

ABUNDANCES OF CARBON, NITROGEN AND OXYGEN IN THE SOLAR WIND MEASURED BY BACKSIDE SIMS DEPTH PROFILING. V.S. Heber¹, Y. Guan², A.J.G. Jurewicz³, S. Smith⁴, C. Olinger⁵, K.D. McKeegan¹, D.S. Burnett²: 1 Dept. Earth and Space Sciences, UCLA, Los Angeles, CA, USA, heber@ess.ucla.edu; 2 CalTech, Pasadena, CA, USA; 3 Arizona State University, Tempe, AZ, USA; 4 Evans Analytical Group, Sunnyvale, CA, USA; 5 LANL, Neutron Science and Technology, Los Alamos, USA.

Introduction: Oxygen, nitrogen and carbon in the solar wind (SW) are key elements to investigate elemental fractionation of the SW. The knowledge of what causes this fractionation and to which extent elements get fractionated during ionization and/or acceleration of SW particles would not only allow us to derive photospheric abundances from SW data but would also solve a long standing problem in solar physics. Photospheric abundances are generally considered to be representative for the composition of the well-mixed solar nebula. Photospheric abundances of C, N, and O (being the 4th, 6th and 3rd most abundant elements in the solar system, respectively), derived from solar spectroscopy, were, however, revised downward over the last two decades by factors of 1.7 (O), 1.7 (N) and 1.3 (C) relative to H [cf. 1, 2], thus reducing the solar metallicity, Z , from 0.0201 to 0.0134 [2]. The new lower metallicity disagrees with models based on helioseismology. Primitive carbonaceous chondrites are also used to infer solar nebula abundances, but the volatile elements C, N and O are severely depleted even in CI chondrites, negating this approach.

The other source of information is the SW composition. Here we have to consider, however, fractionation processes associated with the ionization properties of each element, as various measurements show (*in situ*: e.g. [3]; in Genesis targets: e.g. [4]). Generally, elements with low first ionization potentials (FIP) (e.g., Fe, Mg) are enhanced in the SW relative to photospheric abundances and elements with high FIP (e.g., noble gases, C, N, and O). A detailed characterization of this elemental fractionation, however, has proven illusory, in part because the reference parameters - the true solar abundances of high FIP elements - are either derived indirectly for highly-volatile elements (noble gases) or from solar spectroscopy only and are therefore dependent on solar atmospheric modeling (which can introduce systematic errors). In principle, Genesis provides the advantage that a large number of elements can eventually be analyzed in the exposed targets, which will lead to a more complete picture of SW composition. Here, we present SW abundances of O, C and N (the latter is preliminary) measured on Genesis targets. At the meeting we present the current status and discuss other possible ways to characterize the elemental fractionation of solar wind.

Experimental: We used secondary ion mass spectrometry (Cameca 7f-Geo SIMS at Caltech) to measure

C, N and O abundances in Si targets exposed to bulk SW. Surface contamination and the very shallowly implanted SW (within the uppermost 200 nm) required us to apply a novel technique of depth profiling: to sputter the target from the backside. Since our first report [5] in 2010, we have refined our procedure. We carefully selected a new sample free of scratches and holes on the front side. The sample was mounted and ground from the backside to 2.5 μm thickness, which was monitored in progress using spectral reflectometry (Filmetrics). We also carried out extensive standard measurements in order to assess reproducibility of the SIMS analysis, specifically with regard to quantifications of fluences measured at different positions in the 4-hole Cameca sample holder.

By baking, extensive pumping (~48 h) and cooling with liquid nitrogen, the pressure in the sample chamber was at 8×10^{-11} torr during measurement. Additionally, intensive overnight sputtering of float-zone Si (a Si type very low in impurities) to “clean” the immersion lens extraction plate considerably reduced the instrumental background. A low impact energy (5 keV) Cs^+ beam, as well as a small field aperture (12 μm) and 50% electron gating were used to improve depth resolution and reduce contamination from crater edges. For O and C analysis, the procedure is described in detail in [5]. Each depth profile was analyzed in 3 steps: (1): a $125 \times 125 \mu\text{m}$ raster was sputtered to remove the surface contamination; (2) and (3): the raster size was reduced to $100 \times 100 \mu\text{m}$. During (1) and (2) either atomic ions ^{12}C , ^{16}O , and ^{28}Si were monitored, or, for N analyses, the molecular ions $^{12}\text{C}^{28}\text{Si}$ and $^{14}\text{N}^{28}\text{Si}$ were measured at masses 40 and 42, respectively, along with $^{28}\text{Si}_2$ (since nitrogen doesn't make a negative secondary ion). The masses were sequentially detected. During step (3) only the isotope or molecule of interest (either ^{12}C , ^{16}O or $^{14}\text{N}^{28}\text{Si}$) was measured in order to obtain the highest possible data sampling rate for the SW profile. In one profile dedicated to nitrogen, both $^{12}\text{C}^{28}\text{Si}$ and $^{14}\text{N}^{28}\text{Si}$ were measured in step (3) to deduce the contribution of the $^{12}\text{C}^{30}\text{Si}$ interference to the mass 42 peak. Due to another potential interference on mass 42 ($^{12}\text{C}^{14}\text{N}^{16}\text{O}$ molecule), the given N fluence is preliminary. No interferences are present on the masses 12 and 16. The reference isotope ^{28}Si or $^{28}\text{Si}_2$ for N for (3) was taken from (2). This procedure was justified due to the great stability of the instrument; e.g. the Si count rate was generally constant within 0.2% over a 80 min run. Artifi-

cial implants (^{13}C , ^{18}O , ^{15}N) served as standards. The SIMS crater depths were measured with optical interferometers (Zygo, MicroXam). The instrumental background was calculated from the flat part in the intensity vs. depth curve (measured in step (3)) and subtracted. For the work presented we analyzed two back-side-grounded Genesis samples of different thicknesses: 400nm (60757) and 2500nm (30767). Background level was reached for only 1-2 min in 60757 [5] but ≥ 10 min in 30767 measurements. Background contributions to the signal at peak were $\sim 4\%$ for ^{12}C , $\sim 20\%$ for ^{16}O and $\sim 6\%$ for ^{14}N .

Table 1: Fluences of C, N and O in the bulk SW (Genesis) and comparison with *in situ* data

	Genesis bulk SW fluences ($\times 10^{12}$ atoms/cm 2)	Number of measure- ments
^{12}C	5.96 ± 0.15	5
^{14}N	1.2 ± 0.2	3
^{16}O	10.8 ± 0.7	2

	Genesis	<i>In situ</i> slow solar wind	<i>In situ</i> fast solar wind
He/O	76.9 ± 0.2	90 ± 34	73 ± 8
C/O	0.558 ± 0.015	0.67 ± 0.08	0.69 ± 0.04
N/O	0.11 ± 0.02	0.08 ± 0.04	0.11 ± 0.02
Ne/O	0.126 ± 0.001	0.10 ± 0.03	0.083 ± 0.013

Given errors are 1σ standard deviation. ^{14}N fluences are preliminary. Data are backscatter corrected. Elemental ratios were calculated using the terrestrial isotopic composition (except for noble gases), respective uncertainties do not contain the error of the reference element O. *In situ* data are averages from [3], Genesis He and Ne data are from [7].

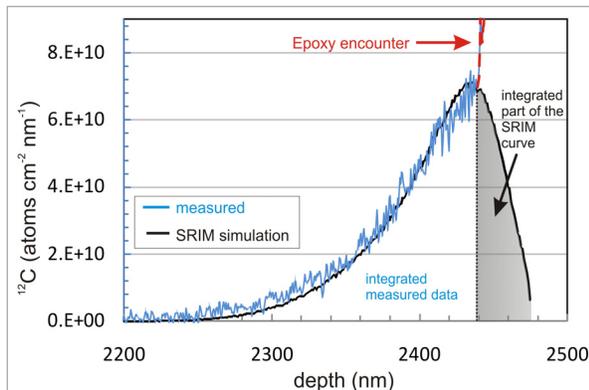


Fig. 1. Measured ^{12}C SW implantation profile in 30767 (in step (3)). Sputter direction is from left to right. The SRIM-simulated ^{12}C curve is adjusted (in height and position) to measured data and provides the missing data for the first 20-30 nm, which contribute $\sim 20\%$ to the total fluences.

Data evaluation and results: Bulk SW C, O and preliminary N fluences are given in Table 1. An example profile is given in Fig. 1. Note, that soon after

reaching the SW implant peak sharply elevated amounts of C, N or O indicated that a portion of the sputtered pit encountered epoxy, used to glue the front-side of the Genesis sample onto the substrate. This prevented the SW analysis in the first 20-30 nm. To calculate the total fluence we integrated the data collected before the break-through then calculated the missing first 20-30nm using a model SW implant profile (using Stopping and Range of Ions in Matter (SRIM) code [6]), which took into account the SW speed distribution that prevailed during Genesis operation (Fig. 1). A quantitative estimate for the uncertainty in the resulting fluences is complex. In Table 1 we give only the variability of n measurements. Reproducibility of the relative sensitivity factor is better than 1%. Errors for implanted standard fluences and depth measurements are $\leq 5\%$ and $\leq 1\%$, respectively. The procedure to adjust the SRIM curve to the measured data also adds a small ($\leq 5\%$) but not accurately quantifiable uncertainty.

Discussion: Here we present the first data on O, N, and C fluences in collected and returned SW samples. In Table 1 elemental ratios to oxygen of the bulk Genesis data are compared with respective spacecraft measured fast and slow SW data [3]. The *in situ* measured abundances of the given elements (relative to O) are within uncertainties identical in the fast and slow solar wind, thus preventing any conclusions on potentially different extents of fractionation of high-FIP elements between fast and slow solar wind. Our bulk SW data, except C, are within uncertainties identical to the *in situ* data, although the abundance of Ne tends to be higher than the respective *in situ* value. The C abundance relative to O from Genesis is about 20% lower than the *in situ* values. We will explore this discrepancy in more detail at the meeting. The bulk SW C/O and N/O ratios are within uncertainties identical to the photospheric composition (C/O: 0.55; N/O: 0.138, [2]) suggesting at first glance that relative to the new photospheric abundances of [2], high-FIP elements are not fractionated during SW formation relative to O.

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