SOLAR ABUNDANCES OF VOLATILE ELEMENTS REVISITED AFTER GENESIS

P. Bochsler[1], V.S. Heber[2], and D.S. Burnett[3]. [1]Space Science Center and Department of Physics, University of New Hampshire, 8 College Road, Durham NH 03824, USA (bochsler@space.unibe.ch) . [2]Department of Earth and Space Sciences, UCLA, 595 Charles Young Drive East, Los Angeles, California 90095-1567, USA, [3]Division of Geological and Planetary Science, MC 170-25, 1200 E. California Blvd., Pasadena, CA 91125, USA

Introduction: The last decade has brought several important developments in the derivation and use of solar abundances. While there was a satisfactory and encourageing agreement between solar models and helioseismological observations at the end of the last century, this situation changed drastically with the first use of three-dimensional models for the derivation of photospherical abundances from spectroscopic observations. Revised abundances of elements heavier than helium no longer matched with the opacities of the solar interior derived from helioseismology. It has also not been entirely realized in the astrophysical and planetary science communities that some of the revised abundances created discrepancies with solar wind composition measurements. Partly this is due to the fact that in situ measurements of the solar wind are not of sufficient precision to yield conclusive results for inferring solar abundances, or, even worse, were reported with unrealistically small uncertainties, so that wrong conclusions were drawn. Furthermore, often some more reliable measurements obtained with the foil collection technique were not considered for the compilation of abundance tables. The comparison of the old Apollo results [1] with the recent results from Genesis [2] has shown that within narrow limits the variability of the solar wind composition is significantly smaller than the one reported from most in-situ measurements. Presumably, a sizeable fraction of the putative variability of in-situ measurements is due to individual measurement uncertainties. Another important result of Genesis is that 40 years after Apollo we also find an excellent agreement with modern calibration standards and apart from the isotopic composition and elemental abundance of He, no significant difference exists [3] .

Solar Energetic Particles - a Solid Reference for Coronal Abundances?

Abundances of solar energetic particles have in general been determined with far better precision by in situ measurements than solar wind abundances. However, it is often not so simple to make inferences about the source composition from these measurements, because during their acceleration various fractionation processes can strongly modify these abundances. In particular, the so-called impulsive events exhibit sometimes strong elemental and isotopic fractionation effects. Conversely, to first order, solar energetic particles from gradual events consist of coronal material accelerated by passing shock waves from coronal mass ejections. If gradual events consisted of coronal material, one would expect that solar energetic particles from gradual events had very similar abundances as the solar wind apart from a weak mass fractionation imposed during shock acceleration. Recent investigations indicate, however, that this is not the case [4,6] and various hypotheses have been discussed to elucidate the source of shock accelerated solar energetic particles.

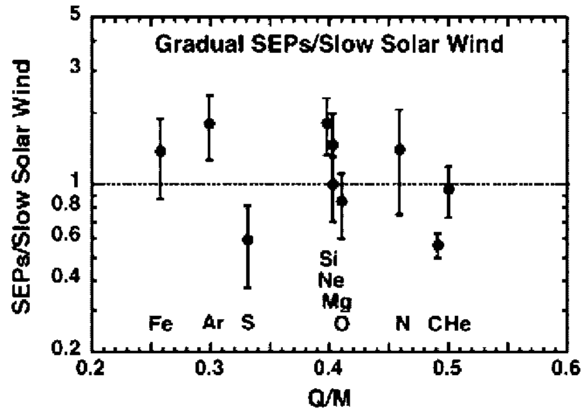

Fig. 1: (from [4)]) Comparison of solar energetic particle abundances with abundances from in-situ-measured slow solar wind [5]. Whereas in several cases a good agreement exists, there are also many elements which exhibit differences. See [4,6] for a discussion of possible reasons.

We have repeated the analysis from [4] using Genesis data and find that the discrepancies are far less dramatic than reported. We have used abundances from the Genesis mission [7,8,9], and if abundances from Genesis are not yet available, as is the case for Na, Si, Cr and Ni, we have included in situ observations – mainly from CELIAS/MTOF on SOHO - which have for unknown reasons not been considered in the literature cited above. The result is shown in Figure 2. The agreement between solar wind and SEP data is satisfactory. Note, however, that this agreement does not imply that SEP and solar wind reflect faithfully the composition of the photosphere.

Solar Abundances of Volatiles: From the comparisons of solar wind results from Genesis and SEP-abundances relative to coronal abundances determined with optical investigations we conclude that coronal abundances are generally better represented by SEP and Genesis solar wind values than from optical observations.

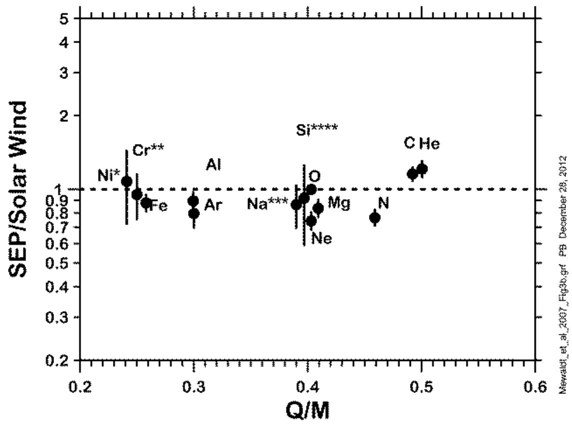

Fig. 2: Comparison of abundances of solar energetic particles from gradual events, with solar wind abundances normalized to oxygen and in the same format as Fig. 1. The SEP abundances are from [10] while the solar wind abundances are results from the GENESIS mission [2,7,8,9]. The solar wind abundances of Ni [11], Cr [12], Si [13], and Na [14] are from in situ measurements. It seems that - with a few exceptions - SEP and solar wind, can now be attributed to the same source.

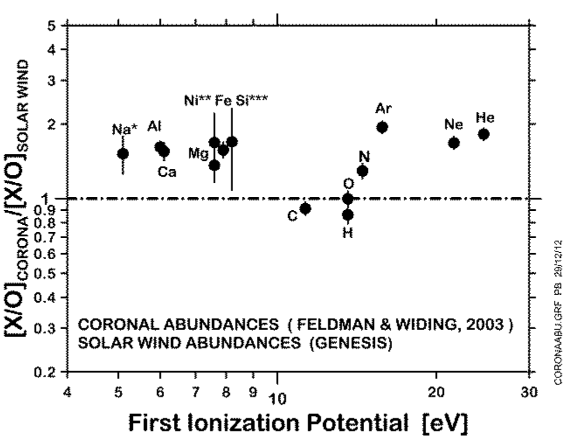

Fig. 3: For coronal abundances from optical observations [15], the agreement with measurements of the solar wind (mostly from Genesis, except for the asterisked elements), is less convincing. Nevertheless, the observations seem to agree fairly well on relative abundances among the low-FIP elements. The scatter is larger for volatile and moderately volatile elements.

In the following we make an attempt to infer neon and argon abundances in the present-day outer convective zone of the Sun, which also represents a sample of the primordial solar nebula: Since helium, neon and argon are all high-FIP elements, we assume that their relative abundances in the solar corona are not influenced by a FIP-related effect. However, following [16] we consider the possibility of elemental fractionation due to inefficient Coulomb drag. Whereas neon, which appears mainly as Ne^{8+} in the corona where Coulomb drag decouples minor species from protons, Ar is present in a variety of charge states. From models of charge exchange in the low corona we assume that the average charge state of Ar is 9.3 [17]. If helium, which has an extraordinarily unfavourable drag factor, was depleted typically by a factor of 2 during the Genesis exposure, using the simple model of [16] we infer that Ne would be typically depleted by a factor of 1.2, whereas Ar is depleted by a factor 1.35. Assuming a solar helium abundance in dex units of 10.925 [18] we then obtain from Genesis measurements a neon abundance of 7.92 and an abundance of argon of 6.39. These preliminary values can be compared with those of [18] who reports 8.05±0.10 for neon and 6.50±0.10 for argon respectively.

Conclusions: Based on the new Genesis measurements it appears that the agreement between SEP-derived coronal abundances and solar wind abundances is much better than previously reported. This has important consequences for the understanding of solar particle acceleration mechanisms. Furthermore, it opens the possibility for cross examination of coronal abundances and for the determination of solar volatile elements, which are difficult or impossible to infer from optical observations. At this time it seems too risky to apply estimated coronal fractionation factors for Kr and Xe and to infer solar abundances of Kr and Xe from solar wind measurements.

References: [1] Geiss J. et al (2004) *Space Sci. Rev. 110*, 307-335. [2] Heber V.S. et al. (2009) *GCA 73*, 7414-7432. [3] Vogel N. et al. (2010) *LPS XLI*, Abstract #1907 [4] Mewaldt R.A. (2007) *Space Sci. Rev. 130,* 207-219. [5] von Steiger et al. (2000) *JGR 105,* 27217-27238. [6] Desai M.I. (2006) *ApJ, 649,* 470-489. [7] Vogel N. et al. (2011) *GCA 75*, 3057-3071. [8] Heber V.S. et al. (2011) *LPS XLII* , Abstract # 2642. [9] Jurewicz A.J.G. et al. (2011) *LPS XLII*, Abstract # 1917. [10] Reames D.V. (1999) *Space Sci. Rev. 90,* 413-491. [11] Karrer R. et al. (2007) *Space Sci. Rev. 130,* 317-321. [12] Paquette J.A. et al. (2001), *AGU CP 598,* 95-100. [13] Bochsler P. (1989) *JGR 94,* 2365-2373. [14] Ipavich F.M. et al. (1999) *EOS 80,* 256. [15] Feldman U. and Widing K.G. (2003) *Space Sci. Rev. 107,* 665-720. [16] Bochsler P. (2007) *A&A 471,* 315-319. [17] Heber V.S. et al. (2012) *ApJ 759,* 121. [18] Lodders K. (2010) *Astrophysics and Space Science Proc., Springer* 379.