SOLAR WIND ELEMENTAL FRACTIONATION: GENESIS C AND O FLUENCES BY BACKSIDE SIMS PROFILING – PRELIMINARY DATA.

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Introduction: Solar wind (SW) fluences of volatile elements, in particular C, O, and N, are critical in defining SW elemental fractionation. Ratios of elements with low and high first ionization potential (FIP), e.g. Fe/Ne, are higher than photospheric abundances [1, 2]. C, O and N are on the threshold between these two extremes and are thus critical as to whether this fractionation is stepwise [1] or gradual [3] as a function of FIP. Quantitative understanding of SW elemental fractionation is required to improve knowledge on the solar nebula abundances, in particular of volatile elements as they are depleted in primitive meteorites.

Experimental: SW ions have an average kinetic energy of 1keV/amu and are therefore shallowly implanted into the uppermost 200nm of the target. Surface contamination and elevated instrumental backgrounds have previously prohibited the analysis of C, O and N. *We here report the first successful analyses of C and O fluences from Genesis.* We analyzed the bulk SW C and O fluences in Si targets with the Cameca 7f-Geo SIMS at CalTech. By baking, extensive pump-down (typically 60h), and intense overnight sputtering of Si to clean the immersion lens extraction plate, we reduced the instrumental background to acceptably small levels. The 7f sample chamber pressure was in the 0.8-1x10^{-10} Torr range.

In a first set of experiments we measured the Genesis implant normally, from the front side. Before the actual analysis surface contamination was reduced by rastering the primary Cs+ beam at low impact E (5keV), which effectively reduces the impact-gardened C and O, a method successfully applied to the concentrator sample [4]. We were able to measure the solar wind below a depth of 40nm, but data at shallower depths were compromised by remaining surface contamination and transient sputtering effects. Fluence estimates might be possible from these data, but more accurate results are obtained with another approach: sputtering a thinned Genesis fragment from the back side. This has the great advantage of avoiding the surface contamination and allowed us to measure to shallow depths, actually detecting the SW O and C peaks.

<u>Sample preparation:</u> A cleaned Si fragment (60757) from the bulk SW collector was ground to a nominal thickness of 1.5µm by Evans Analytical Group (EAG) after attaching - upside down- onto a Si substrate using epoxy. Slope of the section was assessed to be 5µm at 25µm lateral distance; additionally, there was some warping which could be seen by "Newton's rings" in the ultra-thin section. This thickness allowed removal of gardened surface contamination, characterization of blank-level sputtering and measurement of an almost-complete SW profile. However, the Genesis target was only 400nm thick, whereas a separate Si test target was in the range of expected thickness. Ridges of crash-deposited Si and/or micron-sized particles on the surface of the Genesis target could have created an offset of Si surface and substrate, filled up with epoxy (Fig. 1), which was not accounted for during manufacturing.

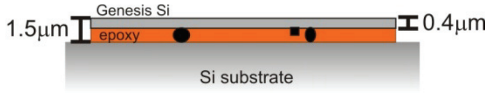

Fig. 1. Genesis Si target glued upside down on a Si substrate. The actual thickness of the Genesis target was 400nm, not 1.5µm, probably due to micron-sized surface particles or defects between the front side and substrate.

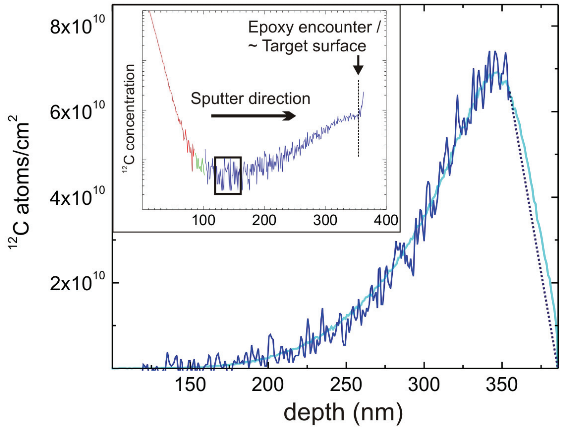

Fig. 2. SW ^{12}C implantation profile in Si: measured (blue) and simulated using SRIM [5] (light blue), according to the prevailing SW speed distribution during Genesis collection period. The SRIM curve was adjusted to the measured data by the peak and the left flank. The integral of all measured data gives a firm lower fluence limit. An actual fluence estimate is obtained from the measured data plus the area extrapolated to the start of the SRIM profile (dashed line). The insert (in log-scale) illustrates our analytical procedure: Raster (a)- red curve- to remove the contamination of the backside surface, raster (b) - green- and (c) –blue- represent the sample analysis. The dashed line marks the sharp increase of C due to the encounter of epoxy, the black rectangle represents data that were used for instrumental background correction.

Analytical condition: To obtain better depth resolution, we used a low impact E (5keV) Cs+ beam. Isotopes were measured sequentially, C and O with the electron multiplier and ^{28}Si with the Faraday cup, as a reference. The Genesis target was sputtered in 3 steps (cf. insert Fig. 2): (a) A 125µm x 125µm raster (30nA beam) was sputtered to remove the surface contamination. ^{12}C, ^{16}O, ^{28}Si were monitored. (b) Raster size and beam current were reduced to 100µm x 100µm and 10nA, respectively. ^{12}C, ^{16}O, and ^{28}Si were measured. (c) To increase data coverage for the SW profile, only ^{12}C, ^{16}O were analyzed in (c), and the Si count rate from (b) was assumed be constant. The backside profiling allowed us the first time to detect the peaks of SW O and C implant (Figs. 2, 3). This great improvement over front side analyses (even at low impact energy) has potential for a number of Genesis studies.

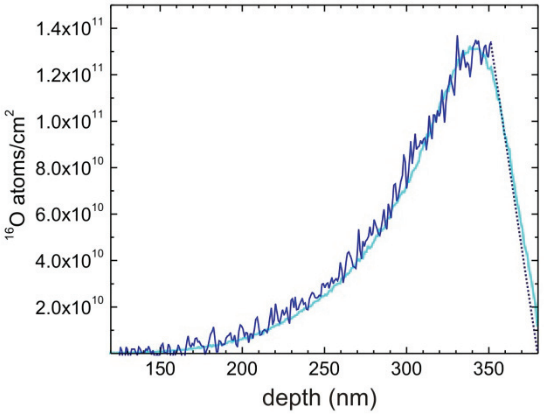

Fig. 3. SW ^{16}O implantation profile in Si: measured (blue) and simulated using SRIM [5] (light blue). See Fig. 2 for further explanation.

Data evaluation: An instrumental background correction was calculated from the flat part of the profile (cf. insert Fig. 2) and subtracted. The blank contribution to ^{12}C around the peak was 7% and to ^{16}O 13%. Fluences were calibrated via ^{28}Si and implant standards (^{18}O and ^{13}C). Soon after reaching the peak of the SW implant, we encountered elevated amounts of C and, a bit earlier, O from either epoxy or the surface SiO_2. This prevented SW analysis from the first 20-30nm. A firm lower limit (integral over all measured data deeper than 30nm) can be obtained, and, with the use of a theoretical depth profile to correct for the first 30nm, a total fluence. Alternatively, a totally empirical "extrapolated fluence" can be calculated assuming a straight-line fit between the last data point and the target surface, as indicated by the start of the SRIM profile (Figs. 2, 3).

Results and Discussion: The lower limit ^{12}C fluence is 4.7E+12 atoms/cm^2, the extrapolated fluence 5.8E+12 atoms/cm^2 (2.1% backscatter correction included). The lower limit ^{16}O fluence is 9.4E+12 atoms/cm^2 and the extrapolated fluence 1.1E+13atoms/cm^2 (backscatter correction of 1.2% included). To avoid contact with epoxy at the end of our depth profiles in subsequent experiments we will coat the front side of a target with Si before glueing it to the substrate. We may also increase the depth resolution by further reduction of the impact E.

These are the first fluences obtained for volatiles in the SW collected by Genesis apart from noble gases. The precision of the data is firmly established; what we give here is preliminary in that possible sources of systematic error remain to be evaluated. To compare our ^{12}C and ^{16}O with *in situ* measured fluences, we anchor available *in situ* C/O and Ne/O ratios to the bulk SW ^{20}Ne fluence derived for Genesis [2]. Respective *in situ* fluences are for C (0.9-1)E+13 atoms/cm^2 [1] and 1.0E+13 atoms/cm^2 for O [e.g. 6]. The *in situ* O is in good agreement with our extrapolated O fluence. The ^{12}C/^{16}O ratio of 0.51 obtained in this work for the SW is similar to the photospheric composition (0.55, [7]), suggesting that C and O relative to each other are not fractionated upon SW formation. Fig. 4 plots the ratio of Genesis SW abundances relative to the new O fluence and photospheric abundances against FIP. Alternative plots in terms of the first ionization time remain to be evaluated, but, if the pattern shown in Fig. 4 can be confirmed, it indicates a continuous trend of fractionation similar to that proposed by [3].

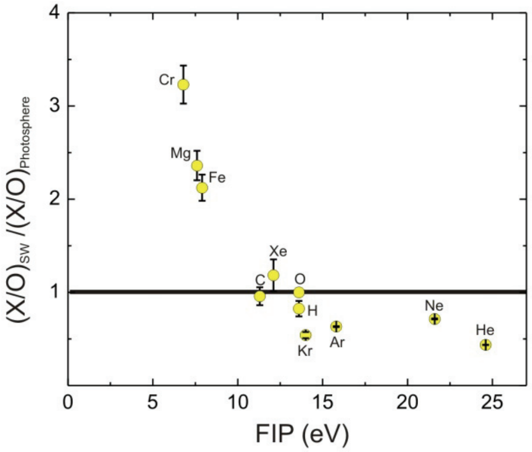

Fig. 4. Genesis SW fluences relative to O and photospheric abundances [7] plotted vs. the FIP.

References:[1] von Steiger, R., et al. (2000) J. Geophys. Res. **105**(A12): p. 27217-27238.[2] Heber, V.S., et al. (2009) Geoch. Cosmoch. Acta. **73**(24): p. 7414–7432.[3] Giammanco, C., et al. (2008) ApJ. **681**: p. 1703-1707.[4] McKeegan, K.D., et al. (2008) *LPSC*#2020.[5] Ziegler, J.F. (2004) Nucl. Inst. Meth. Phys. Res. **219/220**: p. 1027-1036.[6] Collier, M.R., et al. (1996) Geophys. Res. Letters. **23**(10): p. 1191-1194.[7] Asplund, M., et al. (2009) Annu. Rev. Astro. Astrophys. **47**: p. 481-522.