THE AGE SPECTRUM OF ISOTOPES IN THE EARLY SOLAR SYSTEM AND IMPLICATIONS FOR COSMIC CHEMICAL MEMORY

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Introduction: Cosmic chemical memory asserts that isotopic effects in cosmochemical samples cannot be fully understood without accounting for the degree to which those samples or their precursor material record the history of their formation in stars and their alteration in the interstellar medium (ISM) [1]. While the details of chemical memory in the Solar System are complex, an understanding of the age spectrum of isotopes gives a good sense of how that chemical memory might operate.

Galactic Chemical Evolution: In order to infer the age spectrum of isotopes, we model their evolution in the Galaxy with ICE (our Inhomogeneous Chemical Evolution code) [2]. We follow the evolution of a 10^8 Solar mass annulus at the radius of the Sun's orbit around the Galactic center from its build up by infall (on a 10^9 year timescale) to the present time. We break the annulus into 32 zones and allow mixing between the zones which we take to be driven by the passage of three spiral arms. We follow the evolution of isotopes in the annulus using appropriate stellar yields [3,4]. We also include ejecta from rare neutron-star mergers, which we take to produce r-process isotopes [5]. We assume those isotopes are ejected in Solar proportions.

Fictitious Species: To infer the age spectrum of isotopes in the initial dust of the Solar System, we introduce fictitious species into the GCE model. For each type of stellar source, we consider a fictitious element and for each particular instance or time-related instances of that source we consider an isotope of that element. For example, we add to the ejecta from a neutron star merger event an isotope of $Z=150$. A core-collapse supernova ejects an isotope of $Z = 151$, and so forth. The first neutron star merger event uniquely ejects a fixed amount of $Z = 150$ and $A = 300$. The second merger event uniquely ejects the same amount of $Z = 150$ and $A = 301$, and so forth. By looking at the mass fraction of each $Z = 150$ isotope in a solar mass star forming around the time of the Sun's birth, we can then compute the relative contribution of each merger event to that star's inventory of r-process elements. Because we know the time of each merger in the model, we can also correct for the radioactive decay of any species since its production.

Results: As an example of the age spectrum of isotopes expected in the early Solar System, we briefly present our model results for three r-process isotopes: ^{127}I (stable), ^{129}I (half life of 15.7 Myr), and ^{238}U (half life of 4.46 Gyr). Neutron star mergers throughout Galactic history contributed ^{127}I to Solar-type stars forming near the time of the Sun's birth. In our model, each merger contributes ~1% of the ^{127}I in a given star; however, mergers occurring early in Galactic history contributed somewhat less ^{127}I than later mergers. This is because isotopes from the earlier events have a greater probability of being locked up into low-mass stars that do not return their mass. Also interesting is the fact that the last merger events before a Sun-like star's birth can contribute either significant amounts (~10%) or little ^{127}I according to how long it took that matter to mix from the merger to the location of the forming star. In the model, the average age of the ^{127}I nuclei in the Solar-like stars is about 3.5 Gyr at the time of the stars' birth. The age spectrum of ^{238}U looks similar to that of the ^{127}I but is shifted more in favor of later events due to radioactive decay. The average age of ^{238}U in the Solar-like stars is about 2.3 Gyr. Finally, the age spectrum of ^{129}I is strongly shifted towards later events in Galactic history due to the short lifetime of this species. Only a few (~3-7) mergers contribute ^{129}I to a given Solar-like star, and the average age of ^{129}I is only about 10^8 years.

Discussion: The age spectrum of isotopes gives us a sense of the siting of those isotopes in the initial dust in the Solar System. As dust grains sputter and re-accrete in the interstellar medium, the size spectrum tends to shift to larger grains [6]. This suggests that the older an isotope is, the more likely it is to be in larger grains. In this way, we expect size-sorting of dust in the proto-planetary disk will then sort isotopes according to their average age. Similarly, if isotopes ejected from a star plate out on pre-existing dust, those isotopes will be preferentially sited on the surface of small grains since small grains carry most of the surface area in a grain-size distribution appropriate for the ISM. In the ISM, isotopes that are preferentially surface sited tend to move, via sputtering and re-accretion, into the interiors of dust grains [7]. Since isotopes preferentially sited in the surface of dust grains are likely to be more susceptible to thermal processing in the proto-planetary disk, we expect younger isotopes to be more easily removed from their carriers than older isotopes. We are coupling the ICE code to dust evolution models to follow the isotopic evolution in a more detailed manner.

References: [1] Clayton D. D. (1982) *QJRAS*, 23:174-212. [2] Bojazi M. J. and Meyer B. S. (2018) *LPS XLIX,* Abstract #2890. [3] Weaver T. A. and Woosley S. E. (1995) *ApJS,* 101:181-235. [4] Thielemann F.-K. et al. (1986) *A&A* 158:17-33. [5] Kasen D. et al. (2017) *Nature* 551:80-84. [6] Clayton D. D. et al. (1989) *ApJ* 346:531-538. [7] Meyer B. S. and Clayton D. D. (2000) *Space Sci. Rev.* 92:133-152.