SEASONAL MAPPING OF HDO and H_2O IN THE MARTIAN ATMOSPHERE.

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We report investigations of HDO and H_2O on Mars using CSHELL at the NASA IRTF, on dates that span an entire Mars year. Our objective is to understand whether deuterium is preferentially sequestered in the polar regions, and to determine whether the two polar caps are equivalent in that regard. The instrument slit is typically positioned N-S along the central meridian resulting in a one-dimensional map of HDO (1997-2003) and/or H_2O (2001-2003) [1]. Column burdens are extracted at one arc-second intervals along the slit, permitting a direct comparison of the D/H ratio at various latitudes and seasons.

A solid constraint of the D/H ratio on Mars would be extremely useful in constructing atmospheric models, estimating the evolution of water on Mars, and dating Mar meteorites [2-4]. The best determinations to date indicate a five times larger value on Mars than on Earth [5]. The D/H ratio is expected to increase on Mars through Rayleigh distillation [3,4]. The efficiency of deuterium escape compared to hydrogen for the current epoch is about 32% [4]. In addition to the overall increase, the D/H ratio could display a hemispherical variation. The different mean temperatures of the polar caps could cause a different degree of HDO sequestration.

Our group has initiated an observing program to test this hypothesis by providing well-constrained D/H values for the northern and southern hemispheres on Mars. We are conducting nearly simultaneous measurements of H_2O and HDO in the near-IR. DiSanti and Mumma developed a technique for mapping HDO on Mars through its ν_1 fundamental band near 3.67 μm, using CSHELL at the NASA IRTF [6]. Novak et al. (2002) extended the approach significantly, and described nearly simultaneous measurements of ozone and HDO on Mars, acquired in January 1997 (L_s = 67°) [1]. We recently detected new lines of H_2O in absorption (centered at 3035, 8764, and 8827 cm^{-1}), and we now use them to obtain the H_2O abundance. The combination permits a direct investigation of HDO and H_2O on Mars. The approach is illustrated in Figure 1.

Novak et al. (2002) [1] converted the measured HDO abundance to a column burden for H_2O by adopting the D/H enrichment factor of 5.2 ± 0.2 relative to SMOW, reported from KAO spectra [5]. The KAO value refers to disk-integrated measurements made on 5 Aug. 1988 (L_s = 246°, late southern summer); it is not known whether this value changes with season or latitude. It is interesting to compare the CSHELL retrievals for Jan. 1997 with independent measurements of H_2O at the same L_s (but different Mars years) (Figure 2). At mid- and low-latitudes, the ground-based data are systematically higher than the either Viking or TES results, suggesting that a higher D/H ratio is implied. At 12° S latitude, the implied enrichment is a factor of 7.45 with respect to SMOW while at 30° North latitude it is only 5.1 with respect to SMOW. At this season, the northern polar cap is rapidly vaporizing, causing strong latitudinal and temporal gradients in water vapor at near-polar latitudes; the spacecraft and ground-based results have different fields-of-view and so give increasingly divergent results for high latitudes.

Since January, 1997, we have repeated these measurements at different times during the Martian year (Table 1). For all of these dates, we have positioned the slit N-S along the central meridian; for some dates, we also stepped the slit across the planet at 1 arc-sec intervals providing a 2-dimensional map across the planet. We also positioned the slit E-W on Mars thus providing a measurement of diurnal variations of ozone and water.

TABLE I
CSHELL Observations of Mars

UT date	L_s	Del-Dot (km sec^{-1})	Diameter
21 Jan 1997	67°	-15.3	9.6"
01 Mar 1997	84°	-7.2	13.4"
20 Mar 1999	112°	-12.7	12.6"
05 Jul 1999	165°	10.5	11.1"
15 Jan 2001	103°	-17.0	5.7"
20 Mar 2001	133°	-16.5	9.2"
10 Jan 2002	306°	13.0	6.0"
13 Jan 2003	124°	-14.9	4.8"
21 Mar 2003	154°	-15.6	6.9"

In 2001, we began mapping H_2O directly at several wavelengths, along with nearly simultaneous measurements of HDO (Fig. 1). This combination enables direct measurement of the D/H ratio on Mars, and it permits investigation of possible latitudinal and seasonal effects. With CSHELL, measurements for both isotopic species can be made during either day or night.

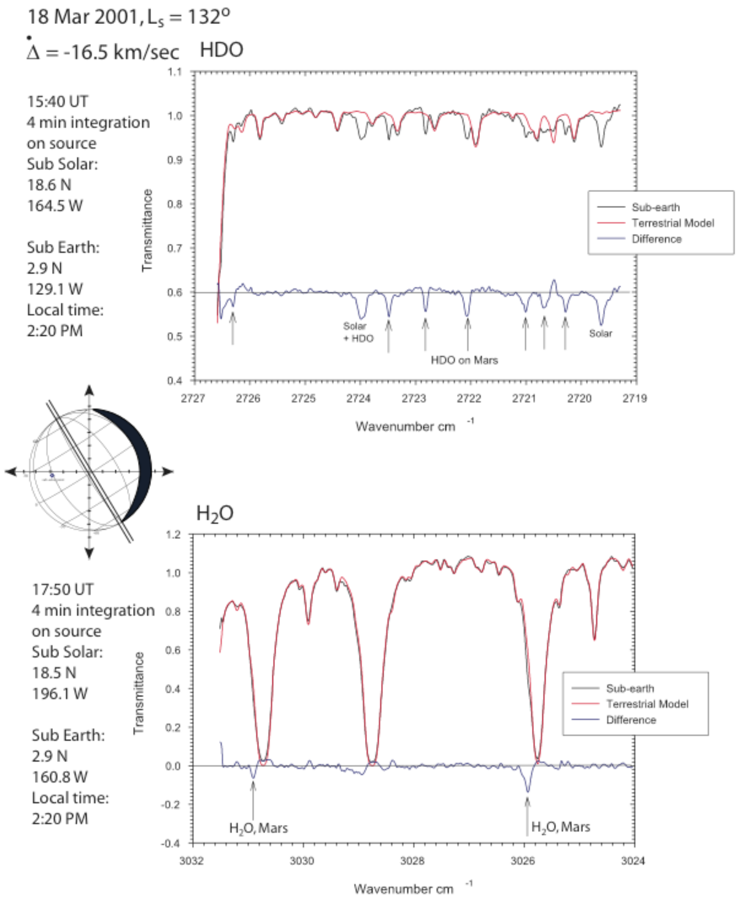

Fig. 1. Detection of HDO (upper panel) and H_2O (lower panel) on Mars. Spectral extracts (5 rows or one arc-second) on Mars are centered at 18.6° N latitude, 2:20 PM local time on 18 March 2001 (L_s = 132°). Spectral lines on Mars (arrows) are seen Doppler-shifted from their terrestrial counterparts. The continuum is contributed by sunlight reflected from Mars' surface, along with thermal emission from the surface; their relative sizes are obtained from solar Fraunhofer lines [1]. The modeled terrestrial atmospheric transmittance is shown for each spectral region, and the difference spectra (residuals) reveal clear detections of HDO and H_2O on Mars. The rotational temperature retrieved from Boltzmann analyses of line-by-line intensities provides information regarding the altitude distribution of the sensed water.

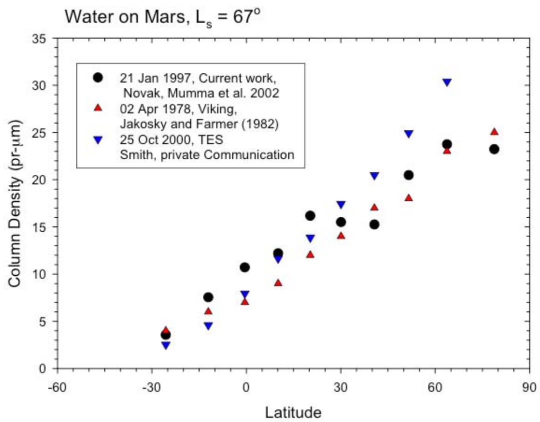

Fig. 2. Comparison of H_2O column burdens measured by Viking MAWD [7], TES [8], and CSHELL, for a common season ($L_s = 67°$) but during different years. The CSHELL measurements are based on measured HDO column burdens and assume D/H enrichment of 5.2 relative to SMOW. The comparison may suggest a changing ratio in HDO/H_2O with latitude.

Seasonal Variation of Water: A summary of our observations of HDO taken at four different times during the Martian year appears in Fig. 3.

Strong variations with latitude and season are evident. The enrichment in D/H seen by KAO [5] was assumed when expressing the measured HDO in terms of total H_2O. For the lowest two panels ($L_s = 133°$ and $306°$) we also measured H_2O directly; the combined data set will permit extraction of D/H enrichment factors directly. This will test whether deuterium is preferentially sequestered in one polar cap, and will provide a very secure value for atmospheric D/H on Mars.

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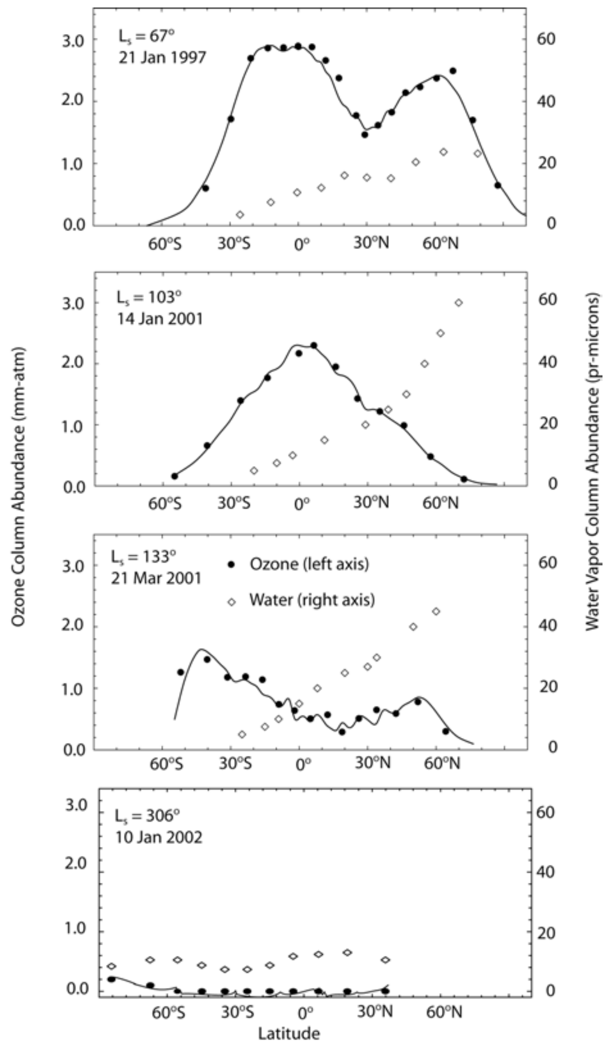

Fig. 3. The column burden measured for HDO and (apparent) ozone taken at different seasons during Mars' year, using CSHELL. The HDO burden is expressed in terms of equivalent H_2O by assuming a constant D/H enrichment of 5.2 relative to SMOW [5]. This eases the comparison with water measurements obtained in other ways (e.g., TES, Viking MAWD). (After Novak et al. 2003 [this volume]).