The NOMAD instrument on board ExoMars: heritage from previous missions towards breakthrough science

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Introduction: The NOMAD ("Nadir and Occultation for MArs Discovery") spectrometer suite [1] on board the ExoMars Trace Gas Orbiter (TGO) has been designed to investigate the composition of Mars' atmosphere, with a particular focus on trace gases, clouds and dust. The detection sensitivity for trace gases is considerably improved compared to previous Mars missions, compliant with the science objectives of the TGO mission. This will allow for a major leap in our knowledge and understanding of the Martian atmospheric composition and the related physical and chemical processes. The instrument is a combination of three channels, covering a spectral range from the UV to the mid-IR, and can perform solar occultation, nadir and limb observations.

Instrumental heritage: NOMAD, the "Nadir and Occultation for MArs Discovery" spectrometer suite, was selected as part of the payload of the ExoMars 2016 Trace Gas Orbiter mission. The instrument will conduct a spectroscopic survey of Mars' atmosphere in ultraviolet (UV), visible and infrared (IR) wavelengths covering large parts of the 0.2-4.3 µm spectral range. NOMAD is composed of 3 channels: a solar occultation only channel (SO – Solar Occultation) operating in the infrared (2.3-4.3 µm), a second infrared channel (2.3-3.8 µm) capable of doing nadir, but also solar occultation and limb observations (LNO – Limb Nadir and solar Occultation), and an ultraviolet/visible channel (UVIS – UV visible, 200-650 nm) that can work in the three observation modes. NOMAD offers an integrated instrument combining a flight-proven concept and innovations based on existing and proven instrumentation: SO is a copy of the Solar Occultation in the IR (SOIR) instrument (Nevejans et al., 2006) on Venus Express (VEx) (Titov et al., 2006), LNO is a modified version of SOIR, and UVIS has heritage from the development in the context of the Humboldt lander.

NOMAD will provide vertical profiling information for atmospheric constituents at unprecedented spatial and temporal resolution. Indeed, in solar occultation, the vertical resolution is less than 1 km for SO and UVIS, with a sampling rate of 1 s (one measurement every 1 km), and occultations will range from the surface to 200 km altitude. NOMAD will also provide mapping of several constituents with an instantaneous footprint of 0.5 x 17 km^2 (LNO channel) and 5 km^2 (UVIS channel) respectively, with a repetition rate of 30 Martian days.

Science heritage: NOMAD science investigation is based on a long series of previous missions. Based on the work developed for SOIR/VEx, solar occultation will be valuable to derive vertical profiles of trace gases [2], but also of the main constituant of the Martian atmosphere, CO_2, from which temperature profiles can be obtained [3]. A recent re-analysis of the SOIR spectra led to a better definition of the transmittances recorded during solar occultations [4]. This is illustrated in **Fig.1** which shows how the reference spectrum is obtained from the occultation measurement.

SPICAM/MEx performed UV observations of Mars in different geometries. In Nadir, such observations deliver information on the ozone content, the presence of clouds and aerosols, and the surface albedo [5]. Through UPWARDS, the method to derive clouds coverage was improved [see Willame abstract]. UPWARDS gave us also the opportunity to test the retrieval code developped for SOIR occultations on SPICAM UV occultations [see Piccialli abstract]. In this case all spectra from one occultation are treated in one go, considering Rayleigh scattering, aerosols/dust and ozone, and delivering profiles of ozone densities. **Fig. 2** illustrates the kind of information which can be derived. This analysis considers non-homogeneities along the line of sight, such as gradients across the terminator or density variations of ozone, due to photochemistry.

Combining SOIR and SPICAV (both on VEx) observations led to a better description of the aerosols/hazes loading and size in the atmosphere of Venus [6]. Similar techniques will be applied to concommittant measurements performed by the IR and UV channels of NOMAD.

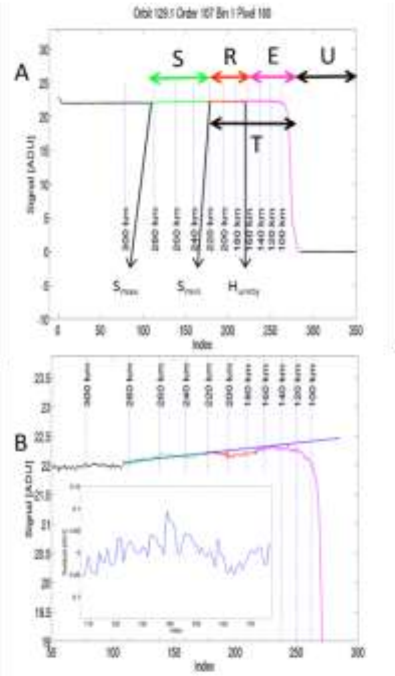

Figure 1: Panel A: Separation of the Sun region in different zones for one detector pixel, as a function of the index, i.e. the time after the beginning of the measurement. Lines corresponding to specific tangent altitudes are plotted. Panel B: Plot of the fit over the S region and extrapolation in the T region. The insert is the residuals of the fit. [4]

Breakthrough science: The TGO orbit will allow NOMAD to sample a much wider range of local times, hence strongly improving existing climatologies for water vapour and carbon monoxide, and developing new climatologies for e.g. HDO and methane.

By providing the best-to-date measurements of H_2O and, co-located and simultaneously, HDO, hence D/H, NOMAD will contribute significantly to improve our knowledge of the Martian water cycle and the hydrogen escape process, and as such to the long-term fate of the Martian atmosphere.

A highly sensitive monitoring of the well mixed, moderately long-lived gas CO will allow NOMAD to provide better insights in important mixing processes related to trace gases that are enriched upon condensation of the main atmospheric constituent, CO_2.

NOMAD will also allow for a highly sensitive diurnal monitoring of CH_4 throughout 1 Martian year, allowing for the first time to assess and understand the presence or absence of this unstable organic trace gas, and in the case of confirmed presence, to provide constraints to its origin and fate.

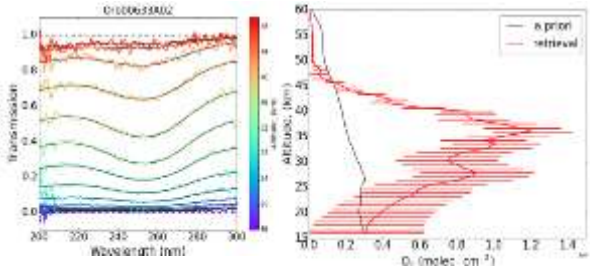

Figure 2: (Left) transmission spectra at different altitudes (see colorbar) compared to synthetic spectra (black solid line) for occultation #633A02. (Right) Vertical ozone profile (red line) compared to the a priori profile (black line). [see Piccialli abstract]

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References:

[1] Vandaele. et al, Planet. Space Science, 119, 233-249 (2015)

[2] Vandaele et al., J. Geophys. Res., 113, E00B23, doi:10.1029/2008JE003140 (2008)

[3] Mahieux et al., J. Geophys. Res. 117 (E07001), doi:10.1029/2012JE004058 (2012)

[4] Trompet et al., Applied Optics 55(32), 9275-9281 (2016)

[5] Willame et al., Planet. Space Science 142, 9-25 (2017)

[6] Wilquet et al., J. Geophys. Res., 114, E00B42, doi:10.1029/2008JE003186 (2009)