ISOTOPIC RELATIONS IN DIFFERENT RESERVOIRS OF CONDENSATION OF THE PRIMORDIAL MATTER.
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Introduction: The isotopic anomalies of some extinct radionuclides testify to the outburst of a nearby supernova just before the collapse of the protosolar nebula. Therefore, there were, at least, two reservoirs of condensation of the primordial matter: expanding shell of the supernova and main volume of the protosolar nebula. They are different in two aspects.

1. Composition. The protosolar nebula consisted of the matter of a giant gas–dust cloud, the ultrasonic turbulence of which homogeneously mixed the matter with the nucleosynthesis products of approximately ten supernovae during the nebula lifetime until its collapse into the protosun [1]. The matter of expanding shell of the last supernova, before the complete mixing with that of the protosolar cloud, was enriched with products of nucleosynthesis, which depend on the type of supernova. If it was a core-collapse Sn II, its shell would be enriched, in particular, with the products of *r*-process. In the case of carbon-detonation Sn Ia, at the explosive burning of carbon and oxygen only elements of intermediate atomic weights (up to iron peak) were synthesized, e.g. from 0.6 to 0.8 $M_{\odot}$ of the iron group elements, and ~ 0.3 $M_{\odot}$ of Si and other elements, including Mg, P, S, and Ca. [2] The expanding zone of the complete destruction of Sn Ia is depleted by the burnt out C and O; besides, the products of *r*-process are absent. In the well-mixed matter of the protosolar nebula the isotopic anomalies of extinct radionuclides typically show, on logarithmic scale, a linear dependence on the squared half-life of all the radionuclides $(T_{1/2})^2$ [3]. However, in minerals of CAIs with a formation interval of ≤ 1 m.y., a large excess of short-lived radionuclides only, the mass of which is less than the mass of iron-peak nuclei, is observed in addition to the radionuclides captured from the nebula (and corresponding to $(T_{1/2})^2$) [4]. That might happen only after a SN Ia explosion [5].

2. Radiation conditions. Other sources of isotopic anomalies were spallation reactions with high-energy particles accelerated in shock waves [6]. The region of a supernova outburst is a zone of strong shock waves, at the front of which the diffusive acceleration of particles with formation of the power-law energy spectrum of high hardness $F(>E_0) \sim E^{-\gamma}$ takes place [7]. Here the spectral index is $\gamma = (\sigma + 2)/(\sigma - 1)$, where σ is the degree of matter compression at the shock front. Obviously, in strong shock waves (at $\sigma >> 1$), a very hard spectrum of accelerated particles (with $\gamma \to 1$) can be formed. As a result, the fluxes of nuclear-active particles above the threshold energies of spallation reactions can increase up to two orders of magnitude in comparison with the average integral fluxes of ~ 10^{19} cm^{-2}, predicted for the early Solar system [8]. Besides, since the energy spectrum of nuclear-active particles changes, the weighted spectrum-averaged cross sections $\bar{\sigma} = \int_{E_0}^{E} \sigma(E)F(E)dE \Big/ \int_{E_0}^{E} F(E)dE$ for the production of many isotopes, the excitation functions of which are sensitive to the shape of the particle spectrum, vary as well. Hence, owing to the diffusive shock wave acceleration of particles, the spallation production rates for all the isotopes must increase, but the rate of the increase is not the same for different isotopes. In other words, in reservoirs reprocessed by shock waves (expanding shells of supernovas) isotopic and elemental ratios being absolutely different from those in the matter not affected by such reprocessing (the main volume of the protosolar nebula) are formed [6,9].

Isotopic Relations: It is important that the quantities of such isotopic anomalies can be exactly calculated. Table1 presents the isotopic relations of $^{26}Al/^{27}Al$, $^{41}Ca/^{40}Ca$ and $^{53}Mn/^{55}Mn$, formed in spallation reactions of high-energy particles of the different energy spectrum hardness (different γ) with some corresponding target nuclei in the early Solar system. The cosmic abundances of the target elements from [10] were used. Experimental and simulated excitation functions of the considered isotopes from their nearby target nuclei were compiled from many papers, the references to which were given in previous works, e.g. [6,9].

Table 1 Dependence of isotopic ratios on the hardness of the energy spectrum (γ) of incident particles

Isot.rat / γ	$^{26}Al/^{27}Al$ 10^{-5}	$^{41}Ca/^{40}Ca$ 10^{-6}	$^{53}Mn/^{55}Mn$ 10^{-4}
1.1	15.76	0.7025	30.39
1.5	6.98	0.3451	14.06
2	0.594	0.1043	3.94
2.5	0.46	0.08073	1.00
3	0.093	0.00852	0.248
3.5	0.023	0.00229	0.0615
4	0.0059	0.000672	0.01702
5	0.00035	0.000043	0.00124
6	0.00002	0.000003	0.00009

The hard energy spectrum of particles is a very important characteristic of radiation from the star formation regions reproduced by the strong shock waves: the index of the integral spectrum may decrease down to $\gamma \sim 1$ as compared with $\gamma \sim 2.5$ in galactic cosmic rays and $\gamma \sim 3–6$ in solar cosmic rays. Measuring the isotopic ratios in a refractory meteoritic mineral one may estimate the radiation conditions in its condensation reservoir, i.e. identify the latter. It is clear that such a quantitative approach provide us with subtle tool for studying peculiarities of formation of the primordial matter and the bodies in the early Solar system.

Discussion: It is clear that, due to the supersonic turbulent mixing, the high anomaly isotopic ratios, as well as unusual composition of the expanding supernova shells, will be diluted and lost among the tremendous quantity of the common isotopic ratios in the main volume of the protosolar nebula. However, during expansion, the newly synthesized matter of supernova was cooled at the periphery of its shell, so that the early high-temperature condensates might capture the isotopes with their anomalous relations, formed in this region, and might conserve them further in the primordial matter. It is worth noting here that D. D. Clayton [11] was, apparently, the first to indicate that the time between the generation of isotopes and their fixation in solid phases is the most cryptic and least studied period in cosmochemistry. The nature and the amount of each specific isotope anomaly in a certain mineral phase were determined by the ability of isotopes to survive and by the ability of the given mineral to retain these isotopes under the extreme *PT*-conditions (pressure and temperature conditions) of the early Solar System. Indeed, just in high-temperature phases of some refractory minerals of CAI in the carbonatheous chondrites the anomalous isotopic relations, formed in hard radiation conditions ($\gamma < 2$), are observed [12-14, etc.]. This allows us to suppose that just the peripheric layers of the supernova expanding shell were zones of condensation of those refractory minerals and formation of CAI of carbonaceous chondrites [6,15].

The most interesting is the situation in differentiated meteorites [1]. The latter bear minerals that were probably condensed under quite different radiation conditions. The very close ratios $^{53}Mn/^{55}Mn \sim (1–2)\cdot10^{-6}$ (corresponding to spectral index $\gamma \sim 4$, see Table 1) are observed in the olivines of meteorites with various thermal history (in pallasite, achondrite, enstatite chondrite, and angrite). However, in sulfides and phosphates of the same meteorites, as well as in the Wiley iron meteorite, these ratios are much higher and they correspond to $\gamma \sim 1.2–2.5$. The striking coexistence of materials from reservoirs with different radiation conditions in the same meteorites allows us to conclude that the parent bodies of differentiated meteorites probably accreted in the zones of the most efficient mixing of the matter of a dust-rich (including ^{26}Al) supernova envelope and of the major reservoir of the protosolar nebula strongly enriched with dust too. Just the decay of simultaneously trapped ^{26}Al promotes heating of the matter and further magmatic processes in differentiated meteorites.

A question arises why just sulfides and phosphates turned out to be condensates of the supernova reservoirs. In the case of SnII explosion, all the shells above the neutronized core were thrown away with the nearest one enriched by the products of oxygen burning, namely, Si, P and S [17]. Just that shell underwent the highest compression and the hardest irradiation with the shock wave accelerated particles. The chemical form of the matter in that shell are just sulfides and phosphates [18]. In the case of Sn Ia complete destruction, induced by the explosive C and O burning, the matter was condensed under gradual cooling at very reducing medium, strongly depleted in O. Therefore, sulfides and phosphides were the most favored condensates. Phosphates are, apparently, the results of subsequent oxidation. It is important that the P-bearing Fe–Ni sulfides are found in CM chondrites, and their paragenesis points out to their extrasolar origin [19].

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