Imprint of asymmetric neutrino emission of a supernova on chemical abundances in a supernova remnant

Shin-ichiro Fujimoto
(NIT Kumamoto, Japan)
Hiroki Nagakura (Princeton)

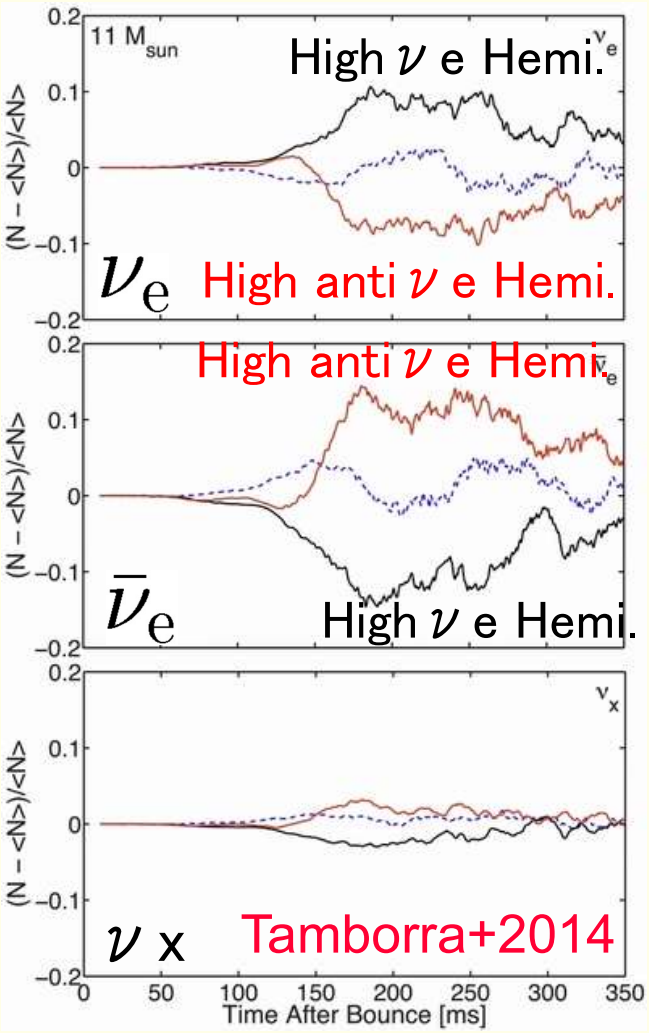
The Evolution of Massive Stars and Formation of Compact Stars: from the Cradle to the Grave
2020.02.26 Waseda University

Summary

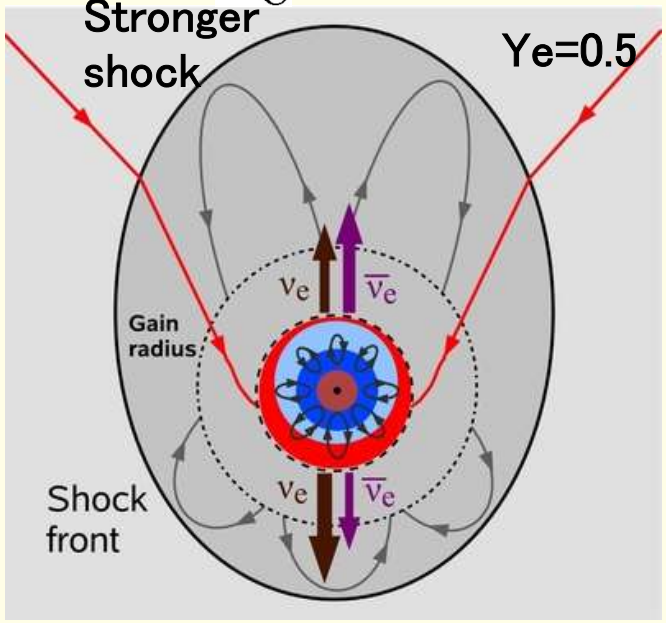
- p-rich ejecta with Ye >0.51 in high ν e hemisphere
- n-rich ejecta with Ye <0.49 in high anti-ν e hemisphere
- Nuclei with Z >= 29 (Cu:Z=29) abundantly produced in n-rich ejecta
- For high ν asymmetry (>=30%), nuclei heavier than Zn(Z = 30) are overproduced compared with the solar abundances.
- For ν asymmetry <= 10%, which is comparable to those in multi-D simulations), nuclei of Zn to Zr (Z=30–40) are appropriately synthesized, compared with the solar abundances.
- X-ray observations (with XRISM, NuSTAR, FORCE) of north-south differences of Ni/Fe and Zn/Fe in Galactic SNRs possibly constrain ν asymmetry.

Asymmetric, Anti-Corrlated ν -emission

Asymmetry of ν emission



High $\bar{\nu}_e$ Hemisphere



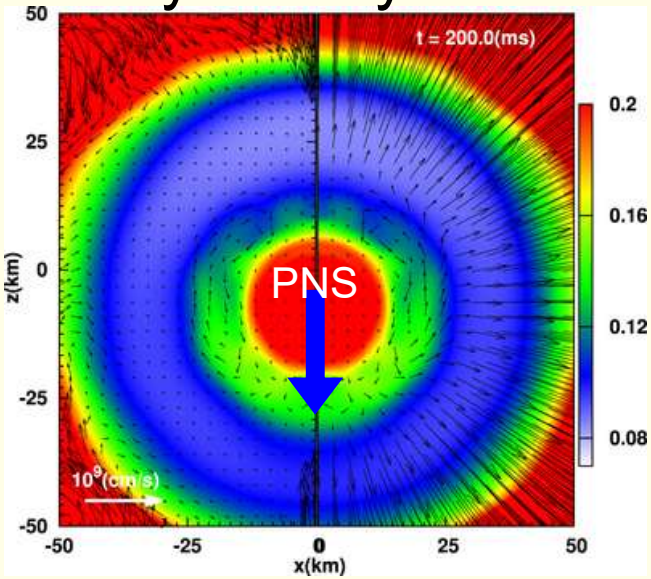
High ν_e Hemisphere

Tamborra+2014

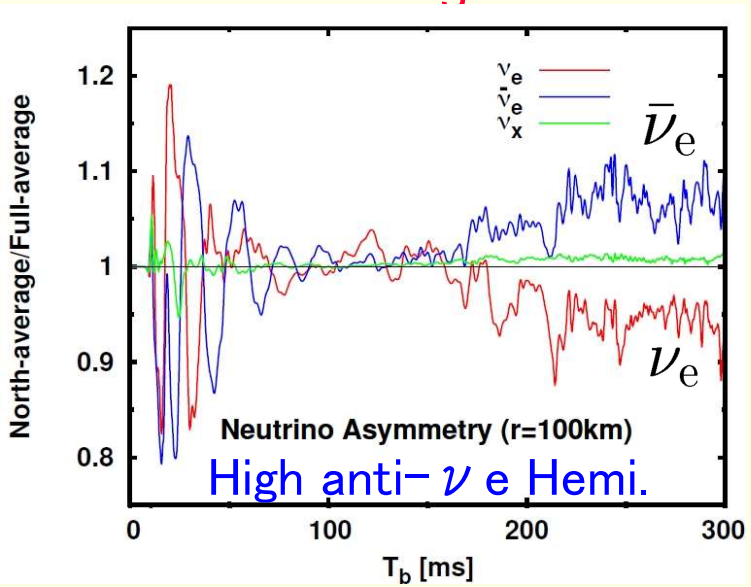
Mms=11.2Msun

Z = Zsun

ν asymmetry with kick

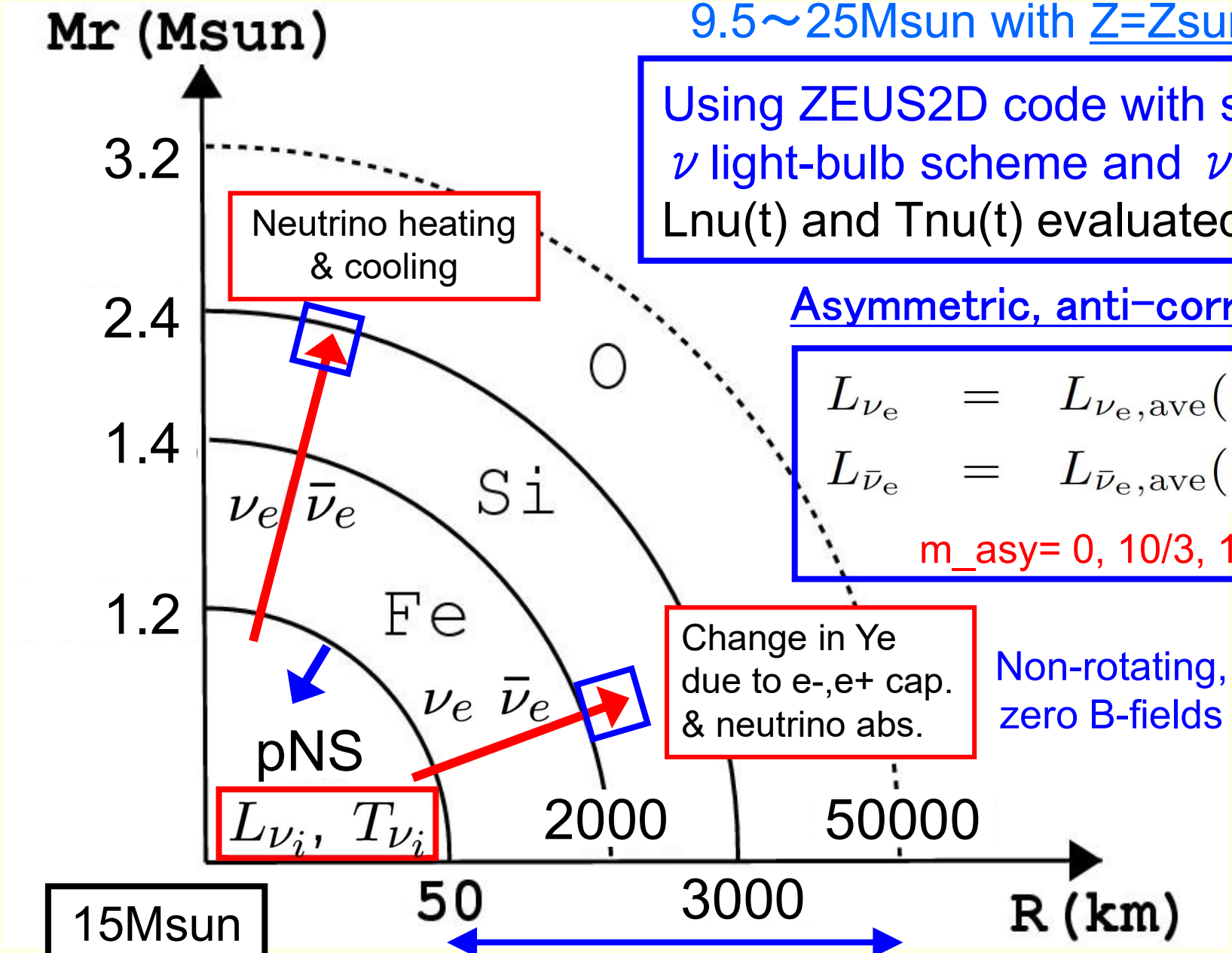


Nagakura+2019



Asymmetric (~10%)、Anti-Corrlated ν w. proto-NS kick

Hydrodynamic model & Initial setup



9.5～25Msun with Z=Zsun (WHW02)

Using ZEUS2D code with simplified ν light-bulb scheme and ν -core model
Lnu(t) and Tnu(t) evaluated from Mdot(t)

Neutrino heating & cooling

Asymmetric, anti-correlated ν emission

$$L_{\nu_e} = L_{\nu_e,\mathrm{ave}}(1 + m_{\mathrm{asy}} \cos\theta)$$
$$L_{\bar{\nu}_e} = L_{\bar{\nu}_e,\mathrm{ave}}(1 - m_{\mathrm{asy}} \cos\theta)$$

m_asy= 0, 10/3, 10, 30, and 50%

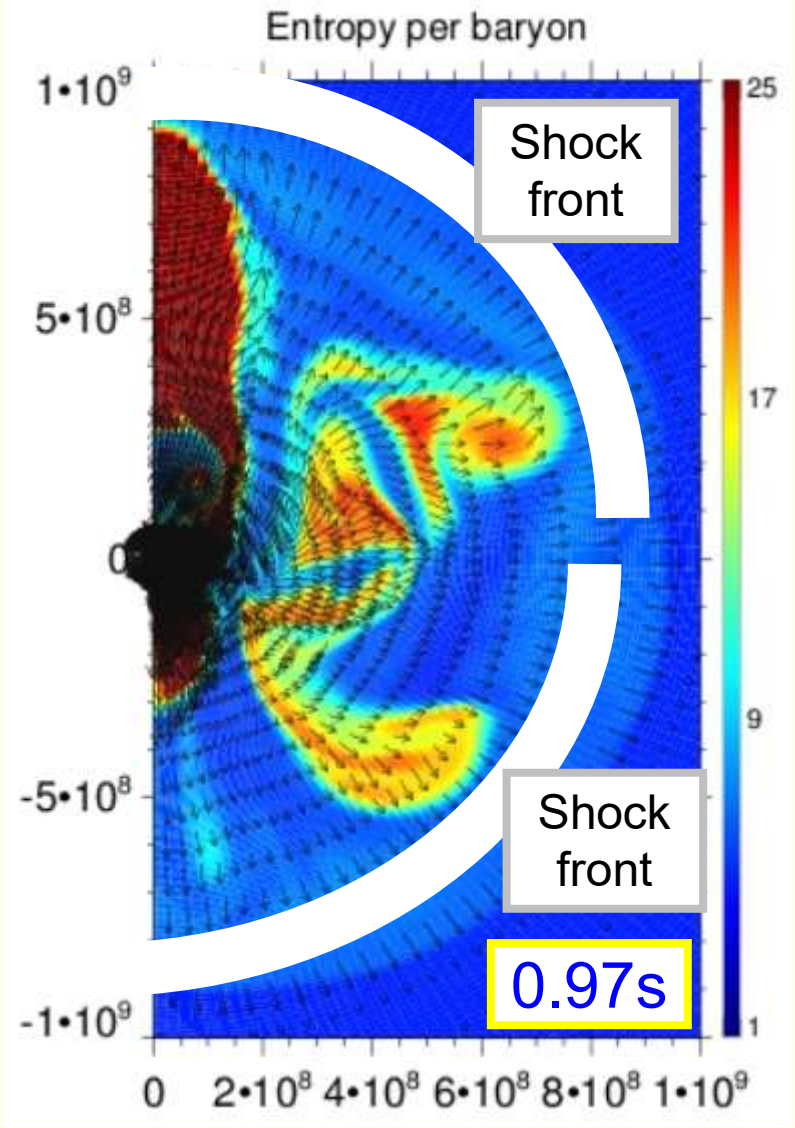
Change in Ye due to e-,e+ cap. & neutrino abs.

Non-rotating, zero B-fields

Computational region (0-π in θ direction)

Asymmetric SN explosion and ejecta

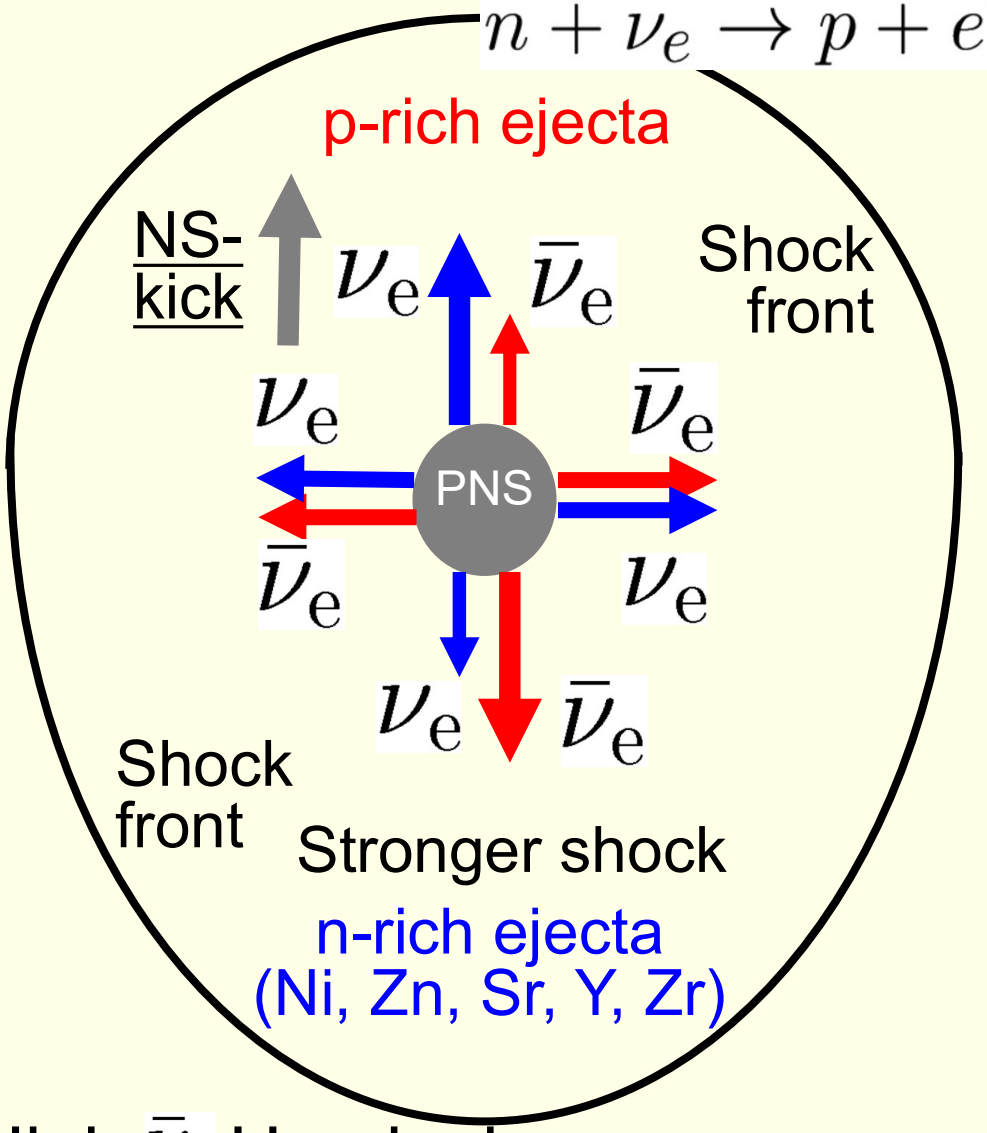
Mms = 19.4Msun, m_asy=0%



10000km x 20000km

High ν_e Hemisphere

$$n + \nu_e \rightarrow p + e^-$$



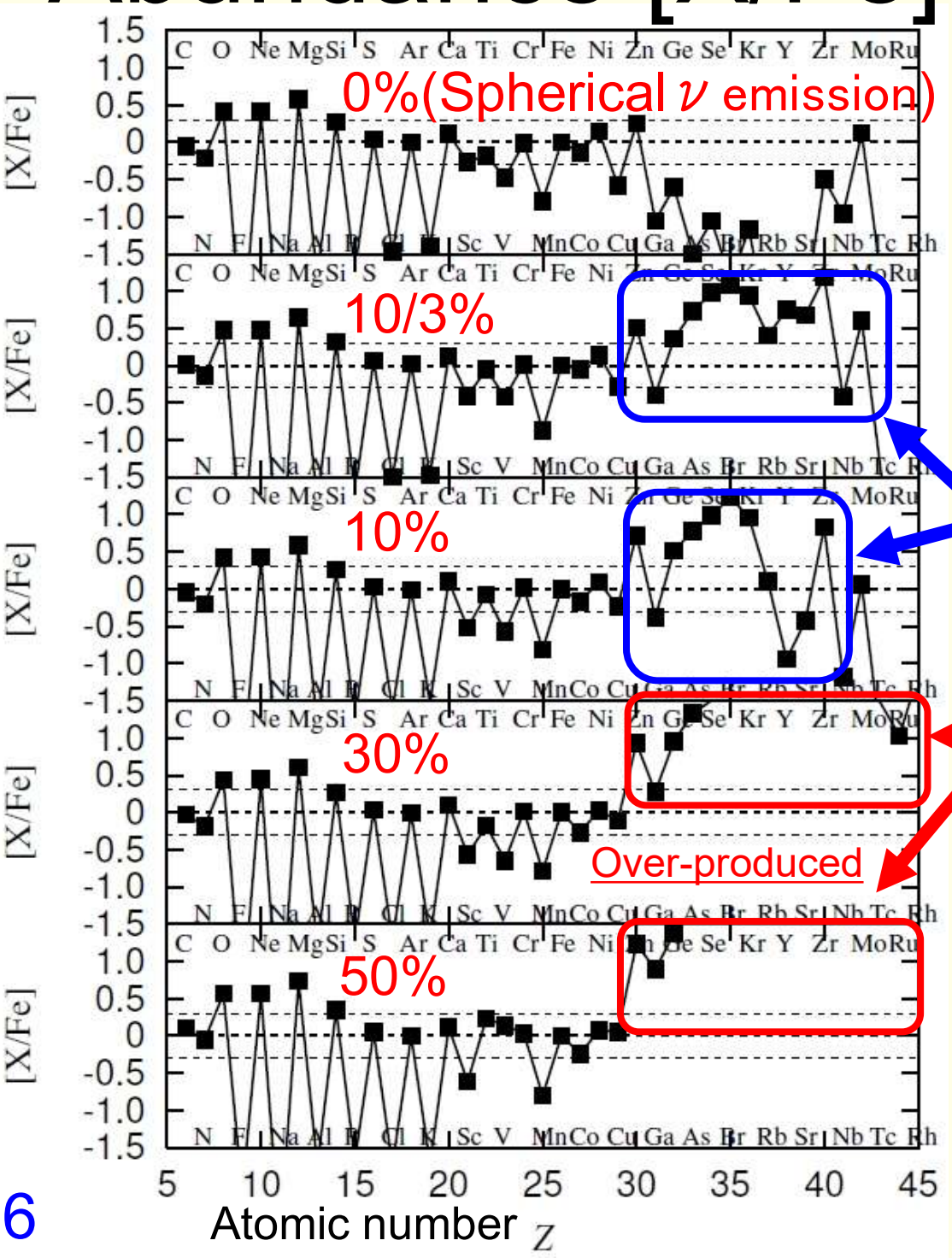
High $\bar{\nu}_e$ Hemisphere

$$p + \bar{\nu}_e \rightarrow n + e^+$$

Abundance [X/Fe]

Mms=19.4Msun

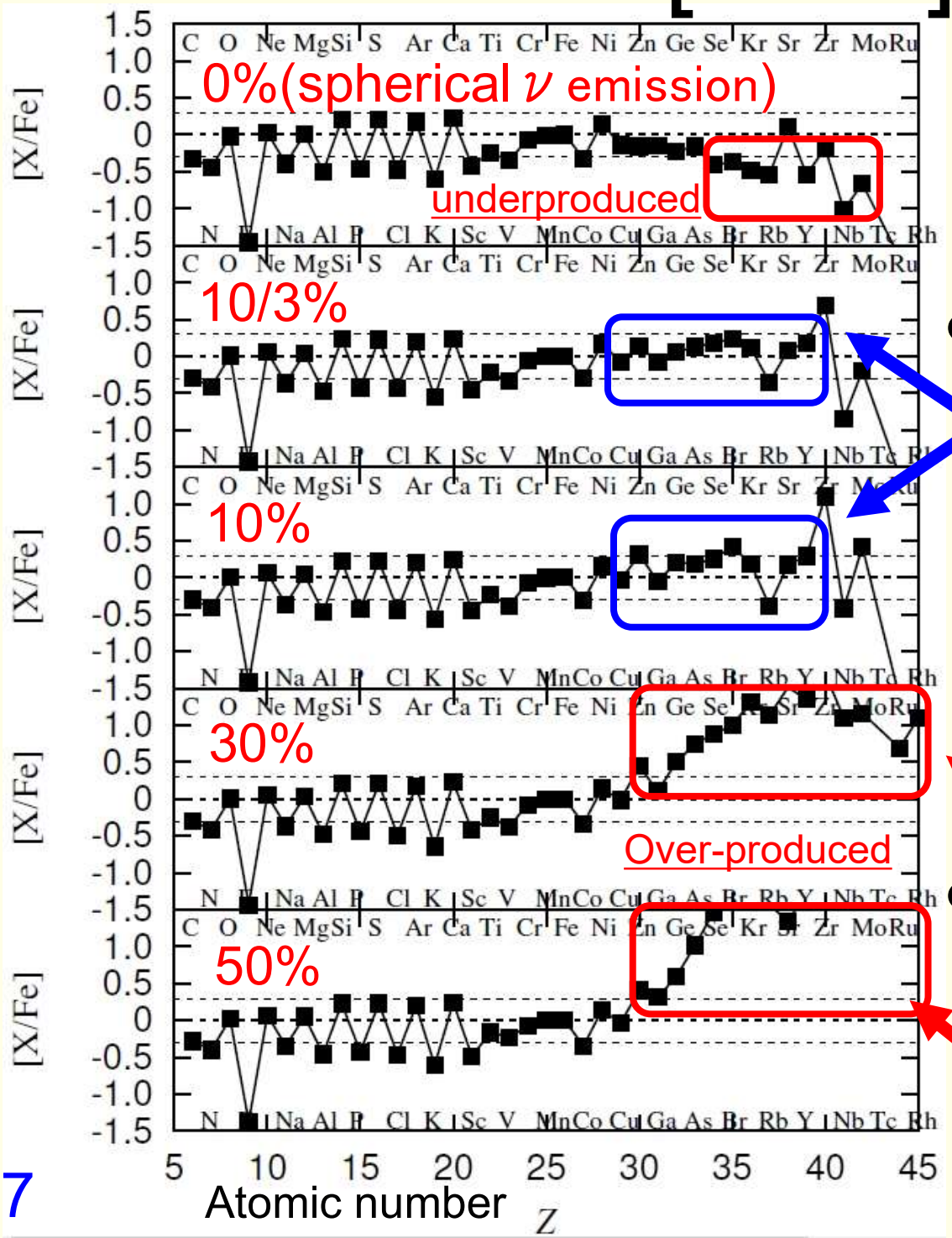
$$[\mathrm{A/B}] = \log \left[\frac{X_\mathrm{A}/X_{\mathrm{A},\odot}}{X_\mathrm{B}/X_{\mathrm{B},\odot}} \right]$$



- Nuclei with Z>=29 (Cu) in n-rich ejecta
- For ν asymmetry <= 10%, nuclei of Zn to Zr (Z=30-40) are appropriately synthesized
- For ν asymmetry >= 30%, nuclei of Zn to Zr are over-produced compared with the solar abundances ([X/Fe]=0).

Abundances [X/Fe]

SN II+ SN Ia



SN II: IMF-averaged our CCSN models (9.5, 11.2, 13, 15, 17, 19.4, 25 Msun)

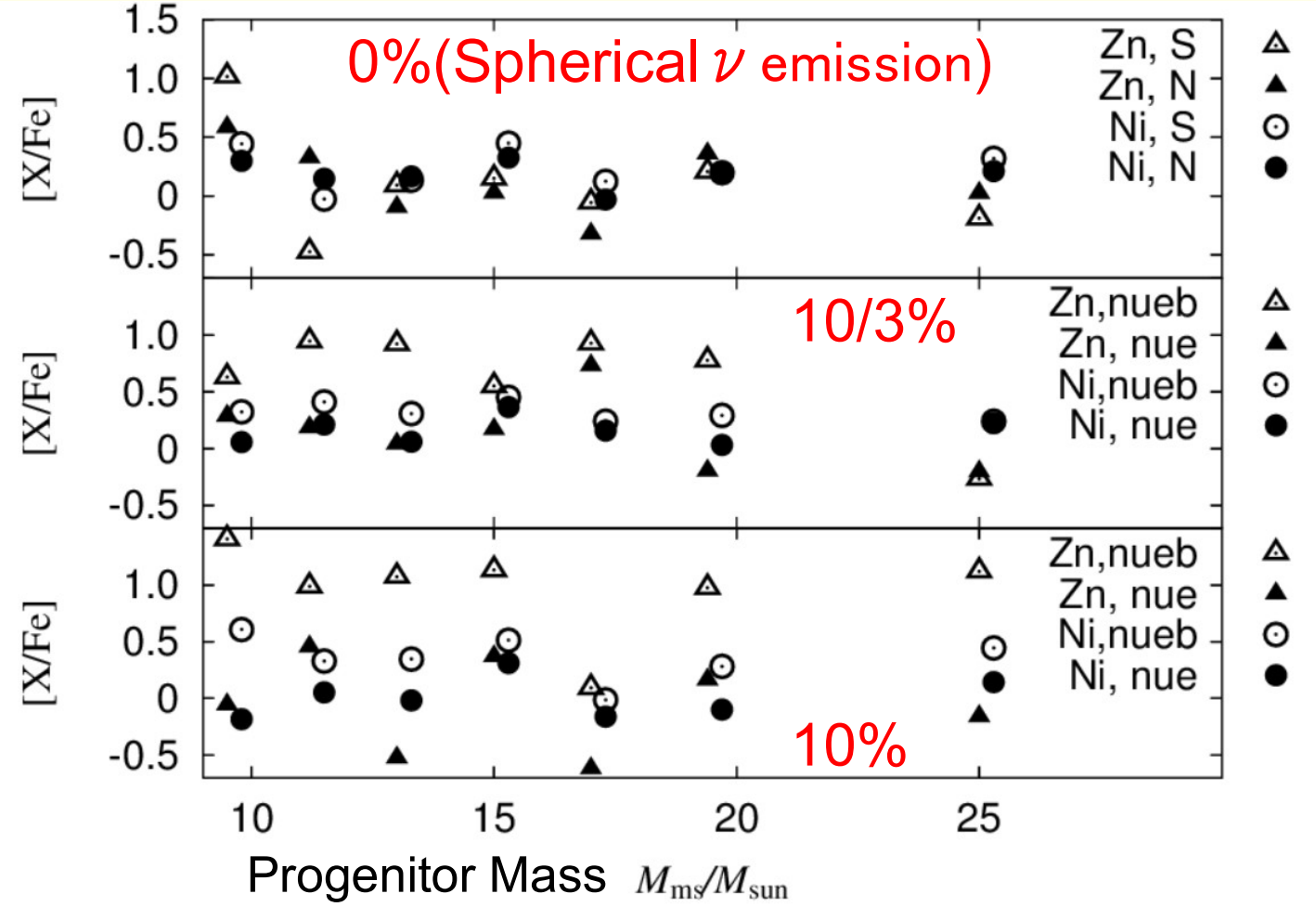
SN Ia: W7 model

- For ν asymmetry <= 10%, our model well reproduces the solar abundances of nuclei from C to Zr (Z<=40)

$$[\mathrm{A/B}] = \log \left[\frac{X_\mathrm{A}/X_{\mathrm{A},\odot}}{X_\mathrm{B}/X_{\mathrm{B},\odot}} \right]$$

- For ν asymmetry >= 30%, nuclei of Zn to Zr are over-produced compared with the solar abundances ([X/Fe]=0).

NS-Differences of Zn/Fe and Ni/Fe



△: Zn South

▲: Zn North

○: Ni South

●: Ni North

$$[\mathrm{A/B}] = \log \left[\frac{X_\mathrm{A}/X_{\mathrm{A},\odot}}{X_\mathrm{B}/X_{\mathrm{B},\odot}} \right]$$

X-ray obs. of SNR（with XRISM, NuSTAR, FORCE)

North-south differences of Ni/Fe and Zn/Fe

→ constrain ν asymmetry