DETECTING TRACE SPECIES ON MARS WITH A SOIR INSTRUMENT.

R. Drummond[1], A.C. Vandaele[1], E. Neefs[1], A. Mahieux[1], V. Wilquet[1] and F. Montmessin[2], [1]Belgian Institute for Space Aeronomy, 3 av Circulaire, 1180 Brussels, Belgium; rachel.drummond@aeronomie.be, [2]Service d'Aéronomie, réduit de Verrières, 91371 Verrières le Buisson, France

Introduction: SOIR (Solar Occultation InfraRed spectrometer) is currently part of the SPICAV/SOIR instrument[1] on board the Venus Express orbiter (VEX). SOIR, an Echelle infrared spectrometer using an acousto-optic tunable filter (AOTF) for the order selection, is probing the atmosphere by solar occultation, operating between 2.2 and 4.3 μm, with a resolution of 0.15 cm^{-1}. This spectral range is suitable for the detection of several key components of planetary atmospheres, including H_2O and its isotopologue HDO, CH_4 and other trace species.

We will present simulations of spectra such as would be recorded by a SOIR instrument probing the Mars atmosphere, allowing the determination of lower limits for the detection of trace constituents. A sensitivity study has also been performed regarding some of instrumental characteristics of the SOIR instrument (band pass of the AOT filter, order separation of the Echelle spectrometer)[2].

The SOIR instrument: The SOIR instrument was designed to have a minimum of moving parts, to be light and compact in order to fit on top of the SPICAV instrument. Light enters through the entrance optics (elements 1 and 2 of Figure 1) and then passes through the AOTF (acousto-optical tunable filter - element 3 of Figure 1). This allows a narrow range of wavelengths to pass, according to the radio frequency applied to the TeO_2 crystal – i.e. the order is selected here. The advantage of the AOTF is that different orders can be observed during one occultation, thanks to the electrical command of the AOTF and its very fast response. To obtain a compact optical scheme, a Littrow configuration was implemented in which the usual collimating and imaging lenses are merged into a single off-axis parabolic mirror (element 6). The light is diffracted on the echelle grating (element 7), where orders overlap and addition occurs, and finally it is recorded by the detector (element 10). The detector is 320x256 pixels large and is cooled to 88K during an occultation measurement, to maximise the signal to noise ratio. On Venus, the slit image generally covers about 320x32 pixels on the detector, and the central 24 lines are selected for their higher signal level.

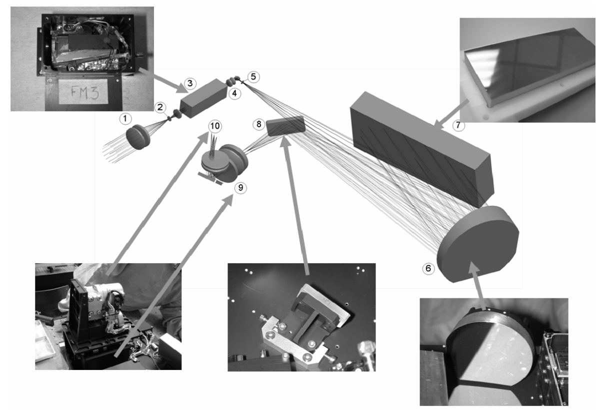

Figure 1 Optical scheme of the SOIR spectrometer. (1) AOTF entrance optics; (2) Diaphragm; (3) AOTF; (4) AOTF exit optics; (5) Spectrometer entrance slit; (6) Collimating and camera lens merged into one off-axis parabolic mirror; (7) echelle grating; (8) Folding mirror; (9) Folded detector optics; (10) Detector assembly placed upright.

Measurement technique: The occultation technique employed by SOIR to make measurements is based on comparing observations of a light source performed outside and through an absorptive medium (the atmosphere of a planet) in order to simultaneously obtain a reference signal and the relative light intensity loss caused by the presence of absorbent molecular species interfering with the beam. The "absorptive" term actually refers to the loss of light intensity either by scattering (Rayleigh, aerosols) or by absorption (usually molecular). One can determine the amount of light that is transmitted by a planetary atmosphere (Venus' or Mars') as a function of altitude and wavelength. Outside the atmosphere, reference observations are carried out, with a goal of at least 40 reference measurements before, or after, occultation. For each occultation, 4 orders are chosen. Each measurement has an integration time of 250ms. There is a tight telemetry bandwidth constraint. On VEX we can only download 320x8 values per second, allowing us 2 'bins' (12 or 16 pixel rows summed together, i.e. 2 full spectra) for 4 orders, or 8 bins (of 3 or 4 summed rows) if only 1 order is selected. The number of bins and the integration time determine the spatial resolution (how thick a layer of the atmosphere is probed per bin during one measurement). This also depends on the distance of the satellite from the planet (i.e. the speed of the spacecraft relative to the sunset).

SOIR at Mars: VEX has been in orbit around Venus since April 2006. To date SOIR has carried out over 287 measurements (154 occultations and 133 calibration measurements). Pre-launch and in-orbit performance analyses allow us to predict what SOIR would be capable of at Mars.

Table 1. Mars- SOIR Performance

Parameter	Value or range	Units
Wavelength Range	2.32 to 4.25	μm
Wavenumber Range	2353 to 4310	cm^{-1}
Spectral Sampling Interval (1 pixel)	0.1	cm^{-1}
Instrument Line Profile	2	pixels
Resolving Power [$\lambda/\Delta\lambda=\upsilon/\Delta\upsilon$]	23,200 to 43,100	
FOV in Spectral Dirn	2	arc mins
FOV in Spatial Dirn	100	arc mins
Expected SNR at Mars	> 1000	

The wavelength range is limited by the AOTF and the Echelle grating, but covers a wide range of molecular bands useful for CO_2, CO, H_2O, HDO, HCl, CH_4 and many more. The spectral sampling interval and instrument line profile combine to give us the spectral resolution of SOIR. These values were measured on VEX-SOIR before launch using a He-Ne laser line at 3.39μm and re-evaluated in orbit using well defined and very sharp solar lines. The in-orbit study gave an instrument line profile that varies from $0.07cm^{-1}$ to $0.22cm^{-1}$ across the spectral interval[2]. This determines the spectral resolution of the instrument. The spatial resolution is determined by the integration time and the binning of the pixels. If a Mars satellite were to have higher bandwidth capacity it would allow download of each pixel row. However, for the Venus data, researchers at BIRA-IASB have developed code that examines various grid points during one measurement, thus taking into account the fact that the slit samples a range of atmospheric layers in one exposure. A grid of x, y and t points (spectral direction, spatial direction and time) breaks down what has been averaged within one measurement.

Signal to Noise ratio.

Studies have also been done on the current signal to noise ratio of SOIR at Mars. We study the evolution of the signal on one pixel during reference observations of the sun, outside the atmosphere. Any oscillation on this signal is due to noise, not absorption. The SNR shows slight variation with wavenumber, due to a different passband width of the AOTF transfer function at different wavelengths, differences in detector sensitivity with wavelength, and differences in diffraction efficiency at different wavelengths. The lowest SNR for the new 12-row binning is 500, but most are above 1000. Some observations reach signal to noise ratios of 3500.

What could SOIR observe at Mars?: SOIR spectra of solar occultations through the Martian atmosphere have been simulated with ASIMUT, a LBL radiative transfer code also used for the retrieval of vertical profiles of atmospheric constituents of Venus[3, 4]. The code takes into account the curvature of the atmosphere, temperature and pressure vertical profiles as well as those of the atmospheric species, but also the instrument function and the overlapping of the diffraction orders of the echelle grating. Figure 2 shows the absorption line intensities for water and methane in order 135 in the top part, and a simulated SOIR spectrum at the bottom, with the yellow band being the noise level. We can see that the methane at the edge of the order should be detectable.

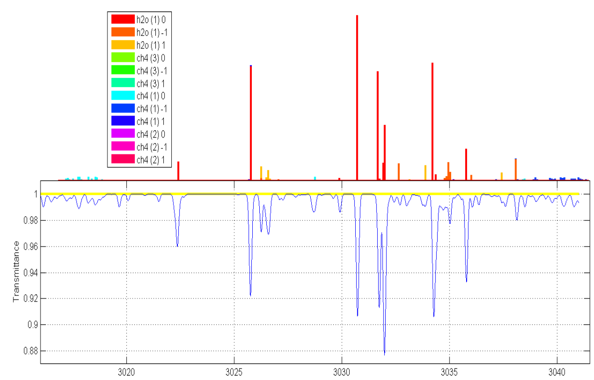

Figure 2 An example of a SOIR spectrum at Mars. This simulates a water and methane spectrum at an altitude of 20km, and shows which absorption lines correspond to which molecule. The yellow band shows a signal to noise level of 1000.

Detection of CH_4 in the Mars atmosphere has already been reported[5] using the PFS instrument on board Mars Express and from ground-based telescope observations[6]. However, due to the resolution of the PFS instrument (1.4 cm^{-1}), the P- and R- branches could not be resolved and the detection relied on the observation of a sharp feature attributed to the Q-branch of the band. However, recent measurements[7, 8] have revealed the presence of $^{16}C^{12}O^{18}C$ lines in the vicinity of the ν_3 CH_4 band, around 2982 cm^{-1}, which might impair the CH_4 detection.

We will present more simulated spectra to show what SOIR would be able to detect in Mars orbit. We will elaborate on VEX calibration results to detail the quality of the instrument.

Conclusions: SOIR is the first high-resolution near IR spectrometer on-board a spacecraft. Its compact, lightweight design makes it an ideal contender for a Mars mission, to confirm levels of methane and water vapour (among others) in the atmosphere.

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