Light Element and *r*-Process Element Synthesis through the ν-Process in Supernova Explosions

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Origin of Matter and Evolution of the Galaxies

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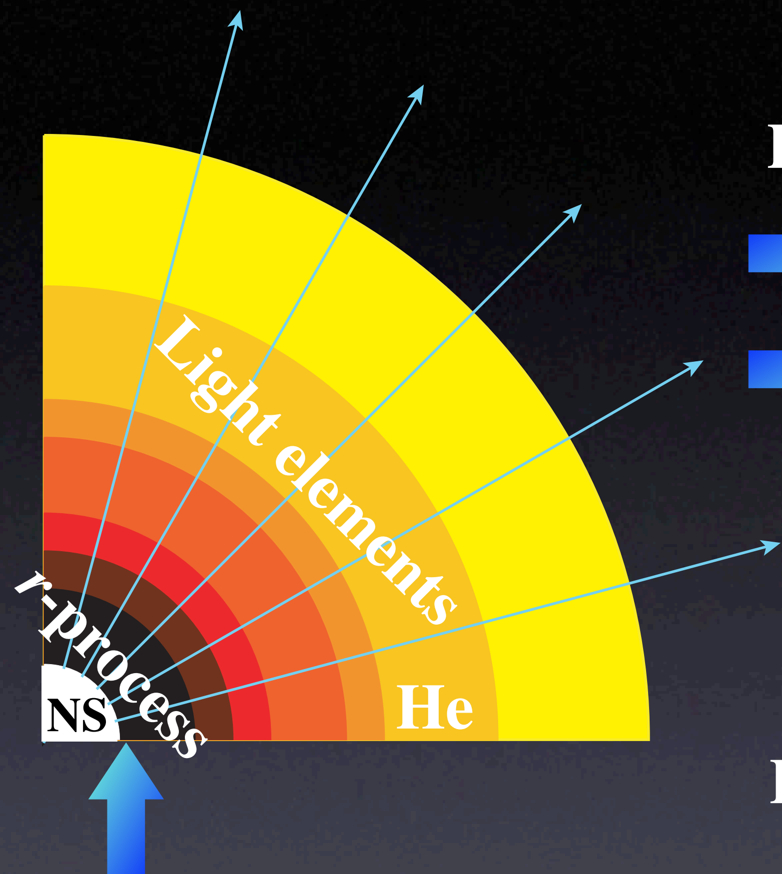
The □-Process in Supernova Explosions



Hot bubble region
“Neutrino driven winds”

Productions affected by the □-process

- Light elements
- *r*-process heavy elements

Different sites in supernova ejecta

Different supernova neutrino models

Important to investigate using a COMMON SUPERNOVA NEUTRINO MODEL.

Overproduction Problem of ^{11}B in GCE

Galactic chemical evolution of the light elements

^{6}Li, ^{9}Be, ^{10}B → Galactic cosmic rays (GCR)

^{7}Li → GCR, Supernovae, AGB stars, Novae

^{11}B → GCR, Supernovae

Supernova contribution of ^{11}B amount during GCE

→ **Determined from meteoritic ^{11}B/^{10}B ratio (=4.05)**

^{11}B amount evaluated from Woosley & Weaver (1995)
a factor of 2~5 OVERPRODUCED

→ **We should find a SUPERNOVA NEITRINO MODEL appropoate for GCE of ^{11}B**

Purpose of the Present Study

We investigate the dependence of the supernova neutrino models on the light element and *r*-process element synthesis using COMMON supernova neutrino models.

We discuss supernova neutrino models appropriate for ^{11}B amount during GCE and *r*-process abundance pattern.

Neutrino Luminosity

Neutrino luminosity

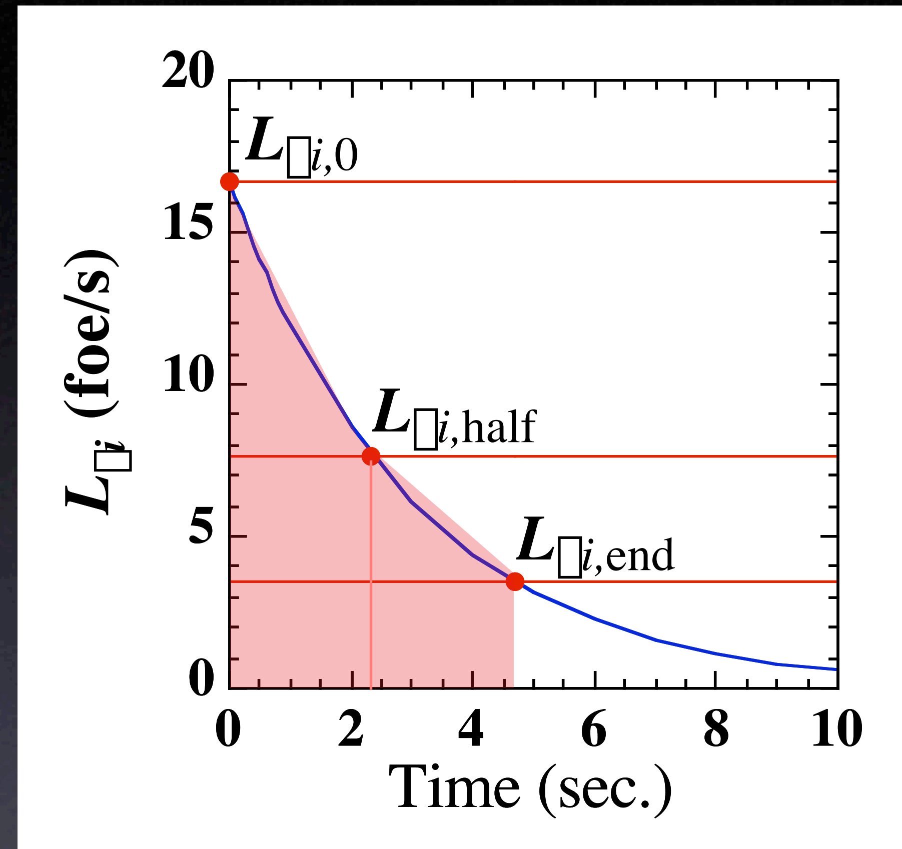
$$L_{\nu_i} = \frac{1}{6}\frac{E_\nu}{\tau_\nu}\exp\left(-\frac{t-r/c}{\tau_\nu}\right)\theta(t-r/c)$$

L_{ν_i} ($\nu_i = \nu_e, \nu_\mu, \nu_\tau, \bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau$)

Parameters

E_ν: Total neutrino energy

τ_ν: Decay time of L_{ν_i}



Neutrino energy spectra

→ Fermi distribution (μ_ν=0)

$T_{\nu_{\mu,\tau}} = T_{\bar{\nu}_{\mu,\tau}}$ = 8 MeV/k

T_{ν_e} = 3.2 MeV/k, $T_{\bar{\nu}_e}$ = 5 MeV/k

For r-process nucleosynthesis

$\dot{M}_{0,i}$, $\dot{M}_{\mathrm{half},i}$, $\dot{M}_{\mathrm{end},i}$, t_{end}

→ $M_{\mathrm{eject},i}$

Supernova Explosion Models

Light element nucleosynthesis

Explosion model (e.g., Shigeyama et al., 1992)

Presupernova 16.2 $M_\odot$ (corresponds to 20 $M_\odot$ ZAMS)

(Shigeyama & Nomoto 1990)

Explosion energy : 1×10^{51} erg

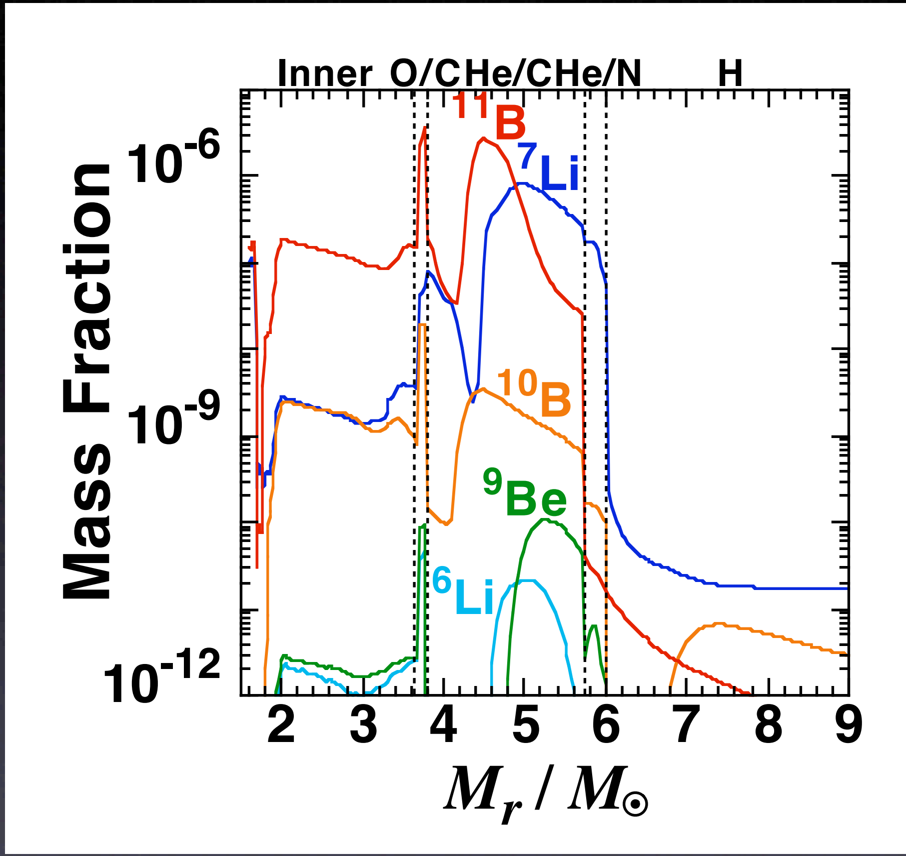
Mass Cut : 1.61 $M_\odot$

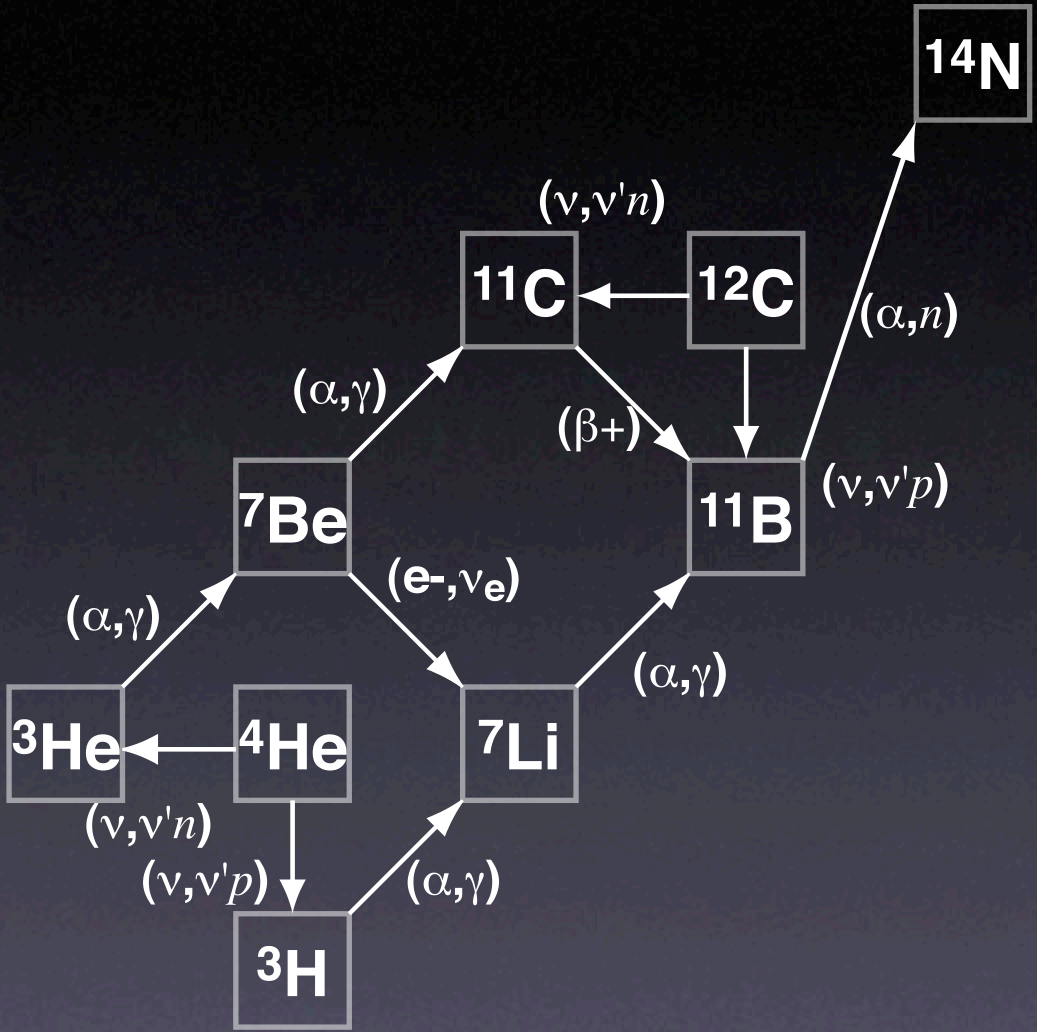
Nuclear reaction network : 291 species of nuclei

r-process nucleosynthesis

Neutrino-driven wind model: 1.4 $M_\odot$ neutron star (Terasawa et al. 2002)

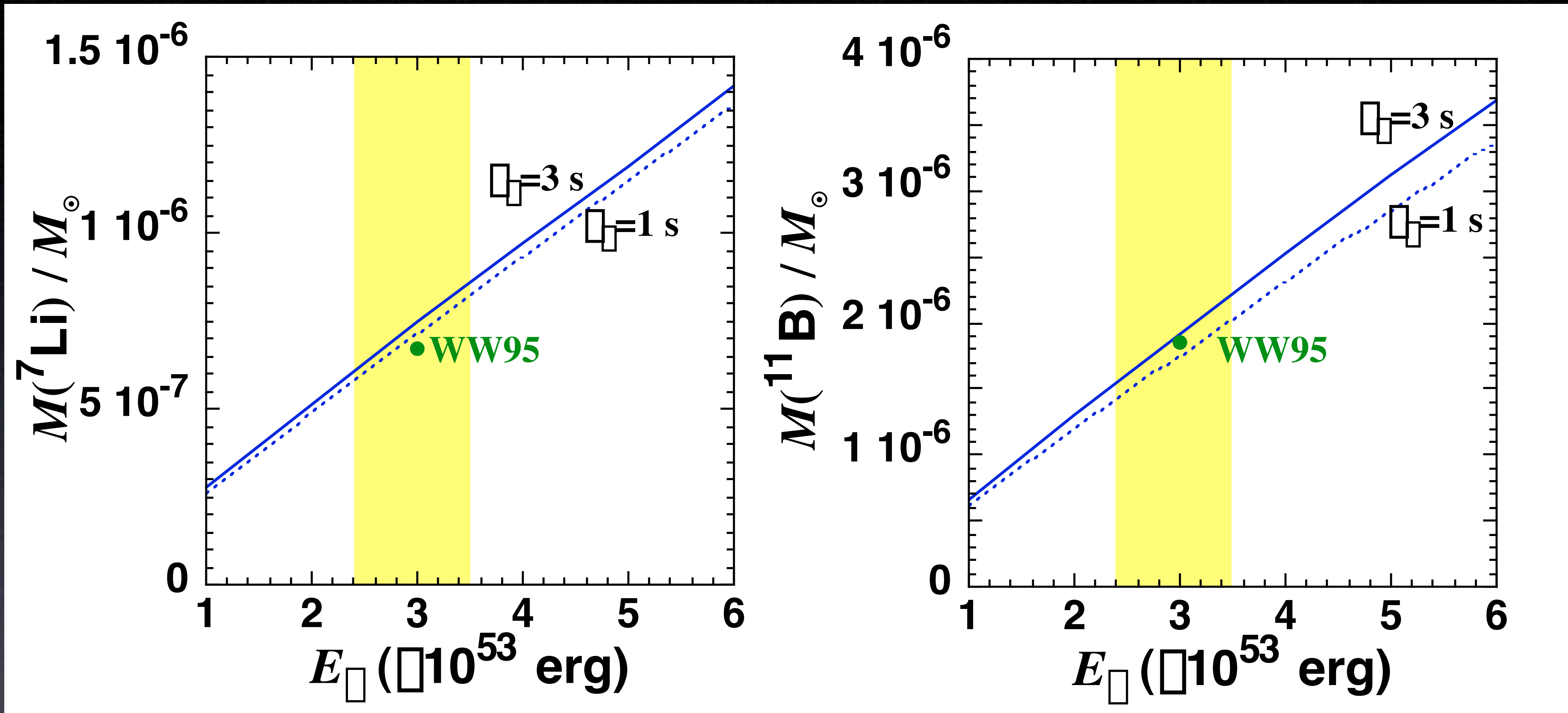
Mass Fraction Distribution of Light Elements





^{7}Li & ^{11}B production in He/C layer

Ejected Masses of ^{7}Li and ^{11}B



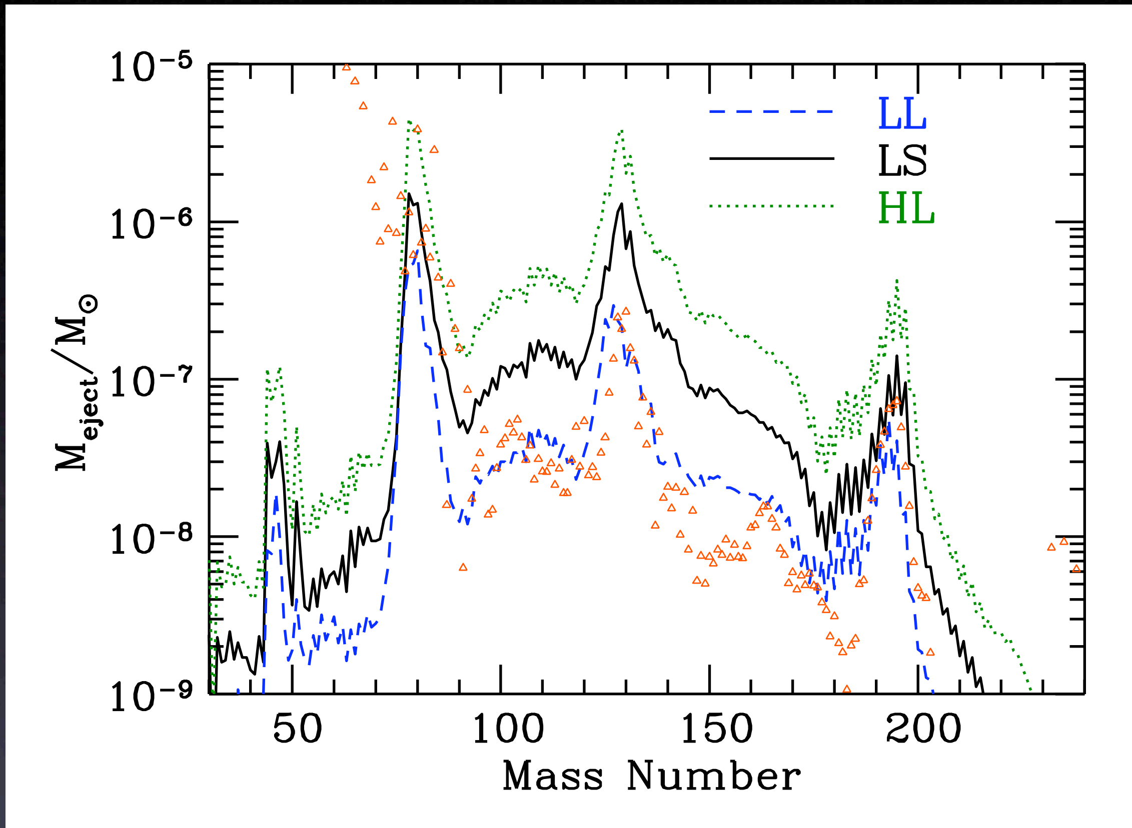
Proportional to the total neutrino energy $E_{□}$

Insensitive to the decay time of $L_{□i}$ □□

Our result is consistent with that of WW95.

$E_{□}$ ~ Binding energy of 1.4 $M_\odot$ neutron star (e.g., Lattimer & Yahil, 1989)

r-Process Abundance Pattern



LL: low E_ν, long τ_ν
(100 foe, 3 s)

LS: low E_ν, short τ_ν
(100 foe, 1 s)

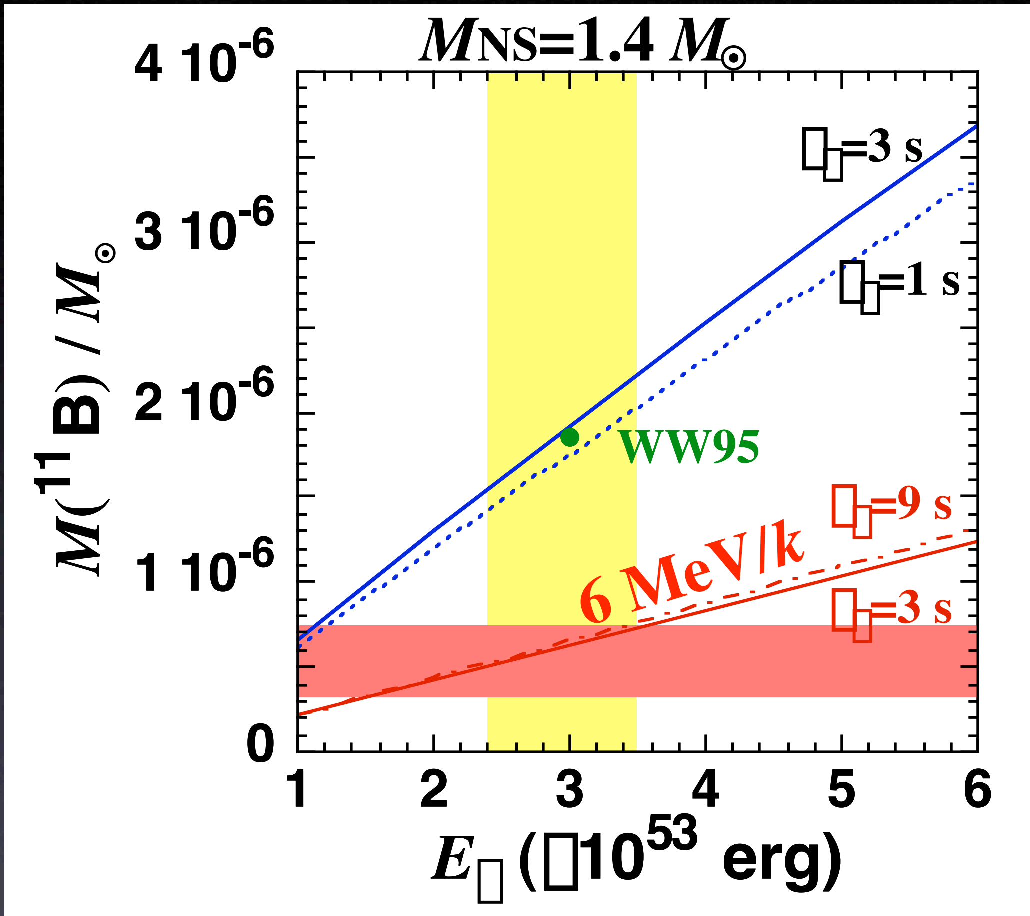
HL: high E_ν, long τ_ν
(300 foe, 3 s)

***r*-process abundance pattern depends on Peak neutrino luminosity**

$$L_{\nu i}(t=0) \propto E_\nu / \tau_\nu$$

LL (Most favorable case)
Third-to-second peak abundance ratio appropriate for the solar abundance pattern (Kappeler et al. 1989)
LS & HL
Third-to-second peak abundance ratio is smaller than that of LL case.
Same relative abundance pattern ⟵ Same value of $L_{\nu i}(t=0)$

Overproduction of ^{11}B in GCE



^{11}B mass evaluated from GCE

Fields et al. 2000
Ramaty et al. 2000
Ramaty, Lingenfelter, & Kozlovsky 2000
Alibes, Labay, & Canal 2002

$0.18 < M / M_{WW95} < 0.40$

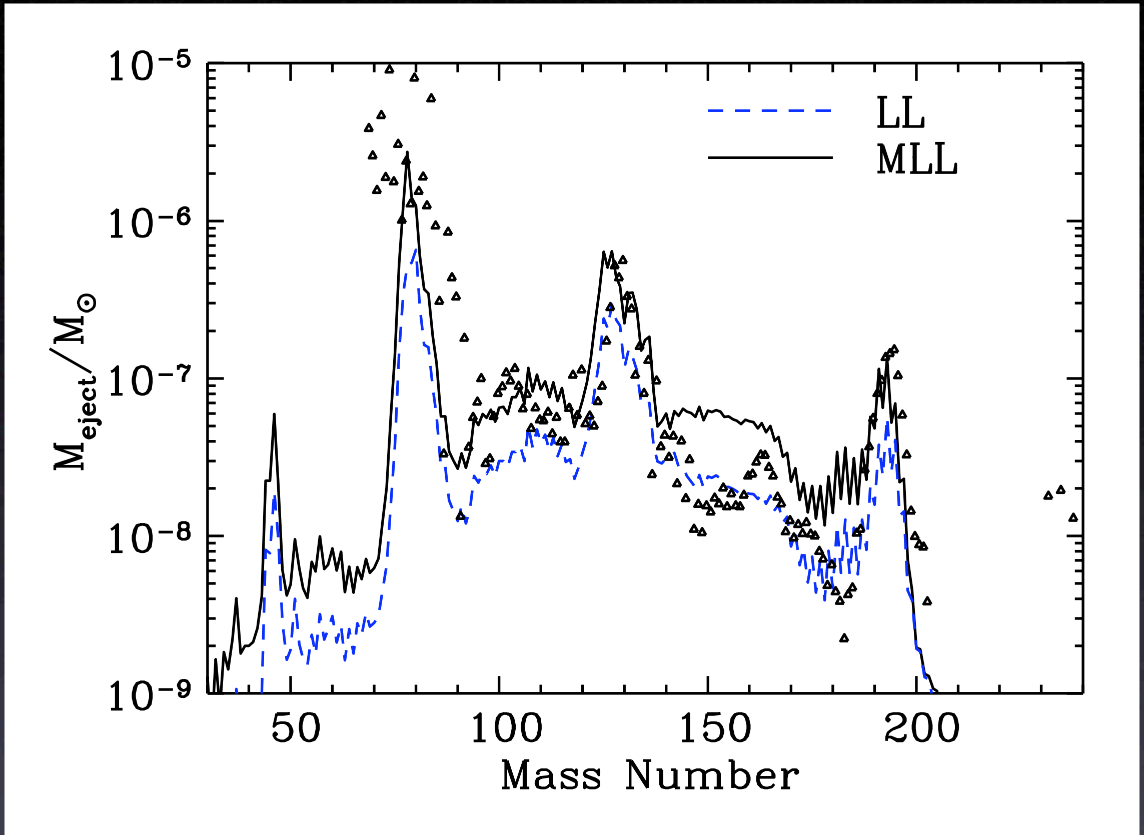
$T_{\nu\mu,\tau} = T_{\bar{\nu}\mu,\tau} = 6$ MeV/k

$T_{\nu e}$= 3.2 MeV/k, $T_{\bar{\nu}e}$= 5 MeV/k

The ejected mass of ^{11}B with the appropriate total neutrino energy successfully reproduces that evaluated from GCE.

$5.2\times10^{-7} M_\odot < M(^{11}B) < 7.4\times10^{-7} M_\odot$

r-Process Abundance Pattern



MLL: The same $L_{\nu i}(t=0)$ as that of LL

$E_{\nu} = 300$ foe, $\tau_{\nu} = 9$ s

$T_{\nu\mu,\tau} = T_{\bar{\nu}\mu,\tau} = 6$ MeV/k

LL: low E_{ν}, long τ_{ν} (100 foe, 3 s)

Peak neutrino luminosity

$$L_{\nu i}(t=0) \propto E_{\nu} / \tau_{\nu}$$

MLL

Appropriate third-to-second peak abundance ratio

Almost same abundance pattern as that of LL

→ Insensitive to $T_{\nu\mu,\tau}$, $T_{\bar{\nu}\mu,\tau}$

Summary

We investigated the dependence of the supernova neutrino models on the light element and *r*-process element synthesis using COMMON supernova neutrino models.

Ejected masses of ^{7}Li & ^{11}B

Proportional to the total neutrino energy $E_{\square}$

Insensitive to the decay time of $L_{\square i}$ $\square_{\square}$

r-process abundance pattern

mainly depends on $L_{\nu i}(t=0) \propto E_{\nu} / \tau_{\nu}$

Small value of $L_{\square i}(t=0)$ is prefered

We discussed the supernova neutrino models appropriate for ^{11}B amount during GCE and *r*-process abundance pattern.

We propose the supernova neutrino models with

$T_{\square\square,\square}=\bar{T}_{\square\square,\square}$ = 6 MeV/k rather than $T_{\square\square,\square}=\bar{T}_{\square\square,\square}$ = 8 MeV/k

$E_{\square}$ ~ 300 foe, $\square_{\square}$ = 9 s

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