The Carbon Isotope Composition Of The Solar Photosphere

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Introduction: Measurements by the Genesis mission have shown that solar wind oxygen is depleted in the rare isotopes, ^{17}O and ^{18}O, by approximately 80‰ and 100‰, respectively, relative to Earth's oceans, with inferred photospheric depletions of 60‰ for both isotopes [1]. This is similar to the isotopically lightest, and oldest, condensates in chondritic meteorites [2], [3]. Direct astronomical measurements of CO absorption lines in the solar photosphere have previously yielded a wide range of O isotope ratios, with the most recent result [4] finding an ^{18}O depletion of 0 to 60‰. This wide range resulted from an uncertainty in the intensity of the CO rovibrational lines as determined from two oscillator strength scales, Goorvitch (1994) [5] and Hure and Roueff (1996) [6]. We have reanalyzed the line intensities, and present new results from direct measurement of photospheric oxygen and carbon isotope ratios.

CO line intensities: CO rovibrational transitions dominate the mid-IR spectral features of the photosphere. Using the shuttle-borne ATMOS (with resolution $\omega/\Delta\omega \sim 150{,}000$), thousands of CO fundamental ($\Delta v=1$) and first-overtone ($\Delta v = 2$) lines of the solar spectrum have been recorded with high signal-to-noise ratio [7]. A direct-fit method has been used to calculate a more accurate dipole moment function [8], from which we computed new oscillator strengths and line intensities. In the radiative transfer model for the solar photosphere, CO lines of similar lower state energy are co-added to reduce the radiative transfer computation required. Sixteen snapshots from a 3-D hydrodynamic atmosphere model are used to more accurately capture the temperature variation associated with convections cells at the base of the photosphere [4]. The O abundance (~610 ppm) is first determined from ^{12}C^{16}O lines with a photospheric temperature profile that yields consistent results for $\Delta v=1$ and $\Delta v=2$ lines. Isotopic abundances are then computed separately.

Results and Conclusions: The analysis yields an ^{18}O depletion in the photosphere of δ^{18}O = -51 ± 11‰ relative to VSMOW. This result confirms the inferred photospheric values from the Genesis mission [1], and provides the first accurate direct measurement of photospheric O isotope ratios (δ^{17}O has a higher uncertainty due to the low SNR of C^{17}O lines). From the same analysis we find a carbon isotope ratio of δ^{13}C = -48 ± 7‰ (1-σ) for the photosphere. This result differs from δ^{13}C ~ 0 ‰ found for TiC in [9]. Computing the fractionation from the corona to the solar wind due to inefficient Coulomb drag [10], we find δ^{13}C = -74‰ and -91‰ for C^{6+} and C^{5+}, respectively, in the solar wind. The result for C^{5+} overlaps with the reported 1-σ range for solar wind implanted in lunar regolith grains [11]. Our photospheric result for δ^{13}C implies that the primary bulk reservoirs of carbon on the terrestrial planets are enriched in ^{13}C relative to the bulk material from which the solar system formed. Self-shielding of CO may have contributed to this process via C(^{1}D) formation from ~95-100 nm. C(^{1}D) rapidly reacts with H_2 to form CH, thereby avoiding formation of the C ion and subsequent exchange with CO, which erases the ^{13}C enrichment in C atoms produced during CO self-shielding. Carbon isotopes are also affected by ion-molecule reactions, and by condensation of CO in the cold, outer nebula, effects that need to be evaluated with models. As with O and N isotopes, it is possible that photochemical processes enriched the nebula in the rare carbon isotope, relative to the bulk starting material.

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