Observing the upper atmosphere of Mars with NOMAD/TGO

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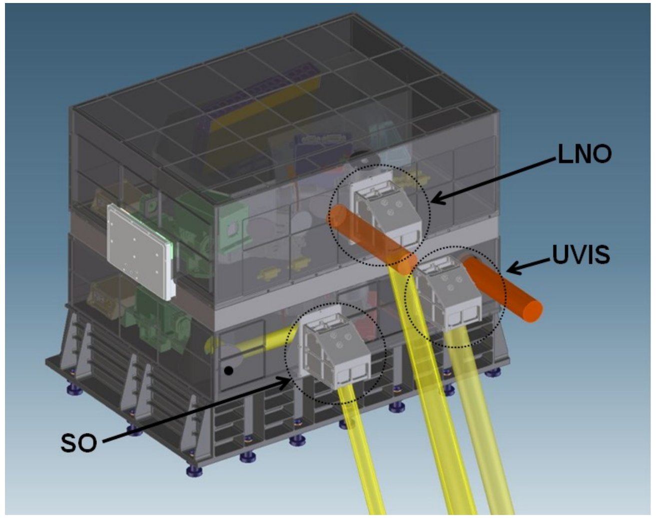
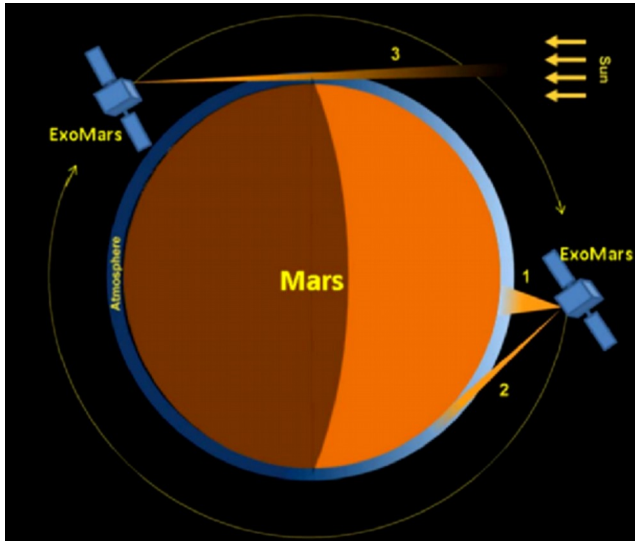
NOMAD is one of the two instruments on board the ESA+Roscosmos Trace Gas Orbiter devoted to search for trace species in the Martian atmosphere using a solar occultation technique in a nearly circular polar orbit. NOMAD started its science phase in April 25th, 2018, after a long period of aerobraking, using its 3 channels, from the UV (200-650 nm, the UVIS channel) to the near-IR (2.3-3.8 um, SO & LNO channels). NOMAD performance, sensitivity and resolution are nominal to date, and the on-board electronics and software module SINBAD, designed and built at the IAA/CSIC, is also performing extremely well. The NOMAD observing geometry is specially suited to sound in the limb with good vertical resolution up to very high altitudes. Densities and temperatures can be retrieved up to 180 km, and we illustrate here an example of the accuracy and vertical resolution achieved with the IAA retrieval suite. Validation of these results with other instruments on board ACS and with atmospheric models is on-going. We also present a couple of recent discoveries in the upper Martian atmosphere, related to the abundance of water vapour and the visible airglow on Mars: [1] Water vapour seems to be injected into the upper atmosphere under specially warm conditions in the lower atmosphere, or when dust storms are present, which can impact the escape of H through Mars history. [2] We report here on the discovery of the atomic oxygen green line emission in the Mars dayglow, which validates current photochemical models and confirms a long debate between laboratory measurements of relaxation rates in the UV/visible.

Grating Spectrometer + Filter (AOTF)





Nominal Observing Geometries

Data analysis/retrieval Methodology *- after operational calibration -*

STEP 1: Pre-Processing:

- Correction for spectral shifts & bending in Level 0 or Level 1
- Prepare Data & Error for next step (TRA ➜ Rads !)
- Visual inspection of data quality & geometry
- Binning in the vertical / Selection of altitude ranges

STEP 2: Inversion :

- KOPRA (non-LTE line-by-line FM)
- RCP (Optimal Estimator / Max.Likelihood solution with a Tikhonov 1st.Ord regularization)

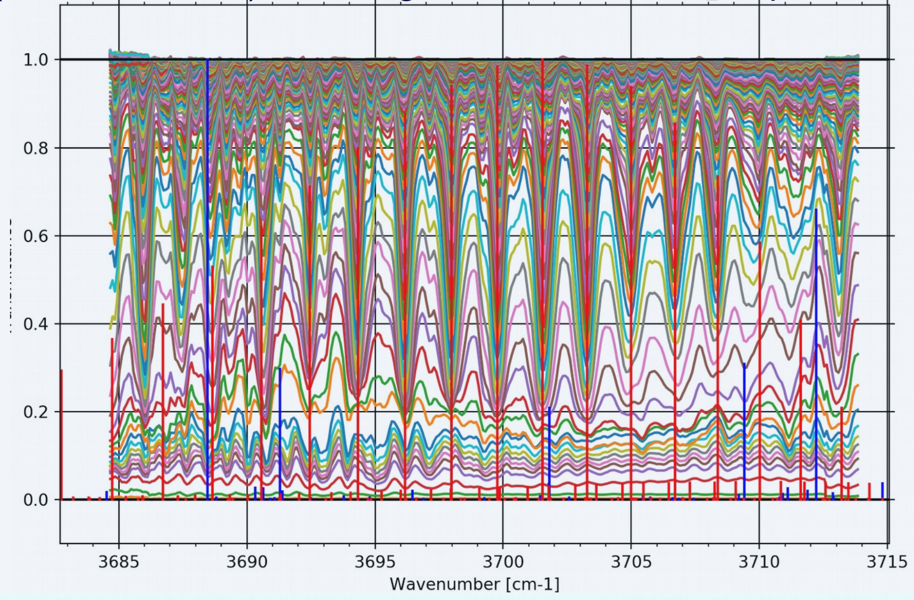
Critical : Instrumental Response

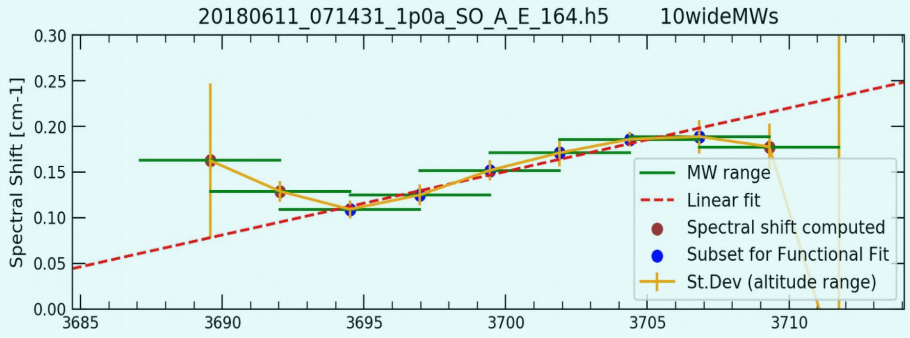
- Line Shape (spectral resolution)
- Acousto-Optical Transfer Function (cristal's optical filter)
- Blaze function of the spectrometer grid

>> Still under investigation by the NOMAD Team <<

Calibrated spectra from one scan:

Example of 1 solar occultaiton scan with about 100 spectra (transmittances), showing CO2 and H2O absorption lines.





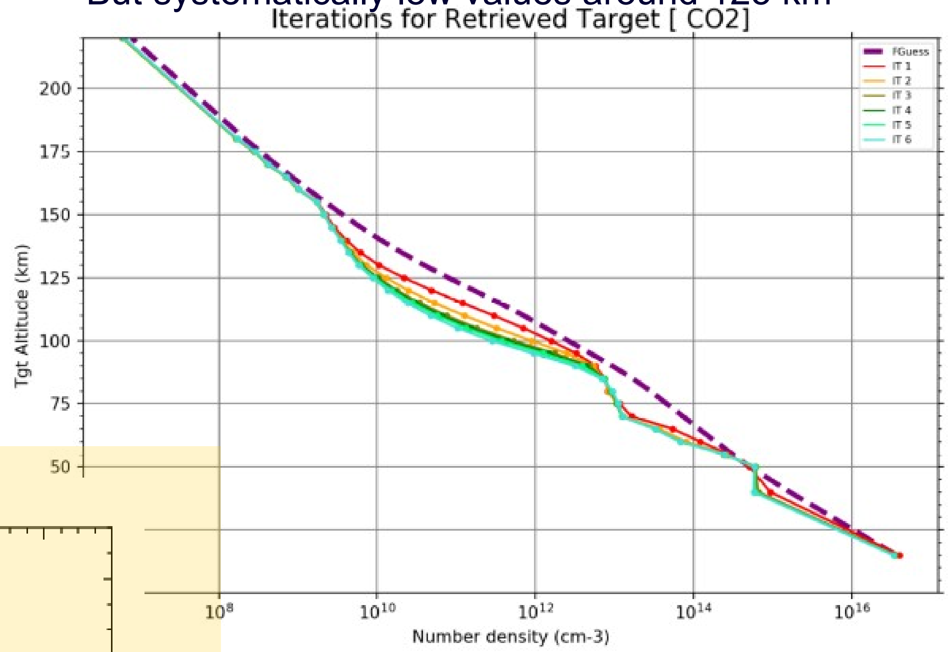
Pre-Processing Task: Spectral shift correction

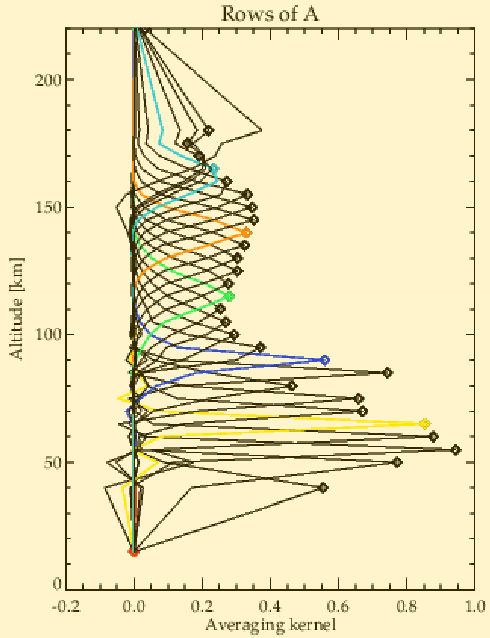
By using 10 narrow windows across the order the spectral shift is characterized, at ~0.15 cm-1 (in this particular orbit), but with a variation which is linear only in the order's center.

RETRIEVAL OF CO2 DENSITY PROFILES

6 iterations, converged to wavy profile .

But systematically low values around 125 km





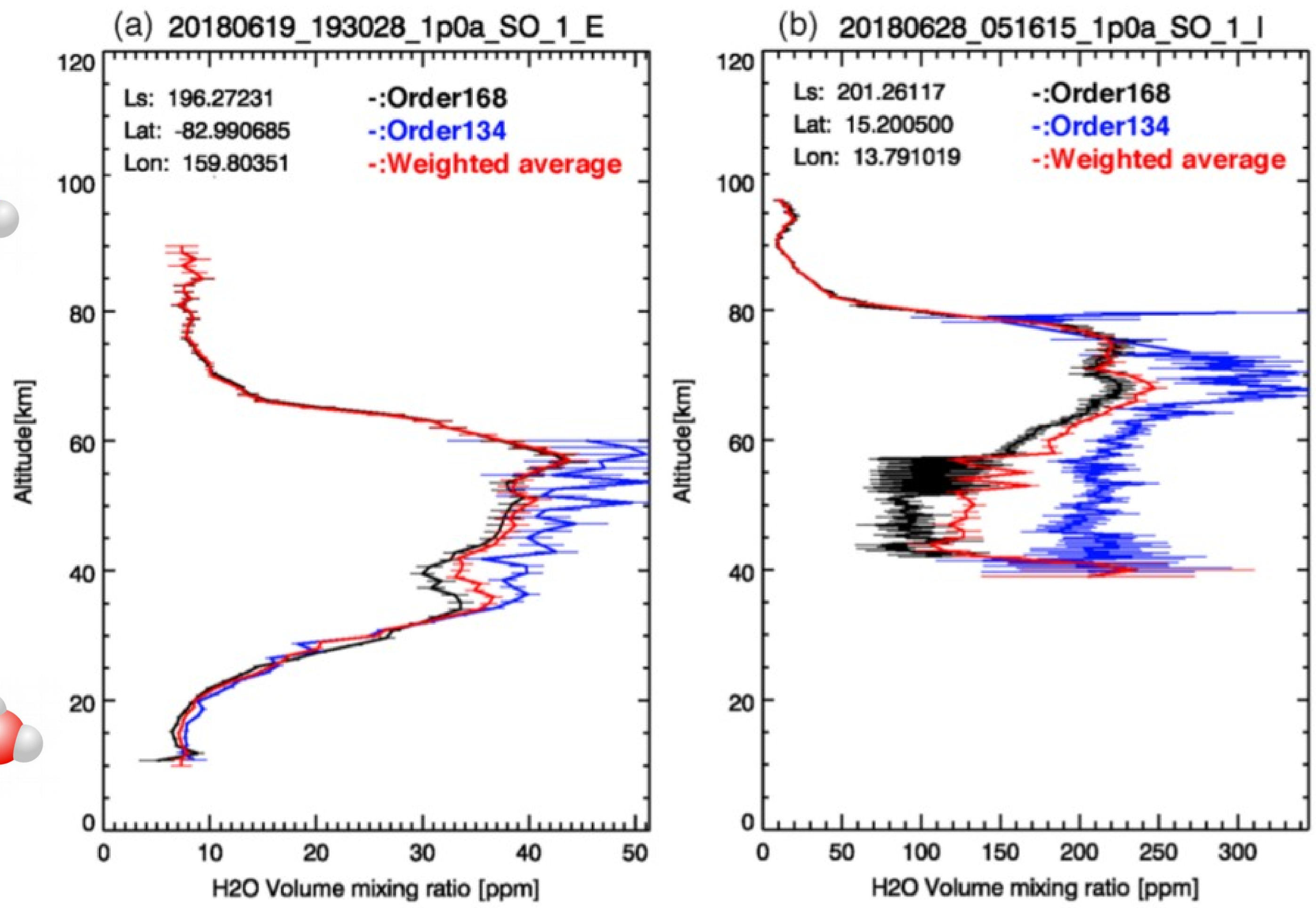
Effective vertical resolution

~ 10-20 km

between 50 and 170 km altitude

Water vapour in the Martian mesosphere during global/regional dust storms

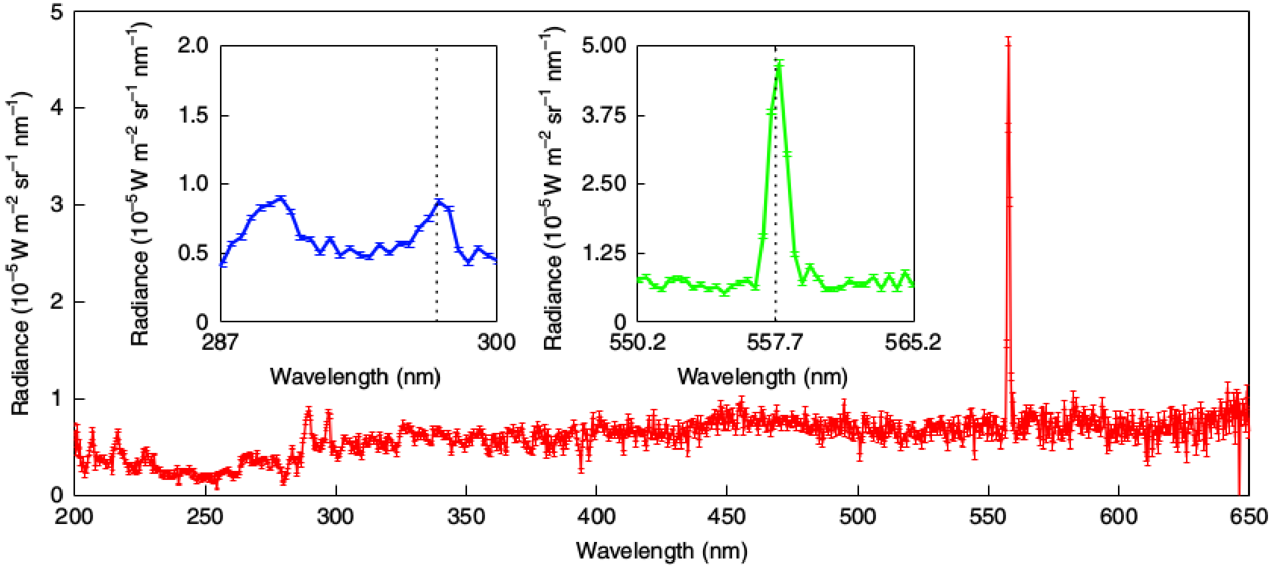
from Aoki et al., JGR, 2020



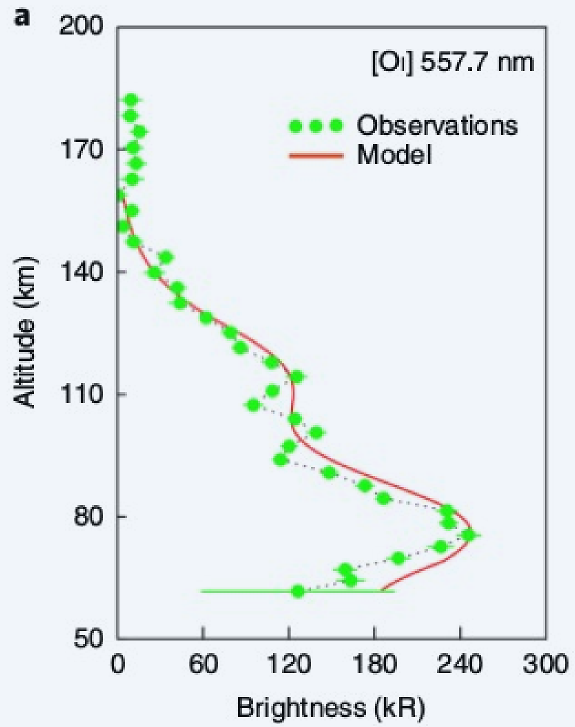
- In June 2018 a global dust storm developed on Mars. In January 2019 there was also a regional dust storm. NOMAD followed both events.
- Inversion from 2 diffraction orders confirm high H2O up to 100 km during global dust storm and up to 90 km during the regional storm.
- H2O increases quickly above 40 km just after the onset of the dust storms, in contrast to its strong depletion at those altitudes in dust-free conditions.
- Heating of the atmosphere by dust absorption prevents H2O to condense above the troposphere, in the so called Martian hygropause.

Discovery of the oxygen Green Line on Mars dayglow

from Gerard et al., Nat.Astron, 2020



Example of UV spectrum from UVIS/NOMAD, with the atomic oxygen line at 557 nm and the CO2+ doublet at 297 nm. Averaging over altitudes 70-100 km during special observation campaign of TGO to permit off-the-terminator pointings to the dayside (no solar occultation).



Model simulation with 2 peaks, shows good agreement with data. The upper peak, around 115 km, is due to absorption of solar radiation in the extreme UV, while the lower peak around 80 km is due to Lyman alpha, which penetrates deeper.

NEXT STEPS & PROSPECTS FOR THE FUTURE

Complete on-going retrievals of CO_2 with fine-tunned instrument response.

- ►Simultaneous derivation of Temperatures, for consistent altitude/pressure scale.
- ►Maps of CO_2 densities and temperatures to investigate upper atm structure.
- ►Validation against other instruments (ACS/TGO, IUVS/Maven) and detailed comparison with GCM and climatologies. Lessons learned on variability?

Extend retrievals of H_2O with more difraction orders and better noise handling.

- ►Cross validation with other TGO measurements.
- ►Extend to more observations.
- ►Simultaneous measurements of HDO from other NOMAD diffraction orders.
- ►Impact on escape processes and the long term evolution of Mars.