

ON POSSIBLE SOLAR ORIGIN OF METEORITIC NANODIAMONDS. Galina K. Ustinova ,
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The laboratory experiments on synthesis of artificial nanodiamonds demonstrate an extremely large spectrum of the physical and chemical conditions for realization of this process. Indeed, the synthetic nanodiamonds are obtained in the processes of detonation synthesis at high pressure and temperature, as well as by low-pressure condensation being similar to chemical vapor deposition at moderate temperatures (CVD-techniques), and as well as by irradiation of carbonaceous materials with laser, intensive ultraviolet radiation or high-energy particles [1]. In view of the variety of the admissible astrophysical conditions, one may anticipate ubiquitous distributions of nanodiamonds in cosmos. Thus, the observations of the interstellar extinction testify to the fact that up to 10% of the interstellar carbon could be bound up in the interstellar diamond [2]. Nanodiamonds with the lognormal size distribution being similar to that for meteoritic ones are observed in circumstellar disks in the systems of Herbig emission stars of HD97048 and Elias 1 [3], in the carbon-enriched protoplanetary nebulae [4] and even in the interplanetary dust [5].

In the case of the presolar diamonds, the bimodal behavior of the xenon release is observed: mainly as the Xe- P_3 component with the normal isotopic composition and as the anomalous Xe-*HL* component with an exotic isotopic composition [6]. In comparison with the solar xenon, the Xe-*HL* component is about twice enriched with the light neutron-deficient isotopes ^{124}Xe , ^{126}Xe , as well as with the heavy neutron-rich isotopes ^{134}Xe , ^{136}Xe . The light isotopes are products of the *p*-process, and the heavy isotopes are products of the *r*-process of nucleosynthesis at the explosions of the core collapse supernova of type II (SnII). At the same time, all isotopes of Xe may have cosmogenic components, formed in the spallation reactions of Ba, Cs, Ce, and La with high-energy particles.

The protosolar nebula contained the nanodiamonds and Xe isotopes generated in about ten of SNII explosions. The last explosion before the formation of the Solar system was the explosion of a carbon-detonation supernova (SnIa) [7], during which all the previously synthesized grains of nanodiamonds practically lost the noble gases of previous generations. At the coreless SnIa explosion, which, besides, has no hydrogen envelope as well, the products of *r*-process are absent, and the *p*-process runs

mainly as spallation reactions due to the ambient proton resources. In the conditions of the SnIa explosive shockwave propagation, the new nanodiamonds were synthesized. At the front of the shock wave they trapped the Xe isotopes produced by spallation of the nearby target nuclei with the shock wave accelerated protons of very hard energy spectrum (spectral index $\gamma \sim 1$), as well as the heaviest isotopes of Xe from the previous SnII explosions, by which the front of the shock wave was especially enriched due to the acceleration mechanism [8].

Indeed, a close fit of the measured Xe isotope ratios in Xe-*HL** and Xe- P_3 * components in the primitive chondrites (* according to [6]) to the isotopic ratios of Xe generated by spallation of the nearby target nuclei with shock wave accelerated protons at the different rigidity of their energy spectra [9] (see below the rows 3 and 6 in Table 1) reveals the spallogenic nature of Xe-*L*, as well as of Xe isotopes of middle mass numbers, i.e. confirms their generation at the front of the explosive shock wave from SnIa. Just for the production of the heaviest isotopes ^{134}Xe and ^{136}Xe , the reactions of spallation are insufficient and an additional nucleogenetic source is required. However, because of fractionation of the ions during their acceleration in shock waves, just the short-time local ranges of the pre-front of the explosive shock wave are the most enriched reservoirs of the heavier isotopes, including ^{134}Xe and ^{136}Xe in the protosolar nebula from the earlier SnII explosions [7,10]. That supplemented the formation of the heavy component Xe-*H*. The trapping of Xe-*L* and Xe-*H* by the fresh-synthesized nanodiamonds in the conditions of the explosive shock wave propagation completed the formation of the anomalous Xe-*HL* component.

It should be emphasized that the synthesis of a nanodiamond and its enrichment with Xe-*HL* are possible in the extreme *PT*-conditions at the pre-front of the shock wave, as well as by nucleation in the range of rarefaction behind the front of the shock wave or by irradiation of carbonaceous grains with high-energy particles. The anomalous isotopic composition of the Xe-*HL* is conditioned by amplifying the rigidity of the energy spectrum of nuclear-active particles and enrichment of the spectrum with heavier ions under their acceleration in shock waves. The possibility of such a process allowed us to assume that, at least, the population of nanodiamonds with the anomalous Xe-*HL* component, which is observed

in chondrites, was synthesized at the formation of the Solar system, in other words, it is not presolar. Such a conception is in accordance with the results of study of the inter planetary dust particles [5], which gives the evidence that the nanodiamonds are absent in the dust of comets and/or their abundance decreases with the increase of the heliocentric distance. Such a model agrees also with the above-mentioned observations of nanodiamonds in the vicinity of some evolving stars with the nascent accretion discs [3].

It should not be supposed, apparently, that the nanodiamonds of this population have not undergone any change from the moment of their formation up to the moment of their investigation in chondrites, and that the xenon has been conserved in those isotopic relations, in which it was generated. In Table 1 there is a comparison of the observed Xe isotopic ratios in Xe-HL component with the theoretical ones at $\gamma \sim 1$ (row 7), and, analogously, of those in Xe-P₃ component with the theoretical ones at $\gamma = 3$ (row 8). It is well seen there that the xenon conserved in nanodiamonds is considerably heavier than that originally generated, and this effect is practically equal for Xe-HL and Xe-P₃ components. The latter indicates to the fact that the processes, which resulted in such weighting, occurred already after the formation of these components. Firstly, it might occur during the xenon trapping by the nanodiamond grains, because at low energy of implantation the heavy ions stick easier in the lattices of crystals [11]. Secondly, many processes of accretion led to multiple acts of partial recrystallization of the nanodiamond grains. It was

followed by diffusion and evaporation of gases from the destroyed traps, cracks and other imperfections of the crystal lattices, which commonly were removed by recrystallization. As a consequence, that led to the progressive essential weighting of the isotopic system of the conserved gases, in comparison with their initial isotopic system at generation, due to the effects of the kinetic isotopic fractionation.

Of course, it cannot be excluded that, somewhere at the periphery of the collapsing protosolar nebula, some presolar grains of other generation could survive and even preserve the noble gases of their astrophysical sources. According to the estimates of [12], the relative abundance in chondrites of presolar nanodiamonds generated in the atmospheres of AGB stars amounts to ~1% only, and that of those synthesized at SNII explosions is < 0.1%.

References: [1] Shenderova O.A. et al. (2002) *Critical reviews in solid state and materials sciences*, 27, 227-356. [2] Lewis R.S. et al. (1989) *Nature*, 339, 117-121. [3] Van Kerckhoven C. et al. (2002) *A & A*, 384, 568-584. [4] Hill H.G. et al. (1998) *A & A*, 336, 41-44. [5] Dai Z.R. et al. (2002) *Nature*, 418, 157-159. [6] Huss G.R. and Lewis R.S. (1994) *Meteoritics*, 29, 791-810. [7] Ustinova G.K. (2007) *Sol. Syst. Res.*, 41, 231-255. [8] Ustinova (2002) *Geochem. Intern.*, 9, 915-932. [9] Ustinova G.K. (2009) *LPS XL*, Abstract #1007. [10] Ustinova G.K. (2009) *Dokl. Earth Sci.*, 429, 1403-1406. [11] Ponganis K.V. et al. (1997) *JGR*, 102, 19335-19343. [12] Verchovsky A.B. et al., (2006) *Ap. J.*, 651, 481-490.

Table 1

N	Xe components	$\frac{^{124}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{126}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{128}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{129}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{130}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{131}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{134}\text{Xe}}{^{132}\text{Xe}}$	$\frac{^{136}\text{Xe}}{^{132}\text{Xe}}$
1	Xe-HL*	0.0084	0.0057	0.091	1.06	0.154	0.844	0.636	0.7
2	Xe-P ₃ *	0.0045	0.004	0.081	1.04	0.159	0.823	0.377	0.31
3	$\frac{\text{Xe-HL}^*}{\text{Xe-P}_3^*}$	1.86	1.43	1.12	1.02	0.97	1.03	1.85	2.26
4	Xe ($\gamma \sim 1$)	0.58	1.38	3.16	4.16	1.29	9.61	0.036	0.0065
5	Xe ($\gamma = 3$)	0.31	0.90	2.69	4.44	1.18	10.44	0.026	0.0045
6	$\frac{\text{Xe}(\gamma \sim 1)}{\text{Xe}(\gamma = 3)}$	1.87	1.53	1.17	0.94	1.09	0.92	1.38	1.44
7	$\frac{\text{Xe}(\gamma \sim 1)}{\text{Xe-HL}^*}$	69.05	242.11	34.73	3.92	8.38	11.39	0.057	0.0093
8	$\frac{\text{Xe}(\gamma = 3)}{\text{Xe-P}_3^*}$	68.89	225.00	33.21	4.27	7.42	12.69	0.069	0.0145