The r-Process in Metal Poor Stars and Black Hole Formation

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Historically r-process studies focused on the ubiquity of the r-process, i.e., the similarity of the r-process abundances in extremely metal poor (EMP) stars to those of the Solar system. In the past decade, however, a number of EMP stars, which might have been thought to exhibit the r-process abundances, have been observed to have abundances very different from those of the standard r-process [1]. They have led to the suggestion that their abundances are produced by two classes of progenitor star r-processes.

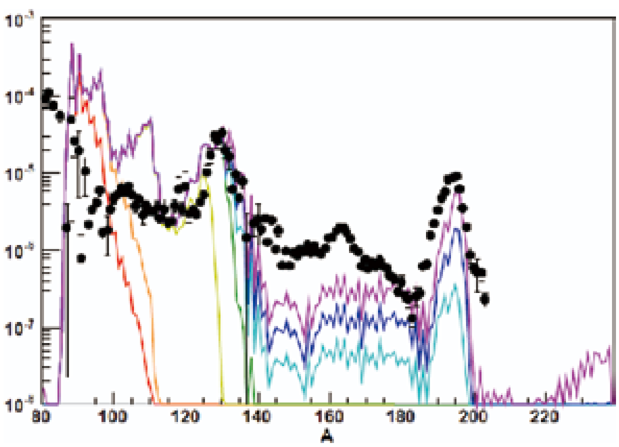

Figure 1: EMP abundance data and r-process calculations [2] using the ref. [6] trajectories, but summing results from trajectory 24 to some later trajectory. The successive curves include trajectory 24, 24–26, 24–28, 24–30, 24 –31, 24–32, and 24–40. The sums to higher trajectories make both the mass 130 and 195 r-process peaks. Data are from [6].

Our papers [2,3] propose one primary site for the r-process, i.e., core-collapse supernovae. Then the r-process outliers result from progenitor stars that lie in the 25-40 solar mass range; these stars are thought to become supernovae by first collapsing to a neutron star, then having fallback onto the nascent neutron star to exceed the maximum mass for a neutron star, producing a black hole [4]. Progenitor stars more massive than 40 solar masses would collapse directly to black holes, adding no r-process material to the interstellar medium, whereas stars less massive than 25 solar masses would expel relatively large amounts to the ISM. In the 25–40 solar mass range some r-process material would be expelled to the ISM through hydrodynamic fluctuations that would produce regions with radial velocities in excess of the black hole escape velocity. The amount of material expelled would vary with the mass of the progenitor star, since the more (less) massive stars would remain as neutron stars for times that approaches zero (infinity).

We [2] applied the approach of [5], which described the r-process as occurring in the neutrino driven wind from a core-collapse supernova in 40 trajectories (thin shell wind elements), all originating within the star, but having different initial density, temperature, entropy, and electron fraction. Processing conditions for individual trajectories evolved with time and trajectory identity. Different trajectories were emitted from the star successively, but ceased when the collapse to the black hole occurred, consistent with [5] in which the total emissions of the trajectories generated a good representation of the Solar r-process abundances. Our calculations are described in more detail in [2].

Our results are shown in the Fig. 1. There it can be seen that truncating the r-process at increasing trajectory number terminates the r-process at increasingly higher mass. Note that although the curve representing trajectories 24 through 31 does reach the mass 195 u peak, the abundances in that region are nearly two orders of magnitude below that of the full r-process, which would render the higher mass nuclides difficult to observe. The abundances for that scenario would therefore appear observationally to terminate at a mass of about 140 u. The figure shows that the tr-process predictions do produce a qualitative representation of the observed abundances for the outlier stars, suggesting that all of these stars can be represented by a single r-process, provided that the truncation possibility is allowed.

References

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[5] Woosley, et al.: 1994, *ApJ*, **433**, 229.
[6] Käppeler, F., et al.: 1989, *Rep. Prog. Phys.*, **52**, 945.