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MSL/SAM Measurements of Volatile Isotopes, and their Implications for Atmospheric Loss

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High precision measurements of the isotopes of carbon and oxygen in CO_2, hydrogen in H_2O, nitrogen in N_2, and argon in the martian atmosphere have been made by the Sample Analysis at Mars (SAM) instrument on the Curiosity Rover [1,2,3,4]. The resulting values in per mil are 46 for δ^{13}C (relative to VPDB reference standard), 48 for δ^{18}O (VSMOW), 5880 for δD (VSMOW), 572 for δ^{15}N (relative to earth atmosphere), and 4.2 for ^{36}Ar/^{38}Ar (or δ^{38}Ar=310 relative to sun reference standard). The observed enrichment of the heavier isotope over the lighter isotope means that loss to space rather than loss to the surface dominates the isotopic composition in the martian atmosphere. Vertical mixing transports the volatiles from the surface up to the upper atmosphere. While eddy diffusion and molecular diffusion control the distribution of the noble gases, photochemistry also plays a significant role in the distribution of the other volatiles as they diffuse to the upper atmosphere. The above SAM data on the isotopic ratios of carbon, oxygen, hydrogen, nitrogen and argon implies a massive loss of the atmosphere from Mars in the past four billion years. Only hydrogen (hence water) is likely to escape thermally due to the low exospheric temperature of Mars. However, the lack of intrinsic magnetic field on Mars allows solar wind to interact directly with the atmosphere, thus opening up a myriad of possibilities for escape of volatiles from Mars. One such mechanism studied by the ion mass analyzer instrument on Mars Express finds that at current rate of erosion by solar wind, Mars may have lost between 0.2 and 4 millibar of the CO_2 atmosphere in the past 3.5 billion years [5]. However, these authors [5] stress that other mechanisms including photochemical, sputtering and cold plasma escape may result in up to 1000 times greater rate of atmospheric loss based on models. Any fractionation in the isotopes of the heavy noble gas, xenon, would have occurred prior to approximately 4 Ga, when hydrodynamic escape triggered by escaping hydrogen is believed to have resulted in an early massive loss of the atmosphere from Mars. The mass spectrometer on SAM will determine the xenon isotopes using an enrichment technique. Combining the xenon isotope data with the isotopes SAM has already determined will reveal more clearly how the planet evolved from an early warmer and wetter Mars into the present colder and dryer Mars.

References: [1]Mahaffy P. R. et al., Science, 341, 263-266, 2013, doi:10.1126/science.1237966. [2]Webster C. R. et al. (2013), Science, 341, 260-263, doi:10.1126/science.1237961. [3]Wong, M. H. et al. (2013), Geophys. Res. Lett., doi:10.1002/2013GL057840. [4]Atreya S. K. et al (2013), Geophys. Res. Lett., 40, 1–5, doi:10.1002/2013GL057763. [5]Barabash S., et al. (2013), Science, 315, 501-503, 2007 doi: 10.1126/science.1134358.