ELEMENTAL ABUNDANCES OF NOBLE GASES IN SOLAR WIND REGIMES COLLECTED BY GENESIS.

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Introduction: To derive elemental and isotopic abundances in the Sun from solar wind (SW) abundance data, isotopic and elemental fractionation effects arising upon injection and acceleration of SW ions need to be understood. The Genesis mission [1, 2] therefore did not only collect "bulk" SW, but also SW from three different regimes [3]: "Slow" interstream SW, "Fast" SW originating in coronal holes, and SW related to coronal mass ejections ("CME"). Earlier [4], we published isotopic and elemental abundances of the light noble gases He, Ne, and Ar in the Fast and Slow regimes. Here we present elemental abundances of Ar, Kr, and Xe in all three regimes (preliminarily published in ref. 5) and elemental and isotopic data of He, Ne, and Ar in CME targets. Since differences in the isotopic composition between the three regimes decreased strongly from He to Ne to Ar [4], we did not attempt to measure Kr and Xe isotopic ratios in regime targets, as any differences can be expected to be below detection limits. We will discuss some significant differences - as well as similarities - in the abundance patterns of the noble gases in the different Genesis regimes in terms of theories on fractionations of elements in the solar wind.

Experimental: The Ar-Kr-Xe analyses were done on Czochralski-grown Si targets, the He-Ne-Ar analyses on Diamond-like Carbon (DOS) targets [6]. Noble gases were released by UV laser ablation. Experimental details are provided in [4, 7]. The very low concentrations of Kr and Xe led to rather substantial uncertainties, as shown for Xe in Fig. 1 (cf. ref. 7).

Results: Table 1 shows the proton fluxes and the noble gas to proton flux ratios in the three regimes, normalized to the values in the bulk SW. The proton data are from the Genesis Ion Monitor (GIM) [8].

Table 1: H fluxes and noble gas to H flux ratios normalized to Bulk SW values

	H	^{4}He/H	^{20}Ne/H	^{36}Ar/H	^{84}Kr/H	^{132}Xe/H
Bulk	1	1	1	1	1	1
Fast	0.85	1.01	1.05	1.09	1.09	1.01
Slow	1.13	0.89	0.91	0.93	0.93	0.97
CME	1.00	1.22	1.14	1.05	1.03	1.07

In situ analyses [9] showed that the proton momentum flux in the SW is ~invariant, hence in the fast SW the proton flux is lower than in the slow SW. The ~25% difference recorded by the GIM (Table 1) is similar to the difference measured by Ulysses for "mean fast" and "mean slow" proton fluxes [10], suggesting that the definition for fast and slow SW regimes used by Genesis and Ulysses agree quite well, at least for protons. On the other hand, the ^{4}He enrichment of ~22% in the CME target is less pronounced than the value of roughly 40% expected for typical CME flows [11], indicating contributions by "normal" SW to the Genesis CME targets. Table 1 also shows that relative to protons the noble gas abundances are somewhat higher in the Fast SW than the Slow SW. The CME target recorded 13-33% higher fluxes of all noble gases than the bulk SW, but relative to protons, only He and Ne fluxes are substantially higher in CMEs (Table 1).

Fig. 1 shows the ratio ^{132}Xe/^{36}Ar in all individual samples as well as the respective weighted averages. Whereas mean ^{84}Kr/^{36}Ar ratios are identical in all three regimes (~$4.1*10^{-4}$) and within uncertainties also identical to inferred solar and measured Jupiter values [12, 13], the Xe abundance relative to Ar is higher by about 12% in the Slow SW than in the Fast SW. In all regimes as well as in the bulk SW, the Xe/Ar ratio is also substantially higher by about a factor of 2-2.5 than the inferred solar and the Jupiter values, a fact already known from lunar soil analyses [14] and Genesis Bulk SW targets [7, 15].

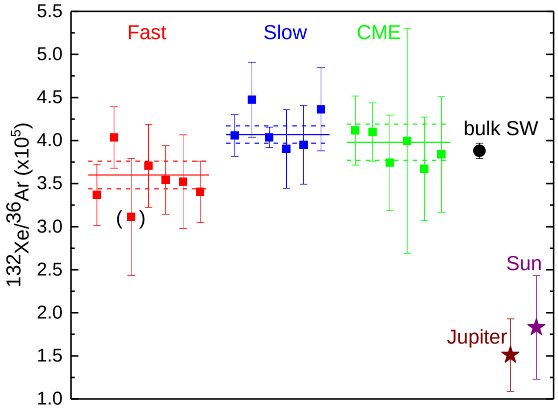

Fig. 1: ^{132}Xe/^{36}Ar in Genesis regime targets. Weighted average values and their 1σ uncertainties shown as solid and dashed lines, resp. Bulk SW value calculated from regime data. Solar value from [12], Jupiter value from [13].

Fig. 2 shows that the average He and Ne abundances are slighly lower in the Fast SW relative to the

Slow SW and Ar, while these two lightest noble gases are substantially enriched in the CME targets.

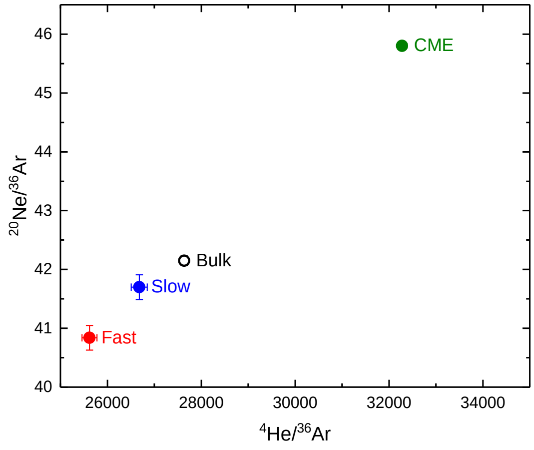

Fig. 2: ^{20}Ne/^{36}Ar vs. ^{4}He/^{36}Ar in Genesis regime targets. Bulk SW calculated from regime data. Data partly from [4].

Discussion: The regime data here confirm previous observations that Xe is significantly enhanced in the solar wind relative to its solar abundance and also relative to its abundance in Jupiter. Considering the unfavourable Coulomb drag factor of Xe [16], one might rather expect a depletion of Xe relative to Ar and Kr, however. The most plausible explanation is an overcompensation of the low drag factor by a particularly efficient ionisation of Xe by coronal EUV in the ion-neutral separation region [17]. Furthermore, the large electron shell of Xe favours its ionisation by electron collisions. It is well known that elements with a low Fist Ionisation Potential (FIP) or a low First Ionisation Time (FIT, e. g. Xe) are enriched in the SW and it is generally accepted that this FIP/FIT effect is stronger in slow wind than in fast wind [18]. The Genesis regime targets show the same pattern and thus support the hypothesis that the FIP-FIT plays a dominant role in shaping abundances of heavy noble gases in the SW.

Species with unfavourable Coulomb-drag factors are conventionally viewed to be enriched in the low corona, while other elements are steadily carried away with the SW. In CMEs the enriched layers are then blown off and can be detected in coronal mass ejecta. A typical case is ^{4}He^{++} with its very unfavourable Coulomb-drag factor. Indeed, ^{4}He/^{36}Ar is higher in CME targets (Fig. 2). However, in this picture one would at face value expect that also the ^{4}He/^{3}He ratio is enhanced in such ejecta, but the He isotopic composition in the CME target remains completely inconspicuous [4]. Similarly, while a slight depletion of ^{22}Ne in the Slow- relative to the Fast-SW target [4] indicates an effect of inefficient Coulomb drag, also the Ne isotopic composition in the CME target hardly differs from the Fast SW value [4], although ^{22}Ne with its unfavourable Coulomb drag factor should be depleted in CMEs. One might alternatively argue that the "normal" He isotopic composition in CMEs indicates that ^{4}He becomes enriched in chromospheric strata due to inefficient ionisation, and its enrichment in CMEs occurs when such strata are blown up into the transition region and lower corona. However, high- and low-FIP elements are simultaneously enhanced in coronal mass ejecta, while elements with an intermediate FIP (e. g. O) remain little affected [8, 11]. Similarly, the heavy noble gases Ar, Kr, and Xe with intermediate FIPs show no enrichment in CMEs compared to Fast and Slow SW. Noble gases in Fig. 4 follow the same general systematics as in-situ observed elements though with less scatter, possibly indicating significant experimental uncertainties of the latter.

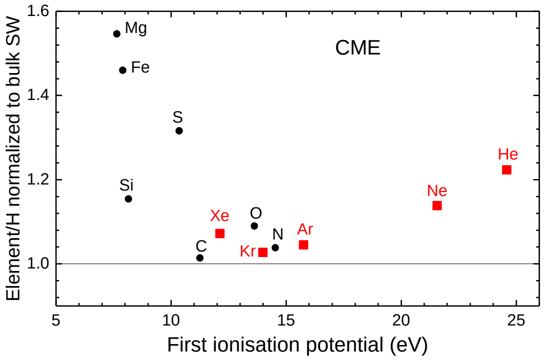

Fig. 3: Enrichments of elements in CMEs relative to H and normalized to Bulk SW. Black dots: Advanced Composition Explorer (ACE) data for same periods as Genesis CME target exposures [8]; red squares: this work and ref. [4].

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