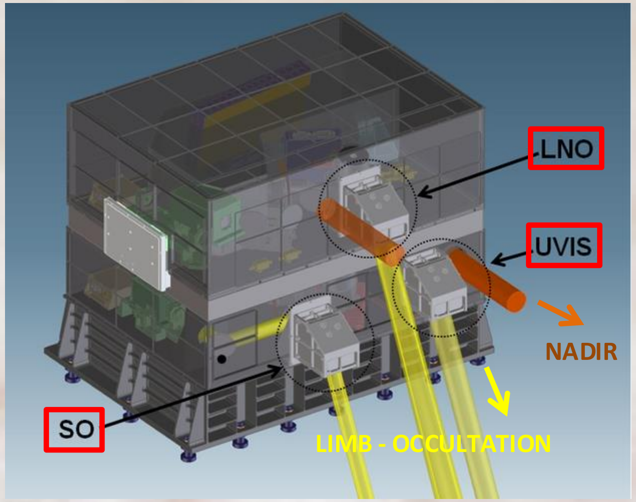
Martian dust properties in Mars Years 34 to 38: TGO/NOMAD UVIS-LNO nadir data preliminary results

F. Oliva[1], E. D'Aversa[1], G. Bellucci[1], F.G. Carrozzo[1], I.R. Thomas[2], L. Ruiz Lozano[6], O. Karatekin[6], F. Altieri[1], F. Daerden[2], B. Ristic[2], M.R. Patel[3], J. Mason[3], Y. Willame[2], M.A. López-Valverde[4], A.C. Vandaele[2] and G. Valentini[5]

[1]Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Rome, Italy;
[2]Royal Belgian Institute for Space Aeronomy (IASB-BIRA), Brussels, Belgium;
[3]School of Physical Sciences, The Open University, Milton Keynes, U.K;
[4]Instituto de Astrofisica de Andalucia (IAA), Consejo Superior de Investigaciones Científicas (CSIC), Granada, Spain;
[5]Agenzia Spaziale Italiana (ASI), Rome, Italy;
[6]Royal Observatory of Belgium,Brussels, Belgium.

NOMAD SPECTROMETERS' SUITE



UVIS:

Nadir, Limb, Solar Occultation
UV-VIS : 200-650 nm
Resolution ~ 1 - 2 nm

Dispersion grating spectrometer
↓
Continuous spectral range

SO:

Solar Occultation
IR : 2.3-4.3 µm
Resolution ~ 0.15 cm^{-1}
Resolving power ~ 20000

LNO:

Nadir, Limb, Solar Occultation
IR : 2.2-3.8 µm
Resolution ~ 0.3 cm^{-1}
Resolving power ~ 10000

Echelle grating spectrometers:
↓
AOTF → spectral orders (~20 nm wide)
+
Blaze function

- **Martian trace gases investigation;**
- Martian surface and ices (Oliva et al., 2022);
- **Martian aerosols characterization**;

- Martian aerosols' properties have been derived in **solar occultation** observing geometry from the **SO** channel (e.g. Liuzzi et al., 2020; Stolzenbach et al., 2023) and from **UVIS** channel (Flimon et al., 2025):
  - Altitudes above 5-10 km;

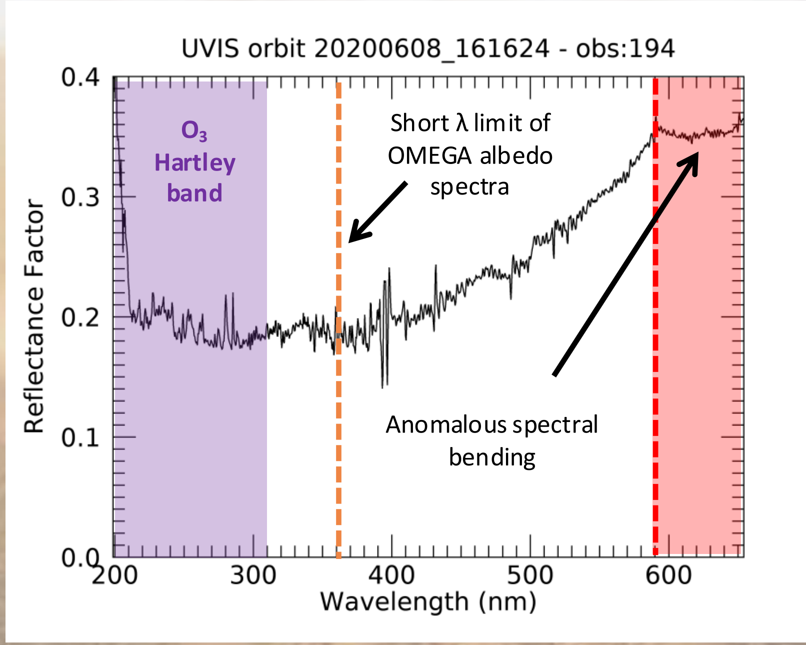
- **Combined UVIS (0.2-0.65 µm)** and **LNO** (**2.2-3.8 µm**) channels **nadir** data:

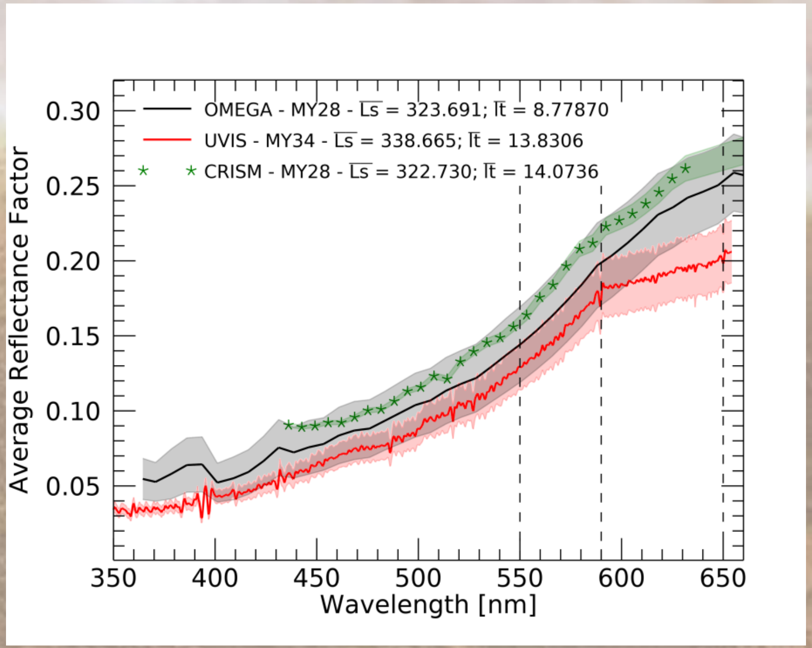
  - **Composite extended spectrum → enhanced spectral information;**
  - **Integrated atmospheric column;**

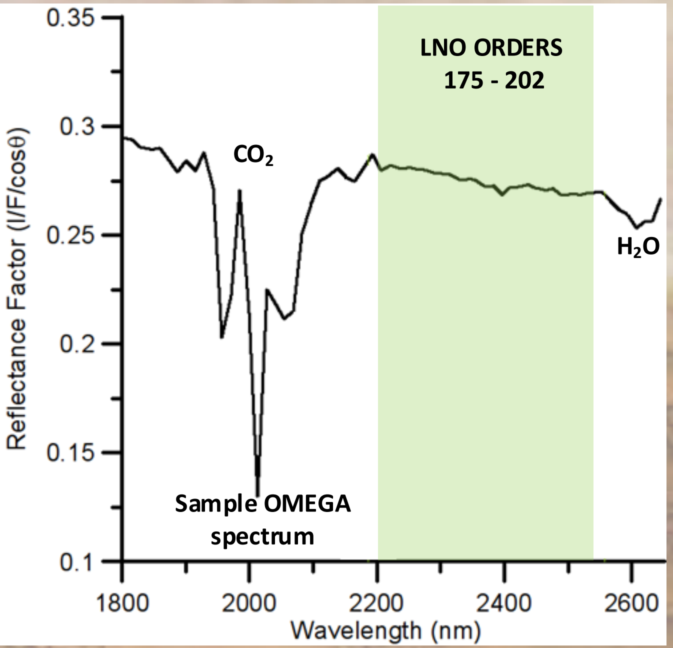
RT MODEL ASSUMPTIONS

- **Retrieve** dust grains' sizes (**r_{eff}**) and column densities (**n_{col}**) → **τ**

- **MITRA** Radiative Transfer tool (Oliva et al., 2016, 2018; Sindoni et al., 2017 ; D'Aversa et al., 2022);
- Full multiple scattering (DISORT)+Mie scatterers;
- Bayesian inversion algorythm based on a χ^2 constrained Gauss-Newton method;
- **Dust only** (Wolff et al., 2009; 2010) → **filter observations with ice for future analysis**;
- **Spectral surface albedo** from MEx/**OMEGA** data (modification of the SAS by Geminale et al., 2015);
- **No gaseous absorption:**
    - 360-590 nm (**UVIS**) → spectral surface albedo and radiometric calibration constraints;
    - 2184-2542 nm (**LNO** orders 175-202) → mostly devoid of thick gaseous lines' envelopes;

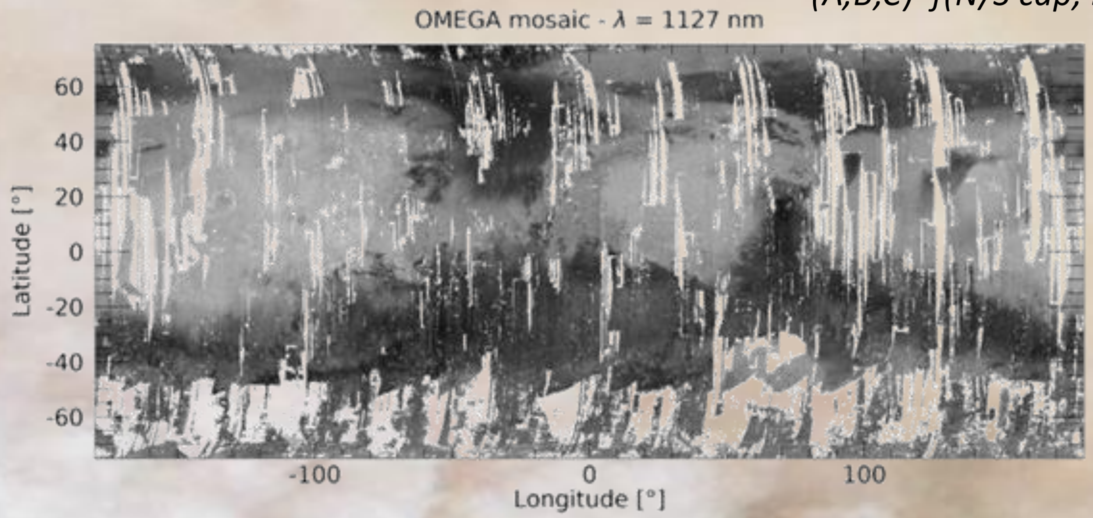




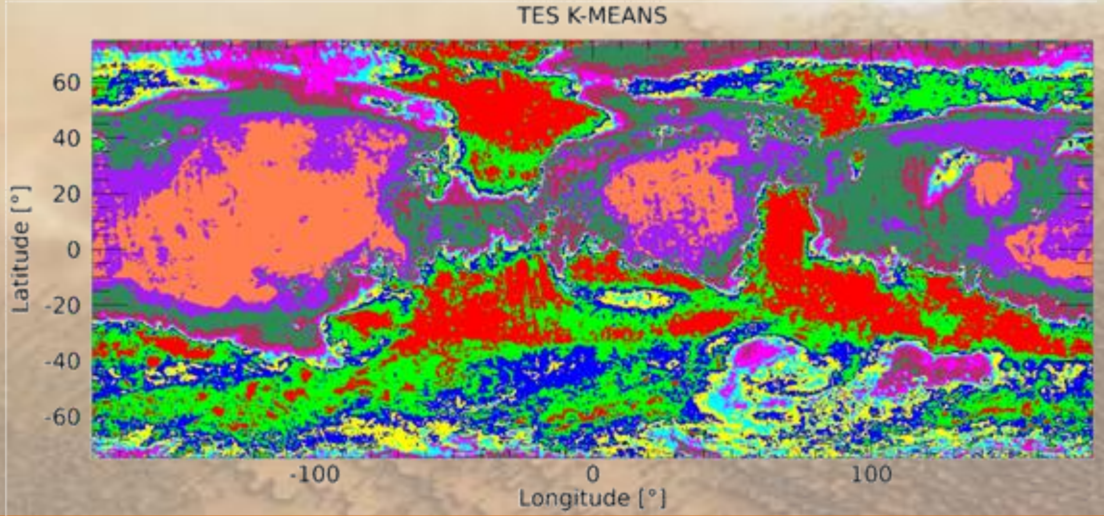


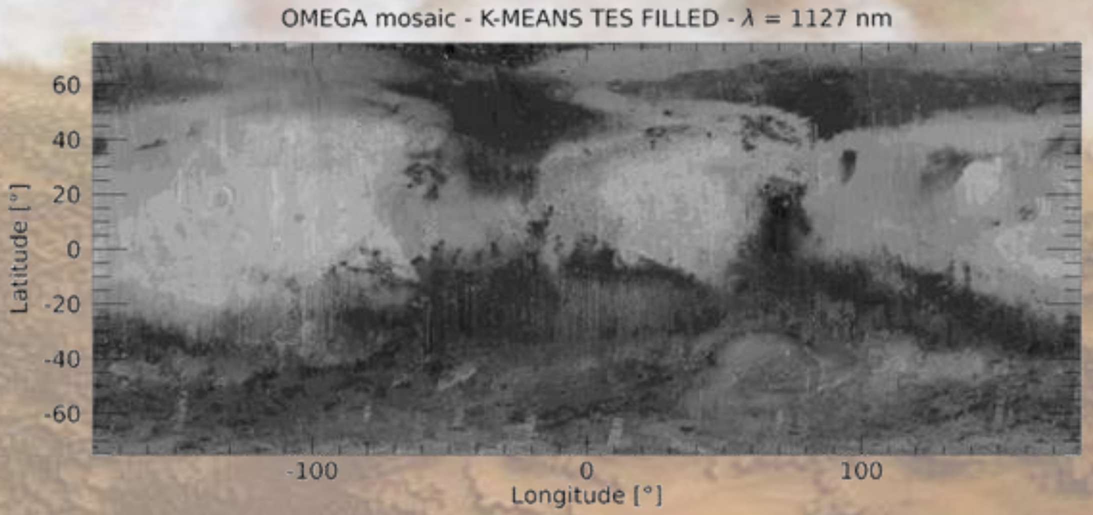
ICE FILTERING AND OMEGA SURFACE ALBEDO

- LNO orders diagnostic of H_2O ice are not always available simultaneously → **Rely on UVIS range alone**;
- Wolff et al., 2019 → enhanced **UV** intensity in presence of ice; parameterization of pola caps edges:
  - **Ice flagged with RF_{320} > 0,04**;
  - Polar caps limit → Lat = A+B·Ls-C;
    (A,B,C)=f(N/S cap, Ls)



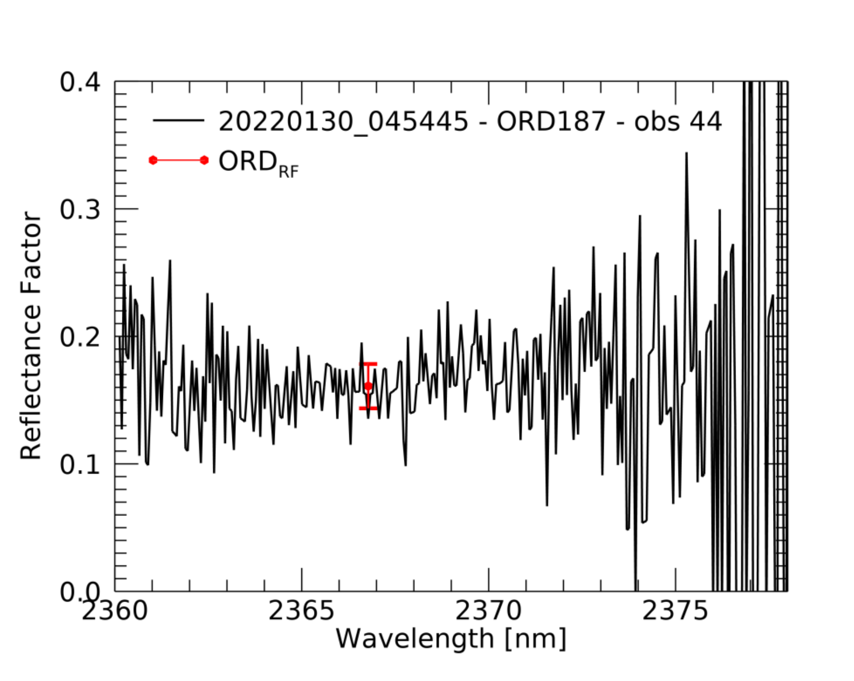
OMEGA mosaic:
- 0,25° x 0,25° longitude-latitude grid;
- no H_2O ice (RF_{320} < 0,04 - Wolff et al., 2019);
- no CO_2 ice (no 2350 nm CO_2 ice absorption band);
- **τ_{MCD} < 0,6**;
- Spectral classification on TES data to fill the gaps (k-means);
- Average errors: 10%



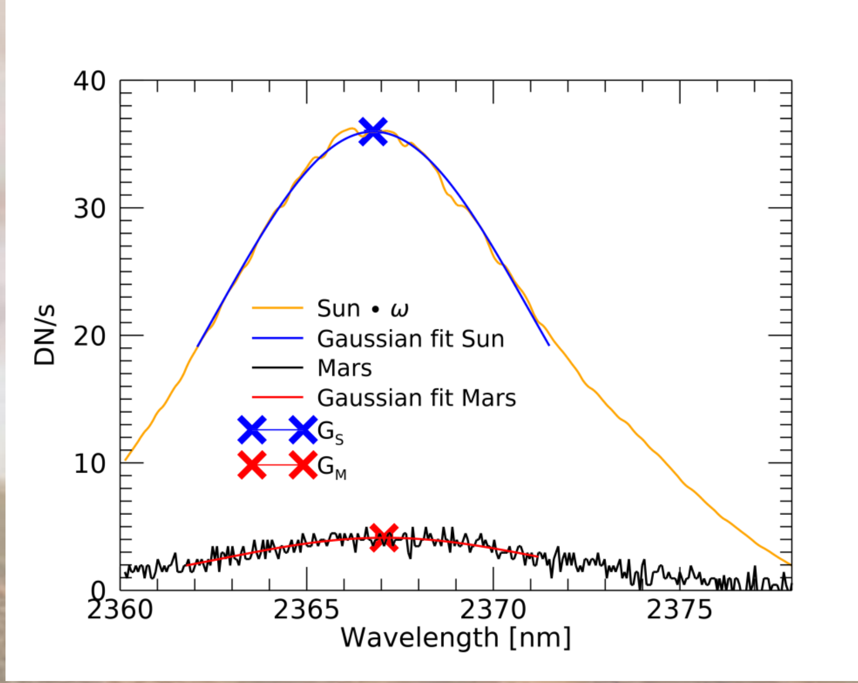


LNO DATA

- **LNO nominal setup**: **cryoradiator+cryosection** — operative **T: -100 °C**; expected average **SNR = 100**;
- **LNO final setup**: **~~cryoradiator+cryosection~~ (programmatic constraints and resource limitations descoping)** — operative **T: 0 °C**; average **SNR ~ 10**;
- **We use data calibrated in reflectance factor** $ORD_{RF} = \frac{G_M}{G_S \cdot \cos(\theta)}$

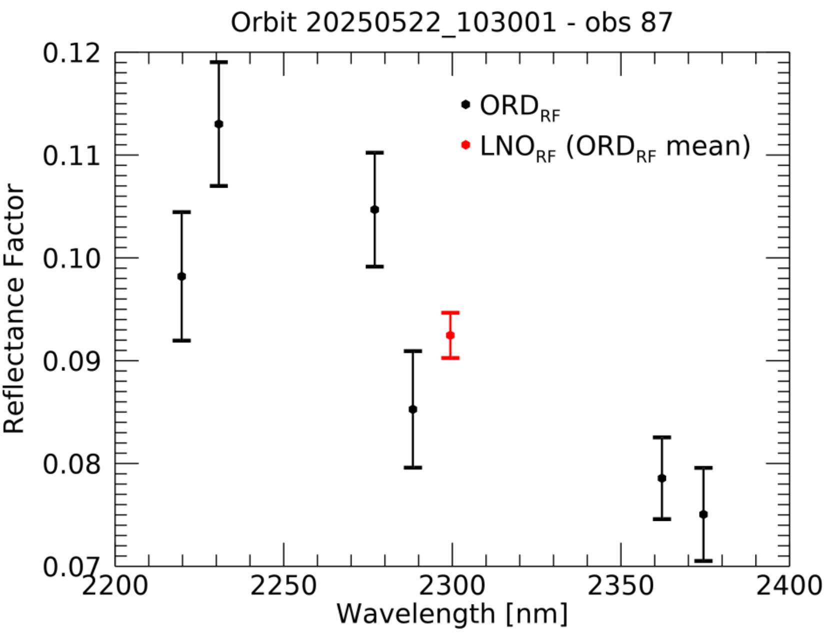


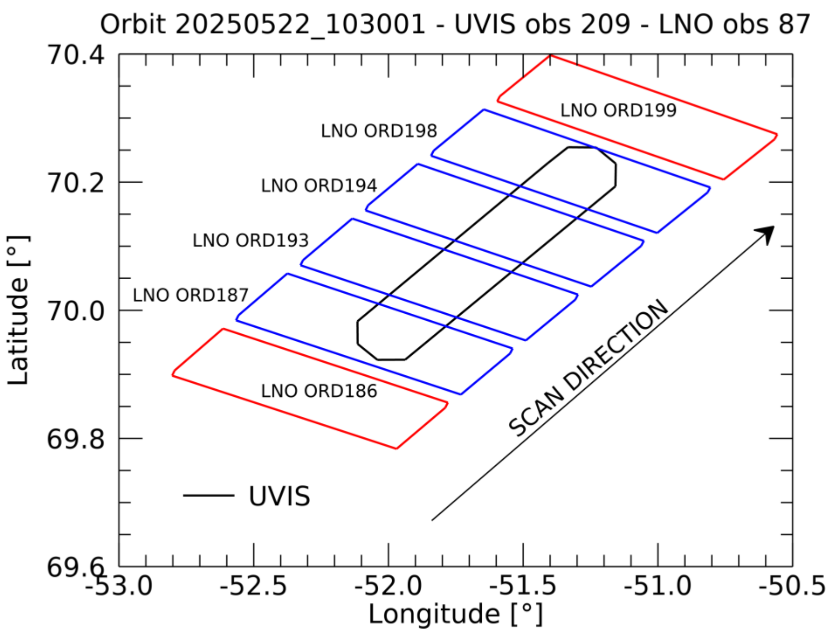
We derive a **single ORD$_{RF}$** value for **each spectral order** (avoid the strong fluctuations at the edges)

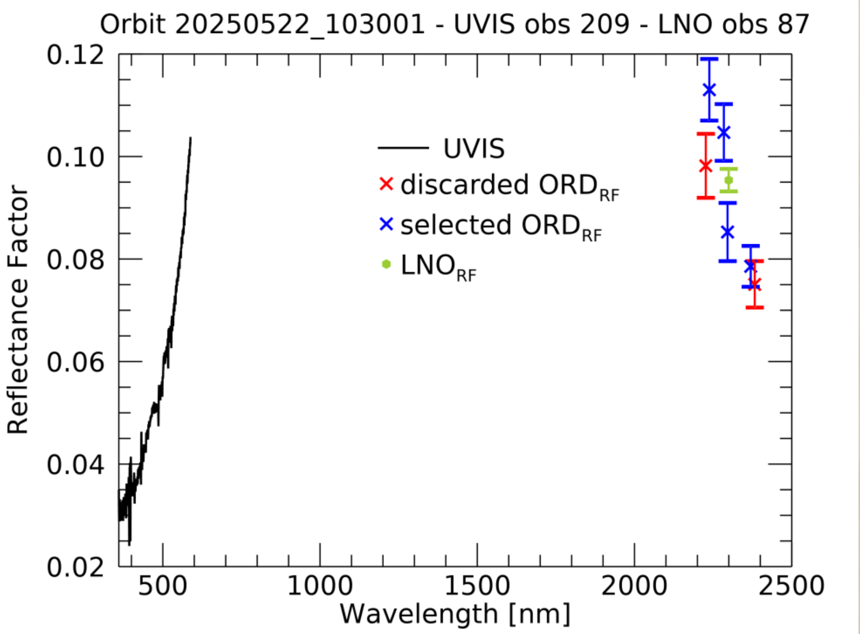


Mars and **Sun** counts both modulated by the instrument AOTF and Blaze function

COMPOSITE UVIS+LNO OBSERVATIONS







ORD_{RF} oscillate more than the expected differences in the observed scenes (*Martian RF almost spectrally flat in the NIR*) → **electrical interference** (associated uncertainty $\boldsymbol{\sigma_F}$)

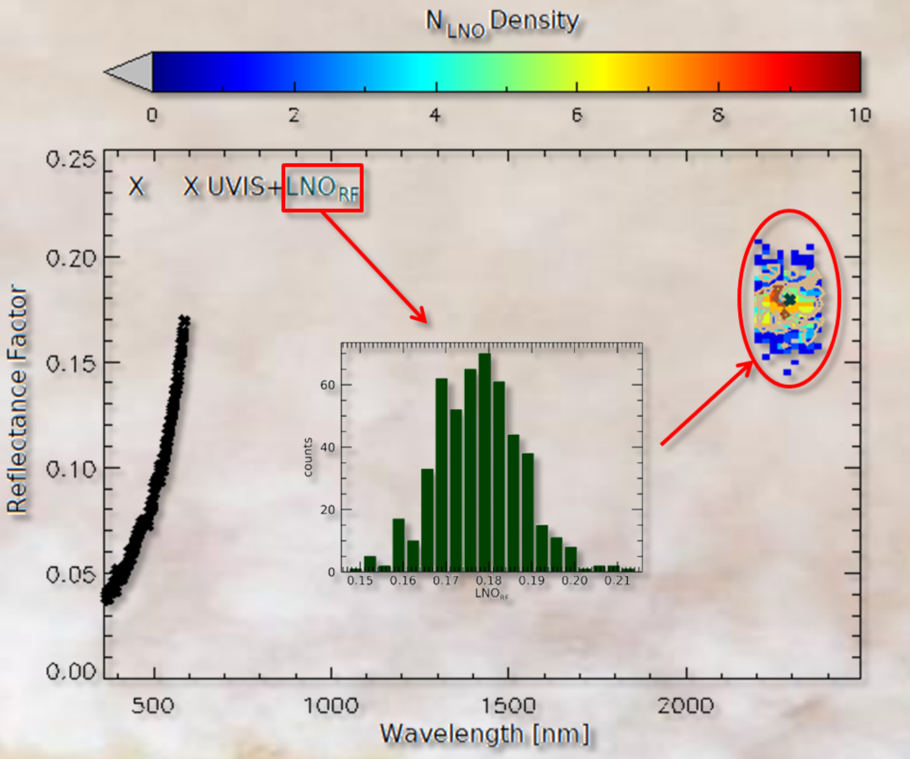
For each coincident **UVIS+LNO** acquisition we consider the average of the ORD_{RF} related to those spectral orders whose footprint actually overlaps to **UVIS** one (blue rectangles) → **LNO_{RF}**

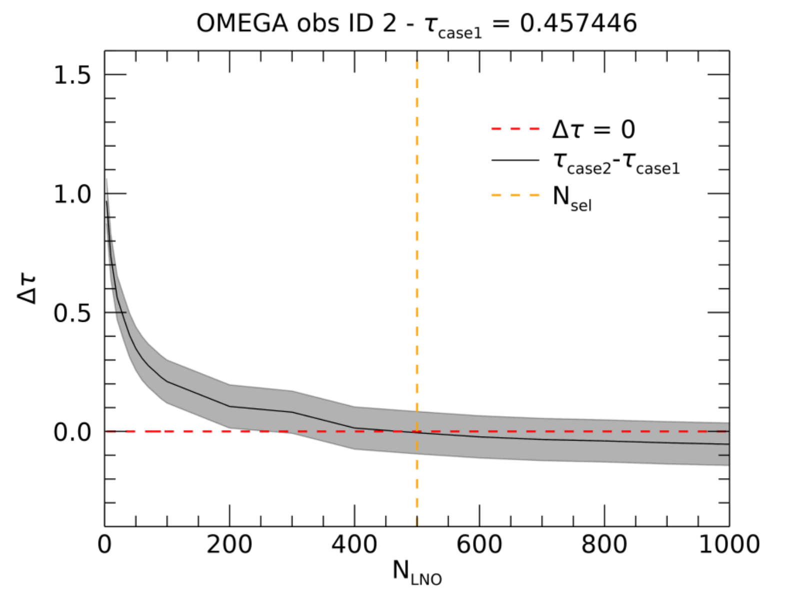
Composite UVIS+LNO spectra consist of **hundreds of points in the UV/VIS** range (*black line*) and a **single LNO_{RF} value in the NIR** (*green point*).

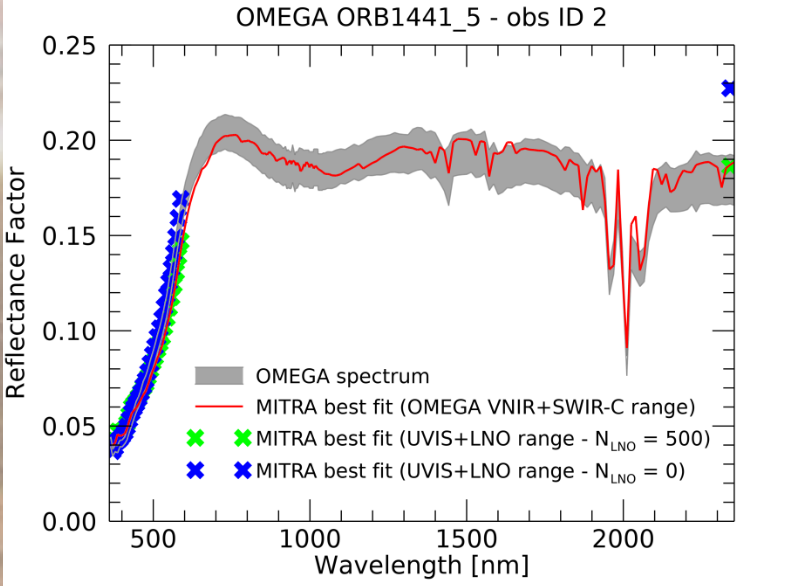
How to balance the spectral information in the retrieval?

- **LNO_{RF}** assumed as the peak position of a **Gaussian distribution of N_{LNO} RF** values with sigma σ_F;

- **How many points?**







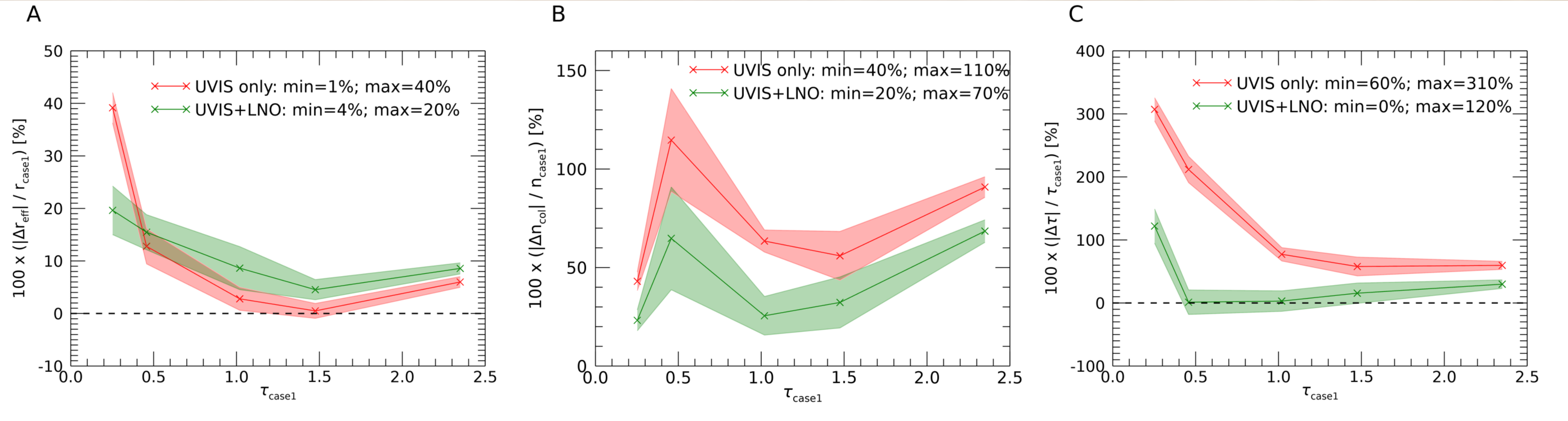
Case 1:

- **Proxy** results from **OMEGA** data (500 – 2500 nm) →local dust storm in the Atlantis Chaos region on Mars (Oliva et al., 2018).

Case 2:

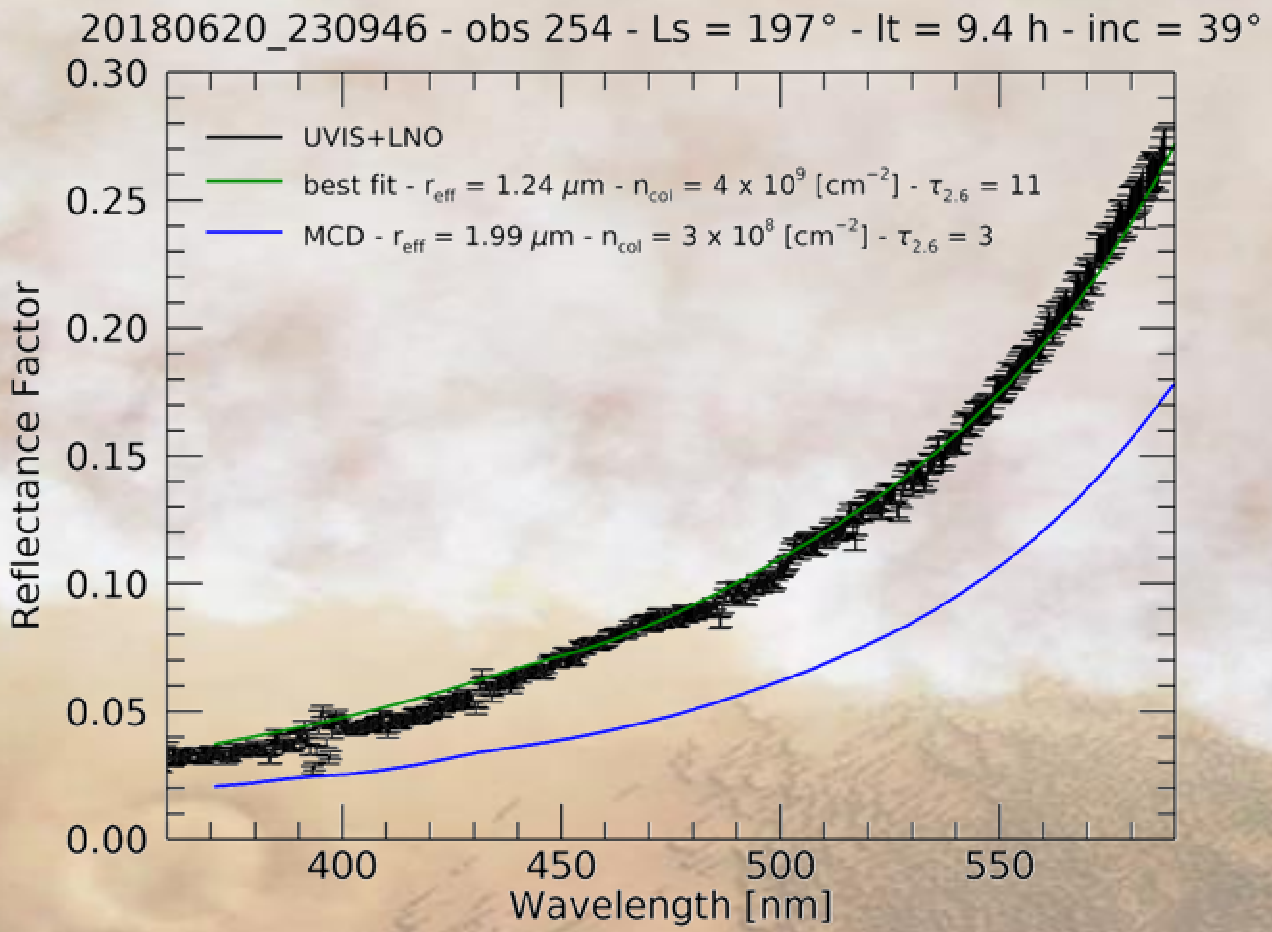
- **OMEGA** observations are **treated as** if they were acquired by **UVIS and LNO** → wavelength gap between 590 and 2100 nm and **variable N_{LNO} spectral points** in the NIR range ($0 < N_{LNO} < 1000$).

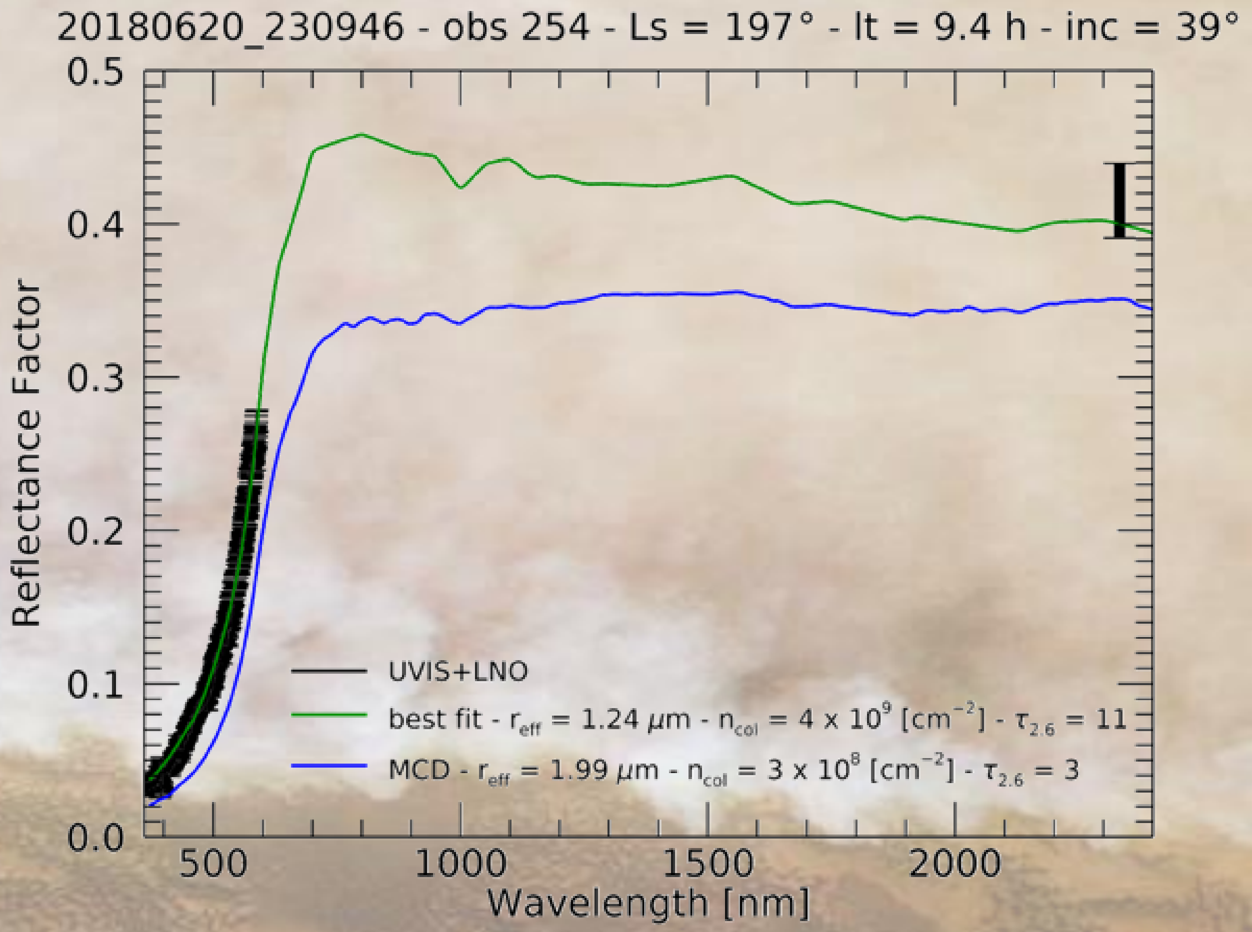
BIASES BETWEEN THE UVIS-ONLY AND THE UVIS+LNO CASES



- r_{eff}: **reduces max bias** from 40% **to 20 %.**
- n_{col}: significant reduction of the bias (**down to 20%**) in the retrieved quantities at all opacities;
- **τ**: the **inclusion of the NIR** range allows **removing the bias** at moderate dust opacities, and significantly reduce it at low (**from >300% to about 100%**) or high τ (**down to 30%**).
- ***Low dust opacities*** → non-perfect assessment of dust scattering properties and surface albedo estimation;

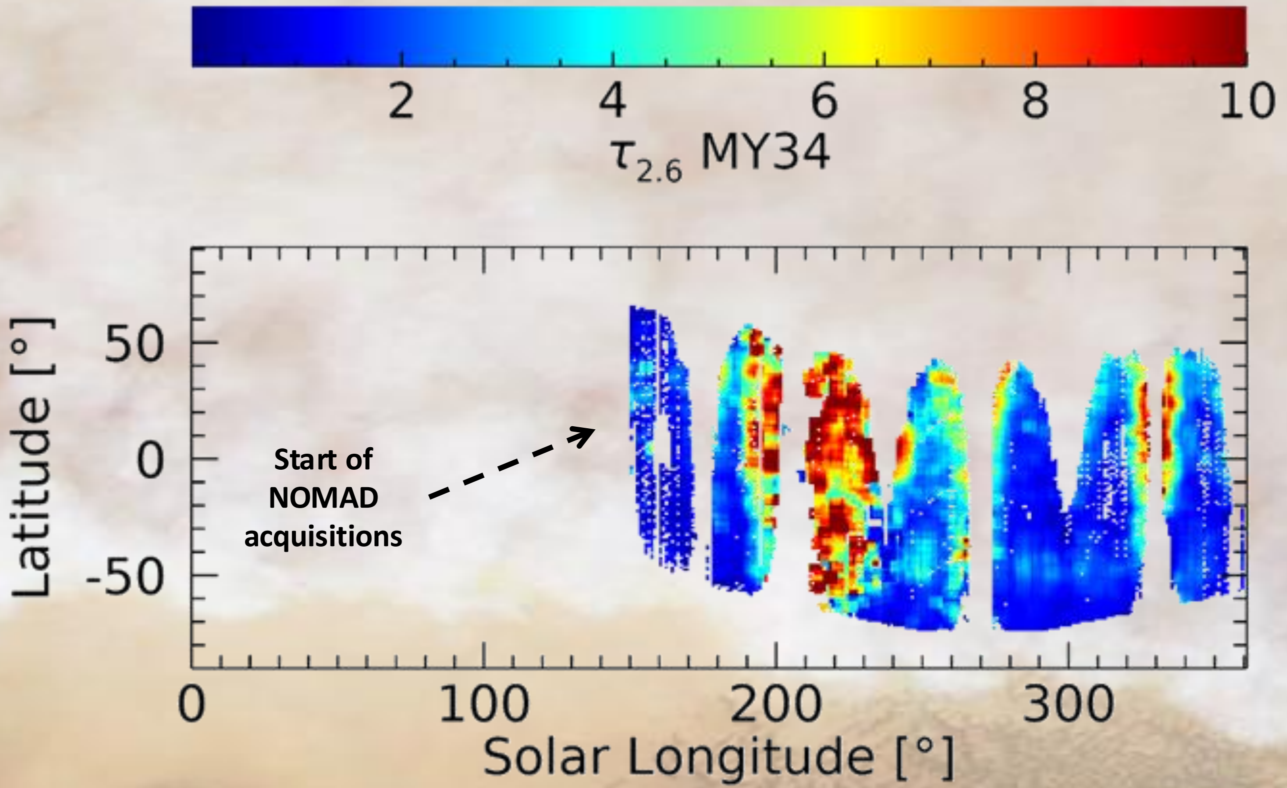
RETRIEVAL RESULTS VS MCD PREDICTIONS

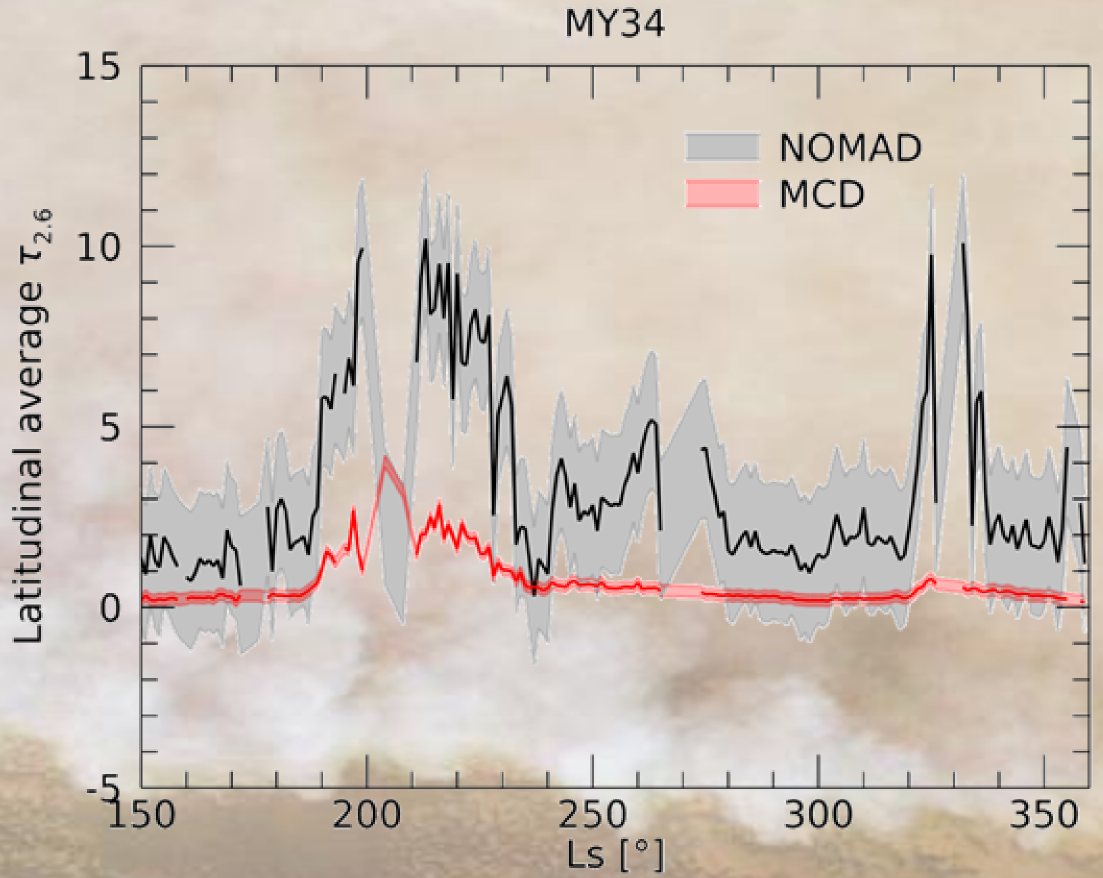




- Our approach can be used to refine the predictions of general circulation models, in turn impacting the investigation of global and seasonal climatologies.

RETRIEVAL RESULTS: MY34 GLOBAL DUST STORM

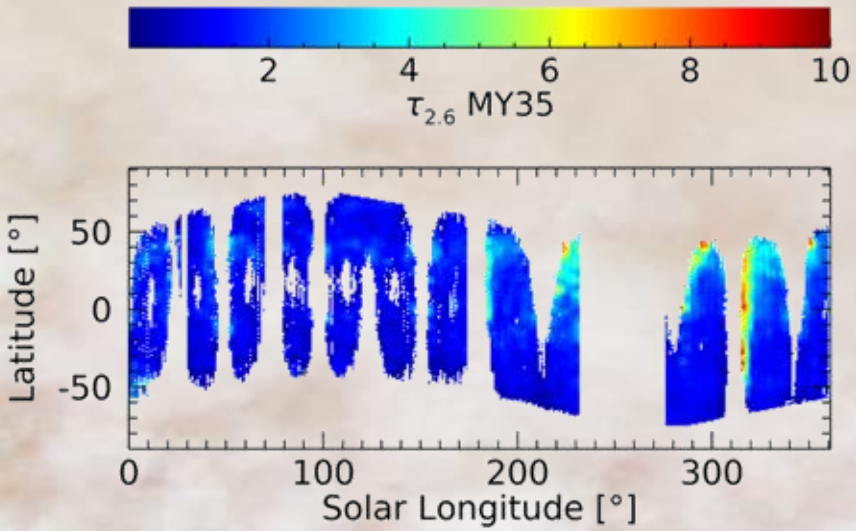


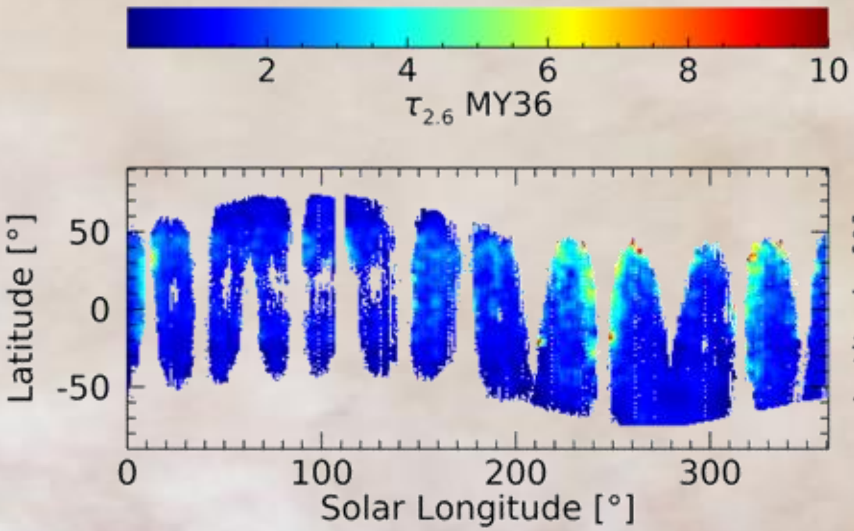


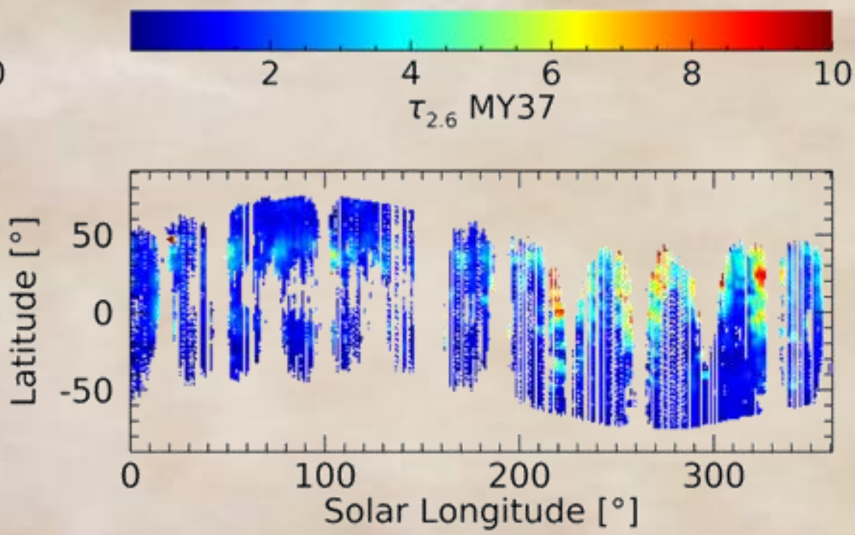
- The 2018 global dust storm is well detected in our results (180° < Ls < 240°) along with the secondary storm at (320° < Ls < 340°).

- For the global storm we report up to three times the dust content with respect to the prediction of the Mars Climate Database (→ **specific local time** snapshots in **UVIS+LNO data** vs **daily average with MCD**).

RETRIEVAL RESULTS: MY35 TO MY38



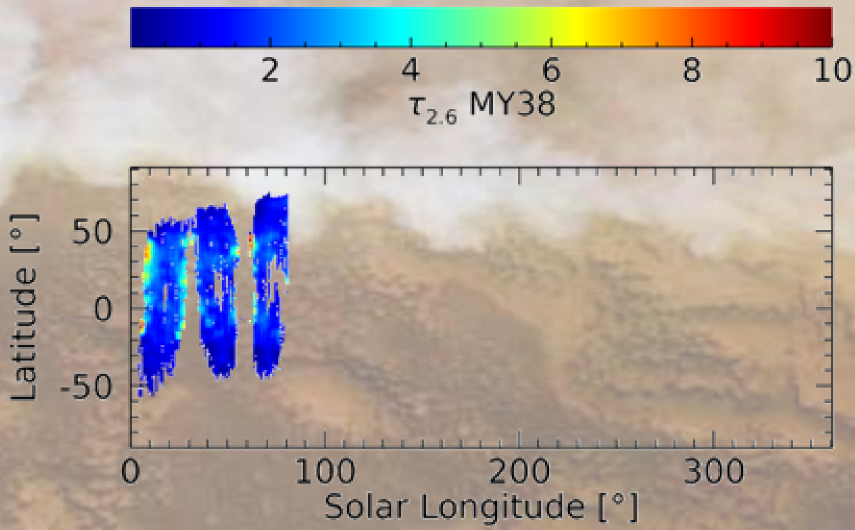




MY35: more quite conditions → dusty season (Ls > 180°) only partially captured (patchy spatial coverage of UVIS+LNO data);

MY36-37: larger opacities result at Ls > 200° → enhanced dust activity;

MY38: retrieval ongoing;



CONCLUSIONS

- Method to combine and investigate spatially/temporally coincident spectroscopic data → balancing of the spectral information;

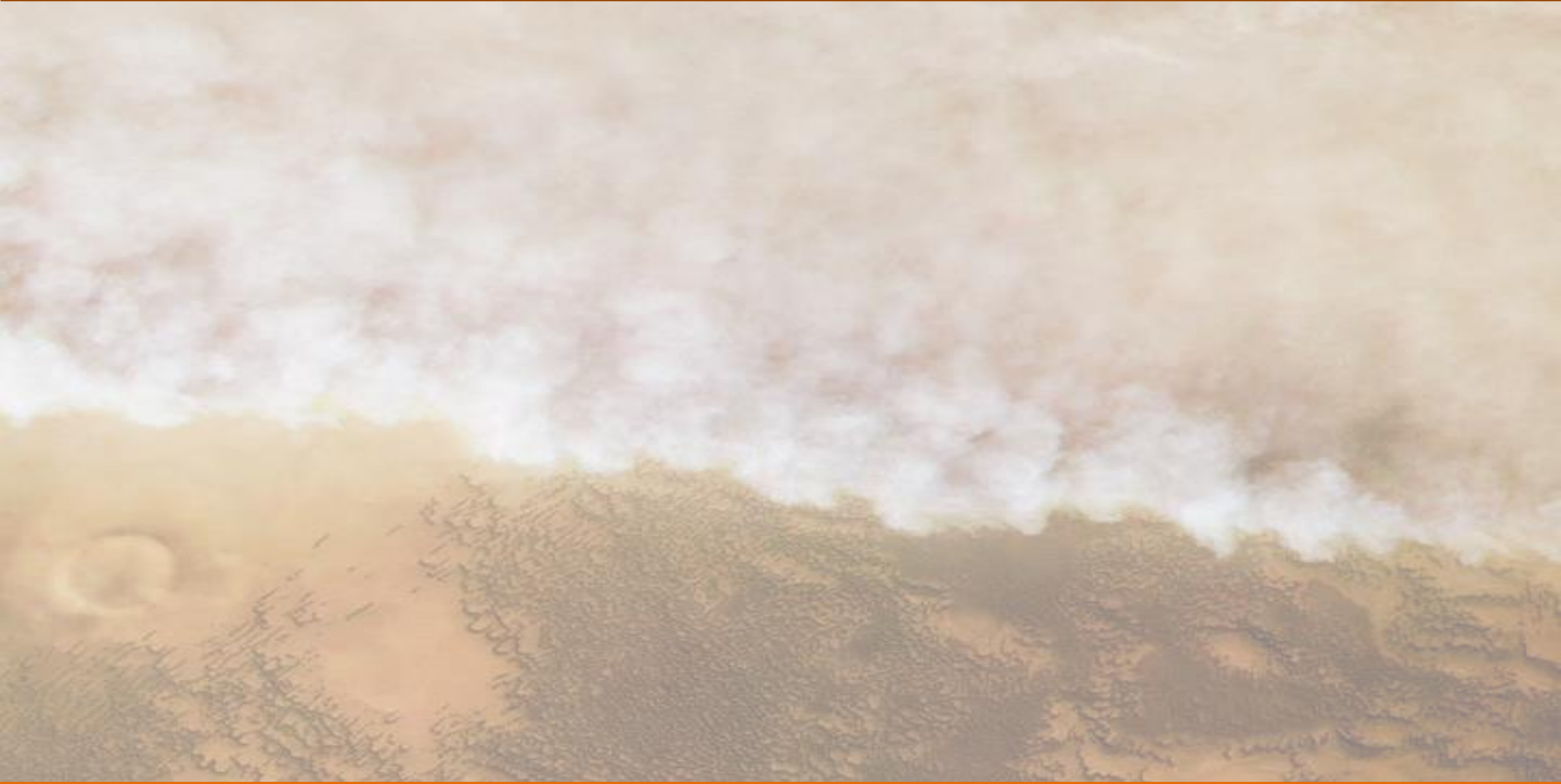
- The combination of the VIS and the NIR range allows reducing the bias related to results obtained from the UV-VIS range alone;

- Retrieval of the full UVIS+LNO combined nadir dataset → r_{eff}, n_{col}, **τ;**

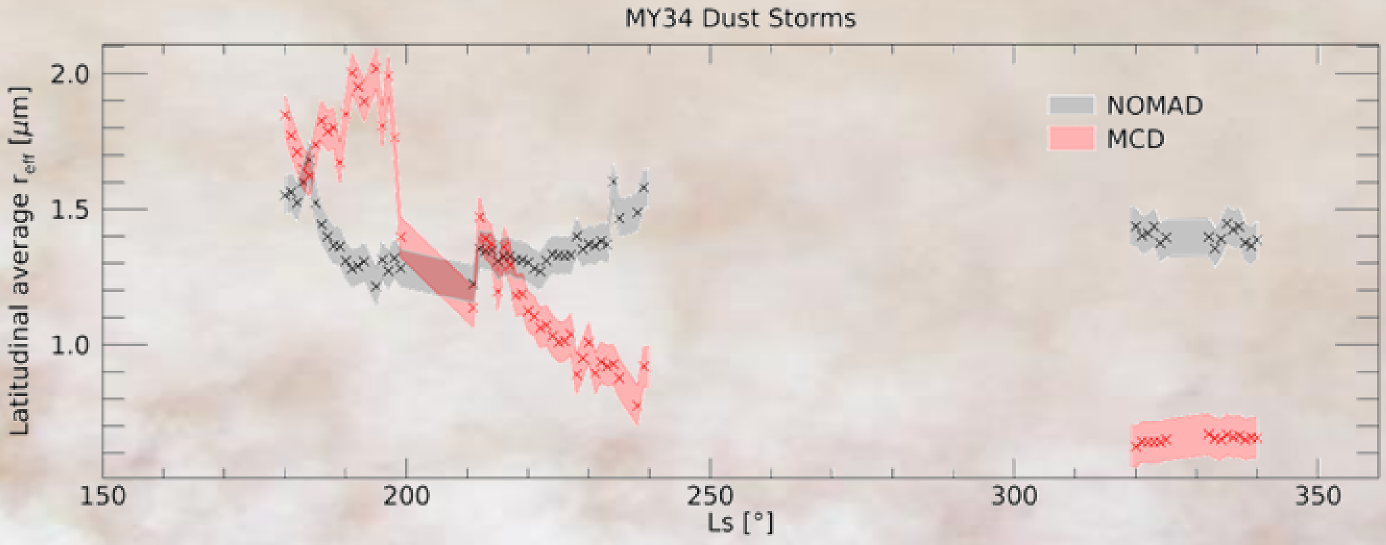
- Preliminary τ results:

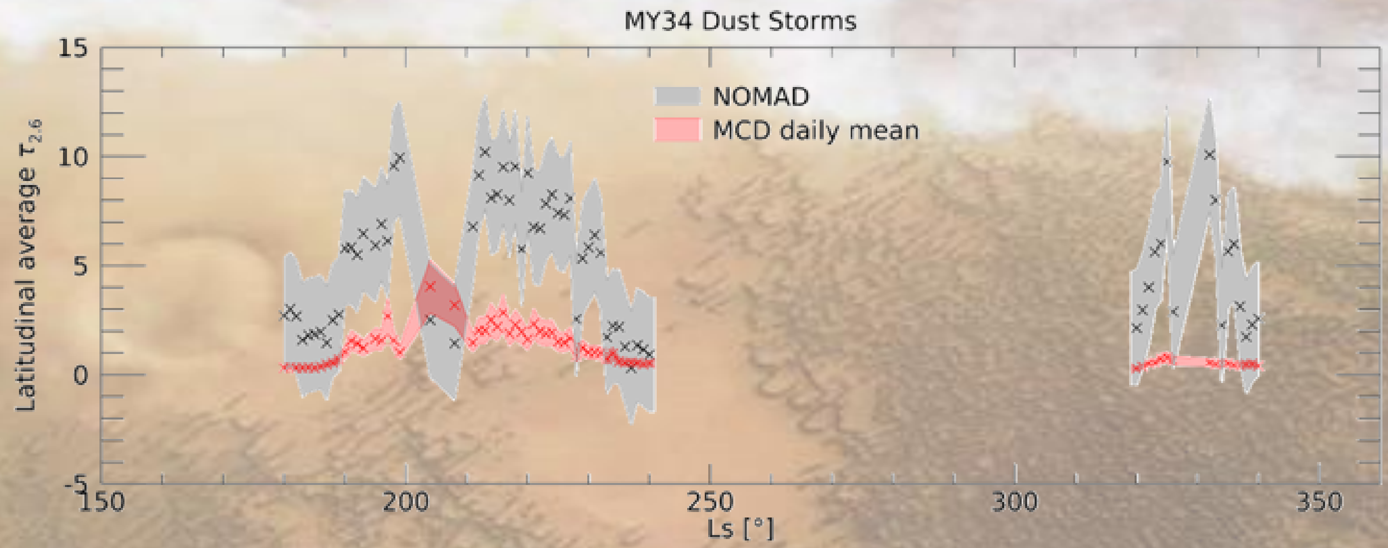
    - **MY34:** 2018 global dust storm and secondary storm (Ls ~ 330°);
        - larger opacities with respect to MCD prediction
        - specific local times snapshots vs daily means;

    - **MY35 to 38:** poor spatial coverage during the dusty season (Ls > 200°);
        - Quieter conditions in MY35;
        - Increasing activity in MY36 and 37
        - Ongoing analysis in MY38



RETRIEVAL RESULTS: MY34 GLOBAL DUST STORM





- r_{eff} estimates (storm periods):
  - *GCM*: daily mean **general circulation and gravitational segregation computations**;
    → *whole integrated atmospheric column*;
  - *NOMAD*: **RT inversion**.
    → **from TOA to z_{thick}**;
- NOMAD: r_{eff} and τ anticorrelation :
  - Smaller particles (**r_{eff} = 1,2 μm**) sampled at maximum τ → overshooting of finer grains at high altitudes during the storm peak phase;
  - Larger particles (**r_{eff} = 1,6 μm**) detected at low opacities → coarse grains at intermediate altitudes during the onset and decay phases of the storm.