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NEW COSMIC-CHEMICAL-MEMORY MECHANISM FOR ISOTOPIC ANOMALIES;

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In this paper I introduce a new mechanism for the chemical memory of isotopic anomalies based on the temporal change during the chemical evolution of the Galaxy of the isotopic composition of the mean ejecta from stars. The words mean ejecta are quite important to this idea, for they are intended to temporarily suppress considerations of the wide variations in compositions among individual SUNOCONs [1] expected from differing zones of different stars. The key idea instead is that the bulk isotopic composition of the total ejecta from stars, summed over all types of stars, changes monotonically and predictably as the Galaxy ages. Thus any physical mechanism (of which I will give two examples) that partially segregates "old ejecta" from "young ejecta" in the interstellar medium will also create macroscopic pools of differing isotopic composition. These pools become differently mapped into the spectrum of molecular-cloud dust particles, and can perhaps therefore be recovered to some degree during the selective histories leading to the aggregation of meteoritic samples.

The key nucleosynthesis idea is the distinction between primary and secondary nucleosynthesis products. A primary nucleosynthesis product is synthesized even in stars born from hydrogen and helium only, whereas a secondary nucleosynthesis product is produced in proportion to the concentration of heavier elements (usually C and O) initially present when the star formed. The most abundant nuclear species (viz. ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, ^{36}Ar, ^{40}Ca, ^{44}Ca, ^{48}Ti, ^{52}Cr, ^{56}Fe) are all primary products, whereas the less abundant isotopes of those elements are in varying degrees secondary. I here single out ^{13}C, $^{17,18}O$, $^{21,22}Ne$, $^{25,26}Mg$ and $^{29,30}Si$ as having yields proportional to the initial C + O content of the stars. This initial C + O content has itself grown with time, as has therefore the isotopic composition of stellar ejecta.

Analytic mathematical models of this differential growth have been created [2]. In the simplest galactic model, the mass of disk gas in the solar neighborhood of the sun has declined exponentially (linear dependence of star formation rate on remaining gas; constant fraction of initial stellar mass returned to interstellar medium; constant yield of primary species per unit mass of star formation [3]). The exact analytic result [3] for that model is that the gas concentration Z_1 of a primary nucleosynthesis product grows linearly in time, $Z_1 = y_1 \omega t$ (primary), where y_1 is the constant yield and ω the e-fold rate of decline of gas. The interstellar concentration of a secondary product, whose yield $y_S = \beta Z_1(t)$ is proportional to the initial stellar metallicity, is $Z_S = y_1 \beta \omega t^2/2$ (secondary) where β is a different constant coefficient for each secondary nuclear species. These equations can clearly also be written in the form $Z_1 = Z_{1\odot}(t/t_\odot)$, $Z_S = Z_{S\odot}(t/t_\odot)^2$ where $Z_\odot$ is the interstellar concentration at the time $t_\odot$ when the solar system formed. These are integral accumulations for the entire Galactic history; however, the current rate of ejection from stars is proportional to dZ/dt. Thus, when evaluated at $t = t_\odot$, the rate of ejection of a primary nucleus is $(dZ_1/dt)_\odot = Z_{1\odot}/t_\odot$, equal to its average past constant rate of growth, whereas $(dZ_S/dt)_\odot = 2Z_{S\odot}/t_\odot$, equal to twice its average past rate. I give physical meaning to this by an example: the bulk isotopic composition of silicon being ejected from stars when the solar system formed

$$\left[\frac{d^{29,30}Si/dt}{d^{28}Si/dt}\right]_{t_\odot} = 2\left(\frac{^{29,30}Si}{^{28}Si}\right)_\odot$$

is *twice* the solar isotopic composition. That is, bulk stellar ejecta at $t = t_\odot$ carried isotopic anomaly $^{29,30}\delta = 1000$ (assuming that ^{29,30}Si are 100% secondary nucleosynthesis products, a slight exaggeration only). This large anomaly is, I repeat, a bulk average which contains the large specific anomalies in different SUNOCON's and STARDUST. It is possible that this "global" anomaly can appear in macroscopic samples more easily than can those of individual SUNOCONs. Two suggested mechanisms follow, both formulated within the framework of stochastic evolution of dust by sputtering and reacretion cycles [4].

Mechanism 1. Thermal condensate dust is younger than the mean age of the nuclei accreted as mantles. The sputtering cycles of refractory SUNOCONs and STARDUST gradually destroy those thermal condensates, but the gaseous atoms in bulk are old and are reaccreted as amorphous mantles in cold clouds. In this description the refractory thermal cores carry *on average* large positive anomalies of secondary isotopes because of their youth. For example, refractory SiC would for this reason alone carry excess ^{29,30}Si and excess ^{13}C in comparison with the older nuclei in amorphous mantles, a result which may have been observed [5].

Mechanism 2. Particle age spectrum. Suppose that *all* thermal SUNOCONs and STARDUST are either destroyed or never condensed, so that only amorphous reaccreted particles exist in interstellar dust. Isotopic anomalies will still be carried by any class of particle having a mean accretion age different from the bulk mean. For example, in thermal sputtering more massive dust particles live longer (through more accretion cycles) than do small particles [4]. Hence aggregates of the younger fine grain size carry positive secondary excess, and aggregates of the older large grains carry negative secondary excess. Interstellar medium evolution has thereby *created* isotopically anomalous dust.

Concluding speculations on oxygen: A ^{16}O excess associates itself naturally with refractory oxides in the second picture. If those refractory oxides (*e.g.* Al_2O_3), whether SUNOCONs are not, live longer than average dust by a mere 5×10^8 yr on average, they will have 5% excess of ^{16}O owing to their age alone. The plausibility of this suggestion renders it a candidate as attractive as the SUNOCON-carrier interpretation [1,6]. It is the first explanation of the correlation of Al with ^{16}O that does not rely on assuming it to have been inserted in SUNOCONs. Surviving ^{16}O-rich Al-rich SUNOCONs strengthen the correlation, but it would nonetheless exist even in their absence. The new interpretation is that interstellar Al (oxidized by ambient oxygen) gradually concentrates into the longest-lived particles (*e.g.* most massive) by the cyclic histories of vaporization and reaccretion, and that those older particles retain their older (*i.e.* ^{16}O-rich) oxygen.

Although this theoretical treatment introduces powerful new variables into the isotopic-anomaly picture, they are of a readily quantifiable type that can accelerate the understanding of the significance of the anomalies.

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