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Origin of Xe-HL and Supernova 1987A

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Supernovae are important events in cosmochemistry. Not only do they create most of the atomic nuclei, whose Galactic abundances are still increasing, but they set the initial chemical context of the newly synthesized nuclei. Strange condensates may occur. This first and most important step in cosmic chemical memory is also the one that freezes in the largest istopic anomalies. Observations of supernova 1987A in the Magellanic cloud are providing literally once-in-a-lifetime data of great significance to meteoritics. I present some of those arguments here, with special attention on radioactivity, CO, carbon condensation, and Xe-HL in interstellar diamonds.

Radioactivity: This naked-eye explosion about 160,000 light years away was the first capable of testing our 20-year-old prediction (1) that 847 keV and 1238 keV gamma rays following ^{56}Co ($\tau_{1/2}$ = 77d) decay within expanding supernova interiors will unambiguously validate Hoyle's theory that the heavy nuclei are born there. The success of Solar Maximum Mission gamma spectrometer (2) and numerous subsequent balloon spectrometers in confirming this radioactivity has changed the status of one of the most important of 20th century physical theories to plain experimental fact. This is the most important cosmochemical consequence of SN1987A. It also suggests that other cosmochemical consequences of nucleosynthesis theory in supernovae be granted elevated empirical basis.

Neutrinos: Clear detection of neutrino burst validated the core-collapse mechanism of Type II supernovae. Emission of hot electron-mu-tau neutrinos carrying 10^4 times more energy than in the optical power agreed with theoretical predictions (3), causing theorists to examine more confidently other consequences of these neutrinos. Hotter mu and tau neutrinos inelastically interact with heavy nuclei via neutral weak currents, resulting in neutron emission from them. This and the rapid recapture of the neutrons alters ejected abundances (4), especially isotopically. The most cosmochemically important consequence appears to be the creation of CCF-Xenon in the carbon-rich helium shell. Another is the origin of flourine in the neon shell (5), because its site of origin has heretofore been totally unknown.

Carbon-rich SUNOCONs: In the 11th Proceedings (6) I explained why the 2 solar masses in the convective He-burning shell provide the simplest venue for carbonaceous supernova condensates (SUNOCONs). Only in that portion of supernova interiors does C abundance exceed O abundance (roughly fivefold), disarming oxygen combustion of any carbon solids that may grow there. This prolific source of carbon SUNOCONs is an important cosmochemical consequence of supernova theory. However, the observations of SN87A have modified this expectation with two startling observations. The infrared detection of CO molecules (7) reveals only 10^{-3} of the CO mass expected if all oxidized carbon emerged cooled as CO molecules. Thus either CO formation is not the chemical dead end it has long been regarded to be or most of the CO has still to form because the gases are still too hot. I suggest that the nonthermal x-ray background from the Compton scattering degredation of radioactive gamma rays maintains an environment too hostile for CO stability even at thermally stable CO temperatures. Carbon solids may therefore be able to grow even in the presence of hot oxygen because the CO breakup recycles carbon to the solid dust, which can itself be stable against photon disruption. Numerical chemical models are required. On the other hand, if all He-shell carbon condensed as 50μ carbon, SN87A would have already been blacked out in the visible! This has not yet been seen. So either only a few percent of that carbon condenses or more is still to condense as the expansion continues. First indications now exist of rising infrared emission from dust, suggesting that some SUNOCON formation has already occurred by December. These continuing observations are another important cosmochemical opportunity from SN1987A, affording the first good chance to test the prediction of the existence of SUNOCONs (8).

Xe-HL in diamonds: Xe-HL and its diamond carriers are much too anomalous to have formed in the solar system. Nor are they rare. They require a massive source. Unless diamonds concentrated into the carbonanceous meteorites, one seems to require about 1% of interstellar carbon to be diamonds, carrying (in bulk) factor of two enrichments in heavy (^{136,} ^{134}Xe) and light (^{126,} ^{124}Xe) isotopes. Because the survival rate of interstellar diamonds is only about 10% (9) it follows that at least 10% of interstellar carbon must have once been ejected from supernovae shells bathed in Xe-HL. Does such a huge source exist? I estimate that 20% of all interstellar carbon has arisen from the He-burning shells of Type II supernovae, so that supply is adequate. My initial proposal (6) of this source on the basis of its carbon excess called for an unknown burst of free neutrons (about 5×10^{25} n/cm^2) just prior to ejection. Such a burst now seems likely to result from the neutrino burst. In a new work (in press in *Astrophys. J.*) I show that ambient xenon becomes Xe-H-like in that shell because the expected fluence of neutrons from ^{4}He(ν,ν')^{4}He*(n)^{3}He and ^{12}C(ν, ν')^{12}C*(n)^{11}C is adequate to push xenon seed out to ^{136}Xe, just as needed. We now have, therefore, the expectation of a massive supply of cooling carbon bathed in Xe-H. It is almost surely the correct source, if its remaining problems can be resolved satisfactorily.

Mixing and Xe-L: The rise time of the gamma-ray flux coupled with the optical light curve demonstrates the existence of radial mixing within the interior of SN1987A. This is probably the explosive penetration of underlying material through overlying mantles, and does not necessarily mix the gas microscopically. Therefore the carbon-rich material can remain carbon-rich even though the bulk interior is oxygen-rich, so that unoxidized carbon may still condense. A reliable timescale for molecular mixing has not yet been calculated. However, the light isotope enrichments in Xe-HL must be admixed upward from the Ne shell where they are overabundant by a factor of about 10^2. Microscopic mixing on average of 1% of the Ne shell into the He-burning mantle would allow Xe-HL to exist there without requiring oxygen to be more abundant than carbon. The major puzzle here is the coincidence, in such an unbalanced admixture, of having ^{124}Xe overabundance equal to ^{136}Xe overabundance - possible, but peculiar. It is also clear that both ^{124}Xe/^{126}Xe and ^{136}Xe/^{134}Xe isotopic ratios should be variable; but the problem is that about 10^9 individual diamonds are needed to measure an Xe isotopic composition, because most diamonds are empty! Perhaps the best hope is that of detecting a gradient in ^{124}Xe/^{136}Xe with diamond size in collections of diamonds sorted according to size. This should be pursued vigorously.

^{129}Xe and ^{13}C normalcy: Normalcy of these isotopes is the major impediment to acceptance of this theory. The ambient ^{129}I/^{136}Xe ratio is calculated by me to be less than 5% of normal, but selective condensation of ^{129}I would nonetheless render ^{129}Xe too abundant in Xe-HL. The data suggest that I and Xe are trapped with equal efficiency in the diamond. To understand this requires understanding the condensation of diamond. The slight ^{12}C richness of diamonds is interesting, but unimpressive in the face of the ^{12}C purity within the He convective shell. Thus the ^{13}C must be mixed in from the upper part of the same He shell, and in just those amounts that make the carbon almost normal isotopically. This requires nitrogen to be ^{15}N-poor. That this is possible, in a couple of ways, does not diminish our skepticism that it should be just so. But any correct explanation of Xe-HL will have this "stranger than fiction" flavor.

I will update these issues in my presentation. This research is supported by the Robert A. Welch Foundation and by NASA.

References: (1) Clayton, D. D., S. A. Colgate and G. J. Fishman, *Astrophys. J.*, **155**, 75 (1969); (2) Matz, S. M. *et al.*, *Nature*, **331**, 416 (1988); (3) Burrows, A. and Lattimer, J., *Astrophys. J (Letters)*, **318**, L63 (1987); (4) Epstein, R. *et al.*, *Phys. Rev. Letters.*, **61**, 2038 (1988); (5) Woosley, S. E. and Haxton, W. C., *Nature*, **334**, 45 (1988); (6) Clayton, D. D., *Proc. Lunar Planet. Sci.*, **12B**, 1781 (1981); (7) Spyromilio, J. *et al.*, *Nature*, **334**, 327 (1988); (8) Hoyle, F. and Wickramasinghe, N. C., *Nature*, **226**, 62 (1970); (9) Liffman, K. and Clayton, D. D., *Proc. Lunar Planet. Conf.*, **18**, 637 (1988).