

PRELIMINARY MAGNESIUM ISOTOPIC COMPOSITION OF SOLAR WIND FROM GENESIS SOS.

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Introduction: The isotopic composition of Mg appears uniform with respect to mass-dependent fractionation and/or nucleosynthetic anomalies in meteorites, lunar and terrestrial samples, implying uniformity of the bulk solar system [1]. The Sun comprises >99% of the current mass of the solar system; moreover, the preponderance of data suggest that it's photosphere still represents the composition of the solar nebula. That is, deviations produced from processes like gravitational settling of heavier isotopes from the base of the solar convective zone should be small. So, we should measure basically the same Mg isotopic composition as meteorites and planets in Genesis collectors UNLESS it happened during the acceleration of ions into the solar wind (SW). Mg isotopes have become important for identifying solar processes and, in turn, understanding whether or not Genesis solar-wind samples need to be corrected for those processes.

The First Ionization Potential or First Ionization Time are thought to fractionate ions as they accelerate into the SW, but are not mass-dependent processes and so should not effect the Mg isotopes. However, inefficient Coulomb drag (ICD) is a theorized mass-dependent process [2] which could fractionate Mg about 10 ‰/a.m.u. for Mg given the Genesis He/H ratio [3]. If active, this process would also affect the isotopic compositions of other high priority Genesis SW elements (e.g., C, N, O, Ne) [4]; however, using these volatile elements to validate the ICD process is limited by their extreme isotopic variability in chondrites and planets. Thus, Mg isotopes are uniquely suited for defining ICD, and thus for recovering solar isotope compositions from measured SW ratios [5].

Current spacecraft-based measurements of solar wind yield a $\delta^{25}\text{Mg}$ value (-5 ± 11 ‰): within error of the terrestrial value [6], but with uncertainties too large to discount ICD effects. Accordingly, terrestrial methods are required. A method for the precise ($\pm 1-2$ ‰) determination of small quantities of solar wind Mg by isotopic analysis by ICP-MS of cm-sized wafers has been developed [7] which has the advantage that it can be reliably standardized against chondritic Mg and interlaboratory standards developed for ICP-MS calibration [8]. However, unlike microanalytical methods, the risk of contamination from debris (cf., the UTTR crash) is hard to avoid when large surface areas (of the order of 1 cm^2) are analyzed, despite the development

of elaborate cleaning procedures shown to remove >99% of the surficial Mg [9-10]. The ICP-MS technique can be applied to either Silicon-on-Sapphire (SoS) or Si wafers; SoS wafers have the advantage that complete recovery of the solar wind collection layer can be visually observed, there is no such marker for the solar-wind implanted layer in pure Si wafers. But SoS wafers present some disadvantages: the flown SoS was too thin to contain the solar wind implant, so the deepest wind (<3%) was implanted in the sapphire substrate. This deep fraction is heavy skewing the ICP-MS results towards light isotopes. Corrections for the fraction in sapphire must be calculated, as sapphire: 1) is not readily dissolved by HF-HNO₃ treatments, and 2) contains a significant Mg blank. Here, we report the first Mg isotopic results and surface Mg concentrations obtained by acid extraction of solar wind Mg from 5 flight SoS wafers provided for cleaning tests.

Samples and Analytical Methodology: Five flight SoS wafers (20636, 20403, 20527, 20538, 30446), each smaller than 1 cm in longest dimension were processed through 24 hours of aqua regia cleaning, which we have previously shown removes Fe and Cr from steel fragments, Ge from wafer debris, and most of the Mg from the crash debris [9-10]. We explored the use of a hot conc. HF treatment on Si and SoS control wafers: these control wafers emerged shiny from hot HF after an overnight emersion, with negligible weight loss of the Si. This process was later used on implanted SOS controls, with the same result. To remove residual silicate hosts of Mg on flight wafers, we performed the same HF treatment; however, the flight SoS wafers reacted rapidly with complete removal of the silicon layer after 2 hours, terminating further cleaning of these wafers. The resulting solution was analyzed for elemental abundances and Mg isotope composition on an Element XR ICP-MS at the NHMFL equipped with an ESI™ ULPA-filtered bench, Thermo™ SuperJet8.23 Ni sampler and Spectron™ T-1002X Ni-X skimmer cones, and an ESI™ Apex sample introduction system with an ESI™ 100 $\mu\text{L}/\text{min}$ PFA nebulizer. The sensitivity of the system measured at ¹¹⁵In was 10^8 cps/ppb. The peaks ²³Na, ²⁴Mg, ⁴⁴Ca, ⁴⁵Sc, ⁴⁷Ti, ⁵¹V, ⁵²Cr, ⁵⁵Mn, ⁵⁶Fe, ⁵⁹Co, ⁶⁰Ni, ⁶³Cu, ⁶⁶Zn, ⁶⁹Ga, and ⁷⁴Ge were acquired in medium resolution and converted to elemental abundances using external standardization to a solution of solar relative elemental abundances. The isotopic composition

of Mg was determined using the Element XR in low resolution mode on masses ^{24}Mg , ^{25}Mg , and ^{26}Mg . A molecular isobaric interference on ^{26}Mg from CN^+ could not be stripped efficiently enough to allow precise determination of the $^{26}\text{Mg}/^{24}\text{Mg}$ ratio. The instrumental fractionation was corrected using sample-standard bracketing with DSM-3 and Cambridge1 Mg isotope standards [8]. Matrix-matching was provided by doping the Mg standard solutions with variable amounts of Si (0, 1, 10, 100 ppm). During the analytical session, no matrix dependence was observed for this range of Si contents against undoped Mg solutions. Due to the limited amount of Mg available in the flight SoS wafers, only a single isotopic measurement of each solution was possible ($\pm 2\%$ precision).

Results: Elemental abundances are given in Fig. 1 and isotope compositions are shown in Fig. 2.

Elemental Abundances. Examination of wafer 50718, cleaned by the same procedures but not subjected to HF treatment, by TXRF [11] revealed the continued presence of white paint chip debris; this residue is consistent with Zn-Ga anomalies in elemental analysis of the extracted SoS wafers. White paint is not a known source of Mg, but may shield other contaminants from the aqua regia cleaning. The elemental abundances in Fig. 1 are for 5 elements not heavily contaminated by crash debris. The results indicate varying individual levels of post-cleaning contamination, from low (close to the expected solar wind values; 20403) to high (10-100xSW; 30466). Quantitative recovery of the Si layer from SoS wafers assures that no SW material remains undissolved. Ni fluences < 1 are problematic, as $< 10\%$ SW Ni penetrates to sapphire.

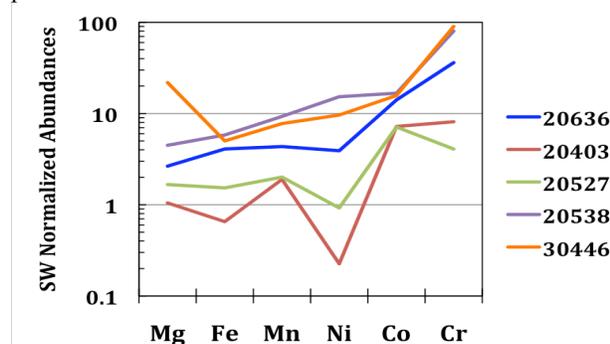


Figure 1: Elemental abundances in dissolved Si from five SoS wafers, Solar Wind normalized [4].

Mg Isotopic Composition. All five samples yielded isotopically light Mg; the lightest Mg (-4%) was in the wafer with solar wind levels of elemental Mg, 20403. Also shown in Fig. 2 are three aqua regia extracts of the surficial Mg recovered during cleaning, which are isotopically normal. A mixing model curve

(green) between terrestrial Mg ($\delta^{25}\text{Mg} = 0\%$) and SW Mg expected for ICD ($\delta^{25}\text{Mg} = -10\%$) [2] is consistent with only 3 data points. The two wafers with the lowest Mg fluences do not plot on the green curve, but are about a factor of two lighter than the prediction of ICD. So, although isotopically light Mg is recovered from the Si layer of flight SoS wafers, the evidence for isotopic fractionation in the solar wind by Coulomb drag is not definitive. Moreover, SIMS elemental profiles and SRIM models indicated that some of the Mg was implanted into the sapphire, below the Si. Thus, the observed Mg isotope fractionation partly reflects the preferential loss of the heavy isotope to the underlying substrate. A second caveat to note is that the cleaning procedure may also strip some of the Si layer [12], and thus bias the result to heavier values. Using SIMS depth profiles and our cleaning procedures, a better constrained Mg isotope measurement is feasible.

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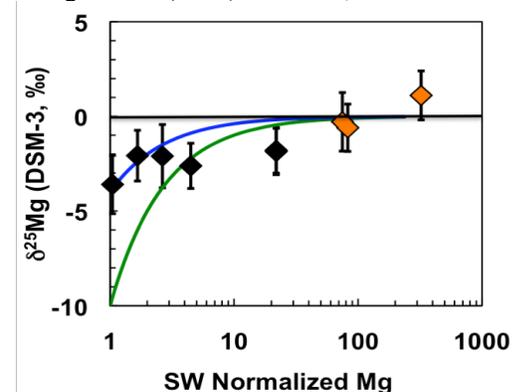


Figure 2: Solar Wind normalized surface Mg abundance vs. $\delta^{25}\text{Mg}$ (normalized to DSM-3 [8]) on flight SoS wafers. Black diamonds: HF extracts of Si layer; orange diamonds: aqua regia extracts of three of the SoS surface contaminants; green curve: mixing line between UTTR dirt [7] and ICD Mg [2]; blue curve: effective mixing line for cleanest extract and UTTR dirt.