Refinement and implications of noble gas measurements from Genesis.

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Introduction: Helium, neon, and argon extracted from Genesis solar wind collectors and analyzed by ion counting noble gas mass spectrometry have yielded solar wind isotopic compositions of much higher precision than previously available. Here we will give refinements and further analysis on this data which was initially reported in [1,2].

Different collectors of aluminum films on sapphire substrates (AloS) were deployed during different solar wind regimes: interstream (slow (IS), <475 km/s), coronal holes (fast (C-H), >475 km/s), and coronal mass ejections (CME), allowing independent measurements of elemental and isotopic ratios between these different regimes. As experience with these samples has progressed, better analytical and calibration techniques have been developed so the final set of measurements represents the best data obtained to date on the Genesis collector. While the depth profiles demonstrate that there is no need for an isotopically heavy SEP component, they do require a light low-energy neutral component.

Summary of Compositions: The ^{40}Ar blank in our system was very low (< 5 × 10^{-10} ccSTP), with observed ^{40}Ar/^{36}Ar ratios between 3 and 10, demonstrating that neither contamination by Utah mud nor system blanks can have appreciable effect on our Ar results. The Ar data from all of the rastered areas formed a nearly perfect straight line when the ratios of ^{36}Ar/^{40}Ar versus ^{38}Ar/^{40}Ar were plotted, indicating mixtures of only two distinct components: solar wind and terrestrial atmosphere. There are no statistically significant differences in isotopic ratios between the different SW regimes. The precision of these isotopic ratios is better by more than an order of magnitude from solar Ar ratios previously determined (e.g. see review paper [3]).

Ne and He data is given below in Table 1, with no statistically significant differences between Ne isotopic ratios in the different SW regimes, but with improvements in precision of an order of magnitude over previous values. Coulomb drag effects should be expected and the most diagnostic indicator of isotopic fractionation related to Coulomb drag comes from the helium isotopes. The helium data do show statistically significant differences between regimes at the 1-sigma level, but these are less than expected. The Coulomb drag theory of solar-wind acceleration suggests a correlation between the He/H ratio and the isotopic fractionation of the solar wind [e.g. 3]. The He/H ratios of the C-H and IS array collection periods were 0.0389 and 0.0358 respectively, as measured by the on-board solar-wind ion monitor, relative to the photosphere. The nominal difference in ^{3}He/^{4}He ratios between C-H and IS arrays is only 40% of the maximum predicted by Coulomb drag theory for these He/H ratios.

Diffusive Losses from the Polished Aluminum: All isotopic ratios ^{20}Ne/^{22}Ne, ^{21}Ne/^{22}Ne and ^{3}He/^{4}He, as well as the ^{4}He/^{20}Ne ratio released from the AloS are somewhat higher (exceeding the statistical errors) than those released from the polished aluminum collectors (PAC). Moreover, the ^{20}Ne and ^{4}He fluxes in AloS are also somewhat higher than in PAC. Larger diffusive losses from the PAC is the most plausible reason for this, a conclusion that is borne out by stepwise heating experiments on both collectors (Figure 1). Since the PAC is a T6 6061 alloy and the film evaporated onto the sapphire substrate is pure aluminum, the lower melting point of the alloy and thermal release properties is clearly shown in this figure. 1.5% of the ^{20}Ne was lost from the PAC when held at 300°C for only 45 minutes, 15x more than was lost from the AloS under the same conditions. The nominal flight temperature is supposed to be near 200°C, not that far from the above temperature. Considering that the actual temperature is determined by both the α/ε of this material (absorbtivity in the visible over the emissivity in the infrared) and the thermal coupling to the spacecraft structure, it is plausible that the equilibrium temperature of this material may well have been sufficient for substantial diffusive losses to occur.

Depth-dependent Isotope Effects: Three independent methods allow isotopic compositions to be measured as functions of depth. Using our stepped UV laser rastering system, we can measure isotopic compositions with a depth resolution of some tens of angstroms. Since diffusive losses occur near the surface, conventional step-wise pyrolysis can provide depth-dependent information. More precise is the closed-system stepped etching done by the Zürich group [4]. The depth profiles provided by all three methods are shown in Figure 2, and are essentially all the same, showing a progressive increase in ^{22}Ne/^{20}Ne, ^{21}Ne/^{20}Ne ratios with depth. All of these are equally consistent with the results of TRIM simulations for constant velocity implantation using the velocity spectrum obtained from on-board instrumentation (essentially the same as that from the 300 km/s nominal solar wind velocity). This provides strong support for the conclusion that an isotopically heavy higher energy component of the solar wind (SEP) is not present in these Genesis samples and is not needed to explain the isotopic composition of Ne released from lunar regolithic material [4]. While these profiles have eliminated the need for a heavy SEP component, they point out the need for an unexpected light neutral component.

Light Neutral Component: Neither diffusive losses nor isotopic fractionation with implantation can explain the light isotopic composition that is observed at the very surface of the collectors. Figure 2 shows that the near-surface (outermost 50-100Å) isotopic compositions, obtained by all three independent methods, do not match the TRIM predictions. In this region, where about 5% of all implanted Ne and He resides, the composition is much "lighter", higher ^{20}Ne/^{22}Ne and, to a lesser extent, ^{3}He/^{4}He ratios, than predicted by constant velocity TRIM simulations. Ironically, now that we have concluded there is no need for a heavy SEP component, we now need to introduce a new light component. A sharp increase in the ^{20}Ne/^{22}Ne, the ^{21}Ne/^{22}Ne, and the ^{3}He/^{4}He ratio (not shown here) is observed at the very surface of the PAC by progressive laser rastering, and qualitatively confirmed by step-wise pyrolysis. The same effect is observed with even greater clarity in the Zurich CSSE of bulk metallic glass (BMG) [4].

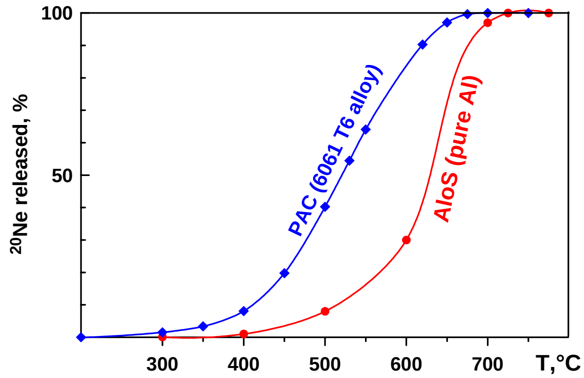

Figure 1: Cumulative release of SW ^{20}Ne from two Genesis collectors [2].

Solar wind ions are bound to solar magnetic fields and are implanted with the radial velocities of these fields, 300 – 900 km/s, corresponding to a few keV/amu. The depth profile of ions implanted at 50 eV/amu match the isotopically light component released from the near-surface. Diffusive losses work in the opposite direction, and the low velocity requires them to be neutral. Thus a low-energy neutral solar component, or an interstellar neutral component is required. This can be explored by study of the aluminum rear of the ion concentrator, which is shielded from ions. Delineation between solar and interstellar neutrals can be made by study of the aluminum collector from the anti-sun direction.

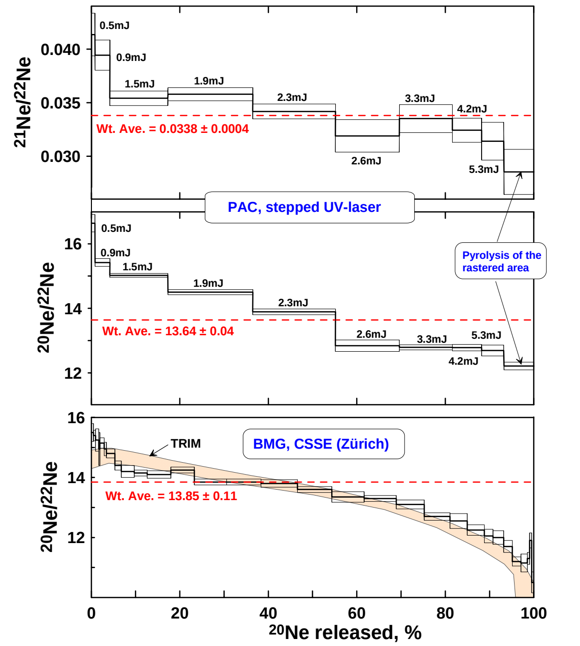

Figure 2: Depth profiles by three different methods [this work, 4].

References: [1] Mabry J. C. et al. (2006) *69th Meteoritical Society Meeting*, Abstract #5287 [2] Meshik A. P. et al. (2006) *69th Meteoritical Society Meeting*, Abstract #5083 [3] Weins R. C. et al. (2004) *EPSL 222*, 697-712. [4] Grimberg A. et al. (2006) *Science*, **314,** 1133. [5] Hohenberg C. M. et al. (2006) *LPSC XXXVII*, Abstract #2439 [6] Ziegler J. F. (2004) *Nucl Instrum. Methods Phys. Res. B*, 1027. [7] Meshik A. P. et al (2000) *31st LPSC*, Abstract #1900. [8] Meshik A. P. et al (2006) *37th LPSC*, Abstract #2433.

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Table 1: Light noble gas AloS data (He and Ne averages are corrected for backscattering).

SW Regime	^{3}He/^{4}He (× 10^{4})	^{4}He flux (10^{11}/m^{2}·s)	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{20}Ne flux (10^{8}/m^{2}·s)	^{36}Ar/^{38}Ar	^{36}Ar flux (10^{6}/m^{2}·s)	^{38}Ar flux (10^{6}/m^{2}·s)
Bulk (BC)	4.33 ± 0.03	1.44	13.945 ± 0.025	0.0346 ± 0.0003	2.23	5.495 ± 0.011	4.04	.734
Coronal hole (H)	4.15 ± 0.03	1.10	13.937 ± 0.041	0.0345 ± 0.0004	1.79	5.536 ± 0.025	2.67	.480
CME (E)	4.30 ± 0.03	1.46	13.947 ± 0.031	0.0336 ± 0.0004	2.15	5.478 ± 0.039	5.49	1.00
Interstream (L)	4.24 ± 0.03	0.88	13.953 ± 0.031	0.0340 ± 0.0004	1.65	5.486 ± 0.02	5.00	.909
Average	**4.34 ± 0.02**	**1.32**	**13.984 ± 0.016**	**0.0342 ± 0.0002**	**1.97**	**5.497 ± 0.009**	-	-