FRACTIONATION PROCESSES IN THE SOLAR WIND REVEALED BY NOBLE GASES COLLECTED BY GENESIS REGIME TARGETS. V. S. Heber [1], R. C. Wiens[2], P. Bochsler[3], R. Wieler[4] and D. S. Burnett[5]. [1]Dept. Earth and Space Sciences, UCLA, Los Angeles, CA, USA, heber@ess.ucla.edu; [2]Space & Atmospheric Science, LANL, Los Alamos, NM, USA; [3]Physikalisches Institut, University of Bern, Switzerland; [4]IGMR, ETH, Zurich, Switzerland; [5]CalTech, JPL, Pasadena, CA, USA.

Introduction: Genesis collected solar wind (SW) ions with one major objective being to obtain abundances and isotopic composition of ultra-volatile elements. The SW is a proxy for the composition of the solar outer convective zone (OCZ) and, hence for the solar nebula. For most elements accurate values for the isotopic composition of sun can be inferred from meteorites. Carbonaceous chondrites also reflect solar composition for most elements. However, the solar isotopic and elemental composition of volatile elements is poorly constrained from meteorites. Moreover, due to the high first excitation potentials of noble gases, it is difficult to obtain solar noble gas abundances from spectroscopic. *In situ* measurements show that the SW from different regimes (e.g. fast and slow) differs in elemental and to some extent also in isotopic compostion [e.g. 1, 2]. Assuming a homogeneously mixed photosphere as the source for SW matter, this compositional variability is ascribed to fractionation processes during SW formation and acceleration. To infer solar abundances from SW abundances it is mandatory to understand and quantify these processes.

In order to constrain the extent of the compositional variability, Genesis collected bulk SW and three major SW regimes separately: Fast, coronal hole associated SW (CH); slow, interstream SW (IS) (both also called "quasi-stationary"); and SW from coronal mass ejections (CMEs). Abundances and isotopic composition of He, Ne, Ar of the bulk SW and the different regimes were presented by [3]. We found significant differences in isotopic as well as elemental compositions among the different SW regimes. Here we discuss what the data of [3] may tell us about elemental and isotopic fractionation processes in the SW. Light noble gases are particularly well suited for such a study because their collection is least affected by contamination. Also, isotopic fractionation effects can be easily quantified because of the large relative mass differences of the stable isotopes.

Isotope fractionation: Differences in the measured isotopic composition are particularly pronounced between IS and CH. The IS is depleted in the heavy isotopes compared to CH. This depletion is large for He (6.3±0.4%/amu) and decreases with atomic mass, i.e. is 0.4±0.1%/amu for Ne and 0.26±0.10%/amu for Ar. We thus confirm indications found by ISEE-3/ICI, Ulysses/SWICS and SOHO/CELIAS. Since isotopic fractionation in the solar wind is purely mass-related and does not depend on atomic properties, it is generally ascribed to inefficient Coulomb drag (CD) from protons [e.g. 4]. Whereas in CH related SW wave-particle interaction heats and accelerates heavy species indiscriminately, Coulomb collisions in the inner corona are important in accelerating species heavier than protons in IS regimes. It is well known from spacecraft observations that inefficient CD can produce SW strongly depleted in He and consequently, it has to be expected that it operates on all isotopes. The measured difference in the He, Ne, and Ar isotopic composition between CH and IS [3] is in general accordance with the systematics of Coulomb drag fractionation.

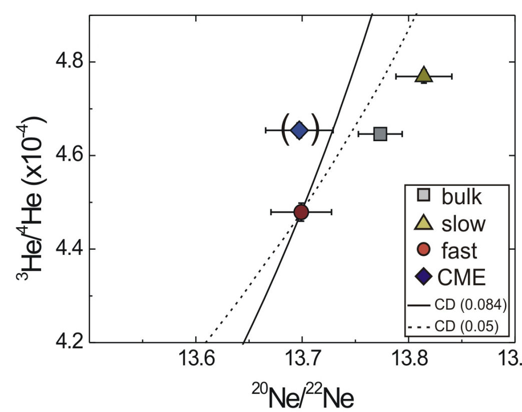

Fig. 1. He vs. Ne isotopic composition measured in the Genesis SW regimes. Data from [3]. Expected fractionation lines due to inefficient CD are shown.

A simple model ascribing the depletion of He to H from a He/H ratio of 0.084 in the OCZ [5] to 0.039 (CH, Genesis ion monitor) in the SW solely to CD, would produce a trend along the solid line in Fig. 1. Assuming a weaker effect, depleting He over H only from 0.05 to 0.039, would also cause a weaker isotope fractionation as indicated by the dotted line. One has to keep in mind, that He might in part also be depleted due to its high first ionization potential (FIP) relative to H. It is argued that elements with a high FIP (>10eV) do not fractionate from each other. However, due to the large difference between the FIPs of He (24eV) and H (13eV), some He depletion relative to H seems conceivable. Isotope fractionation due to the FIP effect is considered to be negligible, though. A He/H of 0.05 is chosen here as this value reflects the composition of fast SW [6] considered to be less affected by inefficient CD fractionation. Our measurements seem to favour models which do not produce a strictly mass-dependent depletion of He but also attribute some role to the FIP-effect for the depletion of He. Evidently, a clear answer to the question how much fractionation is produced due to the antagonism between gravitational settling and CD in the corona, and how much is due to atomic effects (FIP) is necessary to make safe inferences for the solar composition from SW abundances. For example, assuming that inefficient CD is entirely responsible for the He/H fractionation, the bulk SW $^4He/^3He$ ratio of 2150 [3] has to be corrected by 50%, resulting in a solar value of 3200. A potential contribution of the FIP effect to the He/H fractionation (up to a He/H of 0.05) would reduce the required correction and result in a solar $^4He/^3He$ of 2500 only. Analogous, the derivation of the solar isotopic composition of other important elements, most of all oxygen, requires a reliable correction. If the He/H fractionation is entirely due to inefficient CD, according to [4], the bulk SW $^{18}O/^{16}O$ ratio would have to be corrected for by ~6.5% (towards heavier composition) to obtain the solar value.

Elemental fractionation: Most prominent in our elemental data is the strong enrichment of He in the CME target relative to the quasi-stationary SW [3] by about 11.1% over Ne. Strong He enrichments have been observed many times with *in situ* spacecraft observations. He/H enrichments have been used as a selection criterion for the exposure of the CME target [7]. Genesis now shows that the He enrichment in CMEs is also accompanied by an enrichment of similar extent (11.4%) of Ne over Ar. Interestingly, results from all four targets (CME, bulk, IS and CH) line up on a straight line in the three isotope plot in Fig. 2, which might be interpreted as a mixing line between a collection of CMEs as one end member and CH as the other. What produces the fractionation between these putative end members is unclear. To illustrate the action of CD, we have plotted a dotted line which as we expect CD to enrich the Ne/Ar with increasing depletion of He relative to Ar, but this is inconsistent to the measured data. Fractionation according to FIP is well-known for CH and IS [1, 8]. However, previous work mainly concentrated on quasi-stationary SW types, studies also considering CME do not exist. Further, FIP fractionation among high FIP elements (e.g. the noble gases) has not yet been demonstrated. FIP fractionation would affect both ratios, He/Ar and Ne/Ar, in a very similar manner since the photoionisation cross sections of He and Ne have very similar shapes and a variable EUV spectrum cannot produce a strong fractionation between He and Ne. On the other hand, Ar with a considerably lower FIP could be more or less efficiently enriched simultaneously relative to He and Ne, thus producing the diagonal dashed line in Fig. 2.

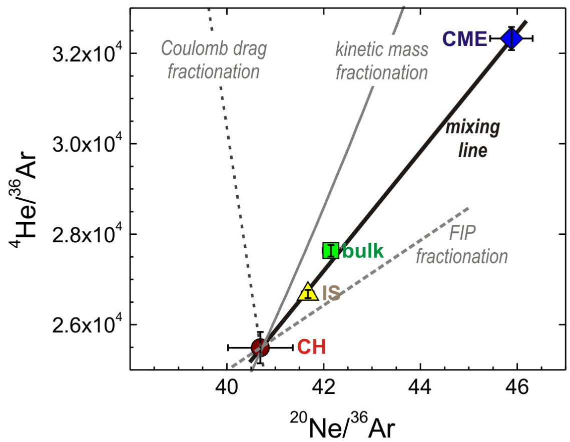

Fig. 2. Measured noble gas elemental composition of Genesis regime samples. Labeled lines indicate conceivable fractionation processes as explained in the text.

Note that the classical FIP process produces stronger enrichments of low-FIP species in IS compared to CH, while here the elements with the *higher* FIPs are rather enriched in IS compared to CH. Finally, mass-dependent fractionated matter, generated by gravitational settling during the storage of plasma in magnetic loops, could contribute to certain extents to the SW matter (solid line in Fig 2). Accordingly, CMEs could contain the largest portion of mass-fractionated matter. IS, originated at least partly from regions above closed magnetic field lines, may still contain some, whereas CH wind, that moves into space along open magnetic field lines, probably does not contain at all mass fractionated matter. However, the discussion here is speculative and details of the underlying fractionation processes need further studies.

Conclusion: Genesis has been able to distinguish efficiently between different SW regimes and to show clear trends in isotopic and elemental fractionation. Noble gases, probably the easiest applicable tracer might be used to make inferences on possible fractionation processes also operating in the SW on less volatile elements, e.g. C,N and O and on refractory elements. Our observations of isotopic fractionation tend to agree with inefficient CD fractionation. The pattern observed in elemental composition is more difficult to interpret and further studies are needed.

References. [1] von Steiger, R., et al. (2000) J. Geophys. Res. **105**(A12): p. 27217-27238.[2] Kallenbach, R., et al. (1998) Space Sci. Rev. **85**: p. 357-370.[3] Heber, V.S., et al. (2008) *LPSC 39th*CD#1779.[4] Bodmer, R., et al. (2000) J. Geophys. Res. **105**(a1): p. 47-60.[5] Basu, S., et al. (2004) Ap.J. **606**: p. L85-L88.[6] Kasper, J.C., et al. (2007) ApJ. **660**: p. 901-910.[7] Neugebauer, M., et al. (2003) Space Sci. Rev. **105**: p. 661-676.[8] Geiss, J. (1998) Space Sci. Rev. **85**: p. 241-252.