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NOMAD and the exploration of habitability on Mars

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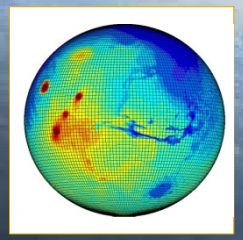
(4) INAF-IAPS, Rome, Italy



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ESA-Roscosmos Configuration

NOMAD

High resolution occultation and nadir spectrometers

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

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		

CaSSIS

High-resolution camera

Mapping of sources; landing site selection

ACS

Suite of 3 high-resolution spectrometers

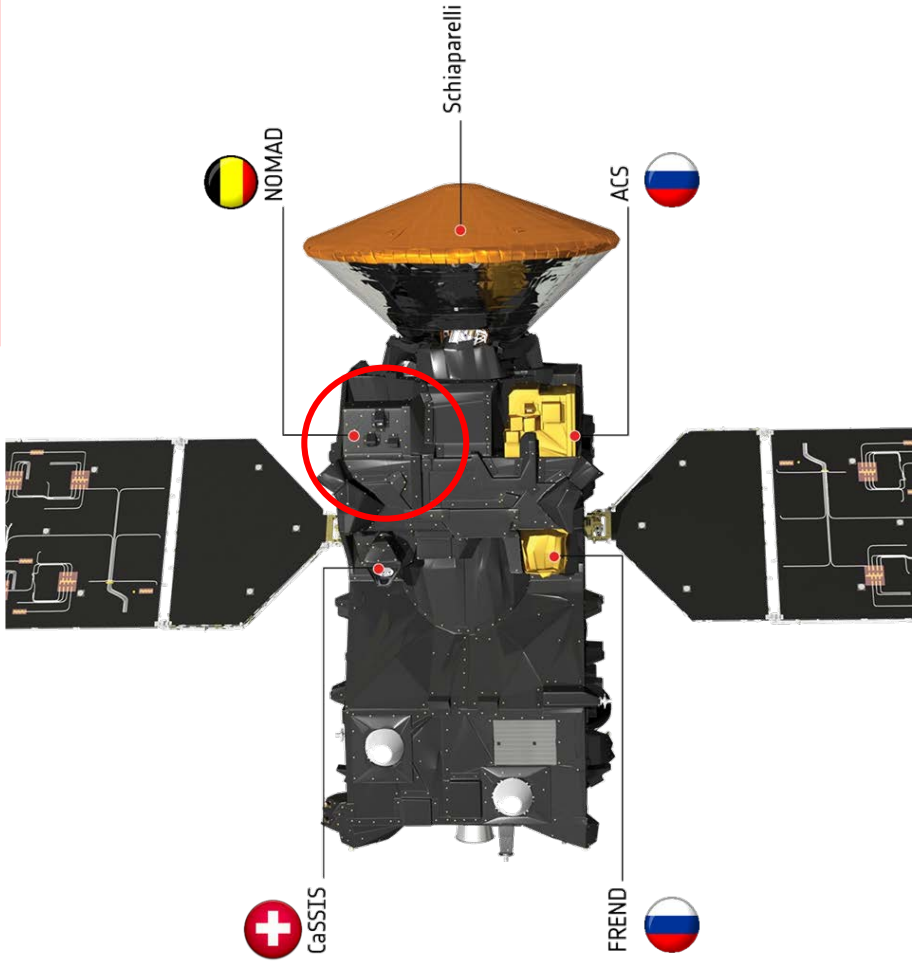
Atmospheric chemistry, aerosols, surface T, structure

Near IR (0.7 – 1.7 μm) λ/Δλ ~ 20,000	SO	Limb	Nadir
IR (Fourier, 2 – 25 μm) λ/Δλ ~ 4000 (SO)/500 (N)	SO		Nadir
Mid IR (2.2 – 4.5 μm) λ/Δλ ~ 50,000	SO		

FREND

Collimated neutron detector

Mapping of subsurface water



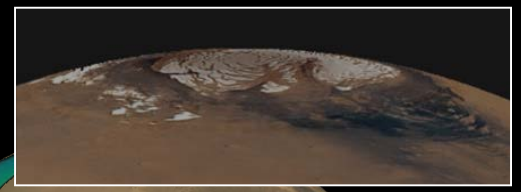
All Power Resolution λ/Δλ calculated at mid-range

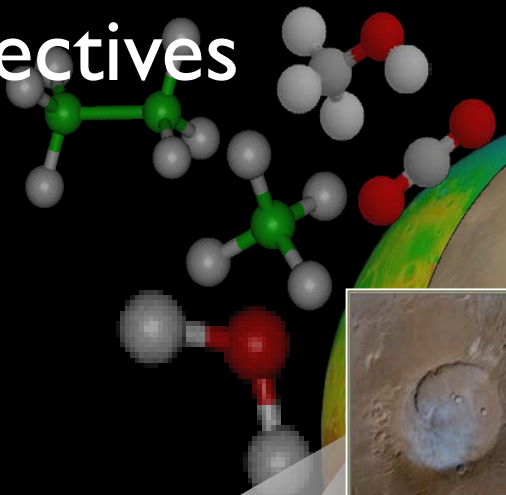
NOMAD science objectives

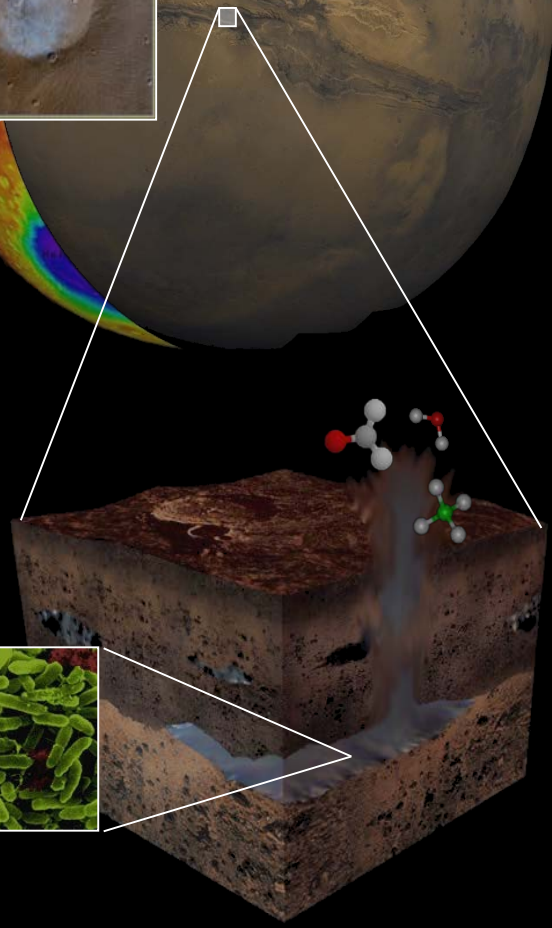
The **chemical composition** of the Martian atmosphere

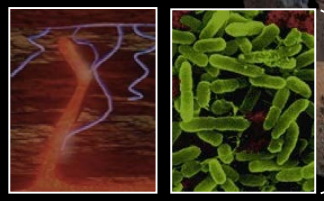
Mars **climatology** and seasonal cycles

Sources and sinks in the Martian atmosphere



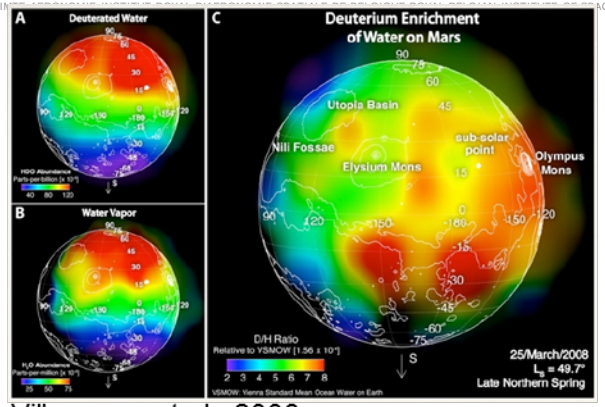






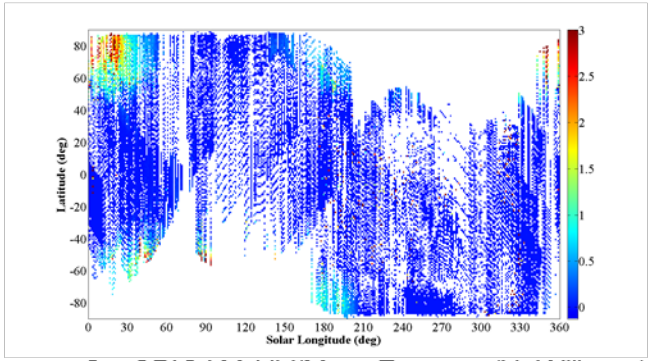
NOMAD : Science Objectives

- Chemical composition
  - Detection of a broad suite of trace gases and key isotopes
    - CO_2, CO, O_3
    - CH_4 related : CH_4, $^{13}CH_4$, CH_3D, C_2H_2, C_2H_4, C_2H_6, H_2CO
    - Escape processes : H_2O, HDO -> D/H
    - Volcanism related : SO_2, H_2S, HCl



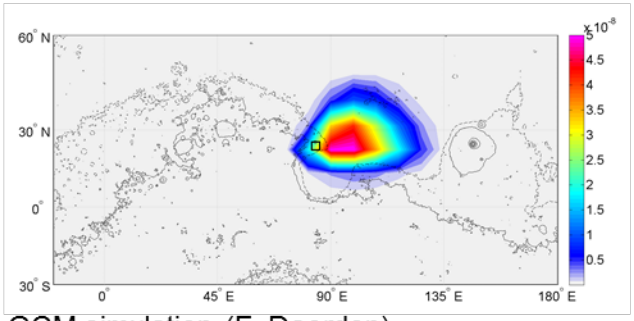
Villanueva et al., 2008

- Mars Climatology & Seasonal cycles
  - 3D spatial & temporal variability of trace gases and aerosols
  - Climatology of O_3 and UV radiation levels



O_3- SPICAM-UV/Mars Express (Y. Willame)

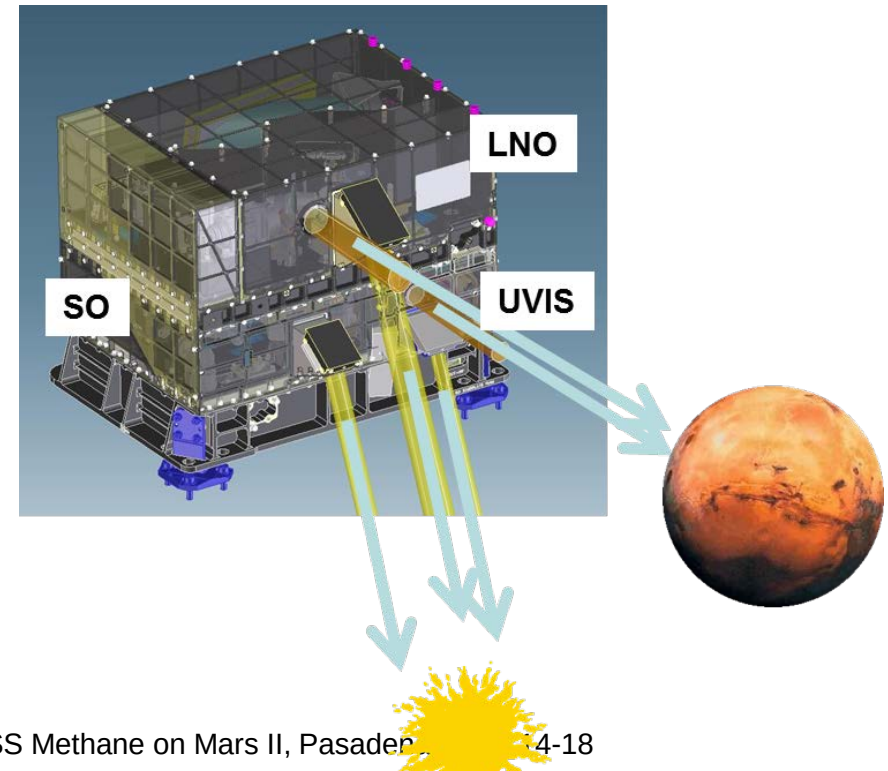
- Sources & Sinks
  - Analyse correlation trace gases – dust – clouds – T&P
  - Use GCM for interpretation



GCM simulation (F. Daerden)

NOMAD

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



- 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 **Humbolt/ExoMars**
  - Nadir, Limb, Solar Occultation
  - UV-vis : 200-650 nm
  - Resolution ~ 1 - 2 nm

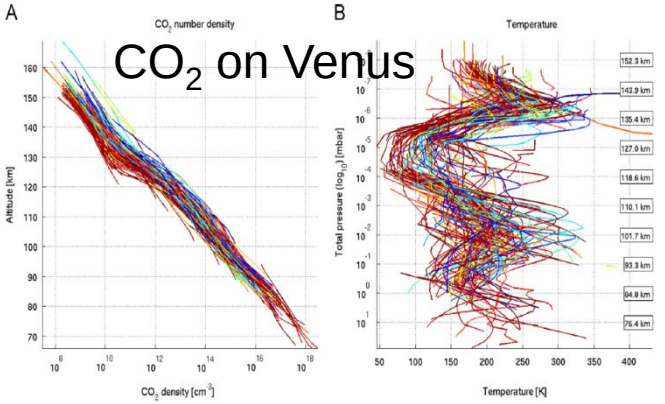
Science implementation (1)

- IR channels : heritage from SOIR/VEx

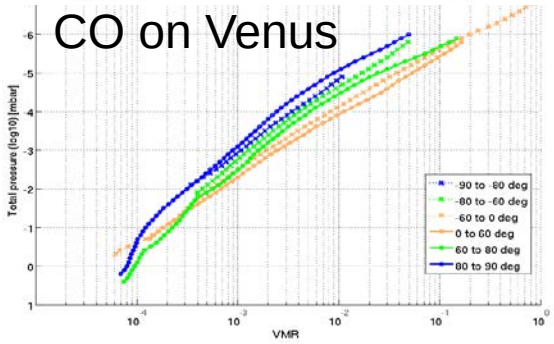
  - Venus Express (VEx) - ESA
    - Launch in Baikonur in 2006
    - End in Dec. 2014

  - SOIR spectrometer
    - Channel of SPICAV/SOIR on VEx
    - Echelle grating + AOTF
    - 2200 cm^{-1} to 4400 cm^{-1} (2.2 µm to 4.4 µm)
    - Divided in 94 diffracting orders
    - Order width: 20 to 37 cm^{-1}
    - Spectral resolution: 0.1 to 0.25 cm^{-1}

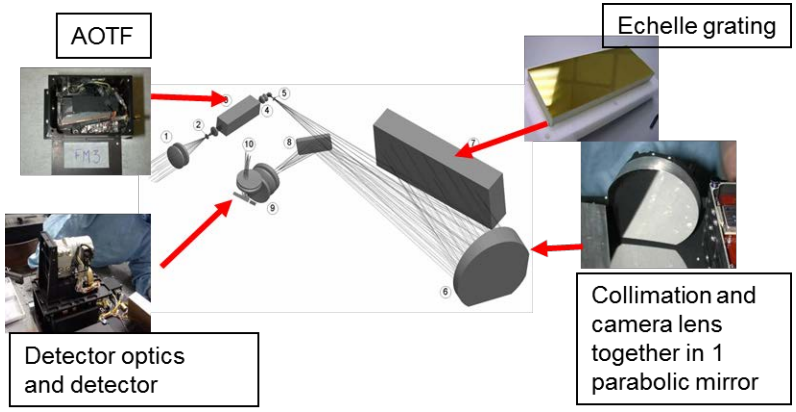
  - Measures 4 orders per second during an occultation

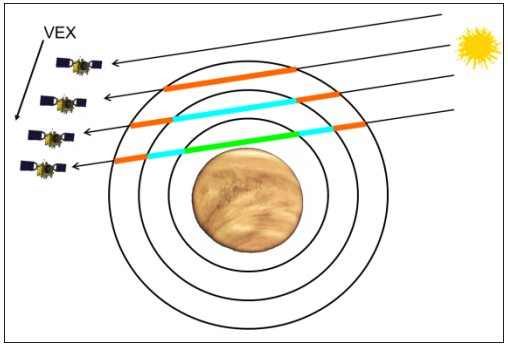


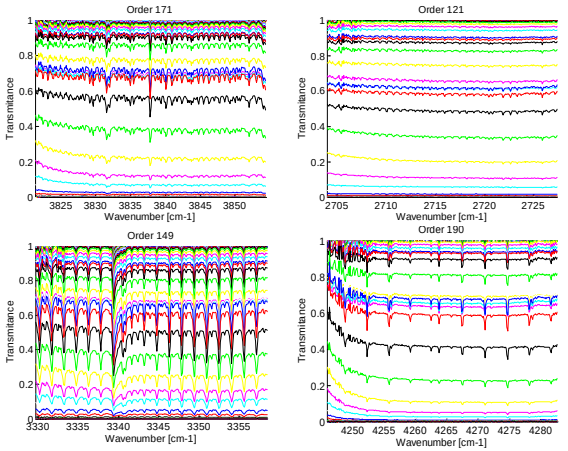
CO_2 on Venus



CO on Venus



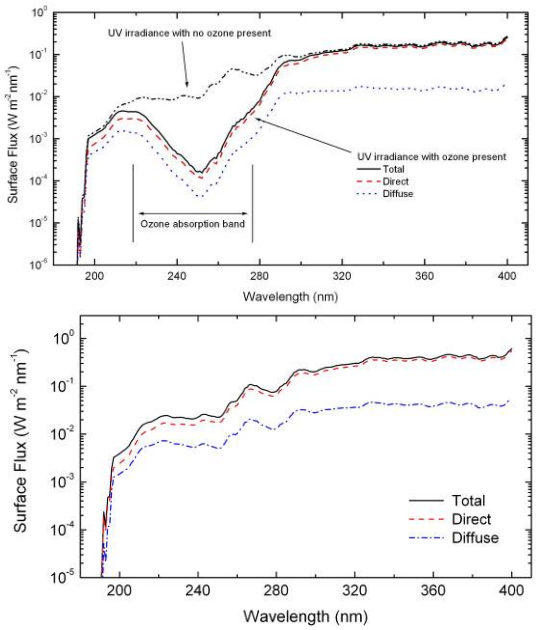


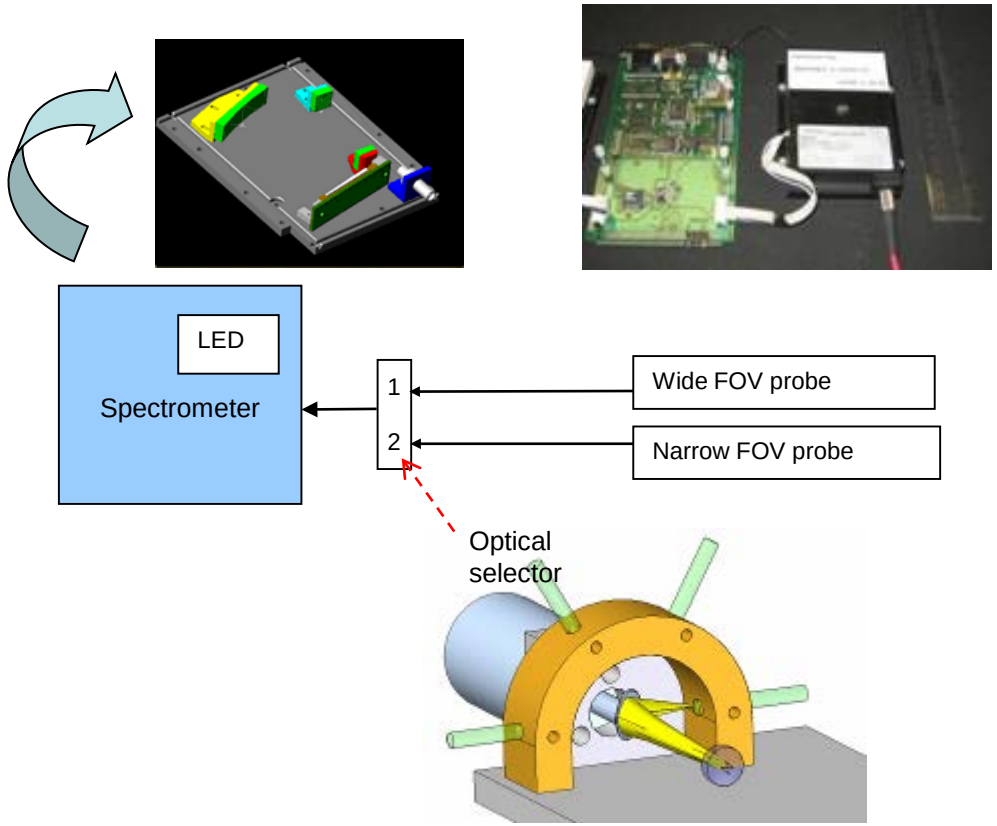


Science implementation (2)

- UVIS Channel: heritage from UVIS on Humbolt/ExoMars

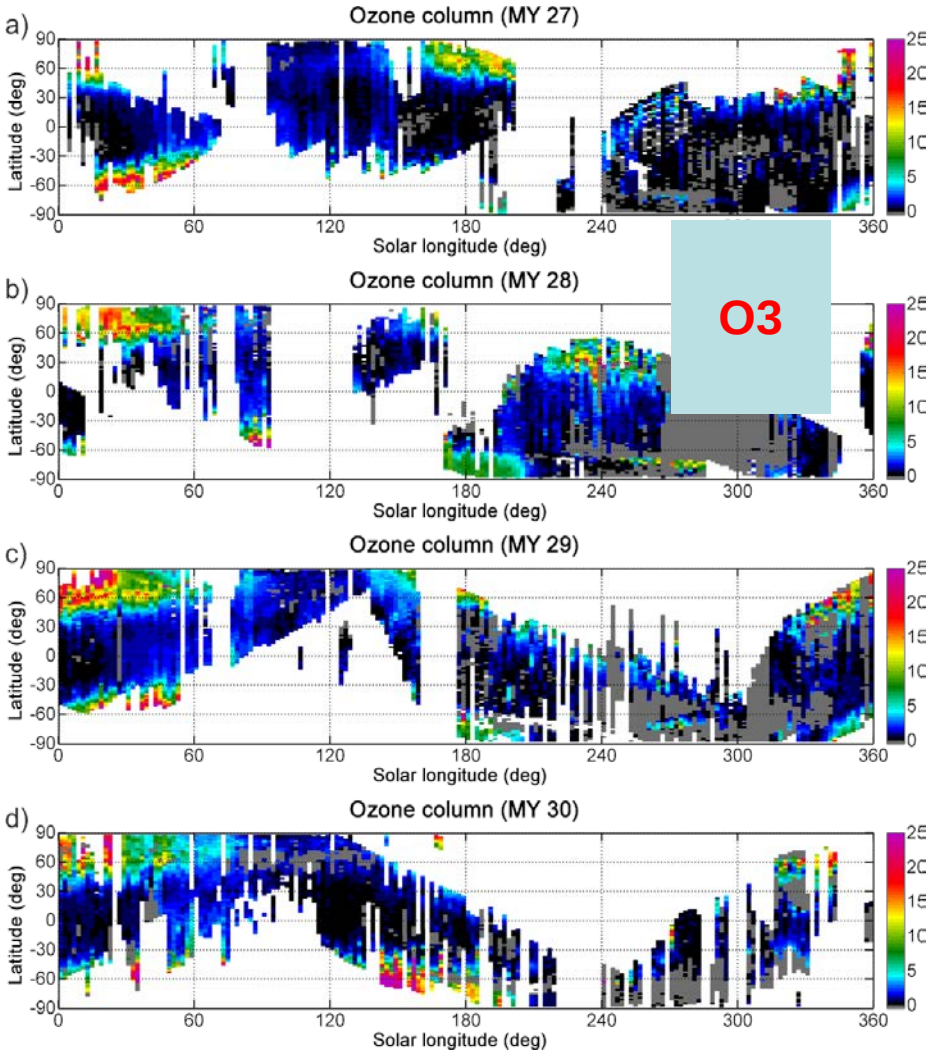
- Science based on SPICAM/MEX

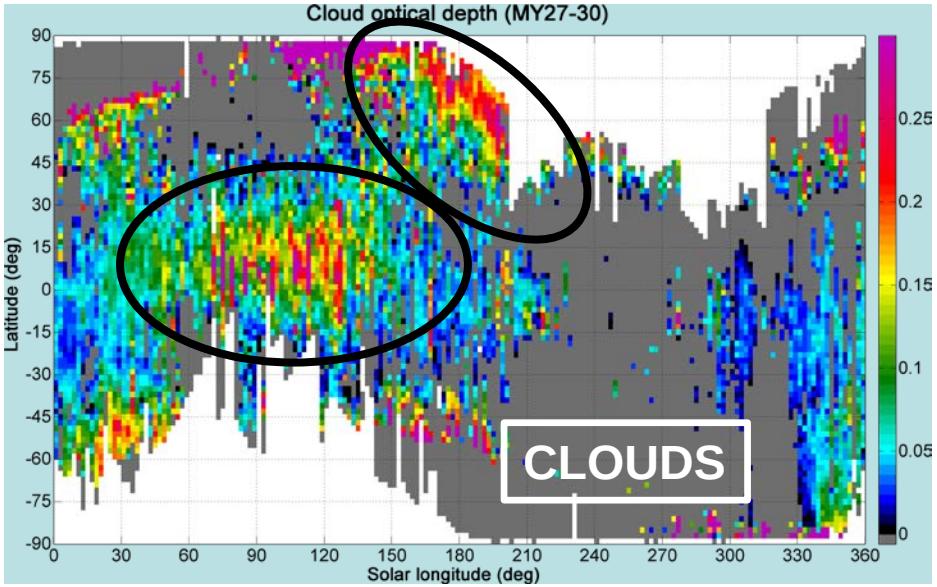


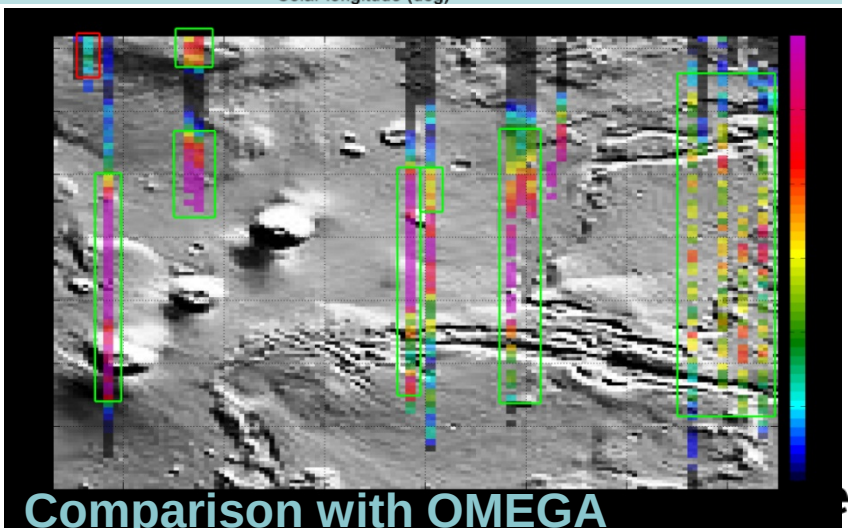


UVIS Science heritage

- Climatologies of O3, dust OD, surface albedo / Clouds

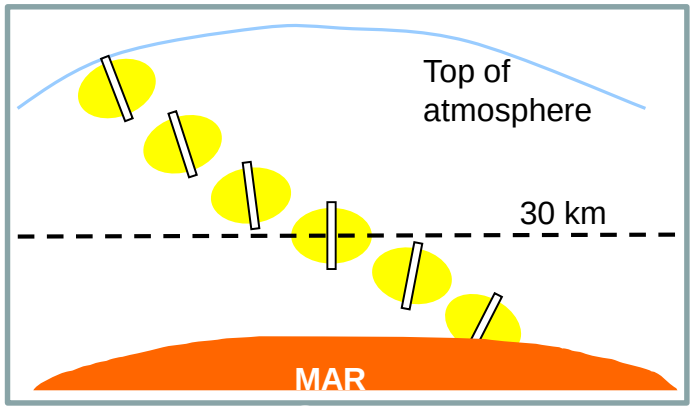






Science implementation (3)

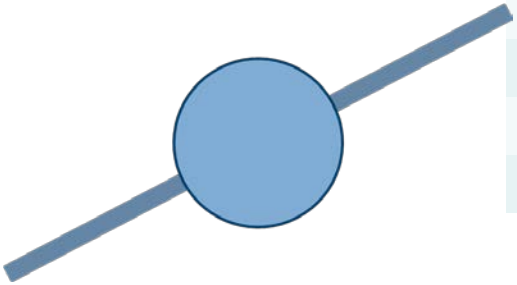
- Improvements/modifications
  - **SO**
    - 6 orders (instead of 4), 1 can be Dark
    - Slit perpendicular to limb → better vertical resolution
    - 2 series of settings for high & low altitudes



  - **LNO**
    - Solar occultation possible, but
    - Optimized for Nadir (& Limb)
      - ➢ increase of SNR : Larger & higher slit; larger optics; ~~radiator~~
  - **UVIS**
    - Extended spectral coverage (200-650 nm)
    - 2 telescopes for solar occultation & nadir

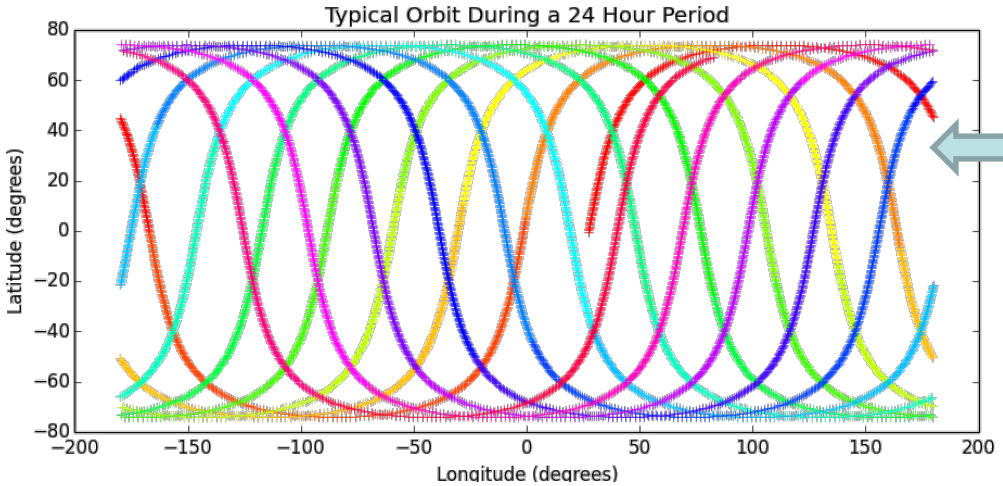
Observations modes

Fields of view



Nadir	
Channel	400 km
LNO 4’	0.47 km
LNO 144’	16.8 km
UVIS 43’	5.00 km
15s motion	50.4 km

Solar Occultation	
Channel	At limb
SO 2’	1.0 km
SO 4-6’ (binned)	2.0-3.0 km
SO 1’ (1 pixel)	0.5 km
UVIS 2’	1.0 km
1/6s motion	~0.4 km

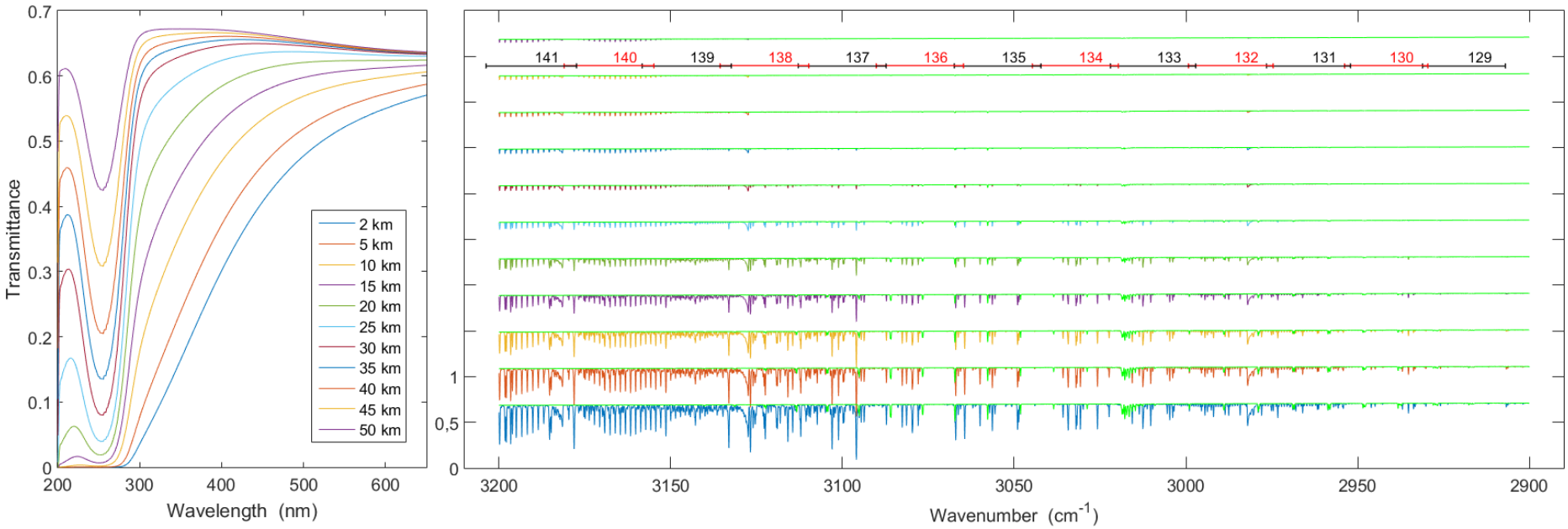


1 day coverage

One orbit every ~2 hours
-74 to +74 degrees latitude

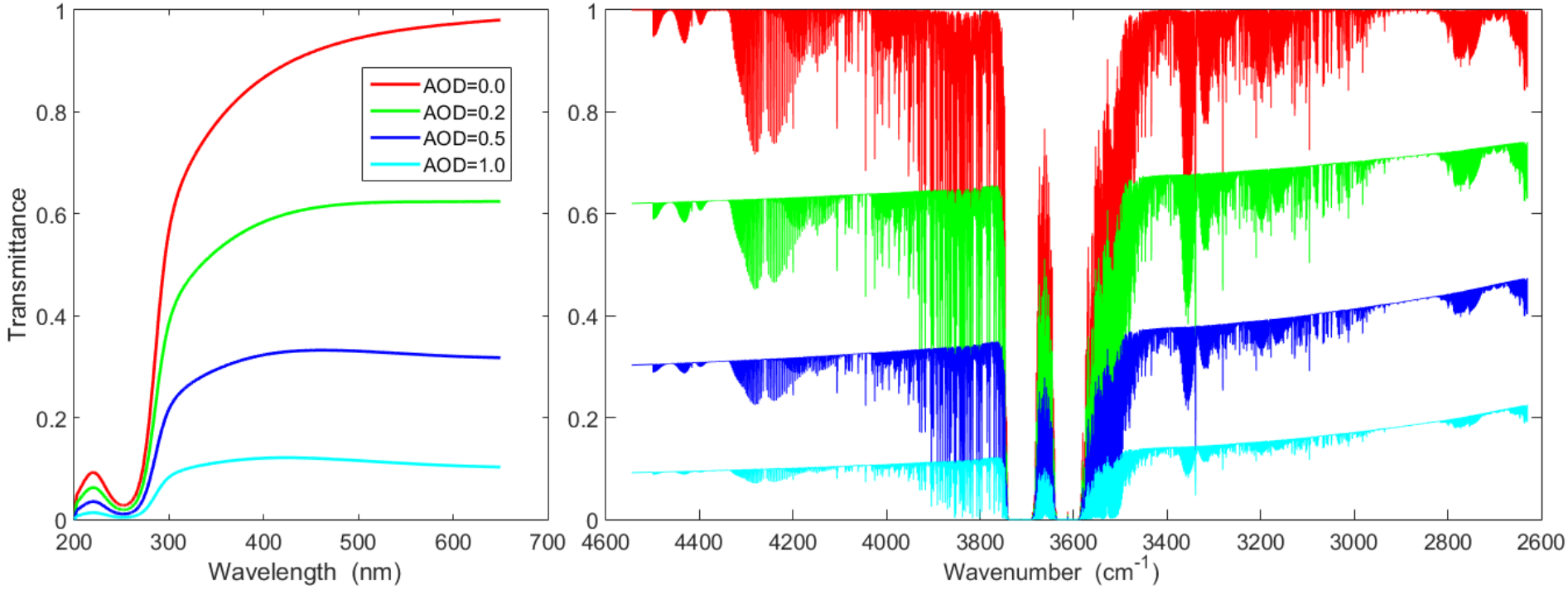
Observations (1)

- Solar Occultation



Observations (2)

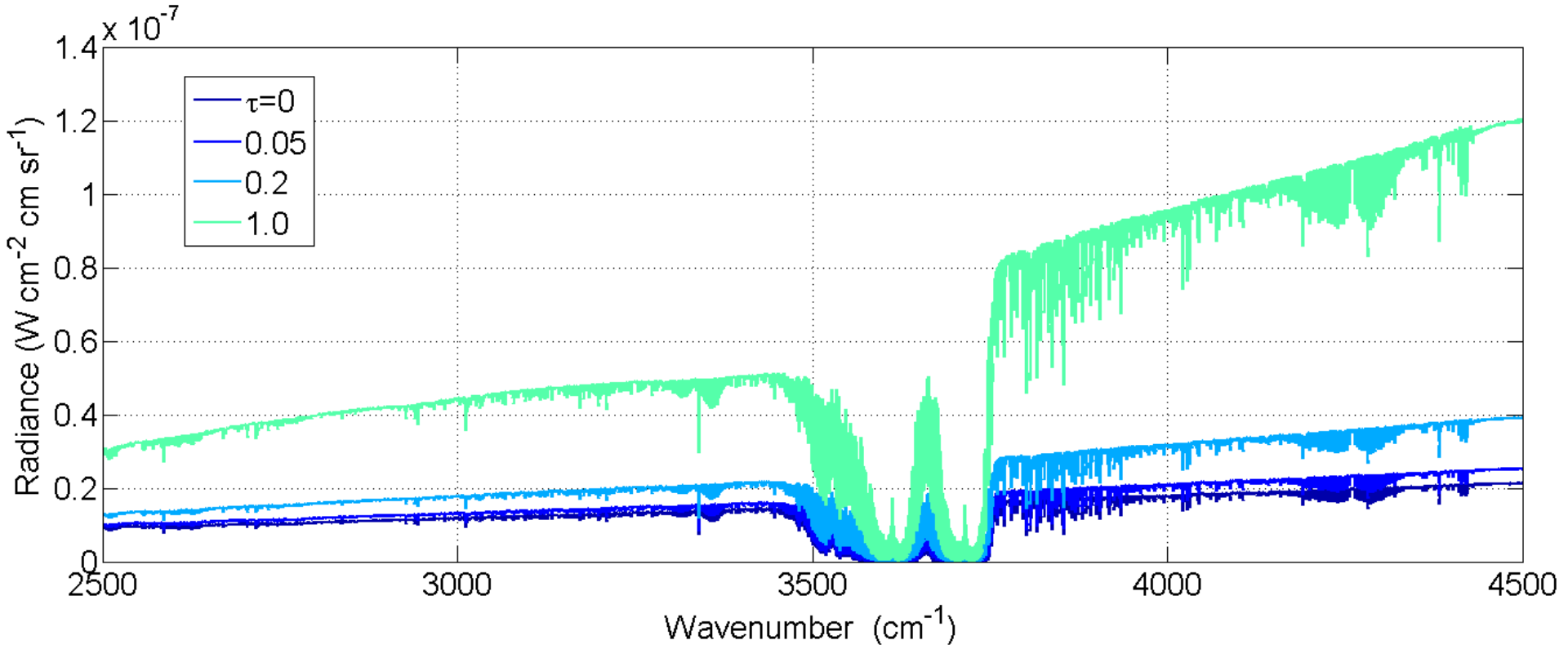
- With dust



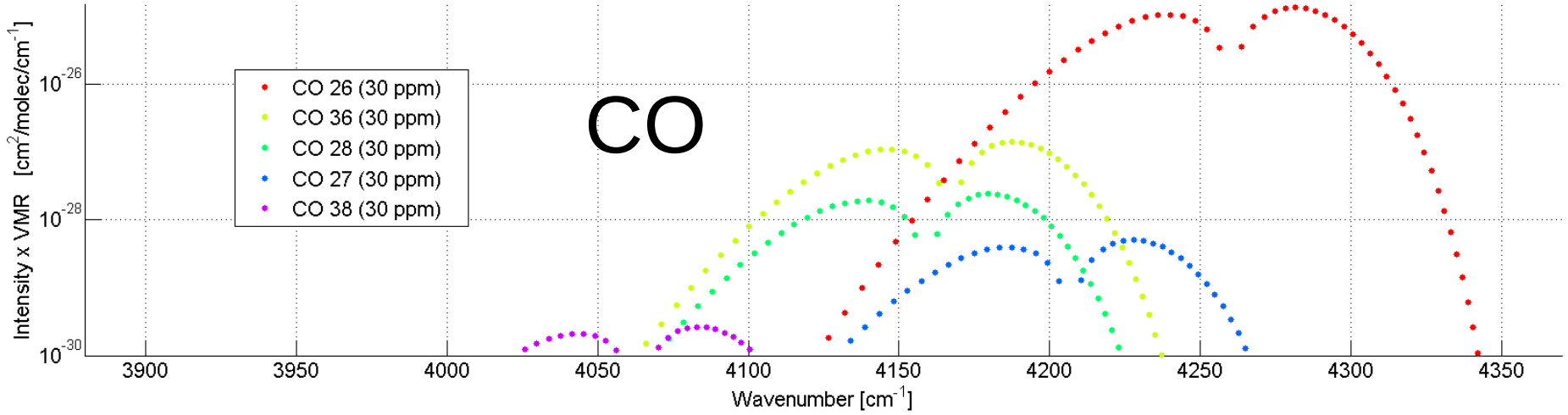
At 20 km tangent height

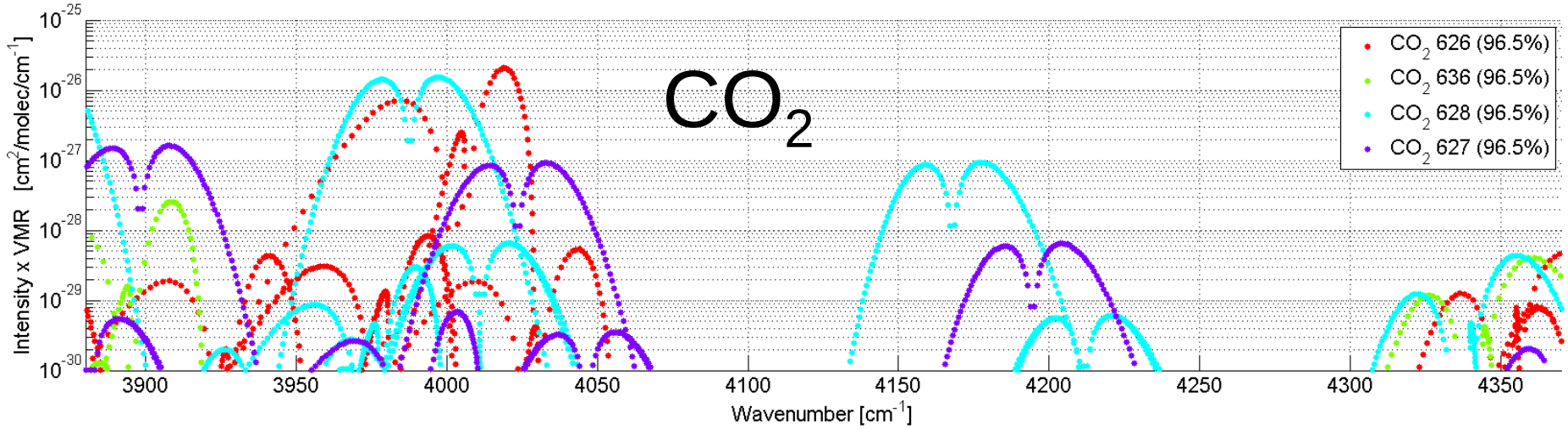
Observations (3)

- Nadir

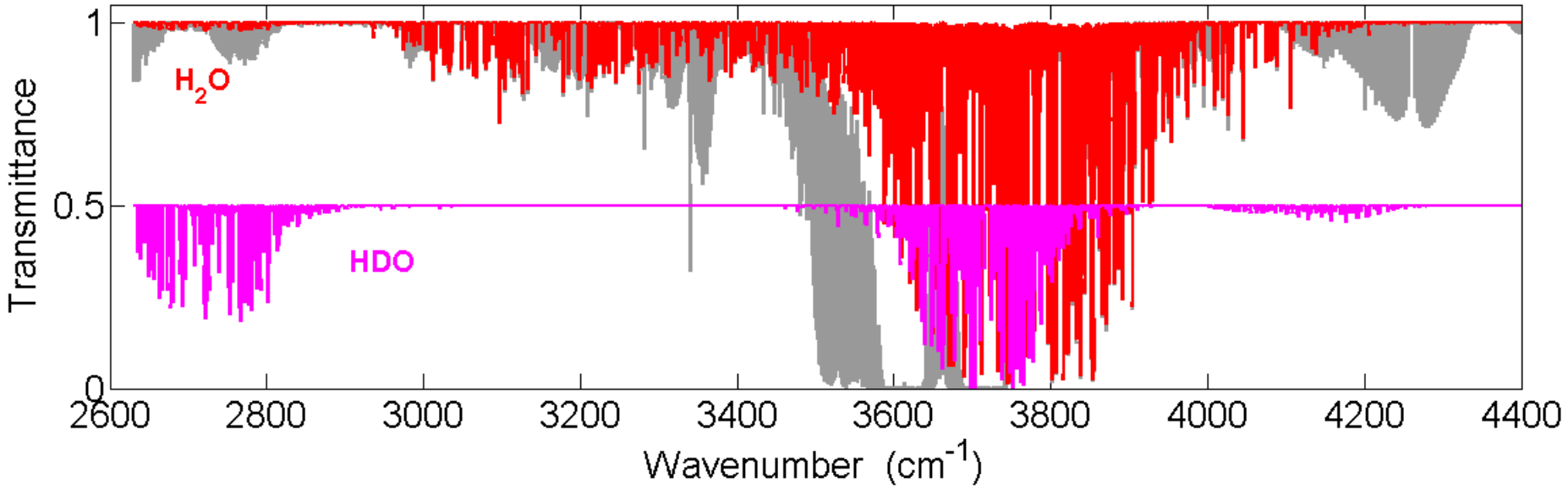


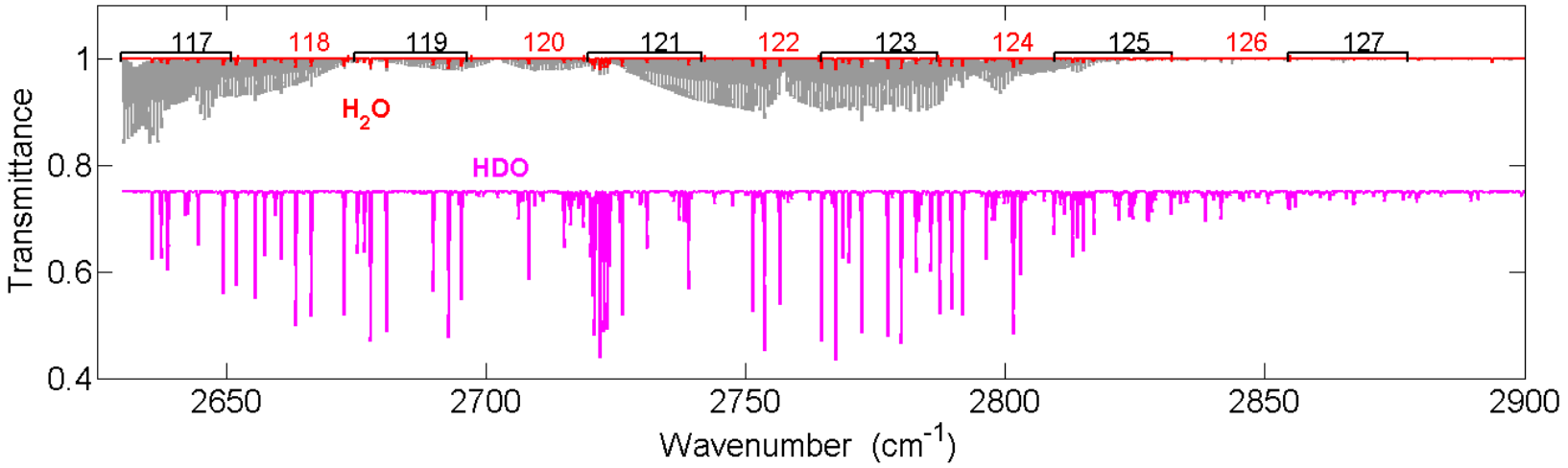
CO_2 and CO isotopologues





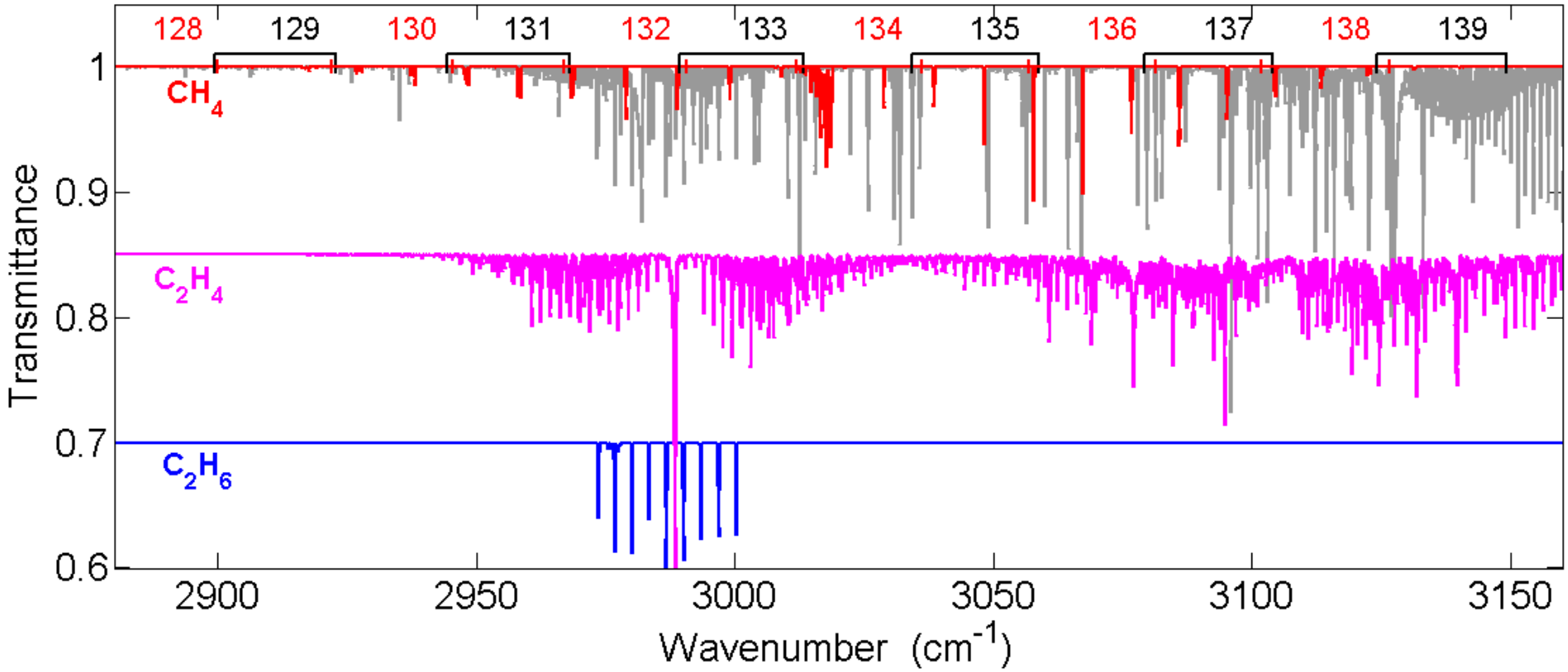
H_2O & HDO





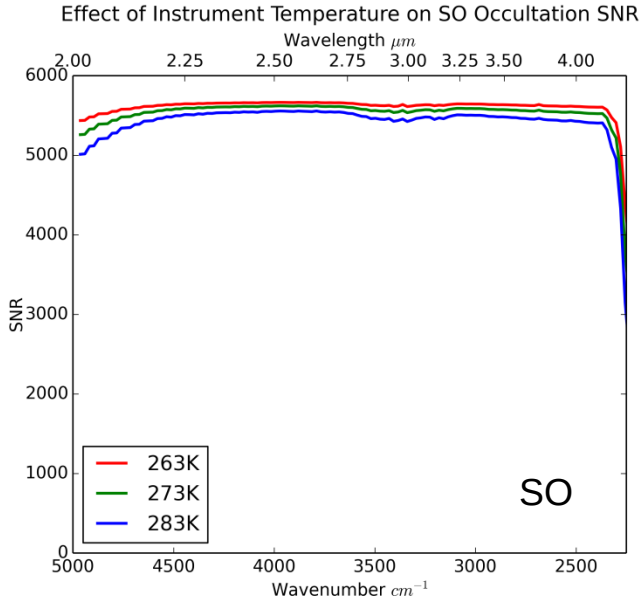
Search for trace gases: CH_4, C_2H_4, C_2H_6

- ν_3 band @ 3000 cm^{-1}

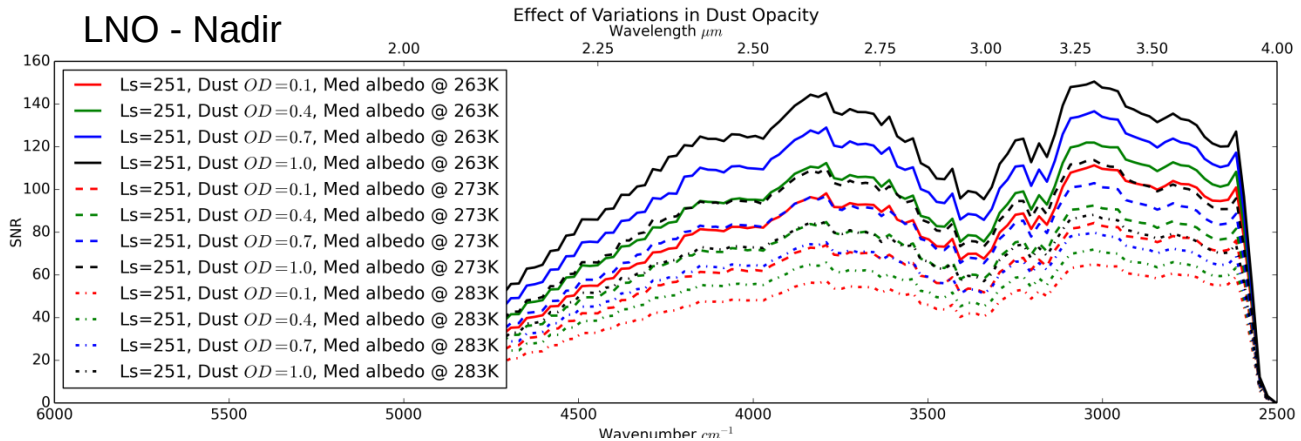


Signal-to Noise ratio determination

- Radiometric models of the three channels.
- Based on:
  1. Computation of the detected signal, considering the incoming radiation and the attenuation due to the different optical components ;
  2. Estimation of the noise on the detector.
- From these quantities signal to noise ratios (SNR) can be calculated and used further to investigate the sensitivity of the instrument.



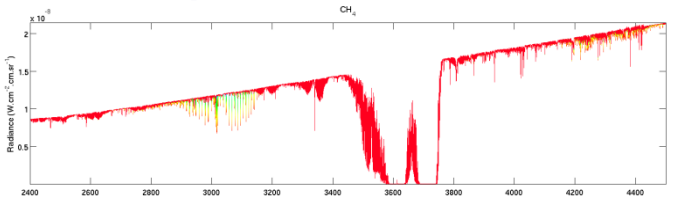
Vandaele et al. 2015 b; Thomas et al. 2016



Detections limits: (1) methodology

1. Simulate a series of spectra with known abundances of the target species ;

- With different abundances covering a large possible interval

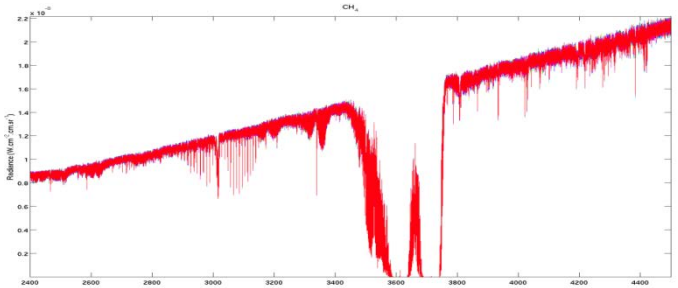


2. Add noise corresponding to the SNR just obtained ;

- **200 noisy spectra per abundance**
- **Considering**

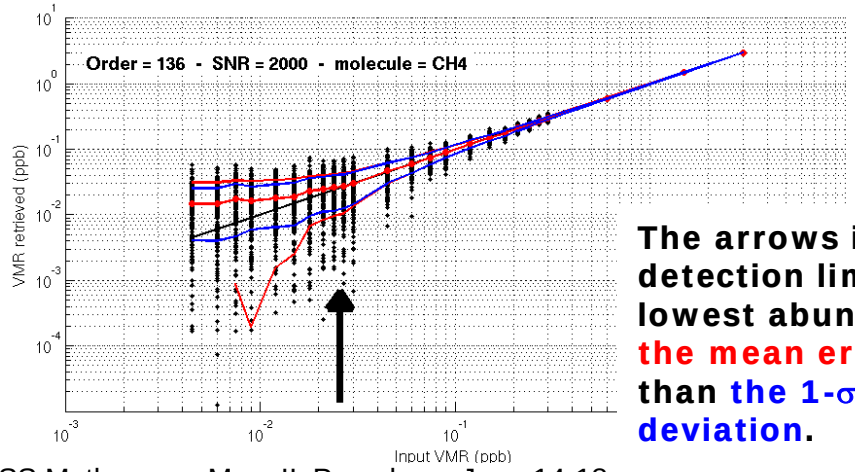
SNR	Socc	Nadir
SO	2000	--
LNO	3000	100
UVIS	500	500

Robert et al. 2016;
Vandaele et al, 2015a

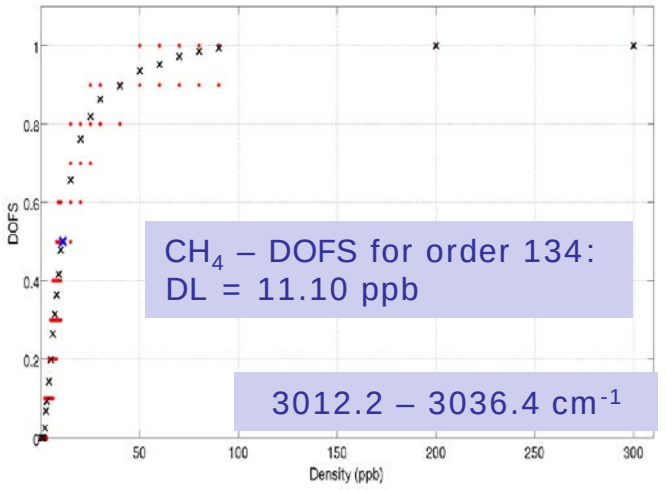


3. Apply a retrieval method to fit the abundances ;

4. Compare with the input values.

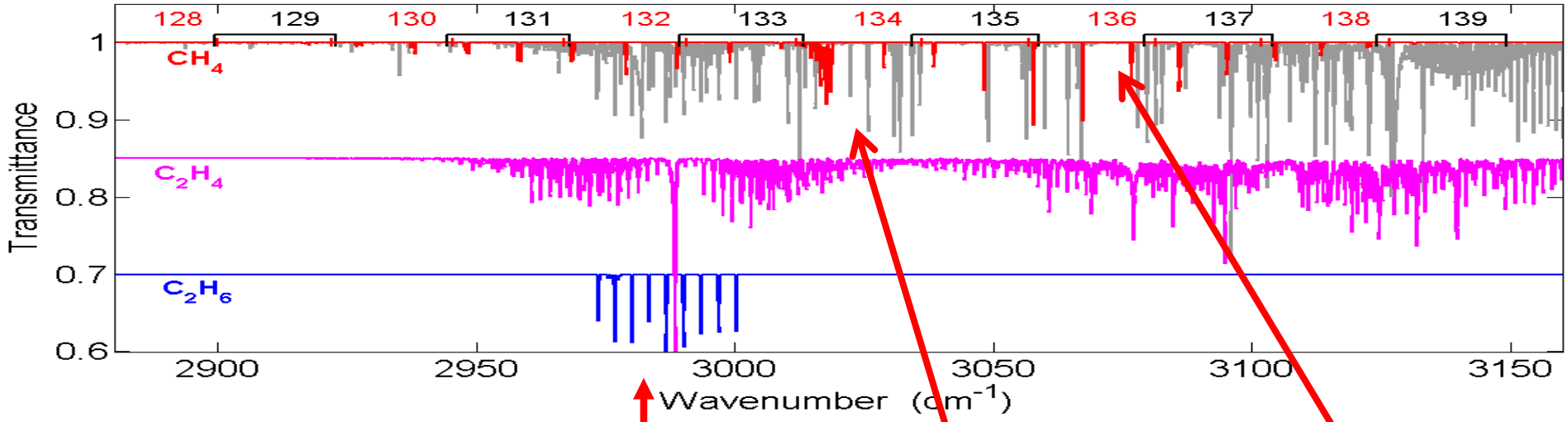


The arrows indicate the detection limit values i.e. the lowest abundance for which the mean error is still lower than the 1-σ standard deviation.



Detections limits: (2) results

- CH4 nadir



C_2H_4	Order	ppb
	132	70
	137	90
	139	80

C_2H_6	Order	ppb
	132	11
	133	14

Q-branch and R(0) line

R-branch ($3 \leq J'' \leq 5$)

CH_4	Order	ppb
	134	11
	135	19
	136	13

Detections limits: (2) results

- Nadir and solar occultations

		SO	LNO	
		Solar Occultation	Solar Occultation	Nadir
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	~ 557 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 [i] < 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	~ 1 -500 ppmv (variable with season)[j]	2.5 ppb	1.5 ppb	0.8 ppm
H_2CO	< 4.5 ppb [e] < 3.9 ppb [g]	0.04 ppb	0.03 ppb	16 ppb

(a) Formisano et al., 2004; Krasnopolsky et al., 2004; Mumma et al., 2009b ; (b) Fedorova et al., 2008; Smith, 2004; Smith et al., 2009b ; (c) Krasnopolsky et al., 1997; Lodders and Fegley, 1997; Owen et al., 1977 ; (d) Mahaffy et al., 2013 ; (e) Krasnopolsky, 1997 ; (f) Hartogh et al., 2010 ; (g) Villanueva et al., 2013; (h) Maguire, 1977; (i) Lefevre et al., 2004 ; (j) Perrier et al., 2006.

NOMAD Science Publications

- **Publications**
  - NOMAD instrument with focus on IR channels, Neefs et al., **Applied Optics** 54 (28), 8494- 8520 (http://dx.doi.org/10.1364/AO.54.008494) (2015).
  - NOMAD instrument with focus on UVIS, Pat
  - NOMAD Science Objectives, Vandaele et al.,
  - Optical & SNR models – Part I: UVIS, Vandae Issue 23, pp. 30028-30042 (2015)
  - Optical & SNR models – Part II: SO & LNO, pp. 3790-3805 (2016)
  - Expected performances of the NOMAD/Exo 124, pp. 94-104 (2016)
  - Two test-cases for synergistic detections in t monoxide and methane, Robert et al., **JQSR**

http://mars.aeronomie.be/en/exomars/publications.htm

NOMAD Ops Working Groups

- Definition of WG for **Operation Strategy** definition

Other space instruments / missions

- Mars Express: M. Giuranna
- CRISM: Mike Smith
- MAVEN: Nick Schneider, A. Stiepen
- EXM ACS: A. Trokhimovskiy, M. Lopez-Valverde, M. Patel, V. Wilquet, JC Gérard
- EXM EDM: M. Patel, O. Karatekin
- EXM 2018 : O. Karatekin /V. Dehant (LARA)
- InSight: O. Karatekin
- JWST: G. Villanueva

- Others ? All welcome

OSWG1 : IR Composition — A.C. Vandaele

CH4 - Trace gases (other than O3) - Isotopic ratios - Structure (CO2, T)

OSWG2 : UV Composition — M.R.Patel

O3 distribution

OSWG3 : Aerosols — V. Wilquet

Aerosol characterization: distribution, optical properties

OSWG4 : Limb — J.-C. Gérard/ M. Lopez-Valverde

Limb observations – Non-LTE observations Airglows - Nightglows

OSWG5 : Other instruments — G. Villanueva/ M. Giuranna

Synergy with other instruments/missions – with Ground-based Observations

OSWG6 : Modeling — F. Daerden

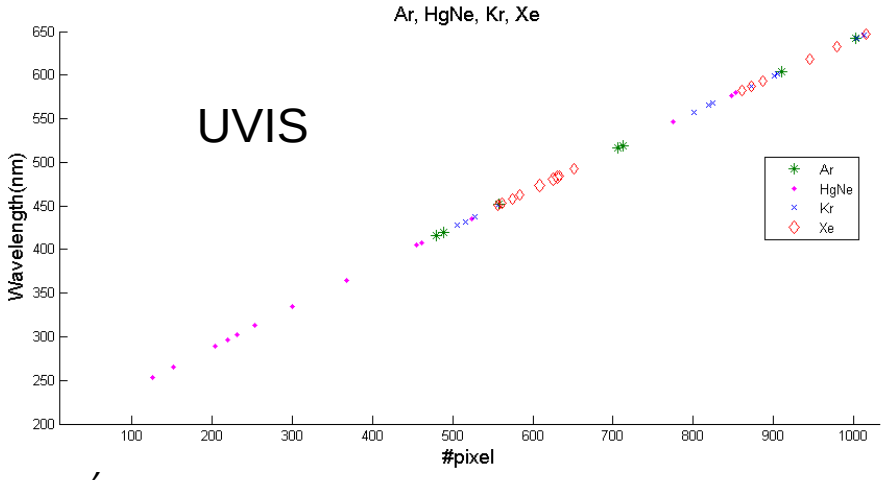
Modelling activities

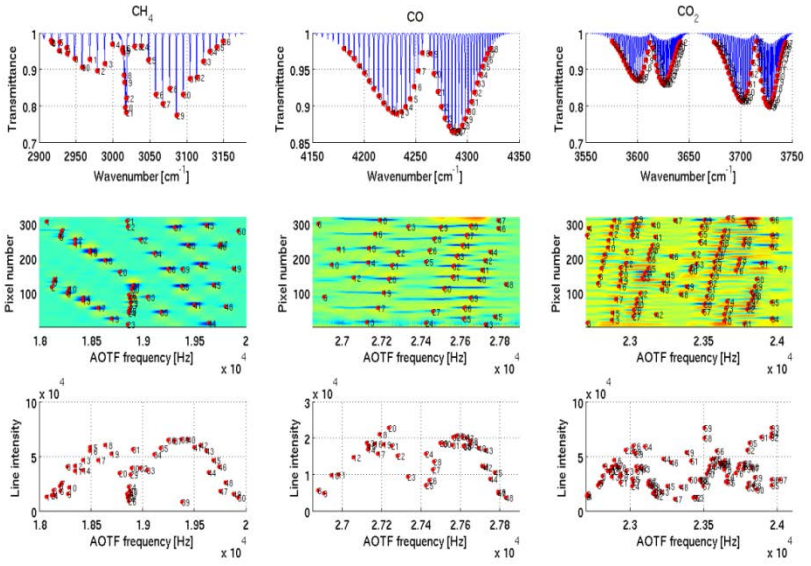
NOMAD: status

- On-ground calibration
  - A terrific number of observations, still being analysed
- NEC
  - Boresight
  - Mini and full Sun scans
  - Dark sky observations
- MCC - Mid-cruise checkout - **NOW**
  - Refine boresight
  - Additional mini-scans and full-scans (SO/LNO)
  - Straylight with larger grid size
  - Dark sky integration time stepping (LNO/UVIS)
  - Mars observation (UVIS only)
- Next: MCO

Ground Calibration

- Done:
  - Performance checks
    - E.g. detector 'smile'
    - Pixel non-linearity vs. radiance
    - Bad pixel mapping
  - Spectral calibration
    - AOTF frequency vs. diffraction order (SC
    - Pixel vs. wavenumber (SO/LNO)
    - Pixel vs. wavelength (UVIS)
  - Integration time vs. instrument temperature
    - SO and LNO dark current measurements





Near Earth Commissioning

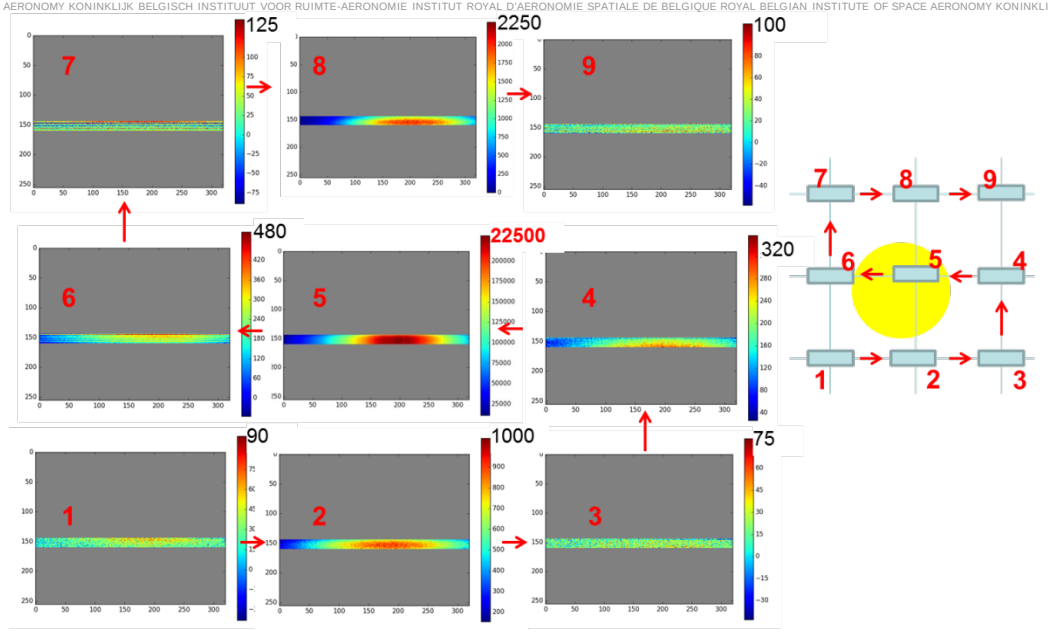
- Most time-critical data already analysed:
  - Boresight direction
  - Detector pixel illumination
  - Sun saturation integration time
  - SO SNR estimate

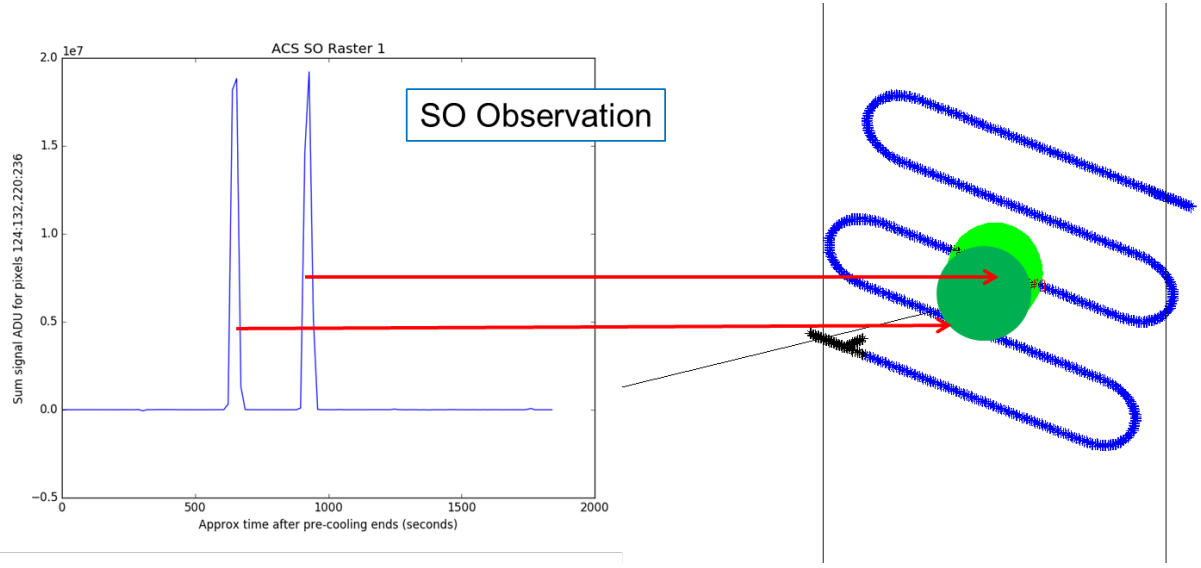
Fed into mid-cruise checkout plan

- Earth-pointing was removed from the plan (forbidden to point CaSSIS within 60° of the Sun)
- AOTF/spectral data not yet compared with ground calibration results
- Jupiter data not yet analysed
- Geometric straylight not yet analysed
  - 15,000 frames of data broke the conversion script

Boresight Direction

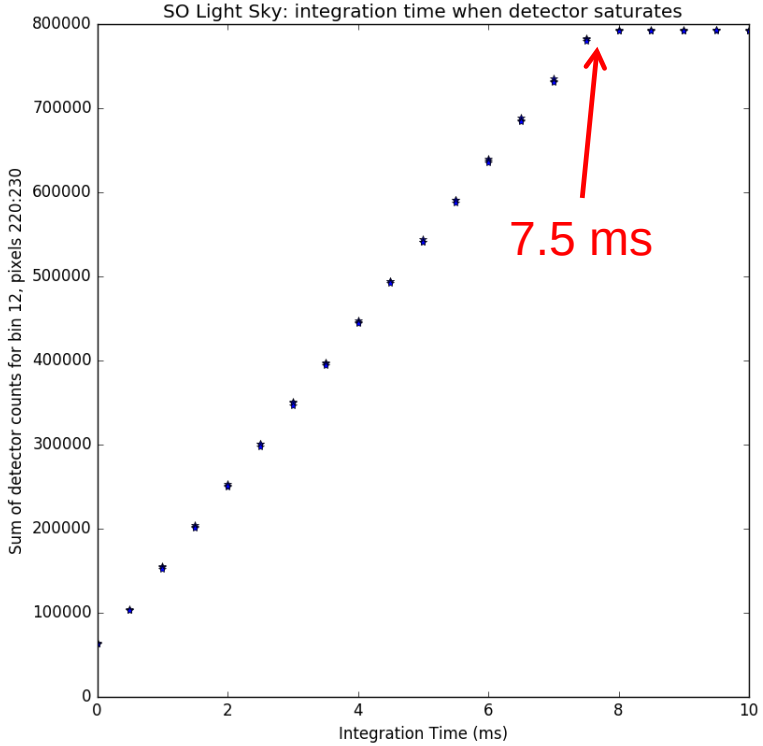
- Dedicated NOMAD raster scans
  - Large grid, to ensure that we see the sun
- Also joint NOMAD-ACS raster scans
  - Smaller grid size
  - More useful to derive boresight offset

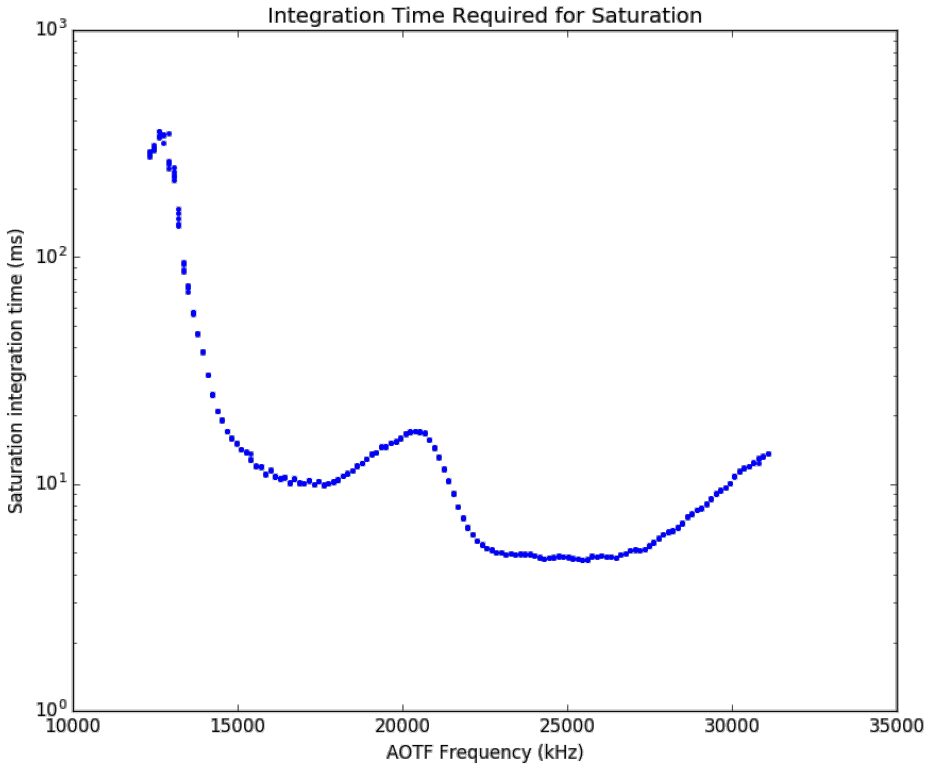




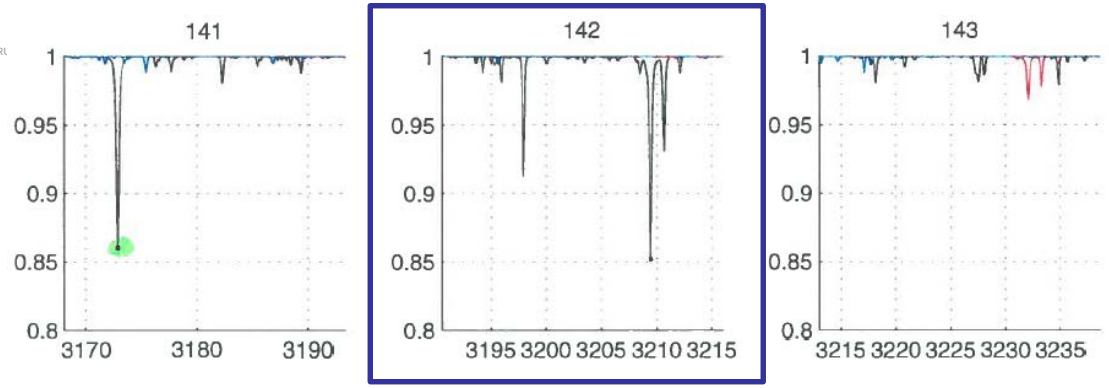
Sun Detector Saturation

SO



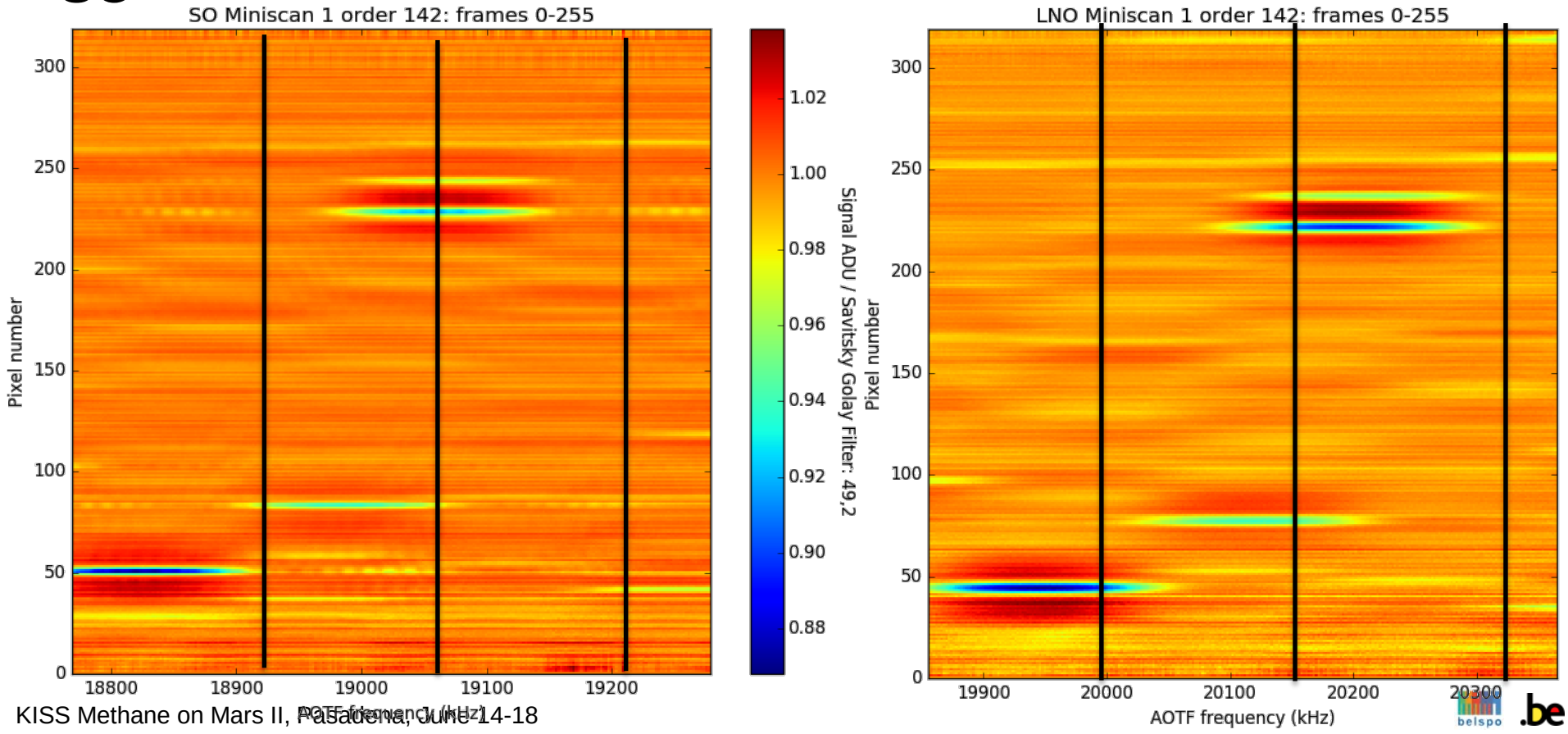


SO and LNO Miniscan Results

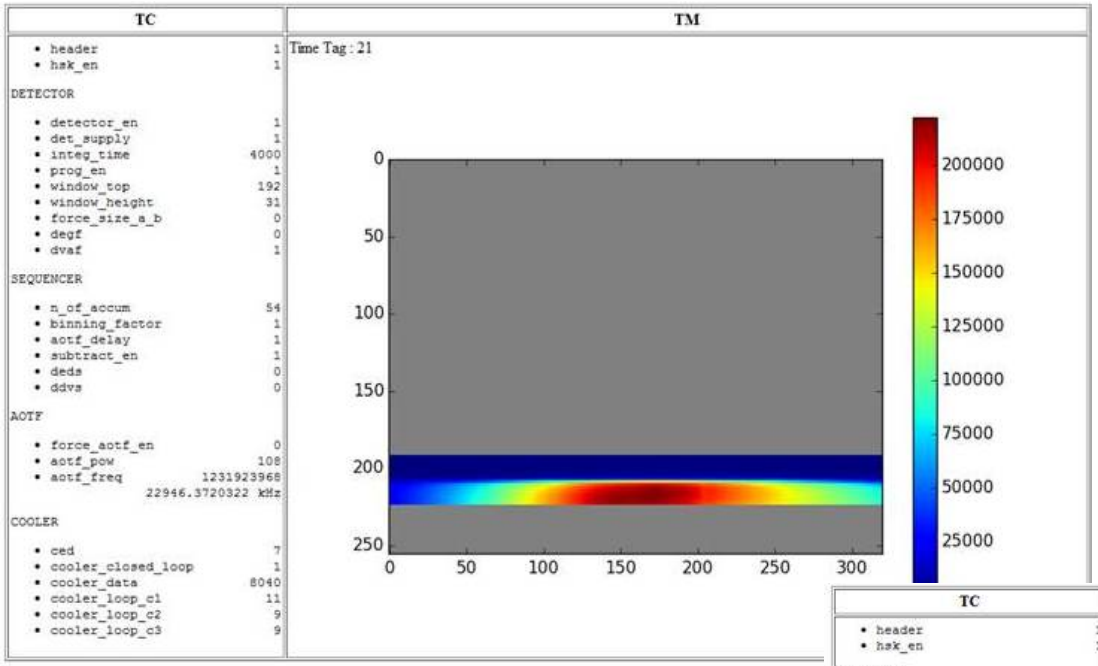


SO

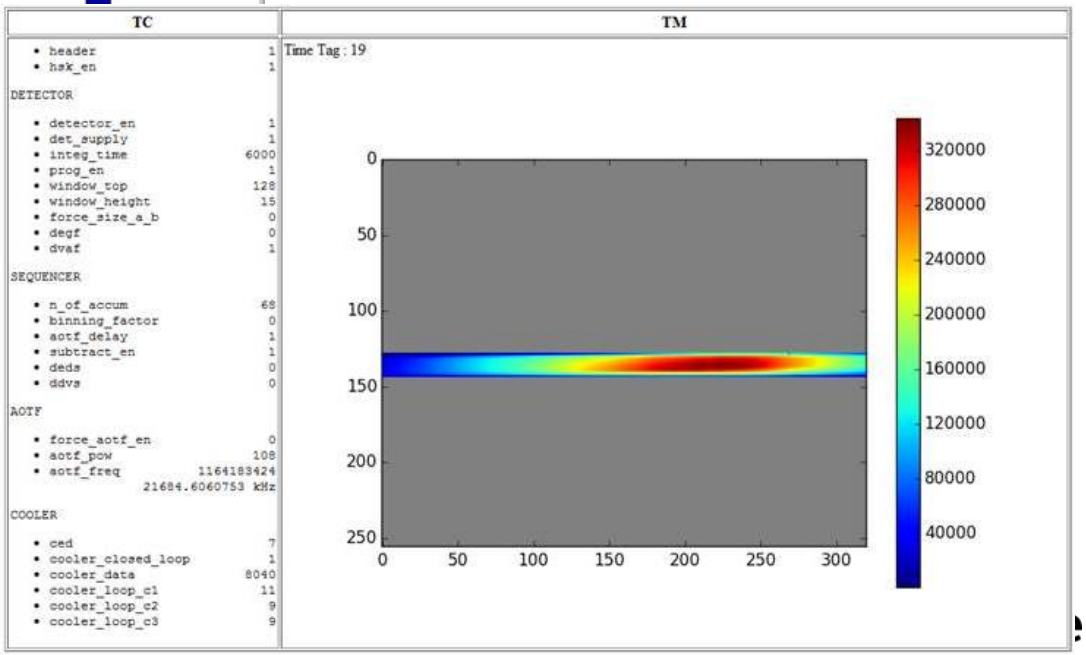
LNO

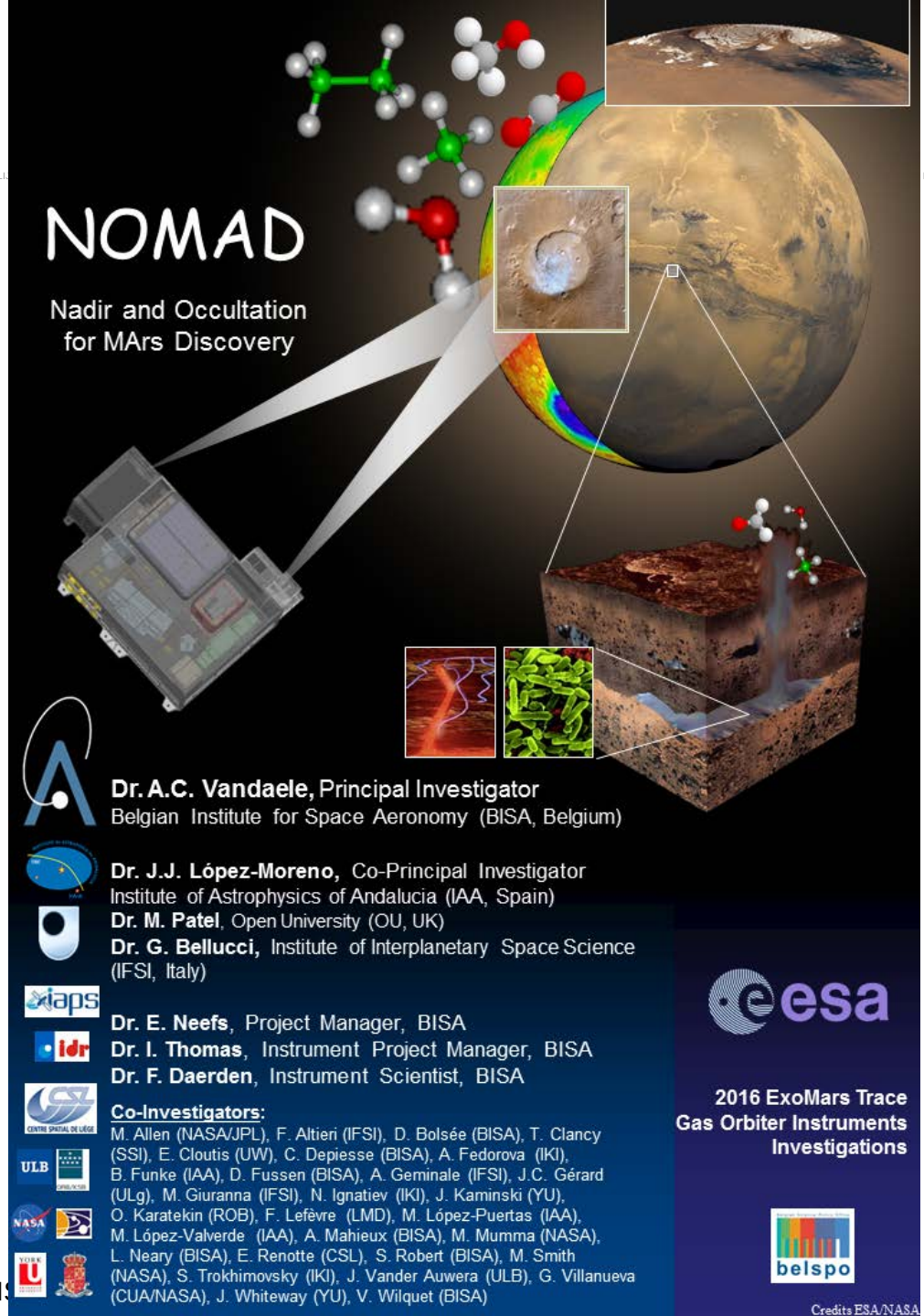


MCC first results !



LNO and SO still seeing the Sun





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