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Oxygen-18 Carbon Dioxide Isotope Ratio in Mars Atmosphere

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Abstract

The determination of isotopic ratios on Mars is important to the study of atmospheric evolution [1]. The relative abundance of isotopes of CO_2 provides insight into the loss of Mars' primordial atmosphere. Isotopic ratios also provide markers in the study of geochemistry of Mars meteorites and future returned samples formed in equilibrium with ambient atmosphere, and are probes of biogenic and abiotic chemistry, which differ in isotope fractionation.

Due to its lesser gravity and relatively thin residual atmosphere, Mars' atmosphere should be enriched in heavy isotopes [1]. However Viking [2] results indicated an Earth-like singly substituted oxygen-18 CO_2 isotopic ratio, ^{18}OCO/OCO, with $\delta^{18}O$ = 0±50‰ relative to Vienna Standard Mean Ocean Water (VSMOW). By comparison, isotopic ratios in Earth atmospheric CO_2 are not uniquely defined due to seasonal and biotic variability, but have a range 0–41‰ relative to VSMOW [3, 4]. Phoenix lander TEGA [3] measurements found a modest enrichment of $\delta^{18}O$ = 31.0±5.7‰. Only the Viking and Phoenix landers have carried a mass spectrometer to Mars, so far, until the arrival of Mars Science Laboratory in August 2012. Using ground-based spectroscopic techniques Krasnopolsky et al. [5] also found modest enrichment $\delta^{18}O$ = 18±18‰.

We present results from fully resolved spectroscopic measurements near 10.6 µm of both the normal and singly substituted oxygen-18 CO_2 lines, taken with the Goddard Space Flight Center Heterodyne Instrument for Planetary Winds And Composition (HIPWAC) at the NASA Infrared Telescope Facility on Mauna Kea, Hawaii. Measurements with spectral resolving power $\lambda/\Delta\lambda=10^7$ were obtained in October 2007 with an instantaneous field-of-view on the planet of ~1 arcsec, at the locations shown in Fig. 1 as open squares. The solid and broken line tracks show Mars SPICAM measurements of ozone corresponding to ozone measurements also obtained with HIPWAC and shown as hatched and solid regions [6].

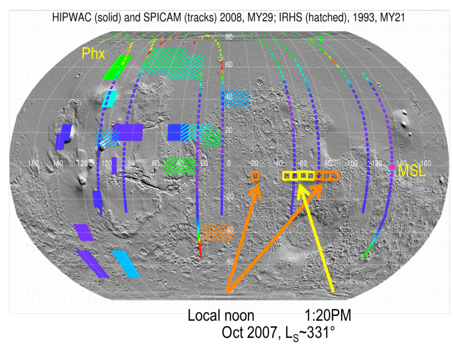

Figure 1: Locations of measured $^{18}O^{12}C^{16}O$ fractional abundance on Mars (open squares). The colored tracks are Mars Express SPICAM measurements of ozone; the solid and hatched areas show contemporaneous HIPWAC measurements of ozone [6].

Figure 2 illustrates the CO_2 normal-isotope and O-18 isotopologue lines measured on Mars at ~1 MHz (0.0003 cm^{-1}) spectral resolution. The strong absorption line constrains the temperature simultaneously at the position of the measurement. The narrow mesospheric non-LTE line emission is also seen at the core of the absorption. The standard Mars Global Surveyor temperature profile was used to obtain the modeled emergent spectrum in blue. It clearly does not fit as well as the thermal profile retrieved from the CO_2 absorption line profile (red fit).

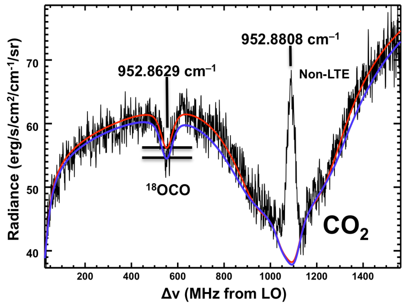

Figure 2: HIPWAC measurements of CO_2 spectrum on Mars near 10.5 μm. The broad absorption retrieves the temperature. The fitted model spectra correspond to using the standard MGS thermal profile (blue), and our retrieved profile (red). The fit to the isotopic line is excellent and yields $\delta^{18}O$ = +9±14‰.

Radiative-transfer software developed in-house at GSFC to be compatible with very high spectral resolving power [7] was used to obtain the temperature profile and spectral fit. The fit on the 952.8629 cm^{-1} $^{18}OC^{16}O$ line retrieves $\delta^{18}O$ = +9±14‰. There appears to be no significant enhancement in the average over the extended region measured. Additional, more global, measurements were acquired in May 2012 and these data are being analyzed.

These and additional high spectral resolution ground-based global measurements of $\delta^{18}O$ can investigate Mars' atmospheric history; help define Mars Science Laboratory (MSL) protocols to sample isotopic ratios diurnally and seasonally, throughout its prime mission; and investigate possible meridional variability due to mass-fractionation in the polar freeze-sublimate cycle, similar to effects in terrestrial polar ice formation [8]. Such measurements would also complement results from future landers drilling into polar caps for isotopic insight into climatic history on Mars.

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