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D/H mapping on Mars with SOFIA at autumn equinox

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Abstract

Since 2014, we have been mapping D/H on Mars using weak transitions of HDO and H_2O around 7.2 µm recorded with the Echelon Cross Echelle Spectrograph (EXES) aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA) [1, 2]. We report a new observation performed at autumn equinox (Ls = 272°) on October 16, 2018. The disk integrated value of D/H is 6.4 x 10^{-4}, or 4.1 times the terrestrial value (VSMOW). This result is in agreement with previous measurements obtained with the same method [1, 2]. In addition, variations from about 3 to 5 times the VSMOW are observed over the disk.

1. Observations

SOFIA is a stratospheric airborne observatory operating at altitudes between 12 and 14 km, allowing us to remove most of the terrestrial contamination due to the terrestrial water vapor. EXES is an Echelon cross echelle spectrograph operating between 5 and 25 µm, which combines a high spectral resolution (10^5 at 7 µm) and a moderate spatial resolution, limited by the pointing capability of the SOFIA telescope (3 arcsec). Observations took place on October 16, 2018. As in the case of previous observations, the 1383-1392 cm^{-1} was recorded with a spectral resolution of 0.014 cm^{-1}. The Mars diameter was 13.2 arcsec and the solar longitude Ls was 272°. The length and the width of the slit were 11.8 and 1.44 arcsec, respectively. In order to map the Martian disk, the slit was nearly aligned along the E-W axis and moved from north to south by steps of about 0.7 arcsec. Several maps were successively recorded between 02:26 and 03:25 TU. As they looked identical, they were co-added in a single map. The sub-earth point (SEP) latitude was -18.10°, so that the southern hemisphere was observed. The SEP and SSP (sub-solar point) mean longitudes were 47.16°W and 1.43°W respectively, so that the morning hemisphere was in the field of view. The Doppler velocity was + 11 km/s, corresponding to a Doppler shift of – 0.051 cm-1 at 1387 cm^{-1}, more than 3 times larger than the spectral resolution of 0.014 cm^{-1}. This configuration, close to our observation of January 2017 [2], to separate the Martian water vapor lines from the terrestrial absorption lines.

2. Results

Figure 1 shows the central part of the disk-integrated spectrum of Mars, which shows a strong telluric absorption at 1387.5 cm^{-1}. The spectrum is very similar to the one of January 2017, also shown in the Figure.

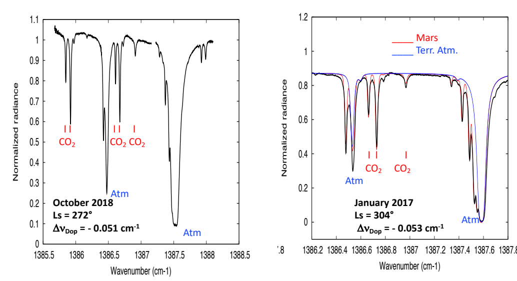

Figure 1. The central region of the 1383-1392 cm^{-1} spectrum, dominated by telluric absorption. Left: 2018 data; right: January 2017 data (from [2]). Red: Martian lines; blue: terrestrial absorption.

Figure 2 shows the disk-integrated spectrum of Mars in the 1387.6-1389.2 cm^{-1} region which contains, in addition to Martian CO_2 lines, two weak transitions of HDO and a weak transition of H_2O; these lines are used to retrieve the D/H ratio.

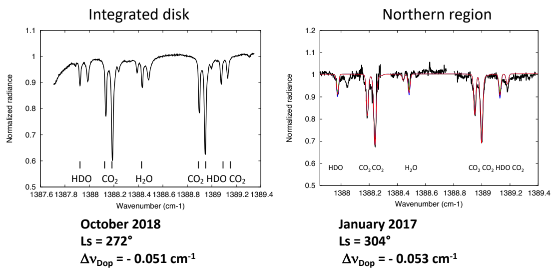

Figure 2: Left: The spectrum of Mars between 1387.6 and 1392.4 cm-1 in October 2018 (left, disk integrated) and January 2017 (right, northern region). The CO_2, HDO and H_2O transitions are indicated at the bottom of the figures.

From this spectrum, we retrieve the following disk-integrated values :

[H2O] = 175 ppmv

[HDO] = 275 ppbv

D/H = 4.1 x VSMOW

The local variations of these quantities over the disk are under reduction, and the uncertainty analysis is on-going. A preliminary analysis indicates that the D/H ratio exhibits longitudinal and latitudinal variations over the southern hemisphere of Mars, ranging from about 3 x VSMOW to 5 x VSMOW.

Table 1 summarizes the results obtained on the Martian D/H ratio with EXES. Comparison with earlier results seems to indicate the absence of significant seasonal variations of the D/H disk-integrated value. Our results, integrated over the Martian disk, are in general agreement with the LMD Mars Climate Database [3, 4] and with earlier measurements by Aoki et al (2015,[5]) and Krasnopolsky (2015, [6]). However, they are globally lower than inferred by Villanueva et al. (2015, [7]) and Khayat et al. (2018, [8]) using ground-based near-infrared spectroscopy.

Table 1: Summary of EXES observations . [H_2O], [HDO] and D/H are disk-integrated values.

Date	Apr. 08, 2014	Mar. 24, 2016	Jan., 24 2017	Oct. 16, 2018
Ls	113°	127°	304°	272°
Mars diameter	15 arcsec	11 arcsec	5.2 arcsec	13
SEP longitude	160°W	167°W	357°W	47°
SEP latitude	22°	-3°	-25°	-18°
[H_2O] (ppmv)	220 +/- 48	280 (+55, - 40)	250 +/- 50	175
[HDO] (ppbv)	300 +/- 12	350 +/- 70	350 +/- 70	275
D/H (VSMOW)	4.4 (+1.0, - 0.6)	4.0 (+1.1, - 0.9)	4.5 (+1.0, - 0.8)	4.1

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