TOWARDS UNDERSTANDING MASS-DEPENDENT FRACTIONATION OF SOLAR WIND ISOTOPIC COMPOSITIONS V.S. Heber and K.D. McKeegan, Dept. Earth and Space Sciences, UCLA, Los Angeles, CA, USA, heber@ess.ucla.edu.

Introduction: A fundamental premise motivating the Genesis mission is that the isotopic composition of the solar wind is representative of the photosphere, which because it samples the convecting outer third of the Sun, would - with limited exceptions - faithfully preserve the average isotopic composition of the primitive solar nebula [1]. Known exceptions are D/H and ^{7}Li/^{6}Li, both affected by nuclear burning during contraction to the main sequence, and ^{3}He/^{4}He, which is additionally affected by gravitational settling [e.g. 2] and ionization/acceleration of solar wind. Indeed, *in situ* spacecraft measurements had detected clear differences in the ^{3}He/^{4}He composition between fast and slow solar wind [e.g., 3, 4, 5], but for other elements any differences in isotopic composition could not resolved within available precision [e.g., 6, 7, 8]. Also, bulk isotopic compositions of non-volatile elements in the solar wind measured by spacecraft [e.g., 9, 10, 11] cannot be used, due to large uncertainties, to test whether the solar wind is isotopically fractionated relative to its source region, the photosphere, which for non-volatile elements is assumed equal to the isotopic compositions derived from primitive carbonaceous (CI) chondrites.

The case for highly-volatile elements is even more complicated as the solar wind is about the only source of information on their solar nebula isotopic compositions. Isotopic compositions for these elements are thought to be significantly fractionated even in CI chondrites due to mass-dependent processes during trapping (noble gases) and chemical/physical reactions early in the solar nebula (O, N). Information on the isotopic composition of reactive highly-volatile elements can, in principle, also be derived from unaltered solar nebula condensates as these should have incorporated the prevailing isotopic composition of the respective element, e.g. O in calcium-aluminum-rich inclusions (CAI) or N in osbornite [12]. However, deciding exactly which samples are appropriate is model dependent.

The solar nebula isotopic composition for most highly-volatile elements is thus best deduced from solar wind data. However, the Genesis solar wind data available so far clearly show evidence for isotopic mass fractionation [13, 14], even beyond what was already known for He. Thus, in order to quantitatively understand photosphere isotopic abundances, we have to understand the processes of solar wind formation that lead to isotopic mass fractionation. In this progress report, we summarize our observations on isotopic fractionation of solar wind based on data obtained from Genesis. The direction and magnitude of the fractionation is evaluated and we discuss the only currently available theoretical model for isotopic fractionation in the solar wind [3, 15]. At the moment two independent lines of evidence for isotopically fractionated solar wind are available from Genesis: a) the isotopic fractionation of He, Ne and Ar between fast and slow solar wind [13]; b) the solar wind O isotopic composition [16].

Evidence from the solar wind noble gas isotopic composition: The isotopic composition of the slow solar wind is enriched in the light isotopes compared to the fast solar wind. This enrichment is especially pronounced in He (6.3±0.4%/amu) and decreases with atomic mass, from Ne (0.42±0.05%/amu) to Ar (0.14±0.03%/amu [13]. What does this fractionation between fast and slow solar wind tell us about the isotopic composition of the source, the photosphere?

The Coulomb drag model [3, 15] uses the He/H ratio measured in the solar wind and the known photospheric He/H abundance [He/H: 0.084; 17] as a basis to extrapolate measured solar wind isotopic compositions back to the photospheric compositions. In detail, He in the solar wind is depleted relative to its photospheric abundance caused upon acceleration of solar wind ions. Helium is "left behind" due to a less efficient Coulomb coupling to protons with the magnitude of the fractionation governed by the charge state and the mass of the ion [15]. Although constructed to explain the He/H fractionation in the solar wind, the Coulomb drag process causing He depletion relative to H should also result in isotope fractionation (as charge states of isotopes of an element are considered to be the same, however their masses are slightly different).

Adopting He/H of 0.038 (slow solar wind) and 0.044 (fast solar wind) [13], respectively, Coulomb drag modeling according to [15] predicts isotopic fractionation of 8.8% for ^{3}He/^{4}He, 0.26%/amu for Ne and 0.18%/amu for Ar (using their main charge states in the solar wind of +2, +8, and +10, respectively). Thus, the fractionation predicted by the inefficient Coulomb drag model is slightly larger but in general accordance with the measured data.

Evidence from the solar wind oxygen isotopic composition: The O isotopic composition measured in the Genesis concentrator target provides another measure to estimate the overall fractionation of solar wind relative to solar nebula isotopic compositions and thus to test the Coulomb drag fractionation model for a non-noble gas element. The measured δ^{18}O composition of the bulk solar wind is -99‰ relative to SMOW [16]

(Fig. 1). The O isotopic composition of the solar wind given here and in Fig. 1 is corrected for instrumental mass fractionation caused by the concentrator and backscatter loss [see 18].

As the fractionation caused by inefficient Coulomb drag is mass dependent, we can consider the measured solar wind composition to be related to the true solar composition by a line having the slope of 0.52 on the oxygen three-isotope plot. The solar wind composition plots to the left (low-mass) side of the CCAM line, the dominant ^{16}O-mixing line for refractory solar nebula materials (Fig. 1), in a region of oxygen isotope space where no other solar system materials plot. It is unlikely that all solar system materials, including especially high temperature condensates, are mass fractionated toward the heavy oxygen isotopes, thus we interpret the measured composition of the solar wind as mass fractionated favoring the light isotopes compared to the source region. In this case, the intersection of a mass fractionation line with the CCAM line probably marks the true O isotopic composition of the solar nebula (Fig. 1).

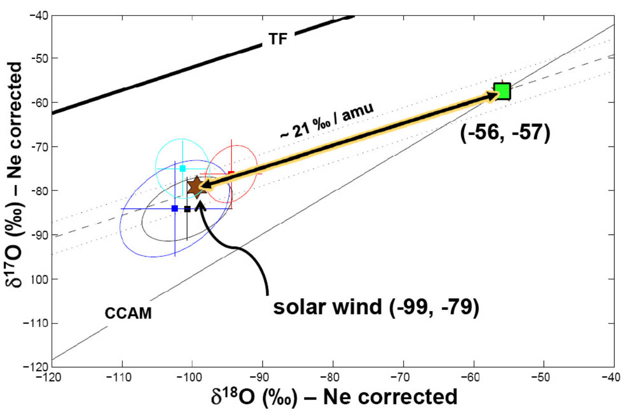

Fig. 1. The oxygen-three isotope plot shows the isotopic composition of solar wind collected by Genesis (brown star) [16]. TF= terrestrial fractionation line; CCAM = carbonaceous chondrite anhydrous mineral line. The point of intersection of a slope 0.52 line connecting the solar wind composition with the CCAM line could mark the true solar nebula O isotopic composition (green rectangle). The difference in composition between the solar nebula and the solar wind might be due to solar wind fractionation.

If true, this hypothesis requires that the O isotopic composition of the solar wind is fractionated by ~21‰/amu toward a lighter composition. The amount predicted by the inefficient Coulomb drag model is 26 ‰/amu in this same direction, considering the major charge state of O to be +6 in the bulk solar wind. The fact that the predicted mass fractionation is very similar to what we would require to put the Sun on the CCAM line gives confidence that the inefficient Coulomb drag model can be used to correct measured solar wind isotopic compositions even if the process is not perfectly understood [15]. Although we recognize the reasoning as somewhat circular, the general agreement of the model predictions with the Genesis noble gas data can likewise support the interpretation that the bulk solar nebula O isotopic value is on the CCAM line at $\delta^{17}O \approx \delta^{18}O \approx$ -56‰.

With a working model, we can now make predictions for the N isotopic composition of the solar nebula based on solar wind measurements by [19, 20]. According to the Coulomb drag model the solar nebula composition of N would be heavier by 4.0% (calculated with the major charge state of N of +5) than the respective solar wind value. The magnitude of the correction is much smaller than published uncertainties, but this is likely to change soon [21].

Finally, independent tests of the inefficient Coulomb drag model may be provided by isotopic measurements of non-volatile elements. This has not yet been accomplished, but the first data could be provided by the Mg isotopic composition measured in Genesis targets and compared with the terrestrial or meteoritic Mg isotopic composition [22]. The Mg isotopic composition of known terrestrial and extraterrestrial solids (except CAI's) is identical within 1‰, thus an agreement with solar photosphere composition is expected. A precision better than about 1% is required for the measurement to be able to detect the potential fractionation of the solar wind Mg isotopic composition since the Coulomb drag model predicts for the $^{26}Mg/^{24}Mg$ an enrichment of ^{24}Mg of 2%.

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