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Two test-cases for synergistic detections in the Martian atmosphere: Carbon monoxide and methane

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ABSTRACT

In the frame of the scientific preparation of ExoMars Trace Gas Orbiter (EMTGO), synergistic retrievals were performed on synthetic spectra of two different remote sensing instruments of the Martian atmosphere. To benefit from their diversity, we have simulated spectra of a Fourier transform spectrometer (FTS), working in the middle to far infrared and of a grating spectrometer (GA) working in the middle infrared. As control runs, non-synergistic retrievals were performed as well. Two molecules of interest in the Martian atmosphere were chosen to test this method: carbon monoxide and methane. Scenarios were selected and two different vibrational bands for each molecule were used to retrieve molecular volume mixing ratios. Synergistic retrievals for CO are useful both in solar occultation and in nadir, while for CH_4, the concentration of which is expected to be very low, the results for FTS and GA in synergy are not as conclusive due to the weak signal in the ν_4 vibrational band (covered by FTS) compared to the stronger ν_3 band (covered by GA). Our results represent a first step to an optimized use of infrared spectra to be recorded in Martian orbit by two instruments of EMTGO.

1. Introduction

Synergies between different types of infrared instruments have been investigated in this study in view of improving the investigation of the Martian atmosphere. Synergistic studies have been performed on test-cases when studying Earth's atmosphere [1,2]. These synergies enable to increase the scientific return of the missions. In the planetary community, this approach has been limited to a theoretical point of view [3]. The objective of our study is to highlight the potential improvements resulting from the capabilities of combined multi-instrument platforms. This study should help in defining payloads for future missions by considering the complementarity between different techniques and spectral regions (spectral synergy). It could also be the first step in a better definition of the observation scenarios. This, in fact, was the starting point of our study, i.e. improve the synergistic operations of two instruments which will be part of the ExoMars Trace Gas Orbiter (EMTGO) mission [4]. The Royal Belgian Institute for Space Aeronomy (BIRA-IASB) is indeed heavily involved in the design, manufacturing, operations and science of the spectrometer suite Nadir and Occultation for Mars Discovery (NOMAD) on board EMTGO [5,6]. On the same spacecraft, another instrument provided by Russia, the Atmospheric Chemistry Suite (ACS) [7], has been accommodated, which offers the possibility of combined observations with NOMAD.

Two species, carbon monoxide and methane, have been considered, both being important for a better understanding of the atmospheric composition and of the different processes taking place at the interface between the surface and the atmosphere. Measurements of CO and CH_4 on Mars have been performed both by Earth-based spectrometers and by several space instruments orbiting Mars [8–21], i.e. the Planetary Fourier transform Spectrometer (PFS) on Mars Express [22] or the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on Mars Reconnaissance Orbiter (MRO) [4,23]. Several future missions to Mars are ongoing or under preparation but not all of them contain instruments able to perform a spectroscopic inventory of the neutral atmosphere. Indeed the only mission that will embark such instruments is EMTGO, successfully inserted in orbit in October 2016.

The remote sensing of CO and CH_4 from space can be performed in different spectral domains, in particular in the thermal infrared (TIR i.e. 5–25 μm) and the mid-wave infrared (MIR i.e. 2–5 μm), and under different geometries (nadir or limb observation viewing).

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Because each of these spectral regions and geometries has its advantages and disadvantages, the possibilities to combine several types of measurements in a synergistic way have been studied in order to better exploit the data available in the near future, in particular to assess the near-surface processes. The challenge is to better capture CO and CH_4 information as close as possible to the associated sources, for improving the understanding, quantification or monitoring of sources and sinks of molecular species in the Martian atmosphere.

CO is a non-condensable gas and its seasonal behaviour can be used to constrain the expected behaviour of other non-condensable gases. The CO seasonal-spatial distribution on Mars is in fact very similar to that of argon, the reference non-condensable gas on Mars [24,25]. Strong deviations of the (to be measured) methane distribution from the one of relatively passive tracers would represent additional indications for the presence of active local sources of CH_4. Indeed, the Martian atmosphere contains several non-condensable gases, such as Ar, N_2 and CO. All these gases are expected to show similar behaviour: seasonal accumulation in polar regions during winter; dilution and transport to low latitudes in late winter and spring; depletion below average value during summer at some latitudes; hydrostatic instability and vertical mixing.

A synthetic dataset of spectra was created for various scenarios. Different parameters were chosen to get a statistical sample of spectra representative of the expected measurements. Then retrievals were performed considering non-synergistic and synergistic observations and analyses. The results of the fitting procedure and the benefits of the synergies are discussed.

2. Database of spectra

The purpose of this study is to investigate the improvement induced by considering the complementarity of different instruments and the analysis is based on simulated spectra. However, in order to investigate realistic payload configurations and because the ExoMars Trace Gas Orbiter (EMTGO) mission is the latest mission toward Mars embarking spectroscopic instruments, we have considered two instruments whose characteristics are very close to those of the real instruments on board the EMTGO mission, i.e. NOMAD and ACS. In this section, we will describe the radiative transfer modular program used to simulate the spectra and to retrieve the trace species abundances. The two instruments of interest will be described and selected scenarios will be presented.

2.1. Instrument specifications

The scientific objectives of the EMTGO mission are well defined [26,27] but the exact performances in orbit of all the instruments relevant for this activity are not yet known in detail. Two instruments will probe the infrared range and will be able to search for trace species in the Martian atmosphere, i.e. NOMAD and ACS [4]. We used them as a baseline to define the two representative instruments considered in this study. The specifications retained here are based mainly on the initial proposals of both experiments, with additional information from more recent and updated instrument status [5,6,28–31]. Nevertheless, some characteristics might not be the final ones and this paper should not be considered as a reference document comparing the exact characteristics of the two instruments which may have changed during the design and manufacturing process and may suffer from launch and cruise.

NOMAD has been selected by ESA and NASA to be part of the payload of the EMTGO mission [32]. This instrument suite will conduct a spectroscopic survey of the Martian atmosphere in the UV, visible and IR spectral regions [5,6]. NOMAD has 3 channels: UVIS (ultraviolet and visible), SO (solar occultation only), and LNO (limb, nadir and occultation) covering the 200–650 nm, 2.2–4.3 μm and 2.2–3.8 μm spectral regions respectively with a spectral resolution of 1.2 nm in the UV-visible and a spectral resolution of 0.15 and 0.3 cm^{-1} in the IR (depending on the channel). The description of the channels can be found with additional technical details in [5,28,29,33].

In the frame of this study, we have simulated spectra considering the characteristics of the SO channel for solar occultation observations and the LNO channel in case of nadir observations. These two spectrometers combine echelle gratings with high order diffraction and specific filters (acousto-optic tunable filter or AOTF) to select the spectral interval analysed by the instrument, and thus which diffraction order will be active. It results from this combination that spectra are recorded at high resolution on small spectral intervals which basically correspond to the width of the selected diffraction order (between 20 and 35 cm^{-1}).

ACS consists of three channels as well, all active in the infrared (IR) domain spanning almost the entire spectral region from 400 to 14,285 cm^{-1}[7]. A Fourier transform spectrometer (FTS), the Thermal Infra-Red V-shape Interferometer Mounting (TIRVIM), will cover both the thermal and the mid-wave infrared spectral regions, from 400 to 5000 cm^{-1}, a mid-wave infrared channel very similar to NOMAD/SO covering the range from 2222 to 4545 cm^{-1} (MIR), and a short-wave and near-IR channel designed to cover the 5882 to 14,285 cm^{-1} region (SWIR and NIR). The detailed characteristics of ACS can be found in [34]. In the following, we have considered only the TIRVIM channel of ACS, which offers the highest complementarity with the NOMAD instrument.

Table 1 summarizes the specifications for the two instruments considered in this study. Note that in the case of NOMAD and ACS, both instruments have been integrated to the spacecraft and co-aligned with respect to the spacecraft axis, implying that the nadir channels will look at the same scene on the Martian surface, and that the solar occultation observations will be acquired looking at the same portion of the atmosphere. However, we do not consider here the difference which might exist in the FOV sizes and might have an impact on the signal recorded, as this is beyond the scope of the exercise described here. In the following, the two instruments will be named GA (for 'Grating with AOTF') and FTS to preserve the more general aspects of this study.

The FTS instrument, covering the entire thermal infrared spectral region and the GA spectrometer offer an interesting complementarity in both observational geometries. The broad range covered by the FTS will enable the user to retrieve surface and atmospheric temperature as well as pressure and aerosol content [35–37], and the high spectral resolution and signal-to-noise ratio (SNR) of the GA spectrometer will provide access to the

Table 1
Instrument channels considered in this study.

Instrument	**GA instrument**		**FTS instrument**	
Geometry	nadir	solar occultation	nadir	solar occultation
Type of instrument	AOTF + echelle spectrometer		Fourier transform spectrometer	
ILS	Gaussian		Sinc = sin(x)/x	
Spectral resolution	0.30 cm^{-1}	0.15 cm^{-1}	1.6 cm^{-1}	0.20 cm^{-1}
Instantaneous spectral coverage	24 cm^{-1}	22 cm^{-1}	Whole range	
Lower limit	2500 cm^{-1}		400 cm^{-1}	
Higher limit	4600 cm^{-1}		5000 cm^{-1}	
Signal-to-noise ratio	1000	4000	500	1000