



# The Genesis solar xenon composition and its relationship to planetary xenon signatures <sup>☆</sup>

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## Abstract

The fluence and isotopic composition of solar wind xenon have been determined from silicon collector targets flown on the NASA Genesis mission. A protocol was developed to extract gas quantitatively from samples of  $\sim 9\text{--}25\text{ mm}^2$ , and xenon measured using the RELAX mass spectrometer. The fluence of implanted solar wind xenon is  $1.202(87) \times 10^6\text{ atoms }^{132}\text{Xe cm}^{-2}$ , which equates to a flux of  $5.14(21) \times 10^6\text{ atoms }^{132}\text{Xe cm}^{-2}\text{ year}^{-1}$  at the L1 point. This value is in good agreement with those reported in other studies. The isotopic composition of the solar wind is consistent with that extracted from the young lunar regolith and other Genesis collector targets.

The more precise xenon isotopic data derived from the Genesis mission confirm models of relationships among planetary xenon signatures. The underlying composition of Xe-Q is mass fractionated solar wind; small, varying contributions of Xe-HL and  $^{129}\text{Xe}$  from  $^{129}\text{I}$  decay are present in reported meteorite analyses. In contrast, an s-process deficit is apparent in Xe-P3, which appears to have been mass fractionated to the same extent as Xe-Q from a precursor composition, suggesting similar trapping mechanisms. Solar wind xenon later evolved by the addition of  $\sim 1\%$  (at  $^{132}\text{Xe}$ ) of s-process xenon to this precursor. As an alternative model to a single source reservoir for Xe-P3, we propose that trapping of xenon onto carbonaceous carriers has been an ongoing process across galactic history, and that preparation of the residues in which Xe-P3 has been identified preferentially preserves longer lived host phases; a higher proportion of these sample xenon isotopic compositions from earlier in galactic chemical evolution, allowing the s-process deficit to become apparent. The relationships among SW-Xe, Xe-Q and Xe-P3 predict that the  $^{124}\text{Xe}/^{132}\text{Xe}$  ratio for the solar wind is 0.00481(6).

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## 1. INTRODUCTION

The solar system is believed to have formed from a molecular cloud which collapsed to form an early star and an accretion disk known as the solar nebula (e.g. [Russell, 2007](#)). The planets and other solar system bodies formed in this disk. The formation processes of solar sys-

tem bodies left traces in their elemental and isotopic compositions, but to fully interpret them it is necessary to know the bulk elemental and isotopic composition of the solar nebula from which the bodies formed. This can be achieved by measuring the solar composition. The sun accounts for 99.86% of the mass of the solar system so its initial composition was the average starting composition of a well mixed solar system. With the exceptions of deuterium and lithium, the mean elemental and isotopic compositions of the solar photosphere, as sampled by the solar wind, are believed to represent this initial composition with only minor differences due to fractionation ([Turcotte and Wimmer-Schweingruber, 2002](#); [Wiens et al., 2004](#)). The Genesis mission sampled the present day solar wind, with the aim of determining elemental and isotopic

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compositions with sufficient precision to improve our understanding of the formation and evolution of the solar system (Burnett et al., 2003).

The traces of formation and evolutionary processes left in noble gas isotopic compositions are key to understanding the volatile evolution of solar system reservoirs, so determining their solar compositions is particularly important; measuring the elemental and isotopic composition of the noble gases (especially the heavy noble gases) is one of the highest priority scientific objectives of the Genesis mission (Burnett et al., 2003). It is also particularly difficult. Noble gas absorption lines are not observed in spectra of the solar photosphere. The solar compositions of the lighter noble gases were determined from the Apollo Solar Wind Composition (SWC) experiments (Geiss et al., 2004), in which aluminium foils were exposed to the solar wind on the lunar surface for periods of up to 45 h. However the concentrations of krypton and xenon in these foils were below detection limits. Before the Genesis mission, the most accurate solar wind data for neon and argon, and the only available solar wind compositions of krypton and xenon, resulted from measurement of material from extraterrestrial regoliths, especially the young lunar regolith (YLR), i.e. samples irradiated by the solar wind on the surface of the Moon within the last ~100 Ma (Benkert et al., 1993; Wieler and Baur, 1994; Pepin et al., 1995; Palma et al., 2002). However noble gas data from the lunar regolith is potentially affected by other components such as fission and spallation products, the relative contributions of which are difficult to correct for because of uncertainties in their isotopic compositions and the varying chemistry of the material. This leads to some uncertainty in the solar wind isotopic compositions obtained in this manner. The long exposure times of Genesis collectors provide an opportunity to make measurements of directly sampled solar wind without the added complications of spallation or fission components in the lunar regolith samples. Contributions from other components can be corrected for or constrained by analysis of identical unflown samples of the collector materials.

In this work we focus on xenon. The accepted isotopic compositions of both Xe-Q, the major xenon component trapped in meteorites (Busemann et al., 2000), and terrestrial atmospheric xenon (Basford et al., 1973) cannot be derived directly from the solar wind xenon composition (as measured in the YLR) (Pepin et al., 1995) by linear mass fractionation alone. Nor can a third similar component that is observed in nanodiamond-rich residues (Xe-P3) (Huss and Lewis, 1994). Gilmour (2010) showed that Xe-Q can be understood as mass fractionated solar xenon (as measured in the YLR) with the addition of variable amounts of excess  $^{129}\text{Xe}$  from decay of  $^{129}\text{I}$  and of Xe-HL, a presolar component enriched in heavy isotopes that is associated with nanodiamonds isolated from primitive meteorites (Huss and Lewis, 1994). A second meteoritic component, labelled Xe-P3, is also of interest. It is released from nanodiamond residues during low temperature heating. Although it is a similar mix of contributions from various nucleosynthetic sources as Xe-Q, and is fractionated to around the same extent, it is slightly deficient in s-process isotopes

compared to mass fractionated solar xenon (Gilmour, 2010). Atmospheric xenon shows an excess of  $^{129}\text{Xe}$  and is depleted in  $^{134,136}\text{Xe}$  relative to mass fractionated solar xenon. The  $^{129}\text{Xe}$  excess is again believed to be the product of  $^{129}\text{I}$  decay. The  $^{134,136}\text{Xe}$  depletions, however, are much more difficult to explain. The observed ratios cannot be obtained from addition of spontaneous fission products from  $^{244}\text{Pu}$  and  $^{238}\text{U}$  to mass fractionated solar wind. It has been proposed that the Earth's atmosphere sampled a xenon reservoir distinct from the well mixed solar system, which was depleted in the heavier isotopes relative to mass fractionated solar xenon (Pepin, 2000). This proposed component is labelled U-Xe, but to date there is no separate experimental evidence for it.

Here we report the abundance and isotopic composition of xenon released from Genesis mission silicon collectors, compare it to the results of other workers, and consider whether the proposed relationships among bulk solar system xenon reservoirs outlined above survive the improved precision in the solar xenon composition derived from Genesis mission data.

## 2. THE GENESIS MISSION

NASA's Genesis mission (Burnett et al., 2003) was launched in August 2001. The spacecraft spent about two and a half years collecting solar wind in a halo orbit around the L1 Lagrangian point. Samples were returned to Earth for elemental and isotopic analyses in September 2004. Solar wind ions were implanted into collector arrays composed of hexagonal wafers of nine different types of ultra-pure material (Jurewicz et al., 2003). Two bulk collector arrays were continuously exposed to the solar wind for a total of 852.83 days (Reisenfeld et al., 2007). These arrays have the longest solar wind exposure time to date of any artificial material, more than 400 times longer than any of the SWC foils exposed during the Apollo programme (Geiss et al., 2004). The concentrations of implanted solar wind are consequently much higher than in the SWC foils.

## 3. PREVIOUS WORK

We reported the first isotopic analysis of solar wind xenon sampled by the Genesis mission in 2008 (Crowther et al., 2008a; Burnett et al., 2011), and have previously published details of refinements in our analytical technique and a preliminary composition for directly collected solar wind (Crowther and Gilmour, 2012). In our initial experiments xenon was extracted from silicon collector targets by infra red laser heating, but ultra violet laser ablation proved to be a superior extraction method. We showed that, for the major isotopes  $^{129-136}\text{Xe}$ , the xenon isotopic composition of solar wind sampled by the Genesis mission is consistent with that determined from samples of the YLR (Pepin et al., 1995), with at most minor (<5‰ per amu) mass fractionation favouring the heavier isotopes. We determined a preliminary value of 1.0474(75) for the  $^{129}\text{Xe}/^{132}\text{Xe}$  ratio, which is in excellent agreement with the value of 1.042(9) measured in the YLR (Pepin et al., 1995). With the

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