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Cosmic Chemical Memory of 48Ca/50Ti Correlation

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COSMIC CHEMICAL MEMORY OF $^{48}Ca/^{50}Ti$ CORRELATION; Donald D. Clayton, Rice University

I employ here the numerical model of refractory interstellar dust constructed by Liffman and Clayton [1] to discuss plausible contexts of the $^{48}Ca/^{50}Ti$ correlation found in meteoritic CAI. It becomes important to address this problem in light of recent findings [2,3,4,5] that very large anomalies in both isotopes of both positive and negative sign are found in hibonite crystals from Murchison and from Murray, and that the algebraic sign of these large anomalies is correlated, and especially because at least one of these groups [3] has described these findings as evidence <u>against</u> a cosmic-chemical-memory interpretation and another [5] as evidence <u>for</u> supernova admixture.

Despite some momentary uncertainties, it now seems almost certain that ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe and ^{62}Ni have common nucleosynthesis origin [6,7] in matter ejected in nuclear statistical equilibrium after having been first compressed to such high density that the matter has been made neutron-rich because of electron captures. The location is probably near the mass cut between ejected matter and neutron-star matter outside the collapsed core of massive stars. This common nucleosynthesis origin itself suggests the likelihood of correlated isotopic anomalies in these isotopes, but it still remains necessary, indeed even more necessary in this case, to understand the physical process by which these excess isotopes have been brought together in the meteoritic inclusions. Some [e.g., 3,5] have taken the attitude that matter somehow comes straight from the supernova core into the meteoritic inclusion, without mixing totally with the normal matter. In such a model the numbers of excess atoms of heavy isotopes should stand in the ratio of their production by nucleosynthesis. And the inclusions with correlated deficits must somehow be rich in previously unenriched solar material that was, for the most part, eventually made normal by the injection of excess heavies. In the cosmic chemical memory interpretation it is the chemical properties of the different elements and the chemical composition of the environments in which they are first synthesized and ejected that fix isotopic correlations in specific interstellar dust components. This distinction has already been emphasized in a discussion [8] that also advanced a cosmochemical prediction of the $^{48}Ca/^{50}Ti/^{54}Cr/^{58}Fe$ <u>correlation in the interstellar medium</u>; <u>viz</u>: this suite of isotopes has birthdays in an expanding gas that has just been in nuclear statistical equilibrium, and therefore totally lacking in the oxygen and sulfur that bathed the SUNOCONs of the dominant isotopes of these elements, and also lacking in the major mineral cations Mg, Al, Si, Ca and Ti. It follows that this material cannot condense in ionic structures, causing me to conclude [8] that these isotopes condense, if at all, in metallic droplets dominated by Fe and Ni. I suggested specificially that this is the physical circumstance that rationalizes the very existence of large and endemic anomalies in ^{50}Ti. The concept of small metallic interstellar droplets enriched in these heaviest isotopes is one possible mode for a cosmic-chemical-memory interpretation of their correlated existence in meteoritic inclusions. An excess or deficit in the number of these droplets during aggregation of refractory SUNOCON cores in the hot solar disk could account quite naturally for correlated anomalies of either sign.

In this work I question whether carrying the correlation in metallic droplets is the right idea. As an alternative I suggest that either these equilibrium metallic zones were not able to condense, already anticipated by [8], or that they were able to do so only in a large number of very small particles in comparision with the major ionic SUNOCONs. Either case can be seen with the aid of Liffman and Clayton's [1] models to result in an equivalent new explanation of the correlated anomalies via the CCM theory. The condensation is inhibited by two energy inputs that keep this innermost zone of the supernova ejecta hot. A spinning central neutron star at the center of this expanding zone emits radio power and plasma profusively (the pulsars), and the metallic droplets attempting to condense are continuously heated by this initially violent energy output. This "metallic zone" provides a buffer between pulsar and the exterior mantle of outflowing gas and SUNOCONs, where condensation of larger particles is expedited by their abundance of cations and oxidizing anions. Secondly, a multizone e-process [7] is dominated by ^{56}Ni, whose β^+ decays so heat these e-process zones that condensation is delayed to such a late time that it does not in fact occur [9]. The same net cosmochemical effect obtains if their condensation is in very small particles. Our calculations [1] show only about 8% of refractory SUNOCONs having a ≈ 0.01μ are still in existence after 6 Gyr, whereas 50% of those larger SUNOCONs near a = 0.1μ remain. The small particles are sputtered away quickly so that their atoms join those ejected initially gaseous. In either case they end up as reaccreted refractory mantles (the phase C of Fig. 1 of [1]). The SUNOCONs carrying the most abundant isotopes of Ca and Ti are predicted to be Phase B core particles, and, if they are in fact initially larger than the metallic droplets, they survive much more efficiently.

What is the effect of this scenario. In our evolved model [1], 91.4% of the refractory mass exists as phase C mantles (see their Fig. 1), and those phase C mantles contain almost all of the heavy neutron-rich isotopes. Phase C is therefore the carrier source of their excess. From Fig. 2 of [1] we see that the largest particles, up to 0.3μ, are predominantly phase C material, containing 91% of all refractory atoms and all of ^{48}Ca, ^{50}Ti, so those particles carry $^{48}\delta = {}^{50}\delta \approx 9\%$, typical of the sizes of observed hibonite excesses. The negative anomalies in the phase B cores are intrinsically much larger in this picture, but harder to isolate owing to the difficulty of aggregating macroscopic quantities of phase B cores without substantial phase C mantles. The high ambient temperature in the solar disk may well establish refractory-rich evaporative residues of these particles in the place where they are aggregating into macroscopic collections and sintering to become the observed hibonites, but grain size variations during that aggregation will gather some refractory aggregates rich in 48, 50, 54 and some deficient in them. By histories of this type, isotopic fractionation has been established in particles that initially lacked such fractionation. The absolute numbers of excess atoms do not occur in the same ratio as their nucleosynthesis yields in CCM theory because they are different elements and have encountered also chemical fractionation at any one of several stages of the overall history, so that a simple bimodal mixture is not obtained except in first approximation. But the chemical state of the hibonites and their rare-earth patterns would be expected to be fairly independent of the sign of the anomalies, because positive and negative anomaly hibonites are made of essentially the same stuff by the same processes, sintering of evaporative residues.

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