NIR and MIR science overview

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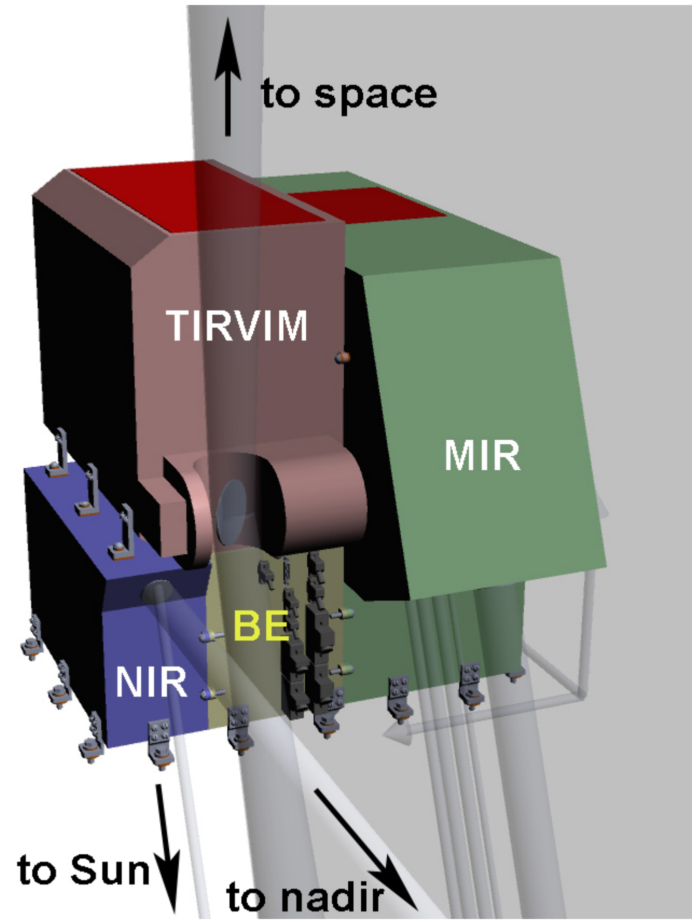
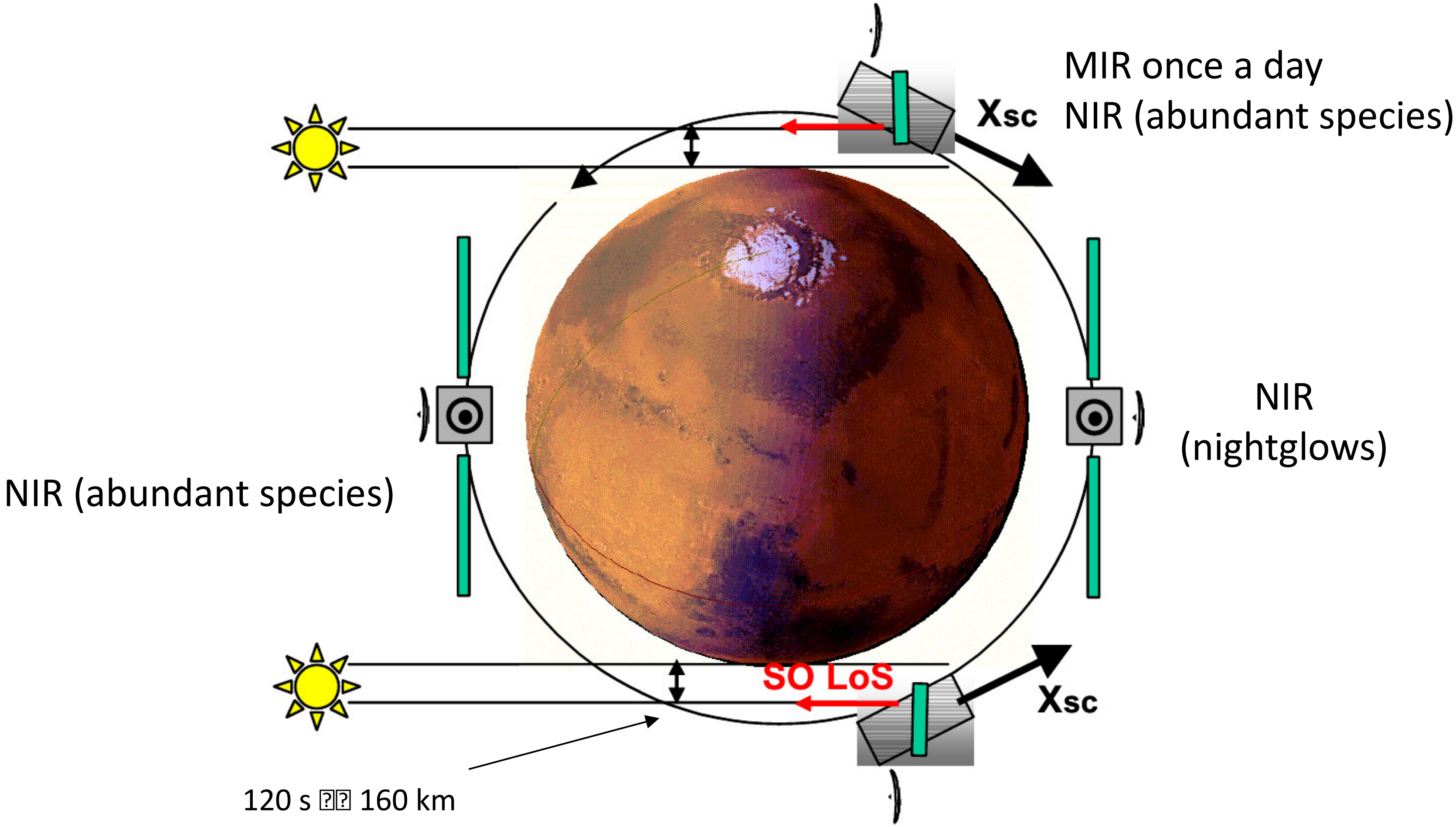


EXPERIMENT OPERATION PLAN

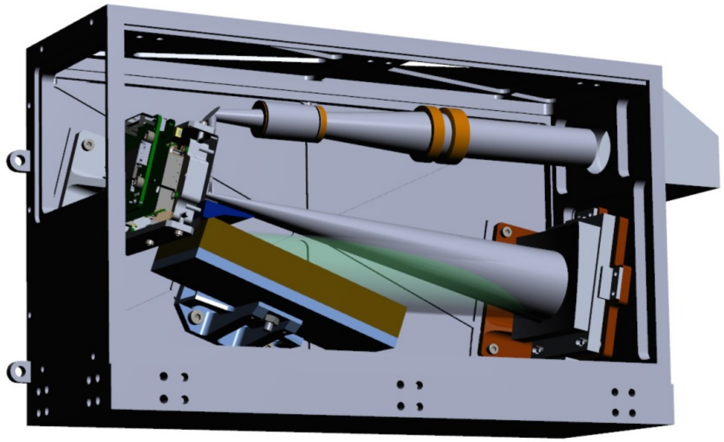
TGO operational orbit T ~ 2 hr orbital period

→ 12 orbits per day, 12 sunrises and 12 sunsets – 24 occultation's per day

Altitude ~ 400 km



NIR: Near-IR Echelle/AOTF spectrometer

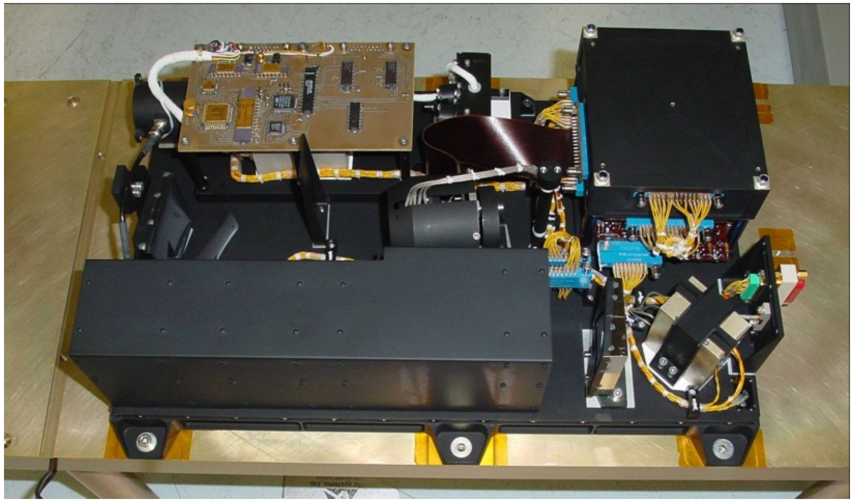


- **Spectral range:** 0.7 – 1.6 µm
- **Spectral resolving power:** ~20 000
- **Operation modes:** Nadir, Solar Occultation
- **FOV:** 30 x 0.3 mrad
- **Mass/Power/Data rate:** 3.5 kg /15W /0.5 Gbit/day

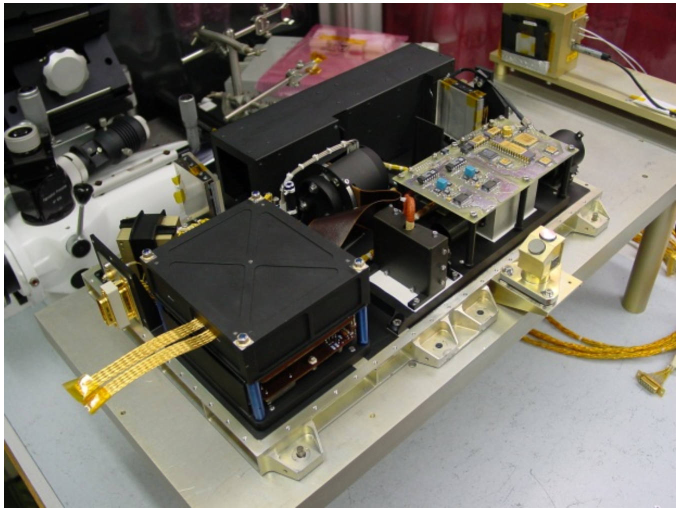
Why this spectral range:

Intersection with SPICAM IR on Mars-Express and SPICAV Vis-IR on Venus-Express

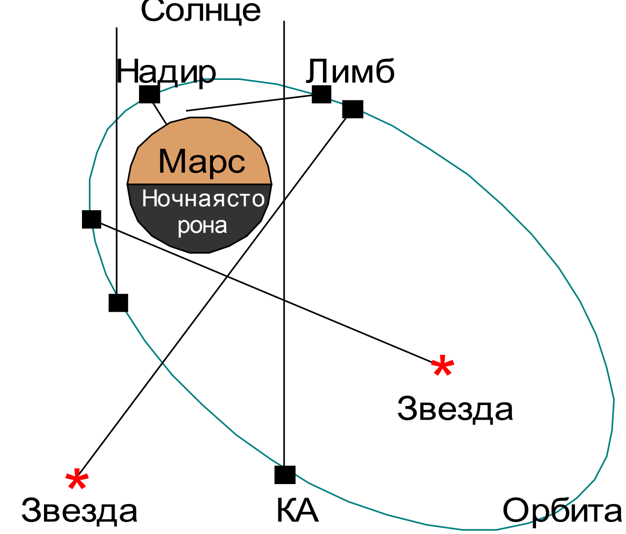
SPICAM IR Mars-Express (LATMOS-IKI-BIRA)



SPICAV Vis-IR Venus-Express (LATMOS-IKI-BIRA)



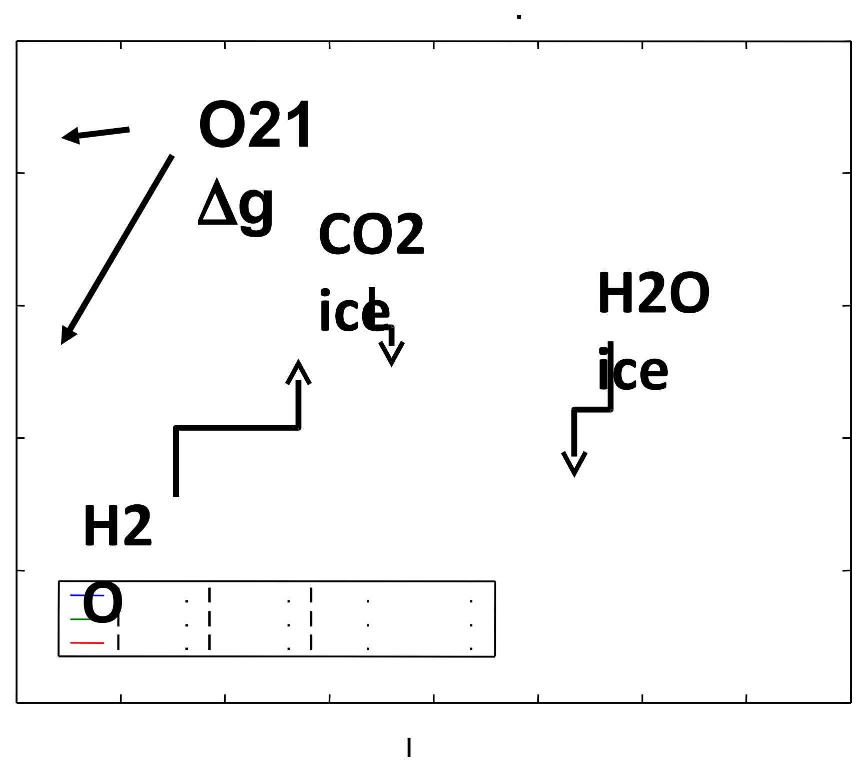
SPICAM IR – AOTF spectrometer:



Spectral range: 1-1.7 µm
Resolving power: 2000
Spectral resolution: 3.5 cm-1
0.5-1.2 nm
FOV nadir: 1°
solar occultation: ~0.07°

Different observation modes

- **Nadir viewing (day side)**
  - H2O abundance at 1.38 µm
  - H2O and CO2 ices
  - O2 dayglow – ozone tracer
- **Solar occultation**
  - CO2, aerosols, H2O
- **Limb**
  - Airglow in IR (O21Δg 1.27 µm)
  - aerosols

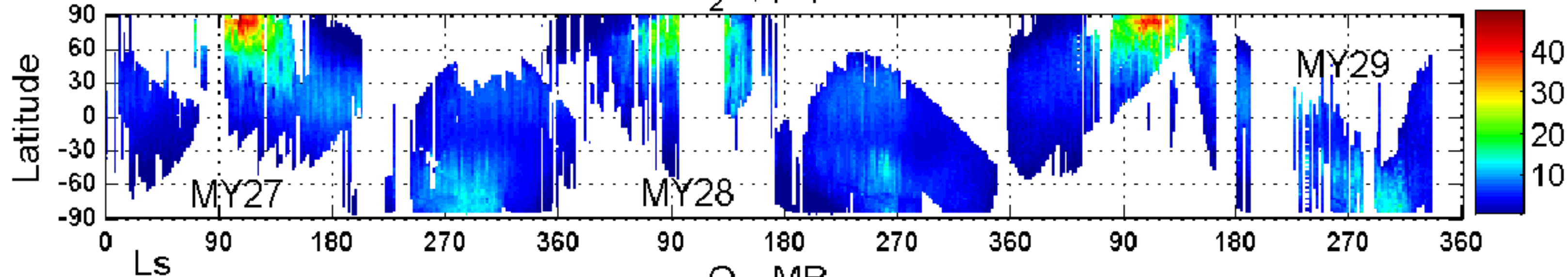


SPICAM IR scientific results

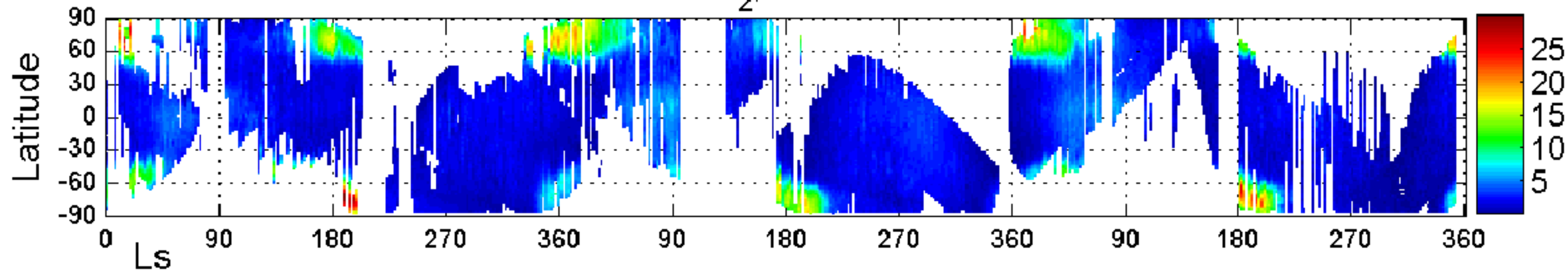
10 years of successful observations

Nadir:

H$_2$O, pr.µm

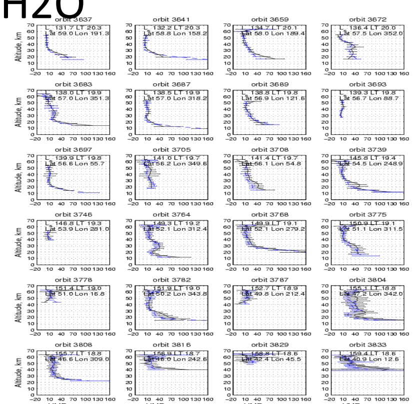


O$_2$, MR



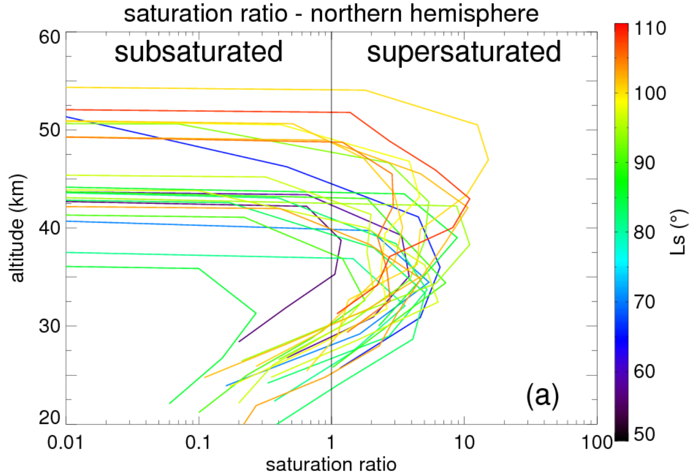
Occultations:

H2O

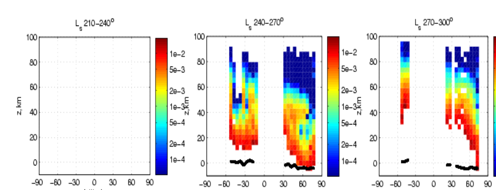


Mixing ratio, ppm

Water vapor vertical profiles

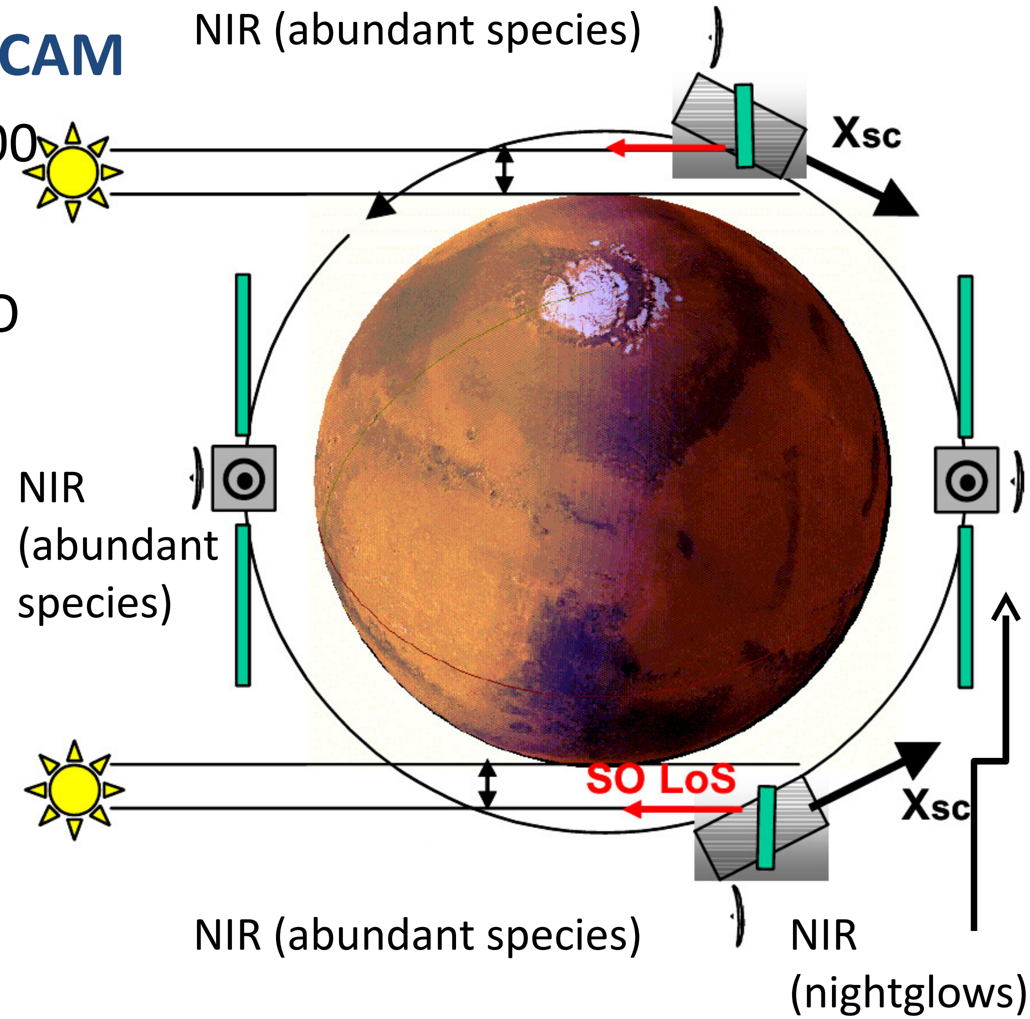


Aerosol extinctions



NIR spectrometer

- **Advantages compared to SPICAM**
  - High spectral resolution 20000
  - Higher SNR
  - Better spatial resolution in SO

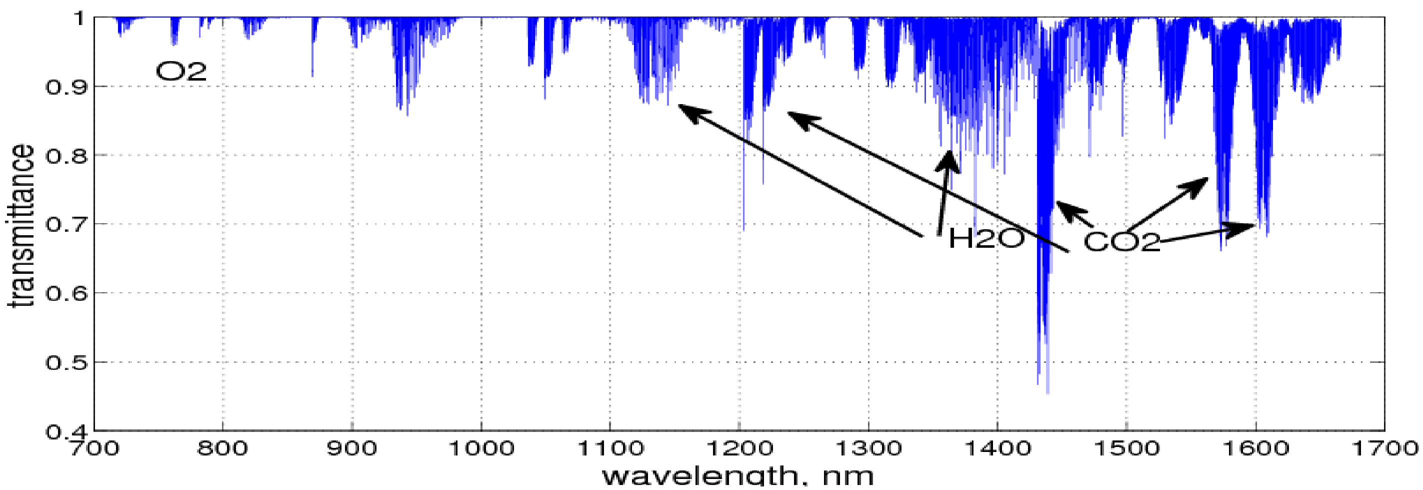


- **Nadir viewing (day side)**
  - H_2O abundance at 1.38 µm
  - O_2 dayglow – ozone tracer
- **Solar occultation**
  - CO_2, H_2O, **O_2**, aerosols
- **Nadir viewing (night side)**
  - O_2 $^1\Delta g$ 1.27 µm airglow

NIR spectrometer (solar occultation)

- Up to 10 orders for 0.5 sec
- Vertical resolution ~0.5 km
- 72 sec for occultation 0-100 km in the atmosphere
- AOTF 70 cm-1

- CO_2 - density and temperature 0 -110 km
- H_2O 0-60(80) km
- **O_2** 0-40 km
- Aerosols 0 – 80 km



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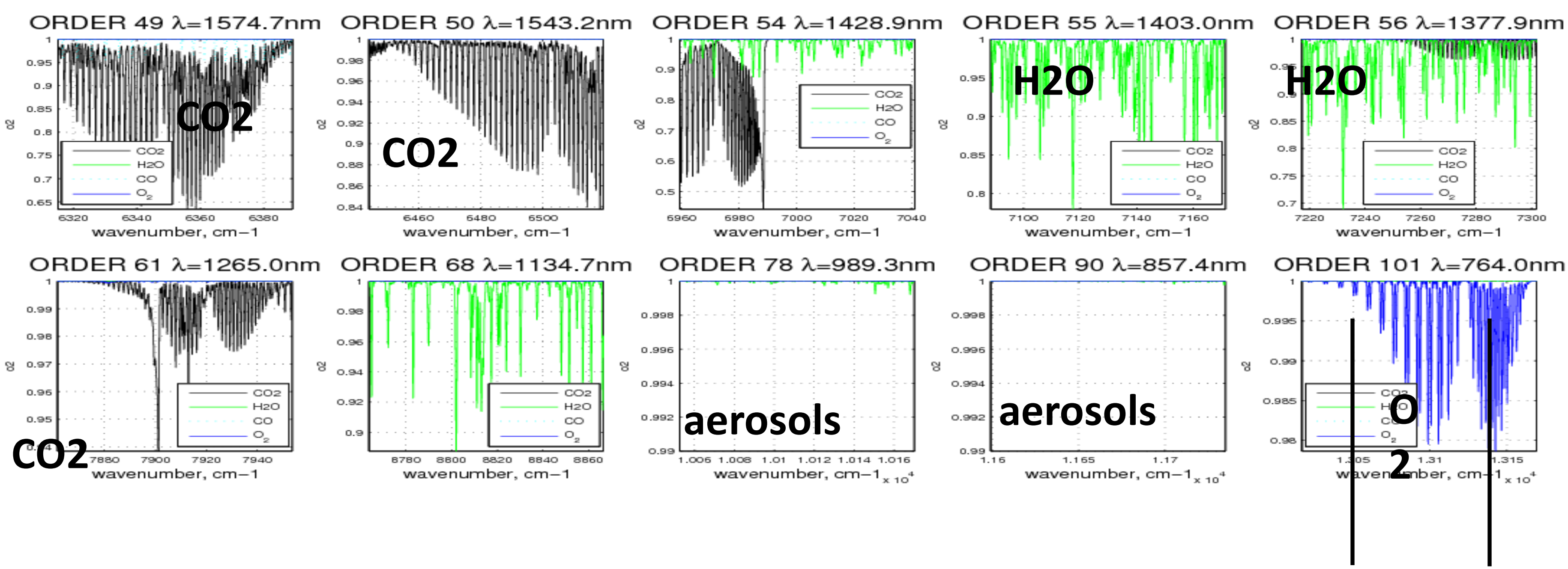
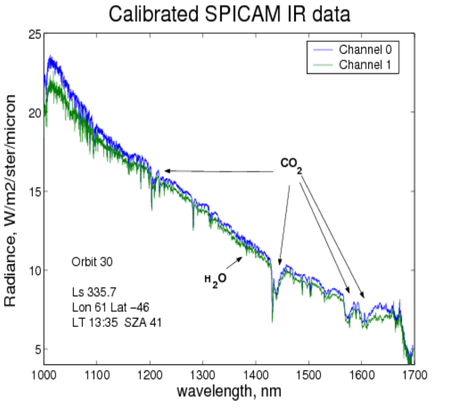
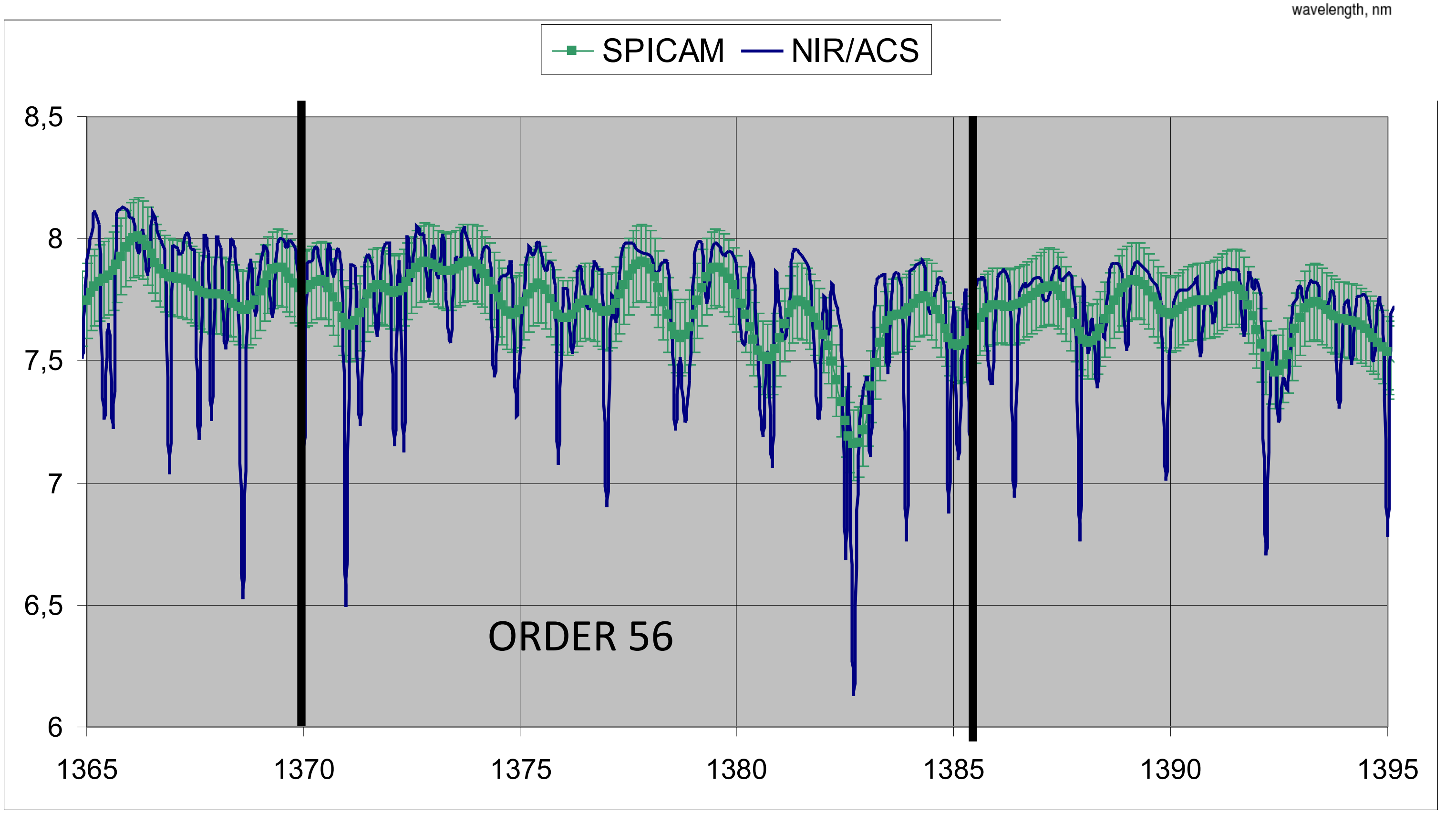


NIR spectrometer (dayside nadir)

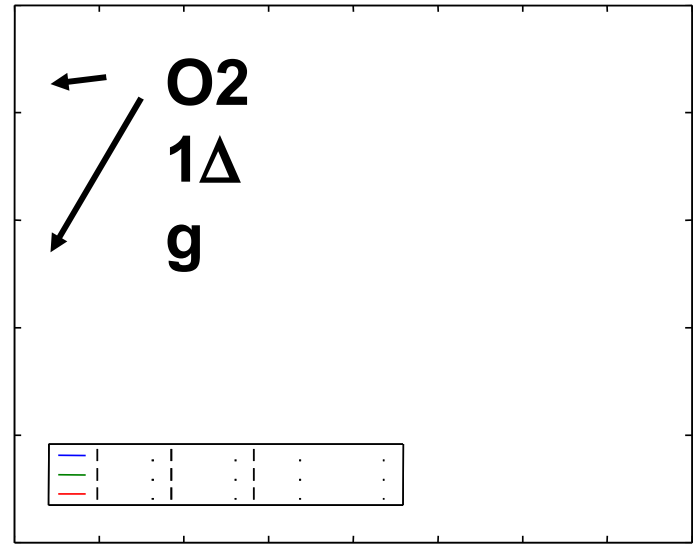
- H_2O abundance at 1.38 μm - **order 56** in 100 times more accurate than SPICAM supported by aerosol and temperature profiles from TIRVIM
- < 1 hour for nadir dayside
- 1 order takes ~ 1-2 sec: 3-4 orders



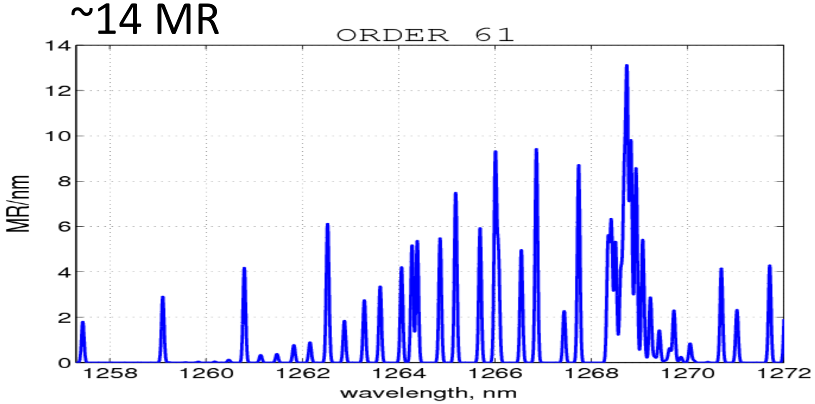


NIR spectrometer (dayside nadir)

- O2 dayglow at 1.27 μm – **order 61**
- < 1 hour for nadir dayside
- 1 order takes ~ 1-2 sec: 3-4 orders



Vertical emission rate
~14 MR

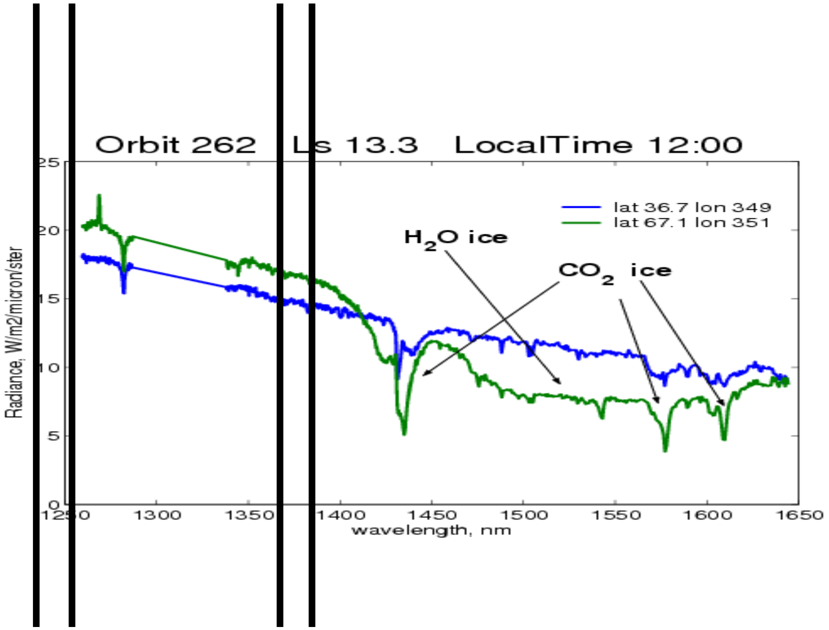


NIR spectrometer (dayside nadir)

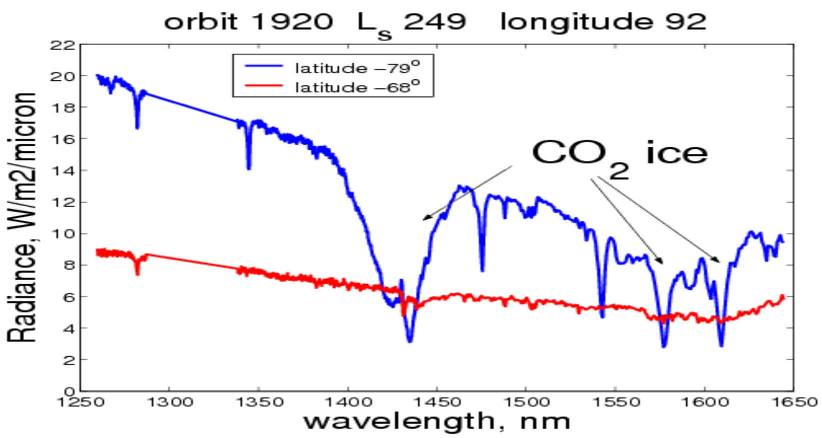
- *CO_2 u H_2O ices mapping???*
- *Spatial resolution ~0.15x3km (1sec of integration) - do we need this?*
- *Very questionable with 3-4 orders for full range*

Examples of CO_2 and H_2O ice observations in the range of 1.1 – 1.65 µm by SPICAM IR

Northern latitudes Ls 262



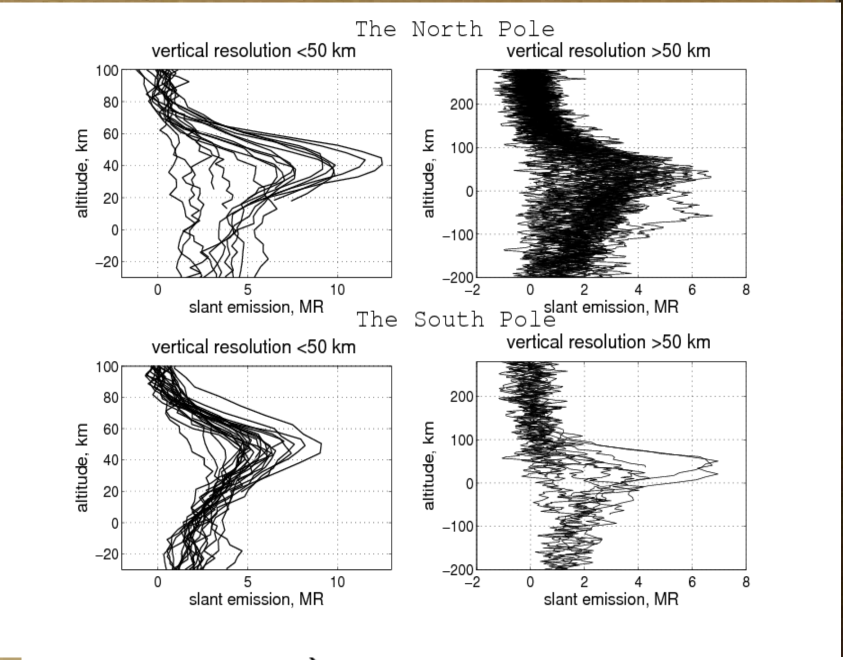
South Pole Ls 250

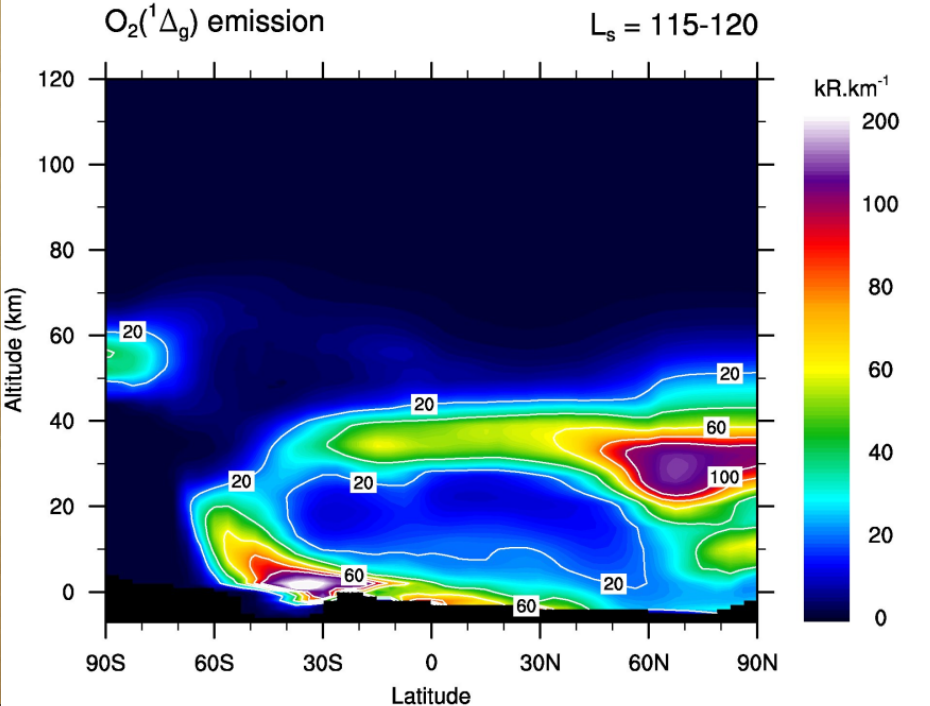


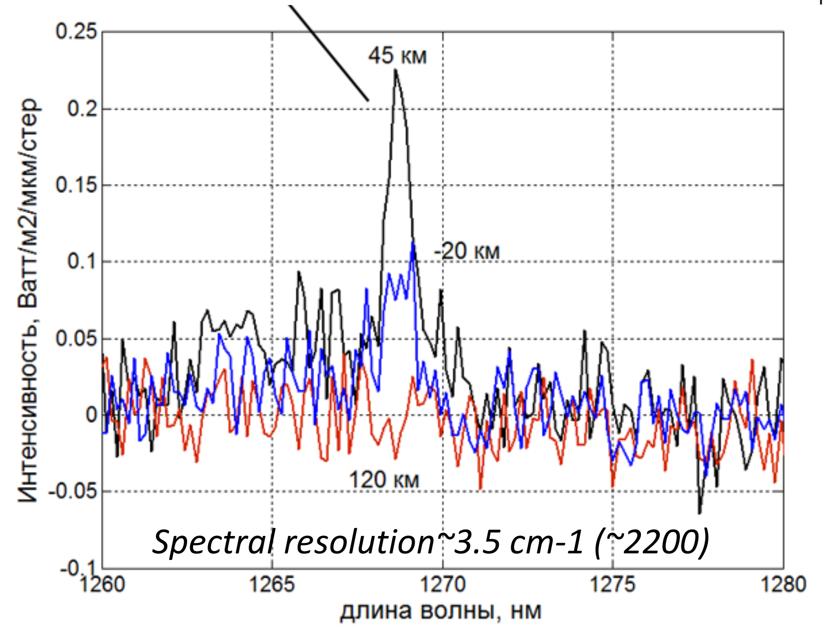
O2(a1Δg) nightglow at 1.27 μm by SPICAM IR

O + O +CO2 → O2(a1Δg) +CO2

- Detected by OMEGA/Mars-Express (Bertaux et al., 2012) and CRISM/MRO (Clancy et al., 2012)
- Only POLAR LIMB observations. This emission is an effective indicator of downward flow of air from the altitudes where the CO2 photodissociation occurs (above 70 km).
- NEB ~1.1 W/m2/μm/ster, 0.85 MR/nm







Spectral resolution~3.5 cm-1 (~2200)

NIR spectrometer (nadir nigthglow)

TGO can not provide the limb observations

Only nadir observations:

Observed polar O2 emission:

100-500 kR

At low latitudes:

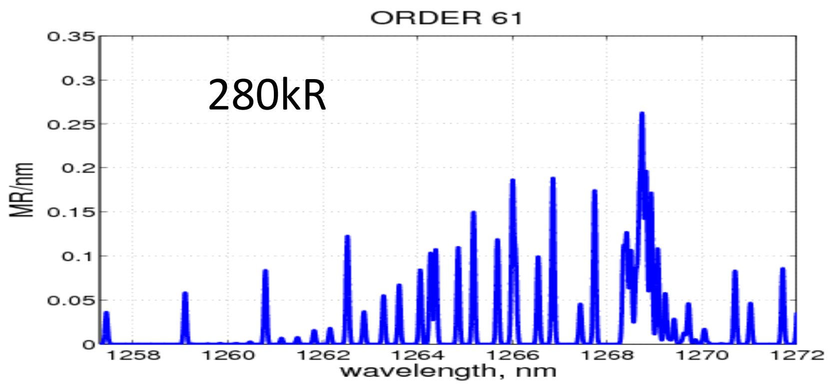
The current models give the intensity **from 13 to 100 kR**.

Krasnopolsky et al. (2013):

10 ± 32 kR

NIR ACS:

- < 1 hour for nadir nightside
- Order 61: 1257-1272 nm
- 1 order takes > 5 sec



$O + O + CO_2 \quad O_2(a^1\Delta g) + CO_2$

PGOPHER, a Program for Simulating Rotational Structure, C. M. Western, University of Bristol, http://pgopher.chm.bris.ac.uk

NIR (OH nigthglow)

Clancy et al. (2013): limb observations by CRISM/MRO

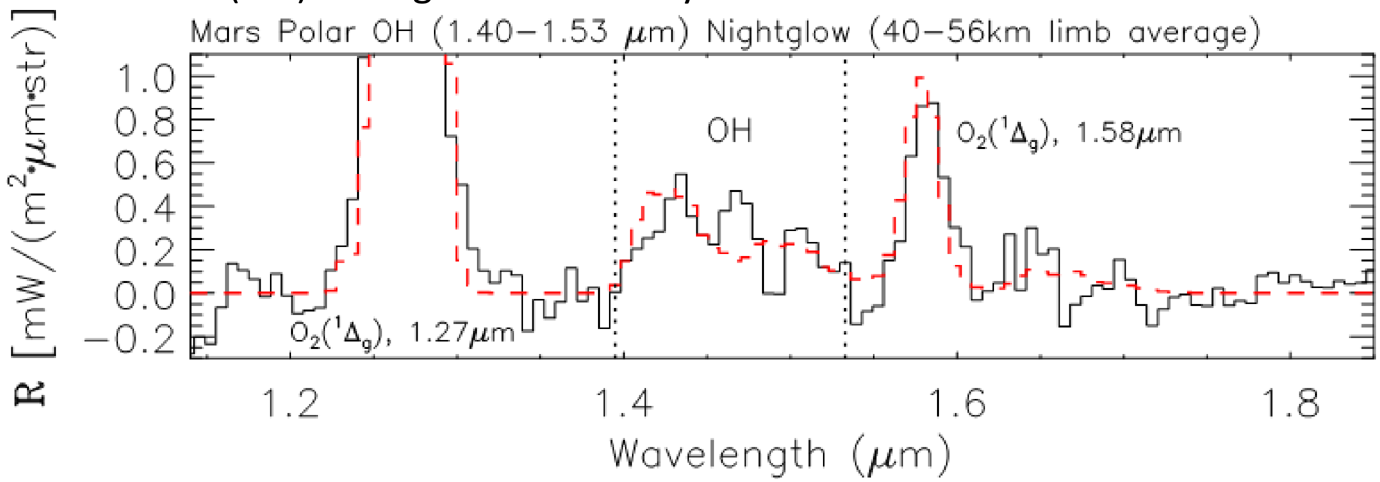
Polar emissions at (2-0) and (3-1) OH bands - 1.45 µm.

at (1-0),(2-1) and (3-2) OH bands - 2.7-3.1 µm

Meinel band (2-0) average limb intensity **200±100** kR.

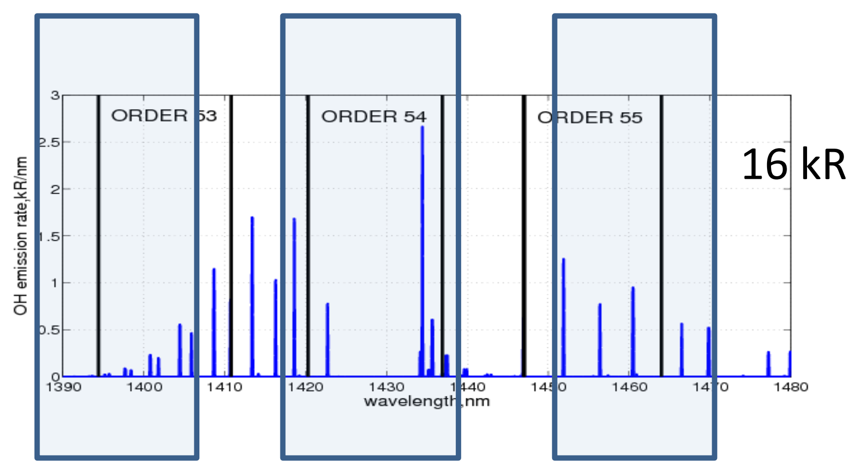
$$H + O_3 \rightarrow OH^* + O_2$$

$$O + HO_2 \rightarrow OH^* + O_2$$



NIR ACS:

- < 1 hour for nadir nightside
- Order 53-55: 1390-1500 nm
- 1 order takes > 5-10 sec (averaging?)
- SNR~5 (for 16 kR)
- Expected detection limit ~ 3 kR
- *CO2 and H2O absorption?*



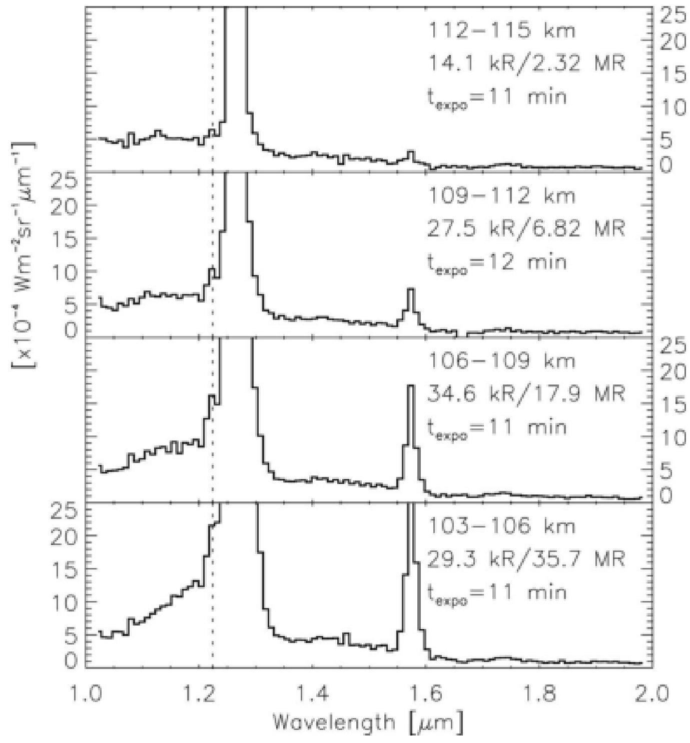
NIR (NO nigthglow)

NO nightglow at 1.224 μm

N+O = NO+hv

VIRTIS/Venus-Express – Garcia-Minoz et al., 2009 night side limb on Venus.

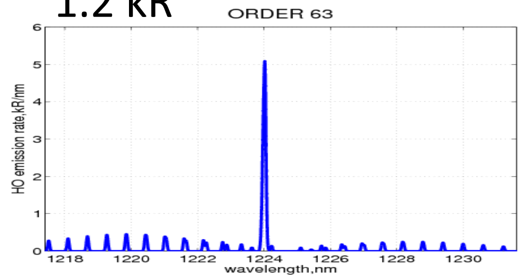
- NO infrared nightglow ≈20 kR for middle northern latitudes at 30°N-50°N.
- All values are inside 7.9–63 kR on limb!



NIR ACS:

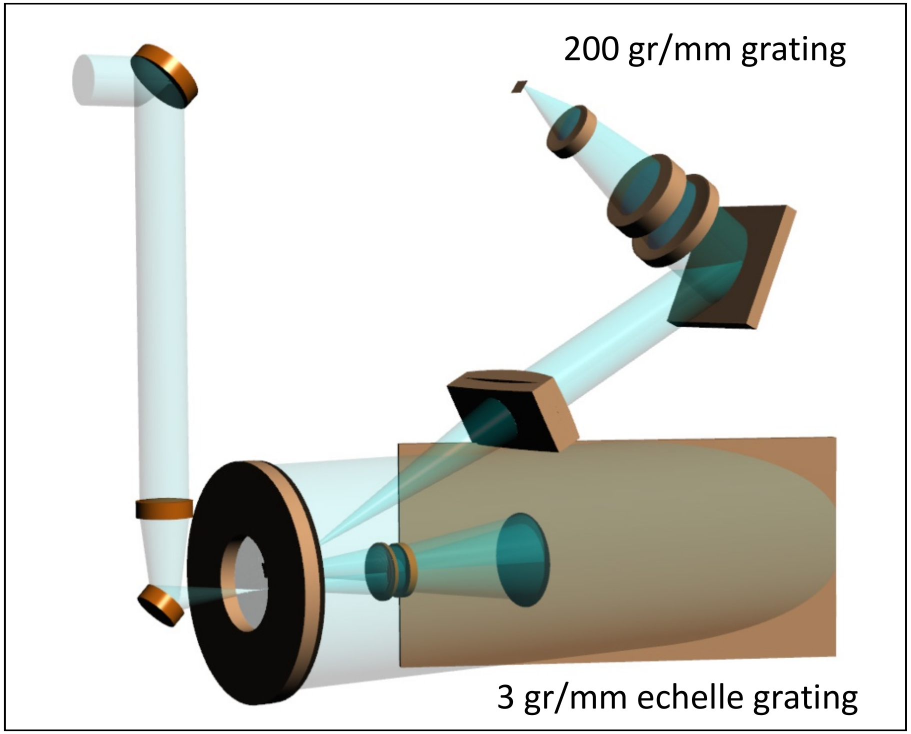
- < 1 hour for nadir nightside
- Order 63: 1217.4-1231.6 nm
- 1 order takes > 5-10 sec (averaging?)
- SNR~10 (for 1.2 kR)
- *CO2 and H2O absorption?*

1.2 kR



MIR: Mid-IR Echelle/cross-dispersion

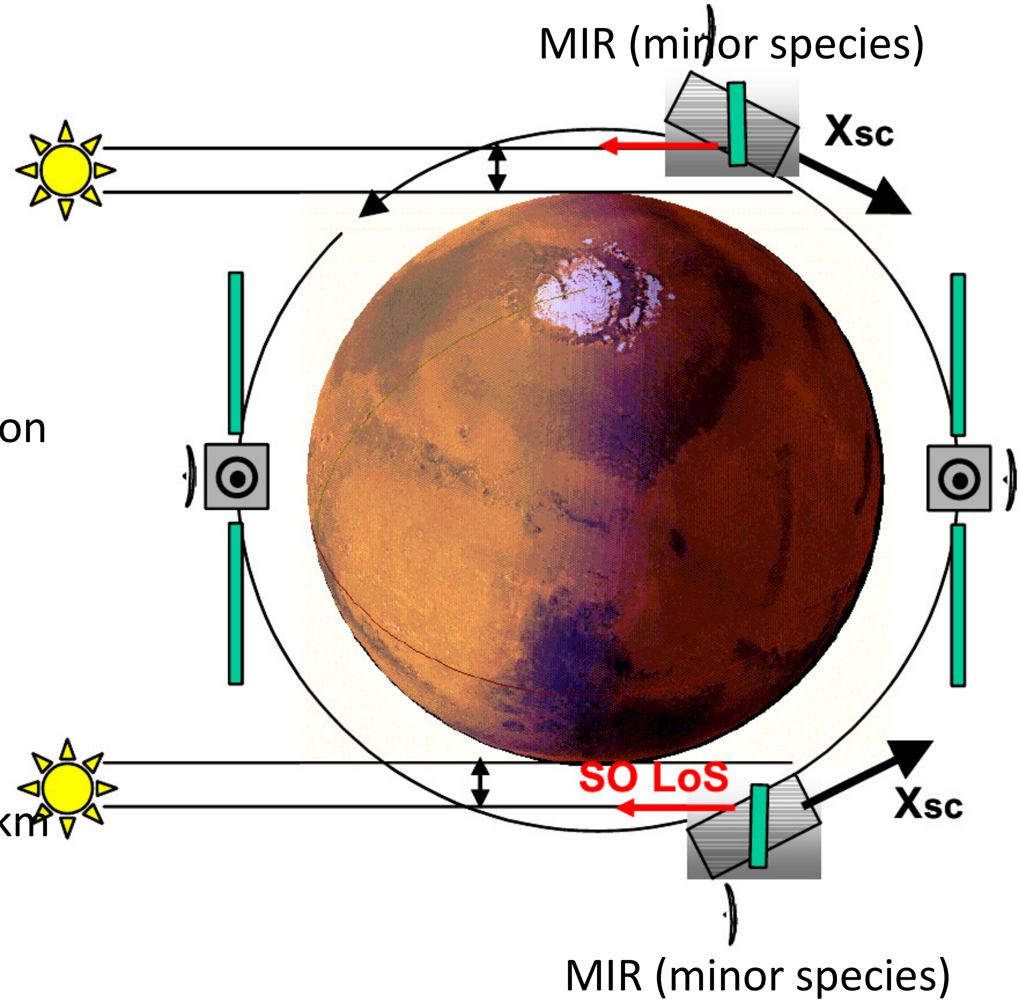
- Spectral range: 2.4 – 4.2 µm
- Instantaneous coverage: 230-300 nm ranges per measurement
- Spectral resolving power: >50 000
- FOV: 0.1 x 2.9 mrad
- Aperture ratio 1:3
- Mass/ Power / Data: 12 kg / 20 W / 1.2 Gbit per day
- Size 460 x 200 x 440 mm
- Operation modes: Solar Occultation
- Operation rate 2 images/s



MIR spectrometer

Solar occultation

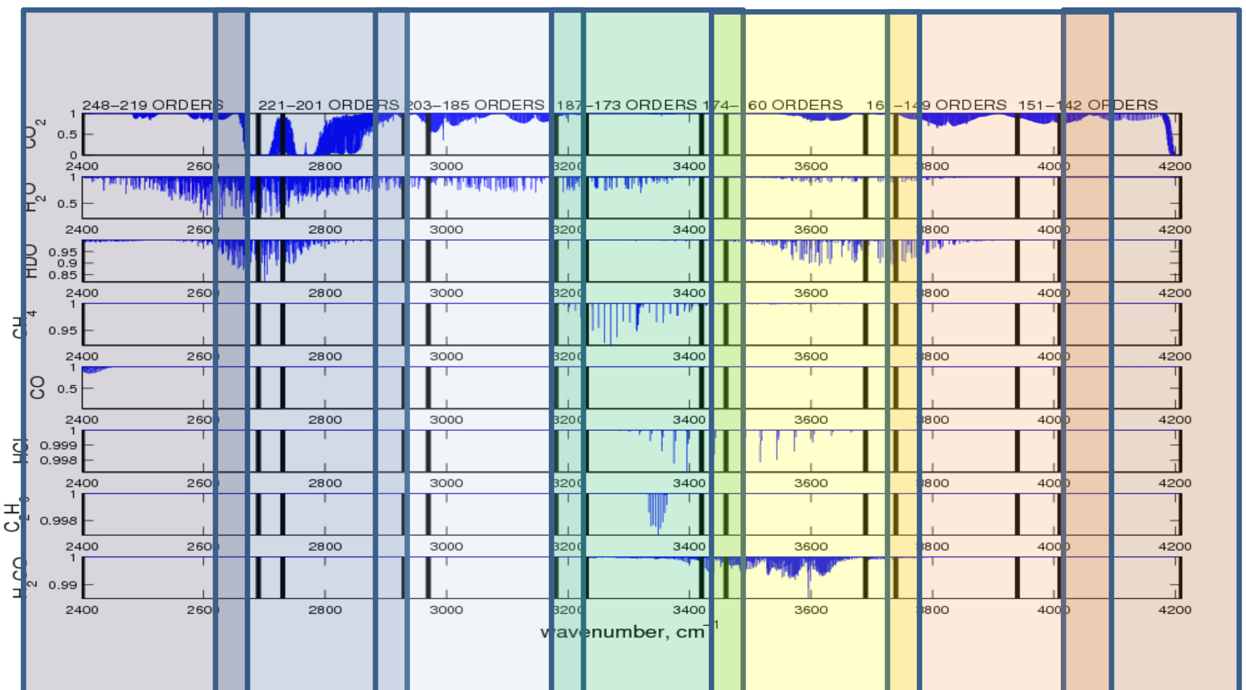
- High spectral resolution ~ 50000
- SNR ~500 (current estimation)
- Spatial resolution in SO ~1 km?
- 0.5-1 sec for measurements – 1-2 position of secondary grating angle
- 72 sec for occultation 0-100 km in the atmosphere
- **CO_2** measurements for density and temperature from 10 to at least 140 km
- Known species **CH_4 , H_2O, CO** at 10-80 km
- Isotopic ratios **HDO/H_2O, $^{13}CO_2/CO_2$, $CO^{18}O/CO_2$** etc.
- Search of minor gaseous species **C_2H_2, C_2H_4, C_2H_6 и, SO_2, HO_2, H_2O_2, H_2CO, HCl, OCS etc.**



MIR: Mid-IR Echelle/cross-dispersion

Secondary grating angle	Diffraction orders	Number of diff. orders	Wavelength range	Optimized (central) order	Wavelength range in central order	Resolving power in central order
48.2°	248-219	30	2.40-2.73 µm	232	110 nm	74000
50°	221-201	20	2.69-2.97 µm	208	137 nm	66000
51.8°	203-185	19	2.93-3.23 µm	193	159 nm	62000
53.6°	187-173	15	3.18-3.45 µm	178	187 nm	57000
55.5°	174-160	14	3.42-3.74 µm	166	215 nm	53000
57.2°	161-149	13	3.69-4.01 µm	155	246 nm	49000
59°	151-142	10	3.94-4.21 µm	146	277 nm	47000

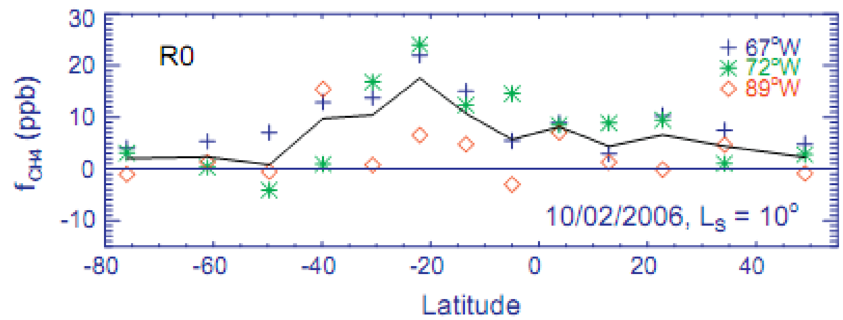
Transmittance with absorption lines of different molecules ***at 22 km*** during occultation



MIR / occultations

CH4 measurements

- Ground-based observations
  Variable values from 0 to 30 ppb
  Krasnopolsky et al. (2004, 2007, 2011), Mumma et al., 2009, Villanueva et al. (2013)

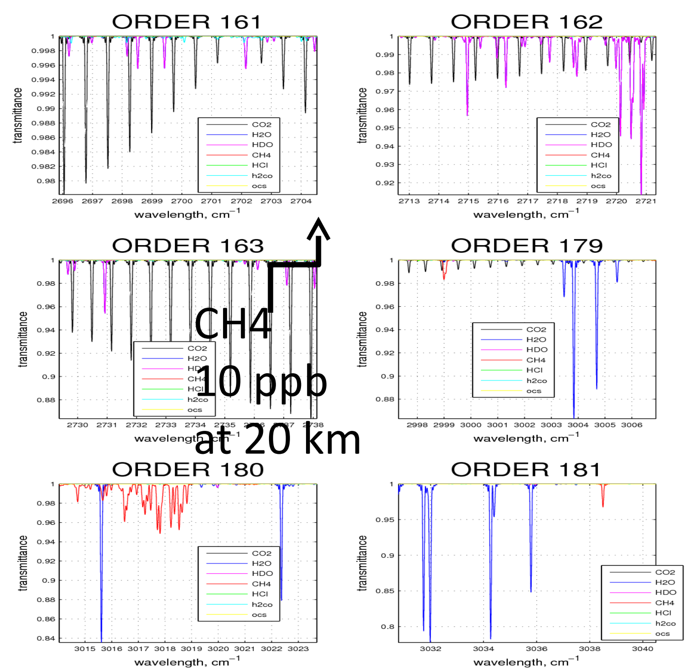


- PFS on MEX: 10 ppb
  Formisano et al. (2004); Geminale et al. (2011)

- TLS on Curiosity:
  0.18 ±0.67 ppbv corresponding to an upper limit of only 1.3 ppbv *Webster et al. (2013)*

Future instruments:

- NOMAD on TGO
- MIR-ACS on TGO
  the orders between 3.18-3.45 μm (secondary grating angle=53.6°)
  The detection limit is better than **0.3 ppb** for target altitude of 20 km (without averaging)



MIR / occultations

H2O/HDO ratio

- Ground-based observations

  5.5±2 relative to the Earth's ocean water

  Krasnopolsky et al. (1997)

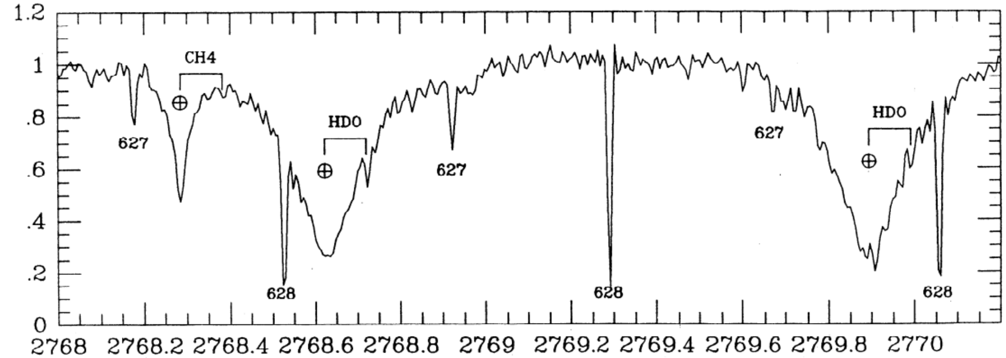
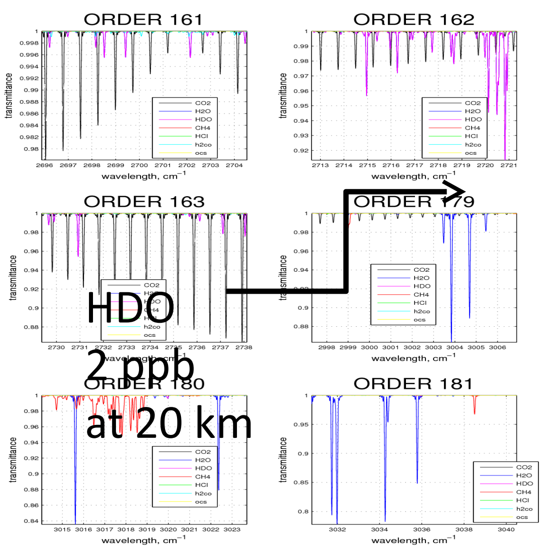


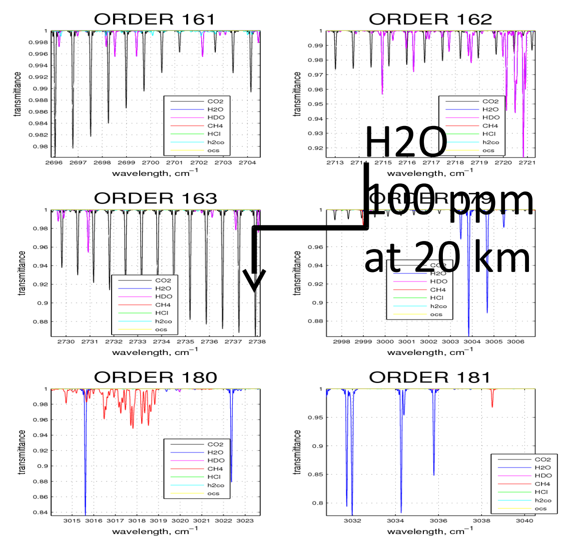
Figure 2. A small portion of the 2650-2800 cm^{-1} spectrum showing three Martian CO_2 (628) lines, three Martian CO_2 (627) lines (absent in HITRAN-92), two telluric HDO lines with Martian satellites, and one CH_4 telluric line with a possible Martian satellite.

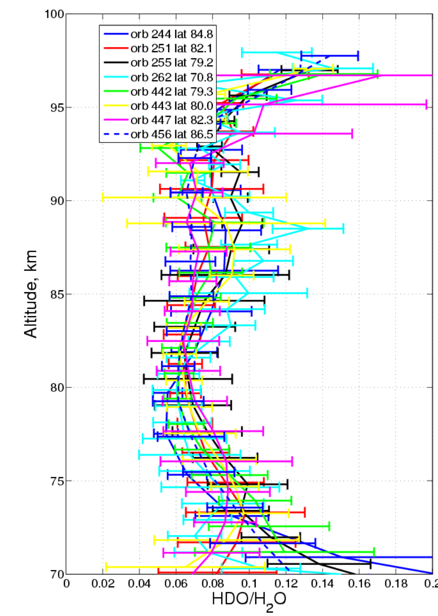
Future instruments:

- NOMAD on TGO
- MIR-ACS on TGO

  the orders between 3.18-3.45 µm or H2O from NIR 1.38 µm band







HDO/H2O Venus' mesosphere
SOIR/Venus-Express,
2.2-4.3 µm, ~20000

MIR and NIR Scientific Objectives and Expected Performance:

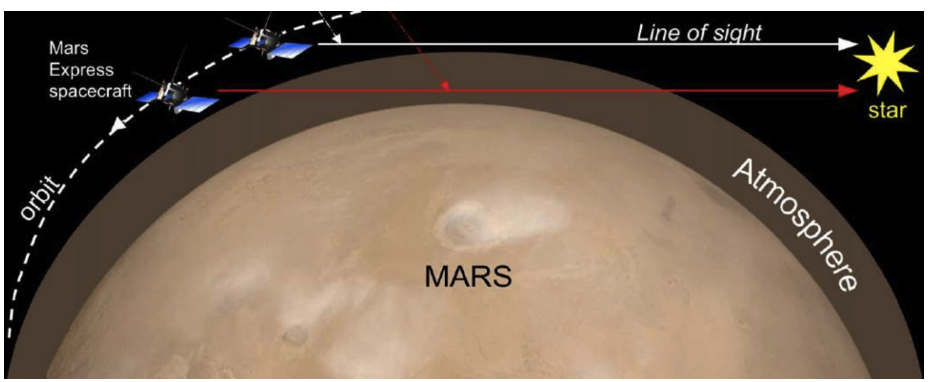
Species	Scientific Objective	Current Knowledge	Wavelengths, µm	Detection limit Solar Occultation	Detection limit Nadir
Abundant species					
CO_2	Profiles, pressure, temperature field	0.965	**1.43, 1.58, 1.60, 2.7, 3.8**	5-140 km	Temperature field
CO_2 isotopes	Profile isotopes	13C/12C=0.967 18O/16O=1.018 Ratios wrt Earth	**1.47, 1.45, 2.6, 2.9, 3.0, 4.0 etc**		
H_2O	Profile. abundance	1-500 ppm (variable with season)	**1.13, 1.38, 2.56**	10-80 km	0.5 ppm
CO	Profile. abundance	300-1000 ppm	**1.57, 2.4**	4 ppm	100 ppm
Aerosol	Properties, extinction profiles	opacities, integrated and limb profiles, particle sizes	**0.65-4**	0.1 µm <reff <10 µm Distinguish H2O/dust	Mapping of dust and ice cloud opacity
O_2	Profile	0.13%	**0.76**	Profiling up to 50-60 km with abundance 0.13%	0.02-0.05%
$O_2(a^1\Delta g)$	Dayglow (ozone)+ Nightglow	0-30MR (dayglow) 0-0.3MR (nightglow)	**1.27**		1 kR in nadir
Trace species					
CH_4	Detection, profiles	<8 ppb (3-50)	**3.3**	0.08 ppb	
C_2H_2	Detection	<3 ppb	**3**	0.4 ppb	
C_2H_4	Detection	<4 ppb	**3.2**	3 ppb	
C_2H_6	Detection	<0.2 ppb	**3.3**	0.2 ppb	
H_2S	Detection	<20 ppb	**2.6**	20 ppb	
OCS	Detection	<10	**2.44, 3.4**	1 ppb	
HDO	Detection	0.1-1 ppm	**3.7**	0.8 ppb	
H_2CO	Detection	<3 ppb	**3.6**	0.1 ppb	
HO_2	Detection	200	**2.94**	4 ppb	
NO_2	Detection	<10	**3.43**	0.4 ppb	

Reported minimal abundances based on MIR: R~50000, **SNR~500** (SO);
NIR: R~20000; SNR~2000 (SO); SNR~1000 (N)

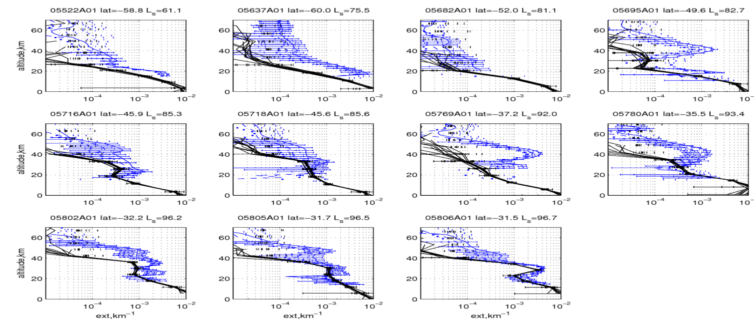
Aerosol studies in solar occultation by SPICAM UV and IR
Vertical profiles of UV and IR extinctions

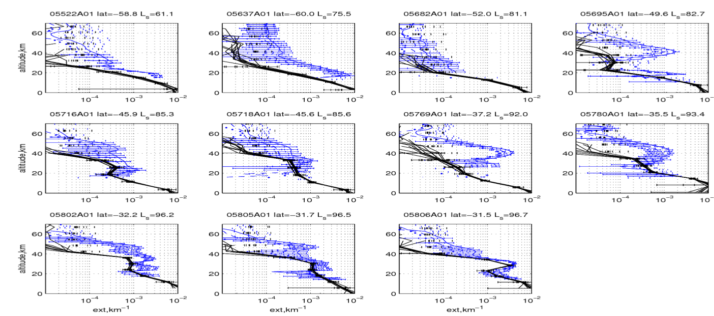
Simultaneous observations of IR and UV channels in solar occultation (SO) mode

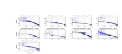
Channel	Spectral range	Spectral resolution	Wavelengths for extinctions, nm
UV	118-320 nm	>100	**3 wavelengths:** 200, 250, 300
Near-IR	1-1.7 µm	~2000	**10 wavelengths :** 996.4, 1093.7, 1158.2, 1197.0, 1241.4, 1272.9, 1304.4, 1321.9, 1514.6, 1552.2

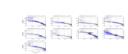


The southern hemisphere (Ls 61-97)









Blue lines are the UV extinctions,
black lines are IR extinctions with errorbars

Particle size inversion for single and bimodal distribution

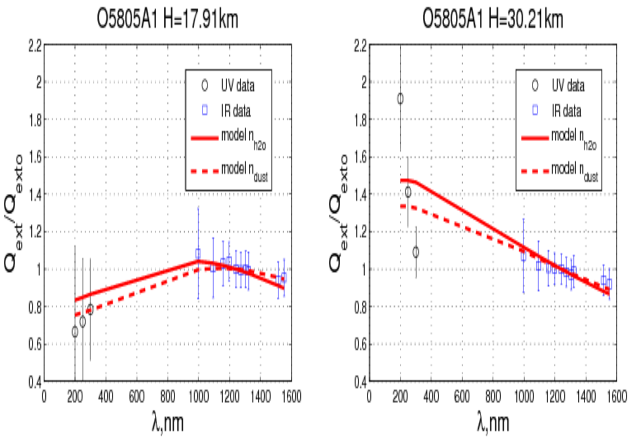
Mie theory is used to retrieve the particle size distribution

For 1 mode

$$\sigma(\lambda) = N_1 \int Q_{ext}(r,\lambda)\pi r^2 n(R_1, \upsilon_1, r)dr$$

For 2 modes :

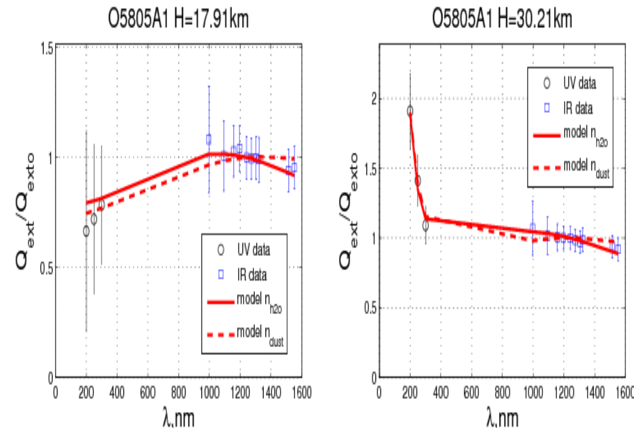
$$\sigma(\lambda) = N_1 \int Q_{ext}(r,\lambda)\pi r^2 n(R_1, \upsilon_1, r)dr + N_2 \int Q_{ext}(r,\lambda)\pi r^2 n(R_2, \upsilon_2, r)dr$$



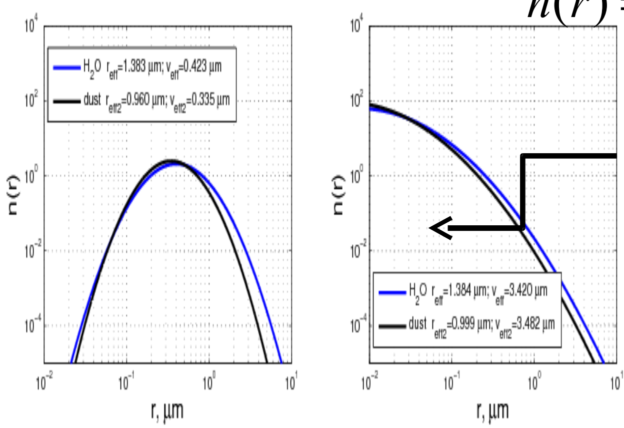
Log-normal distribution:

$$r_{eff} = r_g \exp\left(\frac{5}{2}\ln^2 \sigma_g\right)$$

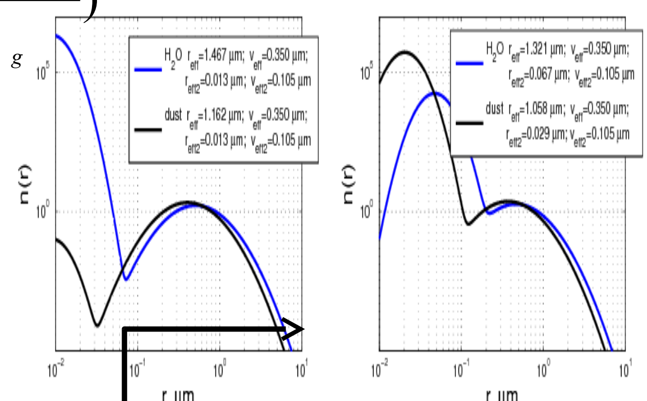
$$v_{eff} = \exp(\ln^2 \sigma_g) - 1$$



$$n(r) = const \times r^{-1} \exp\left(-\frac{(\ln r - \ln r_g)^2}{2\ln^2 \sigma_g}\right)$$

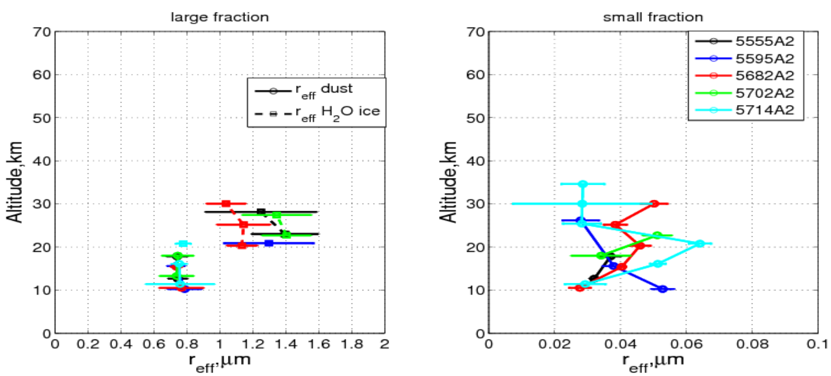


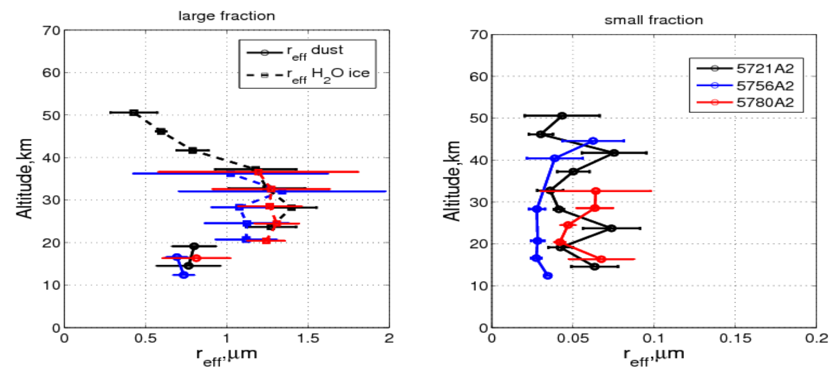
reff and veff are fitted



reff1 and reff2 are fitted and veff is fixed

Evidence for a bimodal size distribution of aerosol particles on Mars by SPICAM/MEX





	r_1, µm	r_2, µm	r_3, µm	N_1, cm^{-3}	N_2, cm^{-3}	N_3, cm^{-3}	H_1, km	H_2, km
Northern hemisphere								
>60N (Ls=65-85)	0.75 ±0.02	1.12 ±0.32	0.039 ±0.006	0.4-2	0.04-0.1	200-104	30	30-35
<60N (Ls=86-93)	0.77 ±0.05	1.25 ±0.12	0.048 ±0.012	0.8-1.5	0.01-0.3	2 100- 5 103	40	50

Maximal altitude (large mode) <30-40 km; (small mode) <30-50 km

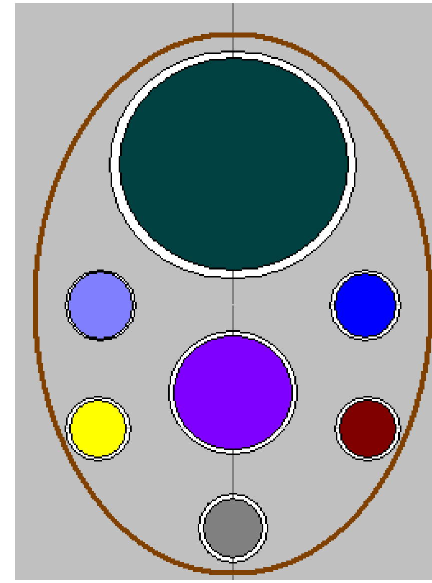
Small mode: reff =40-50 nm, N~200-104 cm-3

r1 is large mode dust radius; r2 is large mode H2O cloud radius; r3 is small mode radius;

Aerosol studies in solar occultations by MIR

Photometric channels of ACS/MIR (TBC)

- Include the UV wavelengths to be sensitive to the small particles and measure the bimodal distributions
- The wavelengths should be outside the CO2 and ozone absorption in Hartley band
- The visible and near-IR wavelengths for better aerosol characterization



#q	λ [nm]	Δλ [nm]	Detector
1	200	10	Si 2.4x2.4 mm Hamamatsu S1336-5BQ x 7
2	310		
3	430		
4	580		
5	750		
6	900		
7	N		

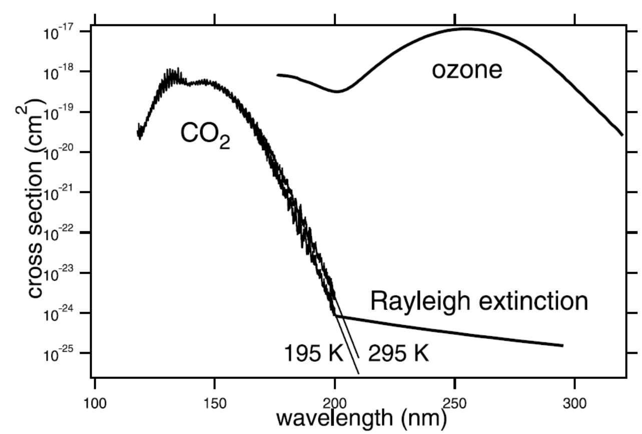
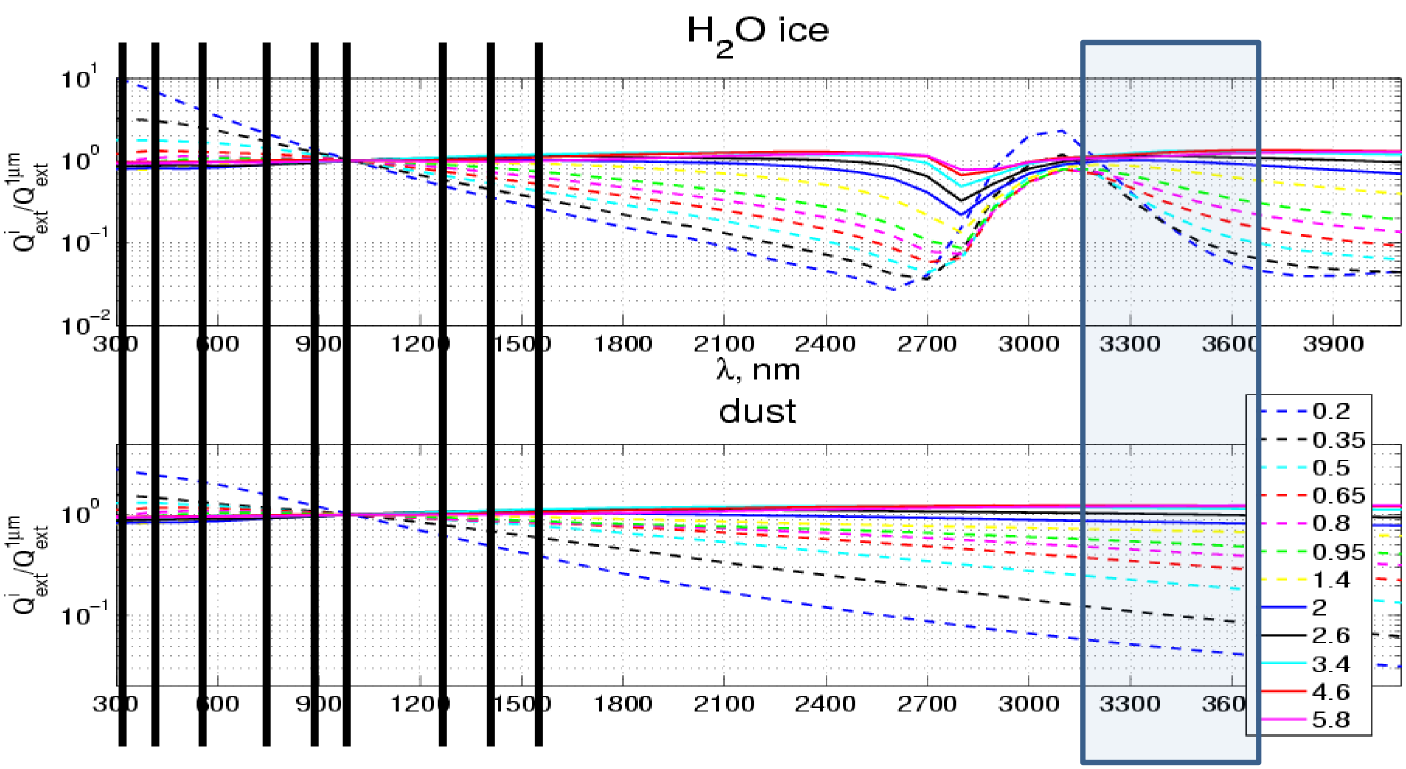


Figure 29. Absorption cross sections of CO_2 and ozone, with Rayleigh extinction of CO_2 in the UV spectral range of SPICAM. The CO_2 cross sections are shown for two temperatures. At 200 nm, it is larger for 295 than 195 K. Aerosols/dust would add to the absorption.

Aerosol studies in solar occultations by MIR and NIR

- The aerosol characterization in the wide spectral range:
  - NIR: 0.763, 0.857, 0.99, 1.26, 1.38, 1.43, 1.55 µm
  - MIR: 3.2-3.7 µm
  - MIR photom. Channels: 0.2, 0.31, 0.43, 0.58, 0.75, 0.9 µm
- Possibility to separate the H2O clouds and mineral dust particles
- Sounding of bimodal distribution. *Difficulties: the different vertical resolution?*
- Altitude range from the surface to 80 km depending of season



1 mode log-normal distribution:
H2O ice veff=0.2 µm
Dust veff=0.4 µ m.
The color marks a reff

The refractive index of **Martian dust**: Ockert-Bell et al. (1997), Wolff et al. (2009, 2010)

Refraction index of **H2O ice**: Warren (2008).

CO2 ice clouds will be also measured