MAPPING D/H ON MARS USING EXES ABOARD SOFIA

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Introduction: The D/H ratio on Mars, on a global scale, is an important measurement for understanding the past history of water on Mars [1]. Locally, through condensation and sublimation processes, it is a possible tracer of the sources and sinks of the Martian water vapor [2]. We have used EXES (Echelon Cross Echelle Spectrograph) aboard SOFIA (Stratospheric Observatory for Infrared Astronomy) to map the D/H ratio on Mars by measuring simultaneously H_2O, HDO and CO_2 transitions in the thermal infrared (7.2 μm and 7.5 μm). We find no evidence for strong local nor seasonal variations of the D/H ratio.

Observations: EXES is an infrared imaging spectrometer [3], operating between 4.5 and 28.3 μm with different modes including a high spectral resolution mode (R > 50,000). Data were recorded during 4 flights: April 8, 2014 (Ls = 113°), March 16, 2016 (Ls = 123°), March 24, 2016 (Ls = 127°) and January 24, 2017 (Ls = 304°). Table 1 summarizes the observing conditions. The resolving power ranged between 60,000 and 90,000. The seeing capability of the SOFIA telescope is unfortunately limited to 3 arcsec. When the diameter of Mars was 11 arcsec or more, the 11"x1.44" slit was moved across the planetary disk to build a map. For smaller sizes of the planet, the slit was positioned at different locations of the disk to obtain informations on latitudinal and longitudinal variations of the D/H ratio.

Table 1: EXES observations of Mars

Date	Ls	Mars diam.	Sub-obs long.	Spectral range (cm^{-1})
April 8, 2014	113°	15"	160°W	1383-1390
March 16, 2016	123°	10"	250°W	1326-1338
March 24, 2016	127°	11"	167°	1383-1391
January 24, 2017	304°	5.2"	350°	1326-1338
January 24, 2017	304°	5.2"	357°	3183-1391

The 1383-1390 cm^{-1} spectral range: Figure 1 shows the 1388-1390 cm^{-1} part of the spectrum recorded on April 8, 2014. Weak transitions of HDO and H_2O were used to retrieve an estimate of D/H by directly ratioing the line depths of these transitions [4]. The same method was used for the data of March 24, 2016 and January 24, 2017. Figure 2 shows the D/H ratio retrieved on April 8, 2014 and March 24, 2016. On January 24, 2017, we derived the D/H ratio as a function of latitude only.

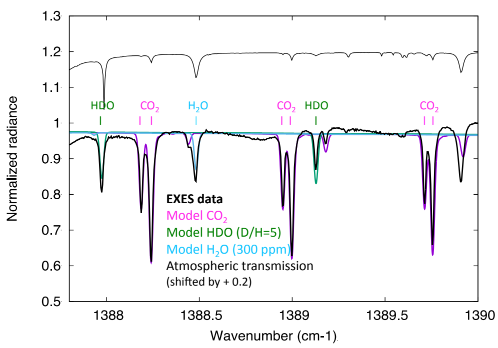

Figure 1: The disk-integrated spectrum of Mars recorded on April 8, 2014 (normalized radiance, thick blanck line). Synthetic models of the Martian atmosphere: contributions from CO_2 (purple), H_2O (300 ppmv, blue), HDO (467 ppbv, green). Thin black line (in absolute units, shifted by +0.20): standard transmission form the terrestrial atmosphere computed with the EXES model. The figure is taken from [4].

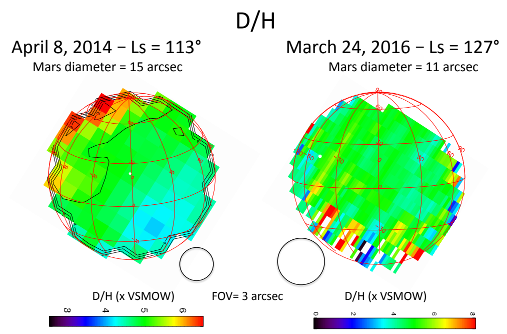

Figure 2: Maps of the D/H ratio retrieved from the data of April 8, 2014 and March 24, 2016.

In the case of the January 24, 2017 run,six scans were successsively recorded from North to South, positioned alternatively at +/- 1" in longitude from the disk center. However, because of the small diameter of Mars (5.2") and the poor seeing of the SOFIA telescope (3"), there is a large uncertainty on the exact positon of the slit. Figure 3 shows the variation of D/H with latitude obtained from the slit-integrated data.

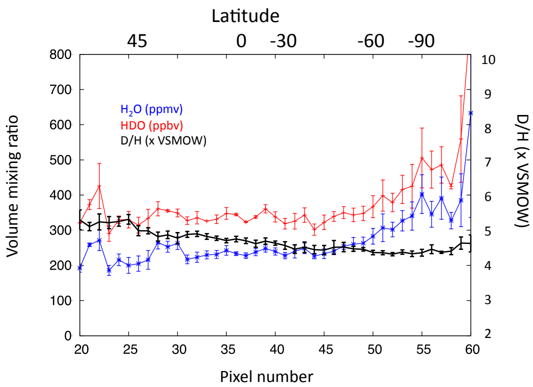

Figure 3: Volume mixing ratios of H_2O (in ppmv, blue), HDO (in ppbv, red), inferred from the H_2O/CO_2 and HDO/CO_2 line depth ratios corresponding to the transitions shown in Figure 1. The increase of these mixing ratios toward the south pole is consistent with the model predictions during southern summer (Ls = 304°). Black: the D/H ratio (in units of the VSMOW) inferred from the HDO/H_2O line depth ratio. In all cases, the error bars are calculated from the dispersion of the six scans, and do not take into account the uncertainties associated with the radiative transfer model.

Table 2 summarizes our results for the H_2O and HDO volume mixing ratios (vmr) and for the D/H ratio, integrated over the disk (April 8, 2014 and March 24, 2016) or over the slit (Jantuary 24, 2017).

Table 2: Summary of results using the 1383-1390 cm^{-1} data

Date	H_2O vmr (ppmv)	HDO vmr (ppbv)	D/H (x VSMOW)
April 8, 2014	220 +/- 48	300+/-12	4.4 (+1.0, -0.6)
March 24, 2016	280 (+37, -27)	350+/-47	4.0 (+0.8, -0.6)
January 24, 2017	250 +/- 34	350+/- 47	4.5 (+0.7, -0.6)

The 1326-1338 cm^{-1} spectral range: The main objective of this study was a sensitive search for methane [5]. In addition, transitions of CO_2, H_2O and HDO were used to infer the H_2O and HDO volume mixing ratios, as well as the D/H ratio. A radiative transfer model was developed on the basis of the Global Climate Model predictions, and an inversion code was used for an automatic retrieval of D/H.

Figure 4 shows a map of D/H inferred from the data of March 16, 2016. The integrated value of D/H appears to be consistent with the result shown in Table 2. In addition, some variations appear to be present, both with latitude and with longitude. The decrease of D/H toward southern latitudes is consistent with the predictions of the Global Climate Model [3].

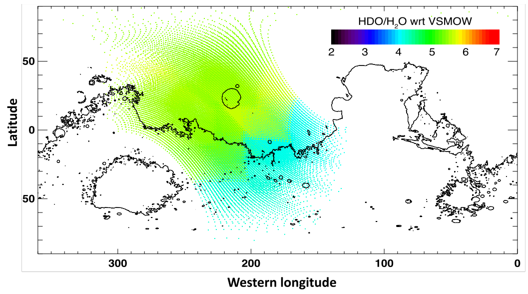

Figure 4: Map of the D/H ratio (in VSMOW units) inferred from the 1326-1338 cm^{-1} dataset of March 16, 2016.

References:

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