Neutrino Oscillation and Nucleosynthesis in Core-Collapse Supernova Explosion [1]

KAJINO, Toshitaka (NAOJ/University of Tokyo)
MATHEWS, Grant. J. (University of Notre Dame)
HAYAKAWA, Takehito (Japan Atomic Energy Agency)

Neutrino interactions are the key component of the mechanism for supernova explosions. Foremost is the role of neutrinos in the explosion itself. Much effort is now invested in understanding the transport of neutrinos from the core and the role of neutrino heated convection in the outer envelopes. They also play an important role in the associated nucleosynthesis, and current topics are regarding the synthesis of the ν-process isotopes ^{180}Ta, ^{138}La and light isotopes ^{7}Li and ^{11}B and impact on the neutrino-flavor oscillations [1].

Most important neutrino-flavor mixing is due to Mikheyev-Smirnov-Wolfenstein (MSW) matter effect [2]. The adiabatic condition can be written as

$$\left|\left(\frac{1}{\rho_e}\frac{d\rho_e}{dr}\right)^{-1}\tan(2\theta)\right| \gg \lambda_{m,res} = \frac{4\pi\epsilon_\nu}{\Delta m^2 \sin(2\theta)} \quad . \ (1)$$

The flavor oscillations occur for a matter density ρ_{res} of

$$\rho_{res} = 1.4\times10^3\left(\frac{\Delta m^2}{10^{-3}\mathrm{eV}}\right)\left(\frac{10\ \mathrm{MeV}}{E_\nu}\right)\left(\frac{Y_e}{0.5}\right)\cos 2\theta \ ,(2)$$

where ρ_{res} is in units of g cm^{-3}, $\Delta m^2 \sim 10^{-3}$ eV is the difference in the square of the neutrino mass eigenstates, and θ is the relevant mixing angle. This implies that the resonant flavor mixing occurs among active neutrinos at the matter density ~10^3 g cm^{-3} located just below the O/C layer at $M_r \approx (3.4\text{–}4)M_\odot$ as shown in Fig. 1.

The dependence on θ_{13} enters here for the 13-mixing resonance. The associated increase in the electron neutrino temperature increases the rates of charged-current ν-process reactions. Although the heavy ν-process elements are produced in the inner layers and unaffected by the MSW resonance, the light isotopes ^{7}Li and ^{11}B are sensitive to the 13 mixing. Moreover, the ratio depends on the still unknown neutrino mass hierarchy [1].

Since the recent reactor and accelerator experiments give $\sin^2 2\theta_{13} \sim 0.1$, the neutrino mass hierarchy can be determined from the strong, robust dependence of the abundance ratio ^{7}Li/^{11}B on the oscillation parameters [1]. According to a recent work based on the deduction of the ratio ^{7}Li/^{11}B from so-called pre-solar supernova grains of a meteorite [3], we can conclude that the inverted mass hierarchy is statistically more favored [4].

We also discussed the flavor mixing effects on the observed signals of supernova neutrinos on Earth [5]. Independent of the neutrino mass hierarchy in the efficient flavor mixing, the observed neutrino fluxes might become

$$\begin{aligned}\phi_{\nu_e} &= |U_{e1}|^2\phi^{(0)}_{\nu_e} + (1-|U_{e1}|^2)\frac{\phi^{(0)}_{\nu_\mu}+\phi^{(0)}_{\nu_\tau}}{2}, \\ \phi_{\nu_{\mu,\tau}} &= \frac{(1-|U_{e1}|^2)}{2}\phi^{(0)}_{\nu_e} + \frac{(1+|U_{e1}|^2)}{2}\frac{\phi^{(0)}_{\nu_\mu}+\phi^{(0)}_{\nu_\tau}}{2},\end{aligned} \quad (3)$$

where U_{ei} are elements of the Cabbibo-Kobayashi-Masukawa matrix in neutrino sector. We can predict the difference of the neutrino signals which depend on mass hierarchy and EoS of proto-neutron stars in mega-ton Gd loaded Water-Chrenkov detector at Hyper-Kamiokande [5].

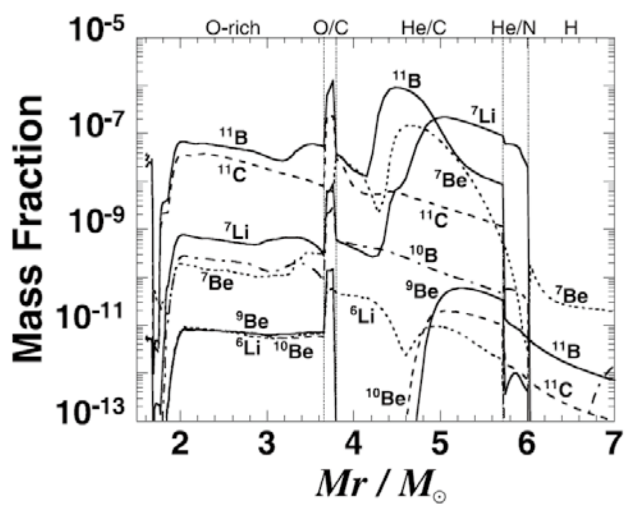

Figure 1: Produced Li, Be, and B isotopes as a function of interior mass of core-collapse supernova. Note the large spike in ^{11}B and ^{7}Li production in the O/C and He/C shells.

References

[1] Kajino, T., Mathews, G. J., Hayakawa, T.: 2014, *J. Phys. G*, **41**, 044007.
[2] Wolfenstein, L.: 1978, *Phys. Rev. D*, **20**, 2634; Mikheyev, S. P. Smirnov, A. Yu.: 1985, *Sov. J. Nucl. Phys.*, **42**, 813.
[3] Fujiya, W., Hoppe, P., Ott, U.: 2011, *ApJ*, **730**, L7.
[4] Mathews, G. J., et al.: 2012, *Phys. Rev. D*, **85**, 105023.
[5] Mathews, G. J., et al.: 2014, *ApJ*, **790**, 115.