HELIUM, NEON, AND ARGON ISOTOPIC AND ELEMENTAL COMPOSITION OF SOLAR WIND REGIMES COLLECTED BY GENESIS: IMPLICATIONS ON FRACTIONATION PROCESSES UPON SOLAR WIND FORMATION.

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Introduction: A major objective of the Genesis mission is to provide solar abundances of ultra-volatile elements. These are depleted in carbonaceous chondrites, otherwise the most primitive accessible material representing solar nebular composition. In particular, noble gases are of great interest because they do not show lines in the photospheric spectrum, thus their photospheric abundances can be derived only indirectly. One approach is to deduce them from the solar wind (SW) composition. In order to do so, however, potential fractionation processes between photosphere and SW need to be understood. Knowledge of the composition of SW emanating from different regions can provide insights into fractionation processes. Therefore, the Genesis spacecraft collected SW from the three main regimes separately: fast, coronal hole (CH) SW, slow, interstream (IS) SW (both considered to be quasi-stationary) and SW from coronal mass ejection (CME) events. Additionally, two collector arrays continuously sampled bulk SW. Here we present a complete data set of elemental abundances and isotopic compositions of He, Ne, and Ar for all three Genesis SW regimes and the bulk SW. Special emphasis will be placed on the relative differences between the single SW regimes.

Experimental: Noble gases were analyzed in Diamond-like carbon on Silicon (DOS) targets: Bulk-SW, IS-SW, CH-SW, and CME-SW. Two CH fragments, 60242 and 60243, contain only 10% of the expected He but 100% of the Ne and show low ^{3}He/^{4}He. Both fragments probably had been partly shadowed by the overlying bulk-SW-array and their He inventory was compromised by scattered atoms. CME fragment 60238 presumably was completely shadowed since no noble gases could be detected.

Noble gases were released by UV laser ablation (λ=213nm). The ablated areas were adjusted to match concentrations between different regimes. Two different procedures were applied to analyse noble gases. With the first He isotopes, Ne isotopes and the ^{4}He/^{20}Ne abundance ratio were analysed in separate runs, using a very sensitive mass spectrometer [1]. This spectrometer allowed high precision analyses by consuming only small target areas [2]. Thus, we could apply a standard-sample-bracketing technique that enabled us to detect small differences between SW regimes. As standard we used the bulk SW target 60253. Samples were the IS, CME, CH, and bulk (60067) SW targets [2]. With the second procedure we measured He, Ne, and Ar with a conventional mass spectrometer. Areas consumed per analysis were 1-4mm^{2}. The blank contribution was insignificant for He and Ne, and ~1% for ^{36,38}Ar. Backscatter loss was modelled and corrected for He and Ne as explained in [2]. Backscattering was insignificant for Ar.

Extensive cross calibration with several independent air standards was carried out to obtain accurate elemental and isotopic composition data of He, Ne, and Ar. Our He/Ne and Ne/Ar ratios are accurate to within 1% (1σ) and the isotopic composition of Ne to within 0.5% (1σ). These uncertainties are not included in the errors stated below. Given errors are statistical and are in the range of analytical uncertainties. Potential errors due to backscatter correction are not included as the accuracy of SRIM is not well known. However, the backscatter correction for DOS is small anyway. An independent cross calibration of He has yet to be done, thus the absolute ^{3}He/^{4}He ratios are still preliminary. Note, however, that for this work relative differences between single SW regimes are of prime importance.

Results and Discussion: a) Bulk SW composition. Isotopic and elemental ratios are given as mean of 11 analyses by the 2nd procedure. The ^{3}He/^{4}He ratio of $(4.53\pm0.03)\times10^{-4}$ is close to the mean value obtained by the Apollo SW composition (SWC) experiment [3]; thus we are confident that our calibration of the He isotope composition is basically correct. The ^{20}Ne/^{22}Ne and ^{21}Ne/^{22}Ne values are 13.77±0.03 and 0.0329±0.0001, respectively, in good agreement with SWC and in-situ data [4, 5]. Recently published Ne ratios by [6] are higher, in particular ^{21}Ne/^{22}Ne. The ^{36}Ar/^{38}Ar is 5.47±0.01 in general agreement with SWC and [6]. Mean ^{4}He/^{20}Ne and ^{20}Ne/^{36}Ar ratios are 656±5 and 42.1±0.3, respectively. Our bulk SW ^{4}He/^{20}Ne is on the upper edge of the respective SWC average of 570±70. One possible reason for this difference could be a larger contribution of CME SW during Genesis (see below) compared to the SWC experiment. We will further track this issue by artificial irradiation experiments. Our ^{20}Ne/^{36}Ar is near the lower edge of the SWC average of 49±7. However, we can neither confirm the high value of 59 nor the large variability of the bulk SW ^{20}Ne/^{36}Ar of 9% by [6].

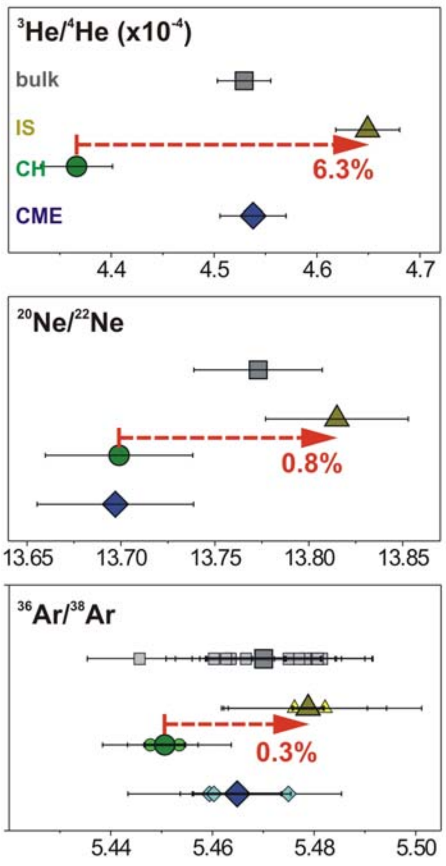

Fig. 1: He, Ne, and Ar isotopic composition of the SW regimes sampled by Genesis. Regime He and Ne data were obtained relative to the bulk SW by the standard-sample-bracketing technique and are averages of ~10 and 5 analyses, respectively, recalculated to absolute values. Error bars include the variability of bulk and the standard deviation of repeated regime analyses. Single Ar analyses are shown in the lower diagram with their analytical errors. Mean ^{36}Ar/^{38}Ar are given by larger symbols. Colours and symbols are the same in all three plots. Arrows mark the fractionation between IS and CH SW.

b) Isotopic composition. Fig. 1 shows the isotopic composition for the single regimes. A closer look at the quasi-stationary SW data shows that heavy isotopes are depleted in IS relative to CH SW and fractionation factors increase with decreasing atomic mass (6.3% for ^{3}He/^{4}He, 0.8% for ^{20}Ne/^{22}Ne, 0.3% for ^{36}Ar/^{38}Ar). A depletion of the heavy isotopes in the IS SW was already detected in-situ by Ulysses and SOHO (~12% for ^{3}He/^{4}He [7], ~1%/amu for Si, Ne, Mg [8]), although the SOHO data for Si, Ne, Mg are only marginally significant. One possible explanation is fractionation due to inefficient Coulomb drag [e.g. 9] taking place in the corona upon acceleration of the SW ions. Coulomb drag, the collisional coupling of heavier ions (including He) to H^{+} depends on mass and charge state of the ionized species and is thus mass fractionating. This effect was proposed to explain the lower He/H in IS relative to CH SW [9]. Adopting He/H of 0.0358 (IS) and 0.0389 (CH), respectively, as measured by the Genesis Ion Monitor (GIM), Coulomb drag modelling [9] predicts isotopic fractionation of 5% for ^{3}He/^{4}He, 0.24% for ^{20}Ne/^{22}Ne and 0.13% for ^{36}Ar/^{38}Ar (assuming charge states of +2, +8 and +11, respectively). These theoretical values agree astonishingly well with the measured fractionation factors. However, caution may be appropriate not to over-interpret these similarities. On the one hand, the modelled fractionation depends on the charge state distribution of the ionized species at the place of fractionation, thus at 1-3 solar radii, which are exclusively based on models. Furthermore, the GIM was not meant to yield accurate He and H abundances, thus true He/H might be somewhat different. Finally, other mechanisms, as fractionation due to first ionization potential (FIP) have been proposed as being responsible for the fractionation of the He/H and the ^{3}He/^{4}He in the IS and CH SW by [7], although it is difficult to understand how this effect could produce the observed isotopic fractionation of He.

c) Elemental composition. In contrast to isotopic compositions, IS and CH SW have within uncertainties identical elemental abundances: ^{4}He/^{20}Ne (631 and 635) and ^{20}Ne/^{36}Ar (41.7 and 40.7). Remarkably, however, elemental composition of the CME SW is distinct from the values of the quasi-stationary SW in contrast to the isotopic composition of this regime. The CME SW is enriched in He over Ne by ~10% (^{4}He/^{20}Ne: 700) and over Ar by ~20%. Helium is also enriched relative to H, as this was a selection criterion for deployment of the CME array. Many authors suspect a gravitational enrichment of He to explain the He over H enrichment in transient events. Also, fractionation due to the FIP might be conceivable as implied by the ACE data evaluated for Genesis by [10].

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