ELSEVIER

Nuclear Physics A718 (2003) 638c–640c

NUCLEAR PHYSICS A

www.elsevier.com/locate/npe

The possibility of r-process in the core-collapse supernova of an ONeMg core

M. Tamamura[a], S. Wanajo[a], N. Itoh[a], K. Nomoto[b] and S. Nozawa[c]

[a]Department of Physics, Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan

[b]Department of Astronoomy, School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

[c]Josai Junior College for Women, 1-1 Keyakidai, Sakado-shi, Saitama 350-0295, Japan

We discuss the possibility of the r-process nucleosynthesis in the core-collapse supernova of a low mass progenitor ($9M_\odot$). This progenitor is composed of an O+Ne+Mg core and has a possibility to explode promptly prior to the neutrino heating. We simulate the prompt supernova explosion with one dimensional spherically symmetric hydrodynamics. In our results, this model cannot produce a successful supernova explosion by the prompt shock. We then obtain explosions by artificial enhancement of shock energy, and argue whether this type of supernovae can be the major r-process site in the Galaxy.

1. Introduction

The mechanism of supernova explosions of massive stars is still not satisfactorily understood. The late stages of stars in the initial mass range $8M_\odot \leq M \leq 10M_\odot$ with O+Ne+Mg (hereafter ONeMg) cores have been suggested there are three possibilities for evolutionary path [12]. 1) If the mass loss rate is high enough during the helium burning phase, these stars evolve into Type II supernovae. 2) If the mass loss during the double shell burnings is sufficiently rapid, these stars lose the envelope and become ONeMg white dwarfs instead of supernovae. 3) If these stars are in close binary systems, they can be progenitors of Type I supernovae.

The ONeMg core, as the final stage of an 8-10$M_\odot$ star, may explode by the prompt shock at the onset of core bounce [6–8]. The ejected shell contains a rather low electron fraction region due to electron capture, which may be a promising r-process site[9,15].

2. Hydrodynamics

We have solved the equations of the Newtonian spherically symmetric hydrodynamics, with an implicit Lagrangian numerical scheme. Neutrino transport is not taken into account. We may as a first approximation ignore the late-time neutrino diffusion and heating which is not clear till later in the explosion. We adopt the equation of state (EOS) of nuclear matter based on the relativistic mean field theory[13].

doi:10.1016/S0375-9474(03)00909-6

The initial model we use is a pre-supernova star with main-sequence mass of about $9M_\odot$[11,12]. For our hydrodynamic simulations we are only concerned with the central $1.376M_\odot$ of the ONeMg core. This core is corrupted by electron capture on ^{20}Ne and ^{24}Mg because of a decrease in electron fraction. As a result, central density becomes so high that oxygen is ignited. A deflagration front incinerates the material into a nuclear statistical equilibrium (NSE) composition. The initial compositions are taken from the pre-supernova model. These compositions are kept fixed until the temperature reaches to 2×10^9 K at which point the matter is put into NSE instantaneously.

We adopt the electron capture rates of Langanke & Martinez-Pinedo (LMP[10]). These rates are on average an order of magnitude smaller than the usually employed rates of Fuller, Fowler, & Newman (FFN[1–4]). A recent study of the effect of these rates on pre-supernova evolution[5] found that electron fraction Y_e in the center of pre-supernova star was 1% to 4% larger and iron core masses were systematically about 0.05 to $0.1M_\odot$ smaller than previous work with FFN rates.

Our simulation is performed in the four models descrived below, using an enhancement factor f multiplied to the shock-heating term in the energy equation as a parameter (Table 1).

3. Results and conclusions

Our spherically symmetric, Newtonian hydrodynamic simulation of a $9M_\odot$ star with a $1.376M_\odot$ ONeMg core gives an explosion by the prompt shock at the onset of core bounce. However the explosion energy of this model (Q0 in Table 1) is three order of magnitude smaller than a typical of supernova explosion energy. If the ONeMg core has a hydrogen-rich envelope, we think this model cannot produce a successful supernova explosion. The following thing can be considered as a reason of this weak explosion. 1) Since the nuclear EOS is relatively stiff, sufficient gravitational energy is not obtained. 2) We do not take the general relativistic effect, as well as the neutrino transport, into consideration.

We make it explode by prompt shock artificially, in order to investigate whether this type of supernovae can be a possible r-process site. Our results are shown in Table 1. Model Q2 shows a weak explosion and will not be an r-process site because of a relatively high electron fraction. We obtain a reasonable explosion energy in model Q5, but Y_e is still high to be an r-process site. In model Q7, we obtain a low electron fraction in

Table 1
Results of numerical simulation

model	f^a	$M_{ej}(M_\odot)$	E_{exp}(ergs)	Y_e^b
Q0	1.0	0.008	1.03×10^{48}	0.469
Q2	1.2	0.020	4.07×10^{49}	0.367
Q5	1.5	0.182	1.21×10^{51}	0.295
Q7	1.7	0.507	7.41×10^{51}	0.175

[a] enhancement factor f multiplied to the shock-heating term in the energy equation
[b] minimum electron fraction in the ejecta

the ejected material as well as an extremely large explosion energy (Figures 1 and 2). If prompt explosions occur, significant neutronization of the prompt ejecta is made (like in model Q7) as already shown by previous works[8,14].

We conclude that the supernova explosion with an ONeMg core remains a possible site for the r-process nucleosynthesis, although it is not evident whether this core explodes by prompt shock when the neutrino transport as well as the general relativistic effect is included.

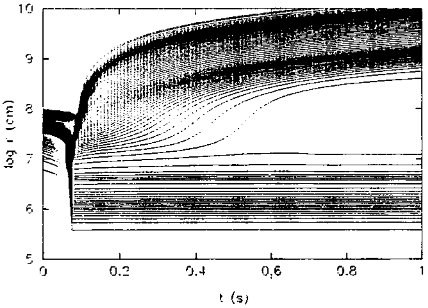

Figure 1. Radii as functions of time for collapse and prompt explosion of a $1.376M_\odot$ ONeMg core in model Q7.

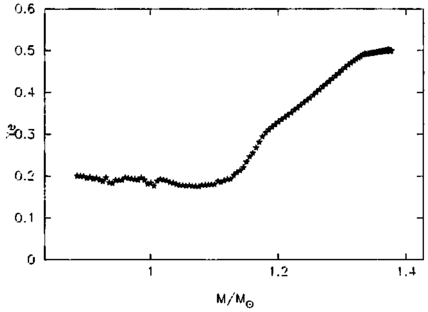

Figure 2. Final electron fractions Y_e for the ejected material as functions of mass in model Q7.

REFERENCES

1. Fuller, G. M., Fowler, W. A., & Newman, M. J. 1980, ApJS, 42, 447.
2. ———. 1982, ApJ, 252, 715.
3. ———. 1982, ApJS, 48, 279.
4. ———. 1985, ApJ, 293, 1.
5. Heger, A., Woosley, S. E., Martinez-Pinedo, G., & Langanke, K. 2000, ApJ, 560, 307
6. Hillebrandt, W., Takahashi, K., & Kodama, T. 1976, A&A, 52, 63.
7. Hillebrandt, W. 1982, A&A, 110, L3.
8. Hillebrandt, W., Nomoto, K., & Wolf, R. G. 1984, A&A, 133, 175.
9. Ishimaru, Y., & Wanajo, S. 1999, ApJL, 511, L33.
10. Langanke, K., & Martinez-Pinedo, G. 2000, Nucl. Phys. A, 673, 481.
11. Miyaji, S., Nomoto, K., Yokoi, K., & Sugimoto, D. 1980, Pub. Astr. Soc. Japan, 32, 303.
12. Nomoto, K. 1984, ApJ, 277, 791.
13. Shen, H., Toki, H., Oyamatsu, k., & Sumiyoshi, K. 1998, Nucl. Phys. A, 637, 435.
14. Sumiyoshi, K., Terasawa, M., Mathews, G. J., Kajino, T., Yamada, S., & Suzuki, H. 2001, ApJ, 562, 880.
15. Wheeler, J. C., Cowan, J. J., & Hillebrandt, W. 1998, ApJL, 493, L101.