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r-process nucleosynthesis in a new supernova model

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We have calculated r-process nucleosynthesis in a new supernova model, which is driven by acoustic power generated in the inner core. In our results, plenty of actinide and the third peak elements are generated. However, light r-process elements around the first and second peak are overproduced. Our present results indicate that further studies of the r-process in this model are desirable.

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The astrophysical site for the r-process is still a mystery despite of decades of studies. Although the core-collapse supernova is a dominant candidate, there is no definitive conclusion. This is partly because of poorly understood explosion mechanisms in current supernova models. Burrows et al. [1] have proposed a new supernova explosion mechanism which is driven by acoustic power generated in the inner core. In their 2D simulation, there are mass elements with high entropy ($S > 500$) which have not been found in previous r-process studies based on neutrino driven winds. We studied r-process nucleosynthesis in their 11 $M_\odot$ progenitor model.

The simulation provides radial velocity, entropy, electron fraction, density, and temperature at r=1000 km of 9086 mass elements. The mass distribution of entropy and electron fraction is shown in Fig. 1. The entropy range is much wider than neutrino driven wind models. The radial velocity of each mass element is shown in Fig. 2. For nucleosynthesis calculations, we extrapolate density and temperature inside and outside of r=1000 km assuming constant velocity and entropy. Nucleosynthesis calculations are started at T= 1.0×10^{10} K except for low entropy case (S<50). At this temperature, the material consists of free protons and neutrons. The calculation starts at T= 9.0×10^9 K for S<50 cases. In this case, α and some light elements already exist at the beginning. We also assume that the initial electron fraction is same as one at r=1000 km.

We use fully dynamical network code with more than 6000 nuclei and 10000 reactions. In this code, neutron capture and other charged current reactions are solved at the same time. Heating from nucleosynthesis is included. Neutron-capture rates, beta-decay rates are consistent with FRDM mass model [2, 3, 4]. The neutron-capture of light elements is included [5]. We adopted a simple fission model which assumes all nuclei of A=260 immediately break symmetrically.

We have calculated nucleosynthesis of 360 mass elements as representatives of 9086. They are chosen from different entropy, electron fraction, and radial velocity. The total abundance is shown in Fig. 3. There are enough actinide elements and third peak elements to reproduce solar amount. There is significant overproduction around the first and second peak. The main reason of this overproduction is the contribution from large amount of low entropy ejecta (Fig.1). Under the assumption of constant velocity, the dynamical timescale of most mass elements become much faster than neutrino driven wind. Such fast drop of temperature shifts the position of the third peak (Fig. 4).

In this supernova model, the entropy distribution ranges from 9 to 18000. At low entropy side, fast expansion is favorable for heavy element production. This is because fewer neutrons are consumed to produce seed elements when temperature decreases fast [6]. On the other hand, Our results show that slow expansion is favorable when entropy is extremely high (over 10000). Such high entropy and fast expansion are similar to the condition of the big bang nucleosynthesis. Heavy elements are not synthesized in this condition.

There are several uncertainties to be solved beside the nuclear physics model in network code. We chose a simple fission model. Over production around the second peak may be improved when mass distribution of fission fragment and fission rates are considered. We did not consider direct capture reactions in these calculations although r-processes in this model tend to occur in lower temperature. In such low temperature, direct capture plays an important role and could change the abundance pattern including the peak position. The assumption of constant velocity is reasonable outside of r=1000 km. However, it may not be suitable at the inside of r=1000 km. Those uncertainties may change the final abundance in this work. Further investigation of r-process

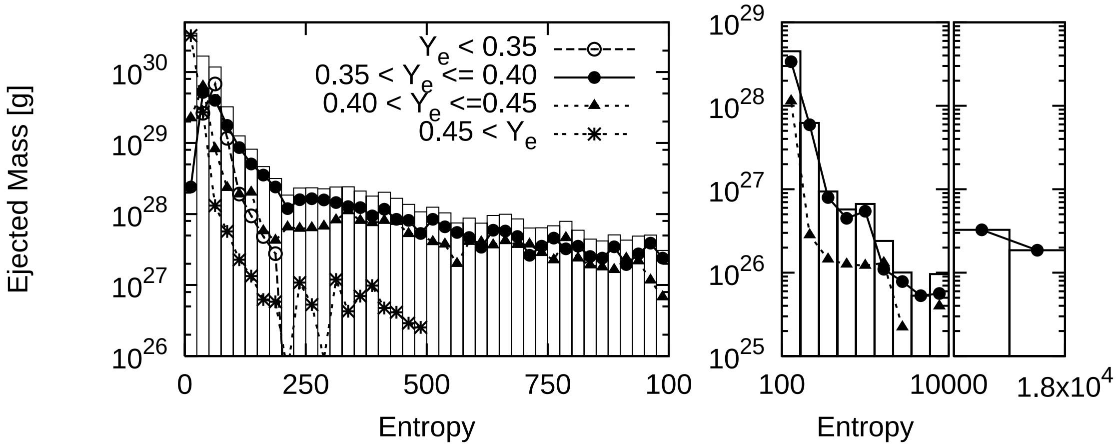

Figure 1: Total ejected mass for each entropy range. The bars indicate the sum of mass of each entropy range. Although entropy range is wide, most dominant contribution come from the lowest entropy group. The points and lines show the sum of mass for different electron fraction group. We divided each entropy group into four by electron fraction and calculated r-process of the mass elements with fastest, slowest and medium radial velocity in each group.

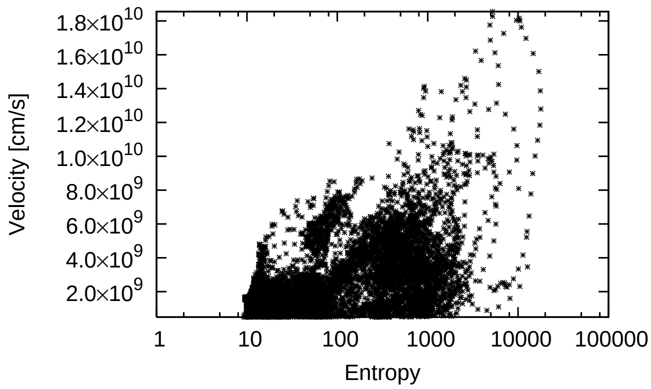

Figure 2: The entropy and radial velocity at r=1000 km for 9086 mass elements. The mass elements with a high entropy (>8000) do not contribute to elemental abundances heavier than A$\sim$140.

in this new supernova model is advisable.

References

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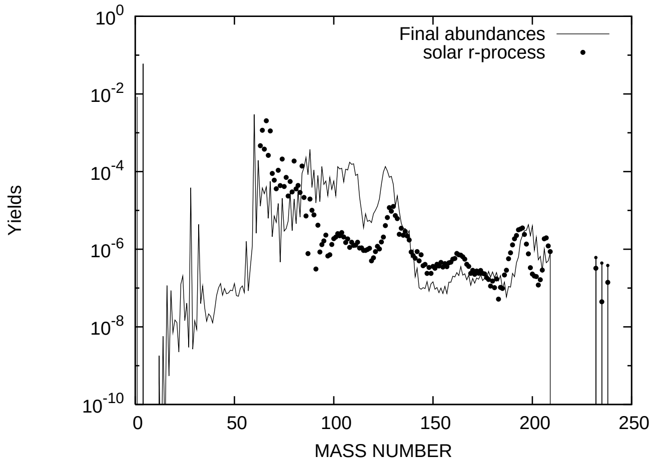

Figure 3: Total abundance of our calculations. This is mass-weighted average of 360 r-process calculations. These 360 were chosen as representatives out of 9086 mass elements. The closed circles indicate scaled solar r-process abundance. There is significant overproduction below A$\sim$140. The position of third peak is also shifted to the left.

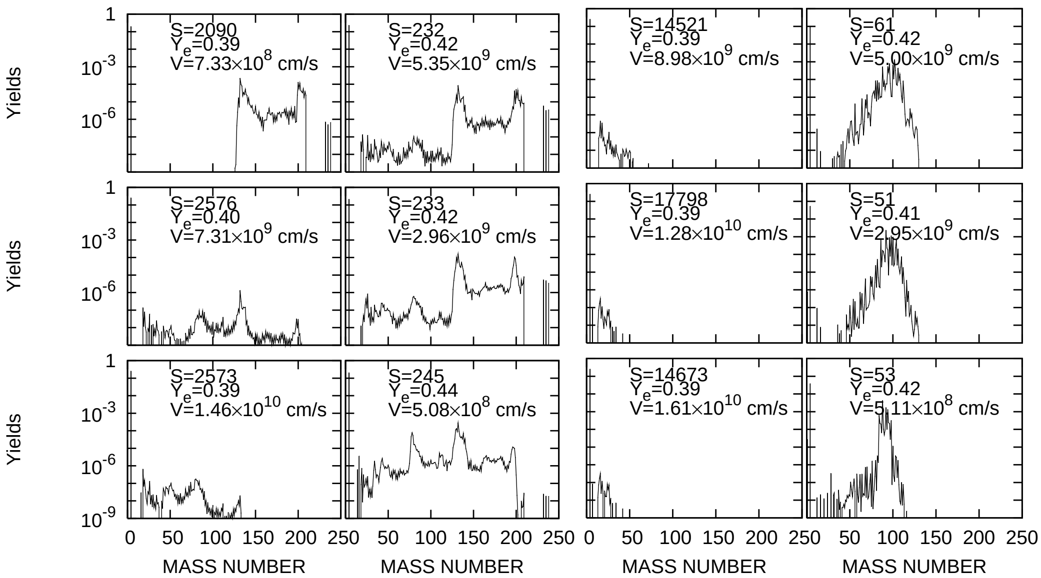

Figure 4: Nucleosynthesis results for 12 different mass elements. At the high entropy(S$\sim$2000), slower expansion is favorable to the r-process. When entropy is around 200, fast expansion produces more heavy elements. The right panel shows the results of condition with highest entropy and lowest entropy of these calculation. With the highest entropy (S>10000), no heavy elements are formed even with low Y_e $\sim$0.39. With the lowest entropy, r-process does not proceed further than A$\sim$ 130. Three figures of entropy $\sim$ 200 shows the shift of the third peak position with expansion velocity.