

OBSERVATIONS OF MARS AT INFRARED AND MICROWAVE WAVELENGTHS: PERSPECTIVES FOR FIRST

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ABSTRACT

Observations of Mars at infrared wavelengths have been performed in July 1997 by the two spectrometers of the Infrared Space Observatory, in the range 2.3-200 μm . By comparing these data with radiative transfer models, the water vapor column density has been inferred. Using this information, the far infrared part of the Mars spectrum was modelled in order to retrieve information on the emissivity of the Martian surface. Observations of Mars with FIRST, using the PACS and SPIRE instruments, are expected to provide new information on the emissivity of the Martian surface at far-infrared and submillimeter wavelengths.

Ground-based heterodyne spectroscopy measurements of Mars have been performed at IRAM, with the 30-m antenna of Pico Veleta, in April 1997. Transitions of HDO and H₂¹⁸O were observed at 226 GHz and 203 GHz respectively, and were used for an estimate of the water vapor vertical distribution. Observations of H₂O and its isotopes with FIRST-HIFI will allow a new determination of the D/H ratio on Mars with a much better accuracy than the current one. In addition, FIRST-HIFI will be well adapted to the search for minor species at submillimeter wavelengths.

Key words: Solar system: Mars – Missions: FIRST

1. INTRODUCTION

There are still many unsolved questions related to the past climate of Mars and, in particular, the history of the H₂O and CO₂ reservoirs. In order to address these problems, we first need to better understand the present aeronomy of Mars and, more precisely, the water cycle with its various sources and sinks. We also need to better characterize the composition of the Martian surface; the search for carbonates, so far inconclusive, should be continued, as such a discovery would bring key information about the past evolution of the Martian carbon dioxide.

Remote sensing spectroscopy in the infrared and millimeter range is an important tool for studying the chemical composition of the Martian atmosphere and surface. The infrared spectrum of Mars has been studied by many

experiments from the ground and from space. Information has been retrieved about the surface mineralogy, the composition of suspended dust and the column density of minor constituents.

Molecular lines formed in the Martian atmosphere are very narrow, due to the small pressure broadening. Heterodyne spectroscopy provides the capability of measuring individual line shapes and is thus especially suited for the study of these spectral lines. Ground-based millimeter heterodyne spectroscopy has been used for over two decades to determine the thermal atmospheric profile from the CO transitions and, more recently, for measuring the water abundance.

We present below some recent observations of Mars performed in the infrared range with the ISO satellite, and at millimeter wavelengths with the 30-m antenna of IRAM. These data are shown to illustrate the expected capabilities of FIRST for providing new information about the Martian atmosphere and surface.

2. OBSERVATIONS OF MARS WITH ISO

Due to severe observability constraints of the ISO satellite, Mars could only be observed during a short time period over the ISO life time, in July and August 1997. The diameter of Mars was about 6 arcsec, and the areocentric longitude L_s ranged between 155 and 166 deg. The whole 2.3-200 μm range was covered, in the grating mode, by the two spectrometers SWS (resolving power about 1500; de Graauw et al., 1997) and LWS (resolving power of about 200; Sidher et al., 2000). Signatures of water vapor appear at 2.6 μm (blue wing of the ν_1 and ν_3 bands), 6.2 μm (ν_2 band), and beyond 20 μm (rotational lines). Some H₂O rotational transitions have also been observed with SWS with the Fabry-Perot mode (R=30000). The ISO LWS data provided the first spectrum of Mars in the far-infrared range, beyond 50 μm .

From the ISO SWS data, the water vapor column density has been inferred by comparison with a radiative transfer model, using the H₂O signatures at 2.6 μm and 5-7 μm . From these fits, a water column density of 12 (+/- 3.5) pr- μm has been derived, with saturation occurring at an altitude of 13 (+/- 2) km (Burgdorf et al., 2000; Lellouch et al., 2001). The H₂O column density measured by ISO is typical of the water vapor abundance, integrated

over the Martian disk, expected for the time of the Martian cycle corresponding to the ISO observations (Jakosky and Haberle, 1992).

At wavelengths larger than 20 μm , the spectrum of Mars only depends upon the water vapor vertical distribution and upon the surface emissivity (also taking into account a possible spectral signature from suspended dust or ice clouds). Knowing the H_2O vertical distribution, it is possible to retrieve, for each water vapor line, the corresponding surface emissivity (Lellouch et al., 2001). Indeed, measuring directly the surface emissivity from the continuum is difficult, as it requires a very precise calibration. The far infrared spectrum of Mars thus allows to infer a spectrum of the far- infrared emissivity of Mars, each H_2O line providing a discrete measurement. This method has been used on the SWS data between 20 and 45 μm by Lellouch et al. (2001). In one of the SWS spectra, two absorptions features were observed around 31 and 44 μm , and were tentatively identified as carbonate signatures, possibly in suspended dust. At longer wavelengths, the same analysis was performed by Burgdorf et al. (2001). However, the LWS data did not confirm this result; rather, a silicate signature was tentatively identified (Burgdorf et al., 2001; Fig.1).

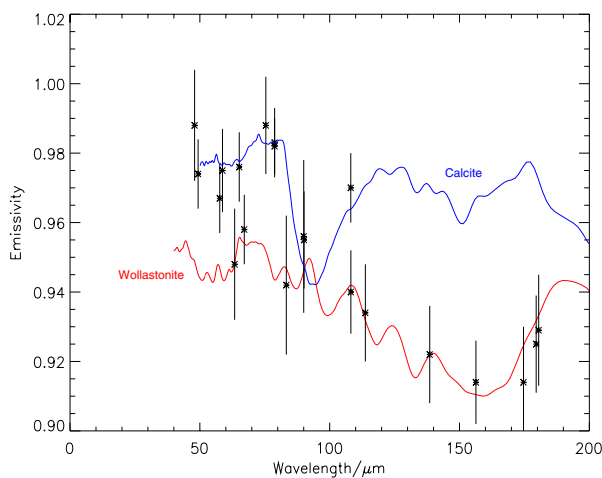


Figure 1. The emissivity of Mars in the far-infrared range, retrieved from the depth of the rotational water lines with LWS. The figure is taken from Burgdorf et al., 2001.

For both the SWS and LWS data, the signal-to-noise ratio was not sufficient for a firm identification; however, the ISO spectra illustrate the capability of inferring the far-infrared emissivity of Mars from high-resolution spectroscopy in this spectral range. A spectral resolution of about 0.1 cm^{-1} (R in the range of 300 at 300 μm , 1500 at 60 μm) is desired for a proper analysis of the water lines. These observations will be easily performed with FIRST, using both the PACS and SPIRE instruments. In

both cases, a complete spectral coverage of the 60-210 μm range (PACS) and the 200-670 μm range (SPIRE) will be obtained at very high signal-to-noise (above 10^3) in less than an hour. At short wavelengths, some low-resolution mapping of the Martian disk may be possible with PACS when Mars is close to opposition. The PACS and SPIRE measurement should be also repeated periodically along the seasonal cycle of Mars, as the aerosol signatures may vary along this cycle.

It should be noted that the PACS and SPIRE instruments of FIRST will be unique for retrieving these data. Indeed, none of the future Mars-orbiting space missions are expected to measure the far-infrared spectrum of Mars.

3. MILLIMETER OBSERVATIONS OF MARS

Ground-based observations of H_2O and its isotopes on Mars have been performed with the IRAM 30-m of Pico Veleta since 1990, and have led to an estimate of the water vapor vertical distribution at various times along the Martian seasonal cycle (Encrenaz et al., 1991, 1995). Observations of HDO and H_2^{18}O have been performed in April 1997, around the time of Martian opposition. The diameter of the Martian disk was 13 arcsec; the latitude of the sub-Earth point was 24 deg. The areocentric longitude was close to 100 deg., which corresponds to the beginning of Martian northern summer, when the water vapor abundance is expected to be maximum at high northern latitudes. The field of view (FWHM) was 10 arcsec at 230 GHz. Five points were observed over the Martian disk, at the center and the North, South, East and West limbs. A strong emission was detected in the 226 GHz transition of HDO at the disk center (latitude = 24 deg.) and around the North pole. The 203 GHz transition of H_2^{18}O was also unambiguously detected. The thermal profile was retrieved from the simultaneous observation of $^{12}\text{CO}(2-1)$ at 230 GHz, $^{13}\text{CO}(2-1)$ at 220 GHz, and $^{12}\text{CO}(1-0)$ at 115 GHz.

Using both HDO and H_2^{18}O transitions, we derived a water vapor content of 52 (+34,-24) pr- μm at the disk center, and 85 (+30,-33) pr- μm at the North pole (Encrenaz et al., 2001). Taking in account the error bars, these high values are still consistent with the analysis performed by Jakosky and Haberle (1992) from the Viking MAWD data about the seasonal water cycle. The H_2O profile was found to be saturated at a level of 9 (+5,-4) km at the disk center and 5 (+3,-2) km at the North pole. These saturation levels are also consistent with millimeter measurements performed by Clancy et al. (1996) and confirm that water is confined in the lower troposphere near aphelion.

It should be mentioned that similar observations of Mars performed at the next opposition, in April 1999, failed to detect the HDO transition, which led to an upper limit of 15 pr- μm for the H_2O column density (Encrenaz et al., 2000), i.e. significantly lower than the expected H_2O

value at that time of the year ($L_s = 125$ deg.). This surprising result was confirmed by the measurement of the 557 GHz H_2O transition, at the same time, by the SWAS satellite, which led to a H_2O column density of 8 (+12, -3) $\text{pr-}\mu\text{m}$ (Gurwell et al., 2000). In November 1999 ($L_s = 238$ deg.), the planet diameter (6 arcsec) was significantly smaller than the field of view, which was much more favorable for the detection of a weak line. We were then again able to detect the HDO 226 GHz transition; the corresponding H_2O column density was 7 $\text{pr-}\mu\text{m}$, in agreement with the expected seasonal behavior (Jakosky and Haberle, 1992). These results altogether seem to show evidence for interannual variations of the water vapor content. Their interpretation remains presently unclear.

In our analysis, we used a terrestrial value for the $^{16}\text{O}/^{18}\text{O}$ ratio, in agreement with IRIS-Mariner 9 (Maguire, 1977) and Viking mass spectrometry measurements (Nier and McElroy, 1977) and, in the case of D/H, an enrichment by a factor 6 with respect to the terrestrial value (Owen et al., 1988; Krasnopolsky et al., 1997). The $^{16}\text{O}/^{18}\text{O}$ ratio on Mars is known within about 5 %, but the uncertainty on the D/H ratio on Mars is 30-50 %. The quality of our data did not allow us to derive a more precise determination of the Martian D/H (Fig. 2).

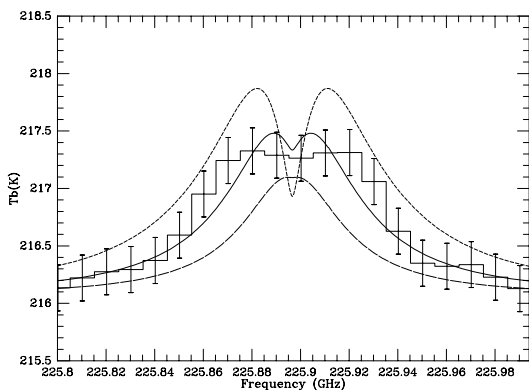


Figure 2. Synthetic spectra of the HDO 226 GHz transition, calculated at the disk center for 3 values of the D/H ratio (from top to bottom in the continuum: 12, 6 and 3 times terrestrial) and compared with the IRAM observations at the disk center. The figure is taken from Encrenaz et al., 2001.

The FIRST HIFI instrument will be ideally suited for monitoring the mean water vapor vertical distribution of Mars. Observations with HIFI of the 557 GHz transition are expected to be achieved at very high signal-to-noise (above 100) in less than an hour. Monitoring a few transitions several times over the seasonal cycle should thus be an easy task; this long-term program will allow to better understand the evolution of the global water vapor vertical distribution along the seasonal cycle.

In addition, the HIFI measurements of H_2O and its isotopes on Mars will be precious for getting precise deter-

minations of D/H, $^{16}\text{O}/^{18}\text{O}$ and $^{16}\text{O}/^{17}\text{O}$ on Mars. This measurement is crucial for D/H which is presently very poorly determined. In the case of the oxygen isotopes, determining isotopic ratios at the percent level of accuracy in H_2O , as compared to CO_2 and CO , will help to better understand the history of the various volatile reservoirs (Owen, 1992).

We note however that these observations could also be done from the Mars orbit, if a dedicated heterodyne spectrometer, devoted to the study of a few H_2O and CO lines, is selected as part of the payload of a Martian orbiter, in the frame of the Mars Sample Return program, within the forthcoming decade.

4. A SPECTROSCOPIC SURVEY OF MARS WITH HIFI

Very few gaseous species have been spectroscopically identified so far in the Martian atmosphere: H_2O , CO_2 , CO and O_3 . Stringent upper limits have been obtained, in particular, on sulfur species (SO_2 , H_2S , OCS), hydrocarbons, HCl , and nitrous species. No information presently exists on other halides on Mars, nor on ClO (Encrenaz et al., 1995).

Two molecules are of specific interest, H_2O_2 and H_2CO . Both molecules have been unsuccessfully searched for, in the infrared and millimeter range, and the corresponding upper limits seem to be lower than predicted by some photochemical models. H_2O_2 , in particular, could be the elusive oxidant on Mars, that could also explain the lack of organics on this planet (Atreya and Gu, 1994).

A complete spectroscopic survey of Mars in all HIFI bands would thus be of great scientific value as an exploratory search for minor atmospheric species. As mentioned above, the very high resolving power of HIFI makes it an ideal tool for detecting the narrow profiles of the Martian lines. The capability of scanning a large spectral interval at such high resolving power will be unique to FIRST, as such a device is not going to be implemented on any space mission in orbit around Mars. From the anticipated performances of HIFI, it can be expected that within about 50 hours, the full spectral coverage could be performed with a sensitivity of about 0.2 K in brightness temperature. Such a sensitivity would correspond to typical detectability limits of about 10^{-8} - 10^{-10} in terms of mixing ratios (Encrenaz et al., 1995).

Specific observations will have to be devoted to the study of oxygen-bearing molecules, including in particular O_2 , O_3 and, as mentioned above, H_2O_2 . Since the abundances of H_2O_2 and O_3 are expected to be respectively correlated and anticorrelated with the H_2O abundance, these observations will have to be scheduled accordingly, at two different times along the seasonal cycle (L_s close to 100-120 deg. for H_2O_2 and 280-300 deg. for O_3).

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