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Light element synthesis constraining the supernova neutrino spectrum

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Abstract. We constrain energy spectra of supernova neutrinos using the ν-process light element synthesis in supernovae and the ^{11}B abundance during Galactic chemical evolution. We calculate supernova nucleosynthesis due to the ν-process assuming that neutrino energy spectra are Fermi-Dirac distributions with zero chemical potential. We investigate the dependence of the ^{11}B yield on the total neutrino energy and the temperature of $\nu_{\mu,\tau}$ and $\bar{\nu}_{\mu,\tau}$. From the obtained yields and the contribution to the ^{11}B yield from supernovae constrained by observed abundances and Galactic chemical evolution models, we find an acceptable range of the temperature of $\nu_{\mu,\tau}$ and $\bar{\nu}_{\mu,\tau}$ of 4.8 MeV to 6.6 MeV.

Keywords. Supernovae: general, nuclear reactions, nucleosynthesis, abundances, Galaxy: evolution

1. Introduction

Supernovae (SNe) are one of the important sites for light element (Li-Be-B) production during Galactic chemical evolution (GCE). SNe provide mainly ^{11}B and ^{7}Li through the neutrino-nucleus interaction, referred to as the ν-process (Woosley, *et al.* 1990). Recent studies of GCE of light elements indicated that the contribution of ^{11}B from SNe derived from explosive nucleosynthesis models (Woosley & Weaver 1995; WW95) is larger by a factor of $2.5 \sim 5.6$ than that evaluated from GCE models (e.g., Fields, *et al.* 2000). However, the ^{11}B and ^{7}Li yields depend on supernova neutrino parameters which have not yet been precisely determined. We investigate the dependence of the ^{11}B and ^{7}Li yields in SNe on the total neutrino energy and the neutrino energy spectra. Then, we constrain the SN neutrino parameters through limitations on the ^{11}B yield determined by input from GCE.

2. Supernova model

We assume that the energy spectra of SN neutrinos obey the form of Fermi-Dirac distributions with zero chemical potentials. The temperatures of ν_e and $\bar{\nu}_e$ are set to be 3.2 MeV and 5.0 MeV. The neutrino luminosity decreases exponentially with time with the decay time of $\sim$3 s. We treat the total neutrino energy E_ν and the temperature of $\nu_{\mu,\tau}$ and $\bar{\nu}_{\mu,\tau}$, $T_{\nu_{\mu,\tau}}$, as free parameters. We use a 16.2 $M_\odot$ presupernova star corresponding to SN 1987A (Shigeyama & Nomoto 1990) as a progenitor model. The

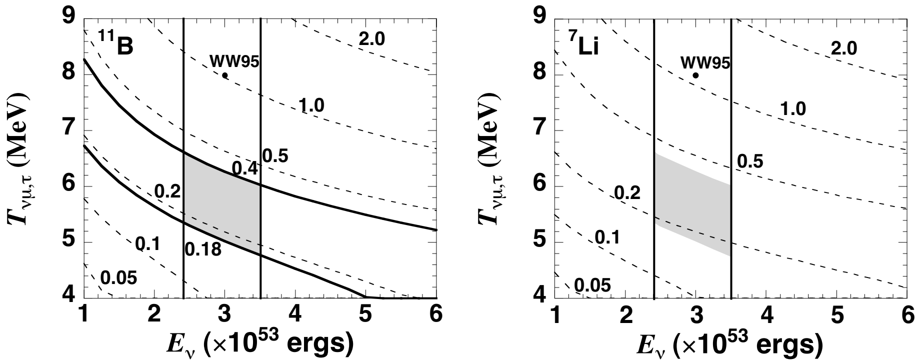

Figure 1. Contour lines of overproduction factor f_ν in the parameter plane of E_ν and $T_{\nu_{\mu,\tau}}$. The region between two vertical lines indicates the gravitational energy range relevant for $\sim 1.4 M_\odot$ neutron star. The point labeled WW95 indicates the specific parameter values used in WW95. The region between the two solid contour lines in ^{11}B panel is the f_ν range appropriate for GCE of ^{11}B. The shaded region is the part of parameter space in which both constraints (GCE ^{11}B yield and neutron star binding energy) are simultaneously satisfied. A similar box is drawn for the case of ^{7}Li.

supernova explosion is calculated with the explosion energy of 1×10^{51} ergs and the mass cut of $1.6 M_\odot$. Detailed nucleosynthesis during the explosion is calculated using a nuclear reaction network containing 291 nuclear species (Yoshida, *et al.* 2004).

3. Results

In our model, ^{11}B and ^{7}Li are mainly produced in the He layer. In there, ^{7}Li is produced through ^{4}He$(\nu,\nu' p)^3$H$(\alpha,\gamma)^7$Li and ^{4}He$(\nu,\nu' n)^3$H$(\alpha,\gamma)^7$Be$(e^-,\nu_e)^7$Li. Most of ^{11}B is produced through ^{7}Li$(\alpha,\gamma)^{11}$B. Less abundant ^{11}B is produced through ^{12}C$(\nu,\nu' p)^{11}$B and ^{12}C$(\nu,\nu' n)^{11}$C$(\beta^+)^{11}$B in the O/C layer. When we set the total neutrino energy E_ν to 3×10^{53} ergs and the neutrino temperature $T_{\nu_{\mu,\tau}}$ equal to 6 MeV, the ^{11}B and ^{7}Li yields are $1.92 \times 10^{-6} M_\odot$ and 7.37×10^{-7}. They are consistent with the yields of S20A model in WW95; the ^{11}B and ^{7}Li yields are $1.85 \times 10^{-6} M_\odot$ and $6.67 \times 10^{-7} M_\odot$.

We constrain the neutrino temperature $T_{\nu_{\mu,\tau}}$ from GCE models of ^{11}B abundance and the constraint on the total neutrino energy. Figure 1 shows the dependence of the ^{11}B and ^{7}Li yields in our model on the total neutrino energy E_ν and the neutrino temperature $T_{\nu_{\mu,\tau}}$. The overproduction factor f_ν is defined by the ratios of the yields of ^{11}B and ^{7}Li to the corresponding yields presented in WW95. We evaluate the range of f_ν from GCE models of ^{11}B abundance (e.g., Fields, *et al.* 2000) as $0.18 < f_\nu < 0.40$. The appropriate range of E_ν is evaluated as 2.4×10^{53} ergs $< E_\nu < 3.5 \times 10^{53}$ ergs from the gravitational energy of a $\sim 1.4 M_\odot$ neutron star (Lattimer & Prakash 2001). Therefore, the neutrino temperature range reproducing the SN contribution of ^{11}B in GCE is 4.8 MeV $< T_{\nu_{\mu,\tau}} <$ 6.6 MeV; lower neutrino temperature is favorable. From this neutrino temperature range, we also constrain the ^{7}Li yield in a $\sim 20 M_\odot$ star SN between $1.3 \times 10^{-7} M_\odot$ and $2.9 \times 10^{-7} M_\odot$. We have also investigated the effect of nonzero chemical potential of the neutrino energy spectra on the production of ^{11}B (see Yoshida, *et al.* (2005)).

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One of the many LOC annoucements at the conference, by Vanessa Hill.

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