A new measurement of D/H on Mars using EXES aboard SOFIA

Thérèse Encrenaz, Curtis N. Dewitt, Matthew J. Richter, Thomas K. Greathouse, Thierry Fouchet, Franck Montmessin, Franck Lefèvre, Bruno Bézard, Sushil K. Atreya, S. Aoki

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A new measurement of D/H on Mars using EXES aboard SOFIA

T. Encrenaz (1), C. DeWitt (2), M. Richter (2), T. Greathouse (3), T. Fouchet (1), F. Montmessin (4), F. Lefèvre (4), B. Bézard (1), S. K. Atreya (5), S. Aoki (6)
(1) LESIA, Paris Observatory, France, (2) UC Davis, CA, USA, (3) SwRI, San Antonio, TX, USA, (4) LATMOS, IPSL, Paris, France, (5) University of Michigan, Ann Arbor, MI, USA, (6) BISA, Brussels, Belgium (therese.encrenaz@obspm.fr))

Abstract

The distribution of D/H ratio on Mars is crucial for understanding the planet's water cycle including the exchange with surface reservoirs, and for estimating the amount of liquid water in the past. We have employed EXES (Echelle Cross Echelle Spectrograph) aboard SOFIA (Stratospheric Observatory For Infrared Astronomy) to map D/H on Mars in the thermal infrared, starting with the first measurement in April 2014 (Ls = 113°). Here we present a new measurement obtained in March 2016 (Ls = 127°). The disk-integrated value of D/H is found be 4.0 (+0.7, -0.6) x VSMOW, in agreement with our earlier result (4.4 (+1.0, -0.6) x VSMOW) [3]

1. Introduction

It has been known for several decades that the D/H ratio in Mars is significantly enriched relative to the terrestrial value (VSMOW, i.e. 1.556 10^{-4}), which has been interpreted as the signature of atmospheric loss due to differential escape [1]. High-resolution imaging spectroscopy now allows us to map the D/H ratio over the Martian disk, and thus provide constraints on the mechanisms responsible for deuterium fractionation through condensation/sublimation processes [2]. The high-resolution imaging spectrometer EXES, aboard the SOFIA aircraft, allows us to measure simultaneously H_2O and HDO transitions, and thus remove the contamination effect due to terrestrial atmospheric opacity. A first measurement was obtained in April 2014 during a commissioning flight of EXES [3]. At that time, Mars was close to opposition and the diameter of Mars was above 15 arcsec). The limitation of this observation was that the Doppler shift was close to zero, and the main difficulty was the removal of the terrestrial water contamination. In March 2016, we have repeated the observation with a different configuration, with a Doppler shift sufficient to separate the terrestrial water absorptions from the Martian ones, making the retrieval of the Martian water content and the D/H ratio much easier.

2. Observations

The observing run took place on March 24, 2016, between 11:43:13 UT and 12:30:27 UT. The altitude of the aircraft was 13.7 km. The diameter of Mars was 11 arcsec and the solar longitude, Ls, was 127°. We used the 1383-1392 cm^{-1} spectral range which contains both strong and weak lines of CO_2, H_2O and HDO. The spectral resolution, measured from the widths of the CO_2 Martian lines, was 0.022 cm^{-1} (Gaussian profile, R=63000). The slit of the spectrograph was moved over the planet to map the whole disk. The spatial resolution of the SOFIA is however limited to 3 arcsec.

Figure 1 shows the EXES disk-integrated spectrum of Mars, compared with a model spectrum of Mars showing the different contributions of CO_2, H_2O and HDO

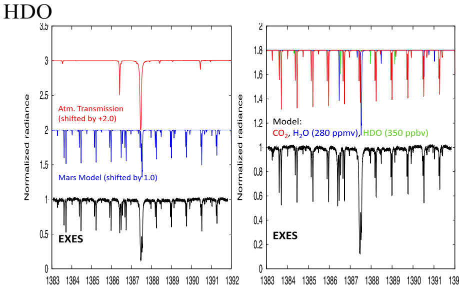

Figure 1: (left) The EXES disk-integrated spectrum (thick black line) compared with best-fit model of the Martian spectrum (blue) and the terrestrial opacity above 13 km (red). (right) The same EXES spectrum compared with best-fit model showing the contributions of CO_2 (red), H_2O (280 ppmv, blue) and HDO (350 ppbv, green)

3. Data analysis and results

The terrestrial absorption spectrum dominates in the 1366-1368 cm^{-1} region. Outside this range, the Martian lines of CO_2, H_2O and HDO are mostly free of terrestrial contamination, thanks to the relatively large Doppler shift. As in the case of our previous analysis [3], we derived the H_2O and HDO mixing ratios from the line depth ratios of H_2O/CO_2 and HDO/CO_2 respectively, and we derived D/H directly from the HDO/H_2O line depth ratio. This method has the advantage of removing, to first order, the geometrical effect (airmass) and the uncertainties associated with the atmospheric thermal structure. Figure 2 shows the best disk-integrated fits obtained for the H_2O and HDO mixing ratios: H_2O = 280 +/- 20 ppbv (in very good agreement with the GCM prediction), and HDO = 350 +/-70 ppbv.

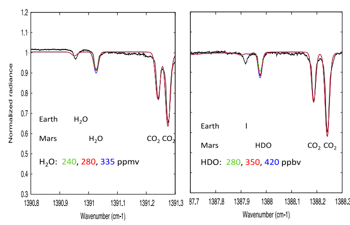

Figure 2: *Retrieval of the H_2O (left) and HDO (right) disk-integrated mixing ratios. The radiative-transfer calculations were done using the LMD-GCM thermal structure corresponding to the observing conditions.*

We have used the 1366-1368 cm^{-1} spectral range to model the terrestrial opacity (using a terrestrial model of the water vertical distribution over an altitude of 13 km), and we have multiplied this terrestrial spectrum by our best fit model for comparison with the EXES spectrum. The result is shown in Figure 3. It can be seen that the best-fit model is in excellent agreement with the EXES data in this spectral range also.

Figure 4 shows the map of D/H on Mars retrieved from the line depth ratio of the HDO and H_2O transitions shown in Figure 2. It can be seen that the H_2O mixing ratio is maximum in the northern region, as expected from the GCM for this season. The D/H map is remarkably uniform over the disk in all regions where it can be reliably measured. At high southern latitudes, the H_2O and HDO lines are too weak for their line depth ratio to be significant.

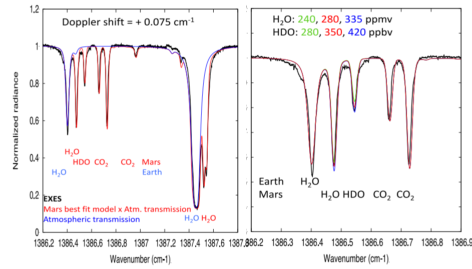

Figure3: *(left) The disk-integrated EXES spectrum compared with our best-fit model in the 1386-1388 cm^{-1} range; (right) Comparison with models including several H_2O and HDO mixing ratios in the 1386.2-1386.9 cm^{-1} range.*

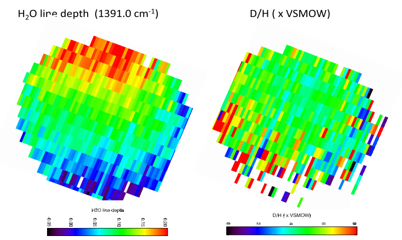

Figure 4*: (left) H_2O line line depth; (right) D/H ratio inferred from the HDO/H_2O line depth ratio.*

Our disk-integrated value of D/H is 4.0 (+0.7, -0.6) x VSMOW, consistent with but slightly lower than our 2014 estimate of 4.4 (+1.0, -0.6) VSMOW [3]. A possible reason for this difference is that, in the case of our 2016 observation, the Tharsis region is in the center of our field of view, and the D/H ratio is known to decrease with altitude above this location [2, 3]. Our result is also consistent with the ground-based map of Villanueva et al. 2015 [4], although our map appears globally more uniform. We should point out, however, that our spatial resolution is strongly limited (3 arcsec) due to the image quality of the SOFIA telescope.

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References: [1] Owen, T. et al. 1988, Science 316,92; [2] Montmessin, F. et al. 2005, JGR 110, E03006; [3] Encrenaz, T. et al.2016, A&A 586, A62; [4] Villanueva, G. et al. 2015, Science 348, 318