

**SOLAR SYSTEM XENON SIGNATURES: SOLAR, FRACTIONATED SOLAR AND AN S-PROCESS DEFICIT.** S. A. Crowther and J. D. Gilmour, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK (sarah.crowther@manchester.ac.uk).

**Introduction:** The noble gases are key tracers of the history of solar system material. Isotopic anomalies in noble gases, notably xenon, led to the first identification of an extinct radioisotope and, ultimately, to the discovery of presolar grains. Solar xenon, as measured in the solar wind (SW-Xe), reflects the integrated contributions from all nucleosynthetic sources that contributed to the solar system over the history of the Galaxy. Alongside the exotic components, xenon isotopes reveal the presence in meteorites of distinct compositions that appear to be mixtures of nucleosynthetic components in proportions similar to, but not identical to, SW-Xe: Xe-Q and Xe-P3. Xe-Q appears to be ubiquitous in primitive meteorites and is associated with an as-yet-unidentified, probably organic, carrier. Xe-P3 is released at low temperature from nanodiamond-rich separates isolated from the most primitive, least processed meteorites.

Gilmour [1] investigated the relationship between these “mixed” components and solar wind xenon as determined in the young lunar regolith (YLR) [2]. He demonstrated that Xe-Q was consistent with mass fractionated SW-Xe with variable additions of exotic Xe-HL and monoisotopic  $^{129}\text{Xe}$  from  $^{129}\text{I}$  decay. It seems likely that an underlying component, fractionated as it was trapped directly from the solar wind, has been modified by additions that vary slightly from parent body to parent body. It was not possible to account for Xe-P3 in such a simple model. Rather, it appeared that Xe-P3 was consistent with a precursor composition from which solar xenon was produced by addition of s-process material. Xe-P3 appeared to be trapped by a similar process to the one that incorporated Xe-Q, but from a gas representative of an earlier period of galactic chemical evolution when the s-process had made a small contribution.

Since that work we and others have analysed xenon from the Genesis collectors, and a more precise definition of solar xenon is now available. Here we show that the relationships advanced by Gilmour [1] still hold and discuss their implications.

**Relationships Between Solar Wind Xenon and Other Solar System Signatures:** The evidence from both our analyses of SW-Xe sampled by the Genesis mission [3] and those of Meshik *et al.* [4] suggests that the lunar measurements appear to be accurate representations of the solar wind. We now examine whether the relationships between SW-Xe, Xe-Q and Xe-P3 hold up when evaluated against the more precise composition of SW-Xe derived from Genesis data. Details of

the methodology can be found in Gilmour [1]. We will use the Genesis SW-Xe data of Meshik *et al.* [4] as they are generally more precise than either our or the YLR data.

We first consider Xe-Q defined as the composition defined by Busemann *et al.* [5] (Fig. 1). As previously, the best fit involves fractionation of SW-Xe by 8.1 ‰  $\text{amu}^{-1}$  favouring the heavy isotopes and addition of Xe-HL (1.5 % contribution to total  $^{132}\text{Xe}$ ). The simplest explanation of this is that the underlying composition of Xe-Q is mass fractionated SW-Xe. On the assumption that the solar wind is not mass fractionated by the acceleration process, mass fractionation is associated with the trapping process. The only isotope that varies from this pattern is  $^{124}\text{Xe}$ ; the  $^{124}\text{Xe}/^{132}\text{Xe}$  ratio of Xe-Q is low compared to the model. We return to this below.

The proposed account of Xe-P3 also withstands the refinement in the composition of SW-Xe (Fig. 2). The accepted composition is defined on a mixing line to Xe-HL, so the (1.1 %) contribution from Xe-HL may or may not reflect a variation between its contribution to SW-Xe and the Xe-P3 source. Once again, neglecting the possibility of mass fractionation during the process that accelerates the solar wind, Xe-P3 appears to have been derived from an ambient gas by a process that introduced the same fractionation as that which was responsible for trapping Q-Xe. However, the ambient gas had an s-process deficit (0.9 % of  $^{132}\text{Xe}$ ) compared to SW-Xe.

Once again  $^{124}\text{Xe}$  is anomalous – Xe-P3 appears to have less than the required amount to act as a parent for SW-Xe by the process outlined above.  $^{124}\text{Xe}$  in the new composition of Meshik *et al.* [4] is notably different from that of the YLR [2]. In Figs. 1 and 2 we also present fits adopting a revised solar composition where the  $^{124}\text{Xe}/^{132}\text{Xe}$  of Meshik *et al.* [4] is replaced by a value based on the YLR measurement. Spallation effects in the lunar regolith could cause an overestimate of the  $^{124}\text{Xe}/^{132}\text{Xe}$  ratio, but this would not be monoisotopic and the variation observed requires the YLR ratio to be an underestimate. For this reason, and because of the relationship to other reservoirs in our solar system, we suggest the apparent high  $^{124}\text{Xe}/^{132}\text{Xe}$  ratio is an artefact and that the revised composition is the best current estimate of the SW-Xe composition – further analyses of Genesis collectors will serve to test this hypothesis.

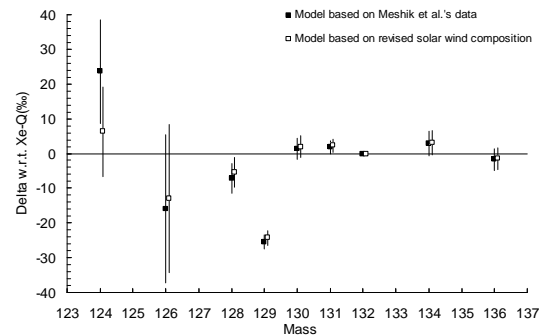
**An s-process deficit in xenon?** The identification of a meteoritic xenon component deficient in s-process isotopes provides an interesting resonance with reports

of s-process deficits in Mo [6, 7]. A possible explanation is that a presolar phase was present in the early solar system that records the isotopic composition of the galaxy earlier in its history, when the s-process had made a smaller contribution to the isotopic inventory. A further insight can be gained from the presence of a  $^{129}\text{Xe}$  anomaly in Xe-P3 relative to the fractionated composition. The  $^{129}\text{Xe}/^{132}\text{Xe}$  ratio of the Xe-P3 component in nanodiamonds varies systematically with the petrologic type of the parent meteorite, showing that  $^{129}\text{I}$  was alive in the early solar system [8]. If this was incorporated at the same time as Xe-P3 was trapped, the trapping process could have occurred no more than  $\sim 10^8$  years before solar system formation. An “initial” iodine ratio for this component (i.e. the ratio that pertained on last closure to xenon loss) provides a further constraint [9].

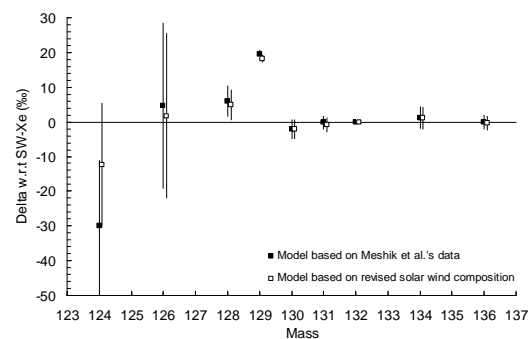
**Origins of Xe-P3 and Xe-Q components:** The Xe-P3 and Xe-Q components exhibit a remarkable similarity apart from the s-process deficit apparent in Xe-P3. Both are fractionated to the same extent from a presumed ambient gas component. Unless this reflects an unexpected fractionation of SW-Xe with respect to the bulk xenon composition of the solar system, it is indicative of a similar trapping process having occurred in different environments separated in time and space on an astronomical scale. In addition, both exhibit excesses of  $^{129}\text{Xe}$  relative to their parent, ambient gas, requiring high I/Xe ratios in their host phase ( $\sim 10^3$  times higher than in the ambient gas, assuming a solar elemental ratio). This high ratio must have held during solar system formation; the excess of  $^{129}\text{Xe}$  varies differently from the other isotopes with petrologic type, indicating that it was present as  $^{129}\text{I}$  during parent body processing. Such elemental fractionation is strongly indicative of a process involving “chemistry”, rather than implantation.

We thus advance a tentative model for the origin of these components. Xenon (and iodine) are continuously incorporated into organic carriers by adsorption in the interstellar medium. Some of these carriers are more resistant to destruction than others. This means that longer lived carriers integrate the evolving xenon isotopic composition over a longer period than shorter-lived carriers. In bulk meteorites the carrier population is dominated by those that incorporated xenon after the last input of freshly synthesised material. A subset of longer-lived carriers survives preparation of nanodiamond-rich residues, so that the Xe-P3 component has a higher contribution of carriers that sampled an earlier stage of galactic chemical evolution and preserves the s-process deficit. The identical processes leading to incorporation imply that Xe-Q is strictly a presolar component (the incorporation occurred in a similar

environment to the incorporation of isotopically distinct xenon reflected in the P3 component) rather than having originated in our solar system.



**Fig. 1.** Models of Xe-Q derived from mixtures of fractionated SW-Xe and Xe-HL.



**Fig. 2.** Models of SW-Xe derived from mixtures of fractionated Xe-P3, Xe-HL and s-process Xe

**References:** [1] Gilmour, J. D. (2010) *GCA*, 74, 380-393. [2] Pepin, R. O. et al. (1995) *GCA*, 59, 4997-5022. [3] Crowther, S. A. and Gilmour, J. D. (2012) *JAAS*, 27, 256-269. [4] Meshik, A. et al. (2012) in *Exploring The Solar Wind*, 93-120. [5] Busemann, H. et al. (2000) *Meteoritics & Planet. Sci.*, 35, 949-973. [6] Dauphas, N. et al. (2004) *EPSL*, 226, 465-475. [7] Burkhardt, C. et al. (2012) *EPSL*, 357-358, 298-307. [8] Gilmour, J. D. et al. (2005) *GCA*, 69, 4133-4148. [9] Gilmour, J. D. (2009) *LPSC XL*, Abstract #1603.

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