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Detectability of trace gases in the Martian atmosphere using gas correlation filter radiometry

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Abstract

We present the results of radiative transfer simulations of a gas correlation filter radiometer (GCFR) in the detection of trace species in the Martian atmosphere. We investigated two scenarios: 1) nadir and/or limb sounding from a Mars orbiter in the thermal infrared, 2) solar occultation measurements in the near-infrared from the Martian surface. In both scenarios, a GCFR would allow detection of trace gases at a lower concentration than that detectable by a conventional filter radiometer. In nadir/limb sounding, we find that CH_4, SO_2, N_2O, C_2H_2 and CH_3OH are detectable at concentrations lower than previously-derived upper limits. From solar occultation measurements, we find that CH_4, SO_2, C_2H_2, C_2H_6 are detectable at concentrations lower than previously-derived upper limits but only in low dust conditions.

1. Introduction

The atmosphere of Mars may contain a number of trace gases, which remain undetected due to their low concentrations. Outgassing from the surface, evaporation of ices, subsurface microbial metabolism and photochemical reactions in the Martian atmosphere are thought to produce a range of organic, nitrogen- and sulphur-based compounds [1,2,3]. The recent *in-situ* detection of CH_4 by Curiosity [4] is highly topical since the molecule could have a biogenic origin. However, other origins of CH_4 such as volcanism, exogenous introduction by meteorites/comets cannot be ruled out.

Some clues of the source of CH_4 could be deduced by searching for other trace gases. For example, a detection of N_2O, in addition to CH_4, may suggest a biogenic origin of CH_4 since bacteria in anoxic environments also produce N_2O [5]. Simiilarly, a detection of SO_2 and CH_4 would indicate a volcanic origin of CH_4. Other organic compounds such as C_2H_2, C_2H_6, CH_2O and CH_3OH are produced by photochemistry or oxidation of CH_4 and thus would serve as a secondary detection of CH_4. However, their lifetimes in the Martian atmosphere are much shorter than that of CH_4 and thus their presence could indicate how recent the source of CH_4.

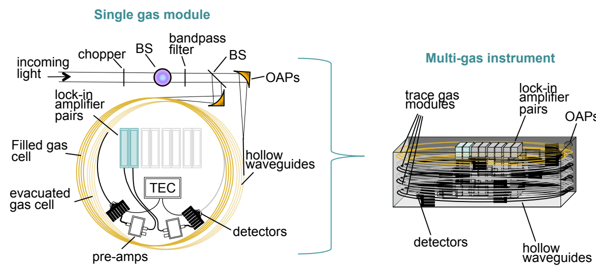

Figure 1: A top-down (left) and side-on (right) schematic of a gas correlation filter radiometer that has proven successful in laboratory tests (e.g. [6]).

Thus, there is significant scope for an instrument with the capabilities of detecting these trace gases. In this paper, we present the results of radiative transfer simulations in order to demonstrate the potential effectiveness of a gas correlation filter radiometer on a future mission to Mars.

2. Gas correlation filter radiometer

Figure 1 shows a schematic of the proposed gas correlation filter radiometer. Light from the planet (R_{source}) is viewed through a narrow band filter and then divided into two optical paths - the first containing an evacuated gas cell and the second containing a gas cell filled with the candidate gas (with a channel transmission of T_c). The average signal between the two optical paths (or wideband signal, R_w, Eq. 1) provides a measure of the overall signal from the planet atmosphere. The difference in signal between the two optical paths (or sideband signal, R_s, Eq. 2) measures the radiance only in the continuum since the filled gas cell blocks light from the planet within the absorption lines of the gas.

$$R_w = \frac{(1 + T_c)}{2} R_{\text{source}} \quad (1)$$

$$R_s = (1 - T_c) R_{\text{source}} \qquad (2)$$

Together, the wideband and sideband radiances allow a discrimination such that the magnitude of signal being absorbed by the gas of interest, and thus its concentration, can be determined.

3. Analysis

Radiative transfer simulatons were performed using Nemesis [7], a forward model and retrieval tool. Table 1 shows the channels in the 200 - 2000 cm^{-1} range selected for detection of each gas.

Channel	$\tilde{\nu}_0$	$\Delta\tilde{\nu}$	NESR
HDO	220	40	0.75
H_2O	240	40	0 .75
C_2H_2	730	40	0.75
C_2H_6	825	40	0.75
CH_3OH	1030	40	0.75
N_2O	1280	40	0.75
CH_4	1300	40	0.75
SO_2	1360	40	0.75
H_2CO	1740	40	0.75

Table 1: The channel centers and bandpass widths (cm^{-1}) selected for each gas and the noise-equivalent spectral radiance (NESR, in units of nW cm^{-2} sr^{-1} cm).

In a nadir viewing geometry, the concentration of each trace gas in the Martian atmosphere was increased from zero to a value such that the signal in the appropriate channel decreased by the NESR. This value in concentration was therefore deemed to be the noise-equivalent volume mixing ratio (NEVMR). Figure 2 shows the results of the NEVMRs for each gas as a function of latitude in low and high dust conditions for a gas correlation filter radiometer (GCFR) and a conventional filter radiometer (FR) for comparison. For both instruments, the lowest detectable concentration is in the northern summer hemisphere where the thermal infrared signal-to-noise ratio is highest. As shown, a GCFR allows 1) detection of all gases at lower concentrations that a FR and 2) detection of HDO, N_2O, CH_4, C_2H_2 and CH_3OH at lower than previous measured values or upper limits [8,9,10,11].

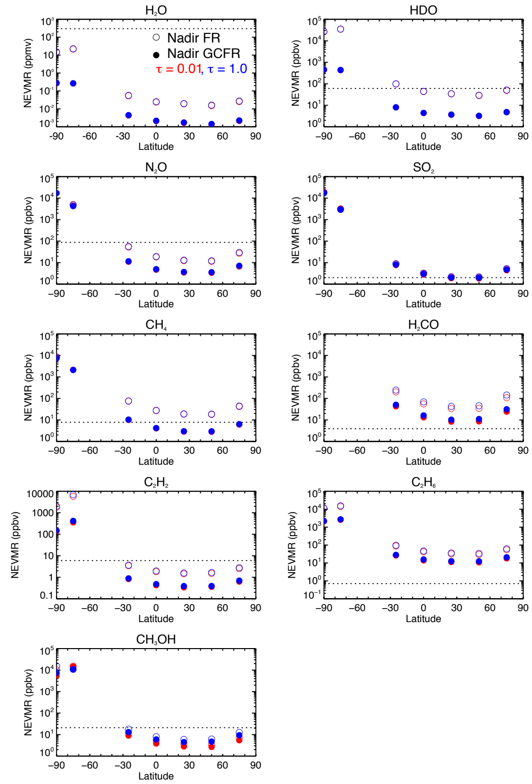

Figure 2: The noise-equivalent volume mixing ratios of each trace gas as a function of latitude in low and high dust condition (optical depths given at 3-μm). Unfilled and filled points respectively indicate the results for a filter radiometer and gas correlation filter radiometer operating in the nadir. Horizonal dashed lines indicate previously measured-abundances or upper limits.

4. Summary

A gas correlation filter radiometer allows detection of trace chemical species at a lower concentration than a conventional filter radiometer. We will present similar results for an instrument performing solar occultation measurements in the near-infrared (2- to 5-μm). In addition, for both scenarios, we will also present the results of a retrieval analysis where the temperature profile, dust concentration and gas abundances are retrieved from synthetic FR and GCFR measurements.

References

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