超新星爆発元素合成における核物質の液相・気相相転移の役割

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ON A POSSIBLE IMPORTANCE OF NUCLEAR LIQUID-GAS PHASE TRANSITION IN SUPERNOVA NUCLEOSYNTHESIS

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The mechanism of nucleosynthesis for heavy-elements is still under discussion. In 1960's, two major processes were proposed. One of them is the slow neutron capture process (s-process), and the other is the rapid neutron capture process (r-process). The former produces stable nuclei upto ^{209}Bi, and the latter produces various stable and unstable nuclei as remnants of weak decays from preformed neutron-rich nuclei. Thus it is widely believed that the synthesis of heavy-elements in the universe can be explained by these two processes.

However, within the above scenarios, there is no path to produce *heavy proton-rich unstable nuclei*, such as ^{196}Hg, ^{190}Pt and ^{162}Er, which are naturally existing. In addition, it is not well known theoretically in which condition the r-process occurs. Therefore, it is still valuable to consider other possible mechanisms to produce heavy-elements.

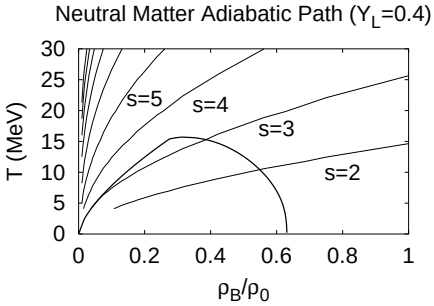

Figure: *Adiabatic paths of free neutral matter at the lepton-to-baryon ratio $Y_L = 0.4$. Entropy per baryon is specified for $s = S/B = 2$, 3, 4 and 5. Thick curve shows the nuclear matter spinodal region calculated with the Skyrme-type soft interaction.*

We here consider a possibility of early formation of various fragments through nuclear liquid-gas phase transition during the supernova explosion (LG process), as a pre-process of rapid neutron captures. This LG pre-process may be preferable, because fragment yields approximately follows the power law behavior ($\propto A^{-\tau}$), thus it effectively produces heavy elements. Actually, the background yield in cosimic abundance (except for s- and r-process peaks) can be well fitted by a power law behavior with the exponential tail from iron. In addition, unstable nuclei including proton-rich ones can be also produced at a certain rate at high temperatures.

In order to verify the possibility of this LG pre-process, we have made a simple model calculation of adiabatic path (isentrope) in supernova matter evolution. In this calculation, we have ignored nuclear potential effects and have assumed that the lepton-to-baryon ratio is conserved. The figure shows that the adiabatic paths hit spinodal region at $S/B = (2-3.5)$, thus we can expect that the multifragmentation of bulk neutron-rich ($Z/A \simeq Y_L \simeq 0.4$) matter would happen at these entropies. In a more realistic hydrodynamical simulation of prompt supernova explosion [1,2], the entropies are in the range of $S/B = (2-10)$ in the early stage, and hydrodynamical path really pass through the spinodal region.

In summary, a new mechanism, LG process, is considered as a pre-process of the rapid neutron capture process. From a simple model calculation of the adiabatic paths in supernova matter, it seems probable that the LG process would affect the supernova nucleosynthesis to some extent. Of course, it is necessary to estimate other effects such as hydrodynamical and EOS effects in the gravitation, the isospin dependence of critical temperature [3], and the fragment formation process, in a more realistic manner. The work in this direction is in progress.

[1] K. Sumiyoshi, private communication; K. Sumiyoshi et al., astro-ph/9912156.
[2] H. Shen et al., Nucl. Phys. A637 ('98), 435.
[3] Ph. Chomaz, F. Gulminelli, Phys. Lett. B447 ('99), 221.