ACOUSTO-OPTIC SPECTROSCOPY IN PLANETARY MISSIONS

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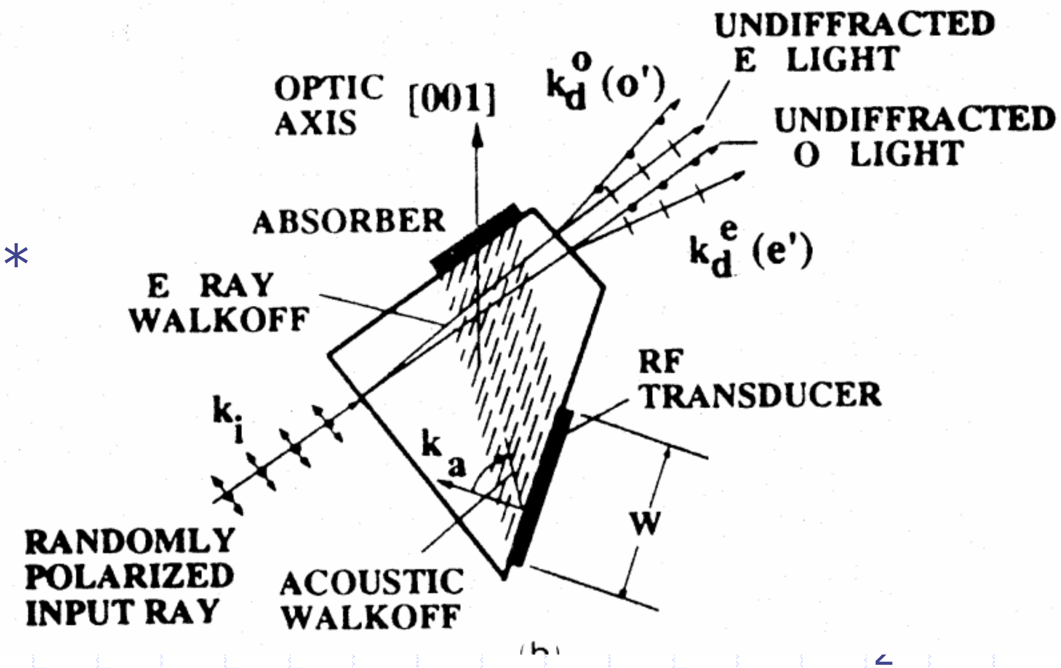
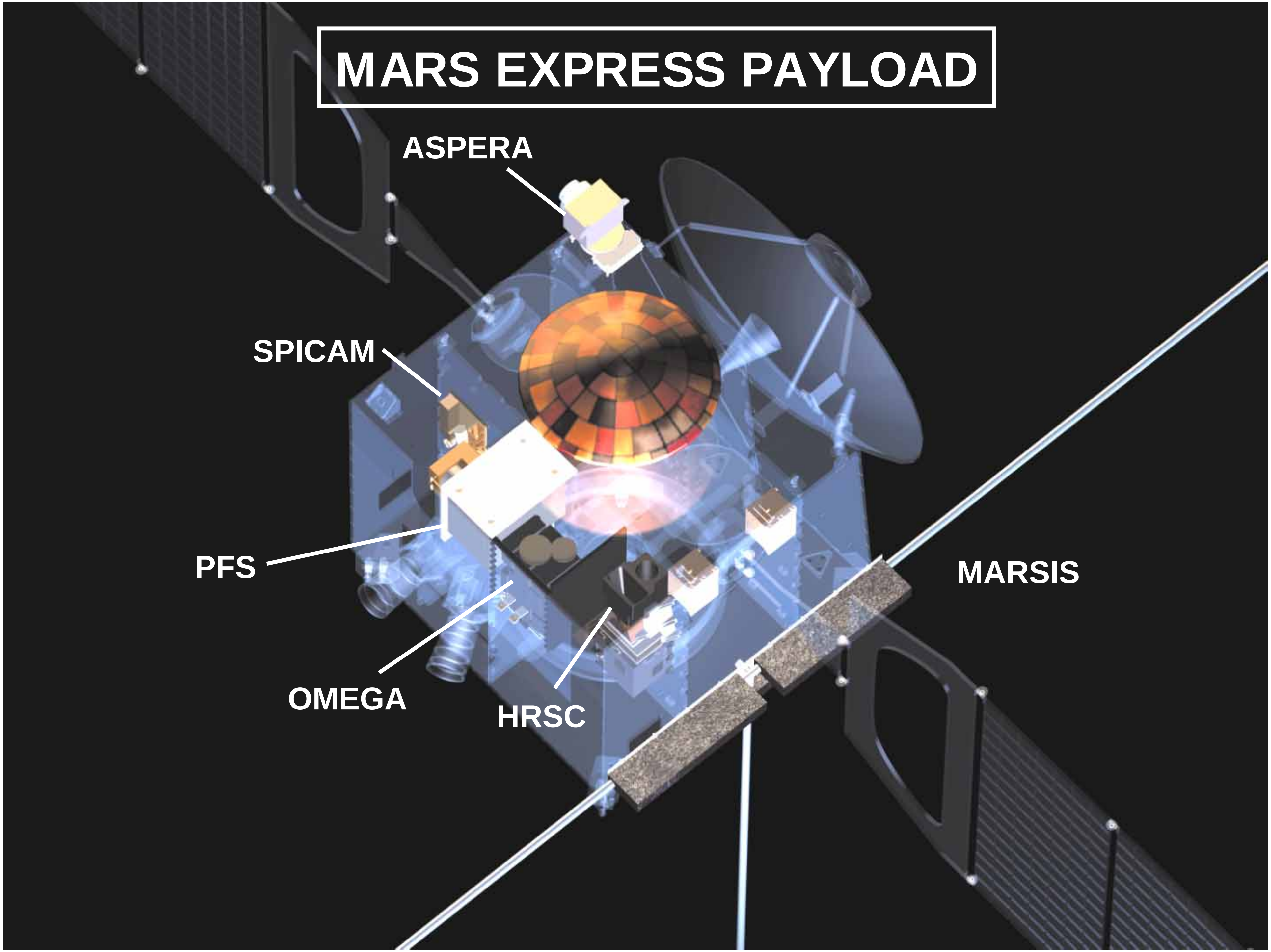
AOTF = Acousto-Optic Tunable Filter

- A birefringent crystal: for example TeO_2 (0.4-5.2 μm)
- Effectiveness 60-70%
- Maximal possible resolving power 1500-2000 (best resolution in wavenumbers ~3.5 cm^{-1})
- Aperture < 1 cm^2, < 5-6º
- Spectral range x2 and more*
- RF ~ 10-200 MHz
- RF power : 0.3 W-3W
- Time to tune ~30 μs.

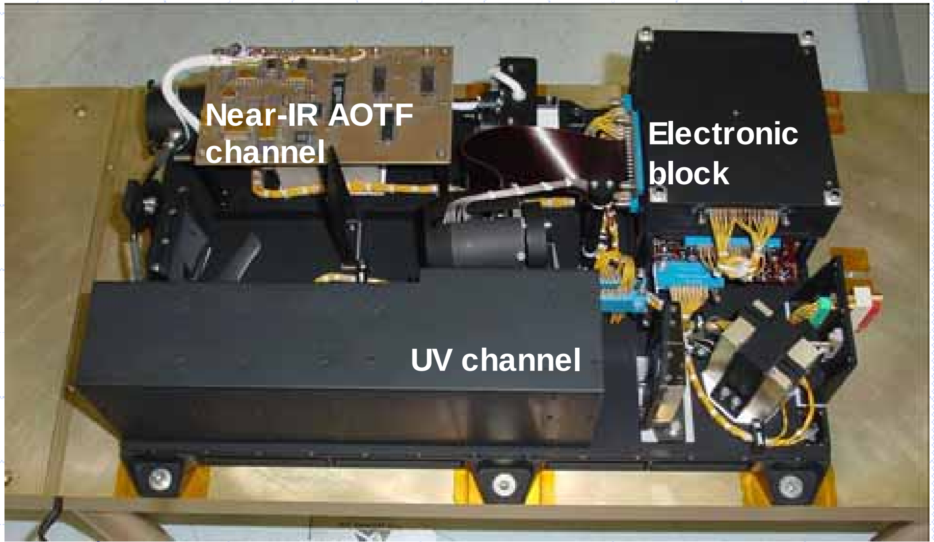


Why AOTF in planetary missions?

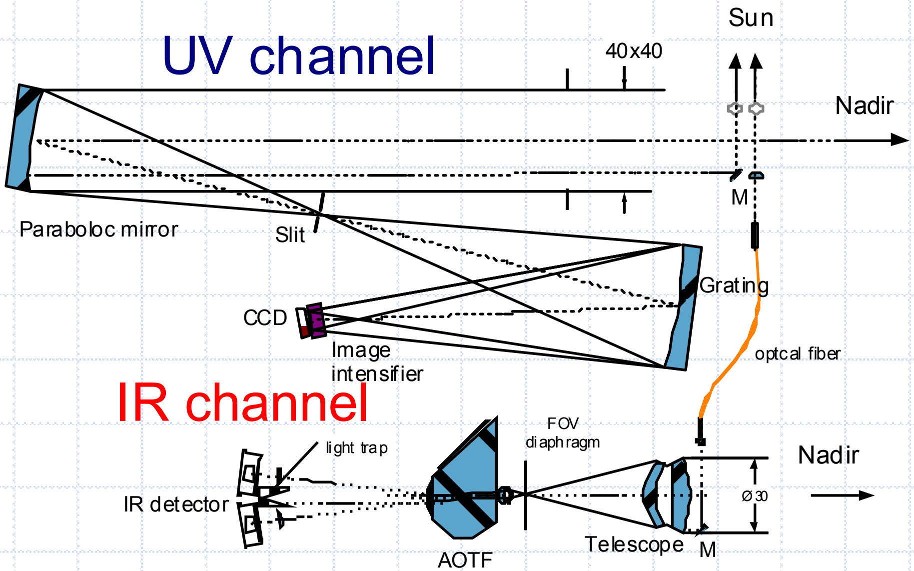
- very light, compact, and robust device with no moving parts
- easily controlled by changing RF
- fast and random tune
- RF=OFF → no diffracted light ➔ easy modulation of signal to reject stray light
- possibility to filter images


MARS EXPRESS PAYLOAD
ASPERA
SPICAM
PFS
MARSIS
OMEGA
HRSC

Mars Express: SPICAM



SPICAM – versatile atmospheric spectrometer
PI Jean Loup Bertaux, SA Verrieres le Buisson
Cooperation: France, Belgium (mechanics), Russia (IR channel), USA



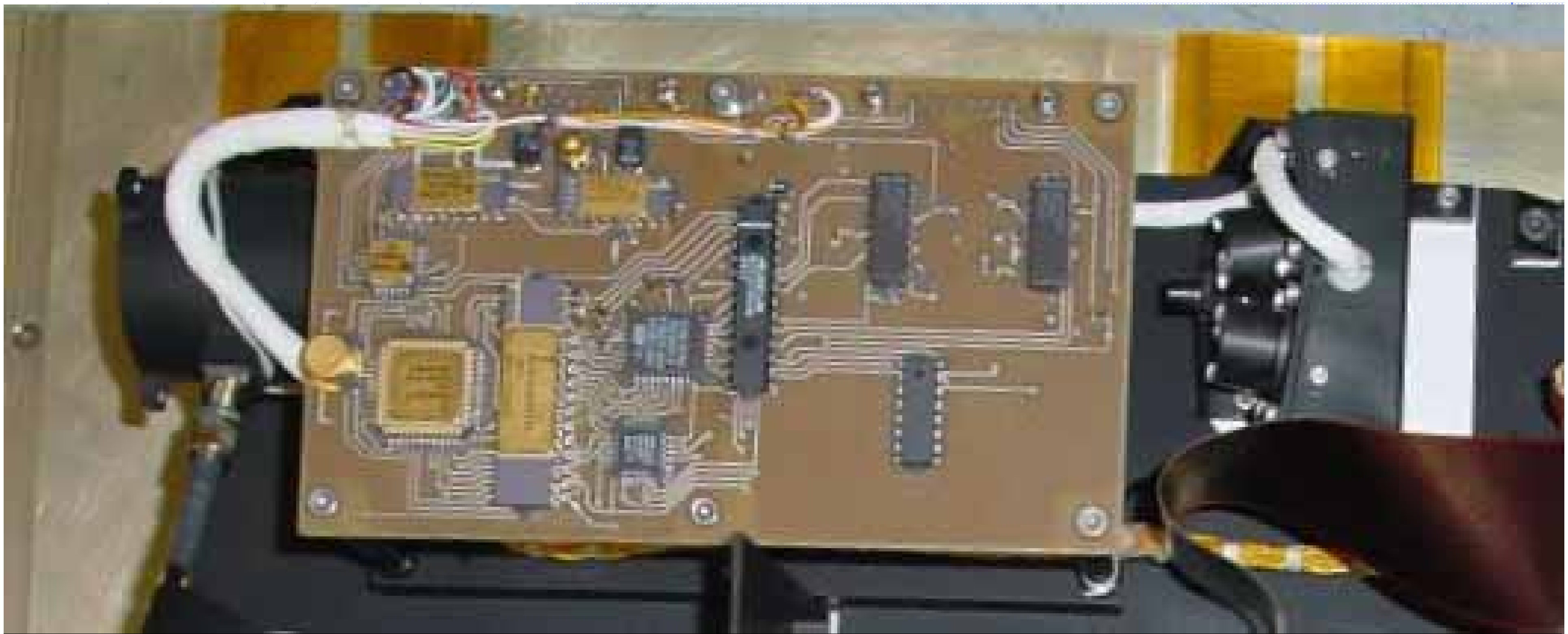
Main characteristics of SPICAM

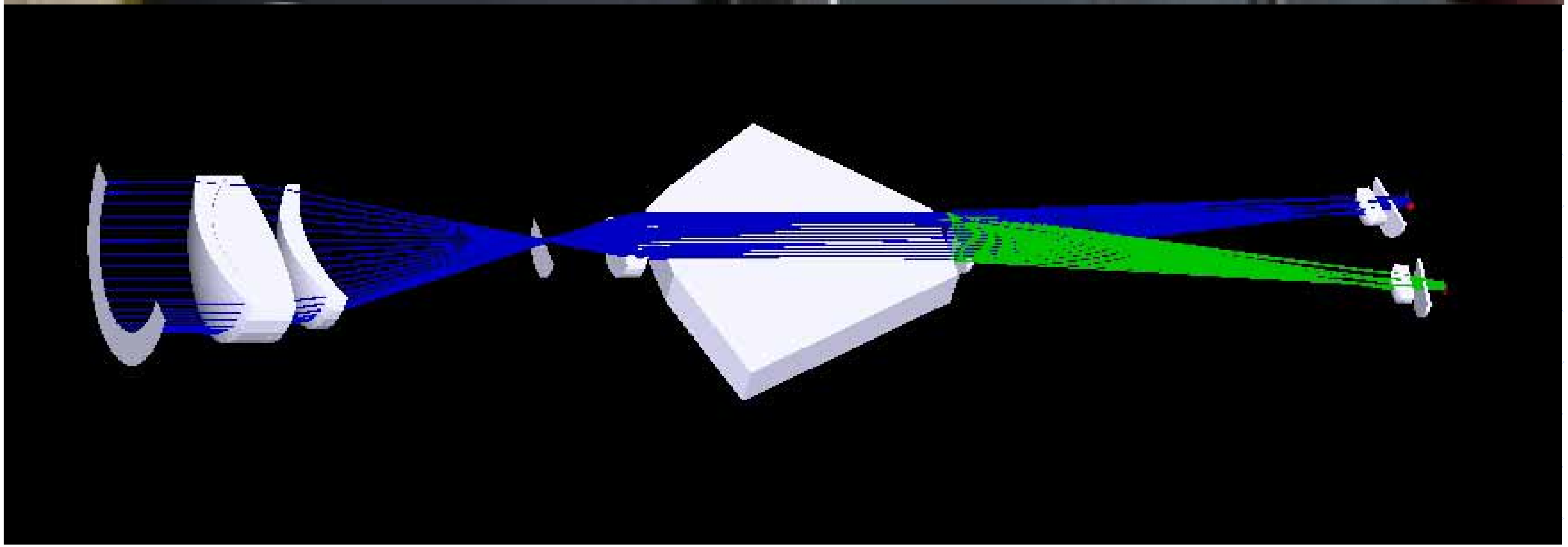
	UV	Near-IR
Spectral range, nm	118-320	1000-1700
Spectral resolution, nm	0.9	0.5-1.2
Angular resolution, mrad nadir occultations	0.2x1 0.2	17.5 1.5
Mass	4.9 kg	
Data volume	30 Mbit/orbit	

SPICAM Light / MEX

IR: 1-1.7 μm
AOTF
spectrometer
Two pixels

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





IR channel of SPICAM : First Acousto Optic Tuneable Filter (AOTF) 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} ($\lambda/\Delta\lambda \sim 1800$)
- Capable of measuring H_2O in Mars atmosphere similar to MAWD

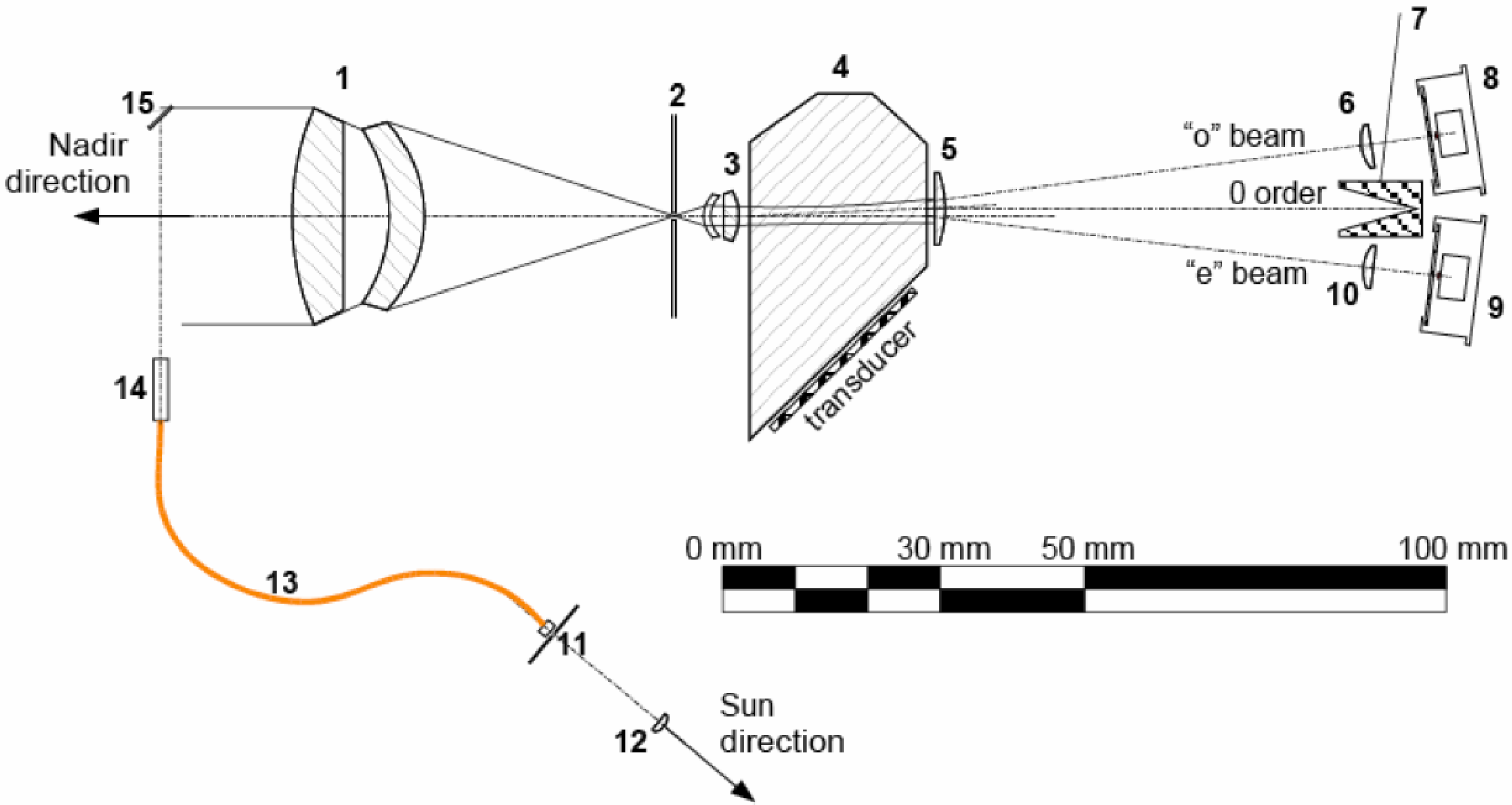
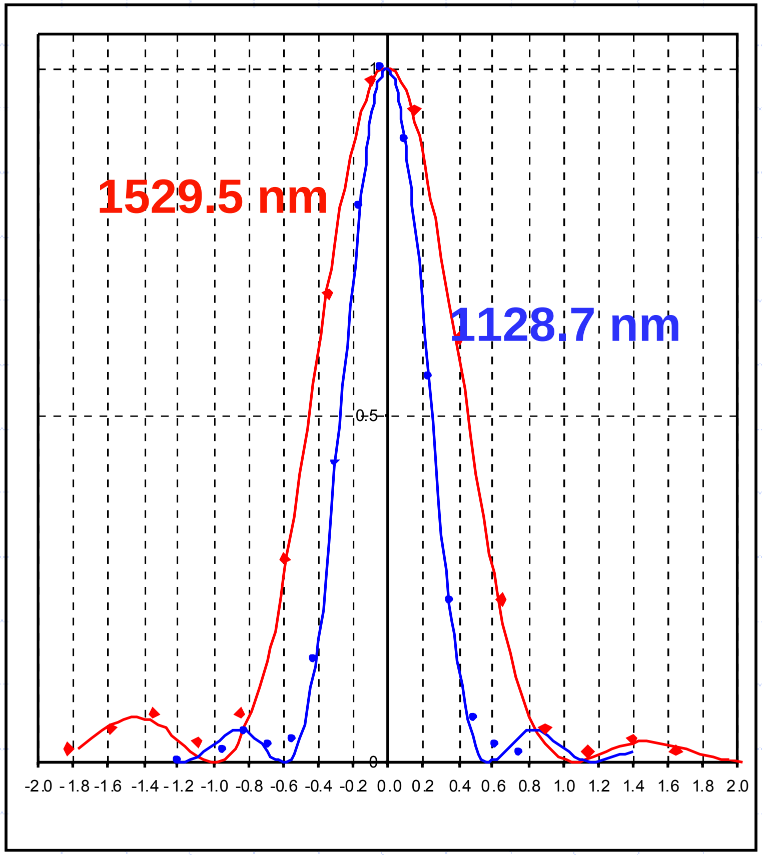


Figure 1. Optical scheme of the IR spectrometer. 1- front-end telescope objective; 2- FOV diaphragm; 3, 5 - collimator; 4- AOTF crystal with actuator; 6, 10- detector proximity lenses; 7 – zero order light trap; 8- detector "1" (ordinary), 9 – detector "2" (extraordinary); 11 – Sun aperture entry lens; 12 – Sun FOV diaphragm; 13- optical fiber; 14- collimating gradient lens; 15 – Sun entry folding mirror.

Wavelengths calibration and resolving power

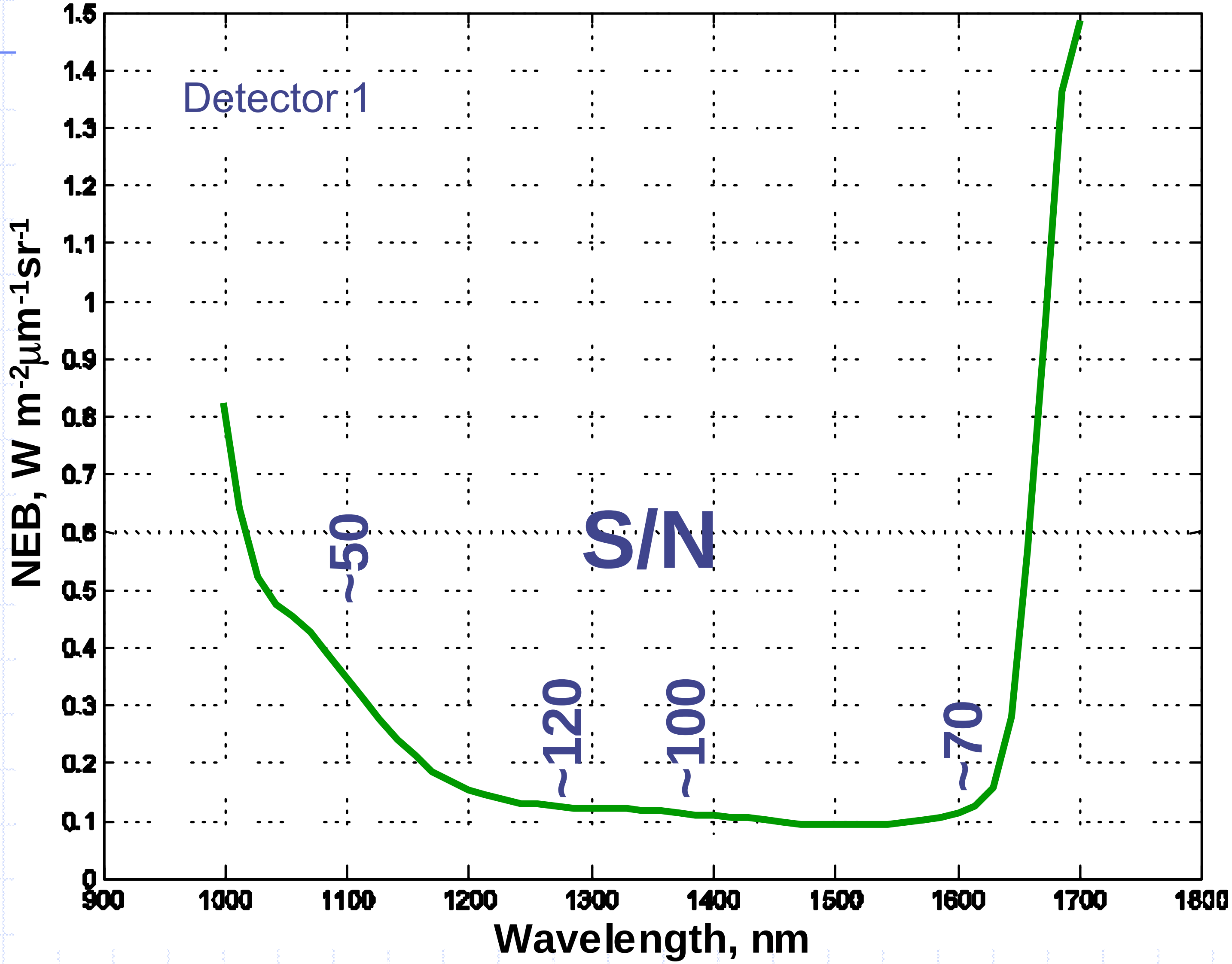
- $\lambda = a(1+\alpha T)/f + b(1+\beta T)$ accuracy ~0.1 nm
- $\alpha, \beta \sim 10^{-5}\ K^{-1}$

- 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

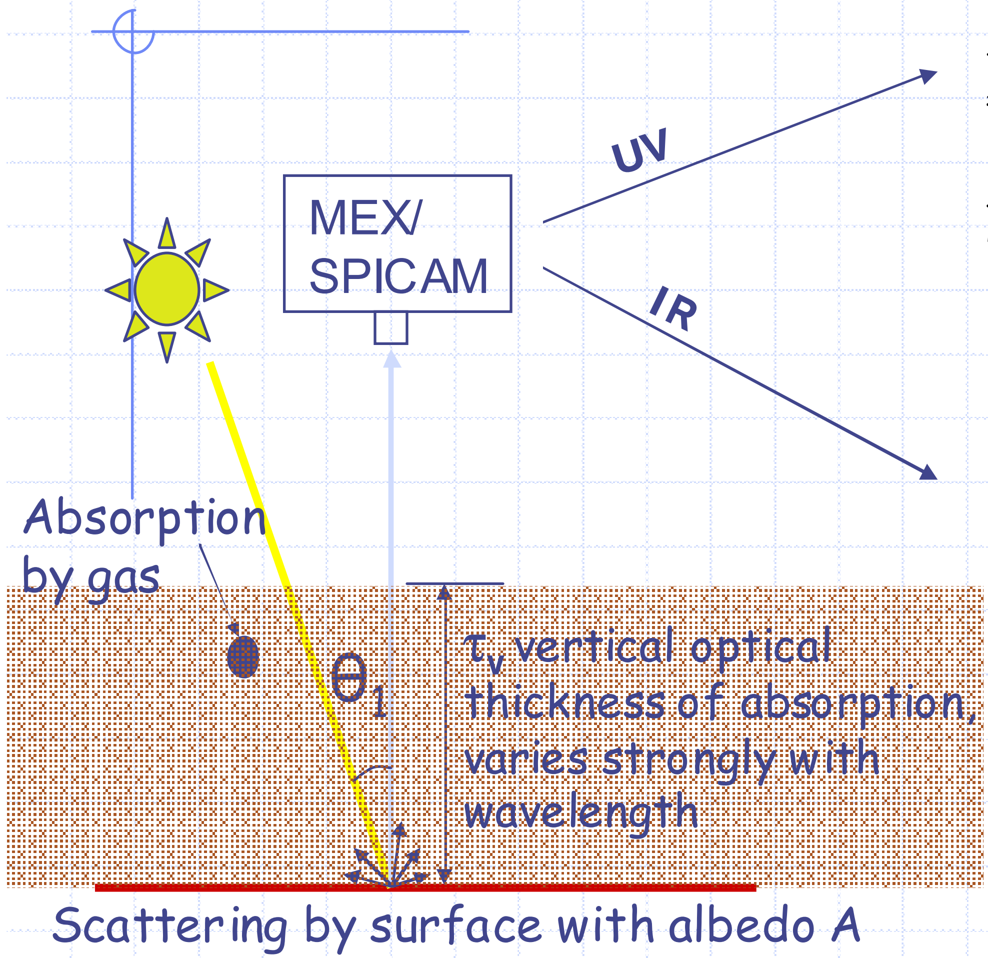


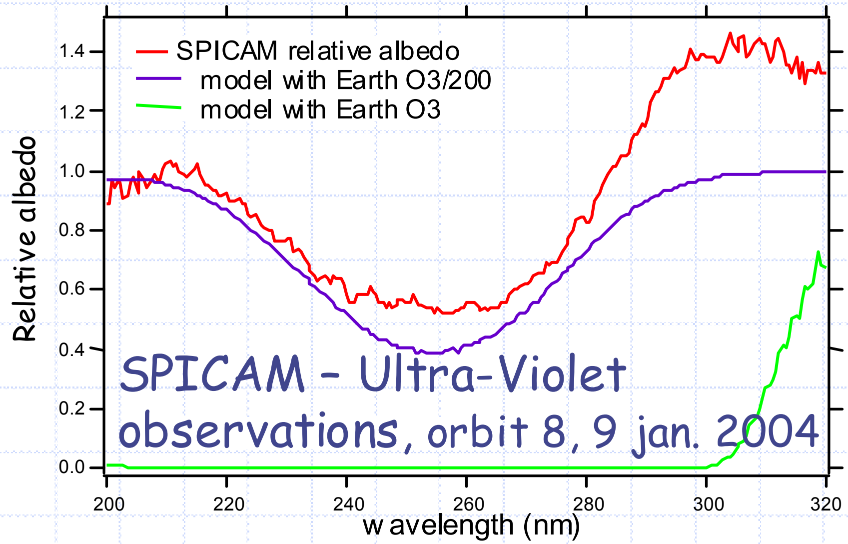
- $Sinc^2 \delta\lambda$ → tails

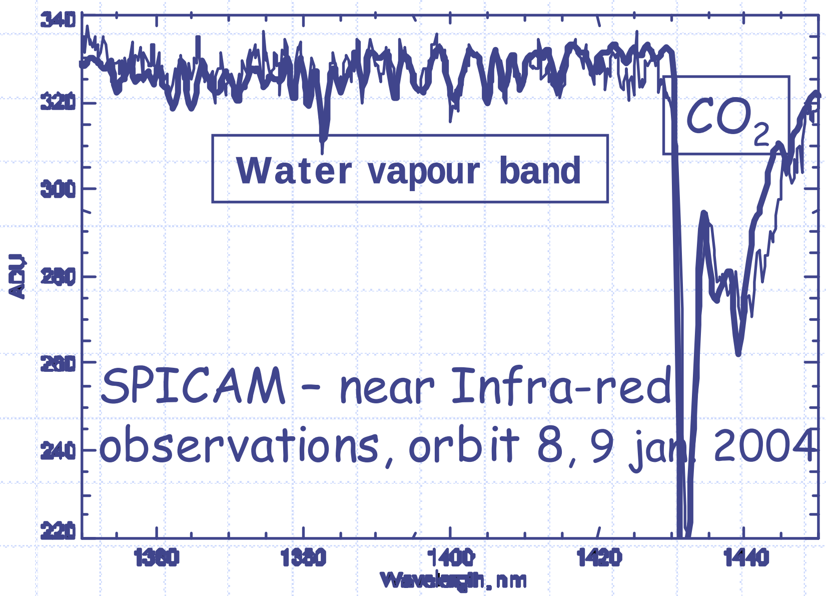
Noise Equivalent Brightness and S/N



MARS with SPICAM in Nadir

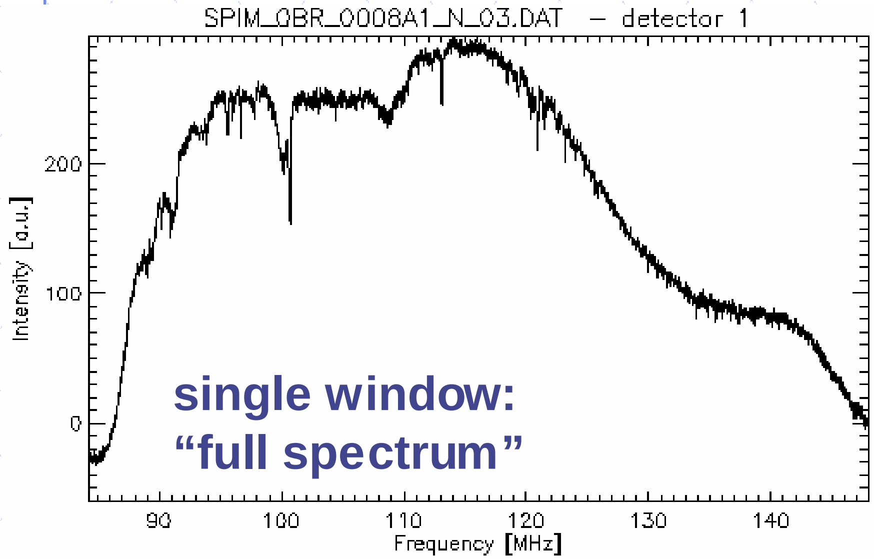


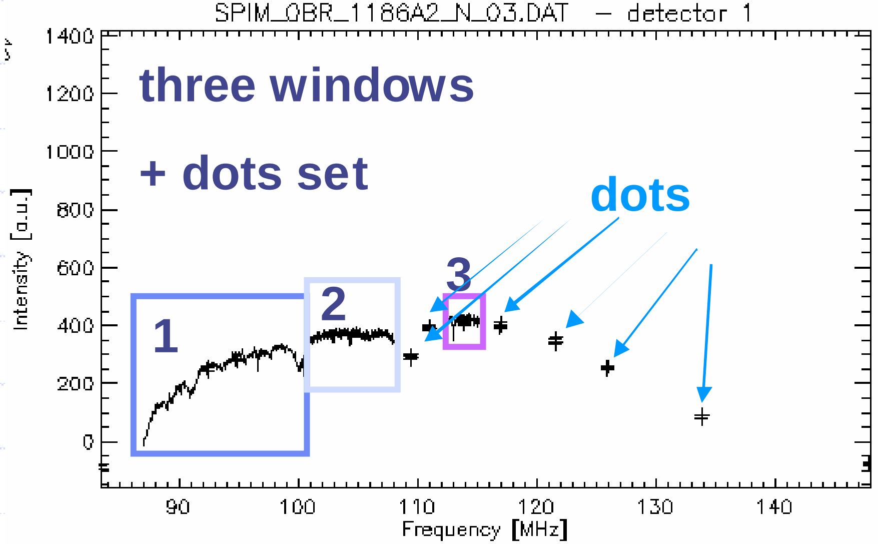




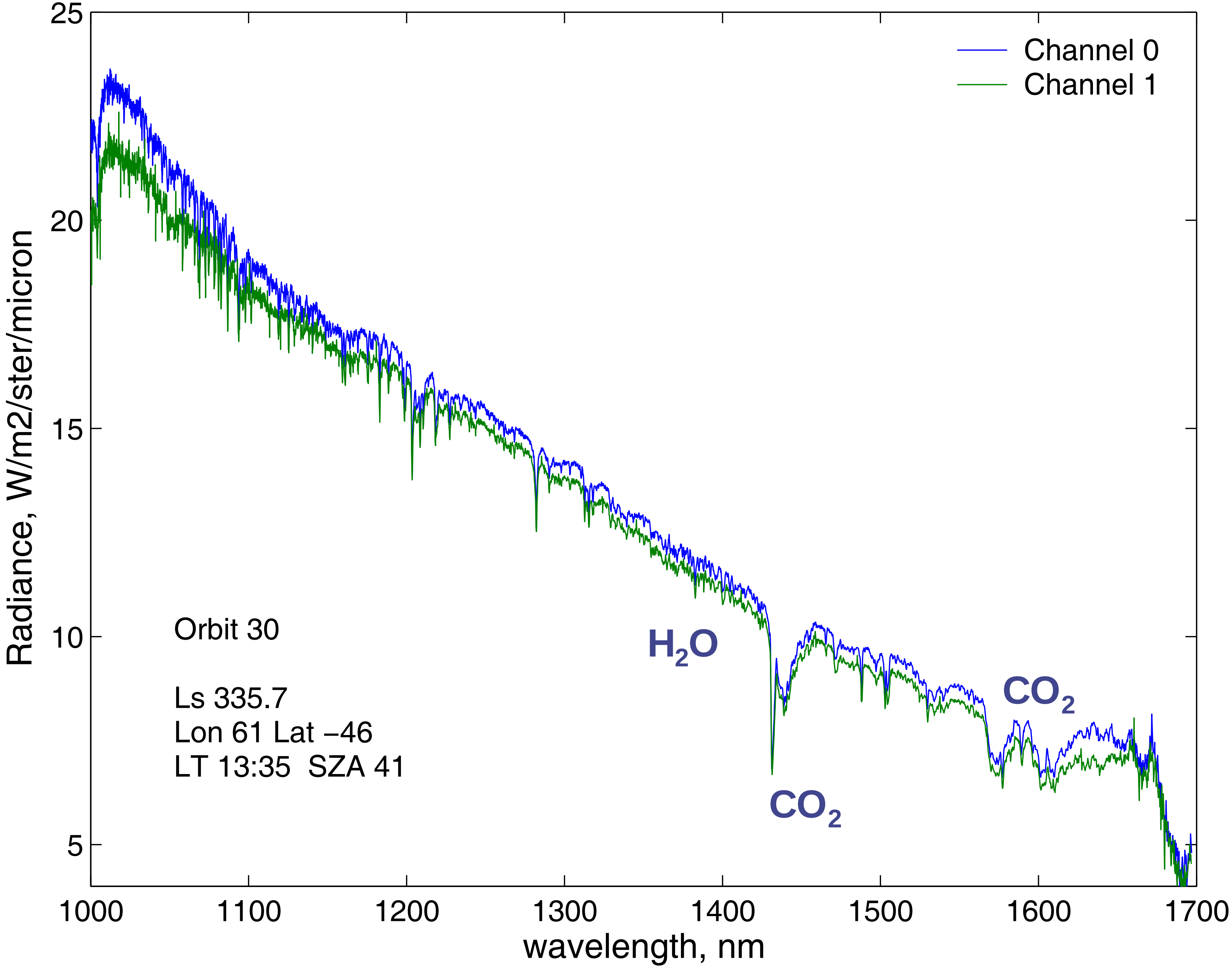
Modes of operation

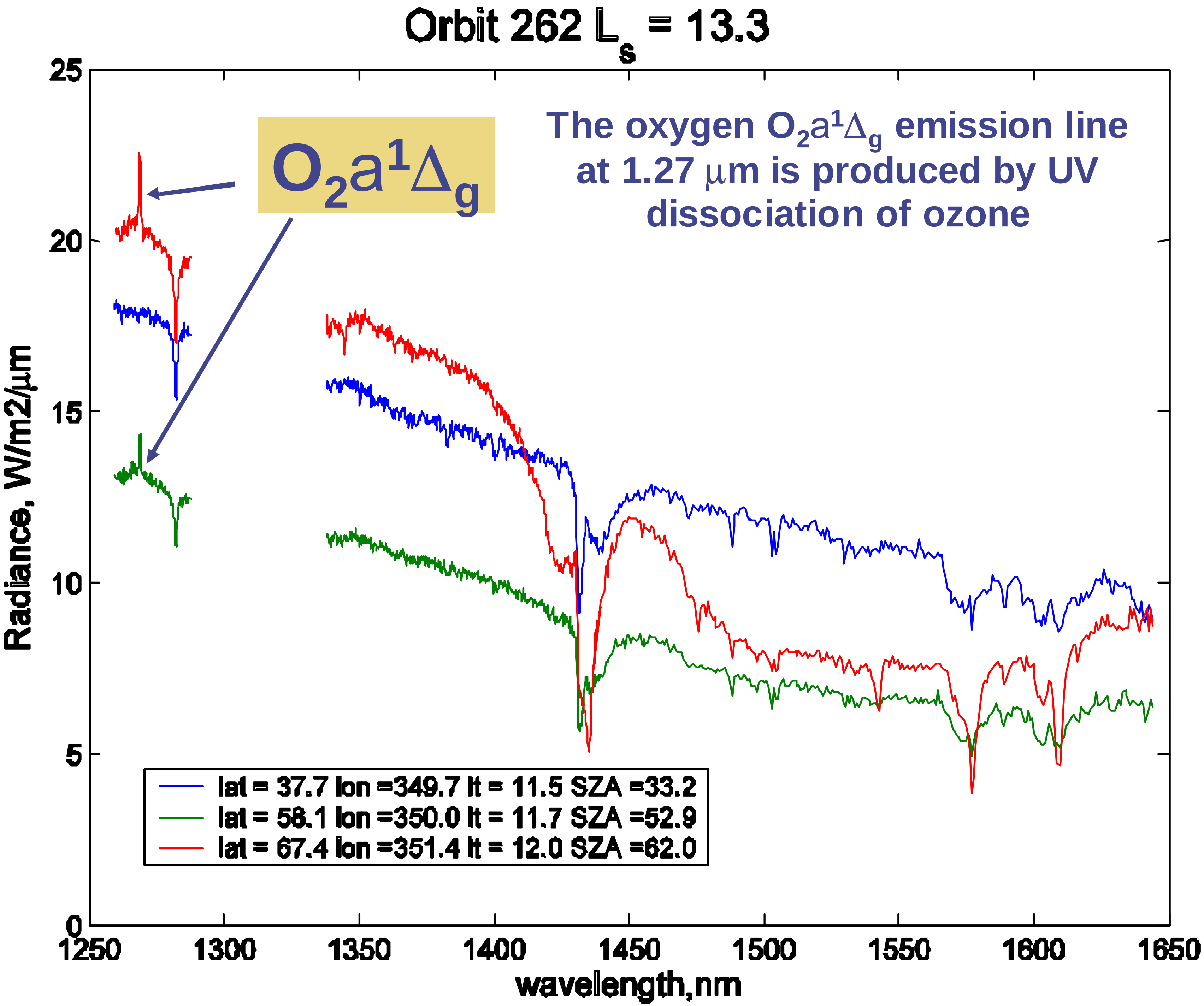
IR channel = 2 detectors (≠ polarization)
Spectra acquisition in 1, 2 or 3 "windows"
+ dots set (starting frequency, points, step)
max points = 3984, max acquisition time = 24s)
normally points = 664-1328, acquisition time = 2-4s



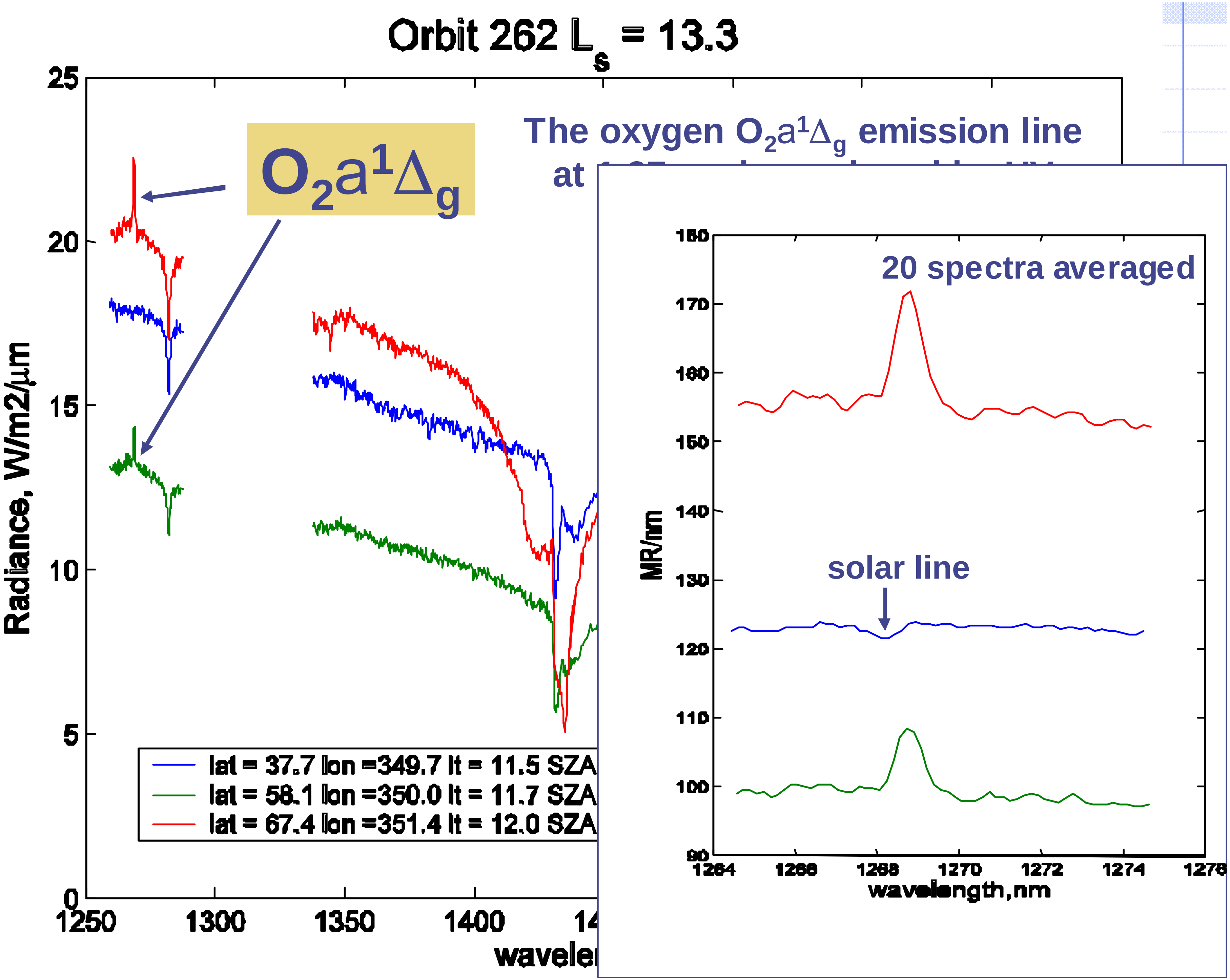


Calibrated SPICAM IR data



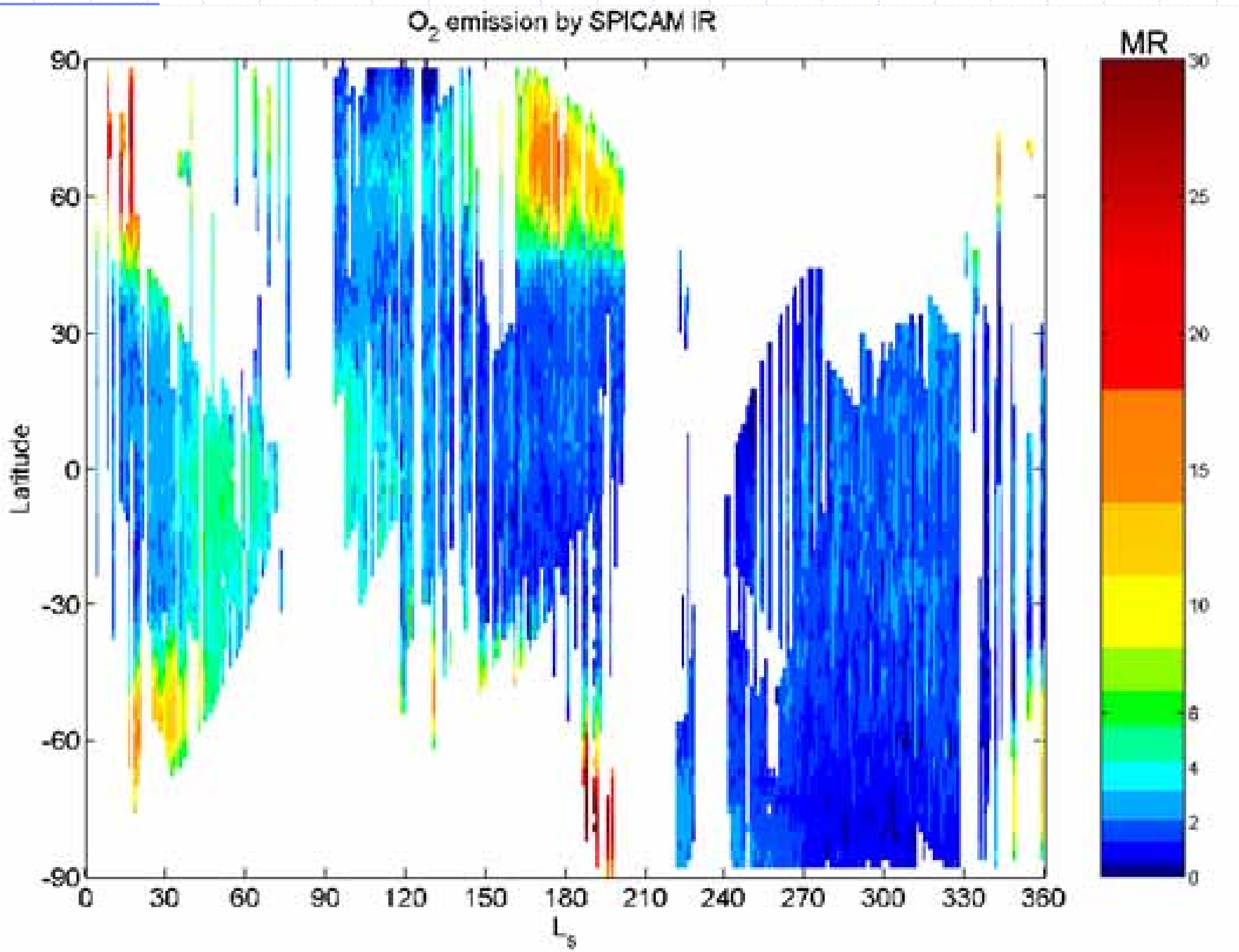


Orbit 262 L_s = 13.3
$O_2a^1\Delta_g$
The oxygen $O_2a^1\Delta_g$ emission line at 1.27 μm is produced by UV dissociation of ozone
Radiance, W/m2/μm
wavelength,nm
lat = 37.7 lon =349.7 lt = 11.5 SZA =33.2
lat = 58.1 lon =350.0 lt = 11.7 SZA =52.9
lat = 67.4 lon =351.4 lt = 12.0 SZA =62.0
0
5
10
15
20
25
1250
1300
1350
1400
1450
1500
1550
1600
1650

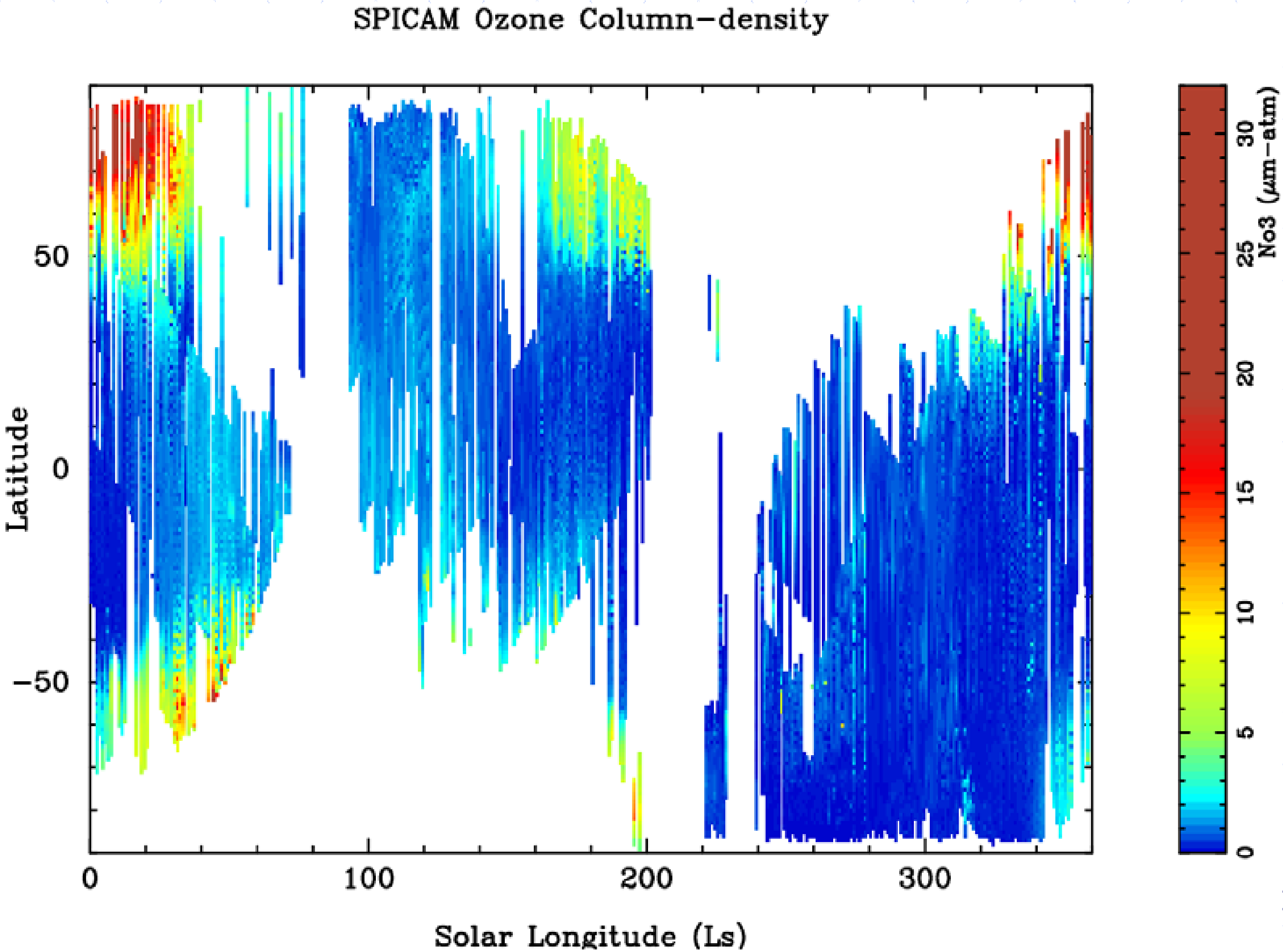


Orbit 262 L_s = 13.3
The oxygen $O_2a^1\Delta_g$ emission line
at
$O_2a^1\Delta_g$
Radiance, W/m2/µm
25
20
15
10
5
0
1250
1300
1350
1400
wavele
lat = 37.7 lon =349.7 lt = 11.5 SZA
lat = 58.1 lon =350.0 lt = 11.7 SZA
lat = 67.4 lon =351.4 lt = 12.0 SZA
20 spectra averaged
solar line
MR/nm
180
170
160
150
140
130
120
110
100
90
1264
1266
1268
1270
1272
1274
1276
wavelength,nm

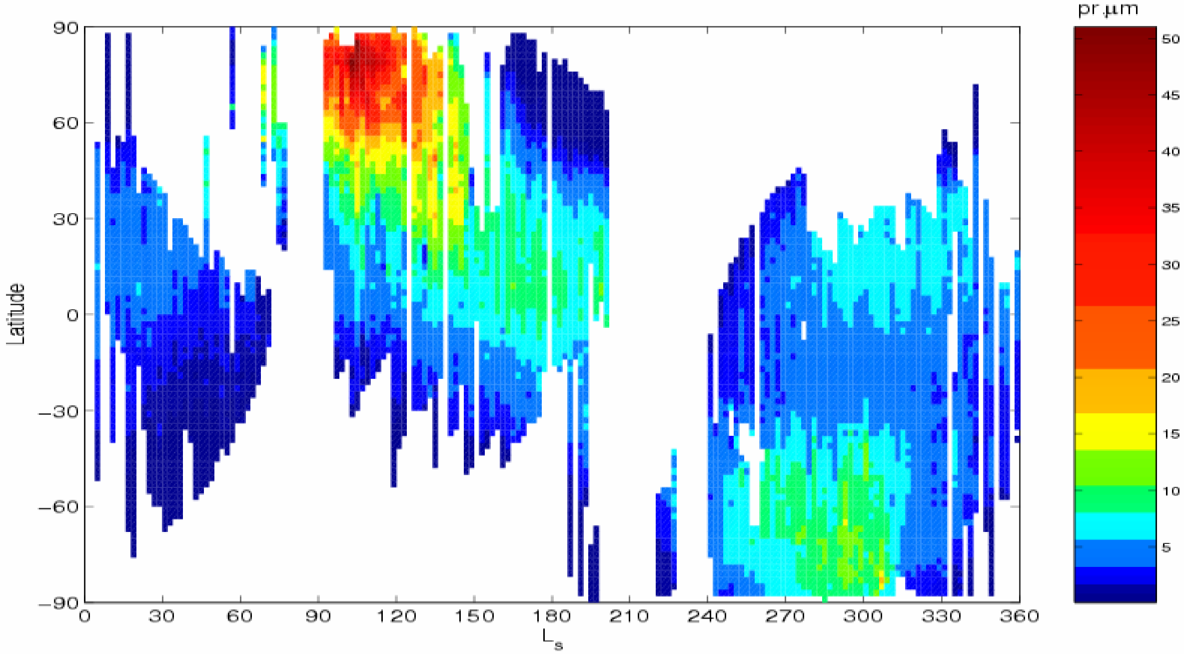
Seasonal map of O_2 emission by SPICAM



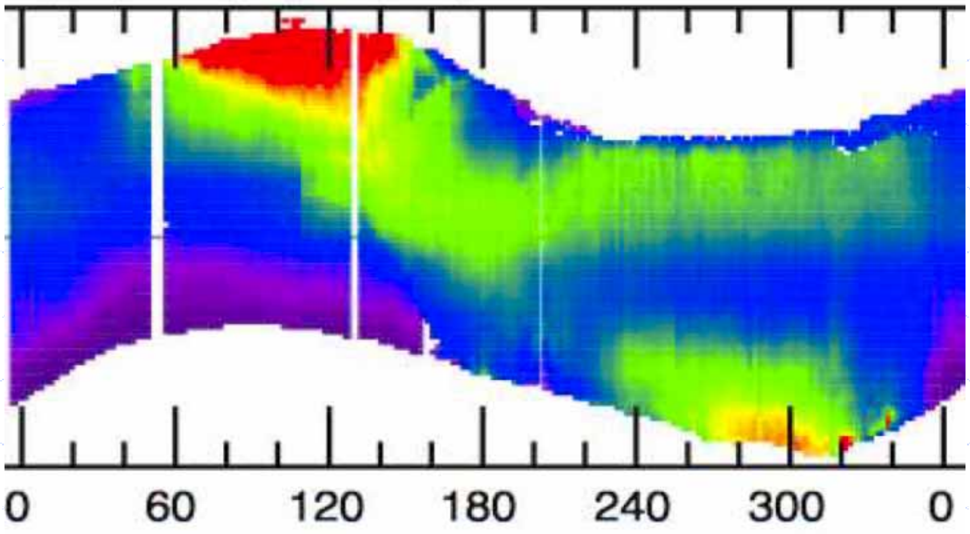
Seasonal map of Ozone by SPICAM



H_2O seasonal distribution on MARS
SPICAM vs TES



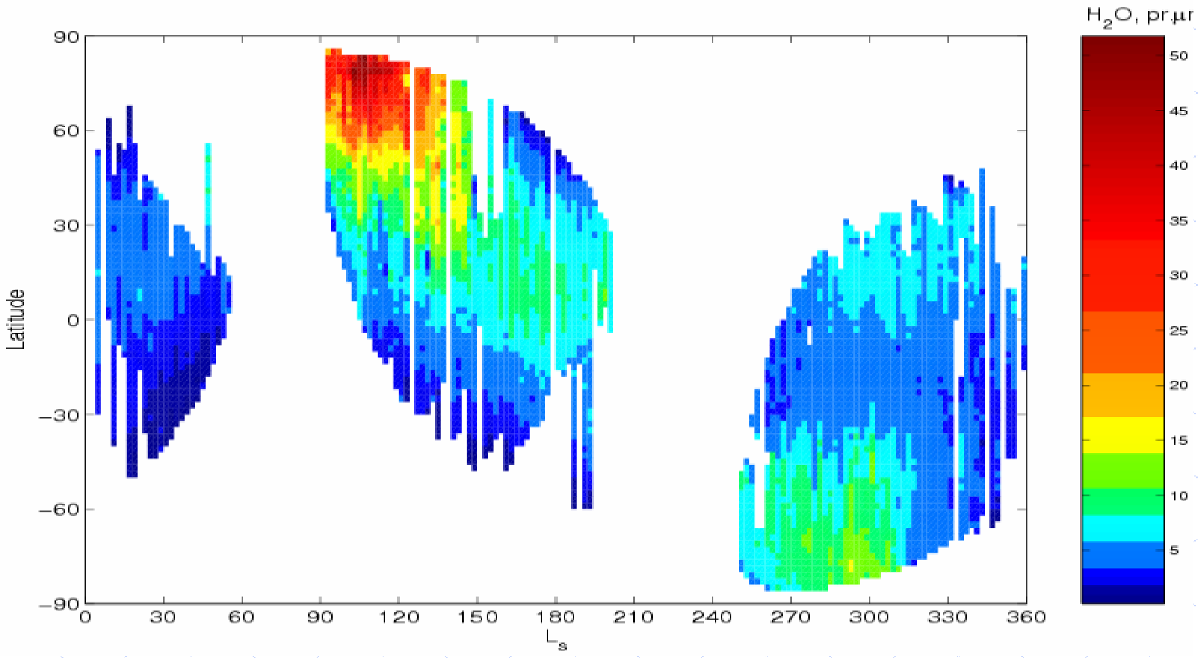
SPICAM MY27



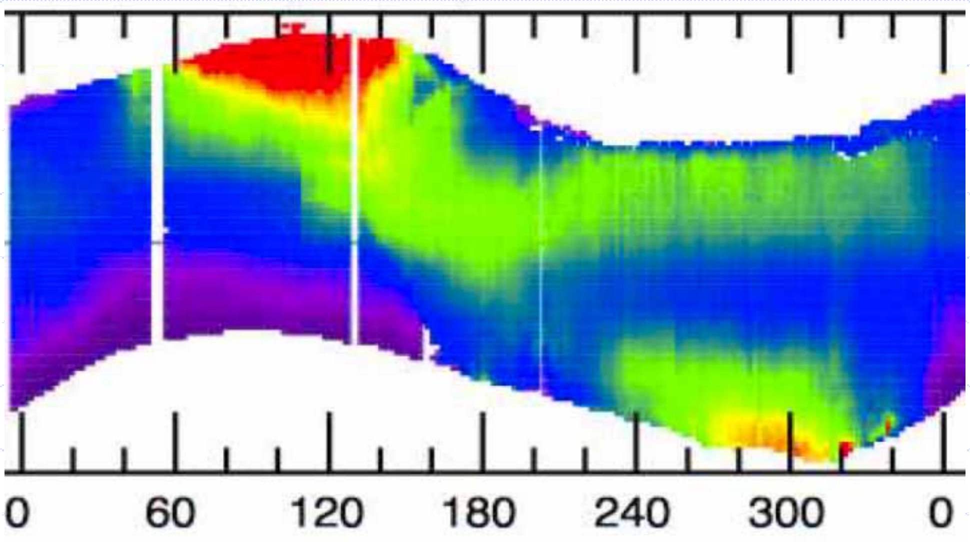
TES MY26

Scale 0 to 50 pr. µm

H_2O seasonal distribution on MARS SPICAM vs TES



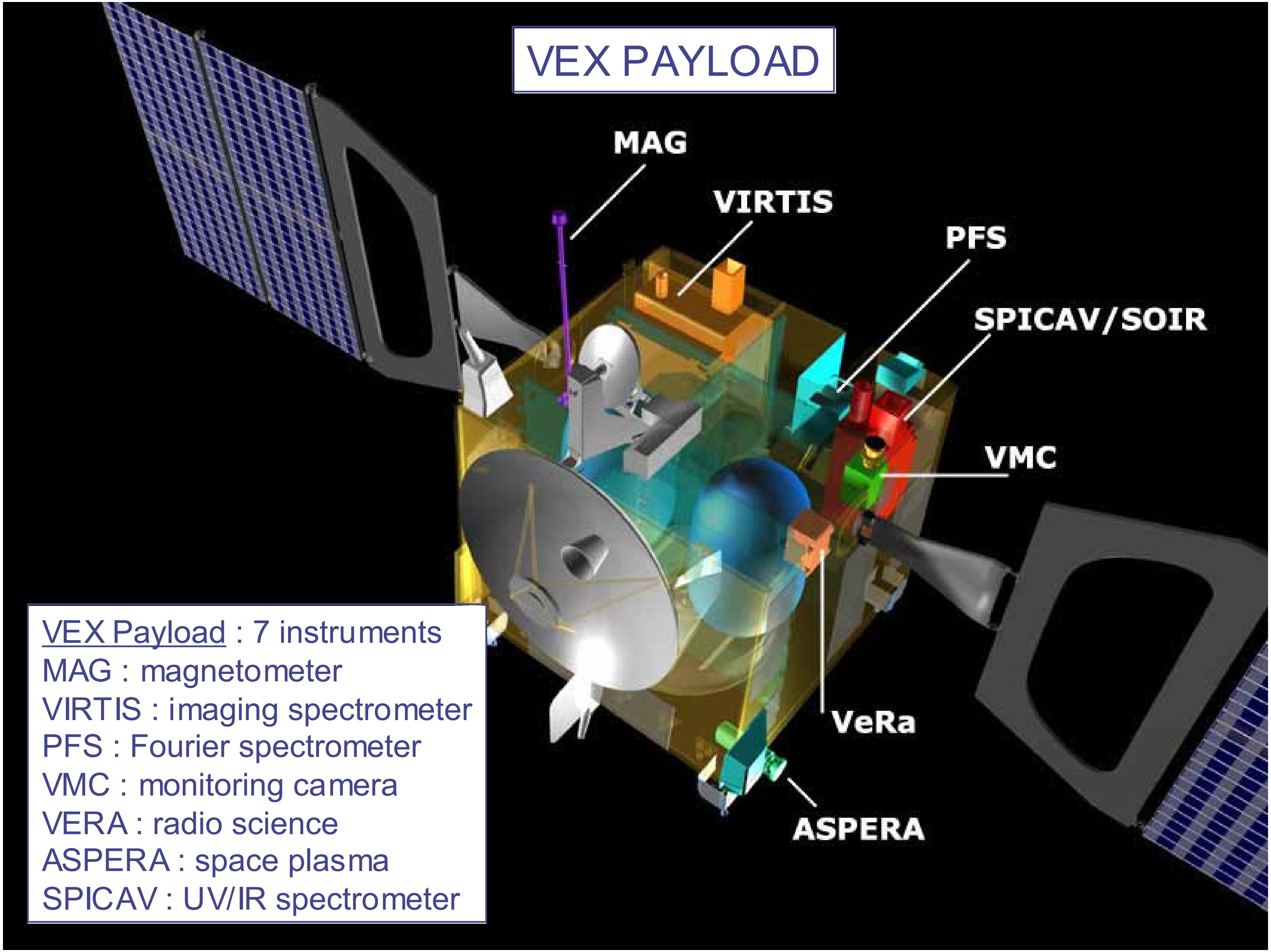
SPICAM MY27



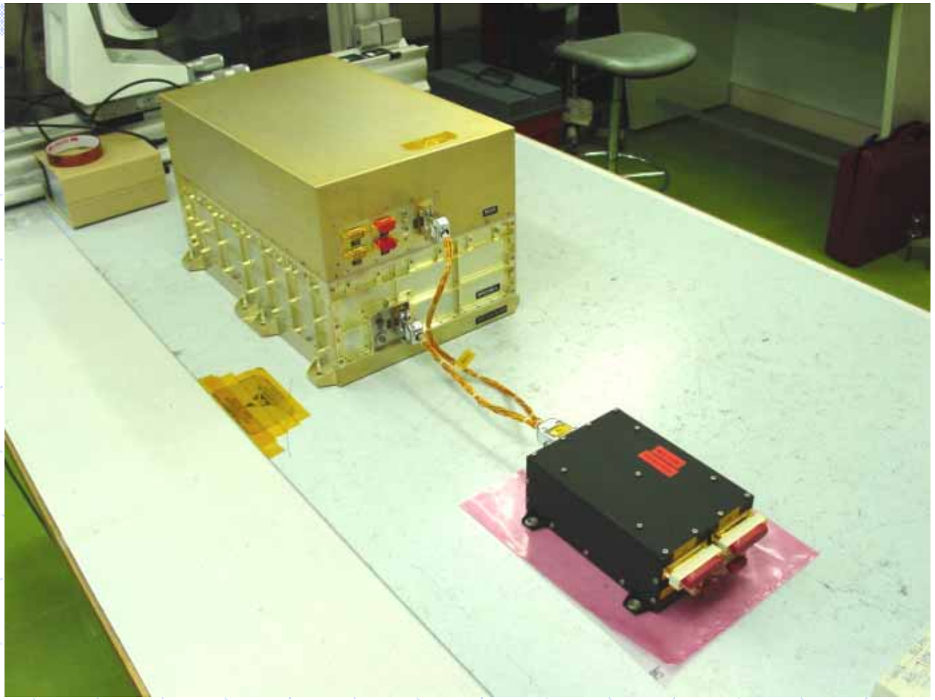
TES MY26

Scale 0 to 50 pr. μm

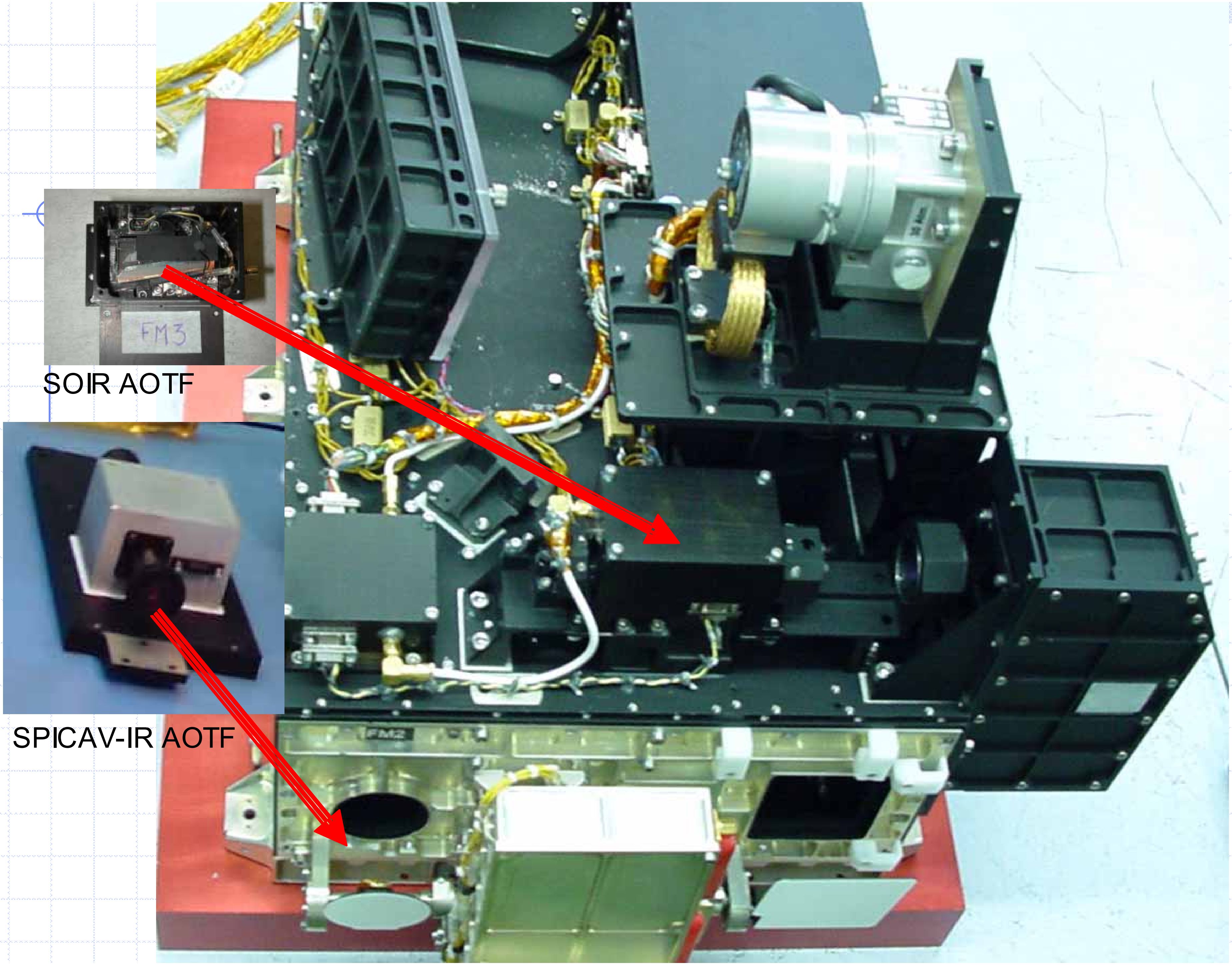
THE SPICAV-SOIR INSTRUMENT


VEX PAYLOAD
MAG
VIRTIS
PFS
SPICAV/SOIR
VMC
VeRa
ASPERA
VEX Payload : 7 instruments
MAG : magnetometer
VIRTIS : imaging spectrometer
PFS : Fourier spectrometer
VMC : monitoring camera
VERA : radio science
ASPERA : space plasma
SPICAV : UV/IR spectrometer

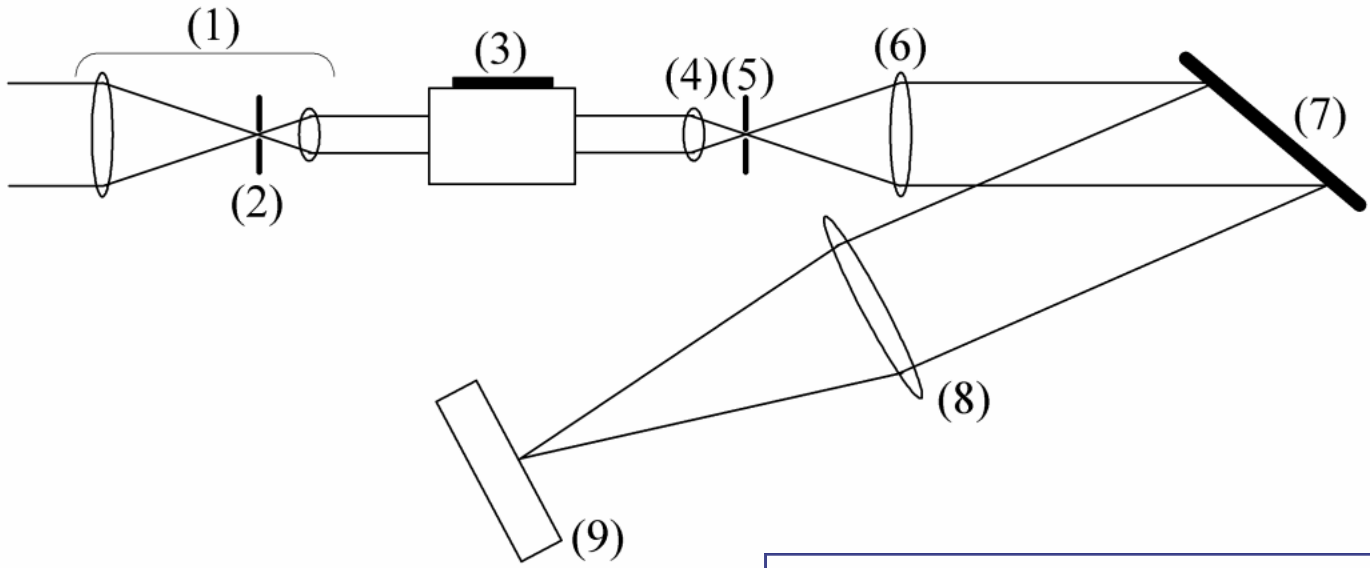
SPICAV/SOIR



- SPICAV-UV
  - Spare of SPICAM-UV
  - Made in France
- SPICAV-IR (AOTF)
  - Modified from SPICAM-IR
  - Made in Russia
- SOIR (with AOTF)
  - Completely new instrument built in two years
  - High spectral resolution: echelle grating+AOTF
  - Built in Belgium with Russian AOTF
- DPU: electronic block


SOIR AOTF
FM3
SPICAV-IR AOTF
FM2

SOIR : SPECTROMETER SCHEME (1)



Front end optics

(1) AOTF entrance optic
→reduces Ø incoming light beam
→to match acceptance aperture of AOTF

(2) diaphragm
→ confines FOV
→ to avoid parasitic light effects

(3) AOTF
→order sorting filter

(4) AOTF exit optics
→ images beam on spectrometer slit

Spectrometer part

(5) spectrometer slit
→ entrance aperture of spectro

(6) collimating lens
→ collimates to parallel beam

(7) echelle grating
→ disperses light

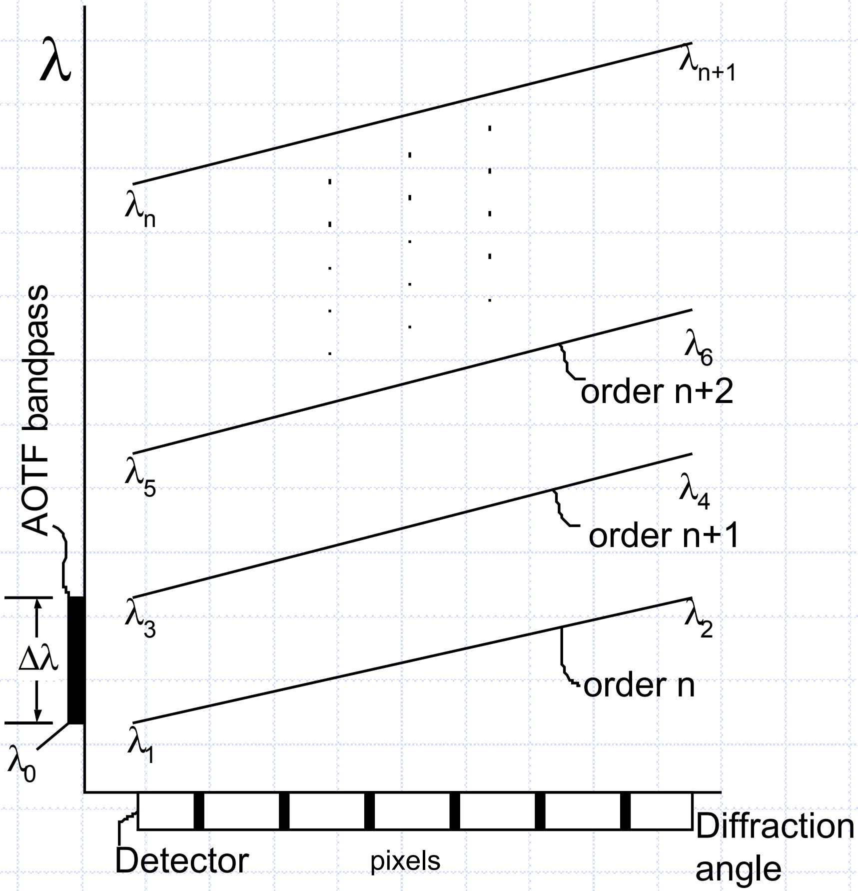
Detector part

(8) camera lens
→ images spectrum to detector

(9) detector

Echelle-spectrometer
The principle of separation of diffraction orders

- divide wavelength domain in small parts
- observe sequentially or at random
- echelle : higher resolution and dispersion
- echelle : orders overlap
→ order sorting



SOIR : OPTICAL DESIGN (3)

choice of design parameters
→ guarantees quasi-continuous coverage in mid IR
→ allows a wavelength to be associated to every pixel

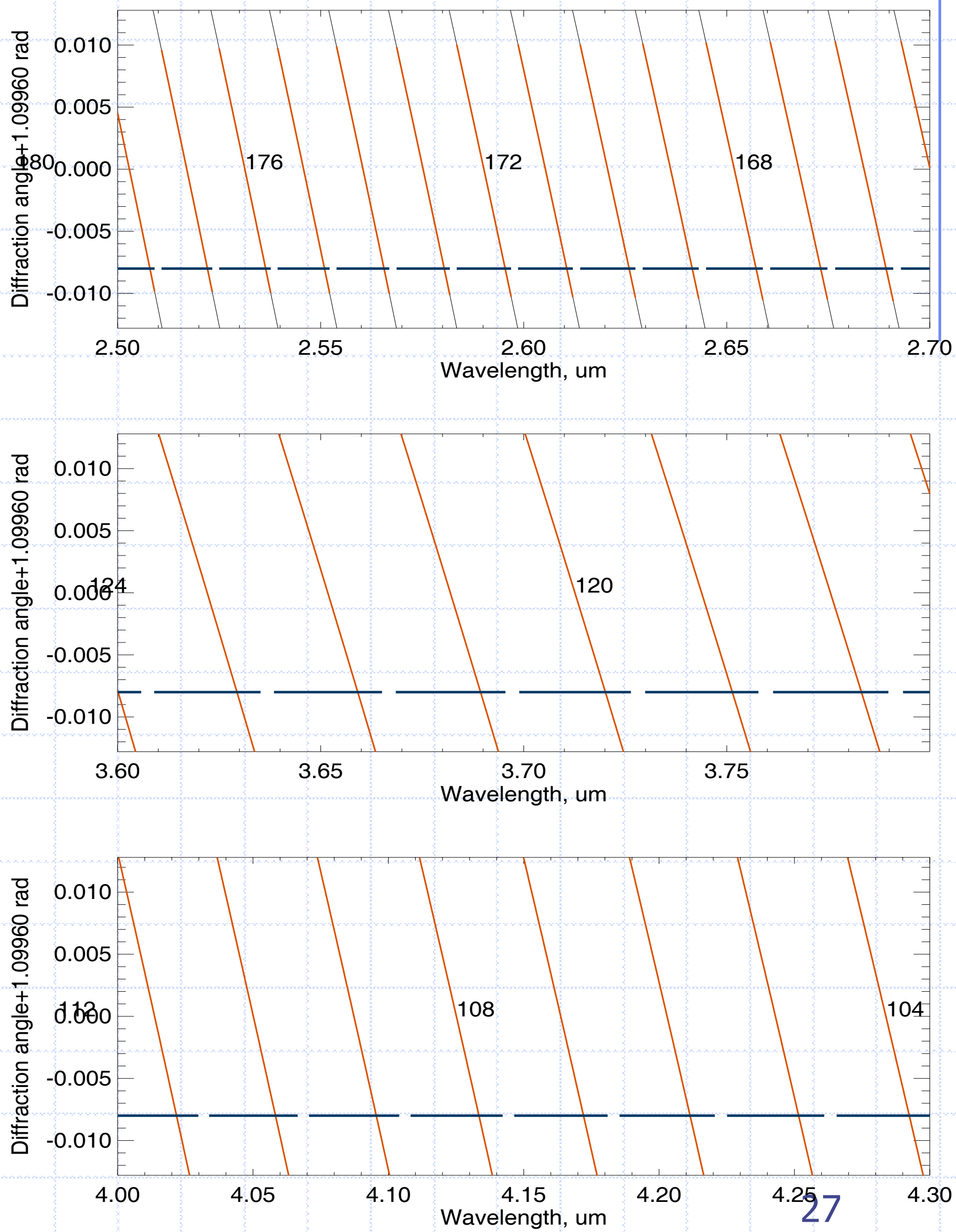
Figure
red lines represent grating diffraction angles (orders 101 till 194)

numbers are diffraction order number

black traces are overlapping parts

blue intervals correspond to AOTF bandpass (20 cm^{-1}) resulting in (nearly perfect) order sorting

full vertical scale gives the angular width of a 320 pixel detector



SOIR

Solar Occultation InfraRed

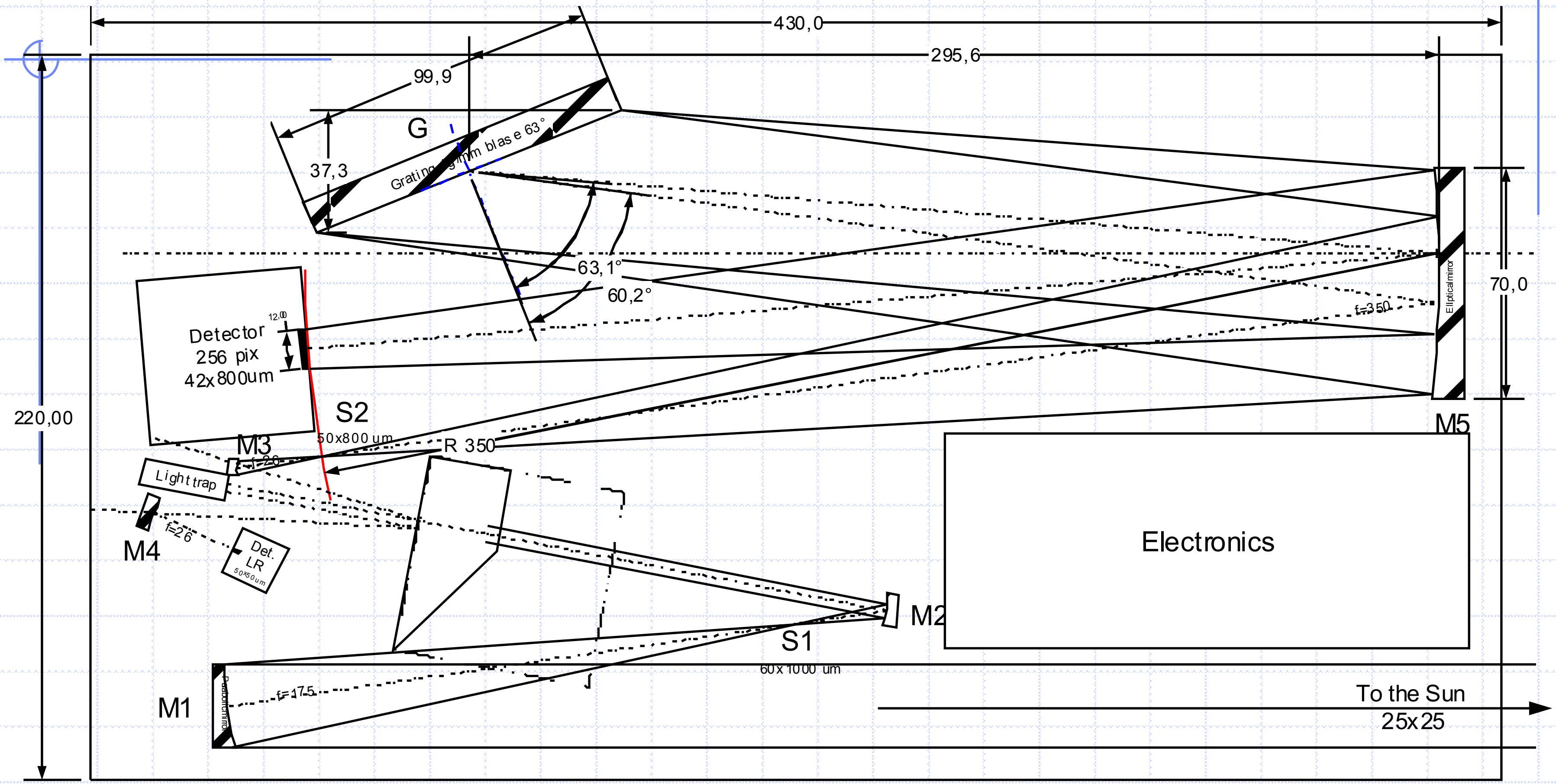
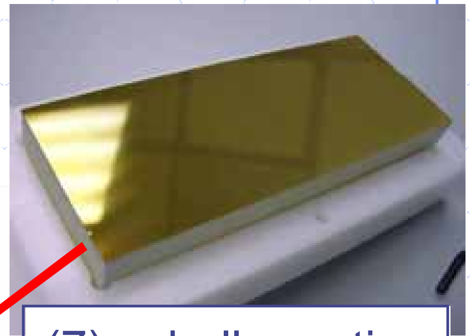


Figure 3. Layout of the high-resolution solar occultation spectrometer. M1 (off-axis parab. f=175) – entrance telescope; S1 – field diaphragm; AOTF; M2, M3, M4 (f=26) – AOTF collimator; light trap; LR detector; S2 – HR spectrometer slit; M5 (off-ax. parab., f=350) – HR spectrometer collimator; G – HR spectrometer grating; HR detector.

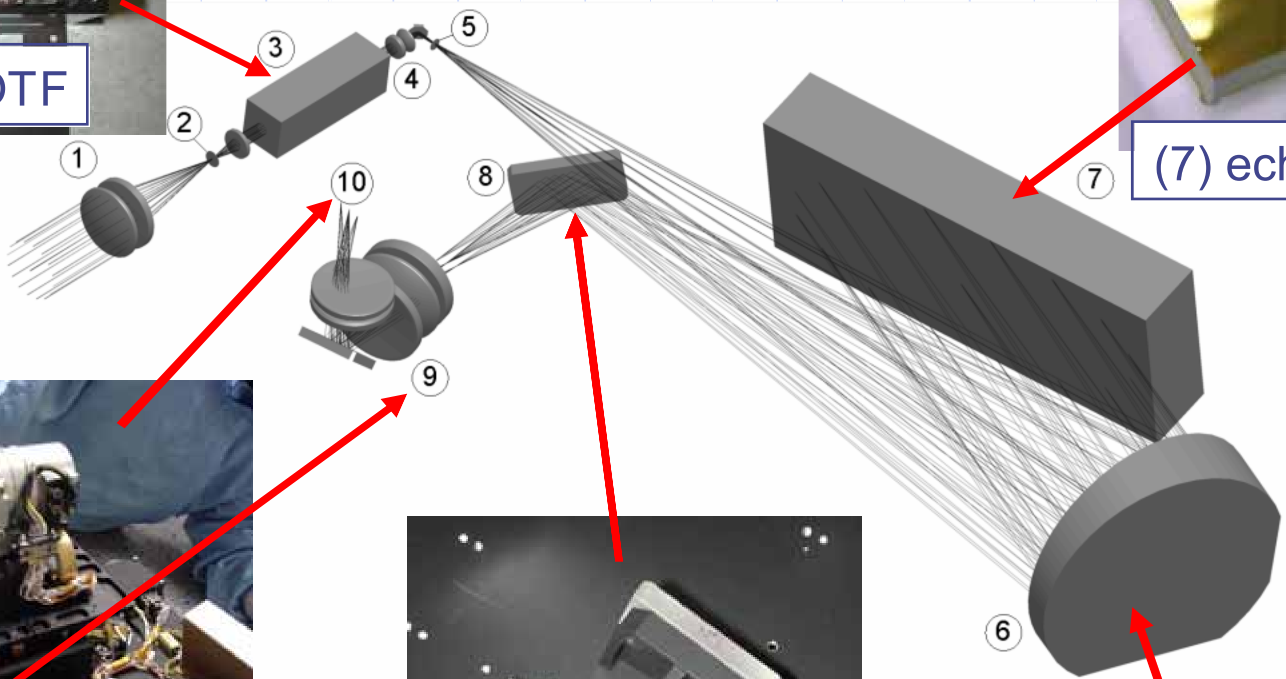
SOIR : SPECTROMETER SCHEME (2)

compacting exercise

(3) AOTF

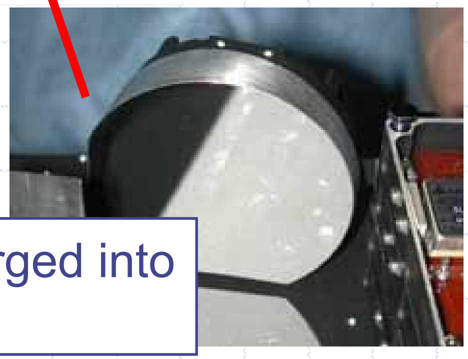


(7) echelle grating

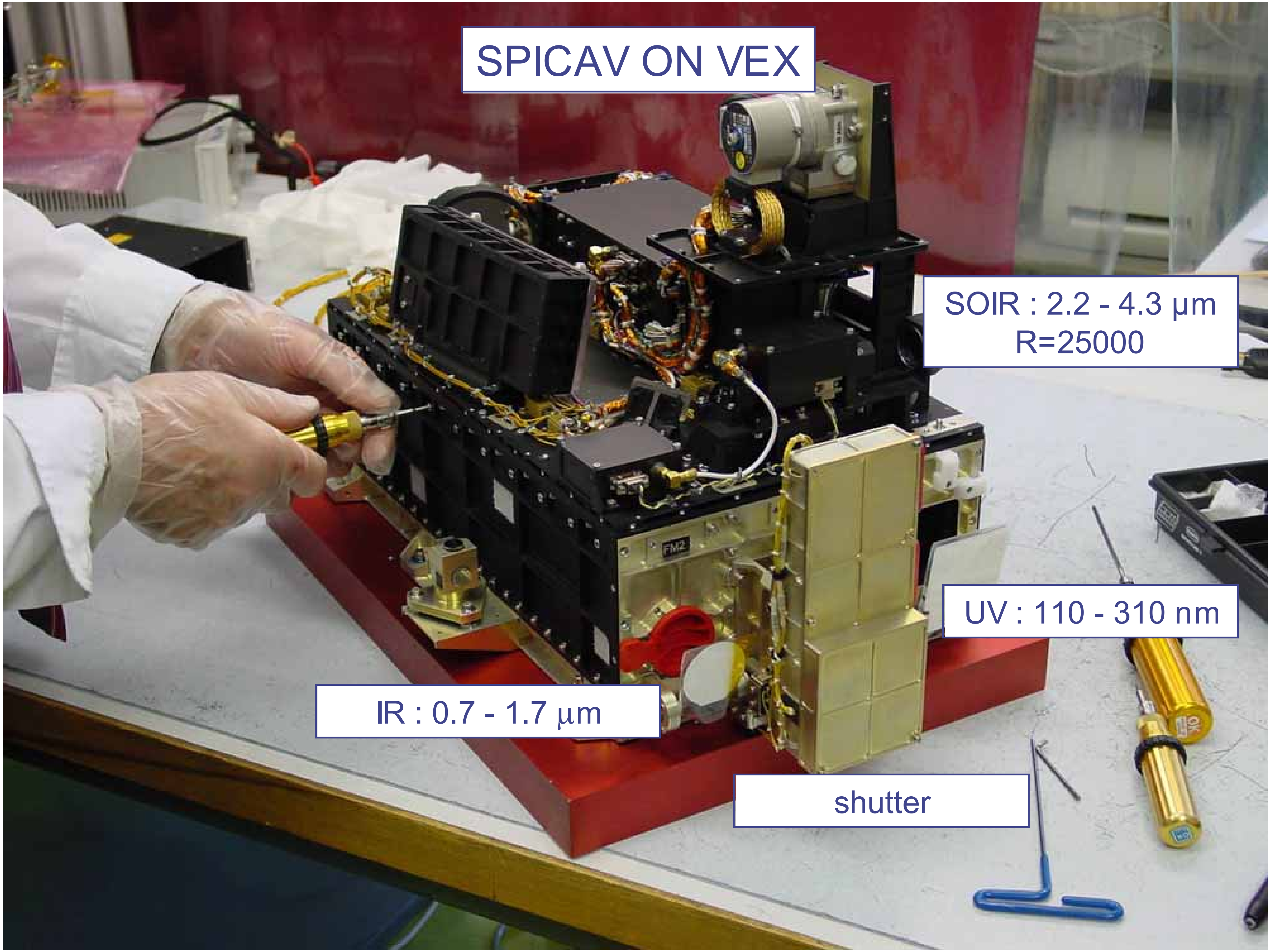


(9) folded detector optics
(10) detector assembly placed upright

(8) folding mirror



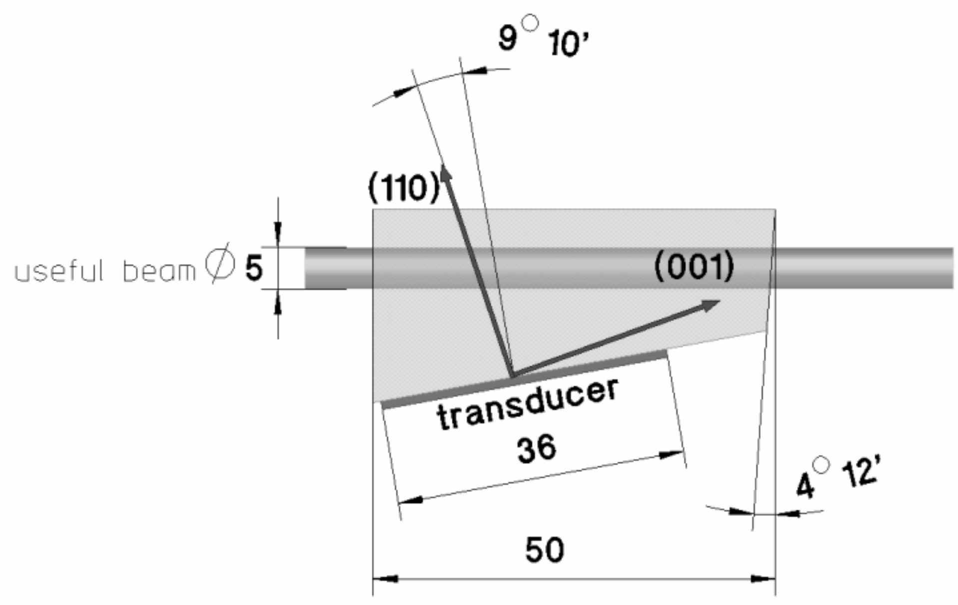
(6) collimating and camera lens merged into one off-axis parabolic mirror

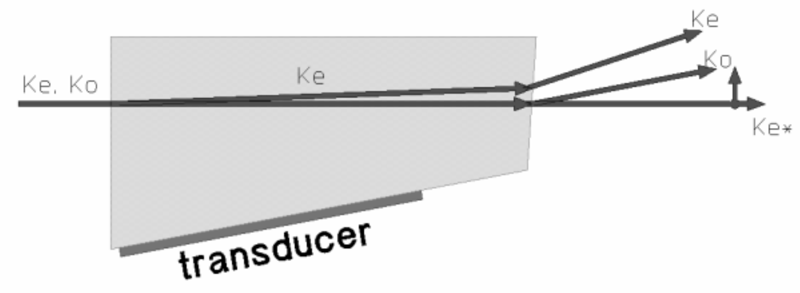

SPICAV ON VEX
SOIR : 2.2 - 4.3 µm
R=25000
UV : 110 - 310 nm
IR : 0.7 - 1.7 µm
shutter
FM2

SOIR/VEX summary

- Features
  - resolving power R=25000 in spectral range 2.35-4.2 μm
  - relatively compact design (~5 kg)
  - no moving parts (except cryocooler)
  - Spectral range with “methane on Mars” potential
- Limitations
  - Solar occultation operations
  - Only a small portion of spectrum at a time

SOIR : AOTF

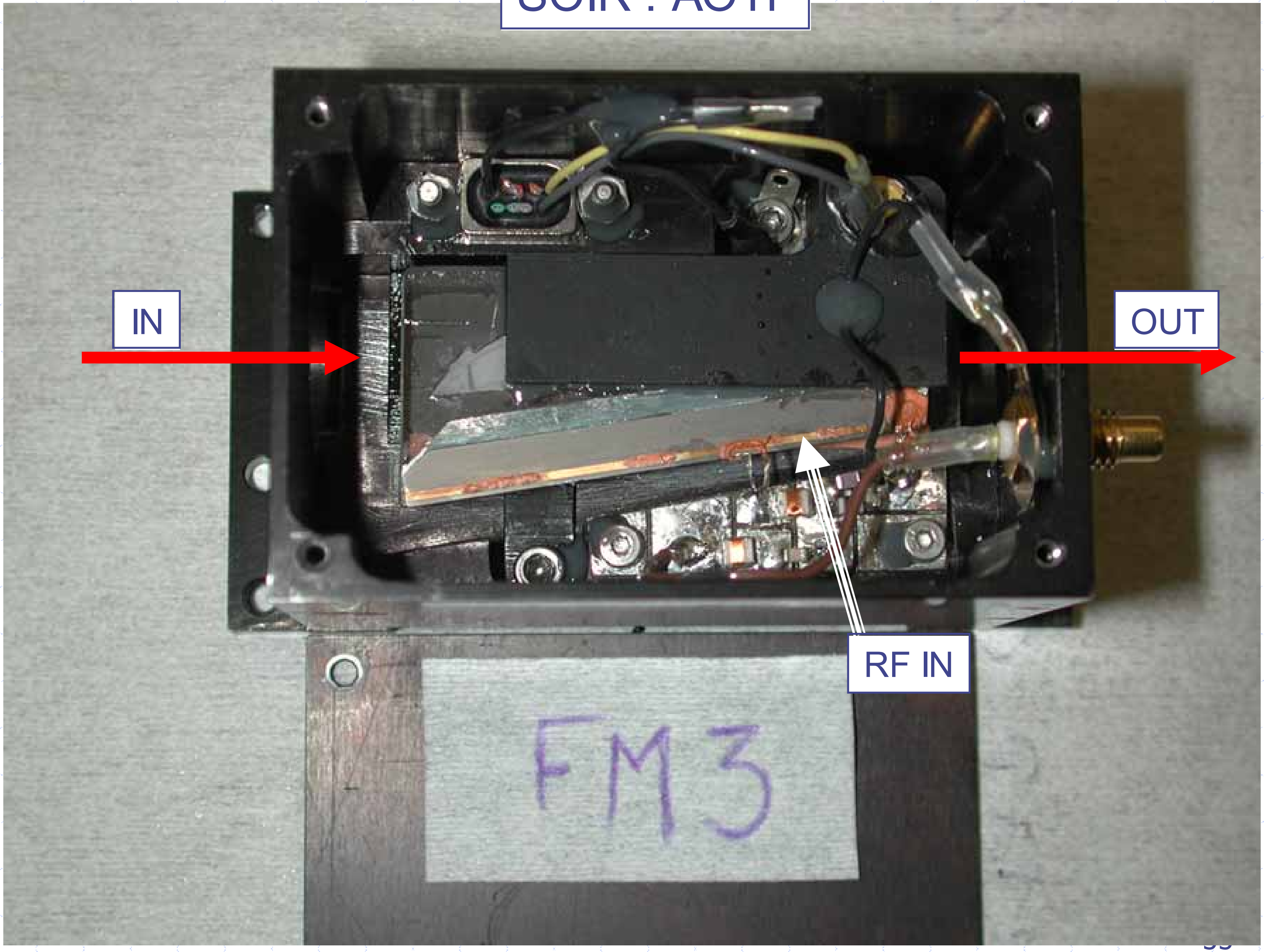




Working principle

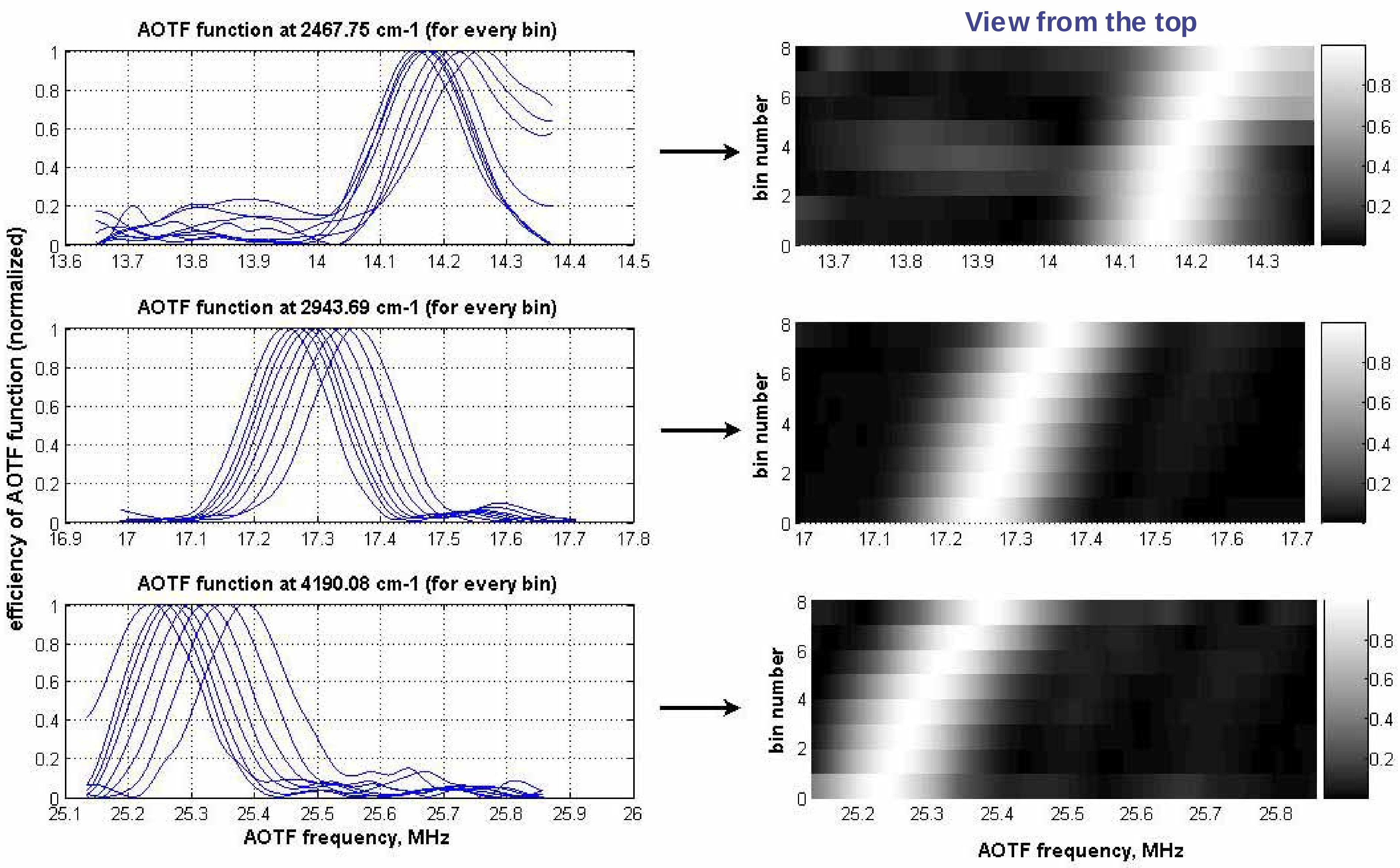
- interaction light beam and acoustic wave → small wavelength domain transmitted
- acoustic RF wave injected via transducer (001-direction)
- transmitted wavelength = electronically tunable
- non-polarized light beam in → 2 diffracted beams out with different polarization
  → small angle between diffracted and undiffracted
- inclined output facet → correction for angular shift caused by Bragg diffraction and polarization rotation
  → refolding of diffracted beam collinear with incoming beam

SOIR : AOTF

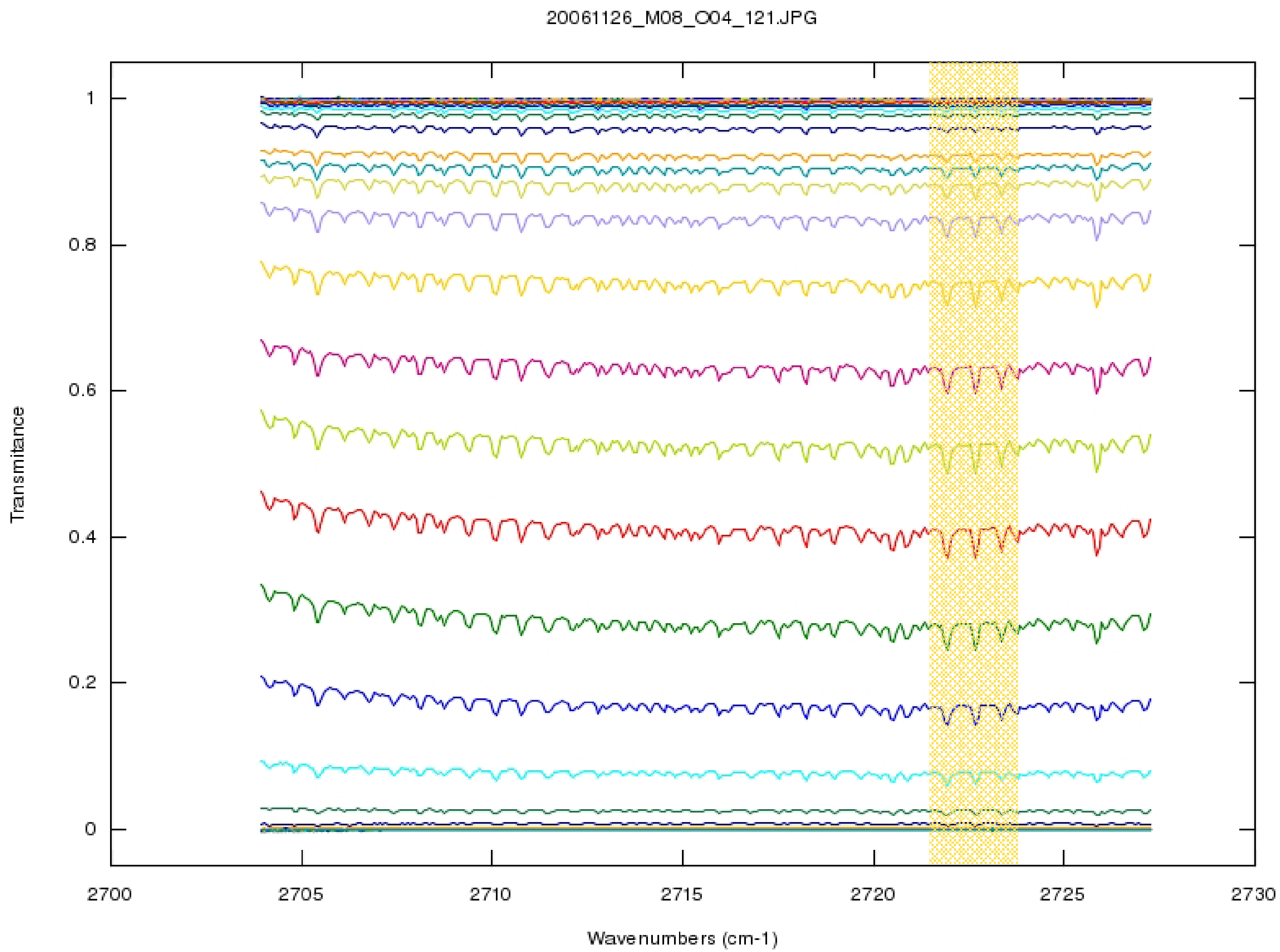


SOIR: in-flight calibration of AOTF bandwidth (orbit 142)

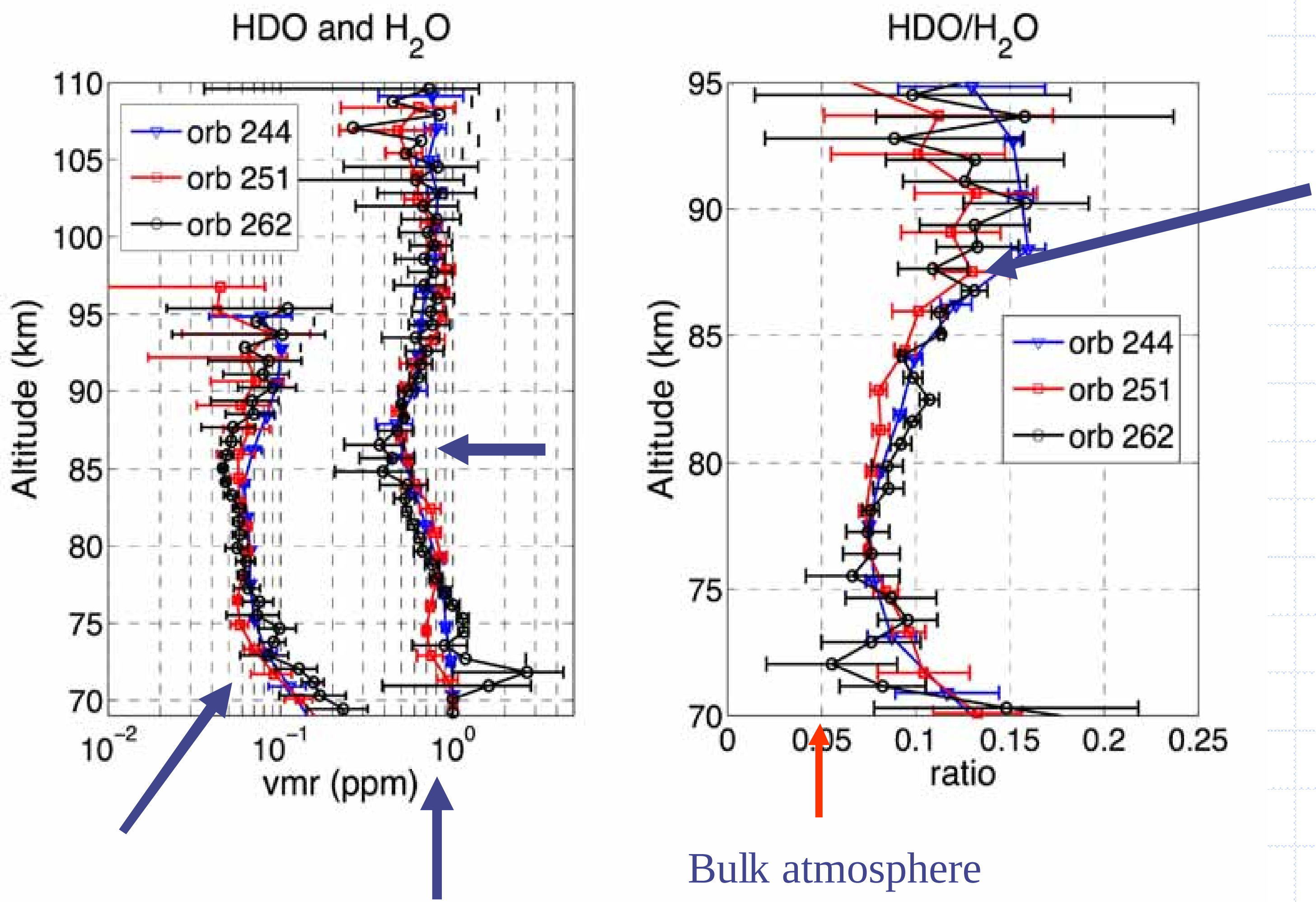
AOTF functions at different wavenumbers and different points of acoustic field



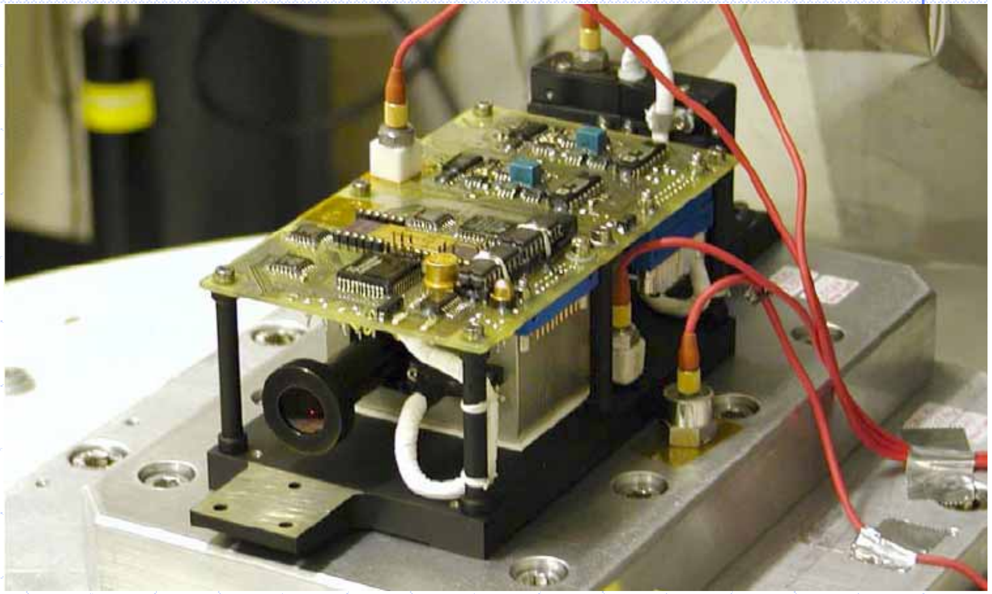
HDO detection by SOIR solar occultation



VENUS H_2O and HDO at 3 orbits, 75° N at terminator (solar occultation)

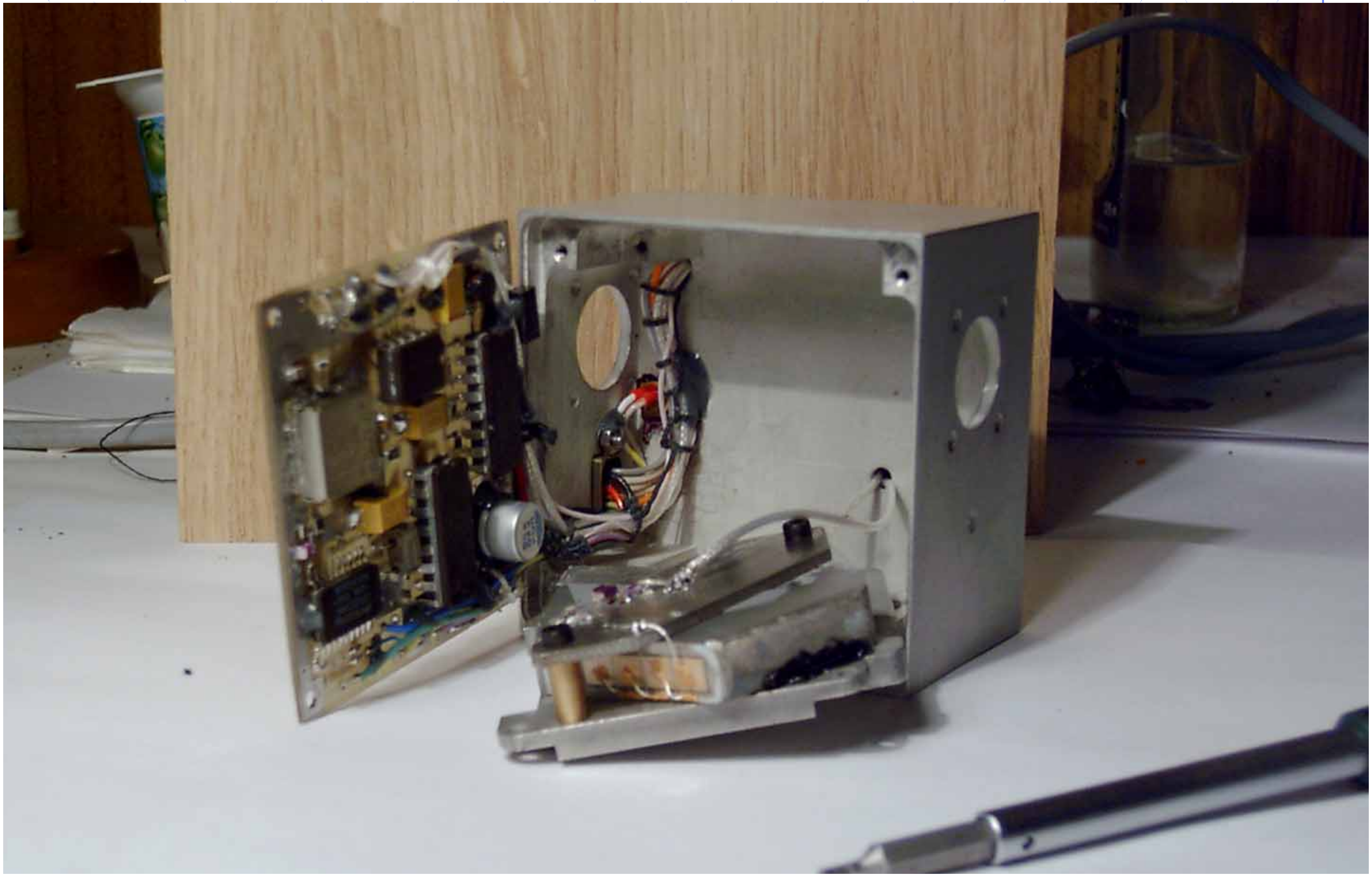


SPICAV AOTF



- Serious modification from MARS EXPRESS version
- Extended spectral range (0.7-1.7 µm)
  - 2 actuators on the AOTF
  - New detectors (Si-InGaAs sandwich detectors)
- Increased sensitivity
  - New registration electronics

SPICAV AOTF: QM



AOTFs operating in flight

Parameter	SPICAM-IR (direct filtration)	SPICAV-IR (direct filtration)	SOIR (selection of orders)
Spectral range	1-1.65μm	0.7-1.05μm 1.05-1.65μm	2.2-4.4 μm
Spectral resolution	0.5-1.2 nm 3.5 cm^{-1}	0.4-1.6 nm 5-8 cm^{-1}	~20 nm 22 cm^{-1}
RF power	~3 W	~3 W	<1W

AOTF in preparation

- MICROMEGA for EXOMARS 2013
  - operational temperature range –150°C …+40°C
  - storage temperature range –200°C … +40°C
  - Spectral range 0.8-4 µm (new version 0.8-2.6 µm)
  - Spectral resolution 10-15 nm
- SOIR-Terre
  - A high-resolution spectrometer for the Earth atmosphere: monitoring of green-house gases (CO_2, CH_4 with O_2 reference)
  - Spectral range 0.7-1.7 µm
  - Spectral resolution ~35 nm

MICROMEGA AOTF illumination system

ÇIVA-M/I optical concept (J-P.Bibring et al.)