The Depth Distribution of Neon and Argon in the Bulk Metallic Glass Flown on Genesis A. Grimberg[1], H. Baur[1], D.S. Burnett[2], P. Bochsler[3] and R. Wieler[1], [1]Isotope Geology and Mineral Resources, NW C, ETH, Clausiusstrasse 25, CH-8092 Zürich, Switzerland, grimberg@erdw.ethz.ch, [2]CalTech, JPL, Pasadena, CA 91109 USA, [3]Physikalisches Institut, University of Bern, Sidlerstr. 5, CH-3012 Bern, Switzerland.

Introduction: We present solar wind (SW) Ar and Ne data from the bulk metallic glass (BMG) [1] flown on Genesis [2]. The main purpose for analyzing this target was to investigate the depth-dependant elemental and isotopic composition of solar noble gases by closed-system stepwise etching (CSSE) [3]. This provides information about the dependence of the SW-elemental and -isotopic composition on energy. Here, we report depth distributions of isotopic and elemental ratios for neon and argon. Overall, Ne and Ar data confirm results previously obtained for Ne [4], although quantitative conclusions for Ar are somewhat compromised by high Ar blanks caused by the manufacturing of the BMG in an Ar-rich atmosphere.

Experimental: We have analyzed Ne and Ar isotopes in a BMG sample of 0.51 cm^2 extracted with CSSE in 22 steps with HNO_3 as the etching agent. Two additional aliquots were analyzed for Ne and are discussed in [4]. The results are compared with ion implantation simulations obtained with the SRIM code [5] for a SW with uniform composition and a velocity distribution for Ne and Ar as observed for the Genesis exposure with instruments onboard the Advanced Composition Explorer.

As had been done for Ne before [4], we also attempted to measure the isotopic composition of bulk SW Ar by pyrolytical total extraction of small BMG samples. In general, the results are somewhat compromised due to high blank Ar contributions from the furnace and especially the BMG itself.

Results and Discussion: The depth distribution of Ne isotopes (not shown) is very similar to the pattern observed previously in two BMG samples [4]. The heavy isotope is enriched with increasing depth in a manner essentially consistent with SRIM simulation for irradiation of a SW with a uniform isotopic composition with a $^{20}Ne/^{22}Ne$ ratio of 13.75±0.05 (BMG bulk average). As discussed in [4], this result shows that the formerly postulated high energy solar noble gas component ("SEP-Ne") in lunar soils [6] actually is an artifact of fractionation upon implantation. However, $^{20}Ne/^{22}Ne$ ratios in gas sited close to the BMG surface plot considerably above the bulk SW value and are also up to 10 % higher than predicted by SRIM. This cannot be explained by a superficial atmospheric contamination nor by losses during or after implantation as both processes would enrich the heavy isotope and lead to low $^{20}Ne/^{22}Ne$ ratios. The observed depletion of the heavy isotope supports the model of fractionation in low-speed SW due to inefficient Coulomb drag [7], which is also consistent with a depletion of α-particles at low SW velocities [8] as measured with the Genesis ion monitor.

The depth distribution of Ar isotopes is consistent with SRIM simulations as well, though just qualitatively. The presence of Ar in the BMG from manufacturing leads to large blank gas corrections for steps with low solar wind contributions. $^{36,38}Ar$ blanks were subtracted assuming ^{40}Ar to be entirely atmospheric. However, this is rather problematic in steps where the background concentration becomes large, because the atmospheric Ar in the BMG might actually be slightly fractionated. This is indeed suggested by the first two etching steps, releasing negligible amounts of solar Ar, with $^{36}Ar/^{38}Ar$ ratios of about 5.27, slightly lower than the atmospheric value of 5.30 [9]. Blank gas contributions from the BMG itself are significant for each step, indicated by the ^{40}Ar amount, which is always 2-10 times higher than the ^{40}Ar amount in a typical acid blank. The measured $^{40}Ar/^{36}Ar$ ratio is close to atmospheric for first etching steps and drops to values >49 only. One step had to be discarded since etching opened a large gas bubble in the BMG totally wiping out the SW signal.

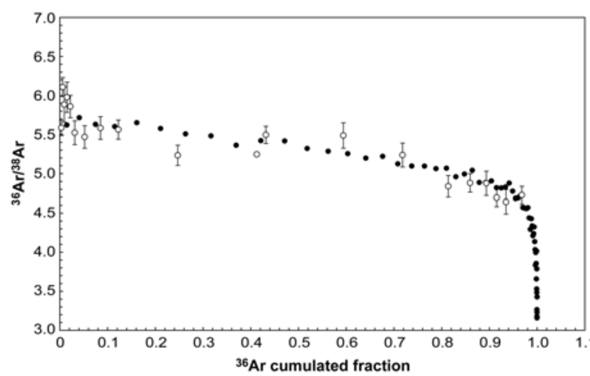

Fig. 1: $^{36}Ar/^{38}Ar$ ratios as measured in the BMG (open symbols) and as simulated with the SRIM code for a uniform SW with a $^{36}Ar/^{38}Ar$ ratio of 5.3 versus the normalized cumulative fraction of ^{36}Ar. One measured data point had to be discarded because of too large blank gas contributions from an opened gas bubble. Note the enhanced measured ratios relative to SRIM predictions in the very first etching steps.

Despite these complications, the general trend for the depth distribution of the blank-corrected $^{36}Ar/^{38}Ar$ ratios is similar to that of $^{20}Ne/^{22}Ne$ ratios in that both ratios decrease with depth (Fig. 1). The Ar data thus confirm the earlier conclusion of mass dependent fractionation upon implantation of a SW with a uniform isotopic composition. Again similar to the $^{20}Ne/^{22}Ne$ ratios, also $^{36}Ar/^{38}Ar$ ratios are slightly elevated relative to SRIM simulations in gas released from close to the surface, although the depletion of ^{38}Ar is less distinct as for ^{22}Ne. Yet, the Ar isotopic data also seem to support the Coulomb drag model for inefficient acceleration in very slow SW by [7]. The "best" value for the $^{36}Ar/^{38}Ar$ ratio of the bulk SW to be deduced from these data is 5.3±0.1, consistent with the Apollo SWC foil ratio of 5.4±0.3 [10], but slightly lower than values of 5.5-5.6 derived from lunar soils and solar-gas rich meteorites [6,11]. However, due to the large blank corrections our BMG value needs some more detailed analysis.

Rather similar to the isotopic ratios also, $^{20}Ne/^{36}Ar$ values in the first few etching steps are enhanced relative to SRIM model predictions (Fig. 2). This is again qualitatively consistent with a depletion of the heavy species due to inefficient Coulomb drag. At larger depths the pattern of $^{20}Ne/^{36}Ar$ ratios flattens out, which is in general agreement with SRIM results. However, many data points plot below the SRIM model data, which is based on a $^{20}Ne/^{36}Ar$ ratio for the SW of 49±7 measured in the Apollo SWC foils [10]. It may well be that this offset at larger depths is mainly a result of an uncertain Ar blank correction (the $^{20}Ne/^{36}Ar$ data points in parentheses are clearly affected by blank gas contributions from an opened bubble).

Conclusions: The depth distribution of Ne and Ar isotopes measured in the BMG can generally be explained by a mass-dependent fractionation of an isotopically uniform SW as a function of implantation depth. No isotopically distinct "SEP" component is required in this interpretation. On the other hand, the Ne and Ar trapped close to the BMG surface is depleted in the heavy isotopes of Ne and Ar, respectively, as well in the heavy element Ar relative to Ne. These observations support the model of inefficient Coulomb drag at very low SW speeds by [7,12] for a small gas fraction of less than 10 %. However, the Ne/Ar ratio might additionally be affected by fractionation as a function of the elements' first ionization potential (FIP). Further investigations are needed for clarification.

The $^{20}Ne/^{22}Ne$ ratio of bulk SW Ne of 13.75±0.05 measured in the BMG agrees well with the established SW average of 13.7±0.3 measured in the Apollo SWC foils [10]. On the other hand, the determination of the bulk SW Ar isotopic composition is compromised by blank gas contributions, and more suitable targets will have to be analyzed for this purpose.

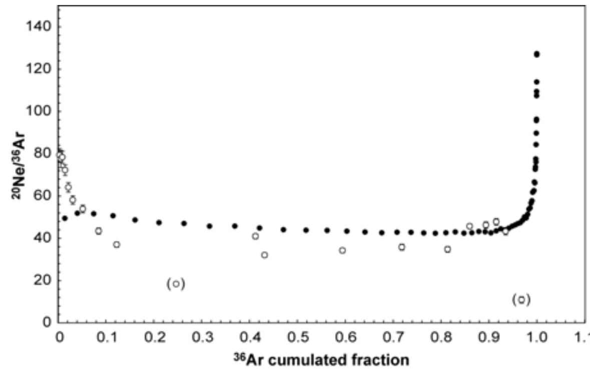

Fig. 2: $^{20}Ne/^{36}Ar$ ratios as measured in the BMG (open symbols) and as simulated with the SRIM code for a uniform SW with a $^{20}Ne/^{36}Ar$ ratio of 49 (bulk SW average from Apollo SWC foils [10]) versus the cumulative fraction of ^{36}Ar. The two data points in parentheses are clearly affected by high blank gas contributions. The enhanced ratios relative to SRIM in the first etching steps agree with the measured isotopic pattern. In larger depth ratios confirm the general trend of SRIM predictions.

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References: [1] Jurewicz A.J.G. et al. (2003) *Space Sci. Rev*. 105, 535-560. [2] Burnett D.S. et al. (2003) *Space Sci. Rev*. 105, 509-534. [3] Heber V.S. (2002) *PhD Thesis*, ETH Zuerich. 535-560. [4] Grimberg A. et al. (2006) *Science 314*, 1133-1135. [5] Ziegler J.F. (2004) *Nucl. Instr. Meth. Phys. Research 219/22*0, 1027-1036. [6] Benkert J.-P. et al. (1993) *J. Geophys. Res. 98*, 13147-13162. [7] Bodmer R. and Bochsler P. (1998) *Astron. Astrophys. 337*, 921-927. [8] Grimberg A. et al. (2007) *Space Sci. Rev.*, submitted. [9] Lee J.-Y. et al. (2006) *Geochim. Cosmochim. Acta 70*, 4507-4512. [10] Geiss J. et al. (2004) *Space Sci. Rev. 110*, 307-335. [11] Becker R.H. et al. (1998) *Meteoritics Planet. Sci. 33*, 109-113. [12] Bochsler P. (2007) *Space Sci. Rev.*, accepted.