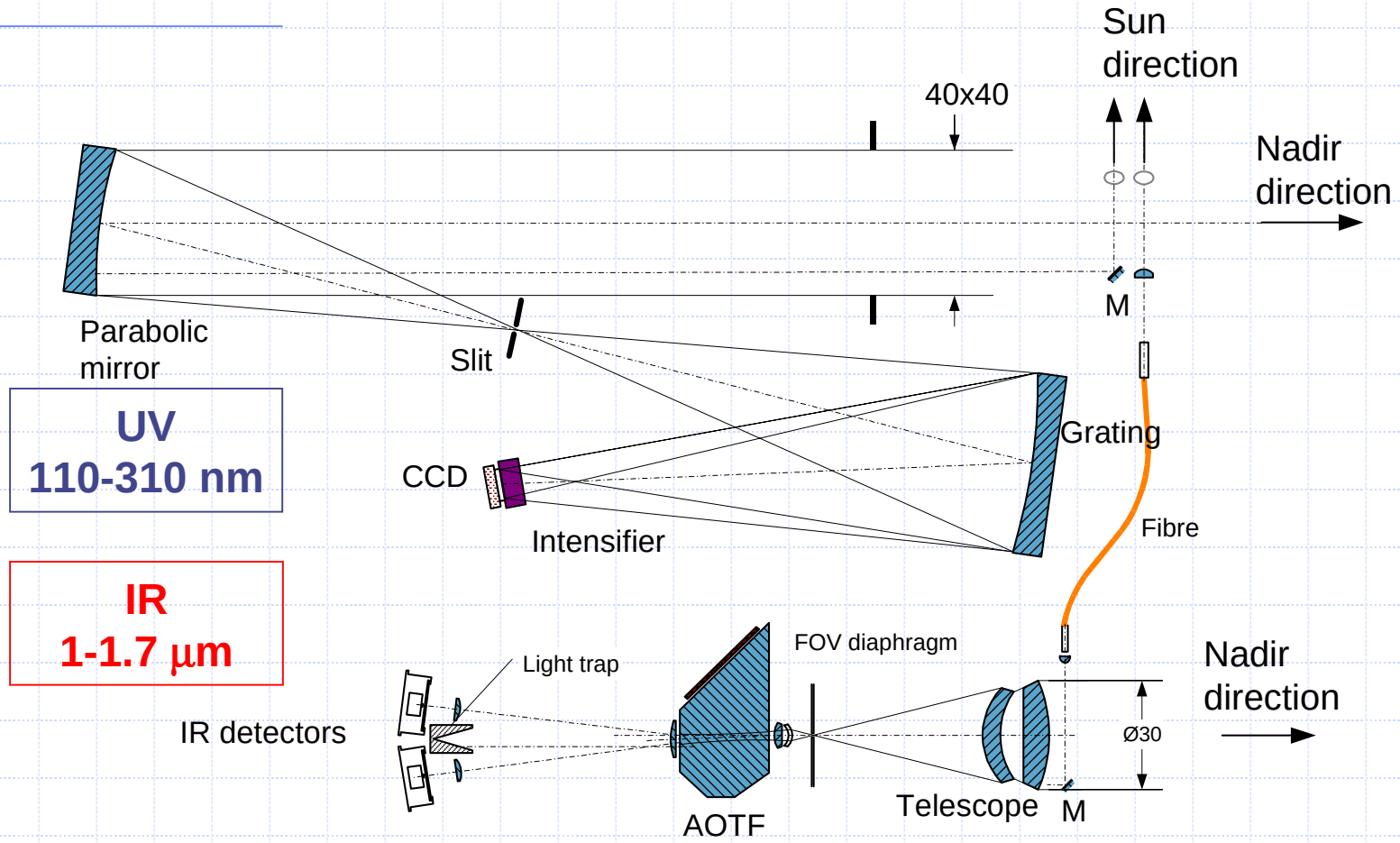
Acousto Optic Filtration

- TeO_2 birefringent crystal (0.4-5.2 μm) 1-1.7 μm
- Efficiency < 60-70% ~25%
- Max resolving power ~1500 >1700
- Aperture < 1 cm^2, < 5-6° 1:1.5
- Imaging not used
- Spectral range x2 and more*
- RF ~ 10-200 MHz
- Power consumptio
- Time to change λ





SPICAM optical scheme



Modes of operation

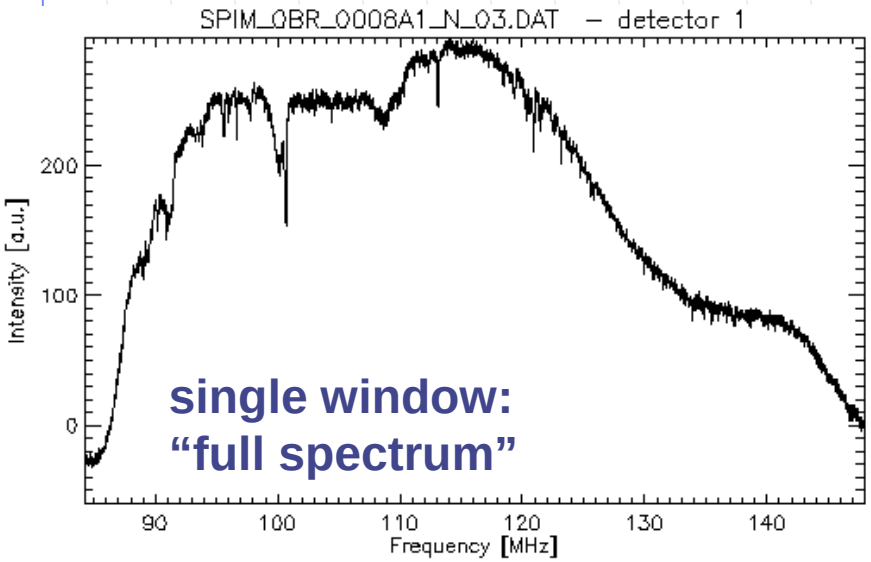
IR channel = 2 detectors (≠ polarization)

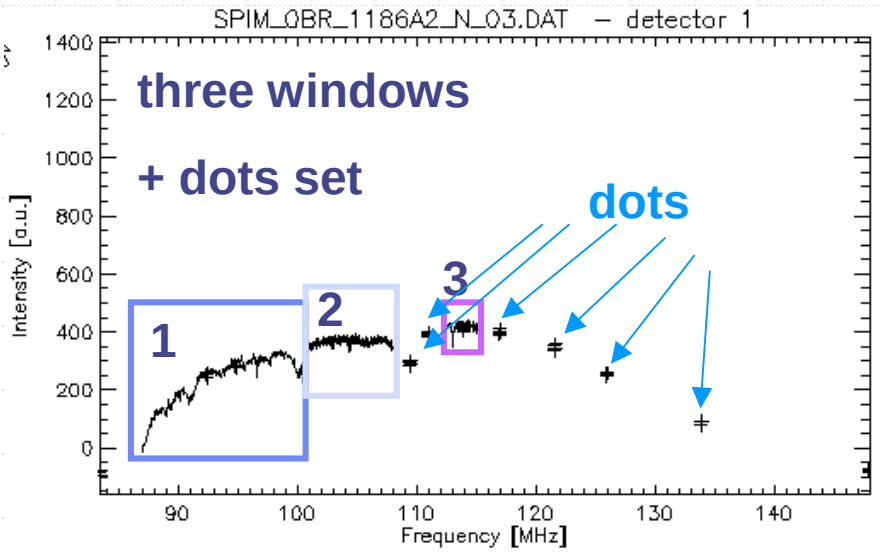
Spectra acquisition in 1, 2 or 3 "windows"

+ dots set (starting frequency, points, step)

max points = 3984, max acquisition time = 24s)

normally points = 664-1328, acquisition time = 2-4s

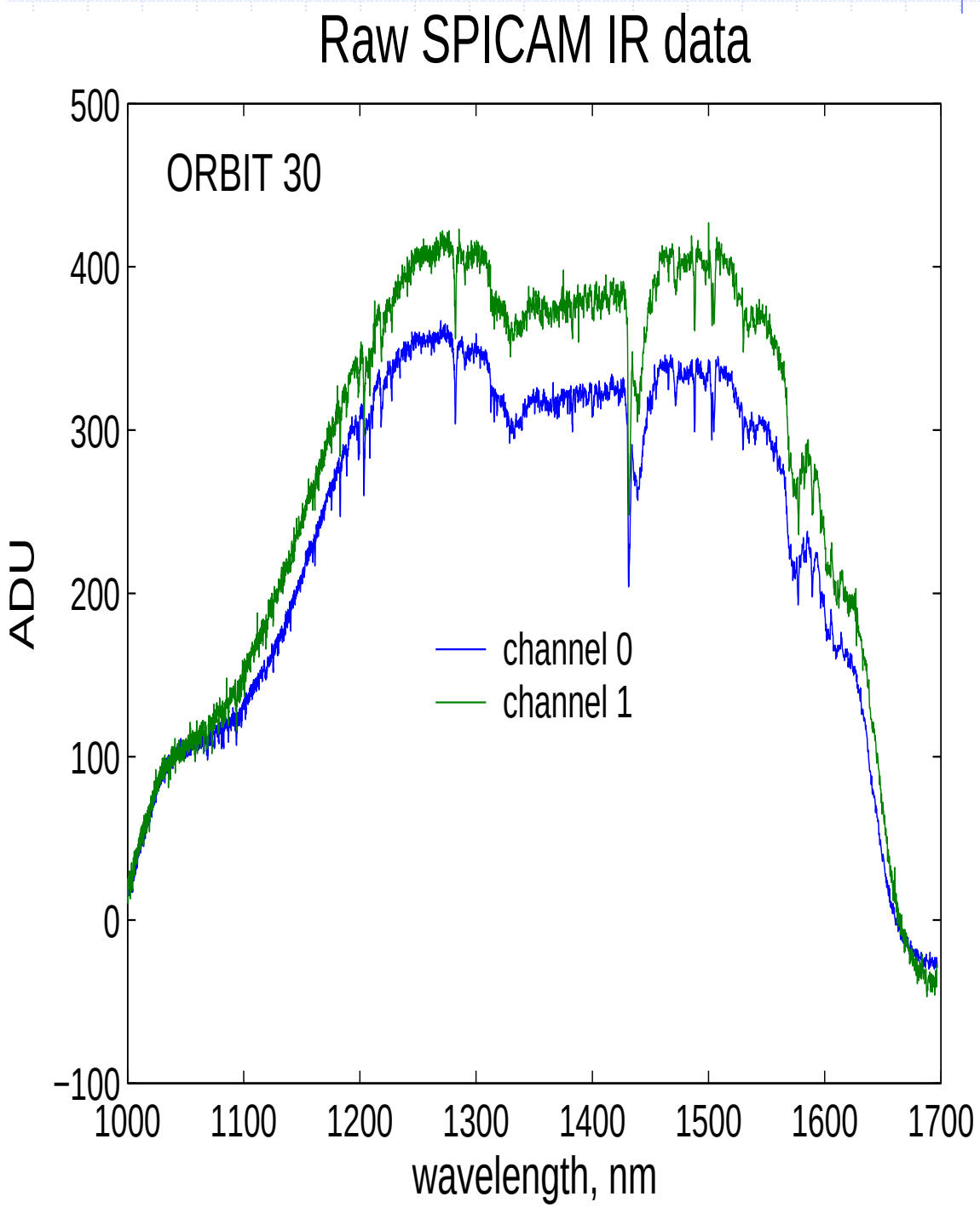


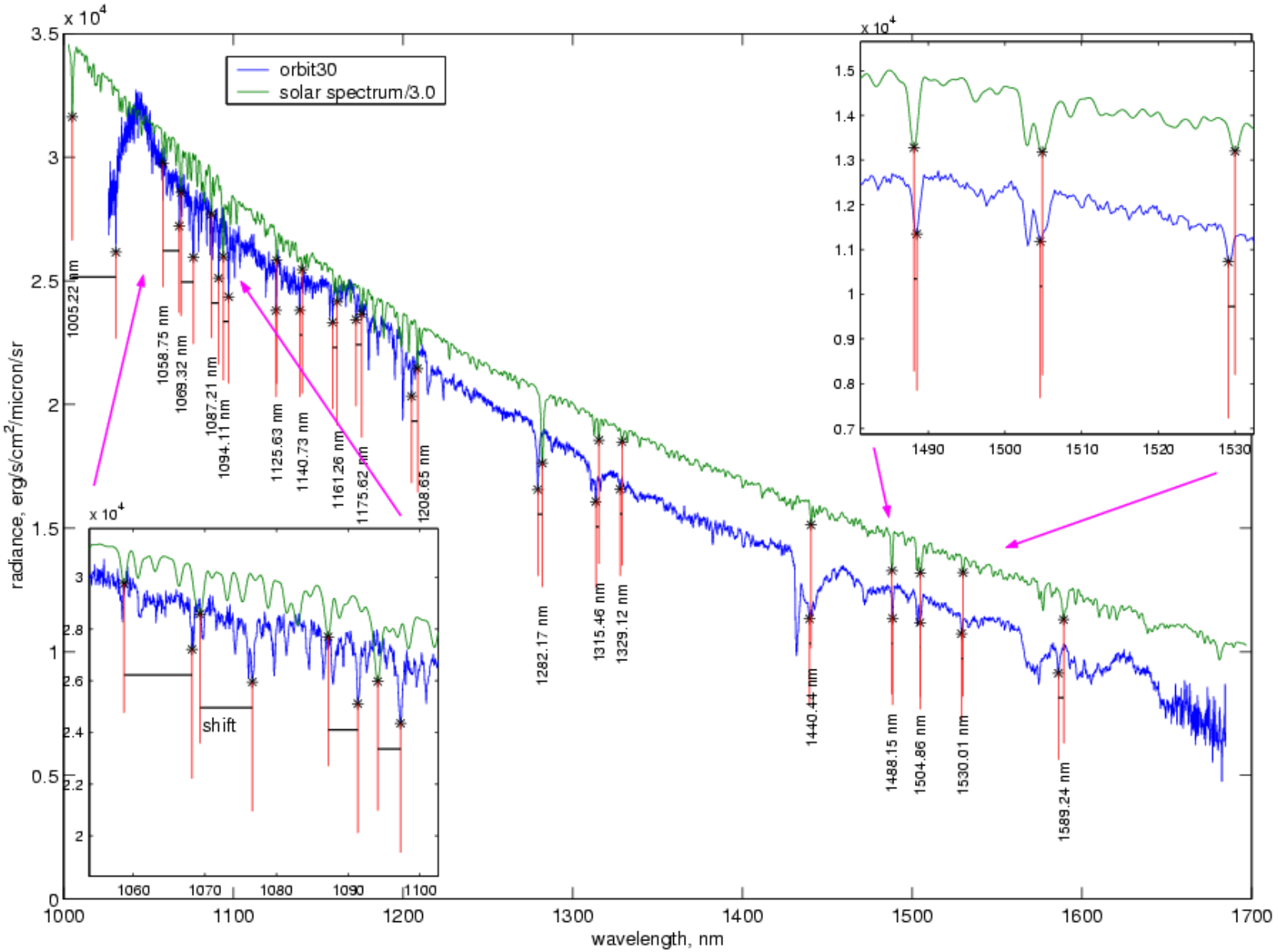


Calibrations

- Radiometric calibration
  - Done by comparison with OMEGA data and using high-resolution solar spectrum
- Wavelength assignment
  - λ versus frequency of the AOTF depends on the crystal temperature
  - Ground calibration done with HgAr pen-ray lamp for temp range -20°+40°C
  - Fitted with $\lambda = a(1+\alpha T)/f + b(1+\beta T)$; $\alpha, \beta \sim 10^{-5}$ K^{-1} with an accuracy ~0.1 nm within the entire spectral range.
- Resolving power
  - Fitted to the shape of the same pen-ray lamp lines
  - $\lambda/\Delta\lambda$ superior to 1700

Raw spectrum example: "full spectrum"



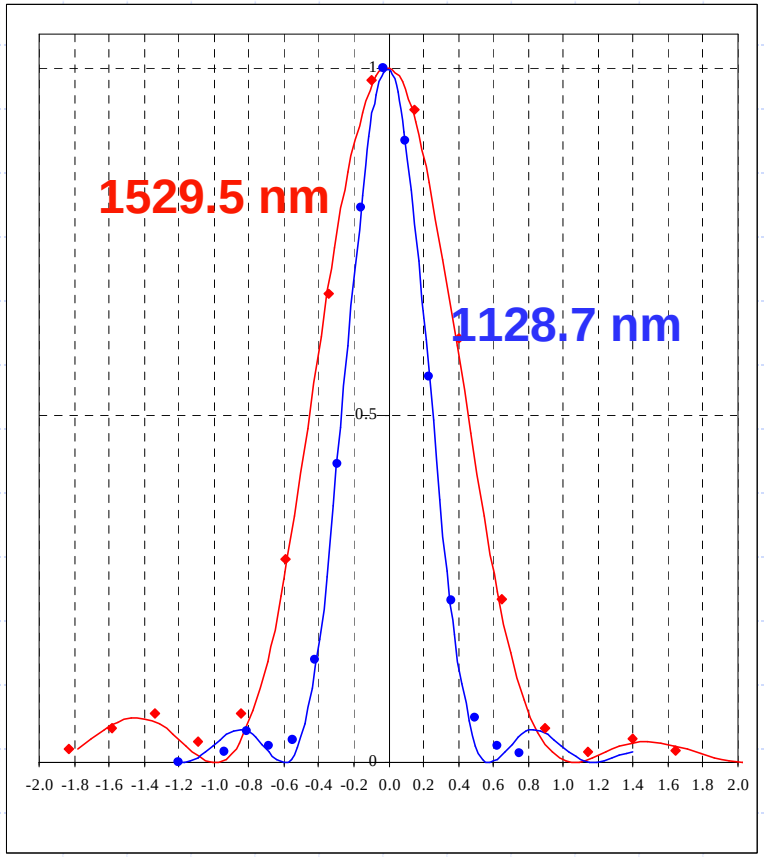

x 10^4
orbit30
solar spectrum/3.0
radiance, erg/s/cm^2/micron/sr
wavelength, nm
1005.22 nm
1058.75 nm
1069.32 nm
1087.21 nm
1094.11 nm
1125.63 nm
1140.73 nm
1161.26 nm
1175.62 nm
1208.65 nm
1282.17 nm
1315.46 nm
1329.12 nm
1440.44 nm
1488.15 nm
1504.86 nm
1530.01 nm
1589.24 nm
shift

Wavelengths calibration and resolving power

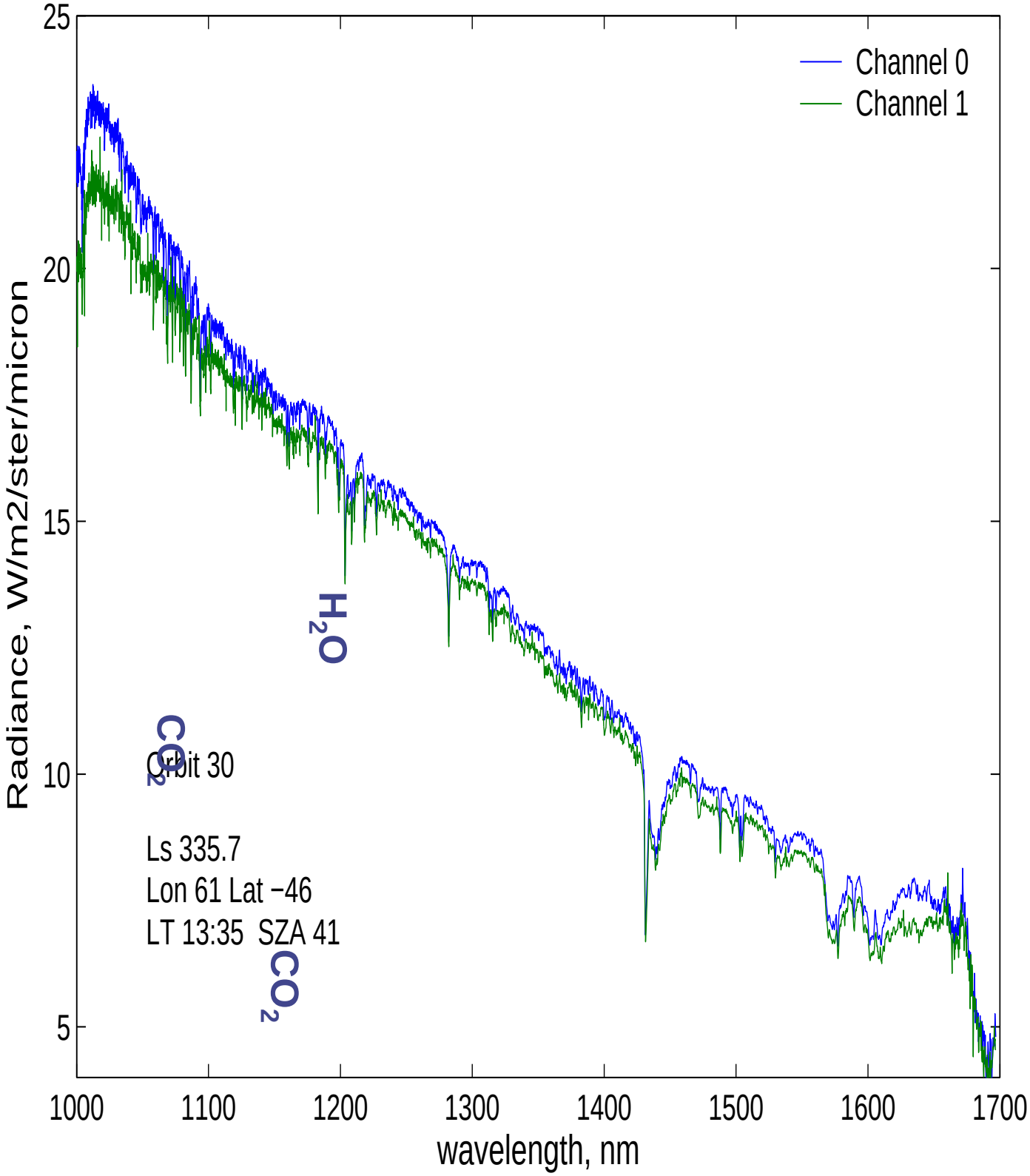
- $\lambda = a(1+\alpha T)/f + b(1+\beta T)$ accuracy ~0.1 nm
- $\alpha, \beta \sim 10^{-5}\ K^{-1}$

- 1130 nm → $\lambda/\Delta\lambda = 2200$
- 1500 nm → $\lambda/\Delta\lambda = 1750$
- Resolving power at least 1800 in the H_2O region at 1.38 μm

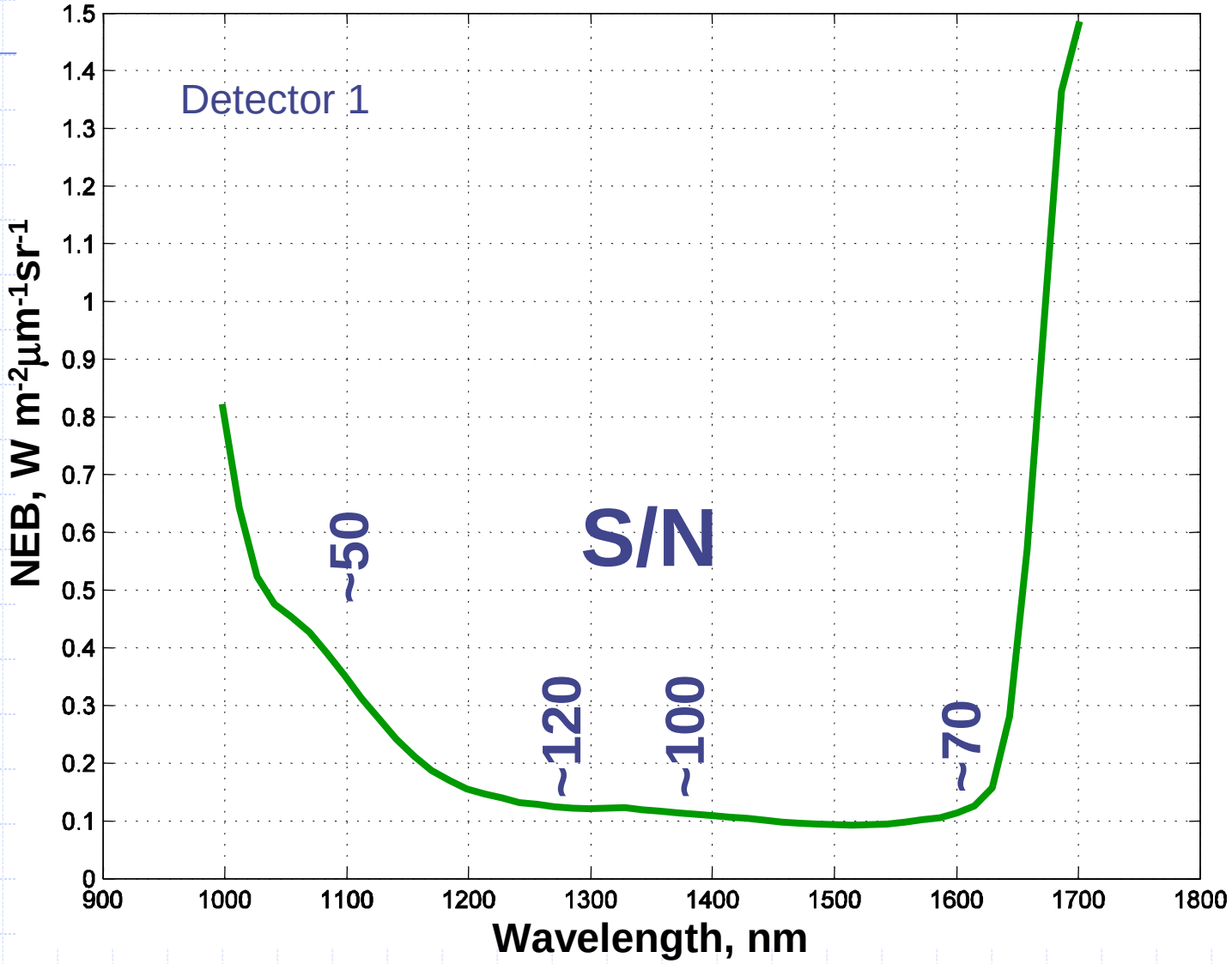
- $Sinc^2 \delta\lambda$ → tails



Calibrated SPICAM IR data



Noise Equivalent Brightness and S/N



Basic performances and most used parameters of the AOTF spectrometer

Spectral range	1-1.7 μm
Spectral resolution	0.5-1.32 nm (≈3.5 cm^{-1})
Detectors	Two InGaAs Hamamatsu photodiodes for two polarizations
FOV	Ø1° circular
Integration time for 1 spectral point	2.8 ms or 5.6 ms
Data rate	2x332 points per second or per 2 seconds
Length of a spectrum	332 to 3984 points (multiples of 332) Always x2 polarizations
Spectral sampling (frequency step)	≈0.25 of resolution element (best sampled) to ≈3 of resolution element (worst undersampled)
Time to measure 1 spectrum	1 to 24 s

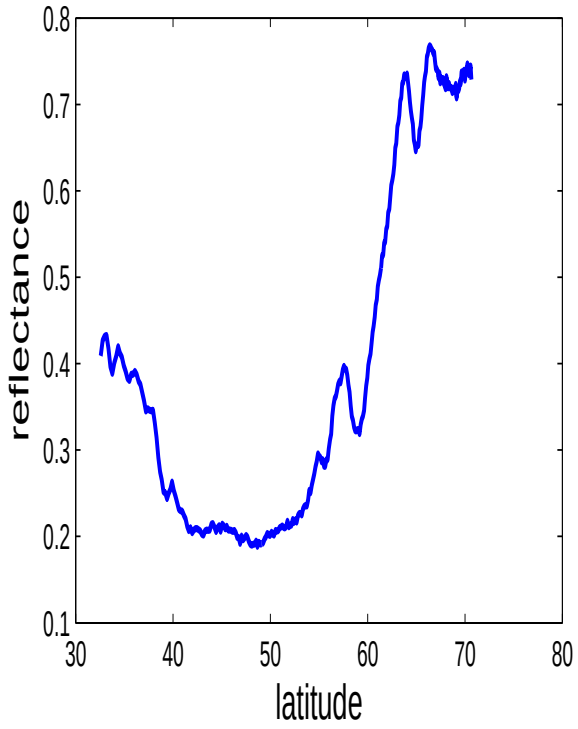
Products of near-IR AOTF spectrometer in Nadir

- Water vapour column (pr. μm)
- Equivalent width of $O_2 {}^1\Delta_g$ emission (in MR) proportional to O_3 column above 15-20 km
- Fitting CO_2 absorption at assumed surface pressure → aerosol optical depth
- Reflectance in the spectral range of 1-1.6 μm
- Equivalent width of CO_2 ice absorption → CO_2 ice detection (on the surface or in clouds)
- Equivalent width of H_2O ice absorption H_2O ice detection

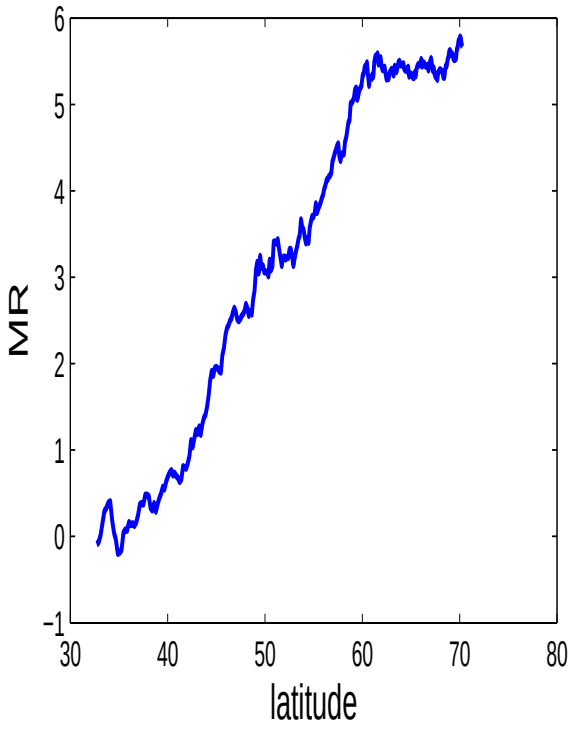
Some of SPICAM-IR products

orb 262 lon = 350.2813 L_s = 13.3269 11:31:31

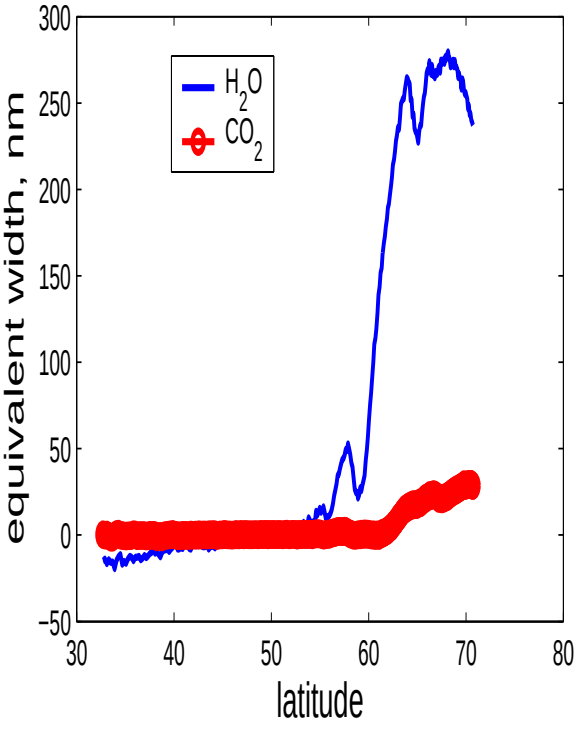
λ = 1321 nm



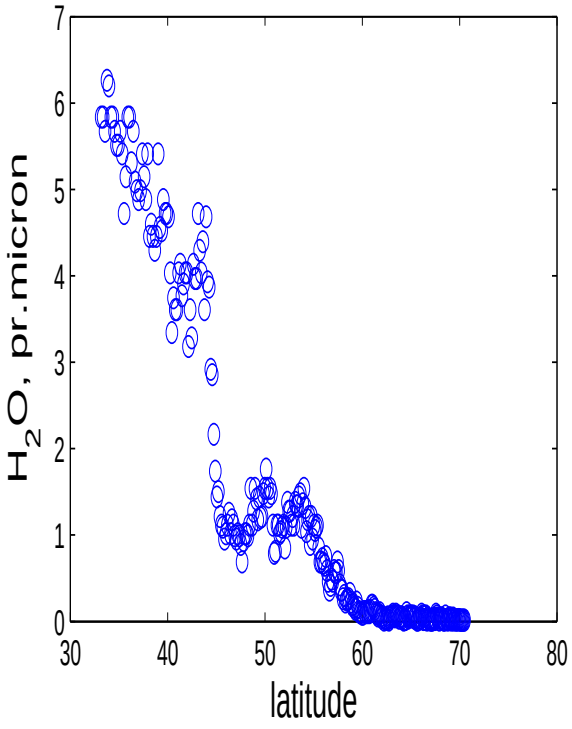
O_2

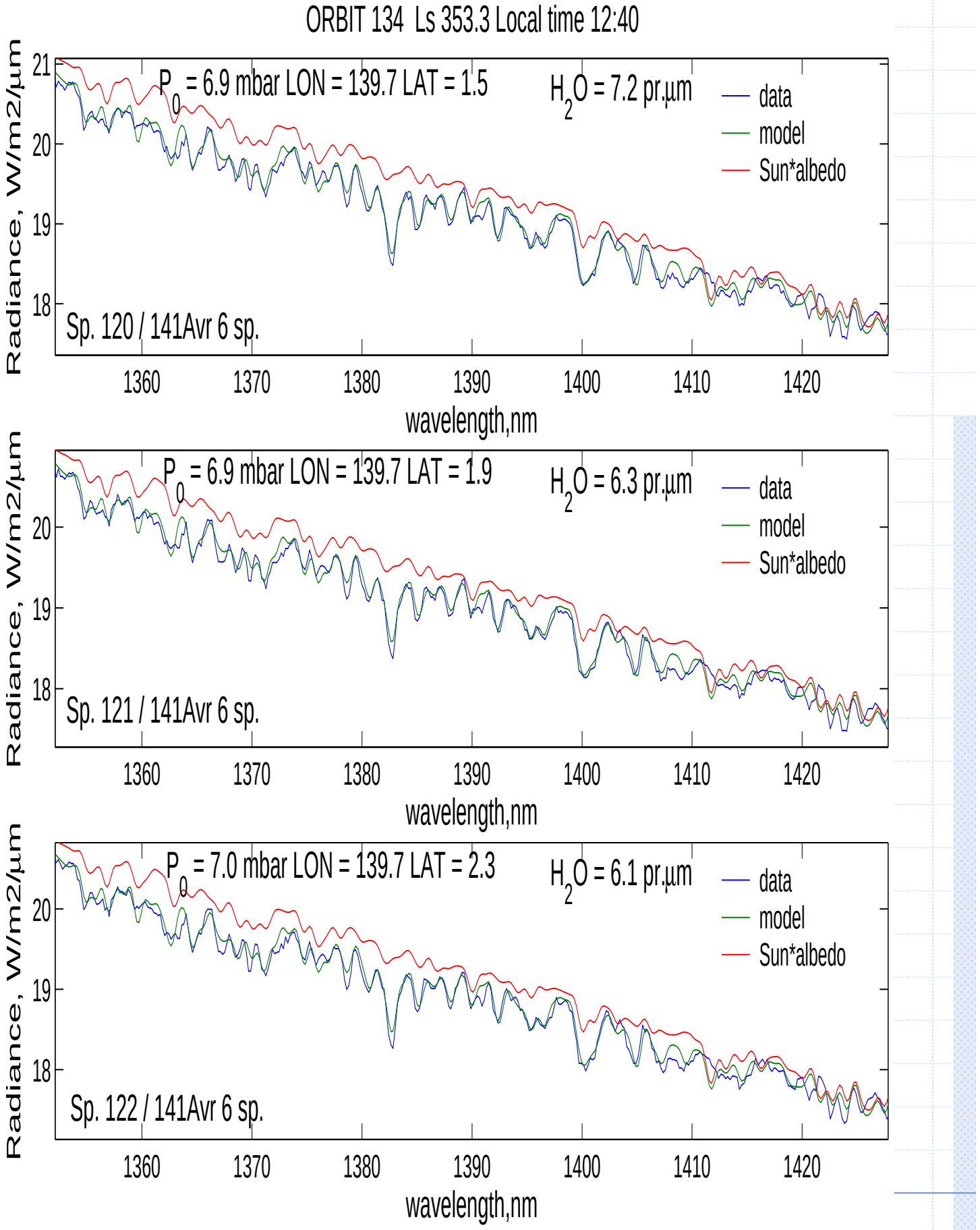


ice

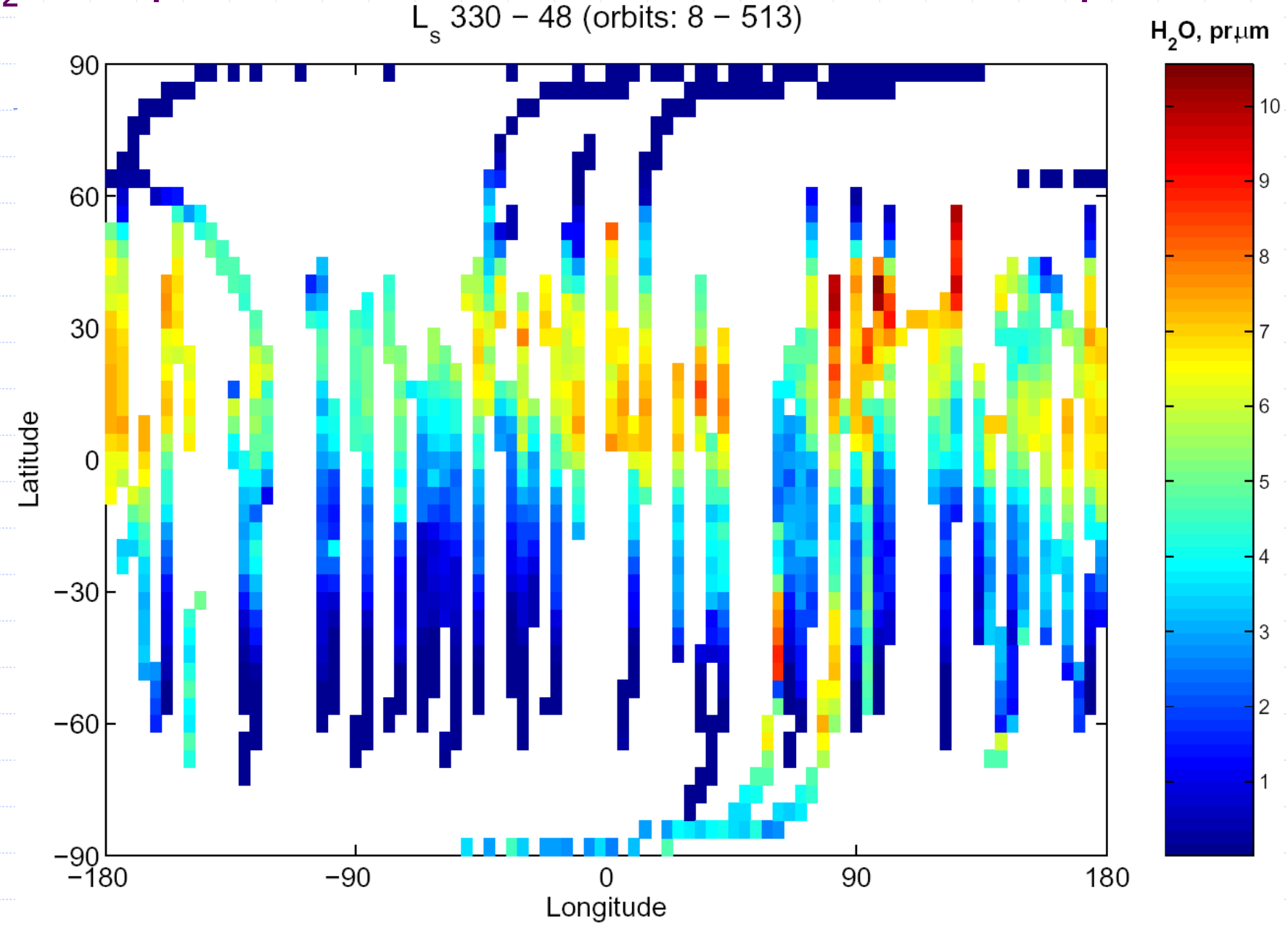


water vapor

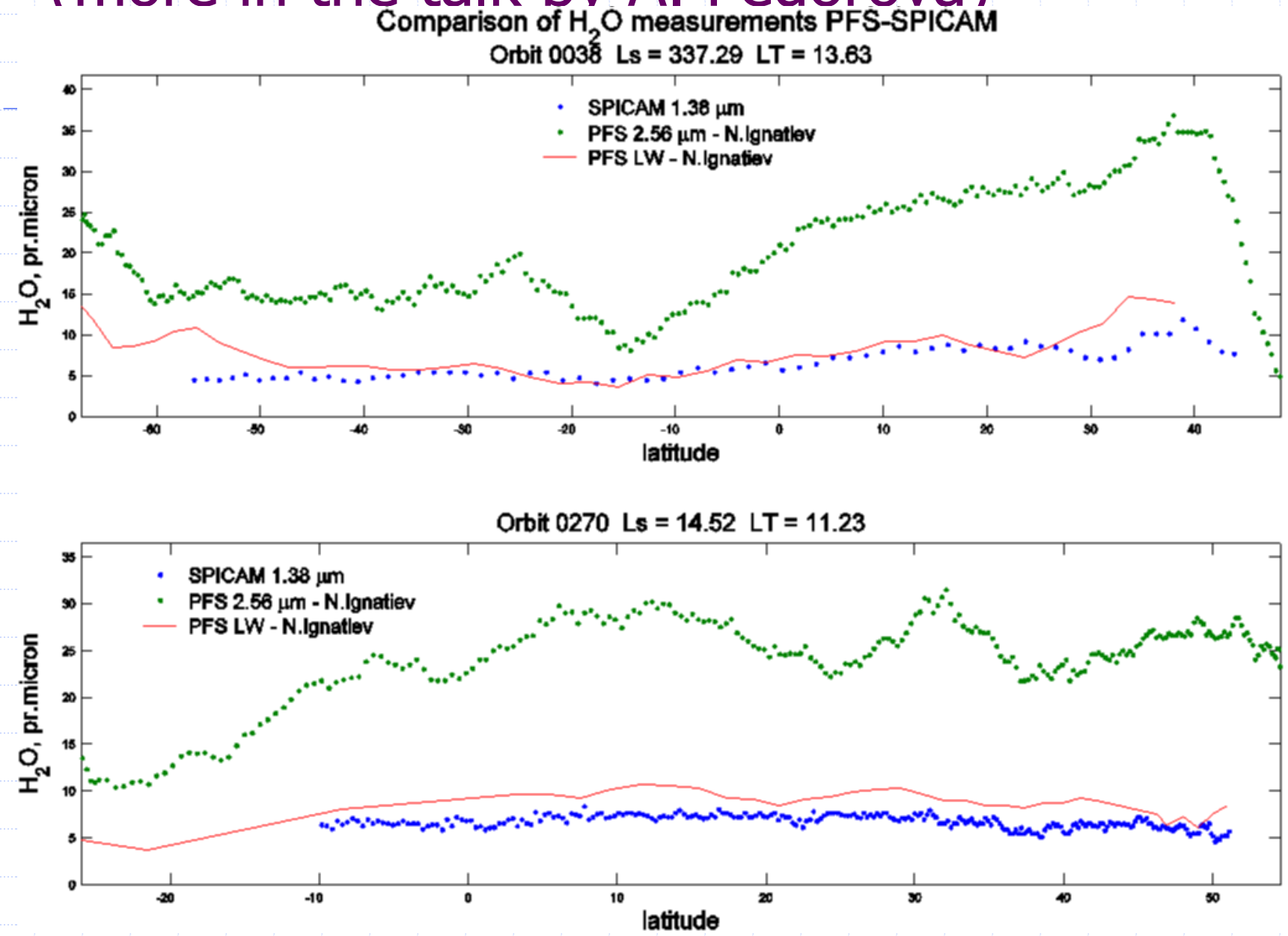


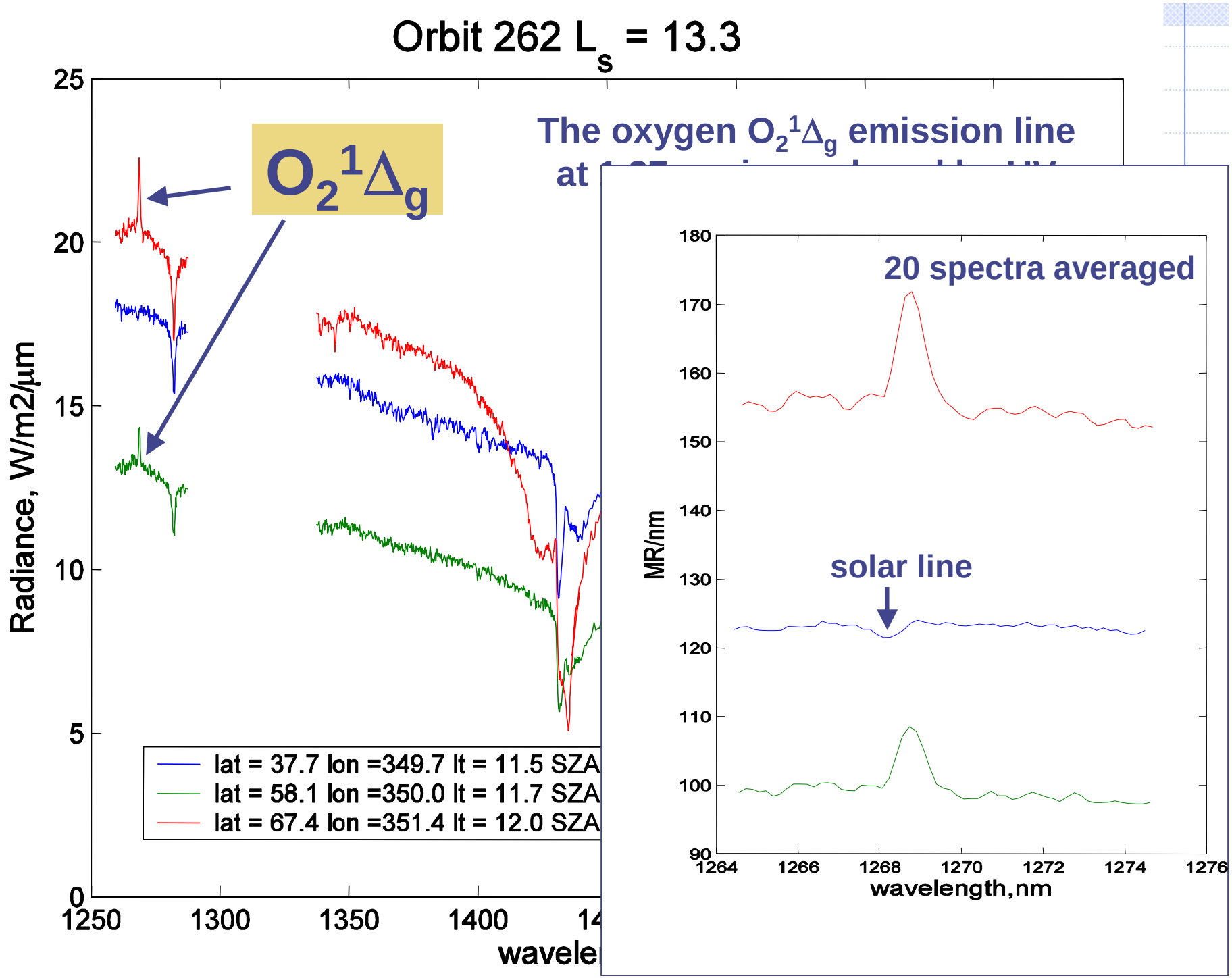

ORBIT 134 Ls 353.3 Local time 12:40
Radiance, W/m2/μm
wavelength,nm
P0 = 6.9 mbar LON = 139.7 LAT = 1.5
H2O = 7.2 pr.μm
data
model
Sun*albedo
Sp. 120 / 141Avr 6 sp.
P0 = 6.9 mbar LON = 139.7 LAT = 1.9
H2O = 6.3 pr.μm
Sp. 121 / 141Avr 6 sp.
P0 = 7.0 mbar LON = 139.7 LAT = 2.3
H2O = 6.1 pr.μm
Sp. 122 / 141Avr 6 sp.

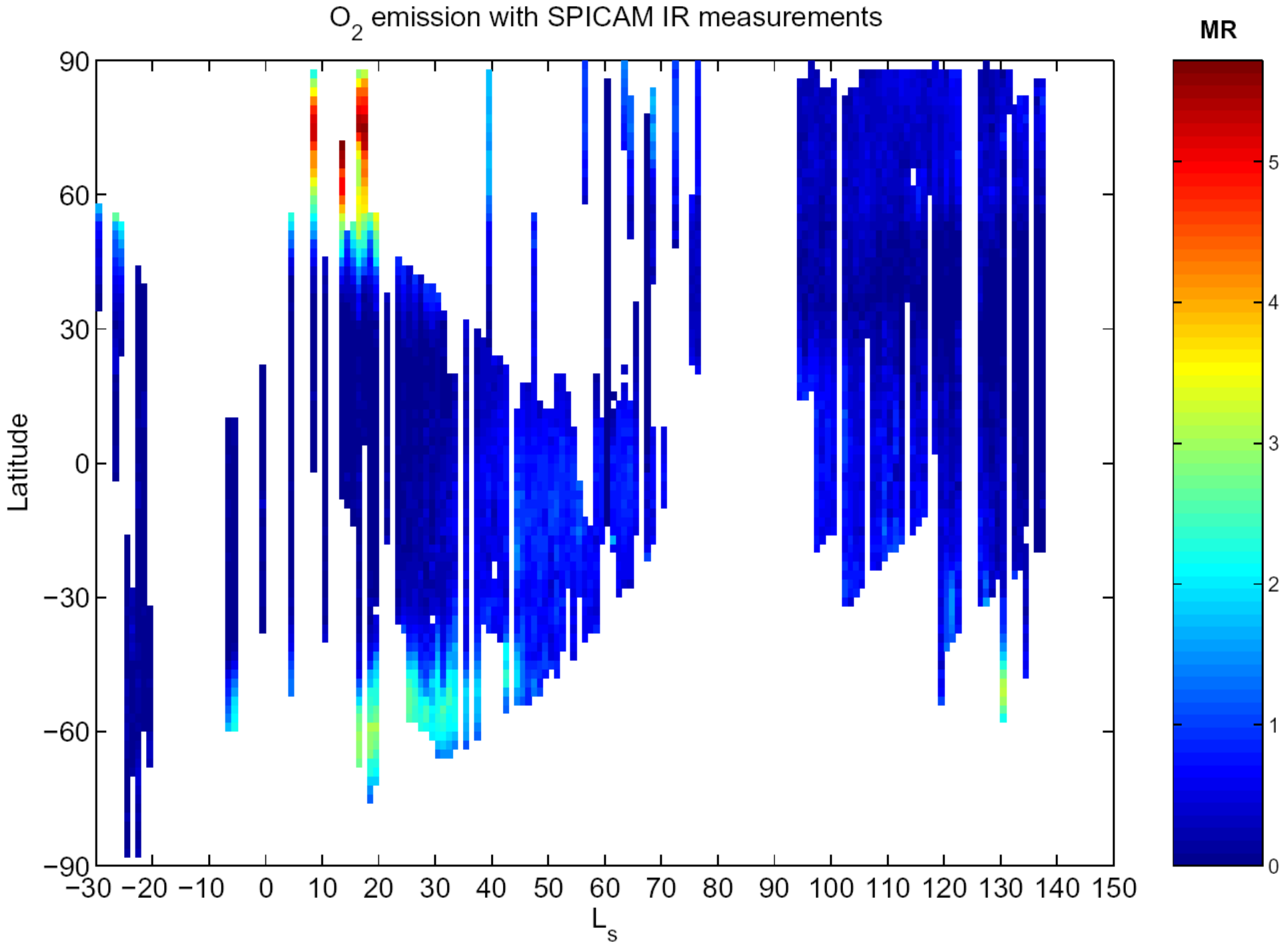
H_2O map from SPICAM measurements in 1.38 μm band

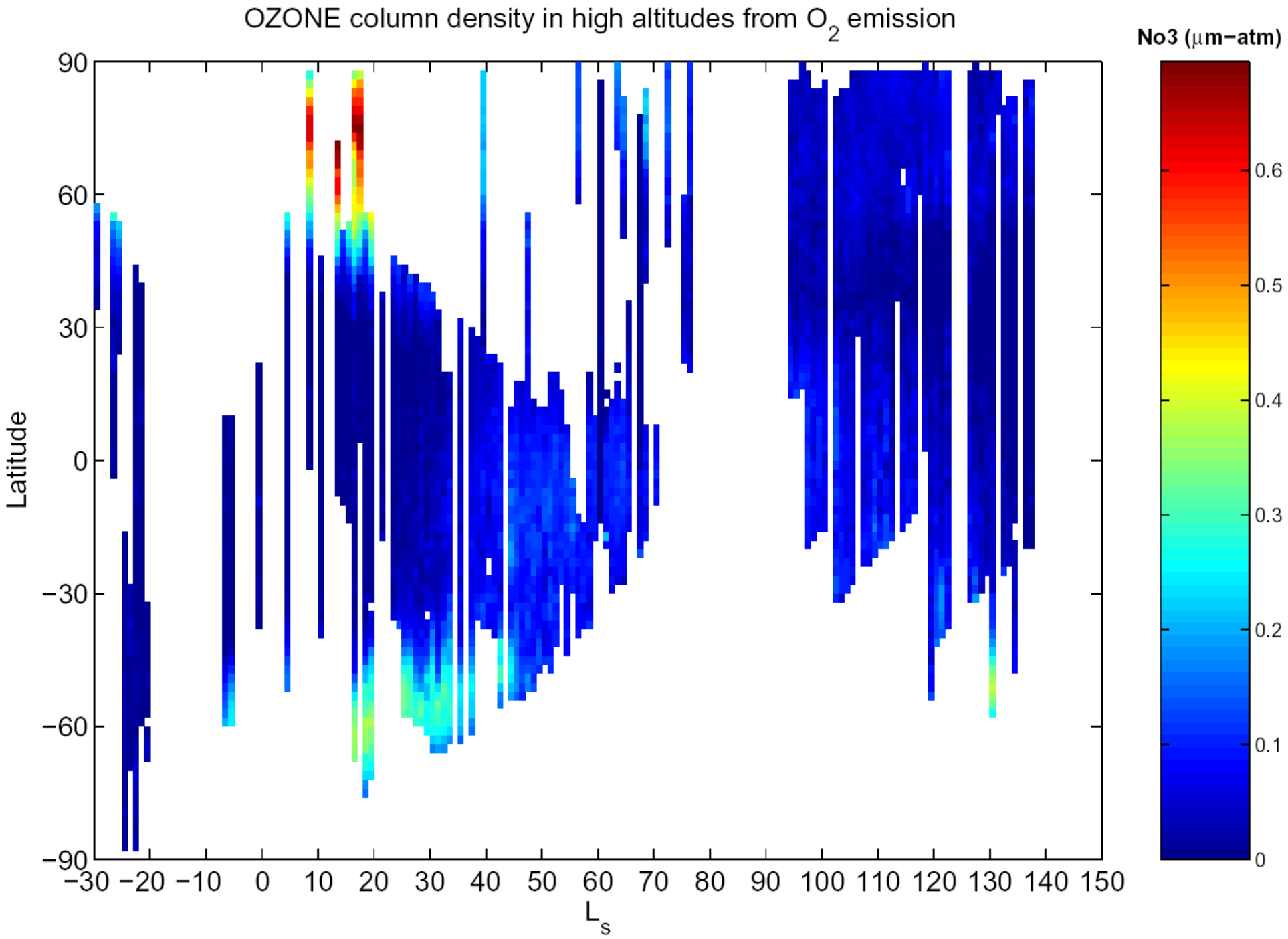


Example of PFS-SPICAM comparison (more in the talk by A. Fedorova)

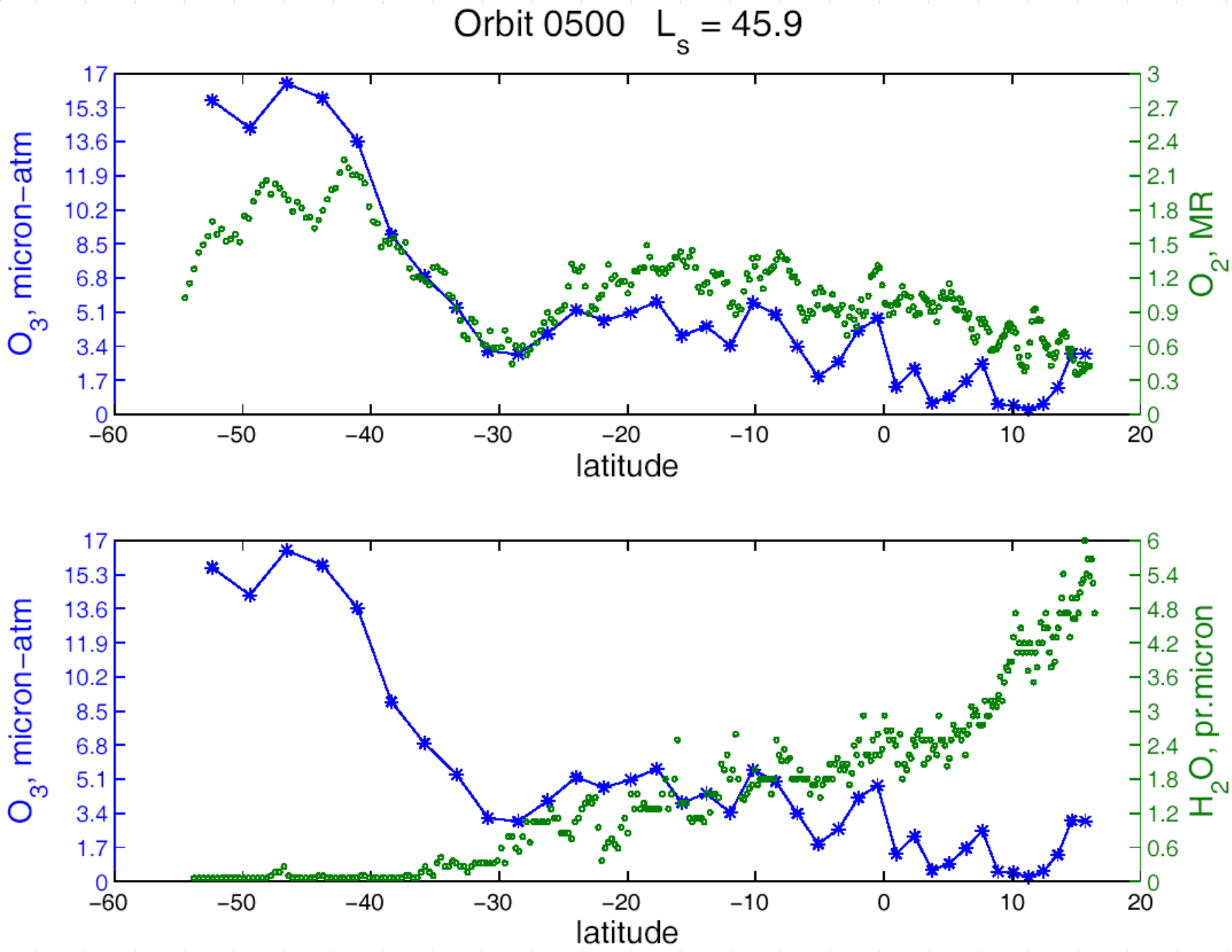



Orbit 262 L_s = 13.3
$O_2{}^1\Delta_g$
The oxygen $O_2{}^1\Delta_g$ emission line
Radiance, W/m2/μm
wavele
lat = 37.7 lon =349.7 lt = 11.5 SZA
lat = 58.1 lon =350.0 lt = 11.7 SZA
lat = 67.4 lon =351.4 lt = 12.0 SZA
20 spectra averaged
solar line
MR/nm
wavelength,nm

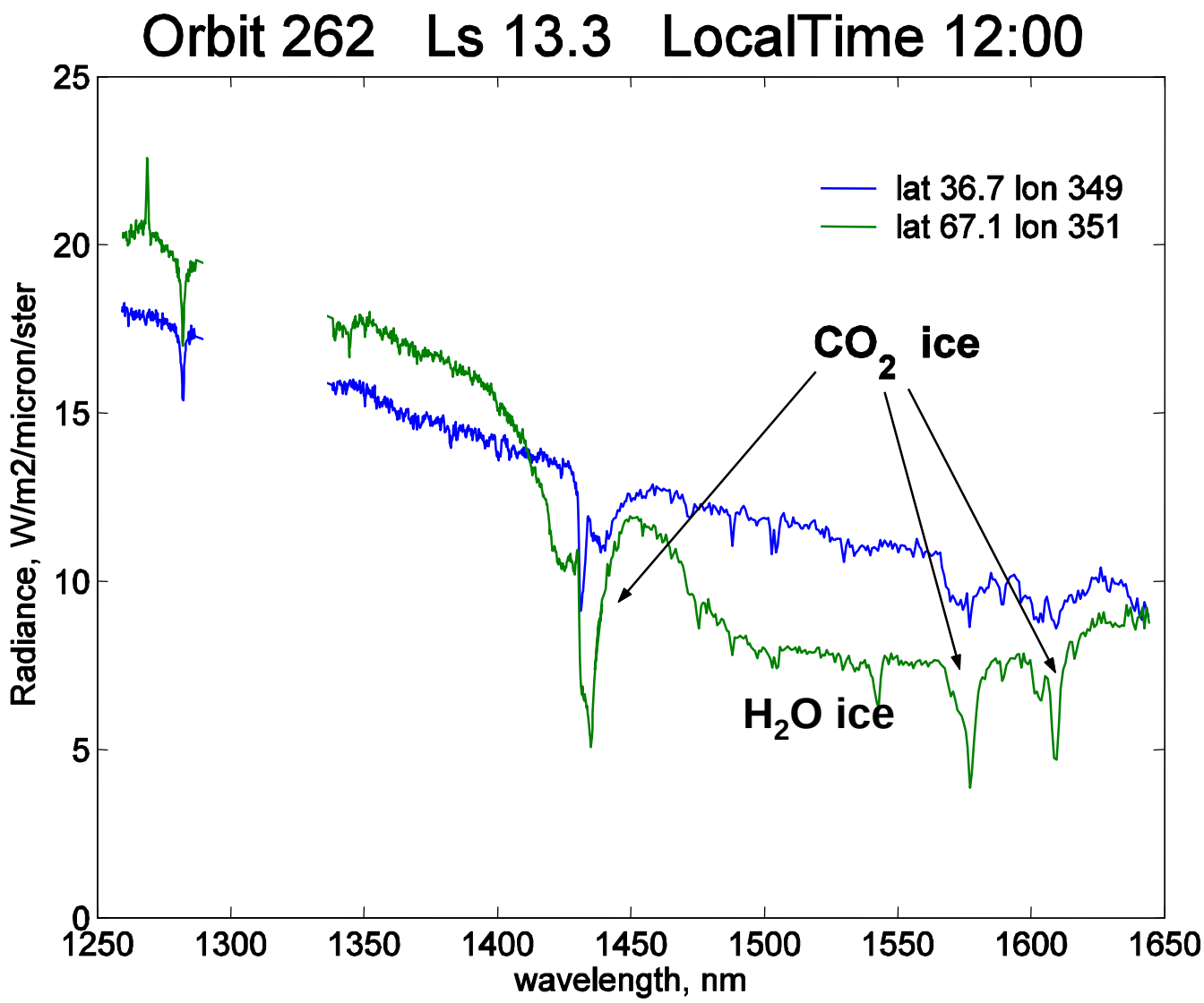

O2 emission with SPICAM IR measurements
MR
Latitude
Ls
90
60
30
0
−30
−60
−90
−30 −20 −10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
5
4
3
2
1
0


OZONE column density in high altitudes from O_2 emission
No3 (μm−atm)
0.6
0.5
0.4
0.3
0.2
0.1
0
Latitude
90
60
30
0
−30
−60
−90
−30 −20 −10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
L_s

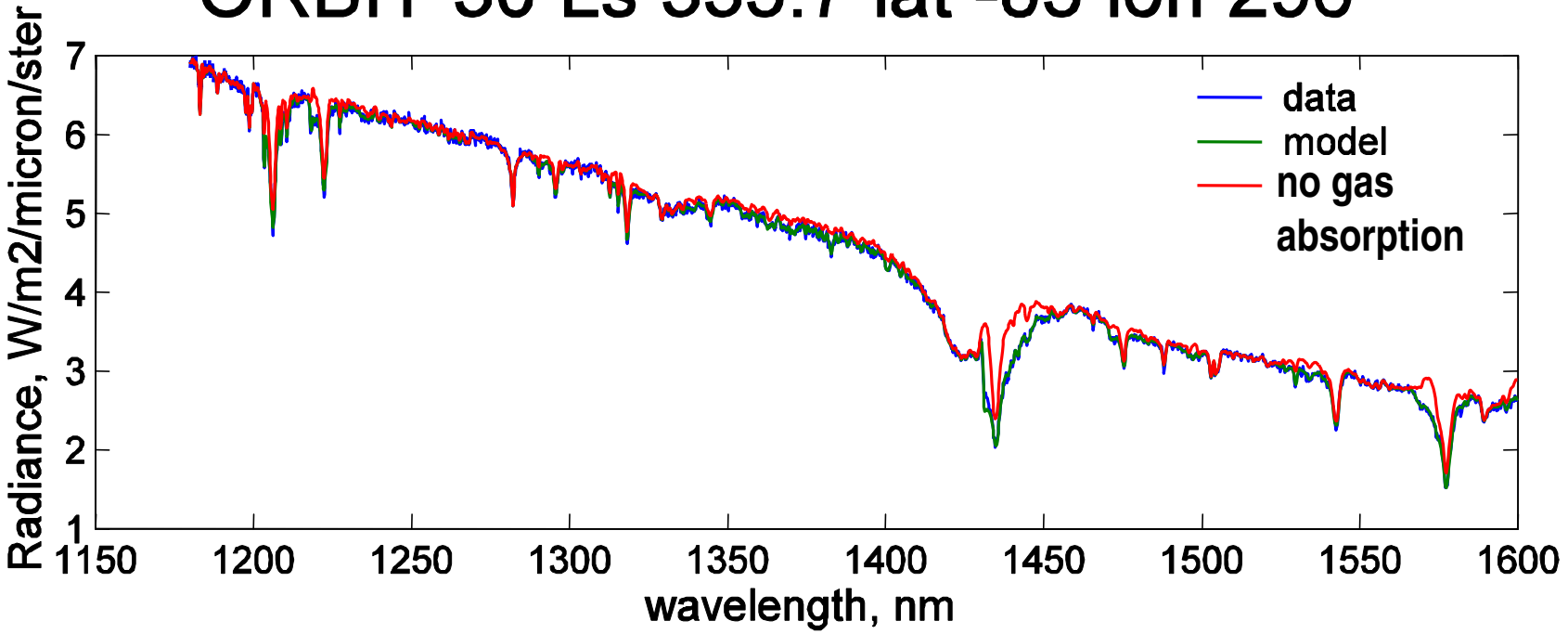
Comparison of H_2O and O_3 data (more in talk by S. Perrier.

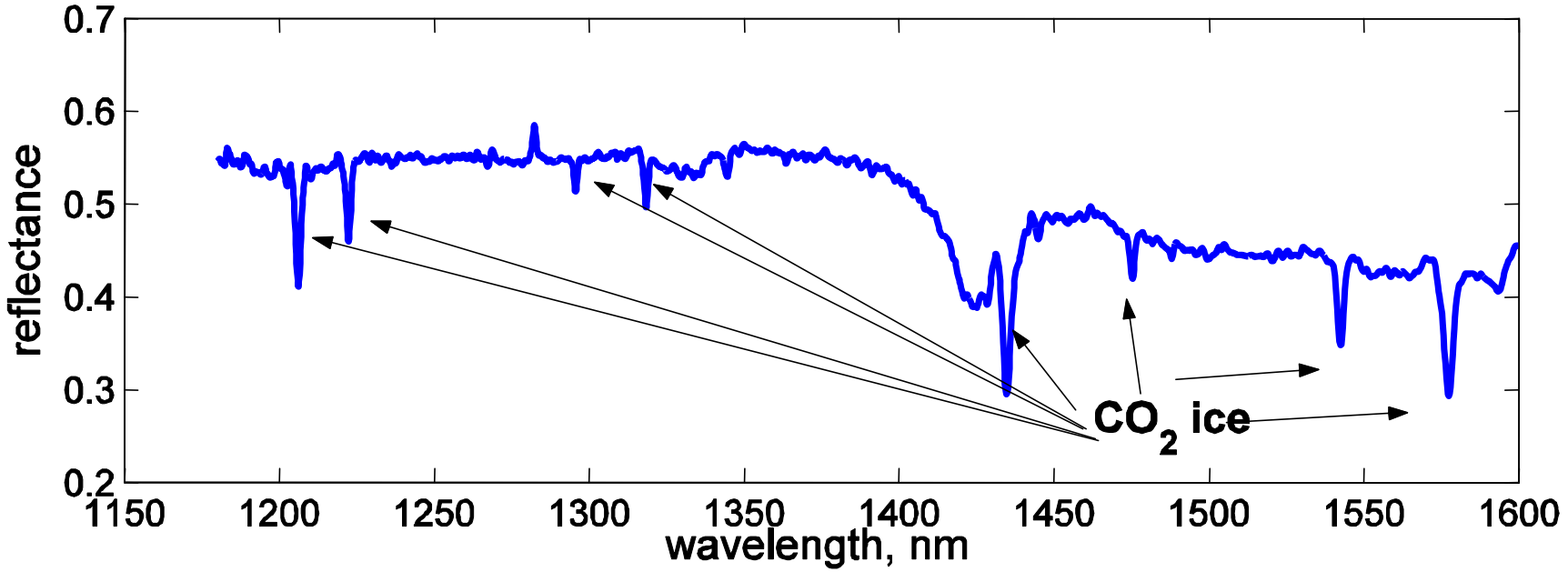


Ice signatures: CO_2 and H_2O



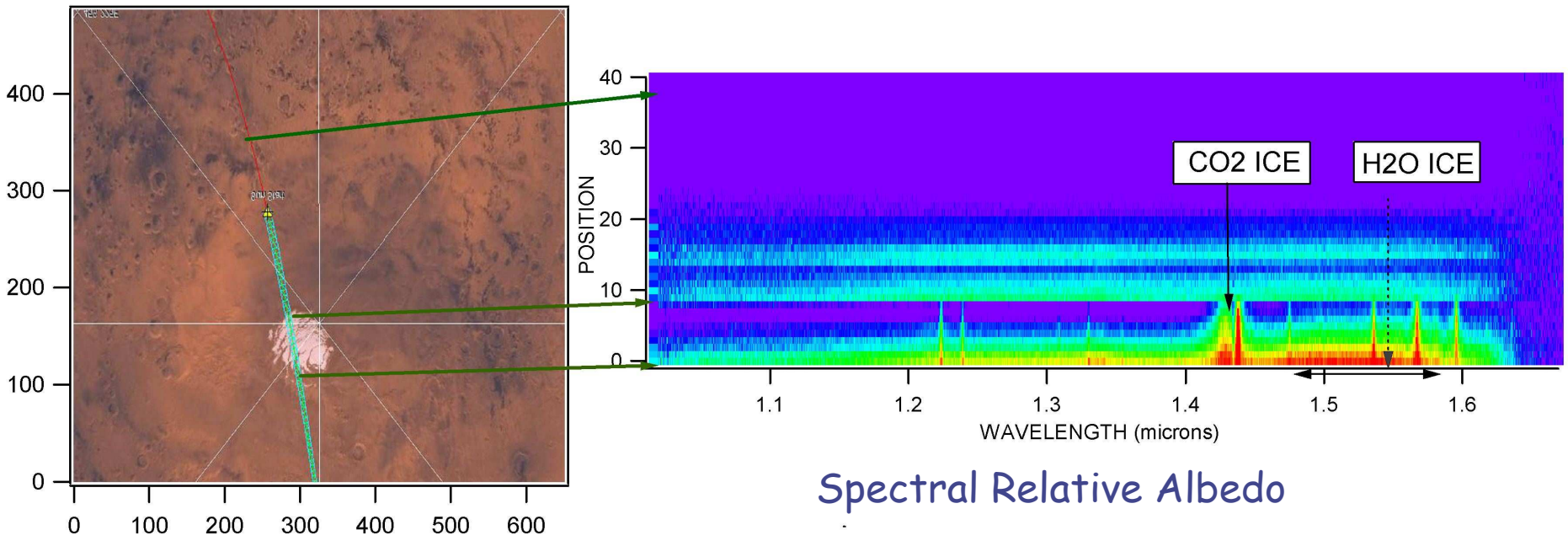
ORBIT 30 Ls 335.7 lat -85 lon 296





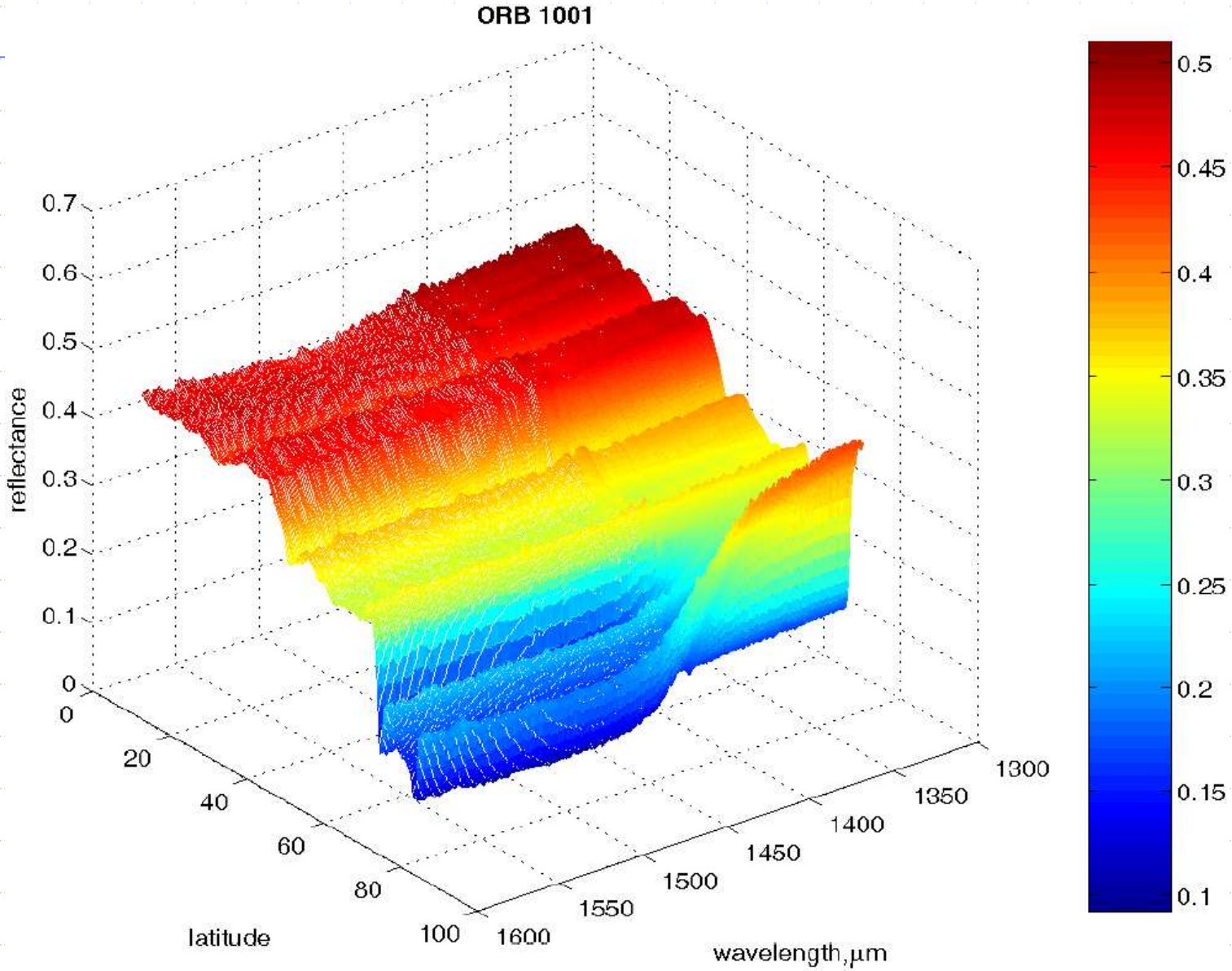
MARS EXPRESS SPICAM/AOTF

SOUTH POLE ORBIT 30



Spectral Relative Albedo

Albedoe in the range 1-1.7 μm



Conclusions and plans for future

- On Mars Express SPICAM IR is to large extent duplicative to such instruments as OMEGA and PFS
- This channel proved to be capable of measuring :
  - water vapour with an accuracy of 1-2 pr.μm
  - ozone through $O_2 {}^1\Delta_g$ emission
- We plan also to implement
  - routine measurements CO_2 and H_2O ices
  - aerosols at limb,
  - Possibly, retrieve aerosol in Nadir
  - And to analyze in detail Solar Occultations (already performed)
- For the future:
  - AOTF sensor is below 1-kg threshold. S/N of SPICAM IR AOTF derivative for Venus Express has been largely improved
  - We believe that this type of instrument should be a routine versatile aeronomy-climate sensor in any future Mars missions