

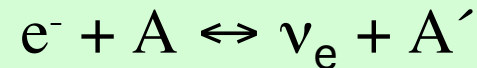
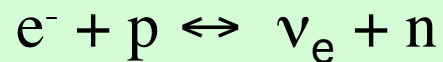
爆発における原子核物理の役割は？

ニュートリノ反応の影響

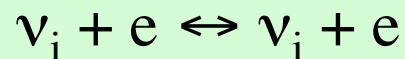
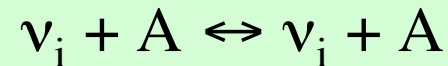
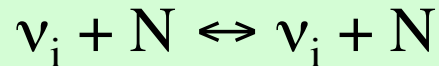
超新星コアでのニュートリノ反応

輸送方程式の散乱項: ν 個数・エネルギー変化 \rightarrow 物質の加熱冷却

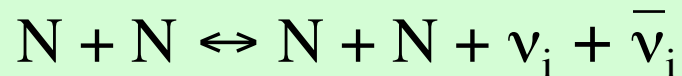
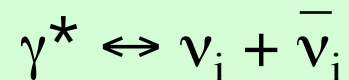
- 放出/吸収:



- 散乱:



- 対生成・消滅:



$$i=e, \mu, \tau$$

- 実験が難しい

- ν 吸収断面積: $\sigma \sim 10^{-41} \text{ cm}^2$
- 高温高密度物質

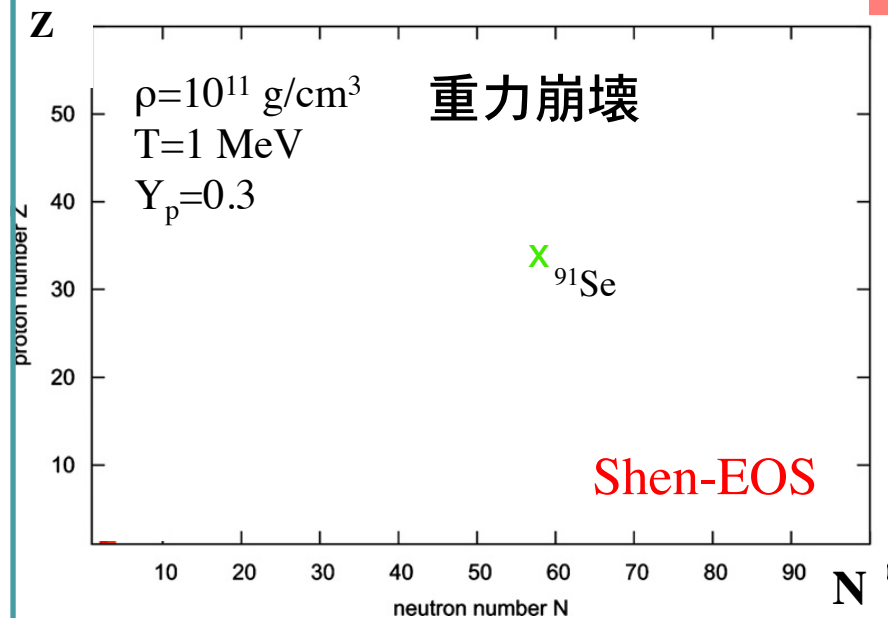
- エネルギー依存性

- 相互作用の特性: $\sigma \sim E_\nu^2$
- 原子核の構造を反映: $\sigma \sim A^2$

超新星コアにおける原子核組成

Shen-EOS

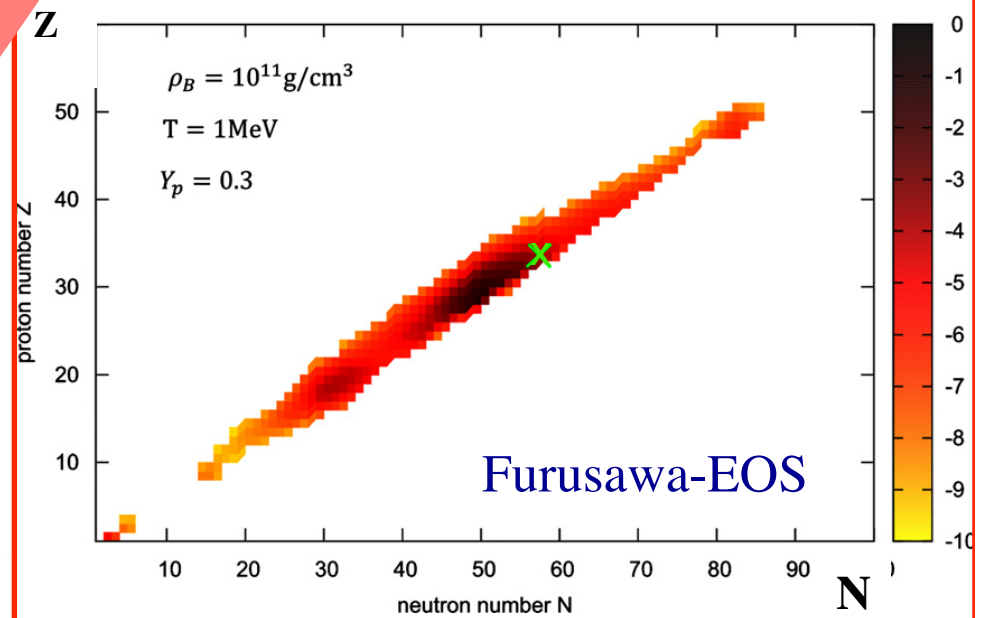
Neutron, proton, ${}^4\text{He}$
One species of nuclei
approximation



代表的な核種1つ

Furusawa-EOS

Neutron, proton, d, t, ${}^3\text{He}$, ${}^4\text{He}$, ...
All of nuclei up to $A \sim 1000$
In nuclear statistical equilibrium



多種多様な核種

原子核組成の影響: 重力崩壊・バウンス(1D)

電子捕獲 ↑ → ニュートリノ閉込め ↓ → 初期衝撃波エネルギー ↓

- 核種混合組成を考慮

New electron capture rates

- Langanke, Pinedo (2003)
- Shell Model + RPA, $45 < A < 112$

- 代表一核種

Electron capture rates

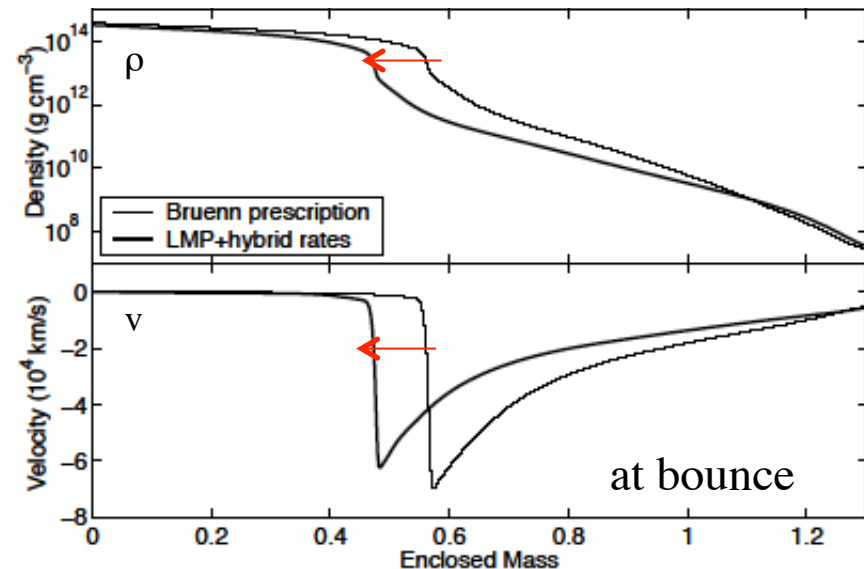
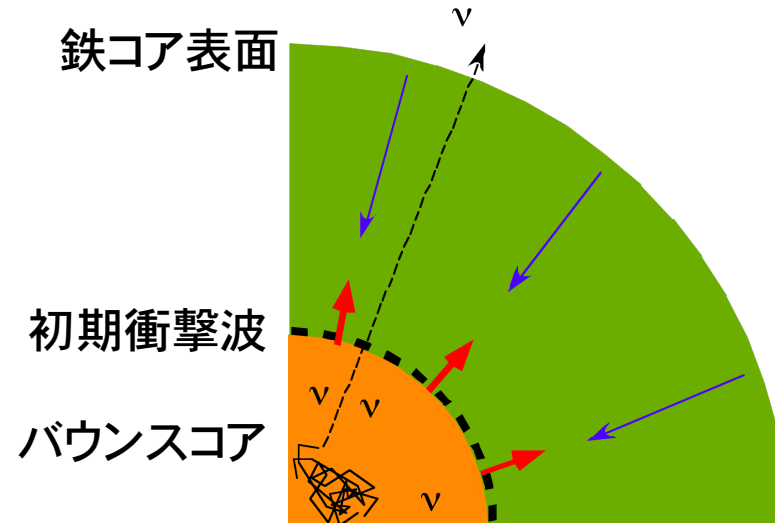
- Bruenn (1985)
- Simple formula, $N > 40$ blocked

- バウンスコアサイズ ↓

衝撃波を阻む外層が増える

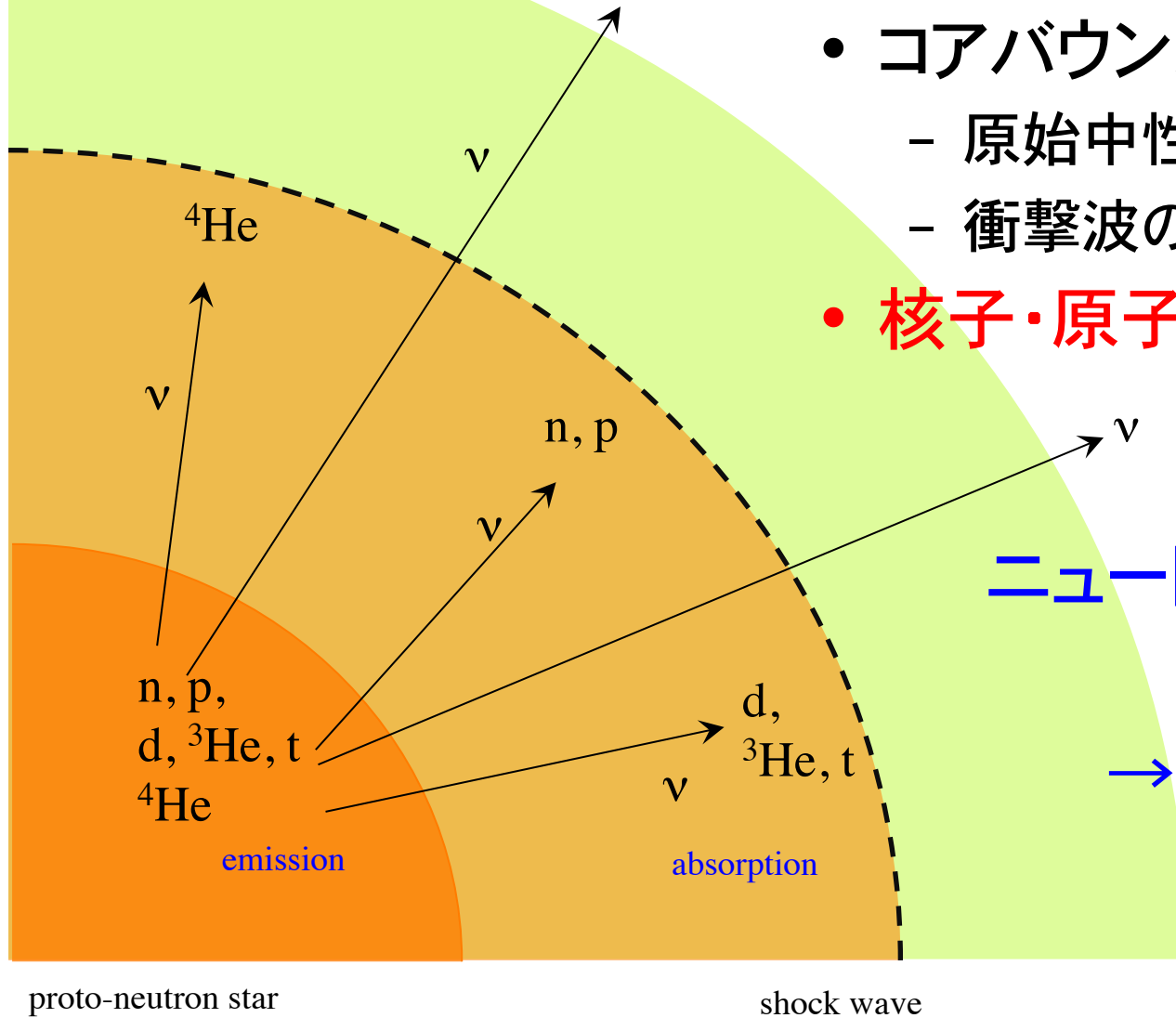
$$\Delta M_{in} = 0.1 M_{solar} \sim 1.6 \times 10^{51} \text{ erg} \downarrow$$

爆発エネルギーに匹敵



Hix et al. PRL (2003)

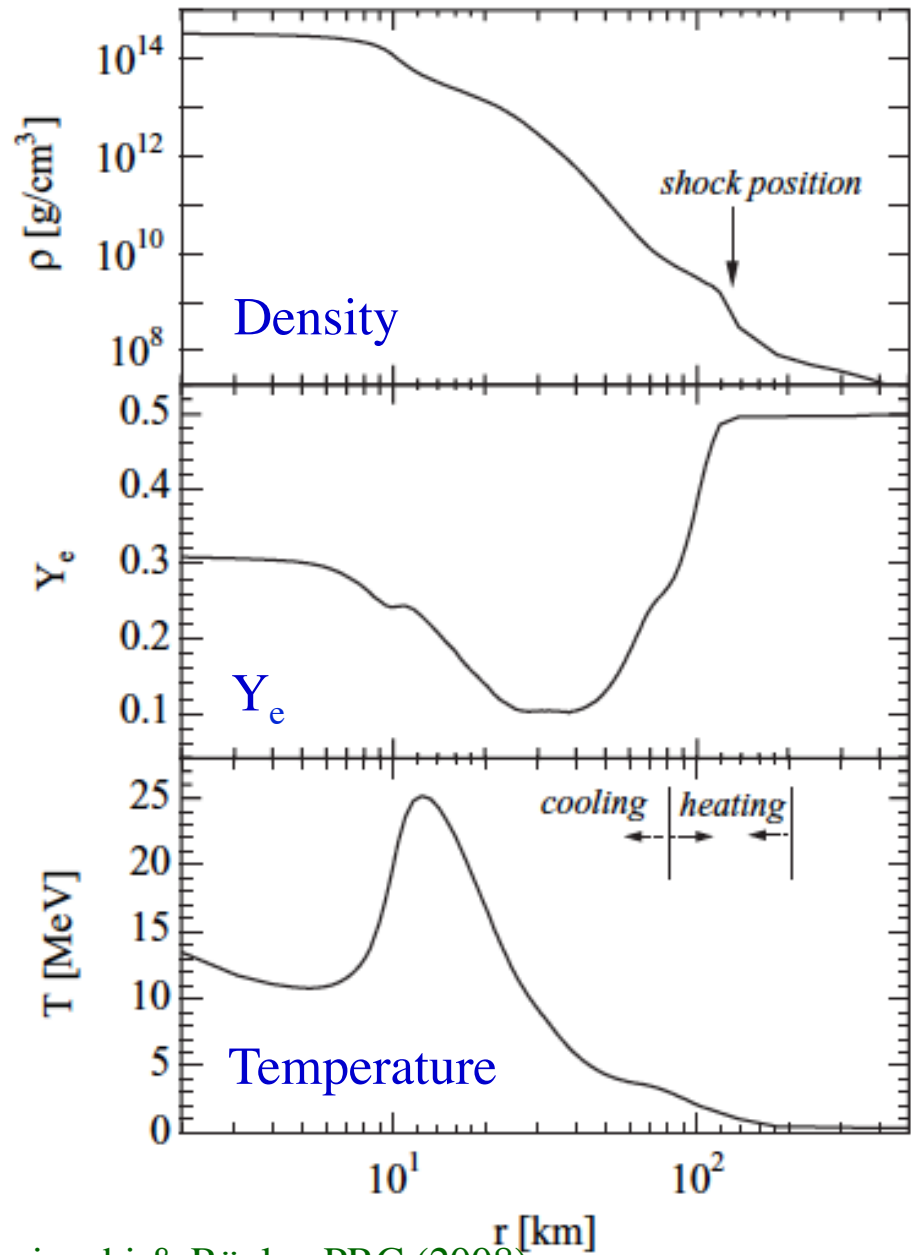
ニュートリノ加熱と状態方程式: 組成



- コアバウンス後において
 - 原始中性子星の表面
 - 衝撃波の背面
- 核子・原子核の組成は?

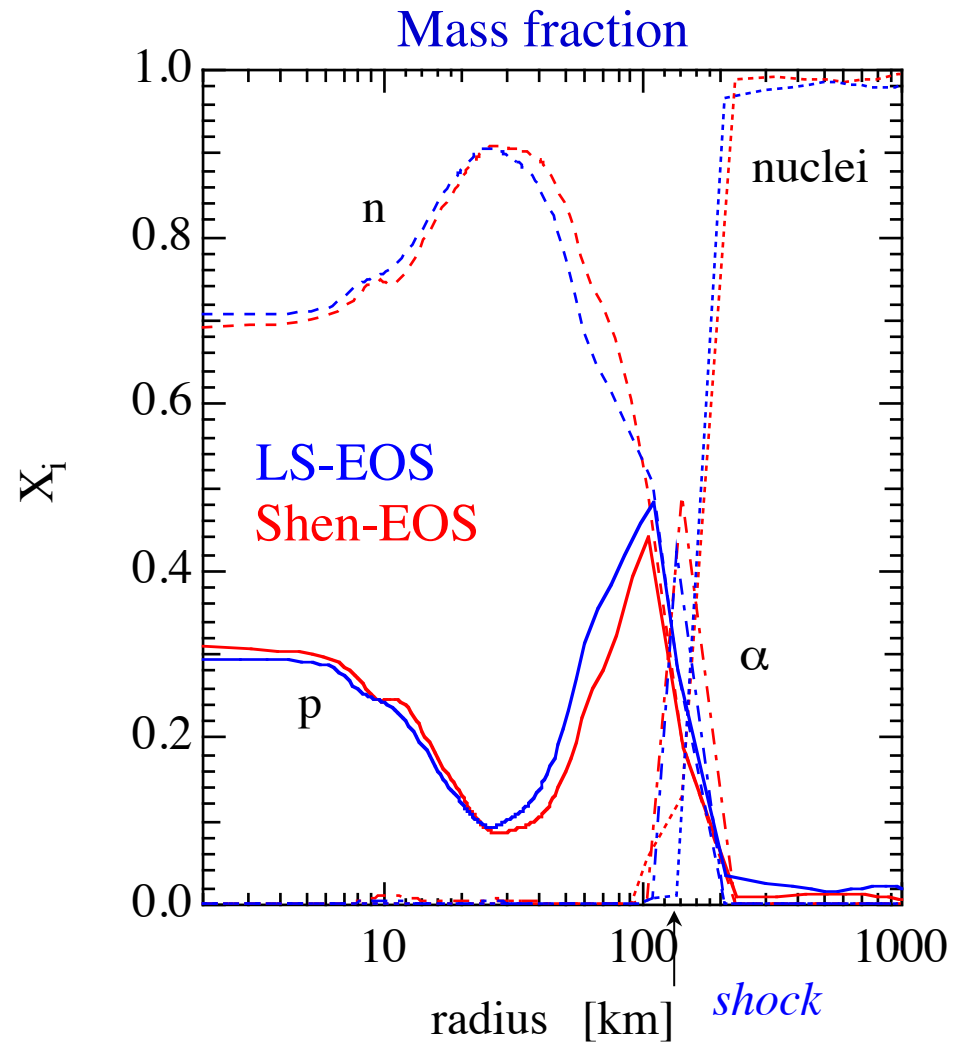
ニュートリノ放出・吸収
→ 冷却/加熱
→ 爆発メカニズム

Hot dense matter after core bounce



Sumiyoshi & Röpke, PRC (2008)

At $t_{\text{pb}}=150\text{ms}$ after bounce



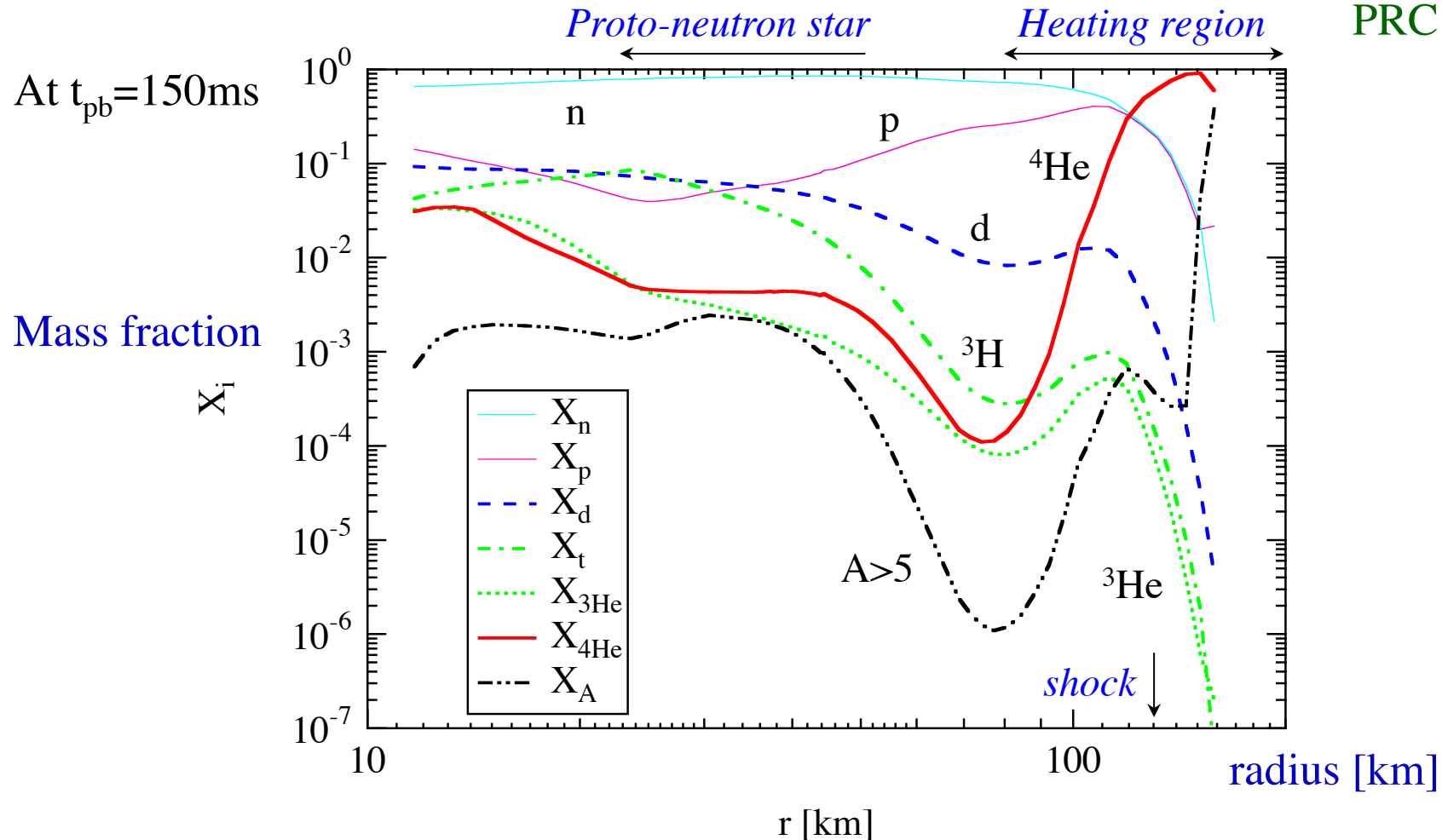
Sumiyoshi et al. ApJ (2005)

軽元素が大量に現れる (${}^4\text{He}$ だけではない)

$p, n, d, {}^3\text{H}, {}^3\text{He}, {}^4\text{He}, \text{nuclei}$

Sumiyoshi & Röpke

PRC (2008)

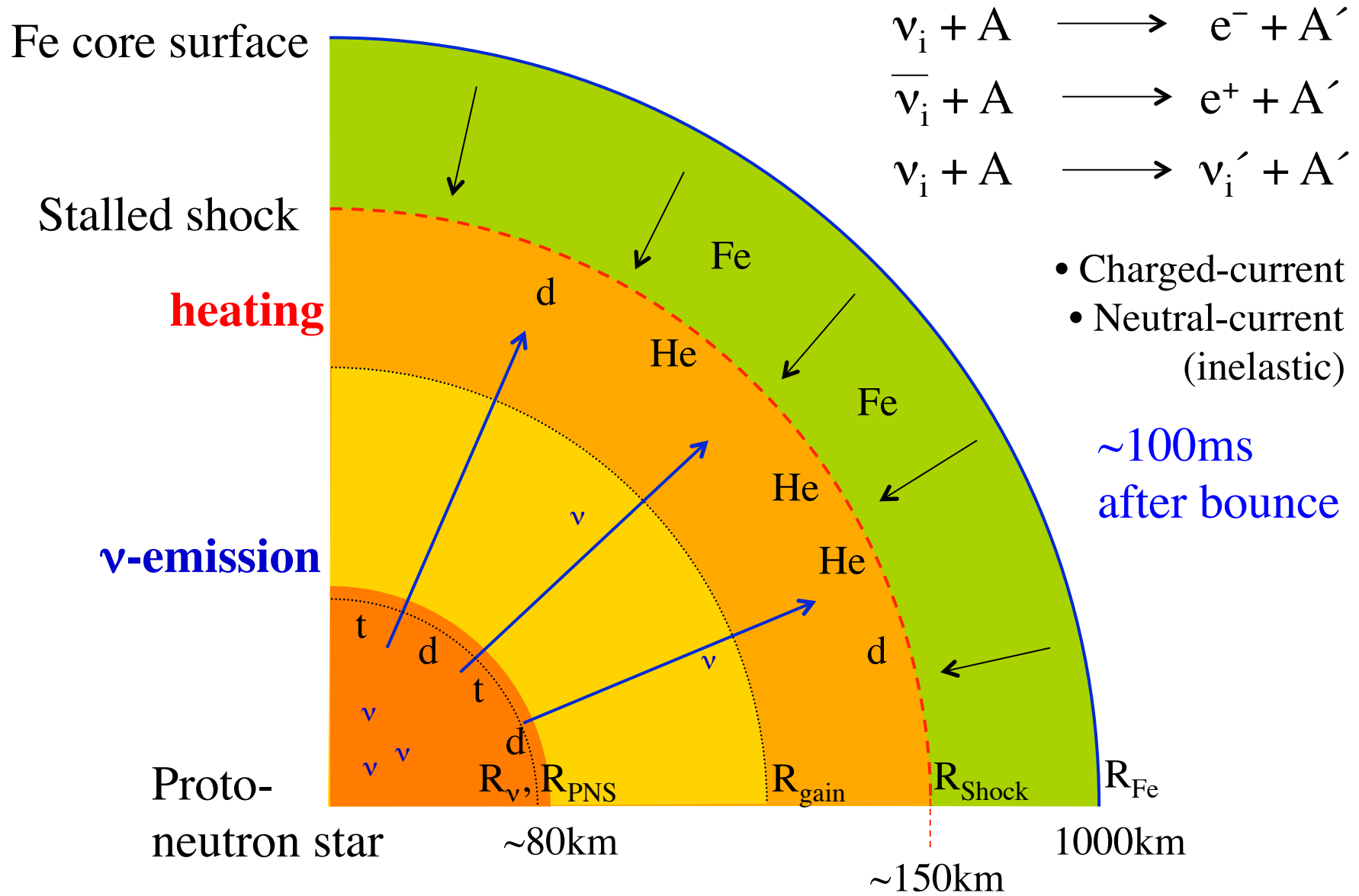


- ${}^4\text{He}$ abundant at $r > 100\text{km}$ → heating/cooling rates
- $d, t, {}^3\text{He}$ abundant at $r < 50\text{km}$ → ν -emission, absorption

See also. Arcones et al. PRC (2008)

ν -heating through light nuclei

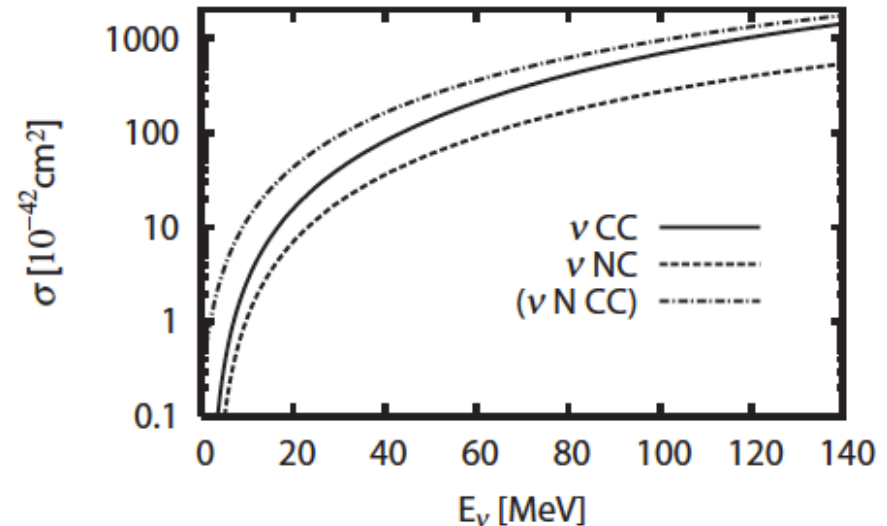
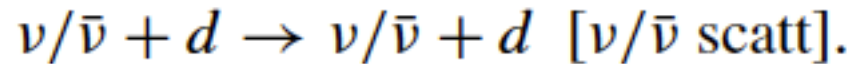
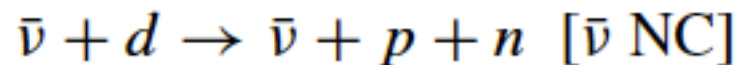
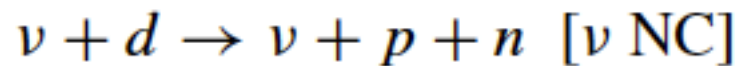
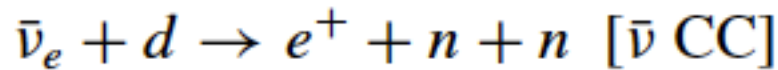
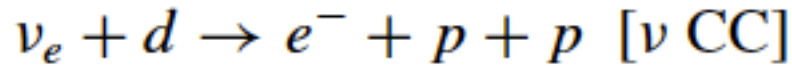
Nakamura (2009), Furusawa (2013)



ν -重陽子反応: ニュートリノ加熱への寄与

Nakamura, Sumiyoshi and Sato PRC (2009)

- Application of neutrino-deuteron reactions



- Average energy transfer from neutrino to matter

$$\langle \sigma \omega \rangle_{T_\nu} = \int dE_\nu f(T_\nu, E_\nu) \sigma \omega(E_\nu). \quad f(T_\nu, E_\nu) = \frac{N}{T_\nu^3} \frac{E_\nu^2}{e^{E_\nu/T_\nu} + 1}.$$

cf. $\nu + {}^3\text{H}, {}^3\text{He}$

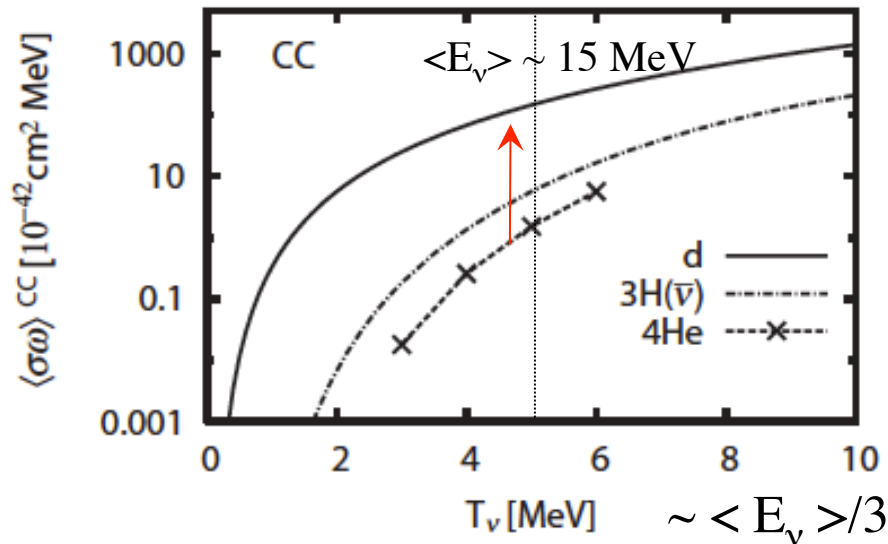
$\nu + {}^4\text{He} \rightarrow \text{breakup}$

ニュートリノ加熱率の評価

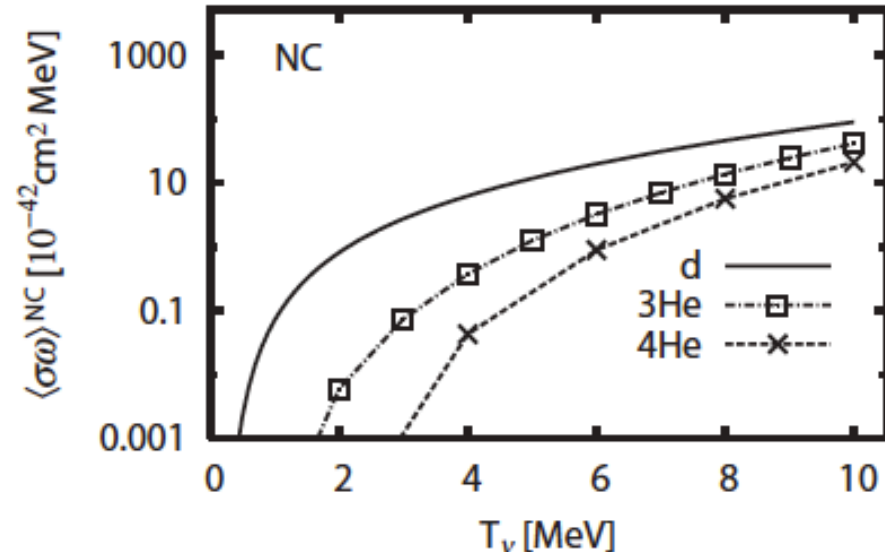
- Nucleon $Q_\nu^N \approx 223 \cdot \frac{L_{\nu,52} E_{\nu,15}^2}{R_7^2} X_i \left[\frac{\text{MeV}}{s \cdot N} \right]$
- Nuclei $Q_\nu^A \approx 32 \cdot \frac{L_{\nu,52}}{R_7^2 E_{\nu,15}} X_i \overline{\langle \sigma E \rangle}_{\nu-A} \left[\frac{\text{MeV}}{s \cdot N} \right]$ Haxton PRL ('88)

Average energy transfer x cross section $\overline{\langle \sigma E \rangle}_{\nu-A} [10^{-40} \text{MeVcm}^2]$

- 加熱率: ν -deuteron $>$ ν - ^3He , $t >$ ν - ^4He dが沢山いれば効く



Nakamura, Sumiyoshi & Sato PRC (2009)



O'Connor et al. PRC (2007)

Neutrino heating via light nuclei in 2D

- Light nuclei may affect shock dynamics

