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A map of D/H on Mars using high-resolution spectroscopy with EXES aboard SOFIA

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Abstract

We have obtained a map of D/H on Mars on April 8, 2014, when the planet was close to opposition (15.3" in diameter) and close to northern summer solstice (Ls = 113°). Data were recorded with the EXES (Echelon Cross Echelle Spectrograph) imaging spectrometer aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA). A preliminary reduction indicates an increase of the D/H ratio from south to north, with a disk-integrated value of about 6.5 times the terrestrial value.

1. Introduction

The D/H ratio on Mars is a key tracer of the atmospheric evolution of the planet, both at global and regional scales. As an effect of differential escape rates of HDO and H_2O (HDO being slightly heavier than H_2O), a measurement of the present D/H, integrated over the planet, is an indicator of the global loss of water over the history of the planet. At a local scale, a measurement of D/H over the Martian disk, and its evolution with latitude, altitude and season, is an indicator of the water cycle and its exchange with surface reservoirs, through fractionation processes associated with differential condensation mechanisms.

The first measurement of D/H on Mars was achieved by Owen et al. (1988)[1] who inferred a disk-integrated D/H enrichment of 6 (+/- 3) with respect to the terrestrial Standard Mean Ocean Water (SMOW) value. This was the first indication of the loss of water from Mars over geologic time, implying that Mars must have been wetter and warmer than today. The previous results for the present day Mars atmosphere have been confirmed by subsequent measurements on a global and local scale [2, 3]. Maps of D/H were also recorded for different seasons [4, 5]. In particular, Villanueva et al. (2015) [5] found a D/H enrichment higher than previously thought, and stronger local variations than expected in the theoretical model [6].

2. Observations

EXES (Echelon Cross-Echelle Spectrograph) is an imaging spectrometer that operates at high, medium or low resolution in the medium infrared range (4.5 – 28.3 μm). It is mounted on the 2.5-m telescope of SOFIA (Stratospheric Observatory for Infrared Astronomy), operating at altitudes of 12 – 14 km and allowing the simultaneous observations of H_2O and HDO lines. Our observations took place on April 8, 2014 between 5:00 and 5:30 UT. The planet was very close to opposition with a diameter of 15.3". The areocentric longitude Ls was 113°, just after northern summer solstice.

Data were recorded between 1383 and 1390 cm^{-1} (7.19 – 7.23 μm), with a spectral resolving power of $5\ 10^4$ ($\Delta\nu$ = 0.028 cm^{-1}). As Mars was close to opposition, the Doppler shift (0.011 cm^{-1}) was about three times smaller than our spectral resolution.

3. Data analysis

Figure 1 shows a portion of the EXES spectrum between 1387.8 and 1390 cm^{-1}, which includes weak transitions of CO_2, H_2O, and HDO. As a first analysis of our data, we have used the line depth ratios of H_2O/CO_2 and HDO/CO_2 to retrieve mixing ratios of H_2O and HDO, respectively, and then to infer the D/H ratio on Mars using the relation D/H = 0.5 x [HDO]/[H_2O]. This method has the advantage of removing, to first order, the effects associated with the thermal structure and the geometry of the observations; it has been successfully applied to study the seasonal variations of H_2O_2 and HDO on Mars [7, 8].

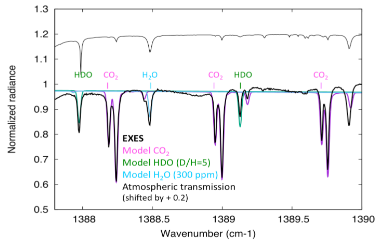

Figure 1: The disk-integrated spectrum of Mars recorded by EXES between 1387.8 and 1390 cm^{-1} (thick black line). Models including absorptions by CO_2, H_2O and HDO are shown for comparison, with a model of the atmospheric transmission.

5. Results

Figure 2 shows the map of D/H on Mars inferred from the line depth ratios of HDO (at 1389.13 cm^{-1}) and H_2O (at 1388.47 cm^{-1}). The contribution of the terrestrial absorption at these two frequencies was inferred from both the atmospheric model (Figure 1) and the measurement of the sky, recorded simultaneously with our Mars spectrum. We derive a disk-integrated D/H value of about 6.5 times the terrestrial value, with variations ranging, from south to north, from 5.5 times to 8 times the terrestrial value.

6. Conclusions

Our results are in good agreement with previous estimates [1-5], in particular with the maps obtained by Villanueva et al. (2015) for Ls = 80° [5]. They illustrate that the latitudinal variation of D/H, although consistent with the trend expected from a fractionation process dominated by condensation, are stronger than predicted in the theoretical model [6]. In the future, we plan to refine this analysis by modeling the entire EXES spectrum to get a more accurate estimate of the uncertainty associated with our measurement.

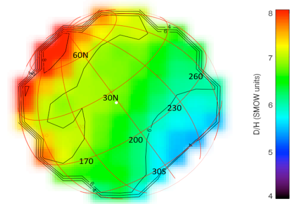

Figure 2: The map of D/H on Mars inferred from the EXES data. Mars was close to opposition, and the season was just after northern summer solstice (Ls = 113°).

Acknowledgements

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