The Exomars Trace Gas Orbiter and the search for Methane

François Forget

LMD, IPSL, Paris

On behalf of the TGO science teams

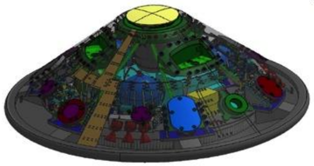
ExoMars Project

Project configuration

ExoMars

2016 Launch

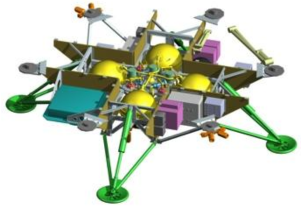
Trace Gas Orbiter



EDL Demonstrator Module (EDM)

2018 Launch

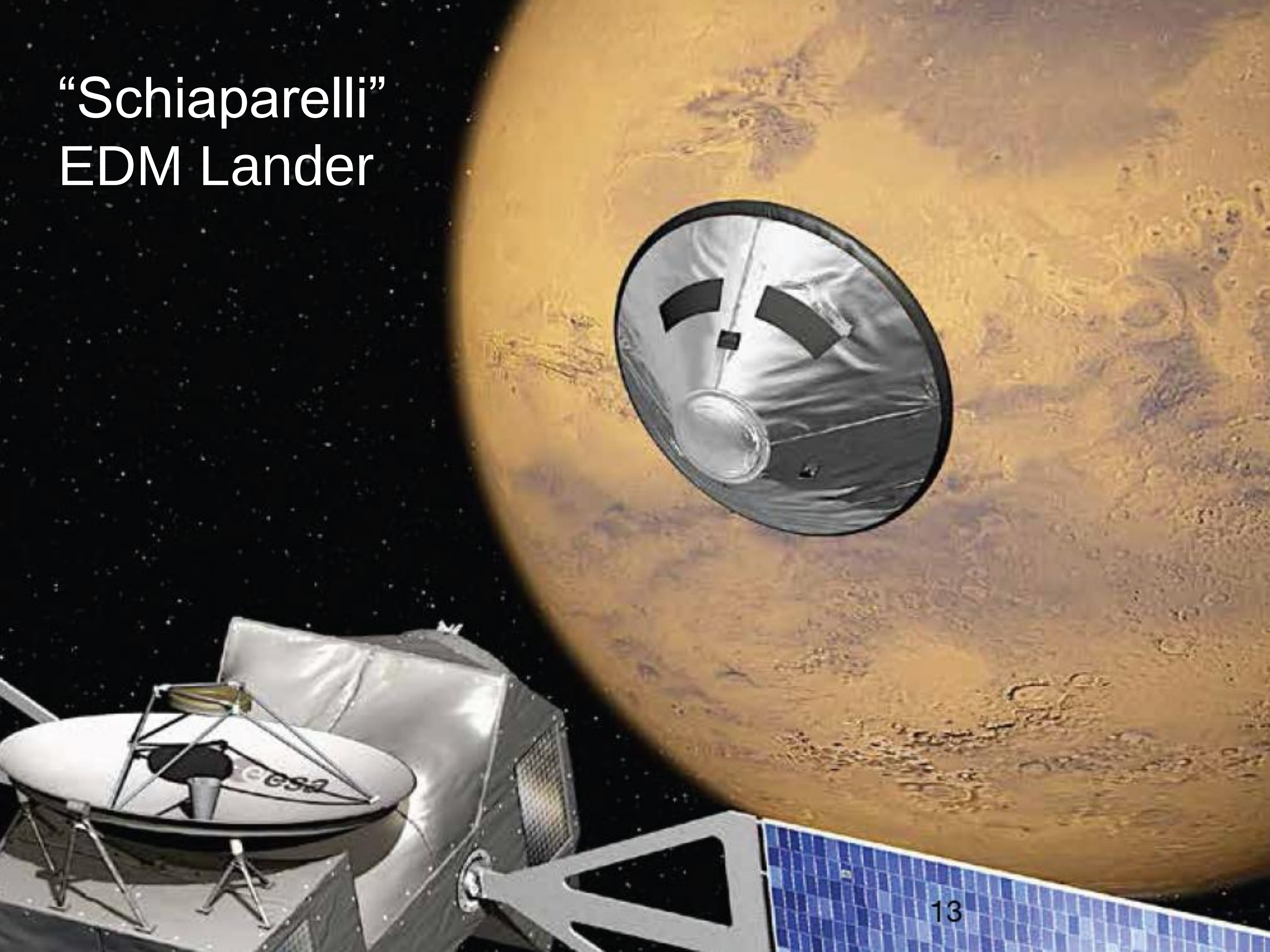
The Rover



Landing Platform

Exomars 2016 Flight Hardware (Assembled in Cannes, France)

“Schiaparelli” EDM Lander



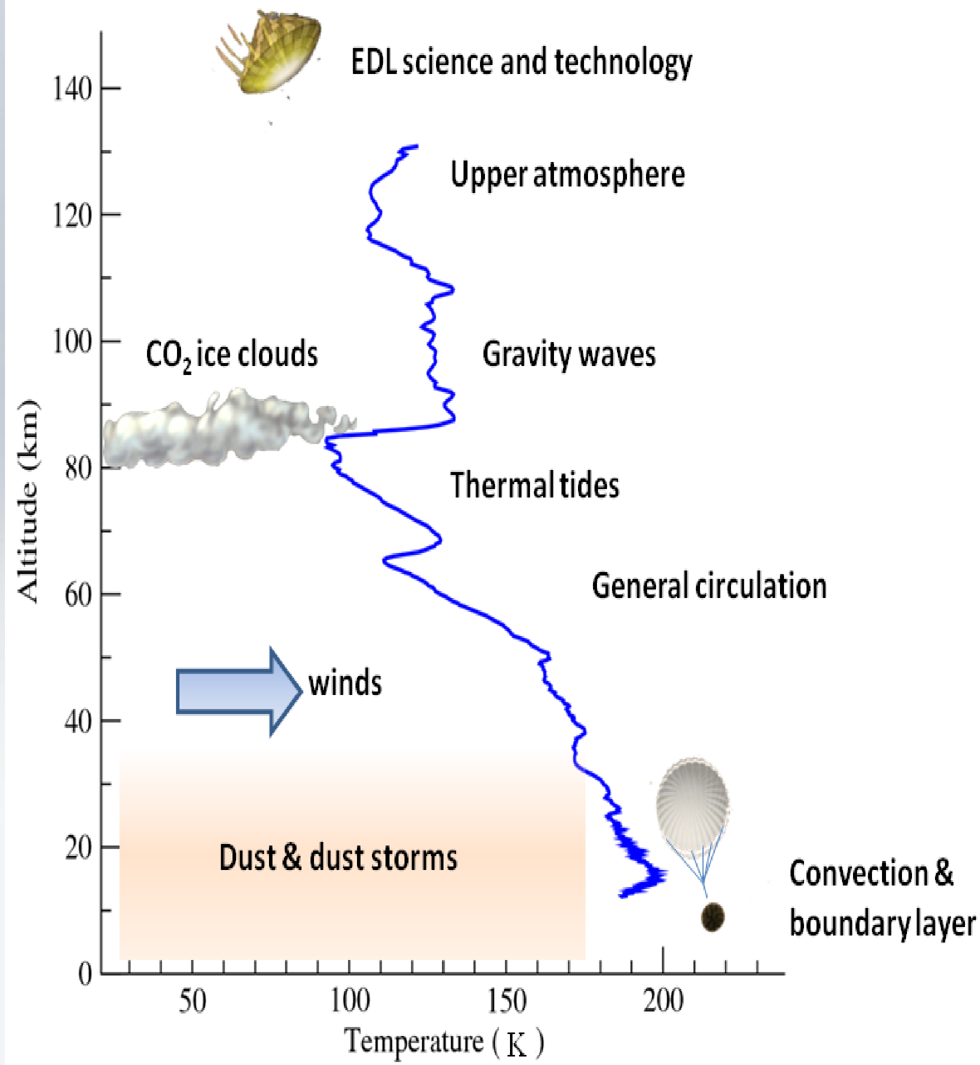

DMTS SN 01
CE

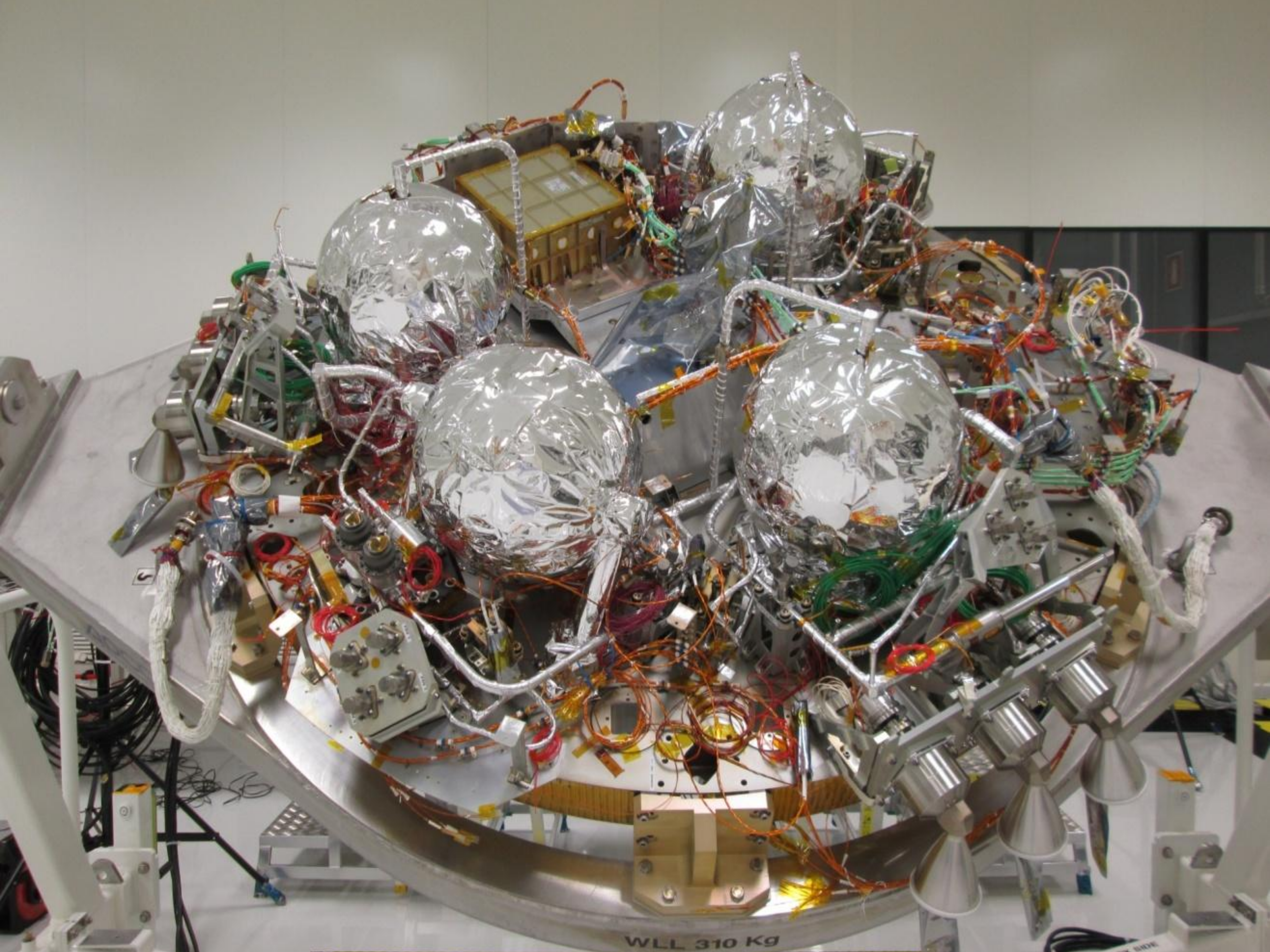
AMELIA science goals

E X O M A R S

Rare, high quality *in situ* observations of the Martian atmosphere over a wide altitude range, for the first time during Mars "dust storm season"

- **Atmospheric general structure**
  - Impact of **dust** on the general circulation
  - Characterize "**thermal tides**" and their sensitivity to dust
  - Observe **gravity waves** and help understand their impact on the mean flow: currently a key question in Mars atmospheric sciences !
- **Boundary layer** (parachute phase)
  - **Detect the top** of the daytime planetary boundary layer (PBL)
  - Observe the scale and intensity of the **turbulence**
  - Tentatively measure horizontal and/or vertical **winds** within the PBL

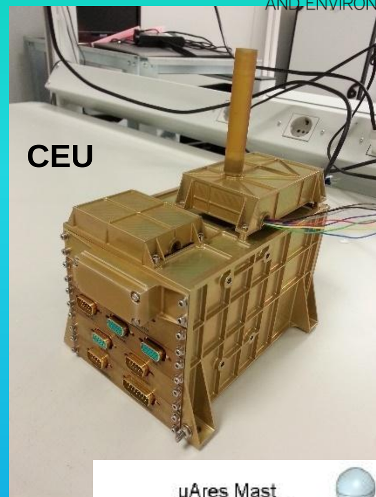


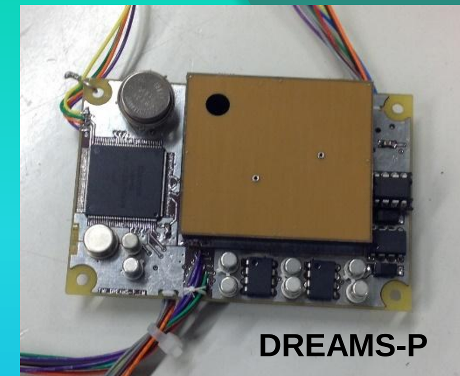

WLL 310 Kg

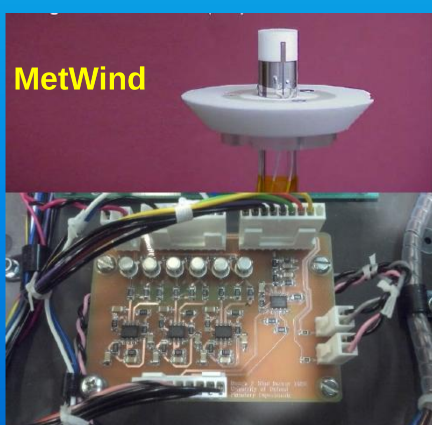
DREAMS

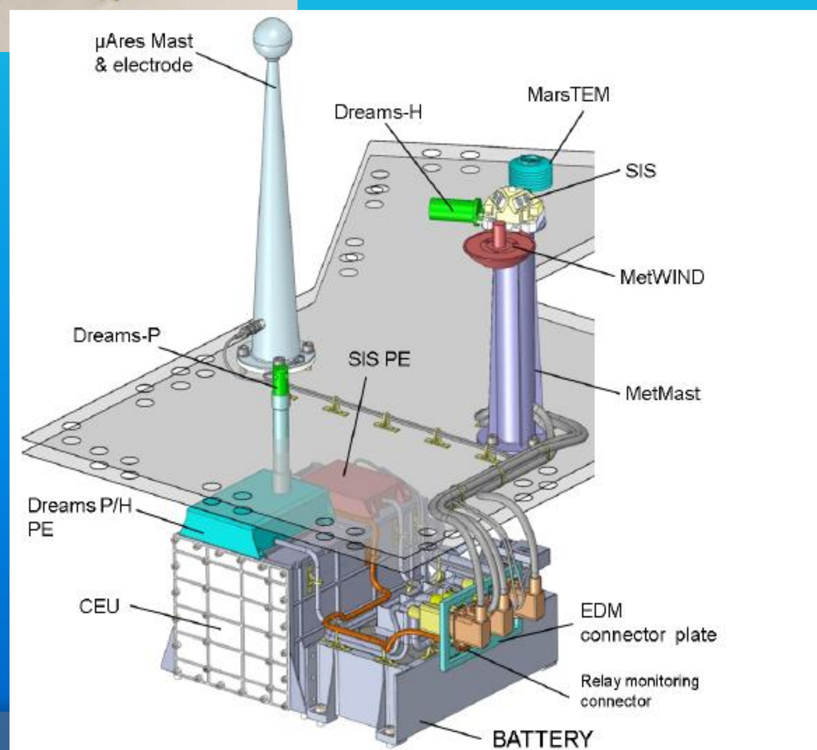
DUST CHARACTERIZATION, RISK ASSESSMENT
AND ENVIRONMENT ANALYSER ON THE MARTIAN SURFACE

μARES









DREAMS sensor specifications

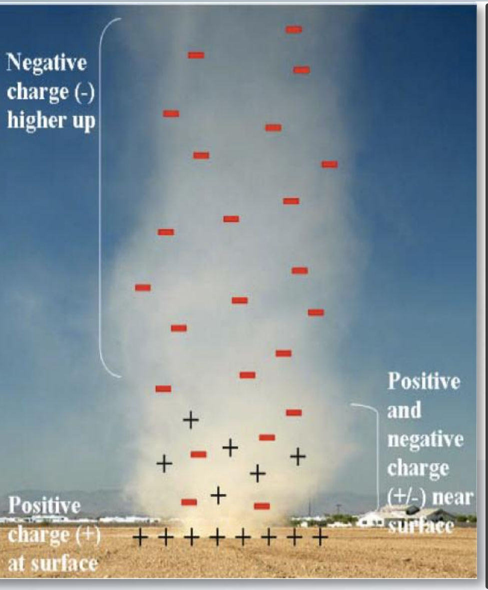
Instrument	Measured Quantity	Range	Resolution	Accuracy
MarsTem	Temperature	70 – 320 K	0.02 K	0.1 K
MetBaro	Pressure	0-1015 hPa	< 0.5 Pa	< 5 Pa (BOL)
MetHumi	Partial humidity	0-100%	0.5 % RH	± 2%RH at 0°C, ±5%RH at -40°C, ±8%RH at -70°C
MetWind	Wind speed Wind direction	0.3 – 30 m/s and above		+/- 1 m/s +/- 10° for wind speeds >5 m/s
MicroARES	Vertical Electric Field and potential	Freq.: DC to 2 kHz Ampl.: 10 mV/m to ~10 kV/m	DC channel: 3 mV/m AC channel: ~ $3\mu V/m.Hz^{1/2}$	10-50% (depending on lander perturbations)
ODS	Dust opacity Dust radius Cloud opacity	0.05 – 7 > 0.01 mm > 0.01	N/A N/A N/A	10% 20-30% 20%

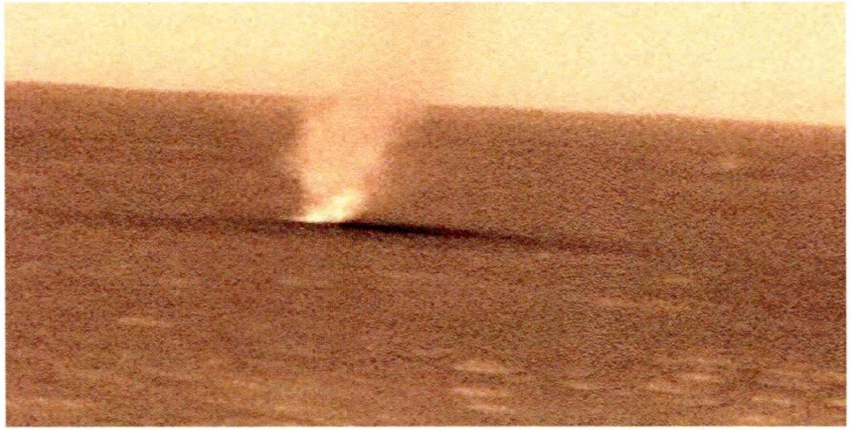
DREAMS shall establish the first ever investigation of atmospheric electric phenomena at Mars

Intense electric fields are expected at times of dust storms and in the vicinity of dust devils.

The "*atmospheric electric fields*" are related to atmospheric charging and discharging processes, possibly creating a global electric circuit on Mars.

Atmospheric electricity could play a significant role in the dust cycle, in chemistry, and shall be considered in the context of human exploration.



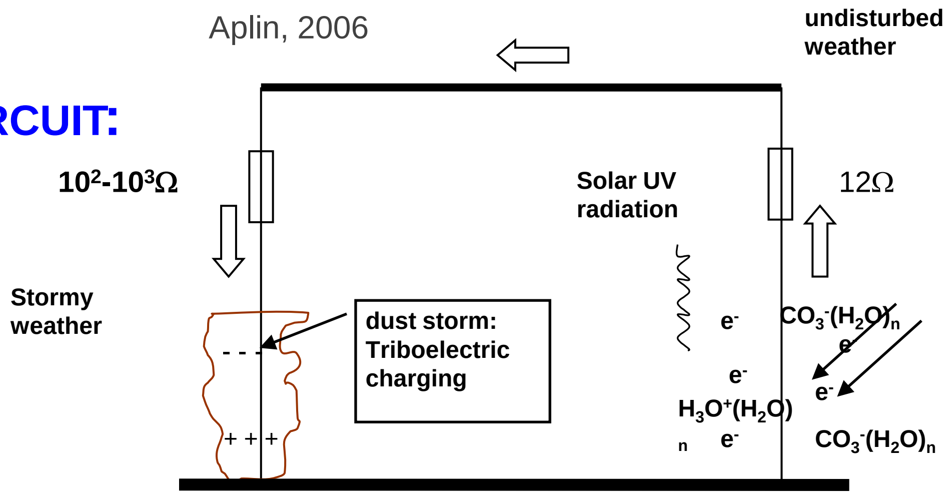


High voltages can be generated in dust devil vortex, they are theoretically limited by ***electrical breakdown*** *to ~25 kV/m.*

IDENTIFY A POTENTIAL MARS GLOBAL CIRCUIT:

- Dust storms/devils as generators?
- Conductive ionosphere and surface
- Slightly conductive atmosphere?

Aplin, 2006



DETECT ELECTRIC ACTIVITY GLOBALLY:

Identification of Schuman Resonances may be indicative of lightning activity anywhere on the planet.

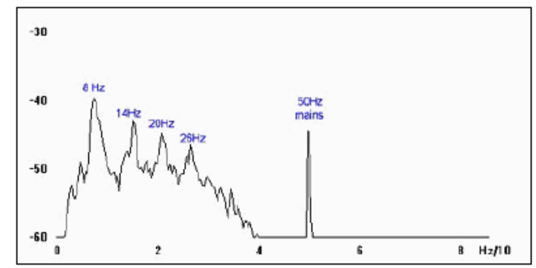
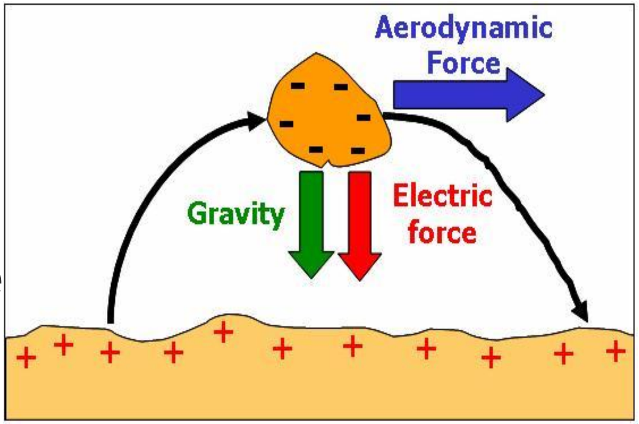


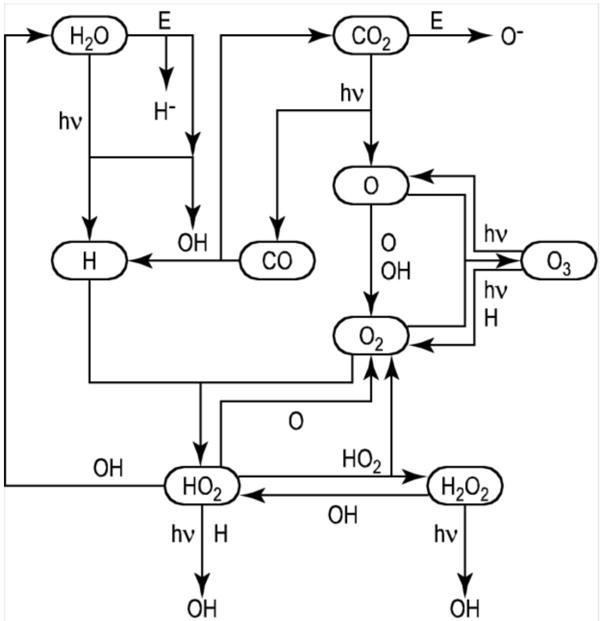
Figure 2.7- Résonances de Schumann relevées sur Terre.

PROVIDE NEW INSIGHTS INTO MARS DUST:

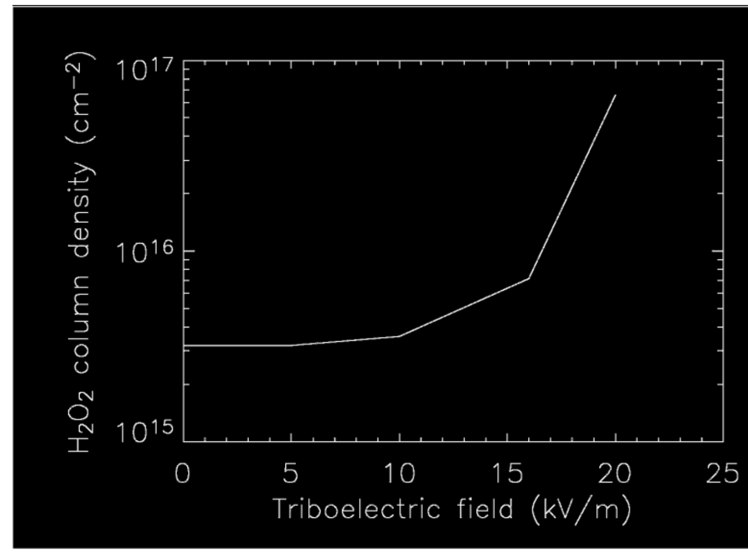
- Electric forces can enhance lifting
- Electric forces alter depth of saltation layer
- Electric forces may be a key player in dust cycle



PROVIDE NEW INSIGHTS INTO MARS CHEMISTRY



Oxidation enhancement under high electrostatic fields



Atreya et al., 2006

- Electric fields energize free electrons and enhance the rate of chemical reactions:

$$CO_2 + e^- \rightarrow CO + O^- \quad \& \quad H_2O + e^- \rightarrow OH + H$$

- According to models (Atreya, 2006), H_2O_2 (HO**x**) production of can be increased by a factor of 200, thereby oxydizing capacity of Martian atmosphere

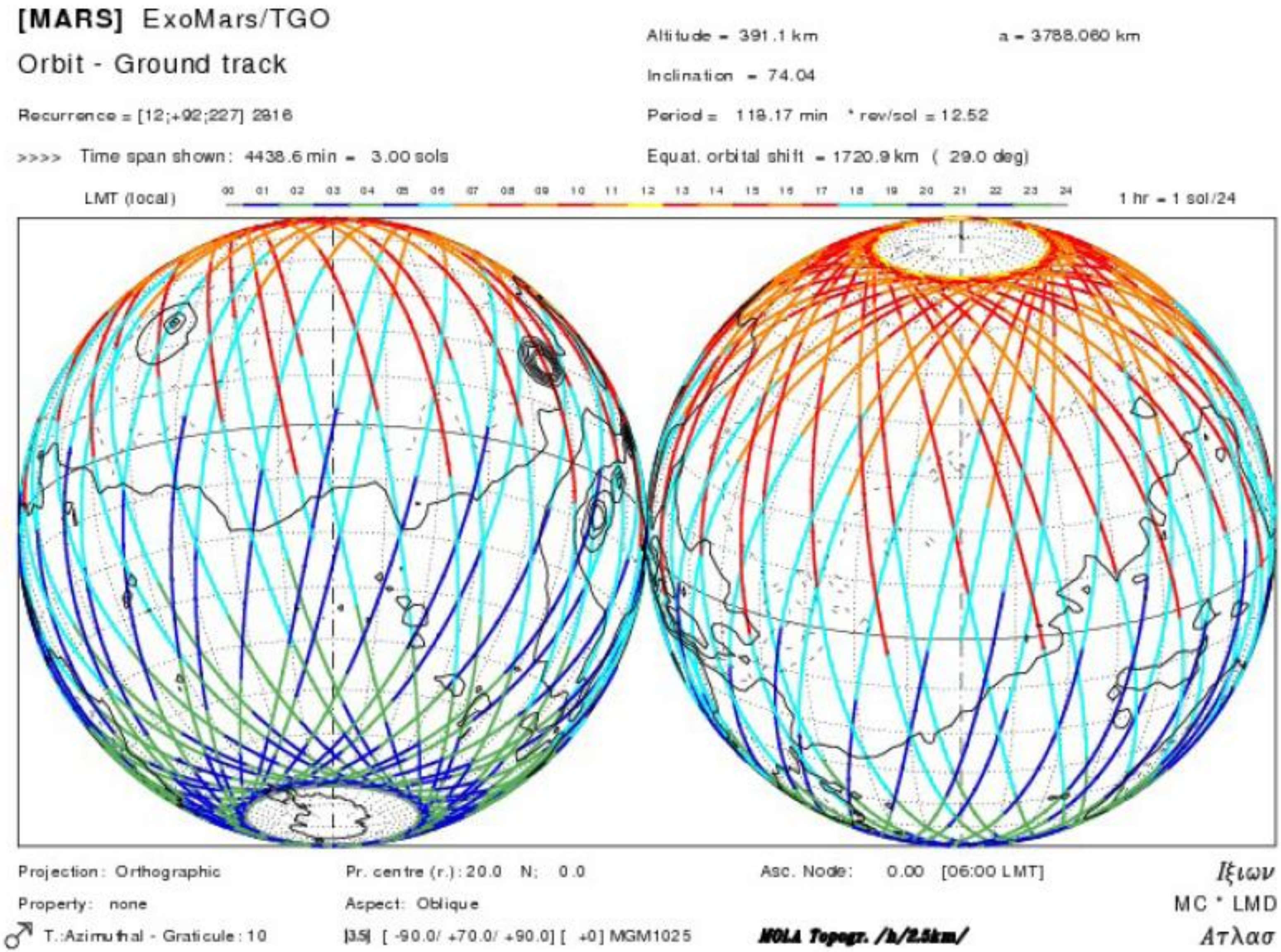
Trace Gas orbiter tests
(Canne, 04/2015)

Trace Gas orbiter
(Canne, 25/11/2015)

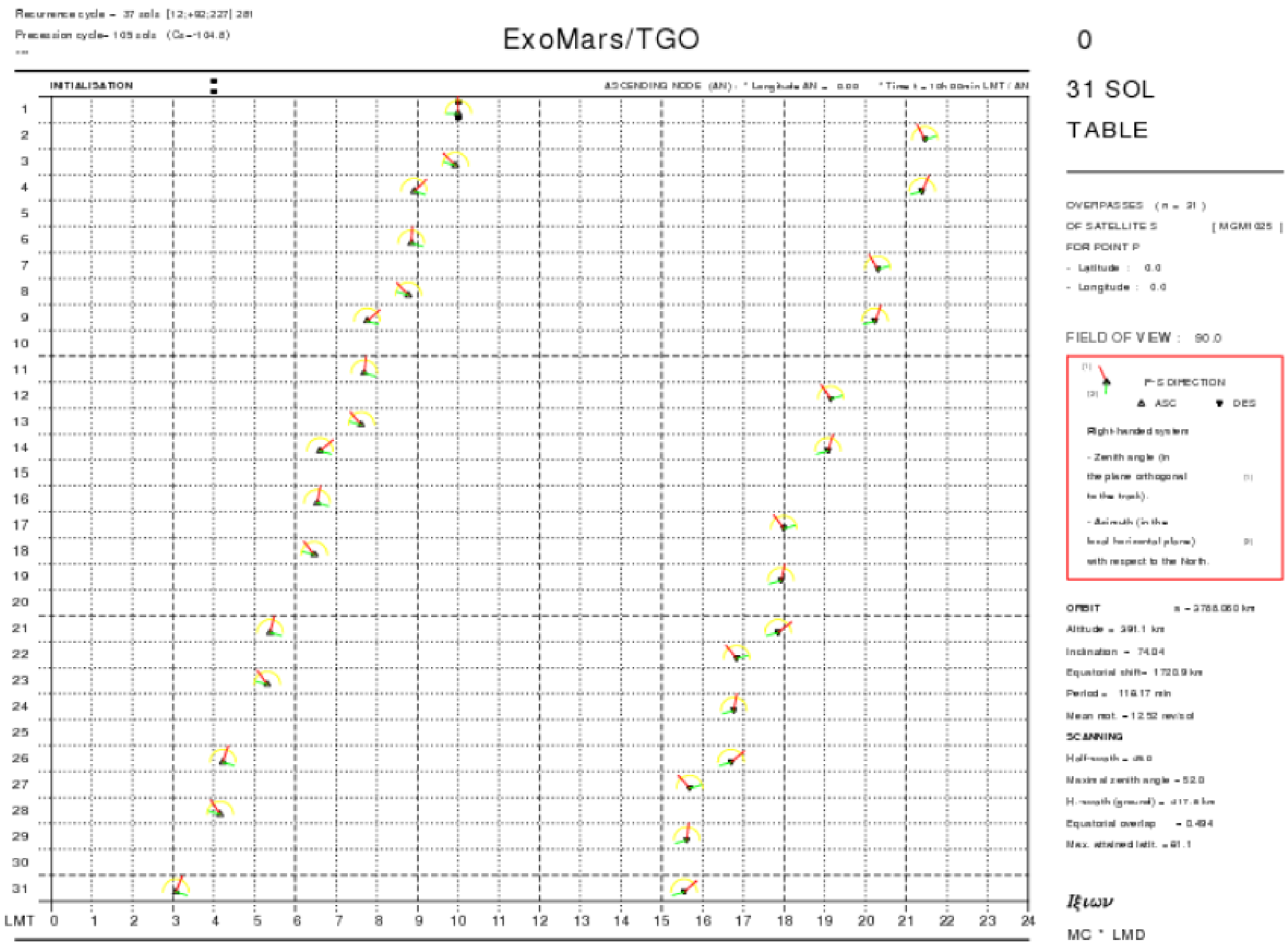
Trace Gas orbiter

- Launch 14-25/03/2016
- Orbit Insertion 19/10/2016
- Some science, then aerobraking until ~10/2017
- Science orbit:
  - Orbit circular 119 min (~40 min eclipse)
  - 373 revolutions over 30 sols (373:30)
  - Altitude 400 km; inclination 74 deg
  - Nadir pointing except for solar occultation

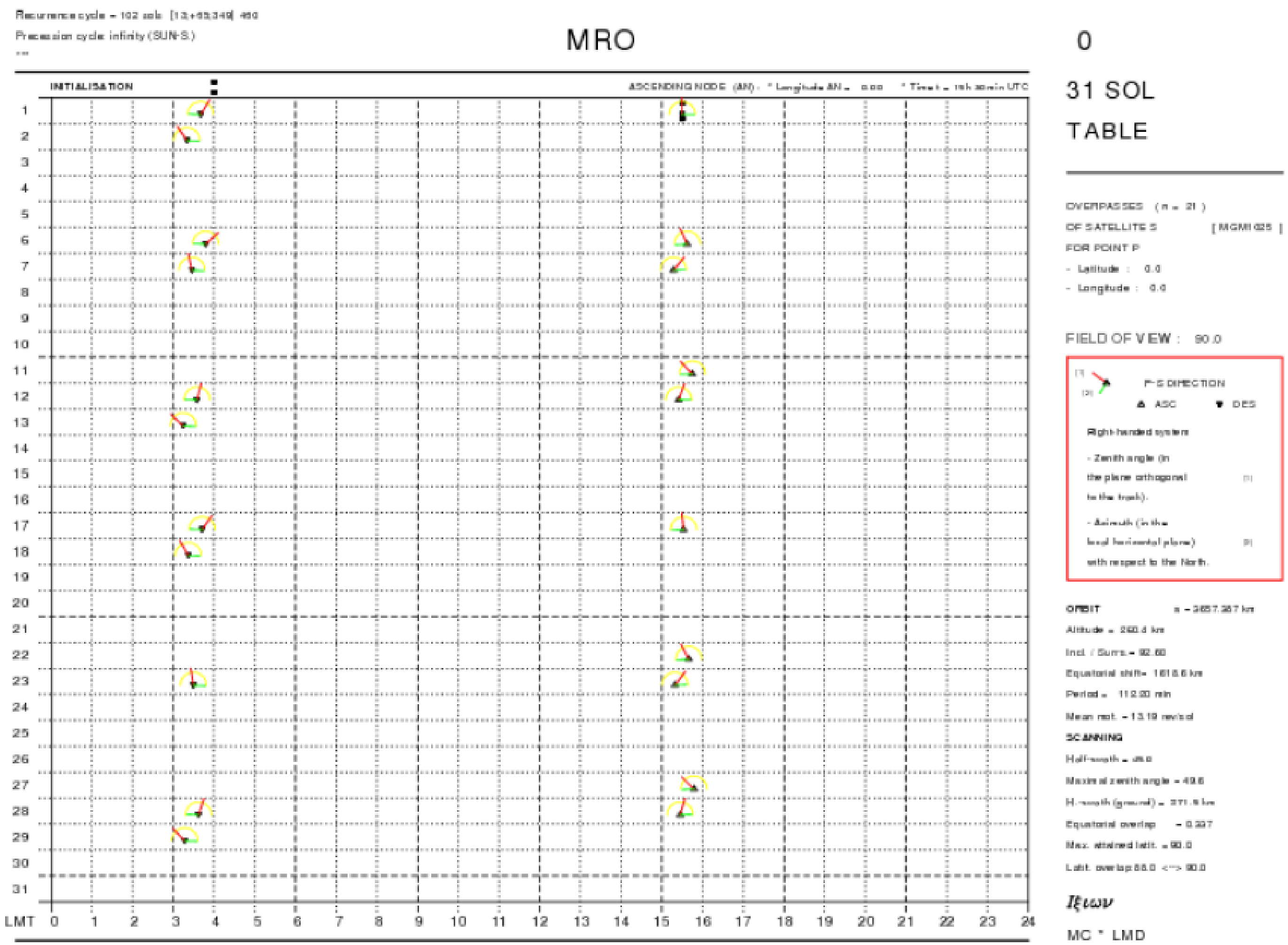
Exomars Science Orbit



TGO local time at 0°N 0°E



MRO local time at 0°N 0°E

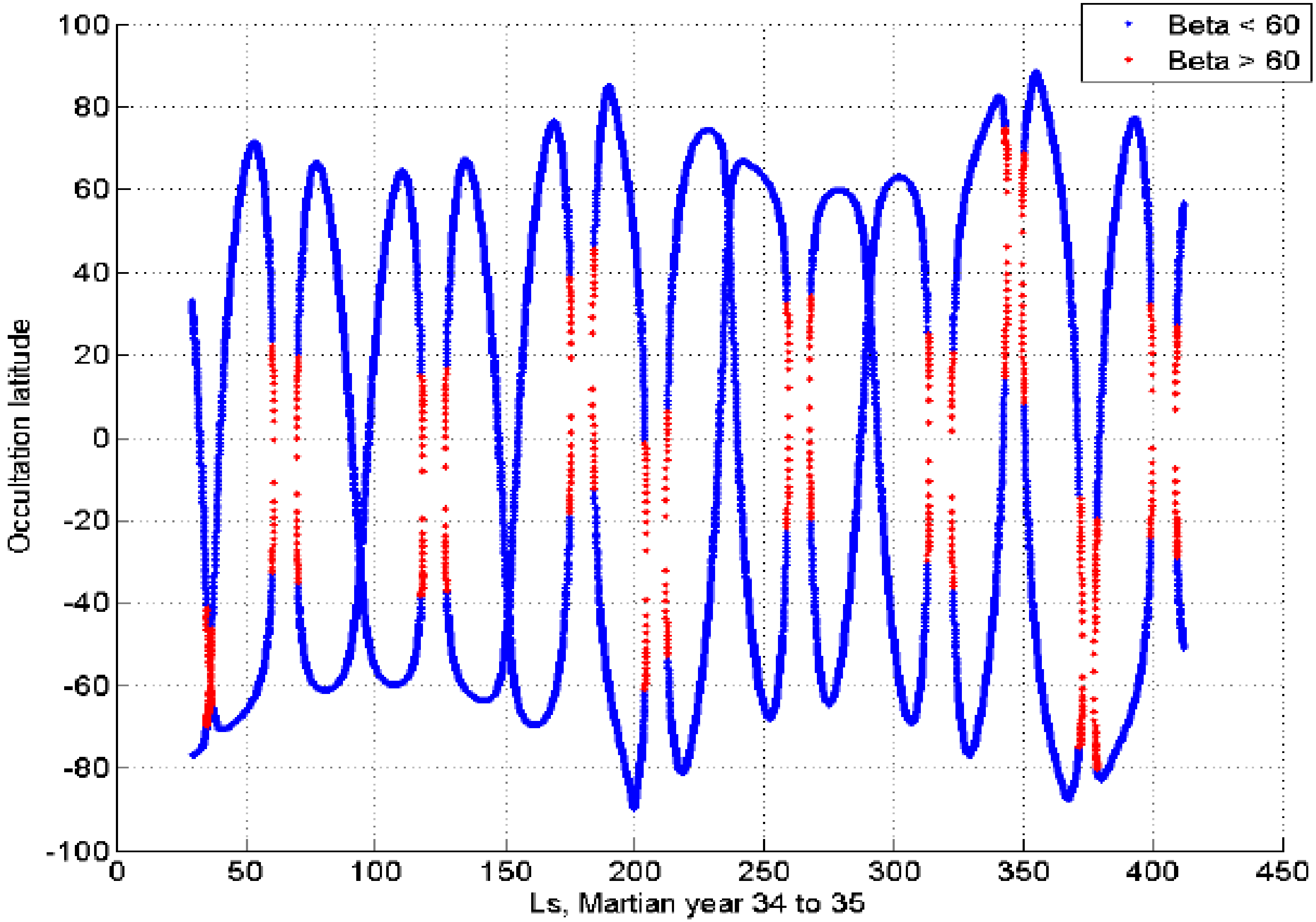


Ixion software:
http://climserv.ipsl.polytechnique.fr/ixion.html

Solar occultations:

24 profiles per day (12 ingress+12 egress)

Example:



TGO science instruments

E X O M A R S

NOMAD

High resolution occultation and nadir spectrometers

Atmospheric composition (CH_4,O_3, trace species, isotopes) dust, clouds, P&T profiles

Channel	Resolving power	Modes
UVIS (0.20 – 0.65 μm)	$\lambda/\Delta\lambda$ ~ 250	SO, Limb, Nadir
IR (2.3 – 3.8 μm)	$\lambda/\Delta\lambda$ ~ 10,000	SO, Limb, Nadir
IR (2.3 – 4.3 μm)	$\lambda/\Delta\lambda$ ~ 20,000	SO

CaSSIS

High-resolution camera

Mapping of sources; landing site selection

5 m/px 3-colour imaging and panchromatic stereo

ACS

Suite of 3 high-resolution spectrometers

Atmospheric chemistry, aerosols, surface T, structure

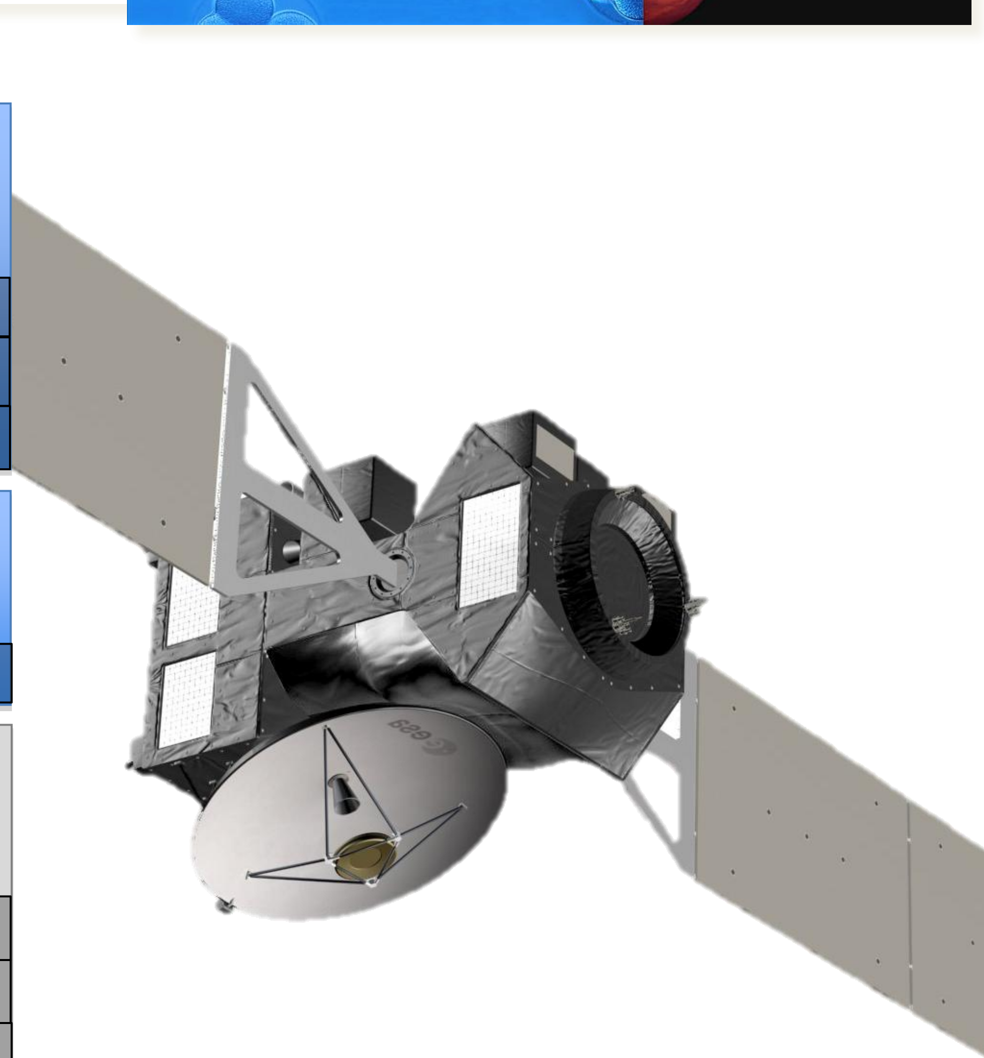
Channel	Resolving power	Modes
Near IR (0.7 – 1.7 μm)	$\lambda/\Delta\lambda$ ~ 20,000	SO, Limb, Nadir
IR (Fourier, 2 – 25 μm)	$\lambda/\Delta\lambda$ ~ 4000 (SO)/500 (N)	SO, Nadir
Mid IR (2.2 – 4.5 μm)	$\lambda/\Delta\lambda$ ~ 50,000	SO

FREND

Collimated neutron detector

Mapping of subsurface water

All resolving power figures $\lambda/\Delta\lambda$ are calculated at mid-range



ExoMars Project

ESA + NASA TGO configuration → ESA + Roscosmos TGO configuration

ESA + NASA TGO configuration

NOMAD
High resolution occultation and nadir spectrometers
Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles

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UVIS (0.20 – 0.65 μm) λ/Δλ ~ 250	SO, Limb, Nadir
IR (2.3 – 3.8 μm) λ/Δλ ~ 10,000	SO, Limb, Nadir
IR (2.3 – 4.3 μm) λ/Δλ ~ 20,000	SO

MATMOS
High-Resolution FT spectrometer
Vertical distribution of water, methane and trace species

Channel	Modes
Infrared (2.3 – 12 μm) λ/Δλ ~ 130,000	SO

EMCS
Limb radiometer
Monitoring of atmospheric structure, water and aerosols

MAGIE
Wide-angle camera
Monitoring of clouds and ozone

HiSCI
High-resolution camera
Mapping of sources; landing site selection

ESA + Roscosmos TGO configuration

NOMAD
High resolution occultation and nadir spectrometers
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CaSSIS
High-resolution camera
Mapping of sources; landing site selection

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Suite of 3 high-resolution spectrometers
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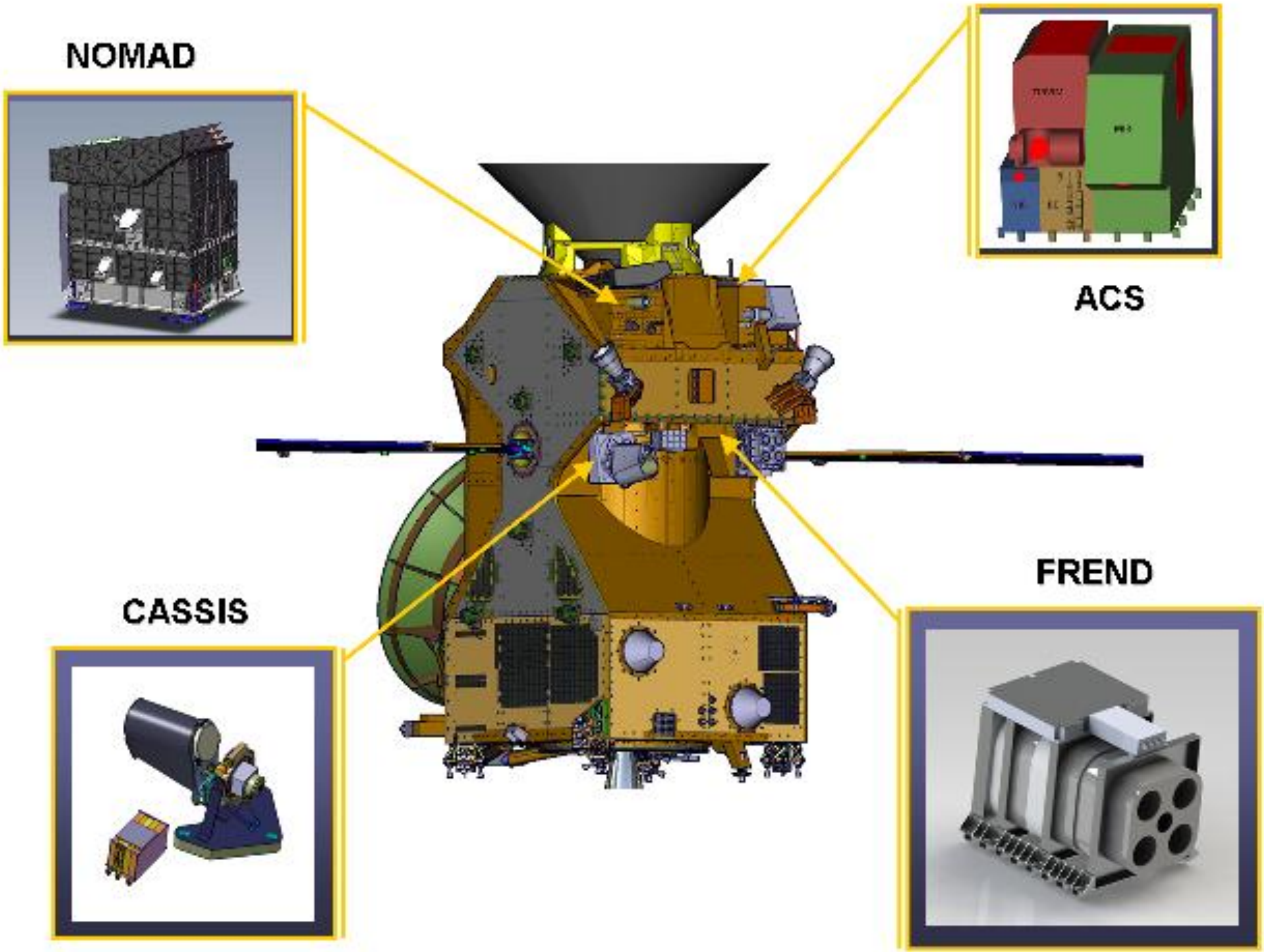
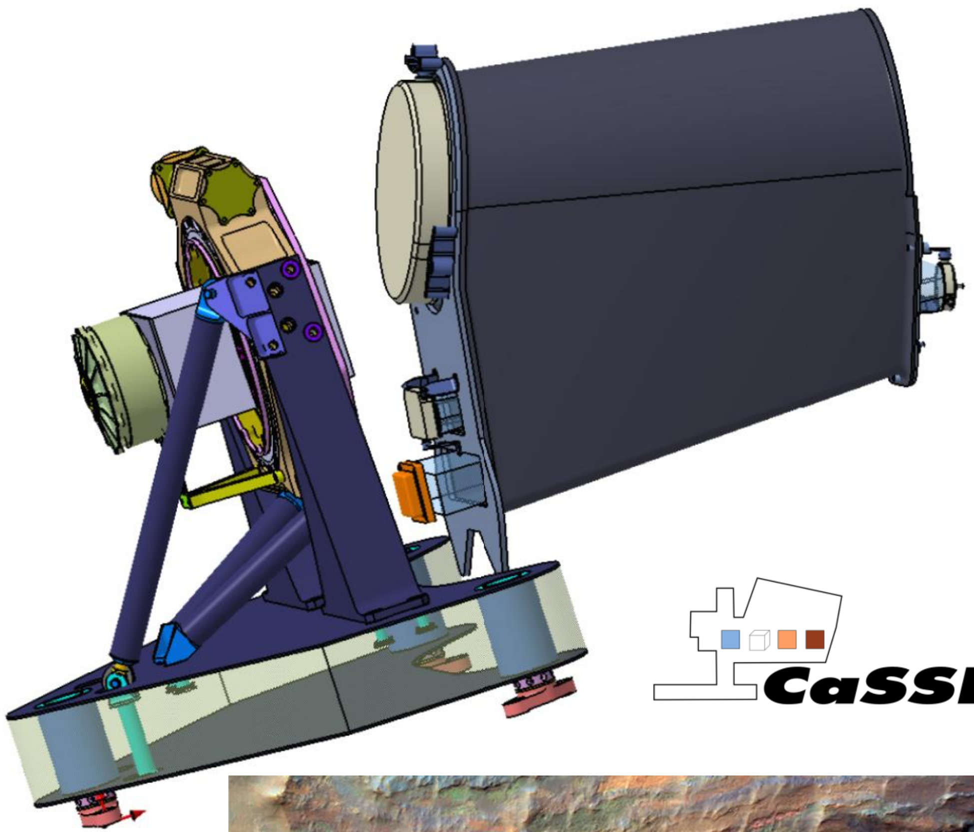
Mid IR (2.2 – 4.5 μm) λ/Δλ ~ 50,000	SO

FREND
Collimated neutron detector
Mapping of subsurface water

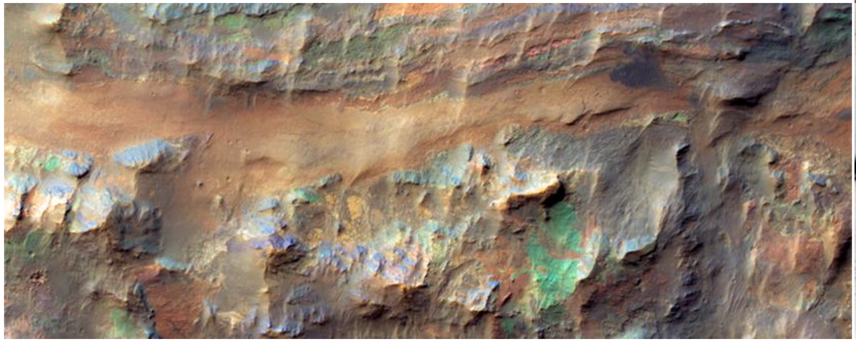


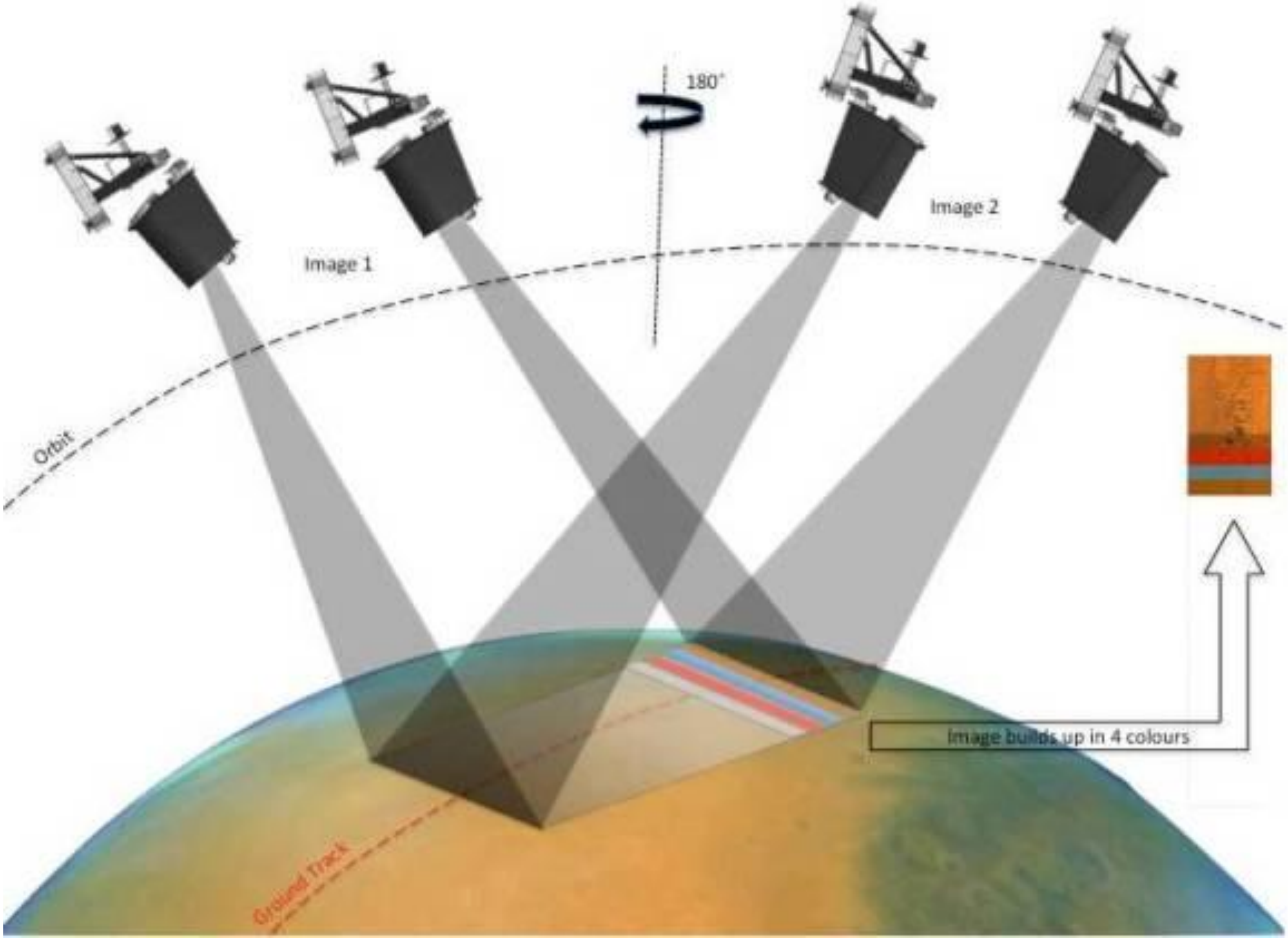
NOMAD
ACS
CASSIS
FREND

CaSSIS - Colour and Stereo Surface Imaging System



CaSSIS




180°
Image 1
Image 2
Orbit
Image builds up in 4 colours
Ground Track

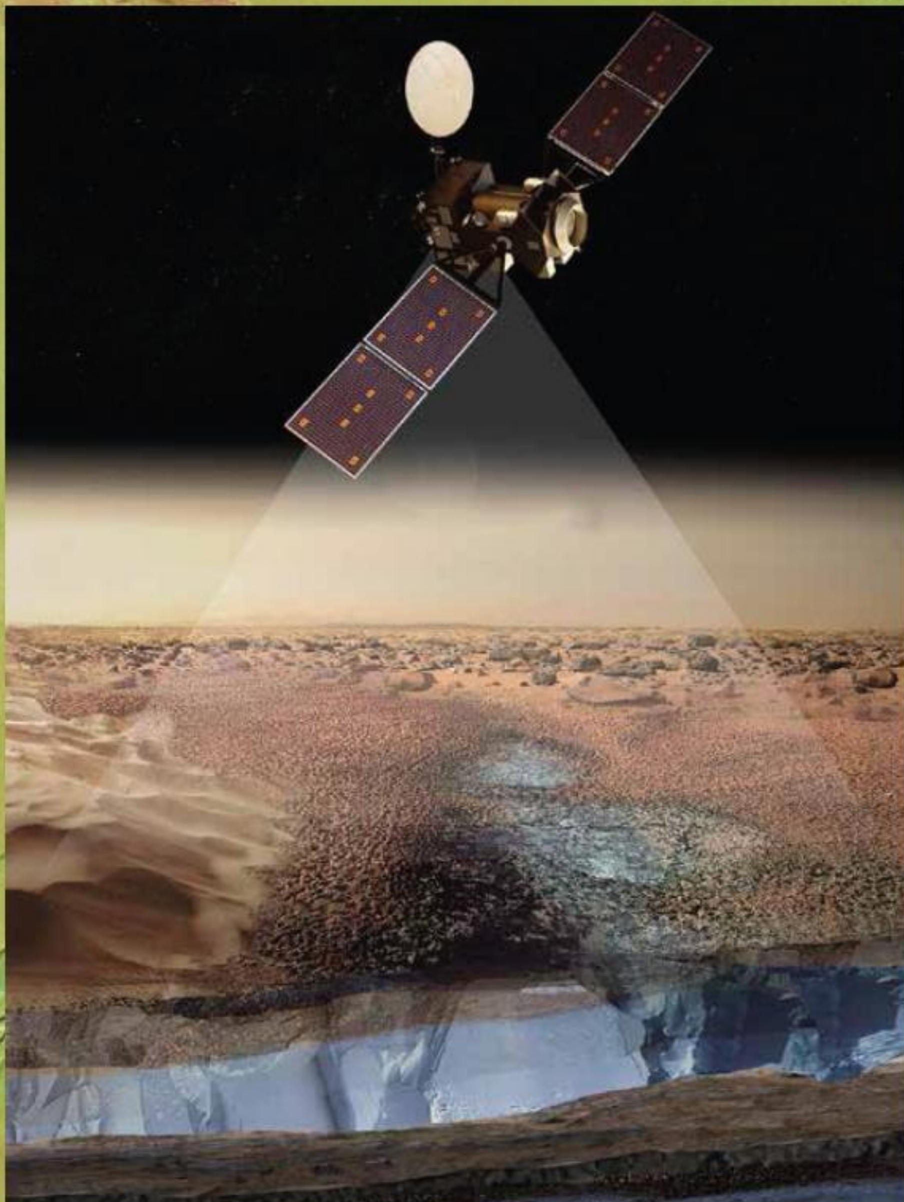
esa

CaSSIS – Basic Properties

Imaging at ≤ 5 m/px (≤ 10 m resolution) compromise because of constraints
Individual image size of >8km x >8km increase coverage over HiRISE
Stereo coverage to provide ≤ 10 m vertical resolution characterize landing sites & local topography
Colour in 3 bands extend the colour coverage of HiRISE

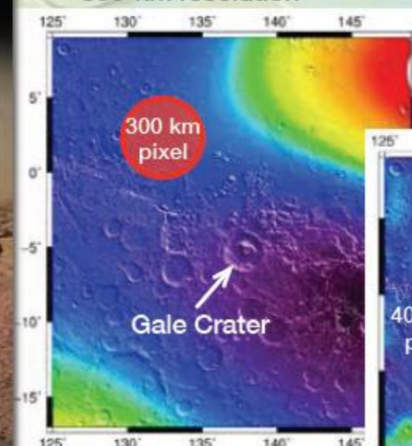
Fine Resolution Epithermal Neutron Detector (FREND)

Subsurface Water/Hydrogen

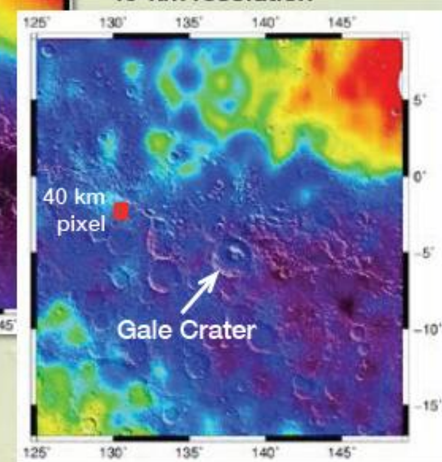



FREND

HEND/Odyssey data, 300-km resolution



Simulation of FREND/TGO data based on HEND/Odyssey, 40-km resolution

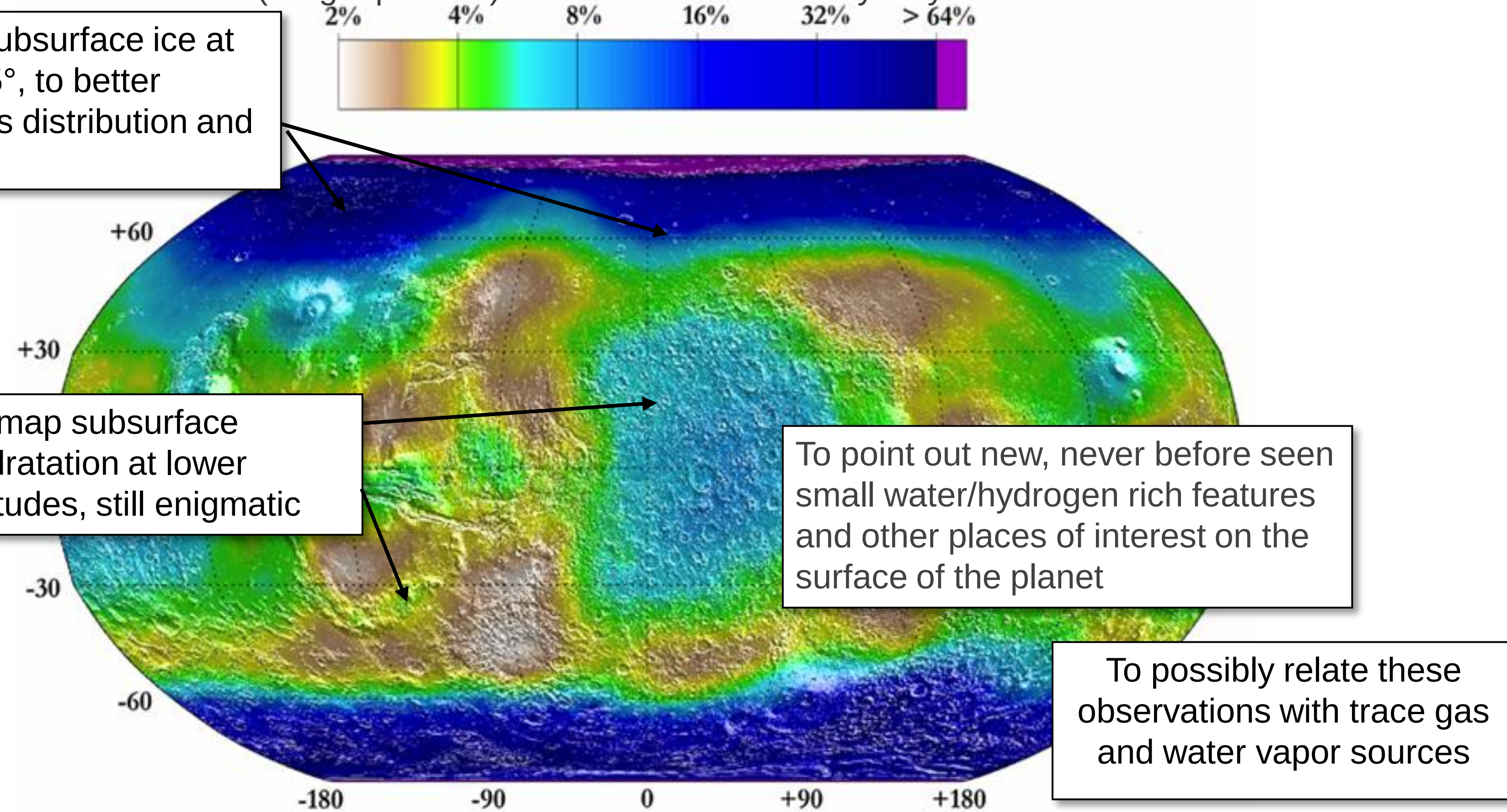


Fine Resolution Epithermal Neutron Detector (FREND)

High resolution mapping of the subsurface (0 - 1m depth) hydrogen (and by inference H_2O) content with a neutron detector.

⇨ *Will resolve the features detected by Mars Odyssey, with a <u>ten times better spatial resolution</u> (40 km)*

Minimum water equivalent hydrogen abundance
(weight percent) deduced from Mars Odyssey observations



Fine Resolution Epithermal Neutron Detector

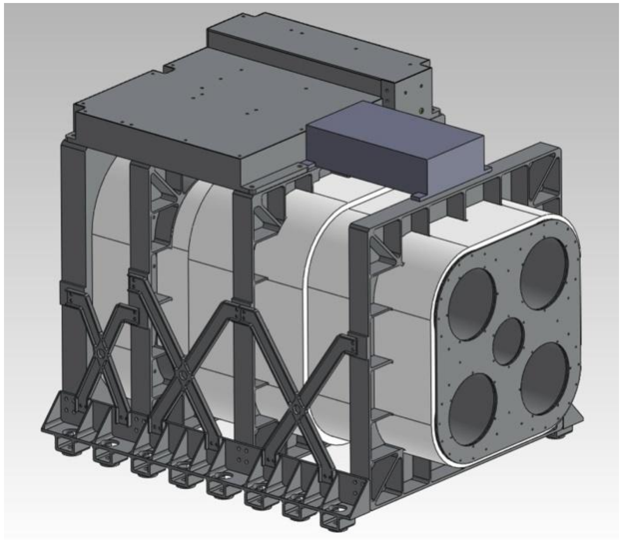
Energy ranges:
Epithermal neutron detectors: 0.4 eV – 500 keV
Fast neutron detector: 0.5 – 10 MeV

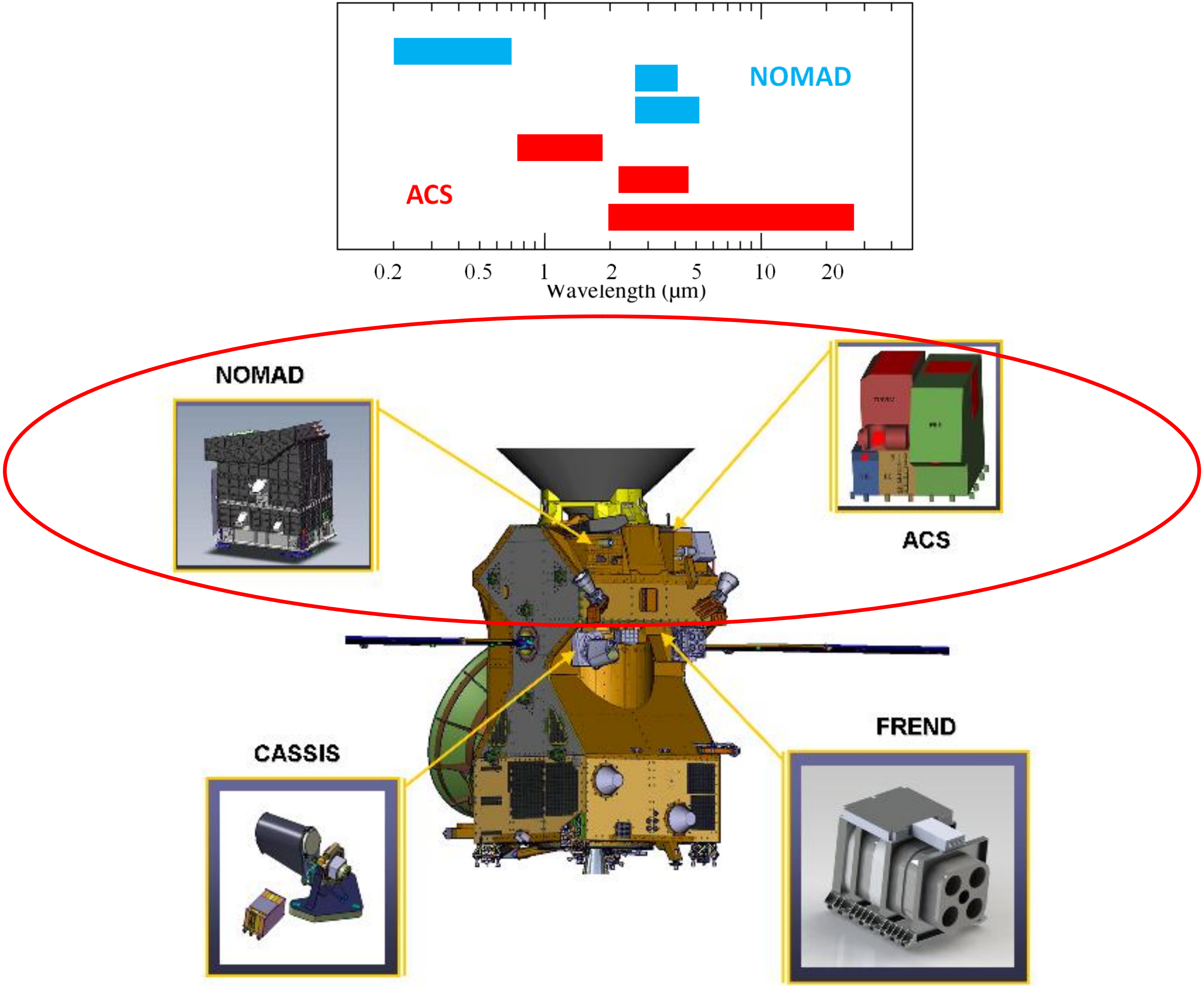
Time resolution: 5 s

Spatial resolution: ~ 40 km from 400 km orbit:10 times better than HEND (Mars-Odyssey)

Mass: 36 kg

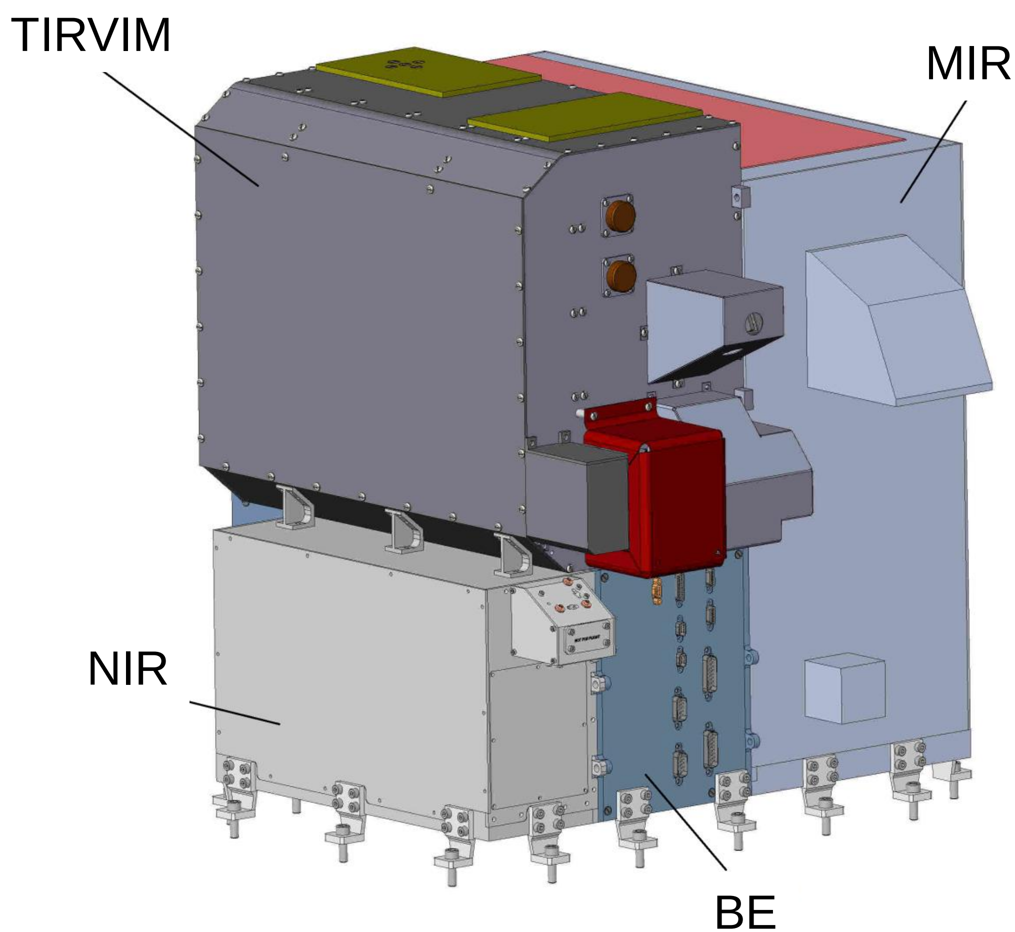
Power: 11W





NOMAD
ACS
0.2
0.5
1
2
5
10
20
Wavelength (μm)
NOMAD
ACS
CASSIS
FREND

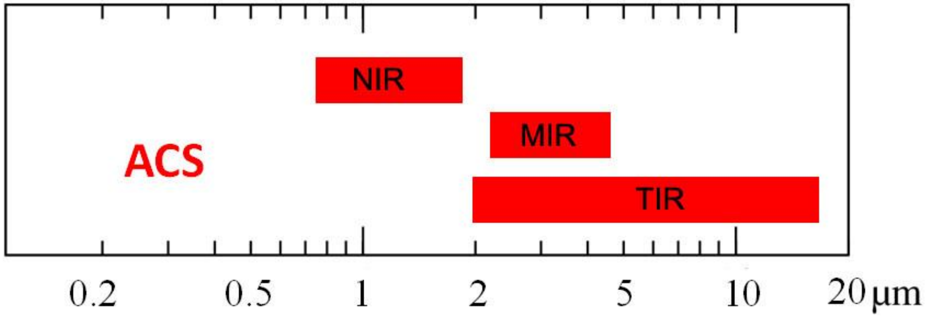
ACS : 3 spectrometers

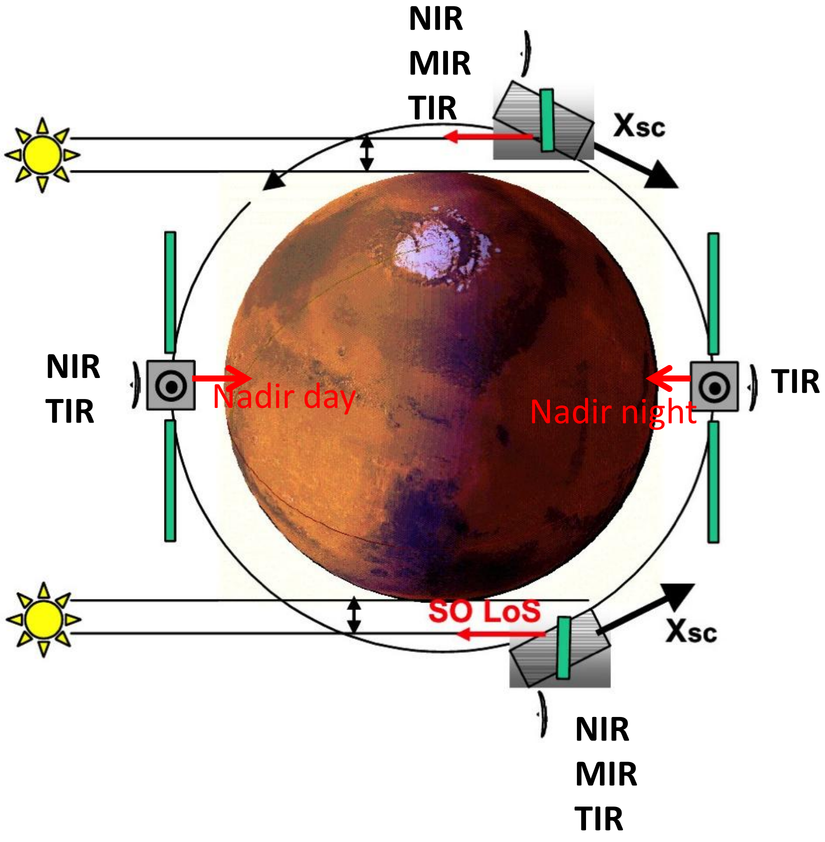


ACS Intro

	Spectral range	Inst. range	Spectral resolution
ACS/MIR	2.3-4.2 µm	0.1-0.25 µm	>40 000
ACS/NIR	0.75-1.7 µm	~0.17 µm	>24 000
ACS/TIR VIM	1.7-17 µm	full range	$0.25 cm^{-1}$ occ $1.6 cm^{-1}$ nad

Mass:	33.5 kg
Dimensions:	$600\times470\times520\ mm^3$
Power consumption:	55 W (ave)
Data rate:	1600 Mbit/day

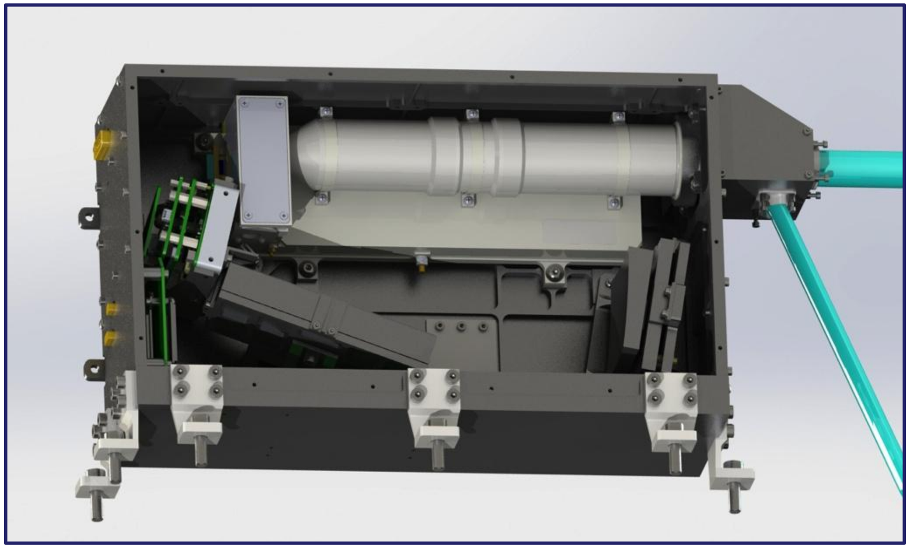


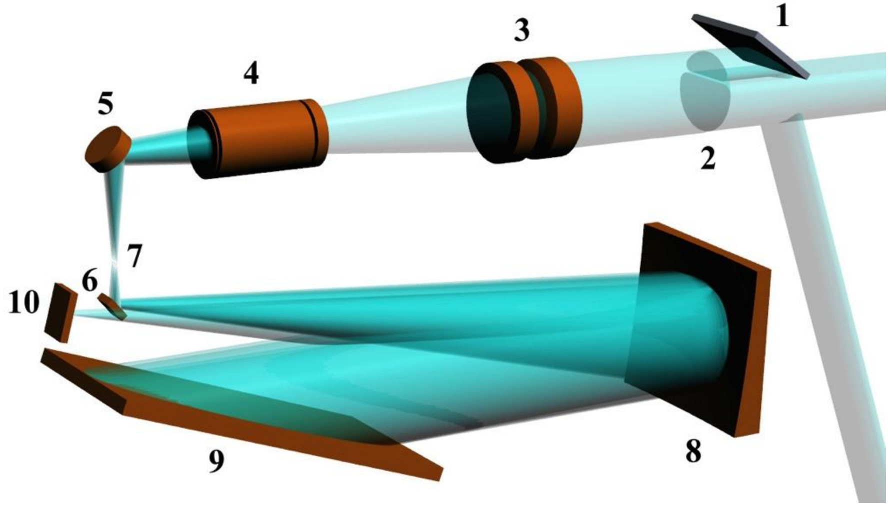


ACS NIR

Near-IR, echelle-AOTF spectrometer

• Spectral range:	0.7 – 1.6 µm (not covered by other instruments)
• Spectral resolving power $\lambda/\Delta\lambda$:	~20 000
• Operation modes:	Nadir, Solar Occultation
• FOV:	30 x 0.3 mrad
• Mass / Power / Data rate:	3.5 kg / 15 W / 0.5 Gbit/day

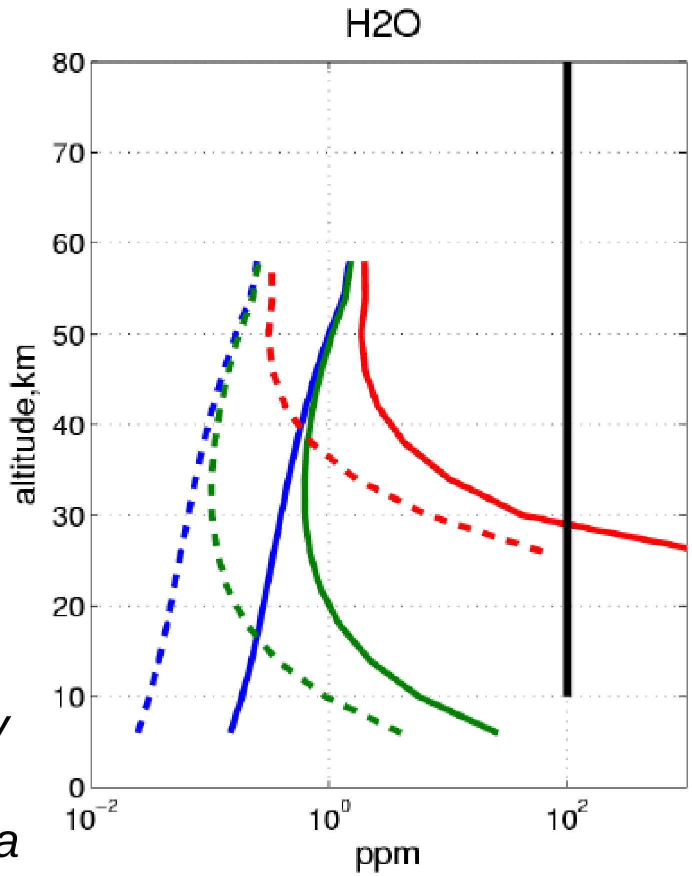


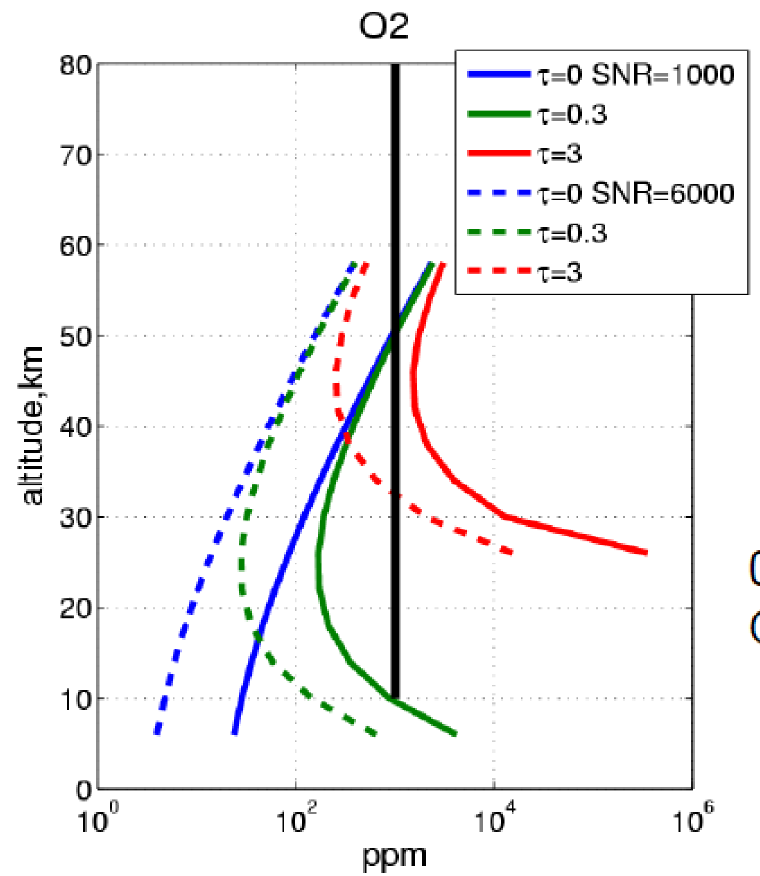


NIR spectrometer (solar occultation)

- Up to 10 orders for 1 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 -120 km
- H_2O 0-80 km
- **O_2** 0-50 km
- Aerosols 0 – 80 km



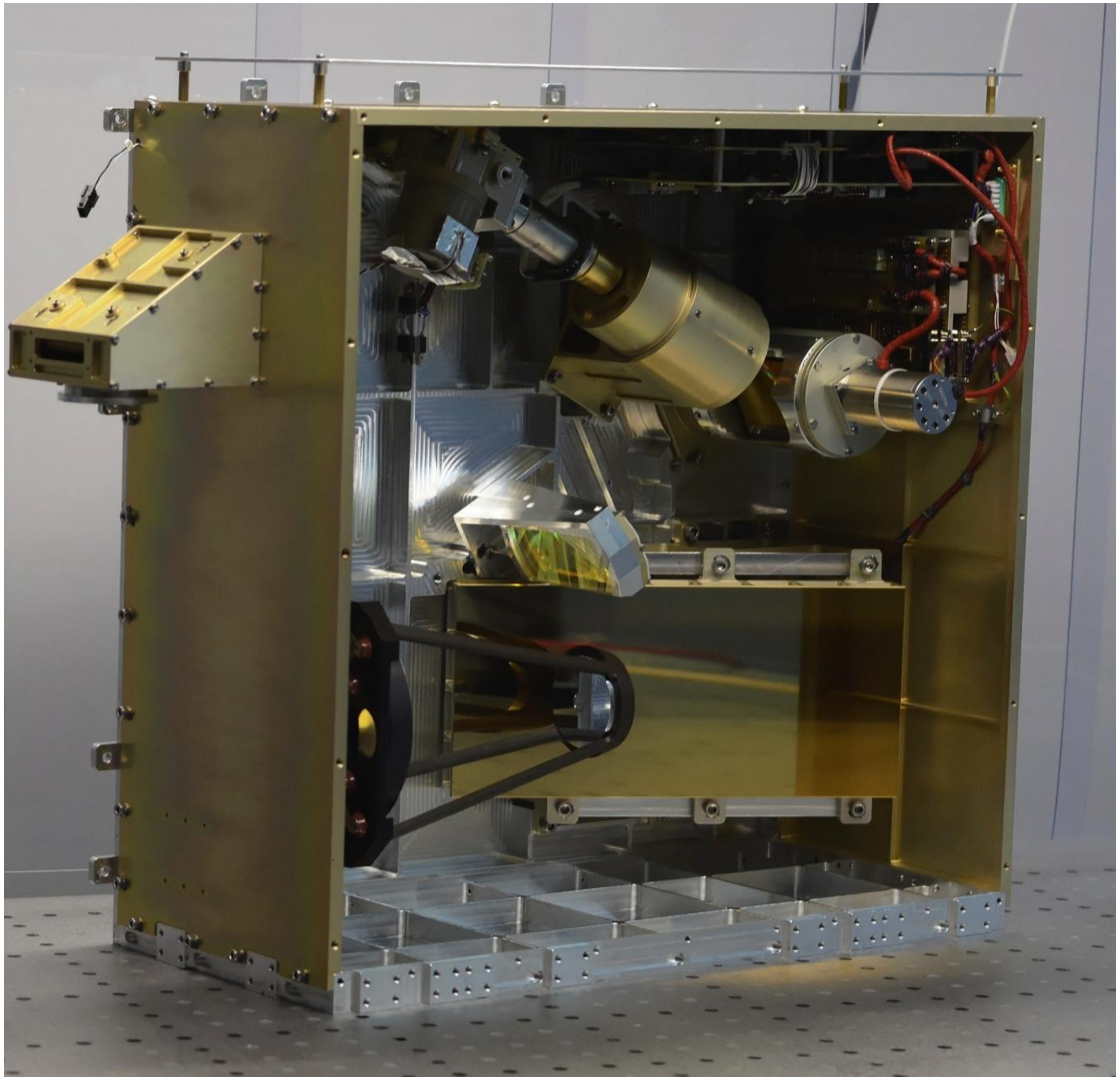


0.13% of O_2

Courtesy of Anna Fedorova

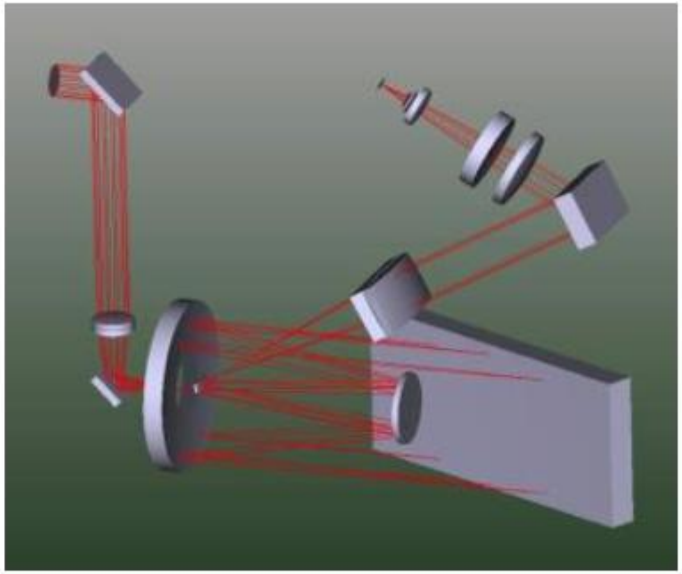
ACS MIR

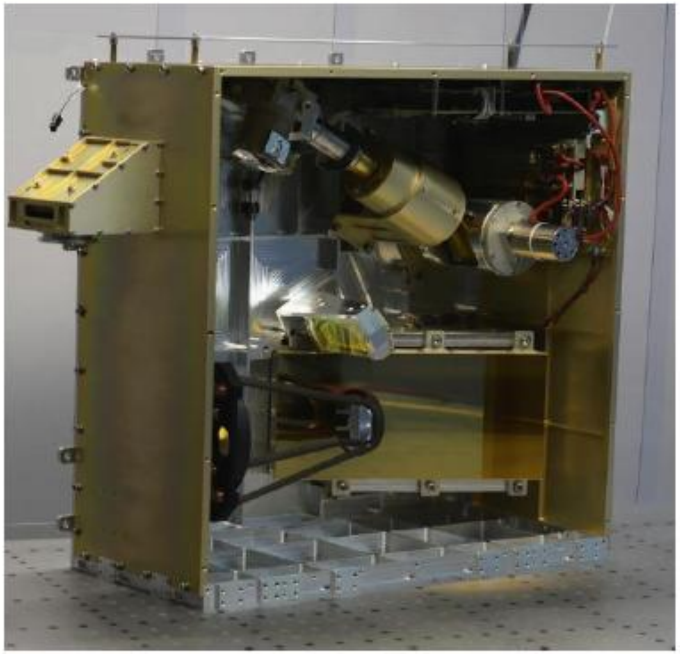
QM



MIR: Mid-IR Echelle/cross-dispersion

• Spectral range:	2.3 – 4.2 µm
• Instantaneous coverage:	230-300 nm ranges per measurement
• Spectral resolving power:	~50 000 in methane range
• FOV:	0.1 x 2.9 mrad
• Aperture ratio	1:3
• Operation modes:	Solar Occultation
• Operation rate	1-2 images/s
• S/N	>500
• Mass/ Power / Data:	12 kg / 20 W / 1.2 Gbit per day
• Dimensions	460 x 200 x 440 mm

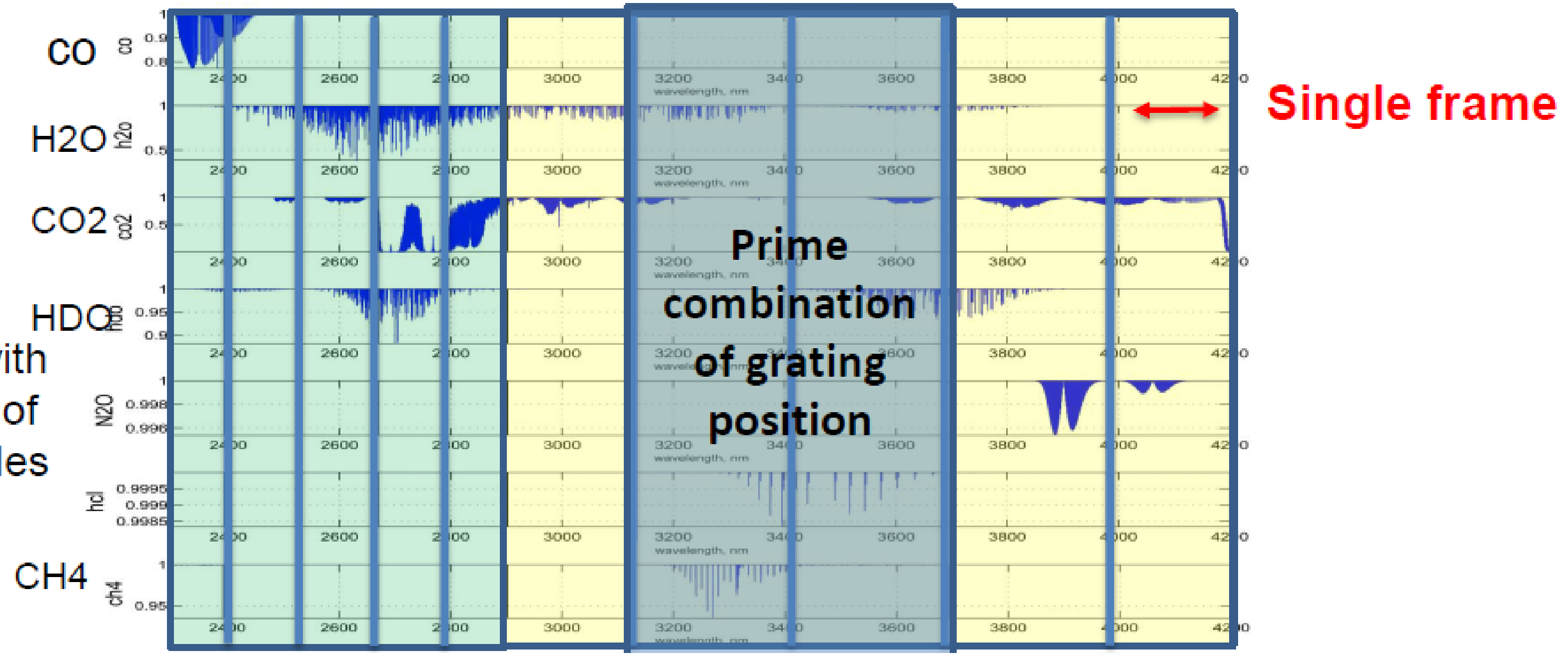




MIR spectral coverage

№ position	Relative angle	Grating	Min wavelength	Max wavelength	Coverage, nm
2	7,5	361	2,7900	2,8986	109
3	5,7	361	2,6652	2,7899	125
4	3,9	361	2,5294	2,6651	136
5	2,1	361	2,3970	2,5293	132
6	0,3	361	2,3043	2,3970	93
7	-1,5	"center"			
8	-3,3	180	3,9844	4,2095	225
9	-5,1	180	3,6883	3,9842	296
10	-6,9	180	3,4136	3,6882	275
11	-8,7	180	3,1269	3,4135	287
12	-10,5	180	2,8569	3,1268	822

0,42 sec per position (including 100 ms per position change)

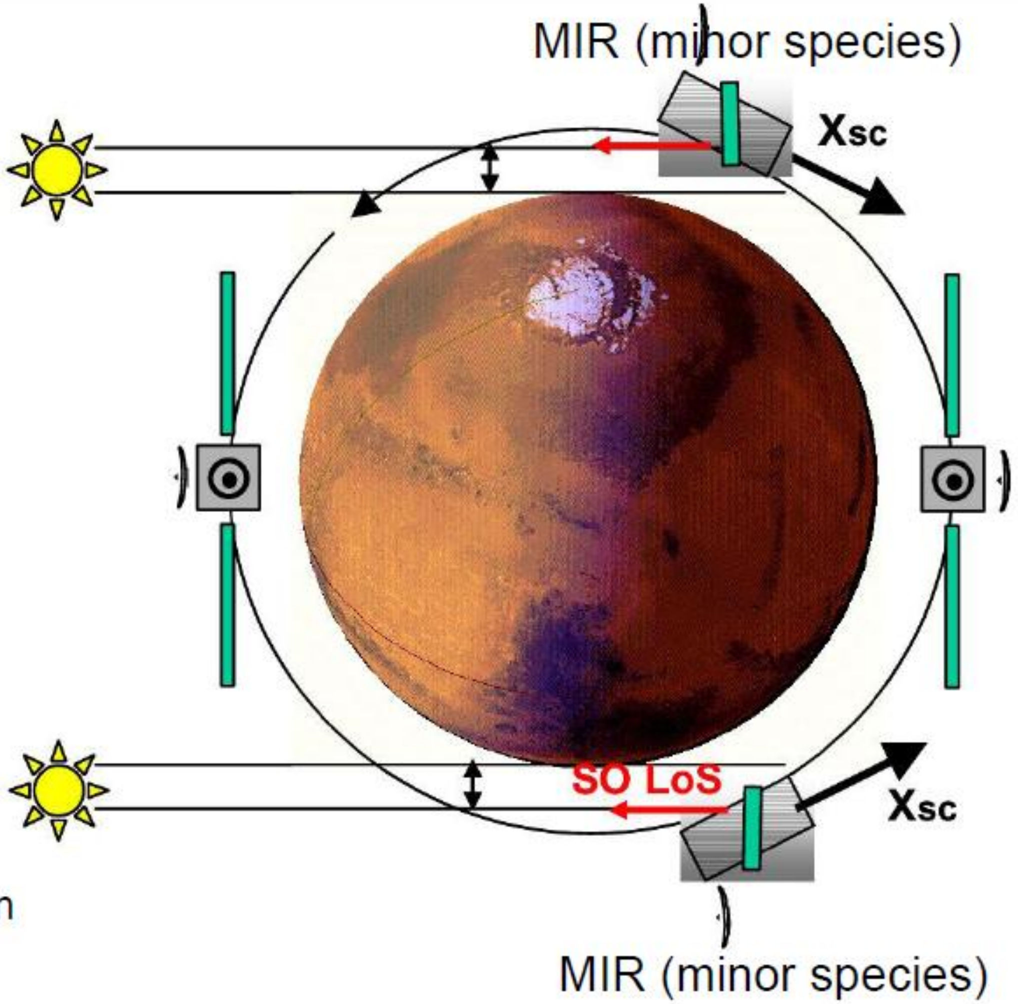


Transmittance with absorption lines of different molecules ***at 22 km*** during occultation

Occultation by MIR

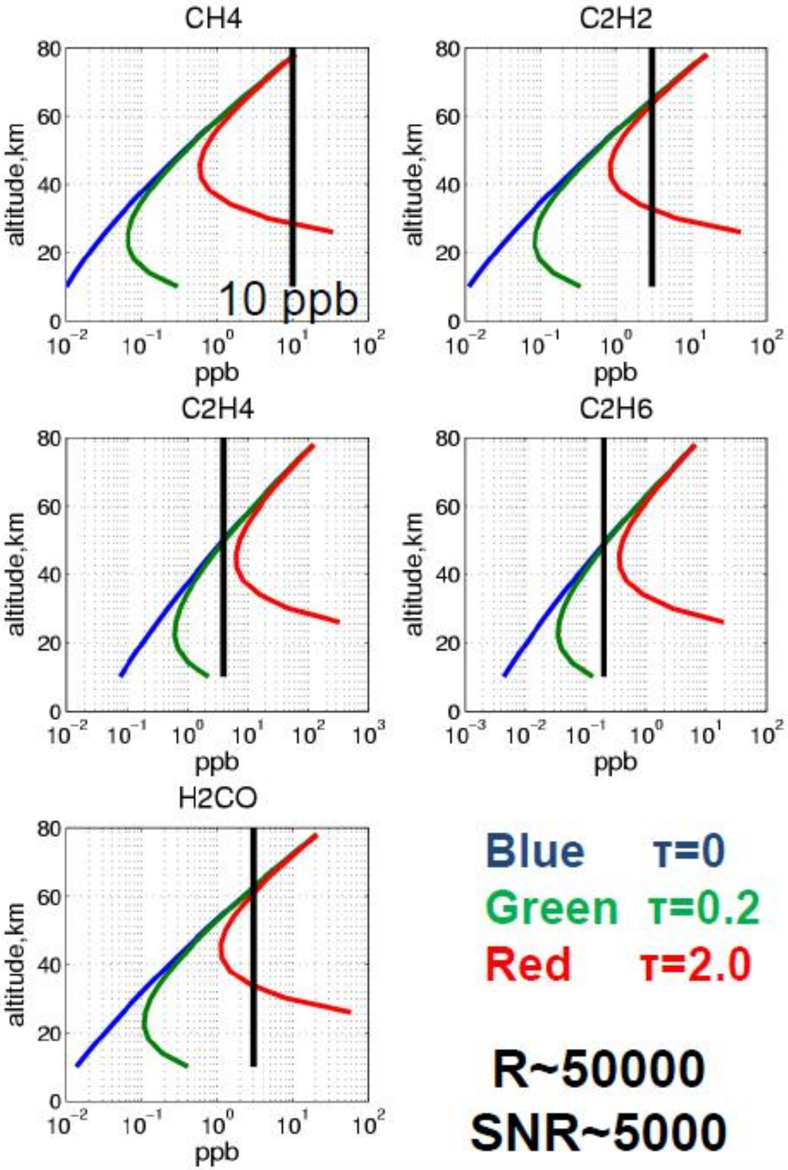
Solar occultation

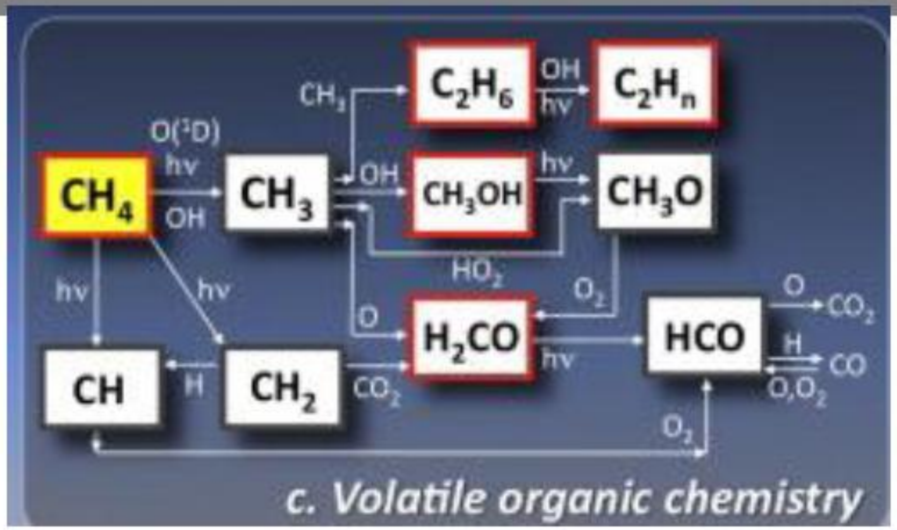
- **Spectral resolution for the latest calibration ~ 50000**
- **SNR ~1000 (for single pixel with 32 averaging – preliminary calibration results) ~5000 optimistic after the averaging of lines**
- Vertical resolution in SO ~1 km?
- 1 sec for measurements – 2 position of secondary grating angle
- **CO_2** 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_2CO, HCl, OCS etc.**



Courtesy of Anna Fedorova

Organic chemistry –detection capability





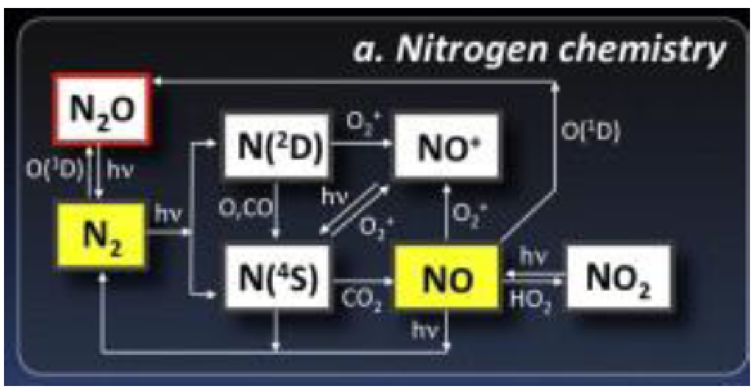
Villanueva et al., 2013

Species	Scientific Objective	Current Knowledge	λ, µm	Detection limit
Trace species				
CH_4	Profiles, detection	0-30 ppb	**3.3**	0.02 ppb
C_2H_2	Detection	<3 ppb	**3**	0.025 ppb
C_2H_4	Detection	<4 ppb	**3.2**	0.2 ppb
C_2H_6	Detection	<0.2 ppb	**3.3**	0.01 ppb
H_2CO	Detection	<3 ppb	**3.6**	0.03 ppb

Nitrogen components

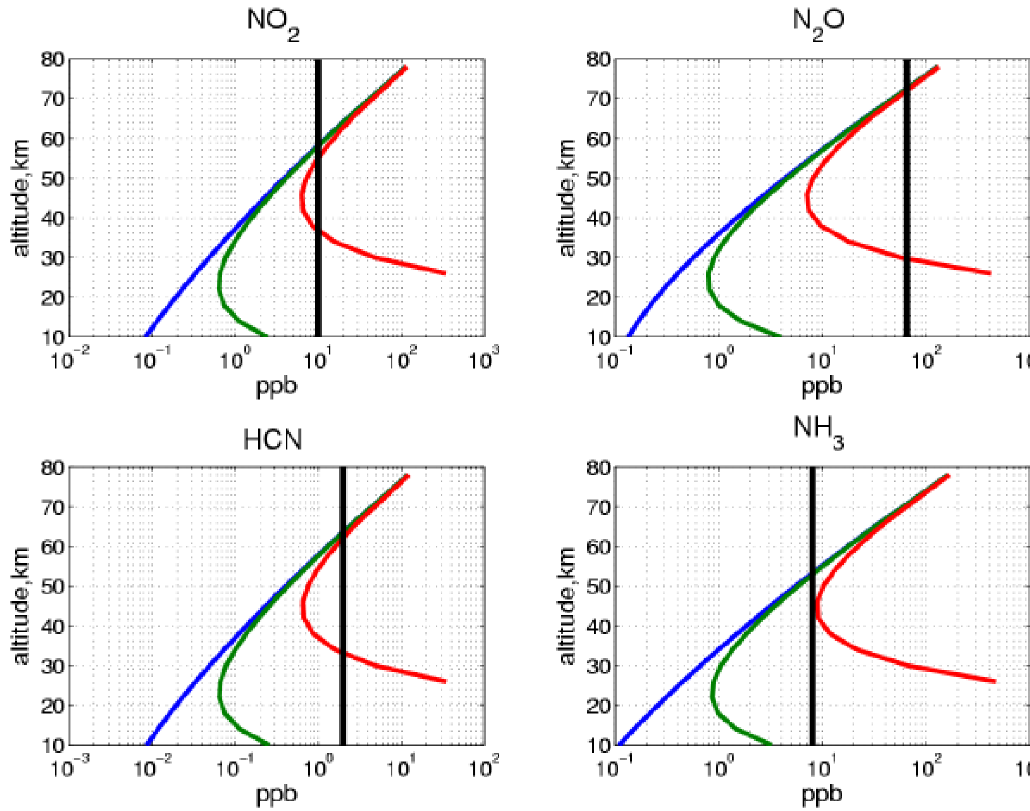
Species	Current Knowledge	Wavelengths, µm	Detection limit Occultation
Trace species			
NO_2	<10 ppb	**3.43**	0.2 ppb
N_2O	<65 ppb V2013	**3.9**	0.25 ppb
HCN	<2 ppb V2103	**3.05**	0.02 ppb
NH_3	<8 ppb M1977	**3**	0.25 ppb

(Villanueva et al., 2013)



Different dust conditions

Blue τ=0
Green τ=0.2
Red τ=2.0



Courtesy of Anna Fedorova

Chlorine and sulfur chemistry. Volcanic release

Species	Scientific Objective	Current Knowledge	Wavelengths, µm	Detection limit Occultation at 20 km
Trace species				
SO2	Detection	1.1 ppb	4	1.5 ppb
H_2S	Detection	1.3 ppb	2.6	3 ppb
HCl	Detection	<0.3	3.42	0.01 ppb

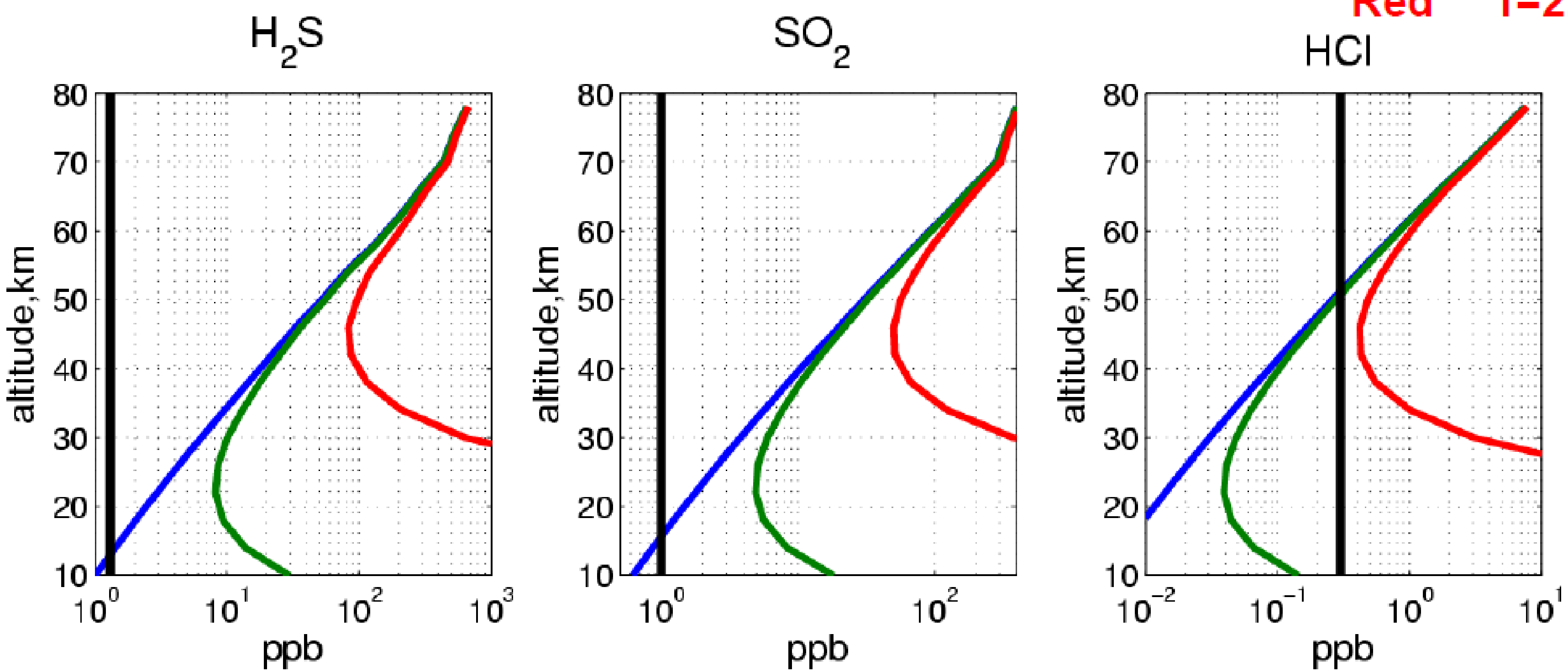
A search for SO_2, H_2S and SO above Tharsis and Syrtis volcanic district on Mars using ground-based high-resolution submillimeter spectroscopy

A.S. Khayat[a,*], G.L. Villanueva[b,c], M.J. Mumma[b], A.T. Tokunaga[a]

[a] Institute for Astronomy, University of Hawaii, Honolulu, HI 96822, USA
[b] Solar System Exploration Division, Mailstop 690, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[c] Department of Physics, Catholic University of America, Washington, DC 20064, USA

Different dust conditions

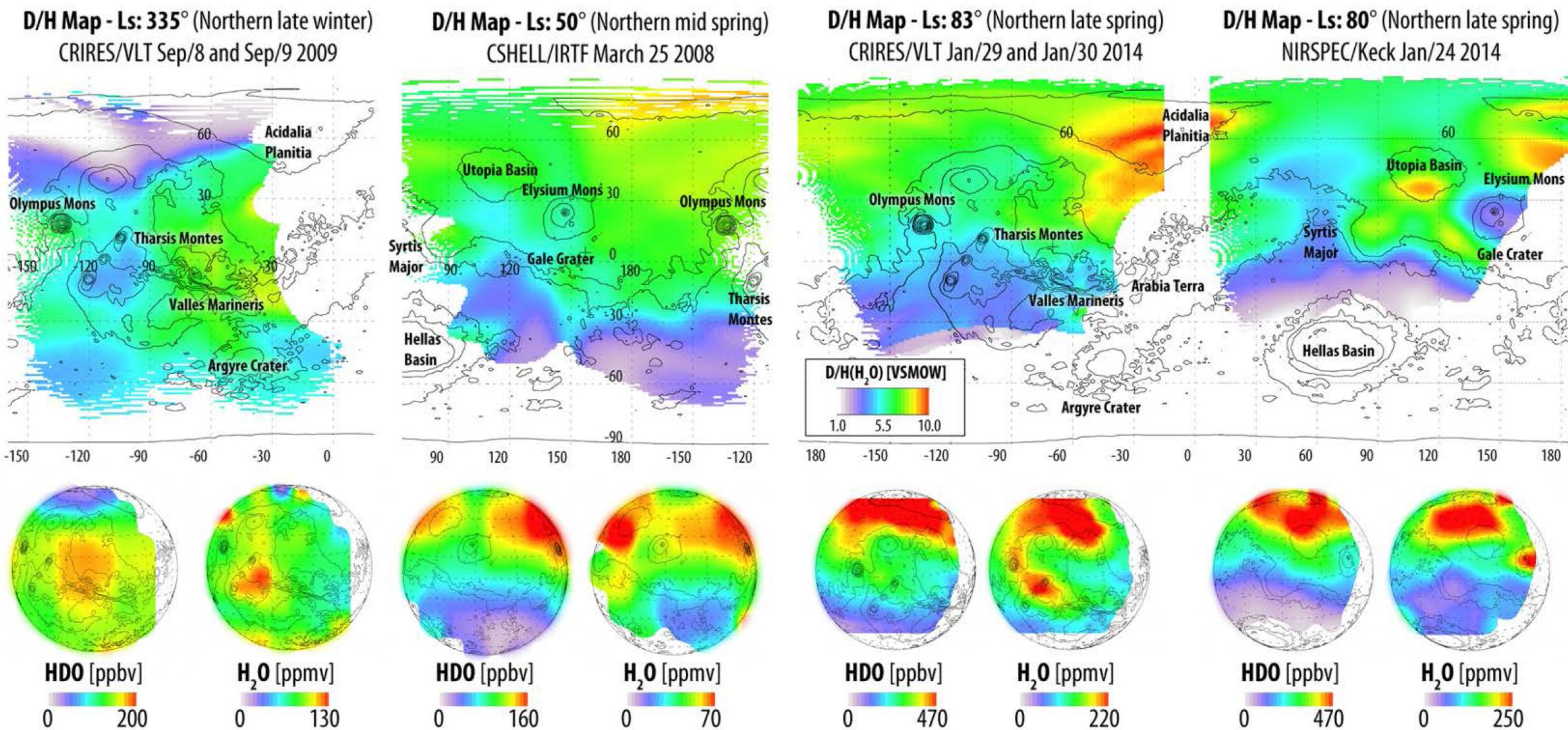
Blue τ=0
Green τ=0.2
Red τ=2.0



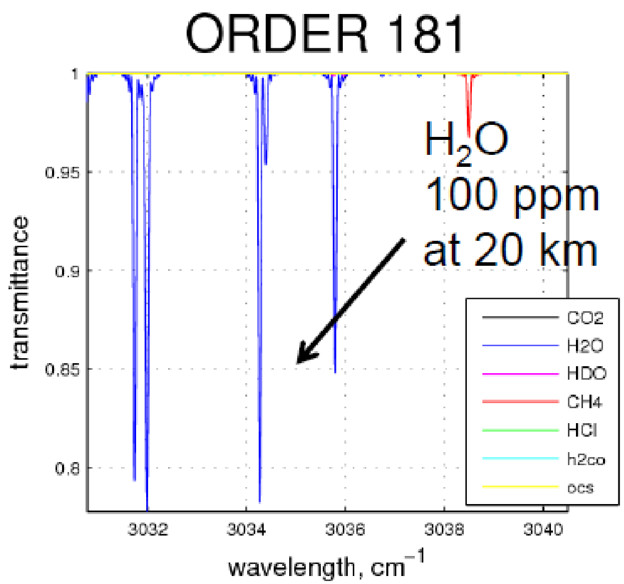
Courtesy of Anna Fedorova

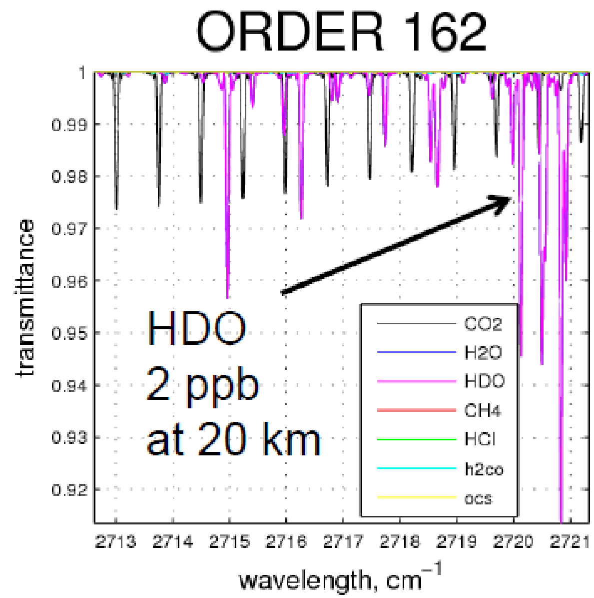
HDO and D/H ratio mapping

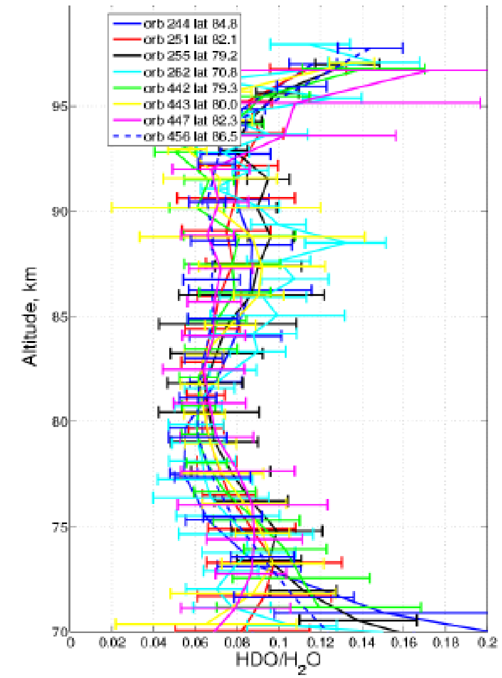
Villanueva et al. 2015:



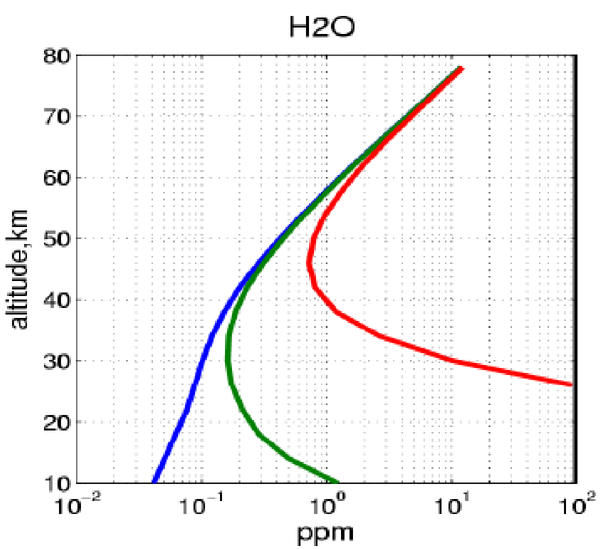
MIR HDO/H2O

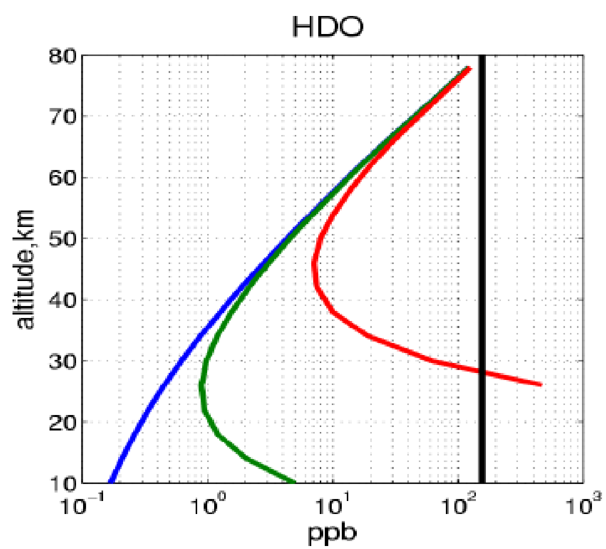






HDO/H_2O Venus' mesosphere
SOIR/Venus-Express,
2.2-4.3 µm, ~20000





MIR and NIR Scientific Objectives and Expected Performance:

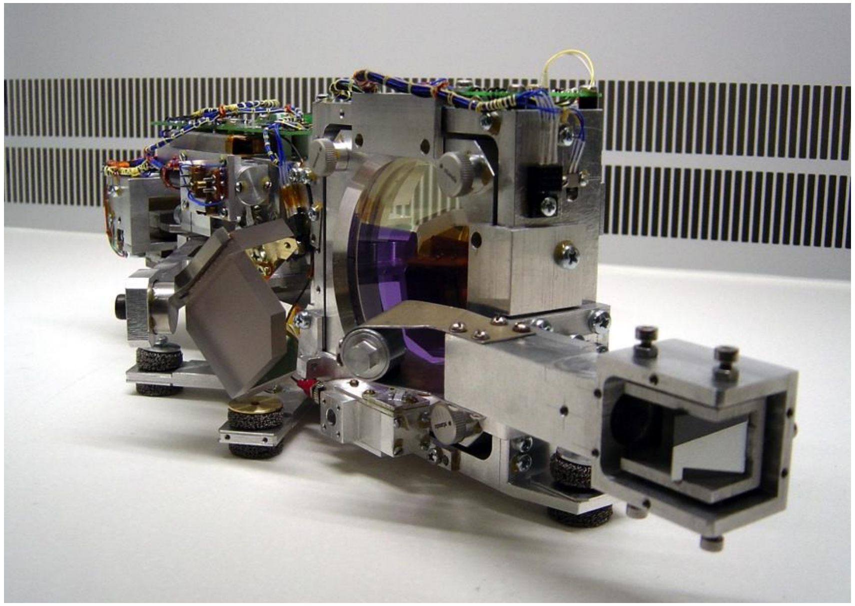
Species	Scientific Objective	Current Knowledge	Wavelengths, µm	Detection limit Solar Occultation	Detection limit Nadir
Abundant species					
CO_2	Profiles, pressure, temperature field	0.965	**1.43, 1.58, 1.60, 2.7, 3.8**	5-140 km	Temperature field
CO_2 isotopes	Profile isotopes	$^{13}C/^{12}C=0.967$ $^{18}O/^{16}O=1.018$ 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	5 ppm?
CO	Profile. abundance	300-1000 ppm	**1.57, 2.4**	2 ppm	500 ppm?
Aerosol	Properties, extinction profiles	opacities, integrated and limb profiles, particle sizes	**0.65-4**	0.1 µm $<r_{eff}<$10 µm Distinguish H_2O/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%	0.1-0.2%
$O_2(a^1\Delta_g)$	Dayglow (ozone)+ Nightglow	0-30MR (dayglow) 0-0.3MR (nightglow)	**1.27**		5 kR in nadir?
Trace species					
CH_4	Detection, profiles	<8 ppb (0-30)	**3.3**	0.02 ppb	
C_2H_2	Detection	<3 ppb	**3**	0.025 ppb	
C_2H_4	Detection	<4 ppb	**3.2**	0.2 ppb	
C_2H_6	Detection	<0.2 ppb	**3.3**	0.01 ppb	
H_2S	Detection	<1.3 ppb	**2.6**	3 ppb	
OCS	Detection	<10	**2.44, 3.4**	0.5 ppb	
HDO	Profiles	0.1-1 ppm	**3.7**	0.03 ppb	
H_2CO	Detection	<3 ppb	**3.6**	0.03 ppb	
HO_2	Detection	200	**2.94**	2 ppb	
NO_2	Detection	<10	**3.43**	0.2 ppb	
HCl	Detection	<0.3 ppb	**3.42**	0.01 ppb	
HCN	Detection	2	**3.05**	0.02 ppb	
OH*, NO*, O_2*	Nightglow emissions	0-100 kR	**1.43, 0.76, 1.224**		Detection in nadir?

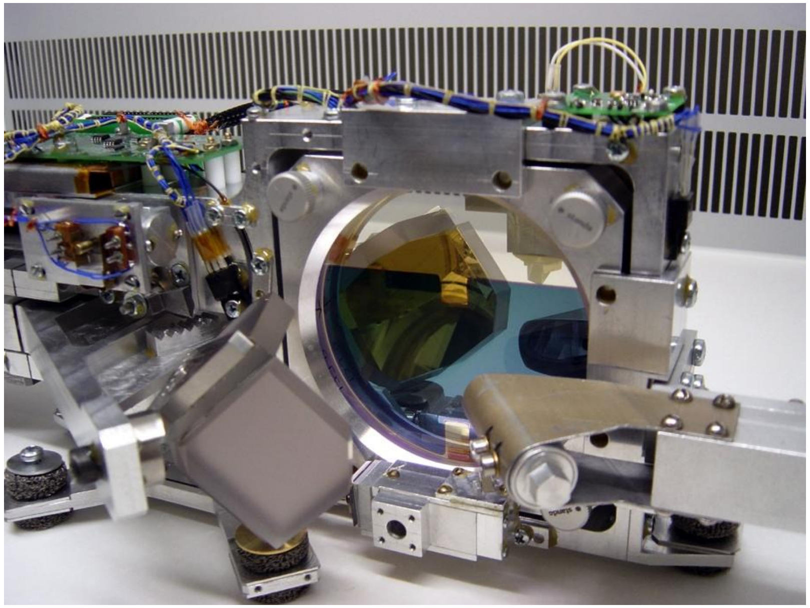
Reported minimal abundances based on MIR: R~50000, **SNR~5000** (SO);
NIR: R~25000; SNR~1000 (SO); SNR~100?? (N)

ACS TIR

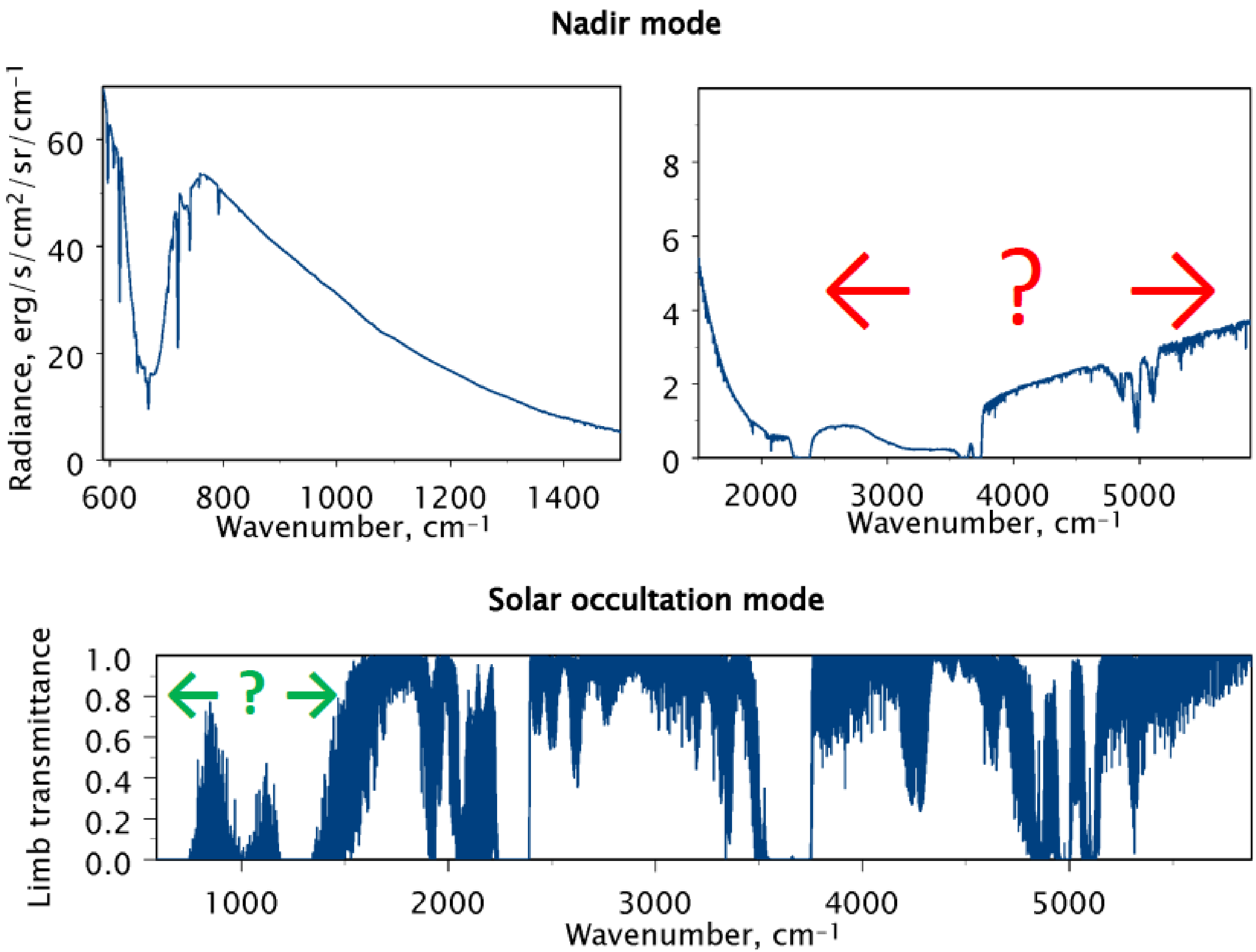
TIRVIM parameters

• Spectral range:	1.7–17 µm (400–5000 cm^{-1})
• Best spectral resolution:	0.25 cm^{-1} (apod., OPD = 6 cm max)
• Interferogram duration:	2 s (shift at Mars surface: 7 km)
• FOV:	2.5° (dia17 km at Mars surface / nadir)
• Cube corners aperture	2 inch
• Observation modes:	Nadir, solar occultation
• Pointing:	Internal 1-axis
• Flight calibrations:	Internal BB, space





TIRVIM simulated spectra

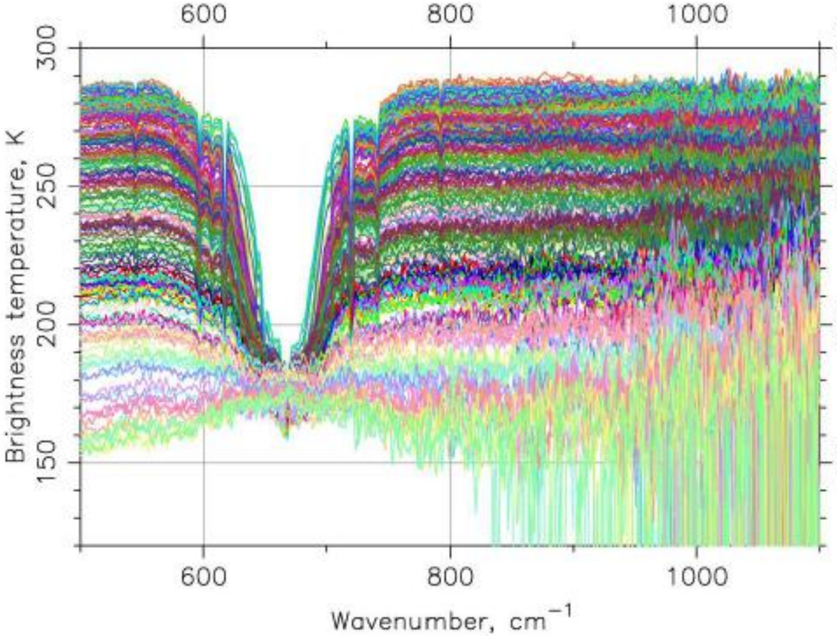


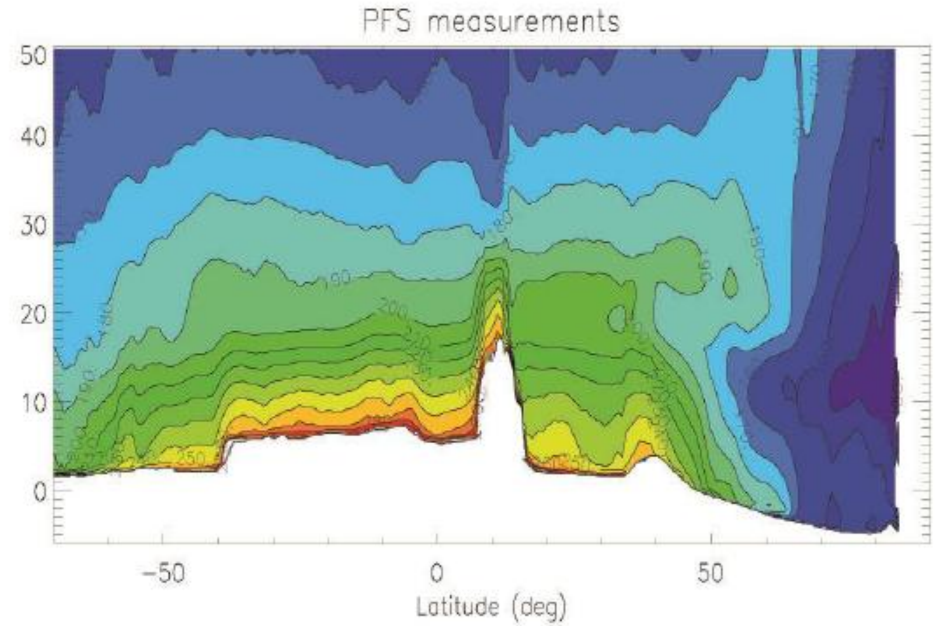
ACS TIRVIM Solar occultations

Gas	Measurements	Reference	Expected detection limit, ppb (S/N≈1000, Δν=0.15cm^{-1})	Spectral range, µm
H_2O	1-500 ppm			
HDO	0.1-1 ppm			
CO	500-1000 ppm			
O_3	0-500 ppb			9.6
O_2	0.13%			
H_2O_2	15 ppb	E08		8
CH_4	10 ppb ?			3.3
	Present upper limit, ppb			
HO_2	200	V13	50	2.94
C_2H_2	4	V13	?	
C_2H_4	4	V13	5	3.36
C_2H_6	0.2	K11, V13	50	3.35
H_2CO	3	K97, V13	100	5.68
CH_3OH	7	V13		
NO_2	10	M77	1	6.25, 3.43
NO			3	5.28, 5.5
N_2O	65	V13	3	4.55, 4.44
NH_3	5 / 45	M77 / V13	5	2.3, 3, 5.7
HNO_3			0.3	5.85
HCN	2	V13	0.5	3.05
CH_3CN				
SO_2	0.3	E11, K11	50	4
SO				
OCS	10	M77	1	3.42, 2.44
H_2S			50	2.59
HCl	0.3	H10, V13	0.2	3.42
HF			0.05	2.48
PH3	100	M77	2	4.14
CH3Cl	14	V13	5	3.34

CO2 15 μm band at Nadir

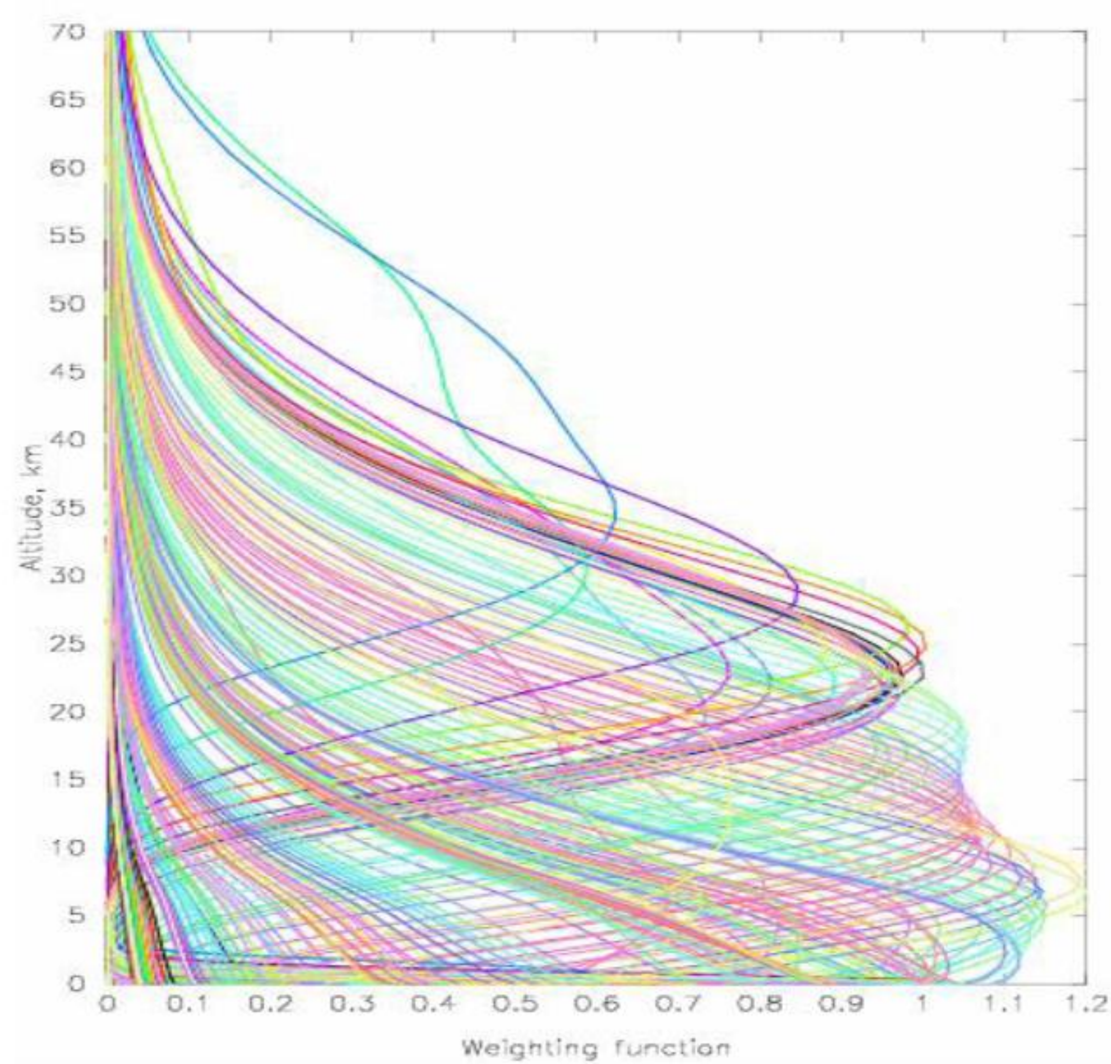
Thermal structure

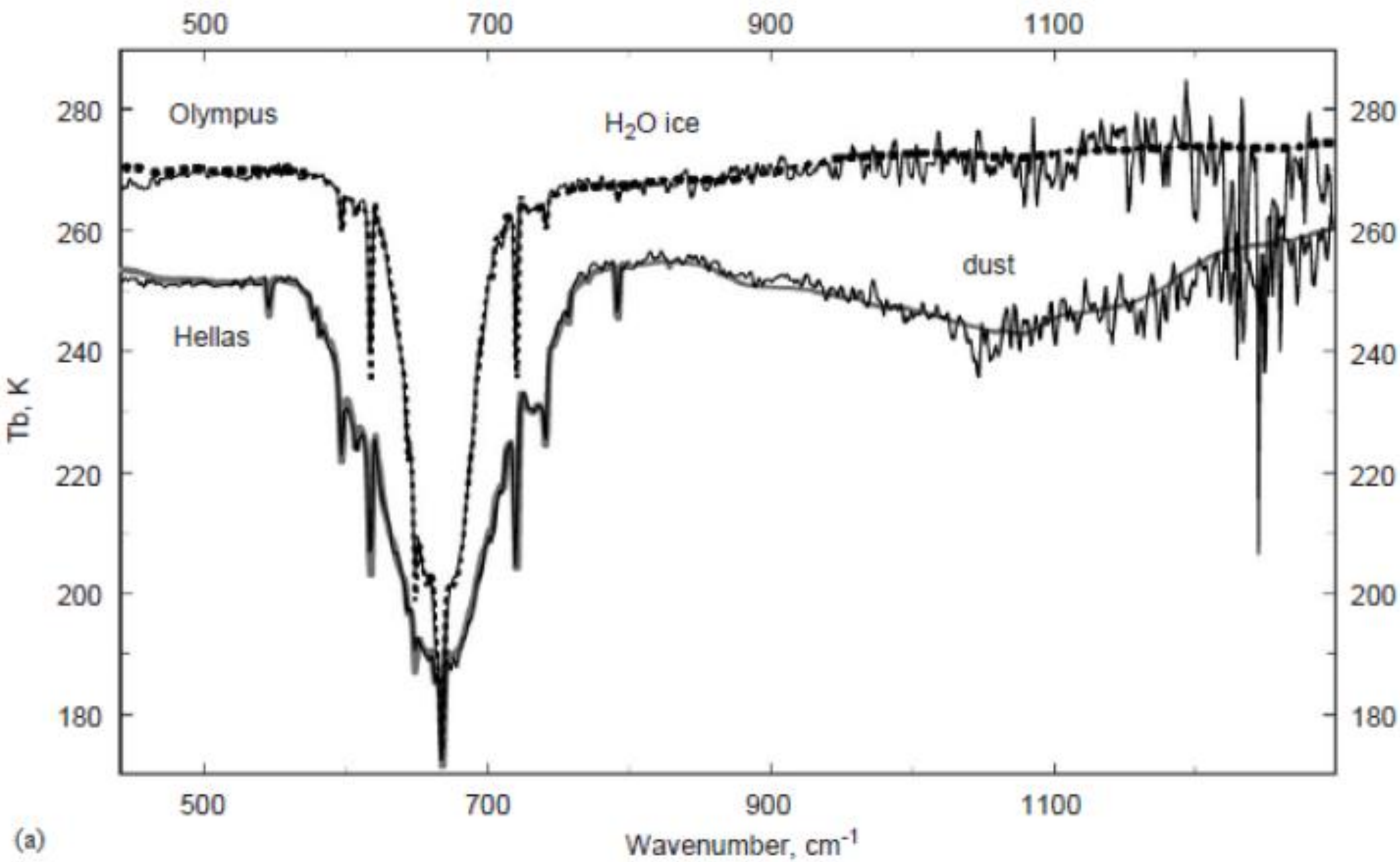




PFS / Mars Express spectra and retrieved temperature field, orbit 68 (Grassi et al., 2005)

Weighting functions in 15 μm CO_2 band

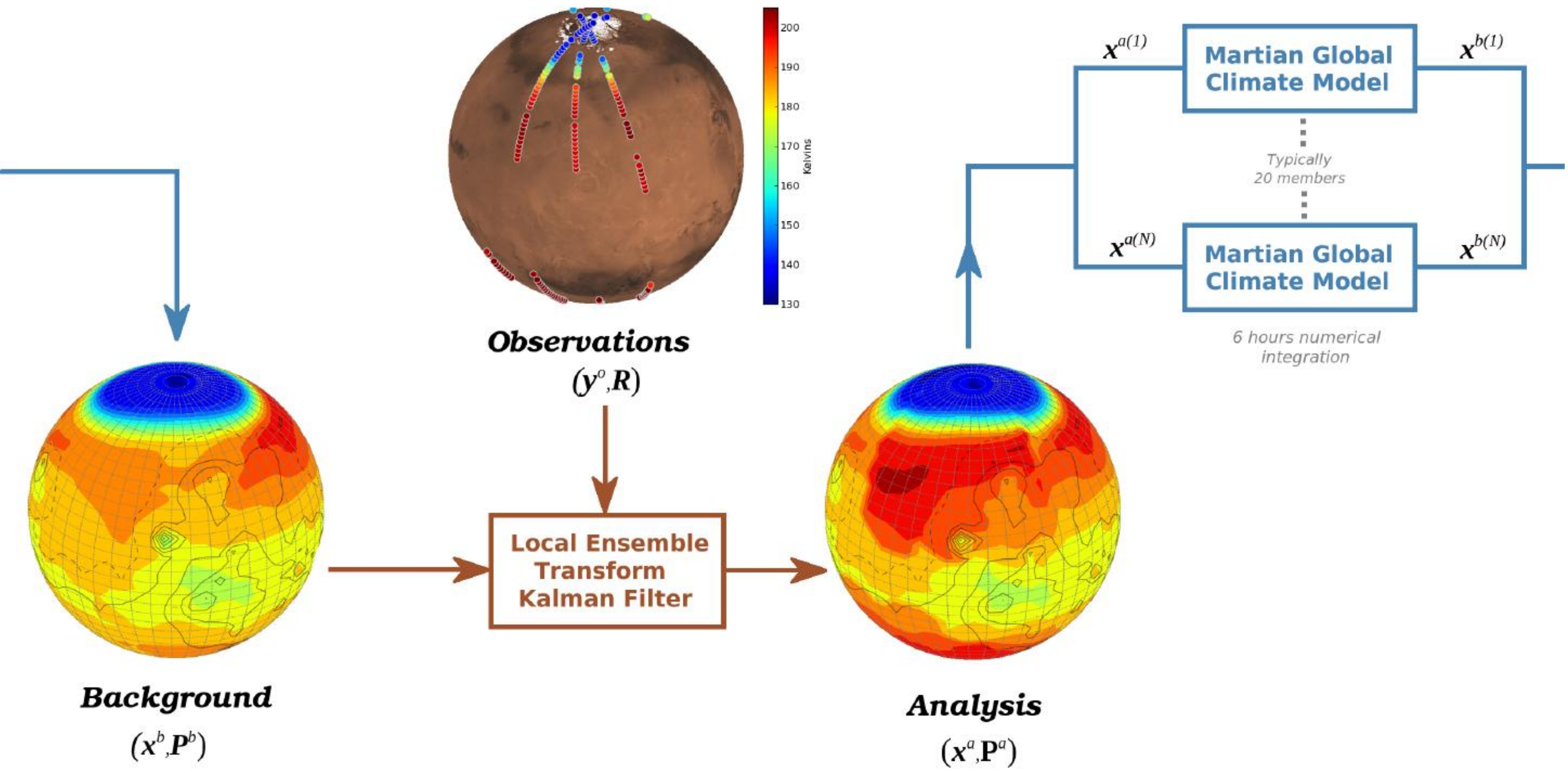




Dust and ice bands in PFS / Mars Express spectra over Olympus Mons and Hellas (Zasova et al., 2005)

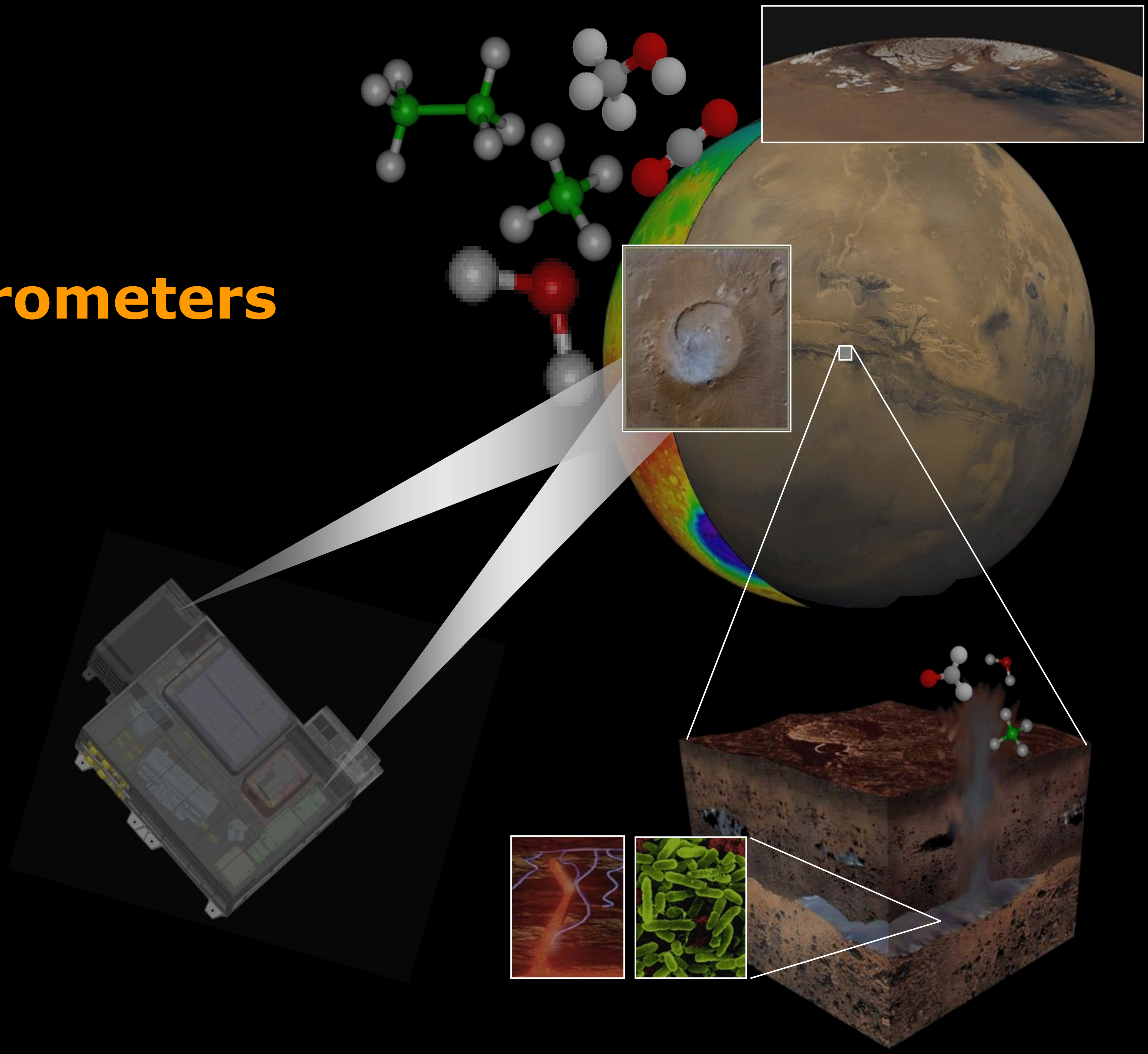
ACS TIR meteorological assimilation (LMD)

⇨ provision of winds and temperatures within a few days…

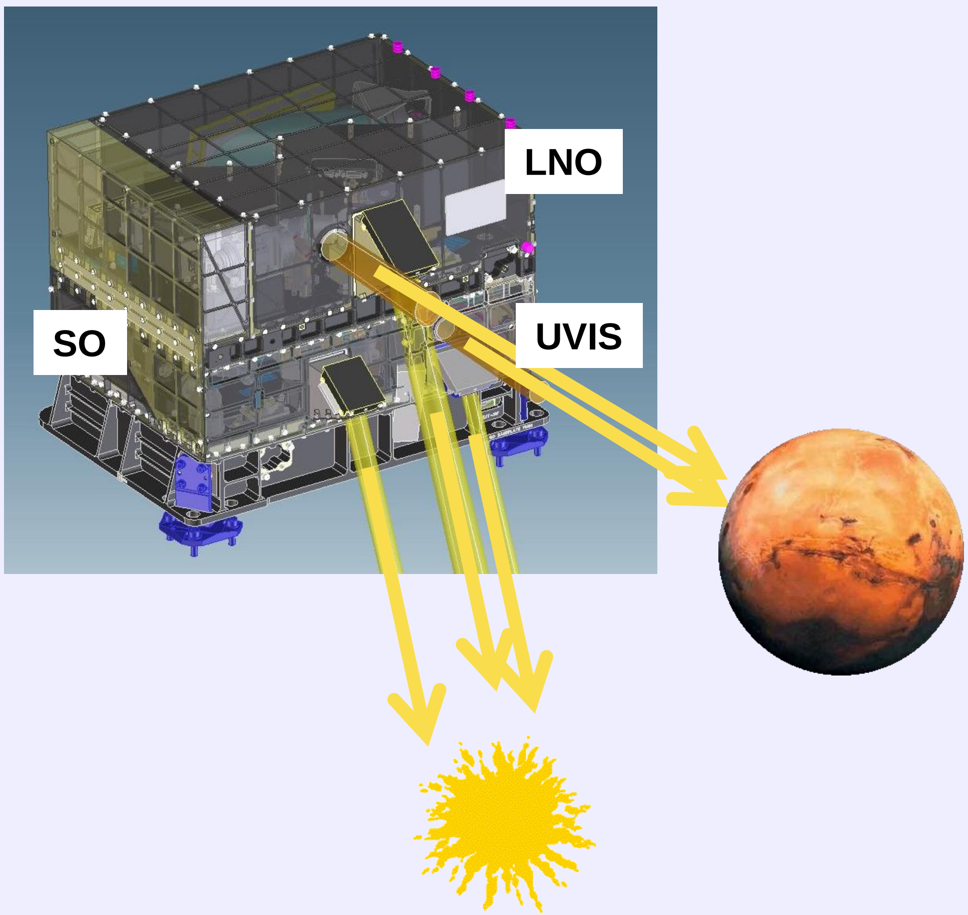


NOMAD

3 spectrometers



NOMAD : 3 channels



- SO *SOIR/ Venus Express*
  - Solar Occultation
  - IR : 2.2-4.3 μm
  - Resolution ~ 0.15 cm^{-1}
  - Resolving power = 22000
- LNO
  - Nadir, Limb, Solar Occultation
  - IR : 2.2-3.8 μm
  - Resolution ~ 0.3 cm^{-1}
  - Resolving power = 11000
- UVIS
  - Nadir, Limb, Solar Occultation
  - UV-vis : 200-650 nm
  - Resolution ~ 1 -2 nm

		SO	LNO		UVIS	
		Solar Occultation (SNR = 2000)	**Solar Occultation (SNR = 3000)**	**Nadir (SNR = 100)**	**Solar Occultation (SNR = 500)**	**Nadir (SNR = 500)**
CH_4	0-60 ppb [a]	25 ppt	20 ppt	11 ppb		
H_2O	< 300 ppm (variable with season)[b]	0.2 ppb	0.15 ppb	31 ppb		
HDO	D/H =5.6 SMOW[c]	0.7 ppb	0.7 ppb	0.8 ppm		
CO	700 - 800 ppm [d]	5 ppb	4 ppb	1.5 ppm		
C_2H_2	< 2 ppb [g]	0.03 ppb	0.03 ppb	20 ppb		
C_2H_4	< 4 ppb [g]	0.2 ppb	0.15 ppb	70 ppb		
C_2H_6	< 0.2 ppb [e] < 0.7 ppb [g]	0.03 ppb	0.02 ppb	11 ppb		
HCl	< 3 ppb [e] < 0.2 ppb [f] < 0.6 ppb [g]	0.03 ppb	0.025 ppb	31 ppb		
HCN	< 5 ppb [g]	0.03 ppb	0.03 ppb	15 ppb		
HO_2	0.1-6 ppb [l] < 200 ppb [g]	1 ppb	1 ppb	0.5 ppm		
H_2S	< 200 ppm [h]	4 ppb	3 ppb	1.6 ppm		
N_2O	< 100 ppb [h] < 90 ppb [g]	0.2 ppb	0.2 ppb	83 ppb		
NO_2	< 10 ppb [h]	0.14 ppb	0.1 ppb	50 ppb		
OCS	< 10 ppb [h]	0.3 ppb	0.3 ppb	122 ppb		
O_3		2.5 ppb	1.5 ppb	0.8 ppm	50 ppt	4.5 ppb
H_2CO	< 4.5 ppb [e] < 3.9 ppb [g]	0.04 ppb	0.03 ppb	16 ppb	7.5 ppb	150 ppb
NH_3	< 5 ppb [h] < 60 ppb [g]				1 ppb	-
SO_2	< 1 ppb [i] < 2 ppb [j,k]				0.5 ppb	18 ppb

Conclusions

- Profiling Methane with >10ppt accuracy
- Meteorological – Surface background ⇨ Monitoring sources
- Lots of other Trace Gases and other science investigations
- In particular: Exploring the atmospheric diurnal cycle