Solving the Red Supergiant and Supernova Rate Problems via Relic Supernova Neutrino Spectrum

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Recent observations suggested that the maximum mass of the red supergiant progenitors of core-collapse SNe may be as small as 16.5–18 $M_\odot$ instead of 25 $M_\odot$ (RSG problem). It has been also recognized that the observational supernova rate is smaller than the theoretical estimate (SNR problem). We have investigated these two astronomical problems via the cosmic relic supernova neutrinos (RSNs) [1].

According to the RSG problem, we assumed the possibility that red supergiants with M > 16.5–18 $M_\odot$ end their lives as failed supernovae ($M_{\rm min}^{\rm fSN}$ =16.5, 18 $M_\odot$) and analyzed their contribution to the RSN spectrum. This change in population of different types of SNe can be seen as the deviation in RSN spectrum. SN explosion mechanism is sensitive to the nuclear equation of state (EoS), which affects the temperature of the neutrino sphere. Therefore it is expected that this mass limit influences the RSN energy spectrum. Under the assumption of a initial mass function, lowering mass limit of progenitors for fSNe decreases the relative abundance of luminous SNe and then reduces the supernova rate. Our results showed these features.

Figure 1 shows the ratio bewteen the theoretical and observational supernova rate ($R_{\rm SN}^{\rm Thr}$ /$R_{\rm SN}^{\rm Obs}$). Dotted lines indicate the upper and lower limits due to the uncertainties of star formation rate. Adopted value $M_{\rm min}^{\rm fSN}$ = 16.5–18 $M_\odot$ clearly solves the SNR problem. The RSN spectrum was evaluated by assuming 10 years of running time in a Hyper-Kamiokande detector, i.e., a 10^6 ton water Čerenkov detector. The result is presented in Figure 2. It shows the RSN detection rate for two cases of $M_{\rm min}^{\rm fSN}$= 16.5, 18 $M_\odot$. In addition, the figure includes the results of $M_{\rm min}^{\rm fSN}$ = 25 $M_\odot$ for comparison. The figure clearly shows the EoS dependence of RSN spectrum in the energy range of E_{e^+} > 30 MeV, and the locations where the event rates exceed the atmospheric background are well separated. This finding suggests a detection of the RSN spectrum can give insight into the SN explosion mechanism in terms of the nuclear matter properties.

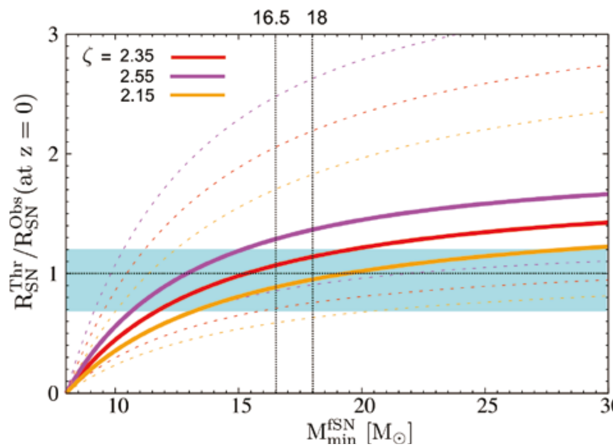

Figure 1: Relationship between $M_{\rm min}^{\rm fSN}$ and $R_{\rm SN}^{\rm Thr}$ /$R_{\rm SN}^{\rm Obs}$ at z = 0 by adopting $R_{\rm SN}^{\rm Obs} \approx 0.6 \pm 0.2 \times 10^{-4}$ yr^{-1} Mpc^{-3}. Three lines are shown due to the uncertainties of IMF. The horizontal blue band indicates the range of uncertainty caused by $R_{\rm SN}^{\rm Obs}$.

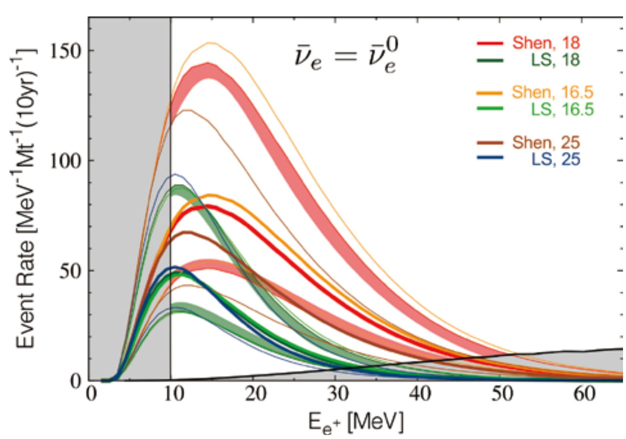

Figure 2: Predicted e^+ energy spectra for the cases of $M_{\rm min}^{\rm fSN}$= 16.5, 18 or 25 $M_\odot$ without neutrino oscillation. The results for two different fSNe models based upon the stiff EoS (Shen) and the soft EoS (LS) are included. The shaded energy range below 10 MeV indicates the region where the background noise due to reactor $\bar{\nu}_e$ may dominate. The shaded energy range near the horizontal axis indicates the region where the background may be dominated by noise from atmospheric neutrinos.

Reference

[1] Hidaka, J., Kajino, T., Mathews, G. J.: 2016, *ApJ*, **827**, 85.