THE EVOLUTION OF THE WATER RESERVOIRS ON MARS REVEALED VIA D/H ISOTOPIC MAPPING

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Abstract: We report maps of atmospheric water (H_2O) and its deuterated form (HDO) across the Martian globe obtained using infrared high-resolution spectroscopy. The hemispheric maps sample the evolution of sublimation from the North polar cap, revealing high variability and showing that atmospheric water replenished during northern spring is notably more enriched in deuterium than is water seen at mid-latitudes.

Introduction: Isotopic maps address fundamental questions such as: what is the current representative ratio of D/H in water, and how much water was lost over the geological life of the planet? Isotopic ratios are among the most valuable indicators for the loss of volatiles from an atmosphere, with deuterium fractionation also revealing information about the cycle of water on the planet and informing us of its stability on short- and long-term scales.

The vapor pressures of HDO and H_2O differ significantly near the freezing point, making the condensation/sublimation cycle of the isotopologues sensitive to local temperatures, saturation levels and presence of condensation nuclei. Until recently, only isolated (in time and in space) measurements of D/H in the atmosphere were available (*1-5*), and they were typically – but incorrectly – assumed to be representative of the bulk atmosphere. But spatially resolved measurements of D/H at different times of day and seasons are necessary to disentangle local from global phenomena, thereby revealing the true isotopic ratio of current water reservoirs and their implications for global loss of water over geologic time. Such maps also enable the search for new sources of water on Mars.

The maps reported herein are based on observations of isotopic water using high-resolution infrared spectrometers (CRIRES, NIRSPEC, CSHELL) at powerful ground-based observatories (VLT, Keck, and IRTF, respectively). Specifically we targeted the ν_1 band of HDO near 2720 cm^{-1} (3.7 μm), and the $2\nu_2$ band of H_2O near 2990 cm^{-1} (3.3 μm). Spectral lines of these bands on Mars are observable through our atmosphere when measured from high-altitude observatories at moderately high Doppler shifts (>11 km s^{-1}), i.e., when Mars' lines are displaced sufficiently far from the cores of their counterpart telluric absorbing lines. CO_2 is co-measured with water in each setting, thereby providing an unambiguous metric of column abundance on Mars for each footprint along the slit.

Mapping: Two-dimensional maps of the targeted species were obtained by orienting the slit N-S or E-W and by stepping the slit across the planet, achieving full disk coverage. For each footprint on Mars, we estimated the local atmospheric conditions by querying the Mars Climate Database v4.2 (*6*), that is based on a realistic general-circulation-model (GCM) as constrained by authentic Mars parameters obtained from spacecraft results. These parameters were fed to a multi-layer planetary radiative transfer model adapted for Mars (GENLN3, see methodology also in (4,7,8)), and the apparent martian column densities were derived from the measured spectral line intensities (H_2O, HDO, CO_2) using a Levenberg-Marquardt (LM) algorithm (see Figure 1). The retrieval of apparent molecular abundances includes corrections for double path absorption (Sun-to-surface and surface-to-observer airmasses) and surface thermal emission for one-way (surface-to-observer) absorption only. The influence of aerosol scattering was removed from the processed data prior to final abundance retrievals for the gaseous species.

Datasets: The data were collected over several years and seasons on Mars from March/2008 until January/2014. From this extensive database, we derived a localized D/H measurement over the Viking 1 landing site (*4*) and a comprehensive search for organics in the Martian atmosphere (*9*). We will present results from the best datasets targeting D/H, obtained at times of low telluric water, high-Doppler shift and maximum spatial coverage (CRIRES: September/8-9/2009, CSHELL: March/25/2008, NIRSPEC: January/24/2014, CRIRES: January/29-30/2014), spanning seasons from late northern winter to late northern spring on Mars (Ls = 335°, 50°, 80°, 83°). The dates span the critical interval when the northern polar cap sublimates and replenishes the atmosphere with water.

Results: Detailed maps will be presented at the meeting since the results are currently under a publication embargo. The H_2O and HDO disk maps reveal strong local anisotropies and seasonal variability. The slow replenishing of water vapor in the northern hemisphere as the polar cap sublimates during northern spring is quite noticeable, in particular when compared to the baseline measurement in late northern winter (Ls 335°). Variability of H_2O with latitude and season is apparent, and is generally consistent with previous spacecraft measurements of the water cycle (10,11). HDO maps superficially resemble those of H_2O by showing strong variability, but their direct comparison reveals strong differences that are most easily seen in maps of the D/H enrichment in water vapor. Strong D/H enrichment, much higher than previously reported, is observed in certain regions of the planet.

Conclusions: Measurements of D/H on Mars are among the main goals of the Curiosity Rover (MSL) and MAVEN missions, but both platforms provide local measurements only (near-surface in Gale Crater by MSL, and ionosphere by MAVEN) that do not provide a measure of the total atmospheric column across the planet. Our new column measurements (of both HDO and H_2O) provide an unprecedented view of their distribution across the planet for each snapshot in time. Over several seasons on Mars, they reveal interactions of the different reservoirs of water on Mars and their ratio provides unique information about water loss over geological times.

We identify regions of strong D/H enrichment, and from our measurements we determine the D/H of the main (labile) water reservoir in Mars. Our results establish the presence of strong local and temporal variability of isotopic ratios in Mars atmosphere, notably increasing previous estimates and permitting us to provide improved constraints on the history of water on Mars.

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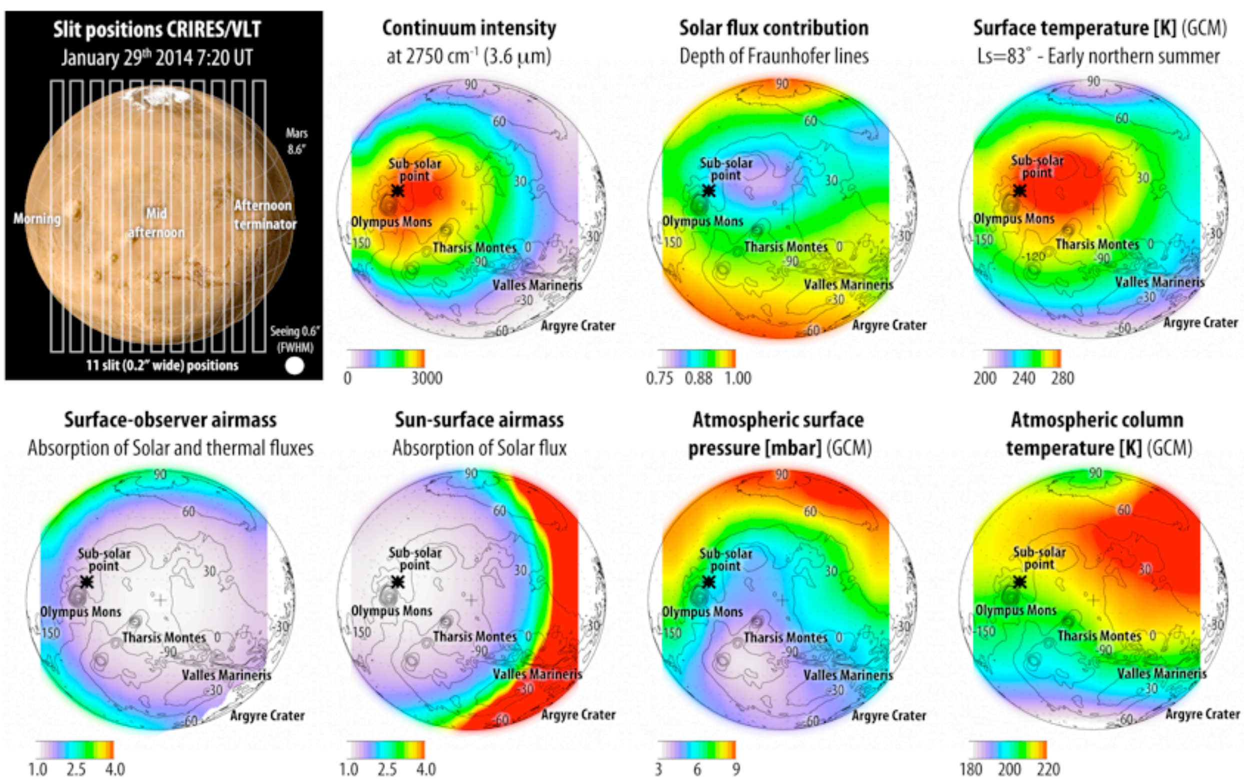

Figure 1: Slit positions on Mars and parameters employed in the retrieval process derived from the observed spectra (continuum, reduced depth of Fraunhofer lines), from the GCM (T_{surf}, P_{surf}, T_{air}) and from geometric considerations (airmasses). All quantities were affected by seeing, which smoothes local variations in latitude and longitude. H_2O, HDO and D/H maps will be presented at the meeting.