Near Infrared Spectrophotometry of Mars at ESO

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In spite of an extensive space exploration programme during the seventies, the planet Mars still raises several unresolved questions about the aeronomy of its atmosphere, the composition of its surface, and, more basically, the whole history of the planet. Infrared spectroscopy has proven to be a major tool for these studies, as illustrated recently by the discovery of HDO at 3 μm and the measurement of the deuterium abundance (Owen et al., 1988). Infrared spectroscopy between 1 and 5 μm is well adapted to the study of the martian atmosphere, as strong vibration bands of several atmospheric compounds (carbon dioxide, the major component, and minor constituents such as H_2O and CO); it is also well suited, even with a low resolving power, for the study of mineralogic signatures of the martian surface (olivine, pyroxene, hydrated minerals, carbonates and other salts . . .).

Mars is going to be the major target of space planetary exploration in the forthcoming decade. Mars Observer, planned by NASA for 1992, and the Mars-94 and forthcoming missions planned by the Soviet Union are part of an intense international effort aiming at a martian sample return by the end of the century. In spite of the recent failure of the soviet Phobos mission, a few days before its approach of the martian satellite Phobos, a major first step has been achieved with the two months observation of Mars from this spacecraft in February and March 1989. In particular, about 40,000 infrared spectra of the planet – in addition to a few hundreds of the Phobos satellite – have been recorded by the ISM experiment 0.76 and 3.16 μm, with a resolving power of 60 and a signal-to-noise ratio close to a thousand (Bibring et al., 1989).

In preparation and support to the ISM experiment, a ground-based coordinated effort was undertaken in 1988, taking advantage of the extremely favourable configuration of the September 1988 opposition. Visible and infrared images (using IRAC in particular) were recorded, for monitoring the dust activity; CO was observed in the millimetre range at IRAM and SEST, and in the infrared range at CFHT (Encrenaz et al., 1989).

At ESO, infrared spectrophotometry was achieved at the 1 m telescope between September and December 1988, in the 1.4–2.4 μm and 2.8–5.2 μm ranges. The objectives of this study were (1) to provide an additional absolute calibration to the ISM instrument; (2) to make absolute measurements of the albedos and surface temperatures in a given set of locations and (3) to obtain measurements or estimates of the gaseous abundances (CO_2, CO and H_2O), just before the beginning of the Phobos mission.

The Observations

Spectra of Mars were recorded during 7 nights from September 30, 1988 (two days after opposition) to December 24, 1988, using the InSb spectrophotometer of the 1 m infrared telescope of La Silla, with the 3 circular variable filters (1.4–2.4 μm, 2.8–4.2 μm and 4.5–5.2 μm). The CVF resolving power is about 60. The aperture diameter was 4 arcsec and the chopping throw was 30 arcsec in the east-west direction.

At the time of our observations, the south pole of Mars was observable, and the north pole was hidden; the latitude of the sub-Earth point was close to –20°. The angular diameter of Mars ranged from 23″5 in September to 10″3 at the end of December 1988. In most of the cases, for a given spectral range, three spectra of Mars have been recorded each night, at the centre of the disk, in the northern region (latitude of about +25°) and in the south pole region. Our aperture corresponded to a region of about 1500 km on September 30, and about 3400 km on December 24 at the centre of the disk.

Taking into account the diaphragm size, the exposure time of each spectrum and the rotation of the planet, the longitude extent of the region observed at the centre is about 35°.

During each exposure, the tracking was achieved on the visual image of the disk, sent to a TV camera through a dichroic plate.

The Infrared Spectrum of Mars

As for any Solar System object, the near-infrared spectrum of Mars is a combination of the reflected sunlight component and the thermal emission of the planet itself which increases at longer wavelengths. Apart from the gaseous and solid signatures, the continuum spectrum of Mars is thus expected to be, at first approximation, the combination of two blackbody curves, at 5770 K and 220–290 K, respectively. The thermal component starts to be im-
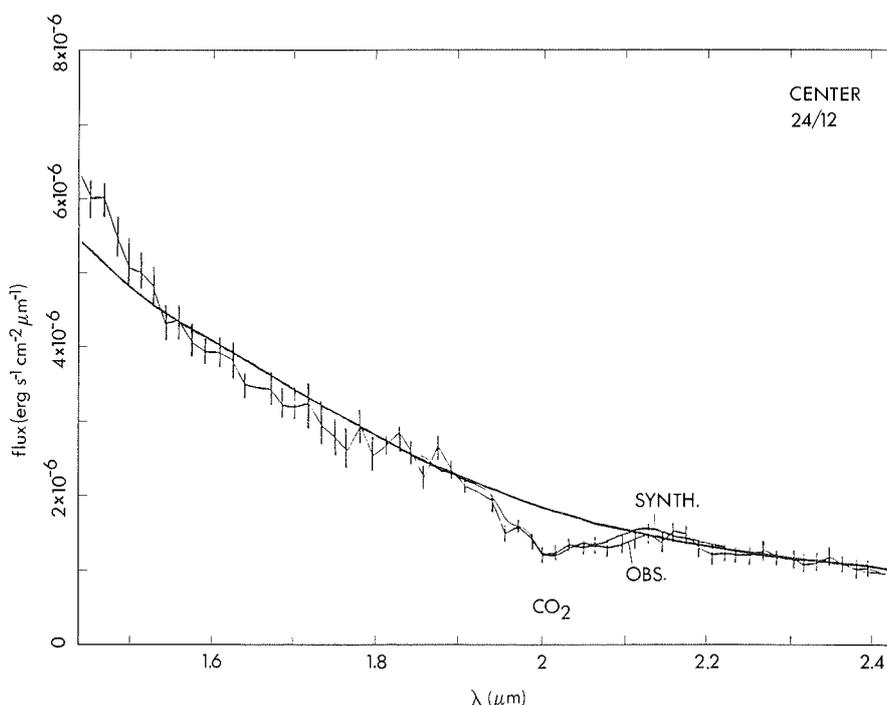
Figure 1: *Spectrum of Mars recorded between 1.4 and 2.4 μm on December 24 at the disk centre. The synthetic curve is calculated for a CO_2 pressure of 7 mb and an airmass factor of 2.*
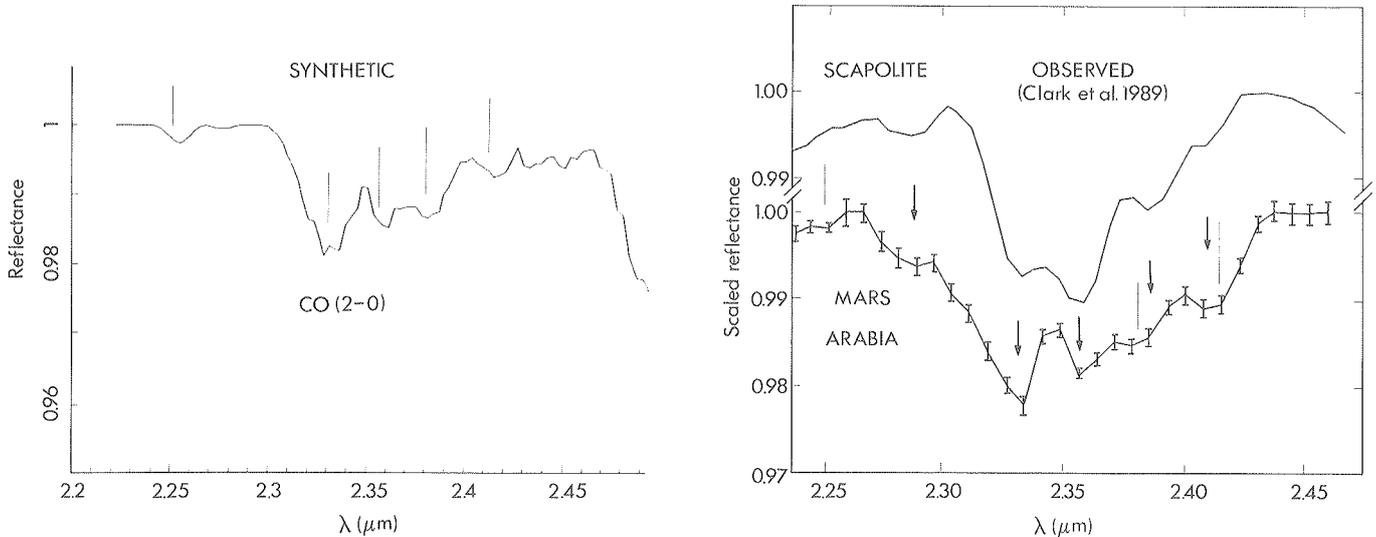
Figure 2: *Synthetic spectrum of the 2.35 μm region, showing absorption by the (2-0) band of gaseous CO. Data of Clark et al. (1989) are shown for comparison. The synthetic curve is calculated for CO/CO₂ = 0.001 and an airmass factor of 2.*

portant above about 3.5 μm, and gives a precise measurement of the surface temperature of the observed area.

A critical problem for understanding the infrared spectrum of Mars is to separate the gaseous and solid signatures. In order to discriminate between these two contributions, the atmospheric absorption spectrum of Mars has been modelled, including the contributions of CO_2, H_2O and CO, for the reflected and thermal components. A statistical band model was used (Goody, 1964; Wallace et al., 1977) with the spectroscopic data of the GEISA bank (Husson et al., 1986; Chedin et al., 1986). In the reflected sunlight component, the absorption depth is basically a function of the column density of the absorber; in the thermal component, the absorption is generally much weaker, and is a critical function of the column density of the absorber; in the thermal component, the absorption is generally much weaker, and is a critical function of the thermal profile. As a consequence, the reflected part of the spectrum, below 3.5 μm, is better suited for an analysis of the features, either of atmospheric or mineralogic origin.

The 1.4–2.4 μm Region

Figure 1 shows a spectrum of Mars recorded on December 24, 1988 at the disk centre, between 1.4 and 2.4 μm. A solar blackbody curve is shown for comparison. It can be seen that the albedo of Mars decreases by about 10 % as the wavelength increases. The broad absorption band around 2.0 μm is due to CO_2 and is well fitted with a CO_2 pressure of 7 ± 1 mb. Watervapour might be marginally present at 1.85 μm; an upper limit of about 3 cm-Am is de-

rived, which corresponds to a H_2O/CO_2 ratio of 3 10^{-4}, in reasonable agreement with previous estimates. Carbon monoxide has a band at 2.35 μm, but the quality of our data is not sufficient for identifying it. However, it has to be noticed that, under nominal conditions (CO/CO_2 = 0.001), the CO absorption band has a depth of a few per cent (Fig. 2). Gaseous carbon monoxide is most likely responsible for the absorption feature reported and tentatively identified as scapolite (Clark et al., 1988, 1989). Figure 2 shows that a good fit is obtained for a CO/CO_2 value of 0.001 and an air mass factor of 2, assuming a CO_2 surface pressure of 7 mb. This CO

value falls within the range of the CO mixing ratios derived in the past from infrared (Kaplan et al., 1969) or millimetre (Lellouch et al., 1989) observations.

The 2.8–5.2 μm Spectrum

In this spectral range, the Mars spectrum is the sum of the reflected and thermal components. The relative intensities of these two components depend upon two factors, the albedo of the observed region and its temperature. If the region is dark and/or warm, the thermal component dominates at long wavelengths; this is illustrated in Fig-
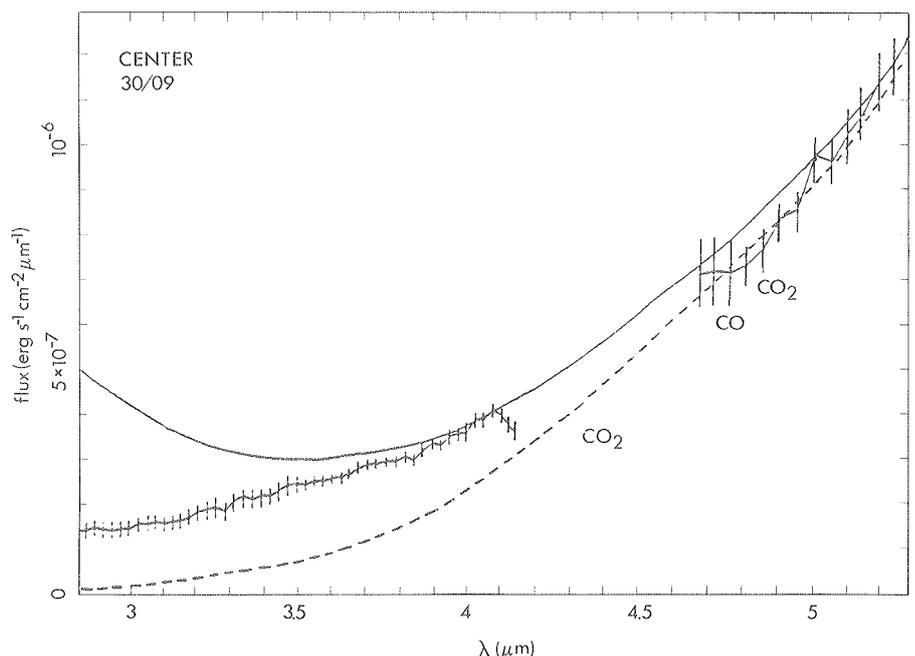
Figure 3: *Spectrum of Mars at the disk centre recorded on September 24 between 2.8 and 5.2 μm. The solid line is the retrieved continuum, sum of a blackbody at the surface temperature and a solar blackbody at 5770 K. The lower curve is the thermal component only.*
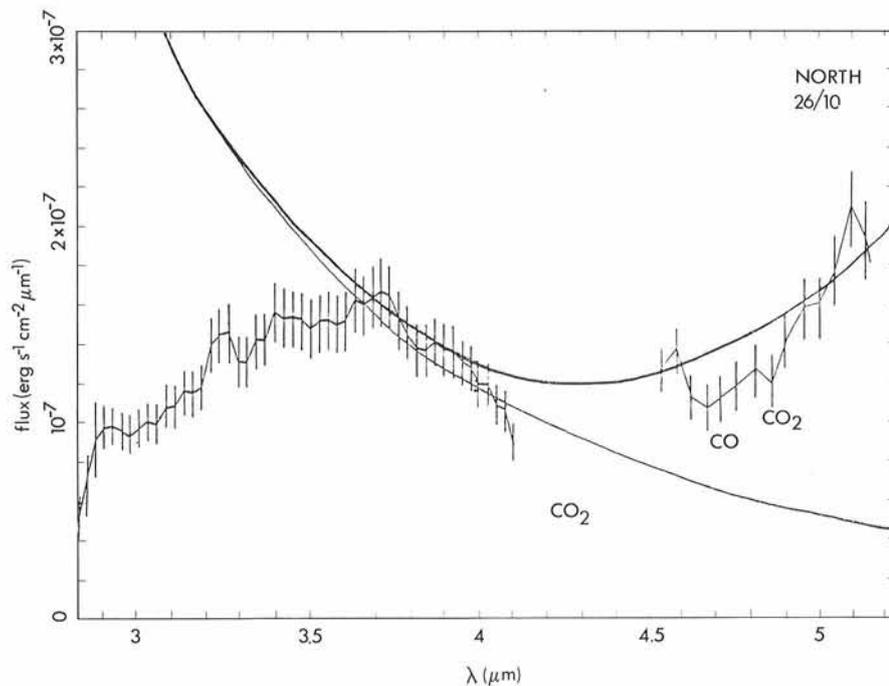
Figure 4: *Spectrum of Mars in the northern region, recorded on October 26 between 2.8 and 5.2 μm. The solid line is the retrieved continuum, sum of a blackbody curve at 5770 K. The lower curve is the reflected component only.*

ure 3. If the region, in contrast, is bright and/or cold, the reflected component dominates at short wavelengths, as illustrated in Figure 4. Albedos and temperatures have been measured from the 2.8–5.2 μm spectra of 15 different areas (see Table 1). An important characteristic of the Mars spectra in this spectral range is the strong and continuous absorption in the 3–4 μm region (Figs. 3 and 4), already identified as hydrated material by previous authors (Houck et al., 1973; Pimentel et al., 1974). The absorption depths of the observed areas is also listed in Table 1.

Between 4.2 and 4.5 μm, the terrestrial atmosphere is opaque, due to the strong CO_2 band at 4.25 μm. However, weaker CO_2 bands are also present between 3.5 and 4.2 μm, and have to be carefully subtracted for a proper analysis of mineralogic features. These features are marginally visible in Figure 3, but were observed with a very good signal-to-noise ratio by Blaney and Mc Cord (1989) who suggested the presence of S-H mineralogic compounds. Assuming an airmass factor of 2, we derive for Blaney and Mc Cord's data a CO_2 pressure of 7 mb in very good agreement with independent estimates.

Beyond the strong CO_2 band at 4.3 μm, other atmospheric bands can

be detected: CO_2 at 4.85 and 5.15 μm, CO at 4.7 μm. A remarkable result is the apparent depletion of CO in the spectra of the South pole area.

Conclusions

In conclusion, infrared spectroscopy of Mars between 1 and 5 μm is a powerful means for studying both the planet's atmosphere and mineralogy. A careful analysis of the atmospheric absorption features has to be performed to make possible the identification of possible weak mineralogic signatures. Finally, substantial information is expected from the data recorded by the ISM-Phobos experiment in February–March 1989, on both the atmosphere and the mineralogy of the planet. In particular, the CO and H_2O mixing ratios, and eventually their vertical profile, will be investigated; mineralogic features should be detectable at a level of about 0.1 %. In support of the future space exploration of Mars, ground-based observations will be especially useful beyond 3 μm with infrared cameras combining both spatial and spectral resolutions.

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TABLE 1: *Characteristics of Mars Spectra*

Spectrum	Surface Temperature	Albedo	Depth of hydrated silicated (2.8 μm)	Longitude	Latitude
Centre, Sept. 30	291.5	0.30	72 %	268	− 22
Centre, Oct. 20	283.0	0.43	81 %	86	− 24
Centre, Oct. 21	286.0	0.31	73 %	80	− 24
Centre, Oct. 26	283.0	0.31	81 %	375	− 24
Centre, Nov. 23	286.0	0.33	70 %	102	− 26
Centre, Dec. 24	272.0	0.39	70 %	157	− 25
North, Sept. 30	225.0	0.27	80 %	282	27
North, Oct. 20	245.0	0.43	82 %	100	25
North, Oct. 26	240.0	0.30	87 %	27	25
North, Nov. 23	250.0	0.45	82 %	123	15
South, Sept. 30	245.0	0.22	80 %	294	− 72
South, Oct. 20	240.0	0.26	78 %	112	− 72
South, Oct. 21	250.0	0.26	82 %	96	− 72
South, Oct. 26	267.0	0.33	84 %	38	− 72
South, Nov. 23	250.0	0.29	91 %	140	− 68