The r-process in the high-entropy bubble scenario

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Using dynamical r-process network calculations based on the high-entropy bubble scenario as a possible cite for the r-process we were able to investigate some quite important features of the nucleosynthesis in the above mentioned astrophysical model.

A brief summary of the high-entropy bubble scenario is as follows. During the final stages of the evolution of a massive ($8 - 25\,M_\odot$) star, an "iron" core forms in its central region and subsequently undergoes gravitational collapse. When the central density reaches nuclear matter density, the collapse stops abruptly to cause a "core bounce". A shock wave is created and starts to propagate outward. According to hydrodynamical calculations [1], this shock wave loses its entire kinetic energy within a few milliseconds to stall well inside the outer edge of the initial iron core, and no immediate disruption (a "prompt" explosion) of the star occurs. On a timescale from several tens of milliseconds to about half a second, the neutrinos streaming out from the new-born neutron star can deposit energy behind the standing accretion shock at a rate high enough to revive its outward motion and initiate the final explosion of the star. This is the neutrino-driven "delayed" explosion mechanism originally suggested by Wilson [2].

The main parameters in this model are the entropy S, the electron abundance Y_e and the expansion speed of the bubble V_{exp}. The relation between those three parameters is given by the simple formula

$$\frac{Y_n}{Y_{seed}} = k_{SN} V_{exp} \left(\frac{S}{Y_e}\right)^3, \quad k_{SN} \approx 8,05835 \times 10^{-11}.$$

In fact, the entropy S is not constant in the whole expanding bubble. In a realistic approach to this problem, one divides the occuring high-entropy bubble in several mass regions, and then with a detailed hydrodynamical simulation one can determine for each mass region the corresponding entropy. Since we do not do hydrodynamical simulations, we used a simple fit function like

$$g_i = g(S_i) = X_1 e^{X_2 S_i}, \quad i = 1, \ldots, n.$$

g_i is the weight factor of the ith component which we mix in, X_2 determines the slope of the weight function and X_1 is a global value shoving the superposition to the experimental measured curve of the istopic solar abundances.

In fact, it is really hard to fit the whole range between A=120 and A=209 because of the lack of the neutron capture rates for the nuclei with $Z \geq 84$ and the occurrence of spontanous and n-induced fission of the nuclei with $A \geq 250$.

The figure 1 shows an example of a superposition by using the ETFSI-Q formula. It was shown that the idea of an instantanous freeze-out is only approved if the neutron-to-seed ratio is about the unity. Nevertheless, in that case an effective r-process cannot take place.

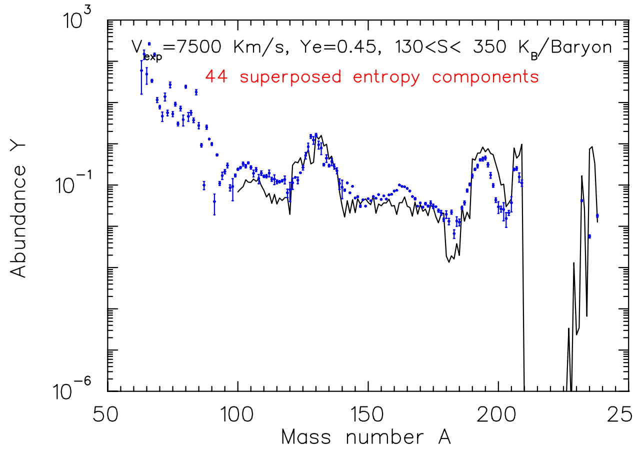

Figure 1: Superposition of abundances from 44 components to reproduce the solar r-abundances beyond $A \simeq 120$

Therefore the canonical approach of the r-process can be seen as a snapshot of the dynamical approach in a certain time t before the total disapearance of the neutrons.

Among other things we determine the odd-to-even ratio of the three barium isotops (A=135, 137 and 138) wich are synthesised by the s- and r-pocess.

The odd-to-even ratio for the solar r-abundances is

$$\text{Ratio} = \frac{Y(^{135}\text{Ba}) + Y(^{137}\text{Ba})}{Y(^{135}\text{Ba}) + Y(^{137}\text{Ba}) + Y(^{138}\text{Ba})} = 0,72.$$

The table below shows the obtained results for a fixed expansion speed and variable Y_e and S.

Mass model	V_{exp} (km/s)	Entropy (k_B/Baryon)	Y_e	Ratio
ETFSI-Q	7500	210	0.49	0.764
		185	0.47	0.758
		165	0.45	0.742
		145	0.43	0.767
		125	0.41	0.818
FRDM	7500	225	0.49	0.804
		205	0.47	0.713
		185	0.45	0.740
		160	0.43	0.788
		145	0.41	0.810

References

[1] Myra & Bludman, 1989, ApJ 340, 384

[2] Wilson, J. R., 1985, in Numerical Astrophysics