ION TRAJECTORY SIMULATIONS OF THE GENESIS SOLAR WIND CONCENTRATOR: Li, C, Mg, S

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Introduction: The GENESIS mission collected samples of solar wind from November, 2001 to April, 2004 and returned them to Earth for isotopic and elemental analyses, with the purpose of precisely determining the solar photospheric composition and thereby obtaining the average composition of the solar nebula [1]. In addition to > 1 m^2 of passive collectors, GENESIS had one active collection experiment on board, called the Solar-Wind Concentrator. The Concentrator was an ion telescope designed to enhance the fluence of SW ions by an average factor of 20x onto a 6 cm diameter target [2]. The purpose of the active collection was to increase the signal to contamination ratio, particularly for oxygen, which is a ubiquitous elemental contaminant in terrestrial materials, but which was also the highest measurement objective of the mission. While the crash-landing of the return capsule resulted in the breakage of a large fraction of the passive collectors, the Concentrator target survived almost completely intact [3]. Consequently, it has been analyzed successfully to date for He, Ne, Ar [4], O [5], and N [6].

Because it was impossible to realistically imitate the solar-wind environment for accurate testing of the Concentrator, a program was begun in 1992 to accurately simulate the Concentrator performance using early versions of the ion trajectory program SIMION [8] and variations thereof. The SIMION Concentrator simulations became the primary means for validating the performance of the Concentrator prior to flight [9]. The model has been continuously updated since launch. The latest simulation results on the noble gases, N, and O were reported last year [10], including comparisons with measured Concentrator yields where solar wind compositions were known, e.g., for noble gases [4], and these simulations will be in an upcoming publication. Here we describe the latest simulations for other isotopes that are or may be analyzed in the Concentrator. These include Li, C, Mg, and S. It must be noted that the Concentrator was designed principally for O, so results on elements far in mass from O are less than optimal.

Rationale for Concentrator Analyses:

Lithium: Lithium represents a very interesting potential observation for solar physics because it is depleted by reactions with protons in the Sun. The minimum temperature at which this reaction occurs differs for the two stable isotopes from ~2 x 10^6 K for ^{6}Li to ~20% higher for ^{7}Li [e.g., 11]. The standard solar model may be consistent with complete destruction of solar Li when the solar convection zone extended deeper pre-main sequence. Photospheric absorption line observations provide Li abundance estimates of 1.02±0.12 DEX [12] and 1.05±0.2 [13] which are approximately factors of 200 below that estimated from meteoritic abundances [e.g., 14], consistent with significant destruction of Li in the Sun. The Concentrator target enriched elements from He to Ne by a factor of 40 in the inner 6 mm radial area [4]. The current best estimate of the photospheric ^{6}Li/^{7}Li ratio is $\leq$ 0.03 [12]. Expected abundances to be measured in the inner 6 mm of the Concentrator target are 2.5E+7 ^{7}Li/cm^2 and $\leq$7.6E+5 ^{6}Li/cm^2, which translates into total amounts of atoms of 2500 (^{7}Li) and $\leq$ 76 (^{6}Li) in a 100 x 100 μm raster used for SIMS analysis. In principle, using the combined data from numerous rasters, as was done for the much more precise O and N measurements [5,6], a low-precision Li isotopic measurement of Genesis-collected solar wind might be feasible in the innermost area of the Concentrator target in absence of Li surface contamination, however, it yet has to be tested.

Carbon: There is as yet no direct and accurate measurement of the solar or solar-wind carbon isotopic composition. Carbon analysis in the Concentrator was thought to be impossible due to its presence as a major constituent in all of the target materials. However, the diamond-on-silicon target [15] has a small area in which the diamond-like carbon coating appears absent. Comparison with pre-flight images of the target assembly appears to confirm that this area was uncoated before the flight, likely the position of a clip holding the sample during carbon coating. The presence of bare silicon in this quadrant allows the possibility that the Concentrator could be used to analyze carbon isotopes.

Magnesium is a non-volatile, low first-ionization-potential element, the isotopic ratios of which are constant to within ±0.04‰ for ^{26}Mg/^{24}Mg for igneous samples and meteorites within the inner solar system [16]. It is expected to be incorporated into the Sun without any of the isotopic fractionations seen in volatile elements O [5] and N [7]. As such, Mg may be the best element to precisely determine solar wind isotopic fractionation [e.g., 17,18,23].

Sulfur: Given the large-scale isotopic differences between the Sun and Earth for volatile but non-inert elements O and N, sulfur may also display unexpected isotopic fractionation. In contrast to N and O, the sulfur isotopic variations in meteorites are more subtle, in the range of $-7.32‰ \leq \delta^{34}S \leq 6.05‰$ for carbonaceous chondrites, but with a total range of less than one permil for ordinary chondrites and just over two permil for achondrites [19].

Description of the Updated Concentrator Simulation Model: The current simulation model [10] runs on SIMION 8.0, which allows a spatial resolution of 0.40 mm using 110 million grid points. The solar wind is simulated corresponding to proton velocities of 350, 450, 550, 650, and 750 km/s. The results of these runs are convolved based on solar-wind velocity distributions. Typicall two million ions are run per velovity bin in a Monte Carlo simulation. Given the radial symmetry of the ion patterns on target, proven by both simulations [3] and by analysis [4], the typical simulation output is the radial position on the target for each ion that is implanted in the target, according to the simulation. Solar wind angular and velocity distributions are discussed in [8] and [10].

Results and Discussion: Table 1 gives predicted Concentrator fractionations (relative to unconcentrated solar wind) for each element of interest averaged over 5 mm wide radial bins on the Concentrator target. The general pattern for Li, C, and Mg follows those predicted and measured for He and Ne [4,10]. In all cases, the concentration factors were within 10% of those predicted for He and Ne [10], near a factor of 55x at the center and dropping to a factor of ~6x near the outer edge. As noted previously [10], the simulations overestimate the concentration near the center, where measurements showed a concentration of ~40x [4].

Lithium: The Li isotopic fractionation matches exactly that expected from interpolating between He and O, accounting for m/Δm. Given that an isotopic measurement accurate to ±20% would be useful, the instrumental fractionation (Table 1) is relatively trivial.

Carbon: Despite its low z, C is affected by a non-negligible solar-wind abundance of a low charge state, +4, which causes significant fractionation for high speed wind, as the Concentrator mirror potential was at its maximum between 667 and 800 km/s. The highest velocity bin was fractionated as much as -37‰, bringing the mean δ^{13}C (Table 1) down by ~3‰ from the expected value.

Magnesium: At z = 24-26, high-speed solar wind Mg is susceptible to instrumental fractionation in the Concentrator and the magnitude depends critically on solar wind parameters. Earlier studies [20-22] indicated that heavy ions tend to travel slower than alphas in high-speed wind, which would give the Table 1 result labeled “heavy differential streaming”. However, ACE/SWICS has consistently not observed this difference, so we consider the line labeled “α differential streaming” to be the most likely result. Unfortunately, the increased instrumental fractionation blurs the ability to establish high-accuracy solar-wind isotopic fractionation results.

Sulfur: Being well above the z range for which the Concentrator was designed, S experiences significant fractionation, similar to that observed for argon implanted in the targets [4]. If the solar S is similarly different from terrestrial as O or N [5-7] the Concentrator targets could yield a clear result. However, a solar-terrestrial difference of only a few permil would likely not be distinguishable from uncertaintly in the Concentrator fractionation, on the order of ±10-15‰ for S.

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Table 1. Predicted Concentrator instrumental fractionation in ‰ relative to the respective light isotope for selected elements over target radial bins. The mean ± statistical uncertainty is also given.

Element	0-5 mm	5-10 mm	10-15 mm	15-20 mm	20-25 mm	25-30 mm	Ave.	Stat.Unc.
δ^{7}Li	40	30	15	-13	-22	-19	3.8	±0.8
$\delta\ ^{13}$C (in Si)	19	14	4	-13	-15	-10	-1.0	±0.6
$\delta\ ^{26}$Mg (heavy diff. stream)	21	12	-4	-15	-15	-10	-3.7	±0.6
$\delta\ ^{26}$Mg (α diff. stream)	8	-1	-17	-27	-26	-21	-16	±0.6
$\delta\ ^{34}$S	-14	-38	-45	-55	-53	-47	-44.6	±1.2