THE 13C/12C ISOTOPIC RATIO IN THE SOLAR WIND.

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Introduction: Carbon is the fourth-most abundant chemical element in the universe, yet, on Earth, it is not even in the top ten. Obviously, carbon was strongly depleted on Earth as a consequence of volatile loss in the inner solar nebula and during planetary formation. The carbon chemistry in the protosolar disk is complex and not fully understood and is likely to result in isotopic fractionation [1]. Because the isotopic composition of carbon on Earth agrees remarkably well with that of primitive meteorites, it is generally assumed that the terrestrial and meteoritic carbon isotopic composition is similar (but not identical) to that of the Sun and solar wind. A possible deviation between solar and solar-wind composition would indicate mass dependent fractionation processes in solar-wind evolution and and gravitational settling is likely to be small. So far all measurements of the solar carbon-isotopic ratio were accomplished via spectroscopic observations (for an overview see [2] and [3]). These determinations are based on measurements of CO absorption lines in the solar (photospheric) spectrum. Most of the previous results show that the solar value is similar to the terrestrial one, e.g., [3] found $^{12}C/^{13}C = 84 \pm 5$. However, newer measurements showed a puzzling, non-terrestrial value of $^{12}C/^{13}C = 80 \pm 1$ [4] for the photospheric $^{12}C/^{13}C$. This situation was reversed when that group revised their value to 91.4 ± 1.3 [5] using much more sophisticated 3D spectral synthesis of rovibrational bands of CO in the solar photosphere. Nevertheless, these photospheric models, as sophisticated as they may be, all necessarily need to make certain assumptions. Critically, the CO column density is quadratically sensitive to the absolute abundance of oxygen [4], the results presented in these studies also depend strongly on it. The O abundance has undergone several dramatic revisions in the past decade [e.g., 6], motivating us to perform the study presented here which uses in situ solar wind data which are much less model dependent. Furthermore, Genesis has not yet published values for the solar wind $^{12}C/^{13}C$ ratio because of a background of CO_2H from ion-molecular reactions of the extracted CO_2 with H from the walls of the vacuum chamber [7]. SOHO/CELIAS/MTOF [8] has published in situ solar wind isotopic composition data, however, MTOF can not be used to determine the solar wind carbon isotopic composition because it is an isochronous time-of-flight instrument. It contains a carbon foil consisting of terrestrial carbon. Solar wind ions impinging on the foil have a certain probability to knock one of the foil carbon atoms out of the foil. Sometimes this knock-on atom is a charged ion. The key property of isochronous mass spectrometers which gives them their excellent mass resolution is that the ion's energy and exit angle do not influence the time of flight because they fly through a harmonic potential. Therefore, a knock-on ion will result in the same time of flight as a solar wind ion of the same mass (per charge). This property results in a very high background of foil carbon, invalidating an accurate solar wind C isotope measurement.

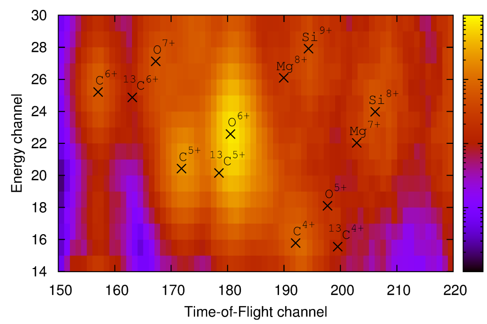

Figure 1: E-T matrix showing multiple solar wind ions. The rare $^{13}C^{6+}$ isotope lies between the much more abundant $^{12}C^{6+}$ and $^{16}O^{7+}$ ions.

Data Selection: We accumulated five years (2001, 2002, 2004, 2006, and 2007) worth of slow (340 km/s $< v_{sw} <$ 500 km/s) solar wind data from the Solar Wind Ion Composition Spectrometer (SWICS) [9] on the Advanced Composition Explorer (ACE) [10]. We selected slow wind because it is generally cooler and thus has a narrower velocity distribution function than the hot fast wind from high-speed streams. The slow wind is also generally more fractionated than fast wind, so it gives us the best opportunity to search for isotopic fractionation in the solar wind acceleration process. No attempt was made to exclude interplanetary coronal mass ejections (ICMEs). These are generally much more variable in composition than the ordinary solar wind [11], but it is still not known whether they systematically fractionate the solar wind. The strongly fractionated May 1998 ICME showed no isotopic fractionation [12]. We intend to extend the analysis described below to the full data set in the near future which will help reduce the statistical uncertainties.

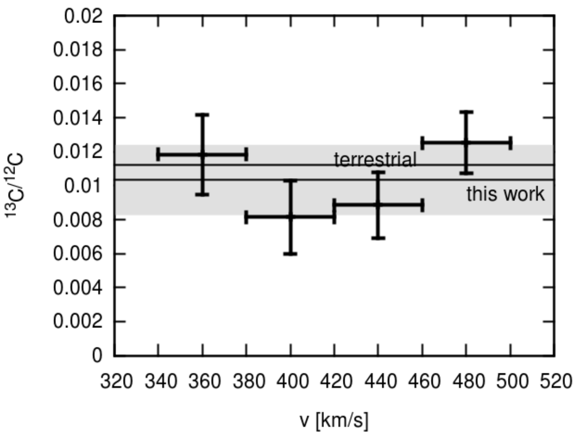

Figure 2: $^{13}C/^{12}C$ ratio vs. speed for predominantly slow solar wind. The shaded region marks the uncertainty in the weighted average (thick solid line). The fine line shows the terrestrial value.

Data Analysis: A solar wind ion is determined by its mass, *m*, charge, *q*, and energy, *E*. SWICS measures these quantities by a combination of *E/q*-selection, time-of-flight, *T*, and total energy, *E*, measurement. Thus, in a given *E/q* step, every ion fills a unique peak region in *E-T* space, as can be seen in Fig. 1. We have carefully characterized this peak for all solar wind ions and subsequently used this information in a Poisson-statistics-based Maximum-Likelihood inversion to determine the flux of individual solar ions. The narrow *E/q* passband allows for crude *m/q* discrimination during cold solar wind conditions under the assumption that the bulk solar wind flows at the same speed. We used this property to select the $^{12}C^{6+}$ and $^{13}C^{6+}$ ions and to reduce the background of more abundant ions such as $^{16}O^{7+}$ or $^{16}O^{6+}$ by selecting only a limited number of E/q bins surrounding the $^{12}C^{6+}$ and $^{13}C^{6+}$ ions. From the inverted counts we computed the $^{12}C^{6+}$ and $^{13}C^{6+}$ differential fluxes which were summed to determine their overall flux. We developed a detailed mathematical model for SWICS which gives us the detection efficiencies of all solar wind ions [13]. We applied this to the individual $^{12}C^{6+}$ and $^{13}C^{6+}$ differential fluxes in the solar wind speed bins selected for this study. We found a slight instrumental bias of ~4% which is nearly independent of solar wind speed and corrected for it in our analysis. This correction is the single-most important contribution to the systematic uncertainties in our results discussed below.

Results: We determined the solar wind $^{12}C/^{13}C$ ratio in four velocity bins , 340 – 380, 380 – 420, 420 – 460, and 460 – 500 km/s and show the results in Fig. 2. The four measurements all lie around the terrestrial value (indicated by a thin line) and no significant trend can be seen. The four points are consistent with a constant value of $^{13}C/^{12}C = 0.010335 \pm 0.00207$ (thick solid line) and with the terrestrial value. Their uncertainties are determined by statistical and systematic effects, the shaded area shows the 1-σ uncertainty of the weighted average. Statistical uncertainties are of the order of 3% and thus of the order of maximum expected isotopic fractionation in the solar wind and gravitational settling. Systematic uncertainties come mainly from the efficiency model discussed above, uncertainties in the exact peak shape in *E-T* space, and from the complex inversion process [14].

Discussion: The weighted average $^{12}C/^{13}C = 97.7 \pm 10$ is higher than but still consistent with the terrestrial ratio of $^{12}C/^{13}C = 89.2$. Nevertheless, the tendency of the points to being enriched in ^{12}C lends further support to the evolving evidence from Genesis that the Sun is isotopically light.

Summary and Conlusions: We have determined the $^{12}C/^{13}C$ isotopic ratio in the slow solar wind and found a value which is consistent with but isotopically lighter the terrestrial value. We expect to extend this study to the full ACE/SWICS data set in the future which will reduce the statistical uncertainties reported here.

References:

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