Short-lived radioisotopes in meteorites from Galactic-scale correlated star formation

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Introduction: Short-lived radioisotopes (SLRs) are radioactive elements with half-lives ranging from 0.1 Myr to more than 15 Myr that existed in the early Solar system. They were incorporated into meteorites' primitive components when the oldest solids formed in the Solar protoplanetary disc. Most SLRs form in the late stages of massive stellar evolution, followed by injection into the interstellar medium (ISM) by stellar winds and supernovae (SNe) [e.g., 1]. Explaining how they travelled from these origin sites to the primitive Solar system before decaying is an outstanding problem [e.g., 2]. Proposed mechanisms fall into three broad scenarios. The first scenario is a SN-triggered collapse: a nearby Type II SN injects SLRs and triggers the collapse of the early Solar nebula [e.g., 3, 4, 5]. The second scenario is direct pollution: the Solar system's SLRs were injected directly into an already-formed protoplanetary disc by SN ejecta within the same star-forming region [e.g., 6, 7]. The third scenario is sequential star formation events and self enrichment in a giant molecular cloud (GMC) [e.g., 8, 9, 10]. Consensus has not reached yet, and no one has yet investigated galactic-scale SLR distributions. However, one should take account of Galactic-scale chemodynamics for chemical enrichment due to massive stars.

Method: We study the abundances of 60Fe and 26Al in newly-formed stars by performing a high-resolution chemo-hydrodynamical simulation of the ISM of a Milky-Way like galaxy. The simulation includes hydrodynamics, self-gravity, radiative cooling, photoelectric heating, stellar feedback in the form of photoionisation, stellar winds and supernovae to represent dynamical evolution of the turbulent multi-phase ISM. Further details on our numerical method are given in Fujimoto et al. (2018) [11].

Results: The distributions of 60Fe and 26Al are strongly correlated with the star-forming regions (see Fig. 3 of [11]). This is as expected, since these isotopes are produced by massive stars, which, due to their short lives, do not have time to wander far from their birth sites. However, there are important morphological differences between the distributions of 60Fe, 26Al, and star-forming regions. The 60Fe distribution is the most extended, with the typical region of 60Fe enrichment exceeding 1 kpc in size, compared to 100 pc or less for the ISM density peaks that represent star-forming regions. The 26Al distribution is intermediate, with enriched regions typically hundreds of pc in scale. The larger extent of 60Fe compared to 26Al is due to its larger lifetime (2.62 Myr versus 0.72 Myr for 26Al) and its origin solely in fast-moving SN ejecta (as opposed to pre-SN winds, which contribute significantly to 26Al).

To investigate abundance ratios of isotopes in newborn stars, whenever a star particle forms in our simulations, we record the abundances of 60Fe and 26Al in the gas from which it forms, since these should be inherited by the resulting stars (see Fig. 5 of [11]). The probability distribution function (PDF) of 60Fe peaks near 60Fe/56Fe ~ 3e−7, but is ~ 2 orders of magnitude wide, placing all the meteoritic estimates well within the ranges covered by the simulated PDF. The 26Al abundance distribution is similarly broad, but the measured meteoritic value sits very close to its peak, as 26Al/27Al ~ 5e−5. Clearly, the abundance ratios measured in meteorites are fairly typical of what one would expect for stars born near the Solar Circle, and thus the Sun is not atypical.

Conclusion: The SLRs are not confined to the molecular clouds in which they are born. However, SLRs are nonetheless abundant in newborn stars because star formation is correlated on Galactic scales. Thus, although SLRs are not confined, they are in effect pre-enriching a halo of the atomic gas around existing GMCs that is very likely to be subsequently accreted or to form another GMC, so that new generations of stars preferentially form in patches of the Galaxy contaminated by previous generations of stellar winds and supernovae.

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