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Exploring HDO and H_2O on Mars with the ACS instrument onboard TGO

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Abstract

1. Introduction

The Trace Gas Orbiter (TGO) of the ESA-Roscosmos ExoMars mission has ended its trip to Mars, reaching the planet in October 2016. After more than a year-long aerobraking phase, its scientific mission has begun on April 22nd 2018 with the execution of the first solar occultation. The primary objective of TGO is to detect, map and locate trace gas sources, possibly revealing a residual geophysical (or even biological) activity on Mars. The instrument of interest here is the infrared spectrometer Atmospheric Chemistry Suite (ACS). ACS covers a wavelength range from 0.7 to 17 µm at very high spectral resolution (λ / $\Delta\lambda$ from 5,000 to 50,000). ACS operates in nadir and in solar occultation. Its performance and scientific objectives make it complementary to NOMAD, the other spectrometer dedicated to trace gas characterization.

The objectives of ACS [1] lie at the core of TGO mission goals (TGO will eventually serve as a telemetry relay for the ExoMars 2020 rover). However, the versatility of ACS makes it possible to contribute, beyond the sole topic of trace gases, to the more general knowledge of the Martian atmosphere, by characterizing in particular the Martian water cycle and that of its isotope HDO.

2. The water and heavy water cycles

Several members of our team have long been involved in the study of Martian HDO, having described their theoretical approach with several original works [2,3,4].

The D / H ratio, determined via the isotope ratio of the water vapor, is more than five times higher than the reference ratio of the terrestrial oceans. This relative enrichment of D appears as the result of a differentiated escape suggesting that a quantity of water at least five times higher was once present on Mars (the Earth managed how to preserve all of its water). What we know today about Martian D / H has been developed essentially from observations made from Earth. The latter have substantially increased in number thanks to several groups [5,6,7,8].

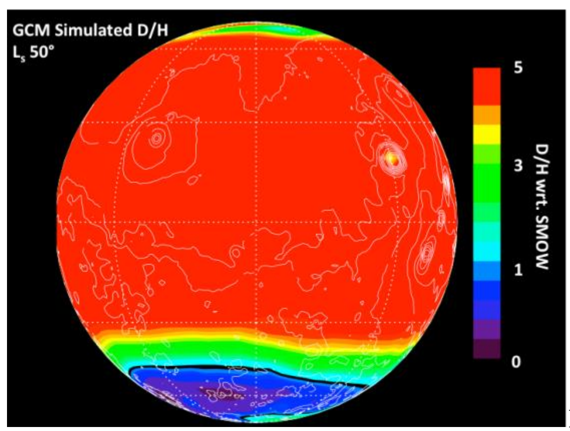

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Figure: Map of the D/H ratio on Mars at Ls 50° as predicted by the GCM presented in [4].

During condensation, a fractionation process takes place between H_2O and HDO, the latter tends to concentrate in the ice phase, distilling an air depleted in deuterium. In fact, an isotopic gradient must theoretically settle between the cold regions subject to condensation and the warmer regions (see Figure). The comparison of predictions of the 3D model published in [4] and ground observations agree well on the existence of a meridional gradient of D/H between the hot and humid summer hemisphere and the cold, dry winter hemisphere.

However, the observations also revealed a D/H contrast in longitude that contradicts model predictions [9]. No viable hypothesis can yet explain the presence of such a gradient. A fractionation action by adsorption / desorption of water in the regolith is theoretically possible, but such a phenomenon requires an exchange flux with the atmosphere that is too high. Many puzzles remain, and the field of HDO needs to be explored by observation.

3. Heavy water vapor: a major goal for ACS

The ACS measurements will produce the first vertical profiles obtained simultaneously for HDO and H_2O in an altitude range limited in its lower part by the thick layer of aerosols (around 10 km typically) and in its upper part (above 80 km) by the gradual decrease in the concentration of these two species and that of the air mass factor. Nevertheless, these profiles will make it possible to identify the altitudes where it a sudden collapse of the two species is expected as a consequence of their condensation (hygropause), the associated formation of clouds (observed by ACS instrument too) and consequently the resulting fractionation. In fact, ACS shall be able to characterize in detail the space-time variability of H_2O and HDO.

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