Constraints on the N isotopic evolution of the solar nebula from volatile analyses of a CAI

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Isotopic analyses of osbornite (TiN), considered as the first solid nitrogen-bearing phase to condensate in the cooling nebula, indicated that the protosolar nebula (PSN) was highly depleted in $^{15}$N compared to the terrestrial atmosphere [1]. Results from NASA’s Genesis mission confirmed the very low $^{15}$N/$^{14}$N ratio of the Sun and the PSN ($\delta^{15}$N$_{PSN} = -383 \pm 8$ ‰ [2]). All other Solar System objects (with the exception of Jupiter) are enriched in $^{15}$N compared to the PSN, possibly as a result of i) $N_2$ photochemical self-shielding [e.g., 3] or ii) low temperature isotopic exchanges [4].

Since early-formed solids such as refractory Ca,Al-rich inclusions (CAIs) may retain a record of the nitrogen isotopic evolution of the nebula, we investigate here the N and noble gas (Ne-Ar) abundance and isotopic signature of a large (~4 cm in diameter) coarse-grained type B CAI from a CV3 chondrite by CO$_2$ extraction-static mass spectrometry analysis. In addition, we determined the O and Al-Mg isotope characteristics of the inclusion by SIMS analysis.

Although the CAI crystallized near “time zero” of Solar System history, as shown by its canonical-like ($^{26}$Al/$^{27}$Al) value of $(5.06 \pm 0.50) \times 10^{-5}$, it experienced later partial isotopic exchange with a $^{16}$O-poor reservoir, resulting in large oxygen isotope variations among its constituent minerals. Mellilite and anorthite are $^{16}$O-poor ($\Delta^{17}$O > -5‰), whereas spinel and fassaite retain the original $^{16}$O-rich signature of the solar nebula ($\Delta^{17}$O ≤ -20 ‰). The low $^{20}$Ne/$^{22}$Ne (≤ 0.83) and $^{36}$Ar/$^{38}$Ar (≤ 0.82) ratios rule out the presence of any trapped planetary or solar noble gases, and the abundances of cosmogenic $^{21}$Ne and $^{38}$Ar are consistent with a cosmic ray exposure age of a few to a few tens of millions of years. Strikingly, the CAI contains 1.4 to 3.4 ppm $N_2$ with a $\delta^{15}$N value of 8 to 30 ‰. Even after correcting the measured $^{15}$N/$^{14}$N ratios for cosmogenic $^{15}$N produced in-situ, the $\delta^{15}$N values resemble the isotopic signatures of chondritic meteorites, suggesting that mixing of the PSN with a $^{15}$N-enriched reservoir occurred at very early times.