MSL/SAM MEASUREMENTS OF NON CONDENSABLE VOLATILES, COMPARISON WITH VIKING LANDER, AND IMPLICATIONS FOR SEASONAL CYCLE

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SUMMARY

The Sample Analysis at Mars (SAM) instrument has carried out the first *in situ* measurements of the composition of Mars atmosphere at the Gale Crater landing site of Curiosity Rover of the Mars Science Laboratory (MSL). Repeated measurements by SAM on different sols yield identical results. They reveal that the volume mixing ratio (vmr) of N_2 is 30% lower, while ^{40}Ar is 21% greater than the Viking Lander (VL) values obtained in 1976. Thus the Ar/N_2 ratio determined by SAM is 1.7 times the Viking value. As N_2 and Ar are both non-condensable volatiles (NCV), and for all practical purposes chemically inert in the homosphere, the ratio between Ar and N_2 is expected to remain constant seasonally and temporally. Thus the SAM value of the Ar/N_2 ratio represents a significant departure of nearly a factor of two from the Viking result that does not seem to be related to the observing conditions. The Ar/N_2 ratio is an important parameter that is used together with nitrogen isotopes to assess the degree of mixing between the Martian atmosphere and the internal gas component of Mars meteorites due to the shock of impact ejection [e.g. 1]. Even though the ratio between NCV's should remain constant, they are expected to undergo seasonal changes. Previous data on seasonal changes in Ar are controversial for the equatorial region, however, and no data exist on seasonal changes in N_2. Monitoring of the non-condensable volatiles, N_2, Ar and CO, by SAM over Curiosity's two-year prime mission will reveal the nature and extent of seasonal changes in NCV's and whether they track one another, as expected, or not. These trends will provide valuable constraints to models of global seasonal cycle of CO_2, climate evolution and the geologic history of Mars.

INTRODUCTION

The Quadrupole Mass Spectrometer of the SAM instrument suite has determined the composition of the Martian atmosphere above Gale Crater [2,3]. The first measurements done in September/October 2012 indicate that although the volume mixing ratios of the major gases are generally similar to those measured by the Viking Landers in 1976 [4], they are notably different for nitrogen (N_2) and argon (^{40}Ar). While N_2 is ultimately of primordial origin – produced from dissociation of nitrogen bearing molecules acquired during planetary accretion or their subsequent derivatives – ^{40}Ar is a radioactive decay product of ^{40}K, a component of the rocks, with a half-life of 1.3 GYr. Thus, for all practical purposes both N_2 and ^{40}Ar should maintain stable levels in the present atmosphere, considering also that they do not condense under Martian conditions. Hence the observed differences between the MSL/SAM and the Viking Lander (VL2) data on N_2 and ^{40}Ar result either from different instrument characteristics or some unknown time variable atmospheric phenomena or both. Note, however, that unlike Viking the high capacity turbomolecular pumps of SAM enable throughput of gas, and SAM can and does repeat the measurements multiple times, all of which result in higher accuracy of data.

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MEASUREMENTS AND ANALYSIS

In this paper we examine the atmospheric process for possible variation in NCV's, N_2 and Ar and CO, in the atmosphere of Mars. Besides being an NCV, CO is expected to have stable levels like N_2 and ^{40}Ar due to its 3-yr photochemical lifetime on Mars [5]. If present, methane would be another NCV, but unlike N_2, Ar and CO, its variability depends on its various geological, biogenic or extraplanetary sources and sinks that include photochemistry and surface loss, as illustrated in Figure 1 [6].

A comparison between SAM and the VL2 data (Table 1) shows that the vmr of N_2 measured by SAM is 30% lower than that measured by Viking, whereas it is 21% greater for Ar (see Fig. 2 for SAM measured vmr's). Since the volume mixing ratio represents the constituent number density (or partial pressure) relative to the total atmospheric number density (or total pressure), it could be argued that the differences between SAM and VL2 vmr's are due to the differences in atmospheric pressure when those data were collected. However, that does not seem to be the case, as the pressures measured at those epochs are very similar (Table 1). Since the NCV's, N_2, Ar and CO, have lifetimes that exceed the martian year, they are not expected to vary diurnally, but their vmr's could still undergo seasonal variations due to the annual CO_2 cycle.

The VL2 data were taken during northern summer (48°N, Ls=135°), whereas the SAM measurements correspond to the beginning of spring season (4.5°S, Ls=182-190°). Previous observations by Mars Odyssey Gamma Ray Spectrometer (ODY/GRS) over three Mars years have shown that the Ar mixing ratio increased by a factor of 6 over the south polar region in the winter, but a much smaller change of a factor of 2-3 was seen for northern high latitudes in the winter, as expected [8]. No significant change was seen between the equator and the midlatitude northern summer, however. Thus the difference between the SAM and VL2 Ar does not appear to be related to differences in the seasons either. On the other hand, the vmr's of NCV's at any latitude are expected to vary seasonally due to global CO_2 cycle discussed below.

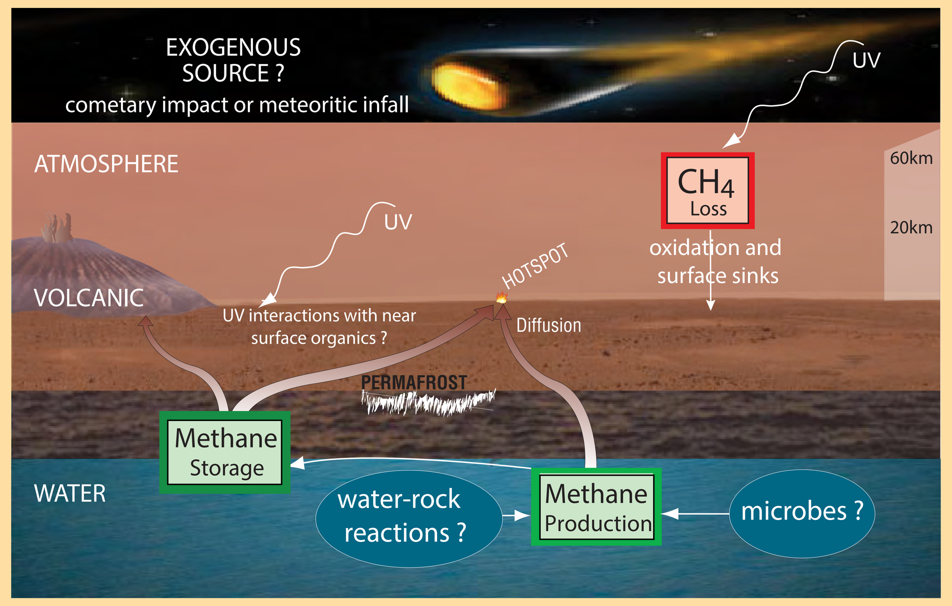

Figure 1. Sources and sinks of any methane on Mars [figure adapted from Fig. 2 of Atreya et al., Planet. Space Sci. 55, 358-369, 2007]. The Tunable Laser Spectrometer of SAM determined an upper limit of 3 ppbv of methane above Gale Crater in the Martian spring [14], which is much lower than 7 ppbv to 10's of ppbv reported from previous remote sensing observations from the ground [15] and Mars orbit [16].

	N_2 vmr	Ar vmr	Ls (deg)	P (mb)	lat/lon (deg)
SAM sol 45	0.0193	0.0196	182°	7.7	4.5°S/ 137°E
SAM sol 77	0.0187	0.0192	190°	7.9	4.5°S/ 137°E
SAM average	0.0189 ± 0.0004	0.0193 ± 0.0002	186° (S-Spring)	7.8	4.5°S/ 137°E
Viking	0.0270	0.0160	135° (N-Summer)	7.0	48°N/ 134°E
SAM/ Viking	0.70 ratio	1.21 ratio			

Table 1. Comparison between SAM and VL2 Atmospheric Data (vmr: volume mixing ratio; vmr uncertainty is the statistical error (standard deviation/number of points) and the systematic error will be refined with further analysis; lat/lon: latitude/longitude; P: atmospheric pressure from [7] for SAM and [8] for VL2).

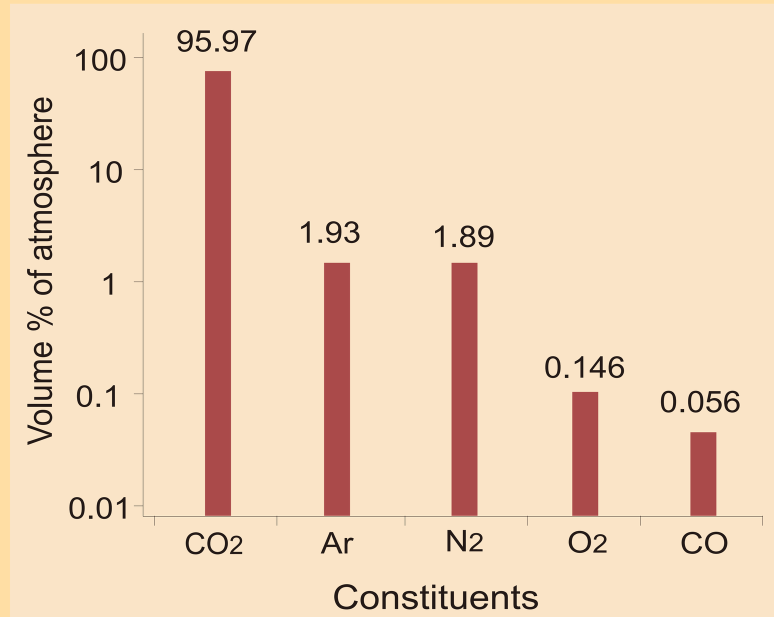

Figure 2. Volume mixing ratios of the five most abundant gases in the Martian atmosphere measured with SAM.

DISCUSSION

It is well known that the atmospheric pressure on Mars undergoes dramatic seasonal change of the order of 35%, due to the deposition of nearly $7x10^{15}$ kg of CO_2 gas as dry ice from the atmosphere on to the surface of Mars each year beginning in late autumn and continuing into the winter. In spring the process reverses with the re-evaporation of dry ice back into CO_2 gas, thus completing the annual global cycle of volatile transport. The CO_2 phase change is most pronounced over the colder south polar region. Since CO_2 is the principal component of the atmosphere, any changes in its atmospheric abundance would result in changes in the volume mixing ratios of the NCV's, even though their total atmospheric abundances remain unchanged. In addition to Ar, seasonal changes have been recorded in CO from ground-based [9] and MRO/CRISM observations but show a much smaller increase of a factor of 2-3 over south polar region in the winter [10]. General Circulation Models [11,12] have achieved varying degrees of agreement with the above CO and Ar data especially at high latitudes. No seasonal change data for N_2 are yet available.

The Ar data in the equatorial region are controversial. While the GRS data reveal no seasonal changes in the Ar vmr (Fig. 3a), the Alpha Particle X-ray Spectrometer (APXS) data from (equatorial) MER indicate that the Ar vmr does vary seasonally, roughly tracking the changes in atmospheric pressure but with several months of phase delay as seen in Fig. 3b [13]. The SAM/QMS measurements of Ar over the course of Curiosity's two-year prime mission will be crucial to resolve the GRS-APXS controversy about seasonal change in the equatorial argon vmr. For the first time, SAM will also monitor the seasonal behavior of N_2, and thus determine whether it tracks the other NCV's, Ar and CO measured simultaneously by SAM. The SAM data on NCV's will reveal whether the present Ar/N_2 =1 ratio continues to hold over the seasons at roughly twice the value obtained by Viking, and will provide crucial constraints to models of climate evolution, atmospheric general circulation and geologic history of Mars.

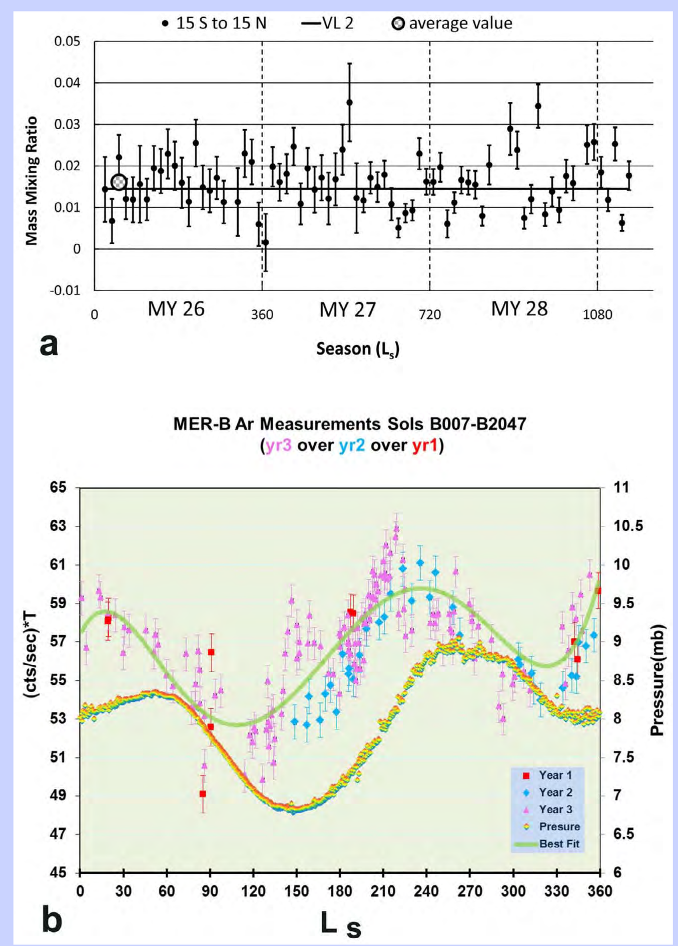

Figure 3. (a) Ar data from GRS averaged from 15°S to 15°N exhibit no seasonal changes over the 3 year period. The grand average Ar mass mixing ratio (black circle with checkered gray interior) falls on and slightly above the VL2 value of 0.0145. (b) MER/APXS data exhibit seasonal changes similar for 3 years of measurements [13]. Absolute mixing ratios are not provided, but trends in data are shown by scaling data with an arbitrary constant for easy comparison to an atmospheric pressure curve for the equatorial location of the MER B rover (scale on the right-hand side ordinate). Notice phase delay between Ar and atmospheric pressure. Figure from [8].