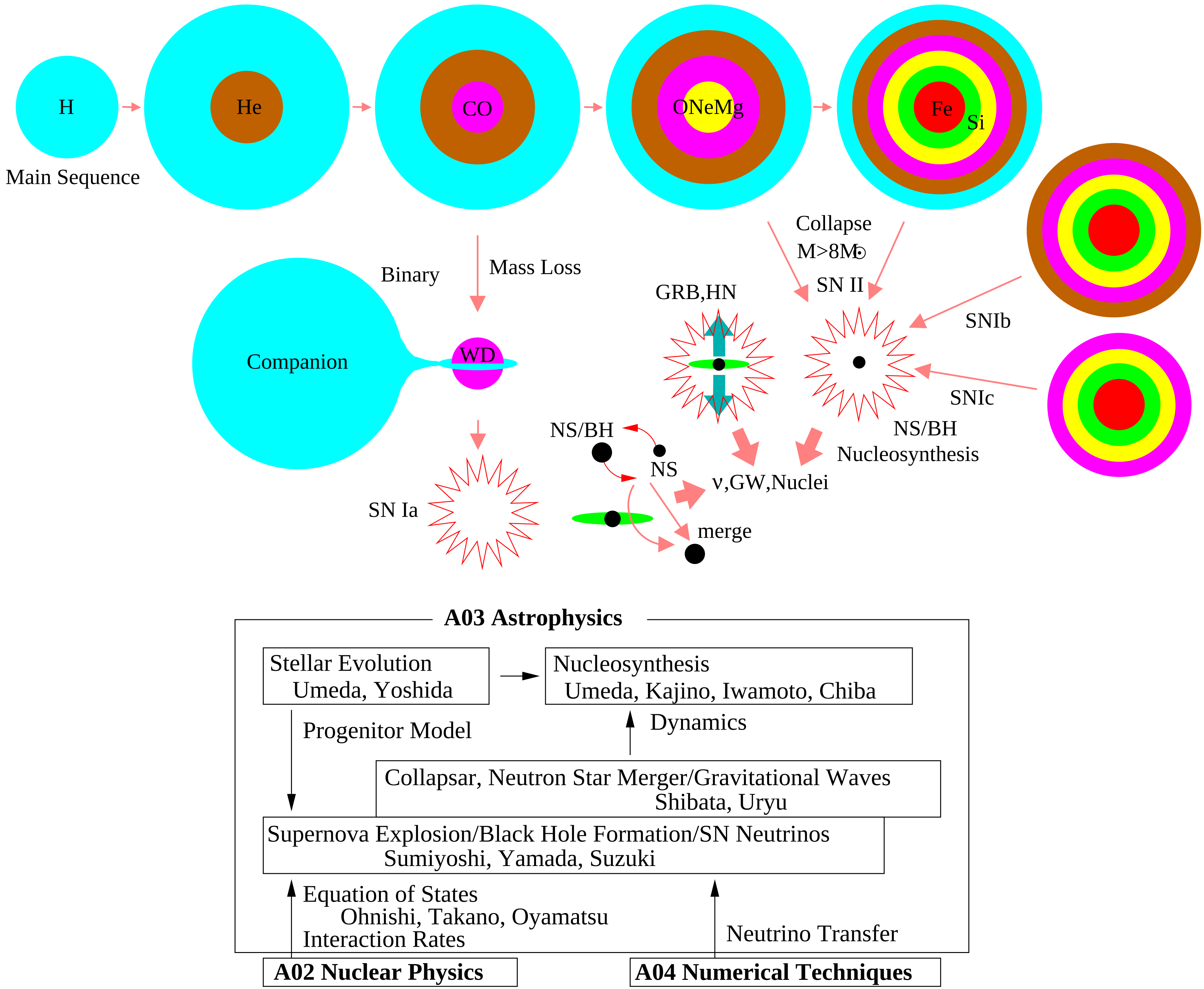
A03: Astrophysics Group

Explosive Astrophysical Phenomena and Nucleosynthesis based on Quark Dynamics and Nuclear Structure

2012.12.13 @ Nara

Hideyuki Suzuki (Tokyo Univ. of Science)

Core Members	Hideyuki Suzuki (TUS)
	Masaru Shibata (Kyoto, Numerical Relativity)
	Toshitaka Kajino (NAOJ, Nuclear Astrophysics)
	Kohsuke Sumiyoshi (Numazu, Supernova Simulation)
	Hideyuki Umeda (Tokyo, Stellar Evolution, Nucleosynthesis)
Collaborators	Akira Ohnishi (Kyoto)
	Shoichi Yamada (Waseda)
	Kohji Uryu (Ryukyu)
	Satoshi Chiba (JAEA)
	Nobuyuki Iwamoto (JAEA)
	Takashi Yoshida (Tokyo)
	Kazuhiro Oyamatsu (Aichi Shukutoku)
	Masatoshi Takano (Waseda)


H
He
CO
ONeMg
Fe
Si
Main Sequence
Collapse
M>8M⊙
SN II
SNIb
SNIc
GRB,HN
Binary
Mass Loss
Companion
WD
NS/BH
NS
ν,GW,Nuclei
NS/BH
Nucleosynthesis
SN Ia
merge
A03 Astrophysics
Stellar Evolution
Umeda, Yoshida
Nucleosynthesis
Umeda, Kajino, Iwamoto, Chiba
Progenitor Model
Dynamics
Collapsar, Neutron Star Merger/Gravitational Waves
Shibata, Uryu
Supernova Explosion/Black Hole Formation/SN Neutrinos
Sumiyoshi, Yamada, Suzuki
Equation of States
Ohnishi, Takano, Oyamatsu
Interaction Rates
Neutrino Transfer
A02 Nuclear Physics
A04 Numerical Techniques

The grant was mainly used for the employment of PDs.

- Luca Baiotti (Kyoto, 2009.11-2010.1)
- Kenta Kiuchi (Kyoto, 2010.2-2011.3)
- Takashi Yoshida (Tokyo, 2009.4-)
- Ko Nakamura (NAOJ, 2009.4-2012.9)
- Chikako Ishizuka (TUS, 2011.4-2012.9)
- Hirotada Okawa (Kyoto, 2012.4-2012.7)

Grants for related research (FY2009-2010,2011-2012)

- T. Hanawa (Chiba): MHD wave
  超新星爆発における磁気流体波の反射増幅効果の研究
- K. Nomoto (Tokyo): r-process
  r プロセス元素の起源の超新星爆発シミュレーションに基づく解明
- S. Nagataki (Kyoto): GRB/HN nucleosynthesis
  ガンマ線バースト・極超新星に於ける爆発的元素合成
- H. Sotani (NAOJ): NS matter - GW
  重力波観測を用いた中性子星内部における物質構造への制限の可能性
- Y. Sekiguchi (NAOJ): NS mergers/SGRB with numerical relativity
  数値相対論で探る連星中性子星の合体とショートガンマ線バースト
- N. Yasutake (NAOJ): QCD phase transition in PNS
  超新星爆発後期の原始中性子星進化におけるＱＣＤ相転移の役割

Workshops

- 1st Workshop(3rd Numazu Workshop on EOS)
  2009.3.16-18, Numazu College of Technology
  第３回沼津ワークショップ「クォーク力学・原子核構造に基づく爆発的天体現象と元素合成」

- 2nd Workshop
  2010.5.31-6.1, Tokyo University
  第２回「クォーク力学・原子核構造に基づく爆発的天体現象と元素合成」研究会

- 3rd Workshop
  2011.1.31-2.1, Ryukyu University
  第３回「クォーク力学・原子核構造に基づく爆発的天体現象と元素合成」研究会

- 4th Workshop with HPCI Field 5, Project-3
  2011.12.26-28, Kyoto University
  超新星爆発と数値シミュレーション

About 100 papers

Topics

- Stellar Evolution of SN Progenitors (ONeMg or Fe cores) and of Rotating Stars (talk by Yoshida, poster by Takahashi)
- SN EOS using the cluster variational method(collaboration with A02, A04) (talk by Togashi, poster by Takano)
- NSE EOS with multi species of nuclei (poster by Furusawa)
- hadron - quark phase transition (poster by Yasutake)
- constructing EOS database
- Numerical Relativity with nuclear EOS + ν(simulations of mergers and collapsar models) (talks by Sekiguchi, Kiuchi)
- 2D/3D SN simulations (talk by Suwa, poster by Nakamura)
- Stellar collapse with nucleon/hyperon/quark EOSs (talk by Nakazato, Sumiyoshi)
- SN,GRB nucleosynthesis with ν oscillations
- r-process at SNe and NS mergers (talk by Wanajo)
- EOS - GW connections (poster by Hotokezaka)

- explosiove nucleosynthesis at GRB and HN (poster by Nagataki)
- GRB jets (poster by Mizuta, A04)
- EOS - NS asteroseismology (poster by Sotani)
- multi-D ν transfer (collaboration with A04) (talk by Sumiyoshi)

toward 3D Numerical Relativity with realistic EOS and ν transfer

Gravitational Waves and Neutrino Emission from the Merger of Binary Neutron Stars (Sekiguchi *et al.*, 2011 PRL107, 051102)

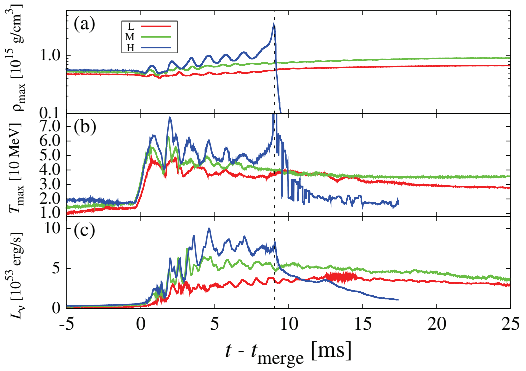


FIG. 1 (color online). (a) Maximum rest-mass density, (b) maximum matter temperature, and (c) total neutrino luminosity as functions of time for three models. The dashed vertical line shows the time at which a BH is formed for model H.

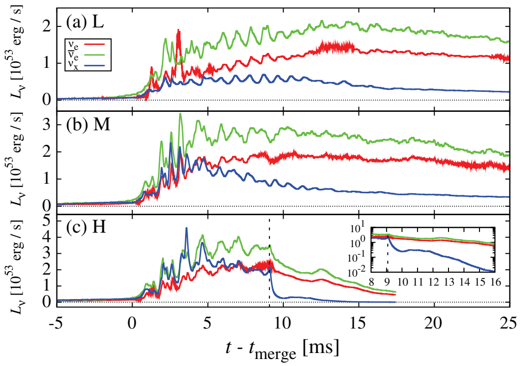


FIG. 3 (color online). Neutrino luminosities for three flavors for three models. (a) L, (b) M, and (c) H. The inset of (c) focuses on the luminosities in the BH formation. The meaning of the dashed line is the same as in Fig. 1.

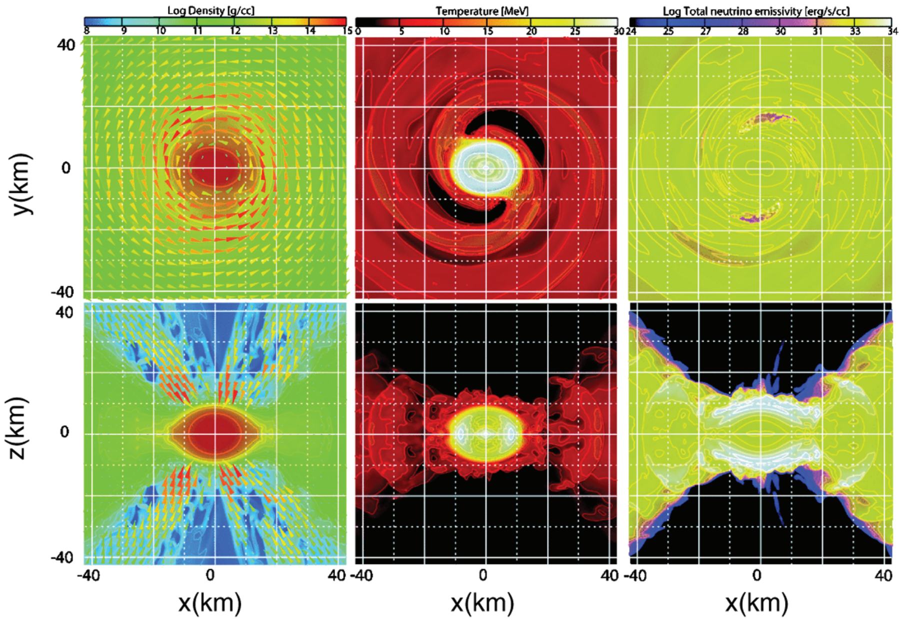


FIG. 2 (color online). Color maps of rest-mass density (with velocity fields), temperature, and total neutrino luminosity at $t \approx 15$ ms after the merger for model M. The upper and lower panels show the configuration in the x-y and x-z planes, respectively.

L: 1.35-1.35$M_\odot$
M: 1.5-1.5$M_\odot$
Hypermassive NS
$\tau \gg \tau_{\rm dyn}$

H: 1.6-1.6$M_\odot$
(BH in $\tau_{\rm dyn}$)

polytropic EOS
no ν transfer
$\downarrow$
realistic EOS
ν transfer
(leakage scheme)
$\downarrow$ 2012
moment scheme

developement of 3D neutrino transfer (collaboration with A04)

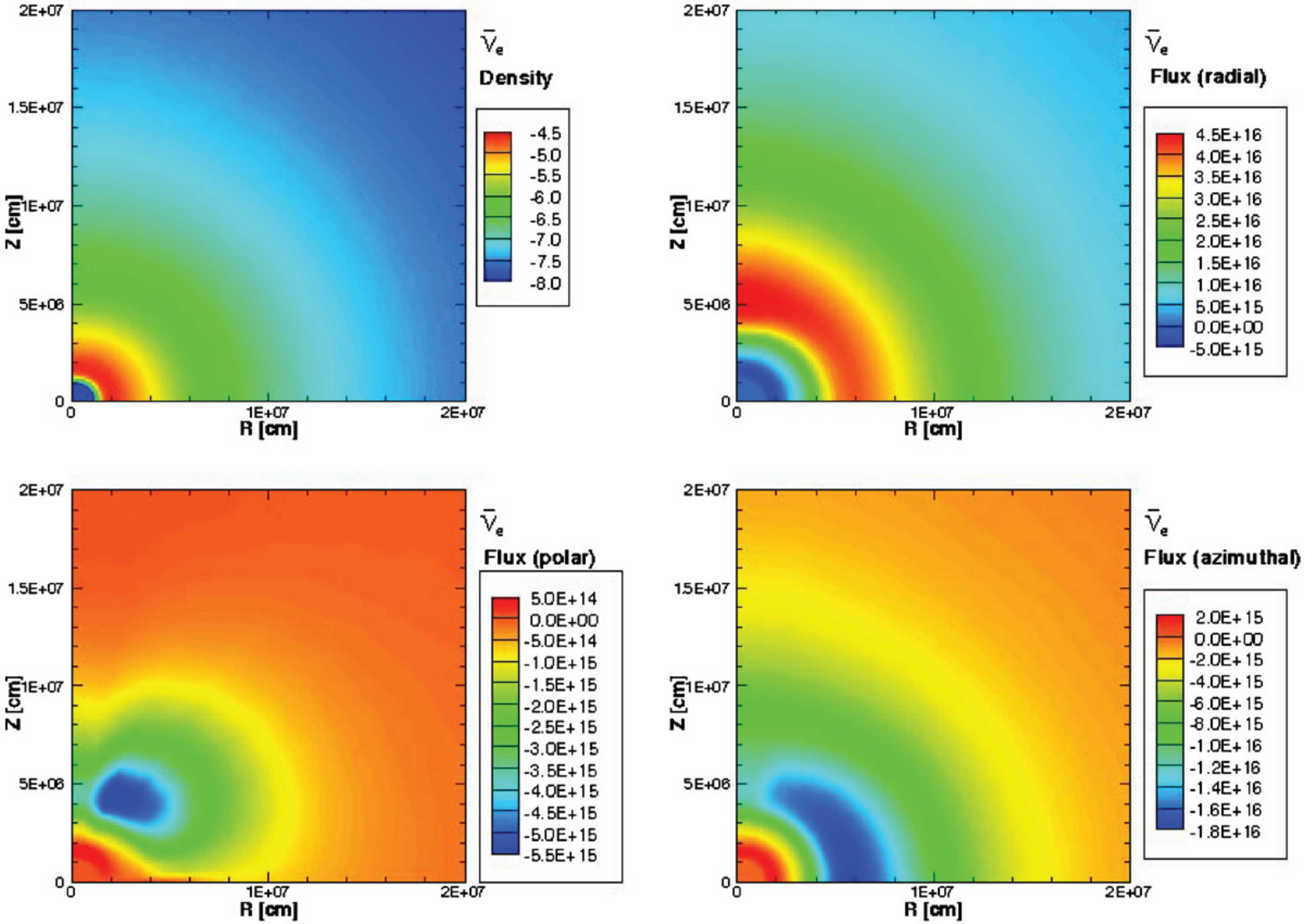


Figure 35. Contour plots of the neutrino distributions on the meridian slice with $\phi = 0.436$ radian (near zx-plane) for electron-type anti-neutrinos in the 3D deformed supernova core. The density, radial, polar, and azimuthal components of the flux are displayed by color codes in the left top, right top, left bottom, and right bottom panels, respectively. The densities are shown in the unit of $\mathrm{fm}^{-3} = 10^{-39}\ \mathrm{cm}^{-3}$ and in log scale. The fluxes are shown in the unit of $\mathrm{fm}^{-2}\ \mathrm{s}^{-1}$.

polar and azimuthal flux from static deformed core

Sumiyoshi and Yamada, ApJS199 (2012) 17, Fig.35

Hyperon Matter and Black Hole Formation in Failed Supernovae (1D study)

(Nakazato *et al.*, 2011)

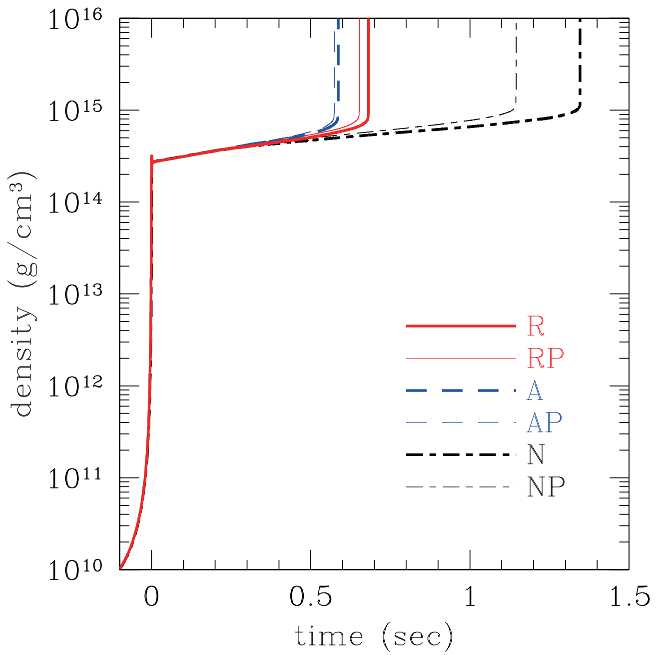


Fig. 2.— Time profiles of the central baryon mass density. Thick solid, thin solid, thick dashed, thin dashed, thick dot-dashed and thin dot-dashed lines correspond to the results for EOS's R, RP, A, AP, N and NP, respectively.

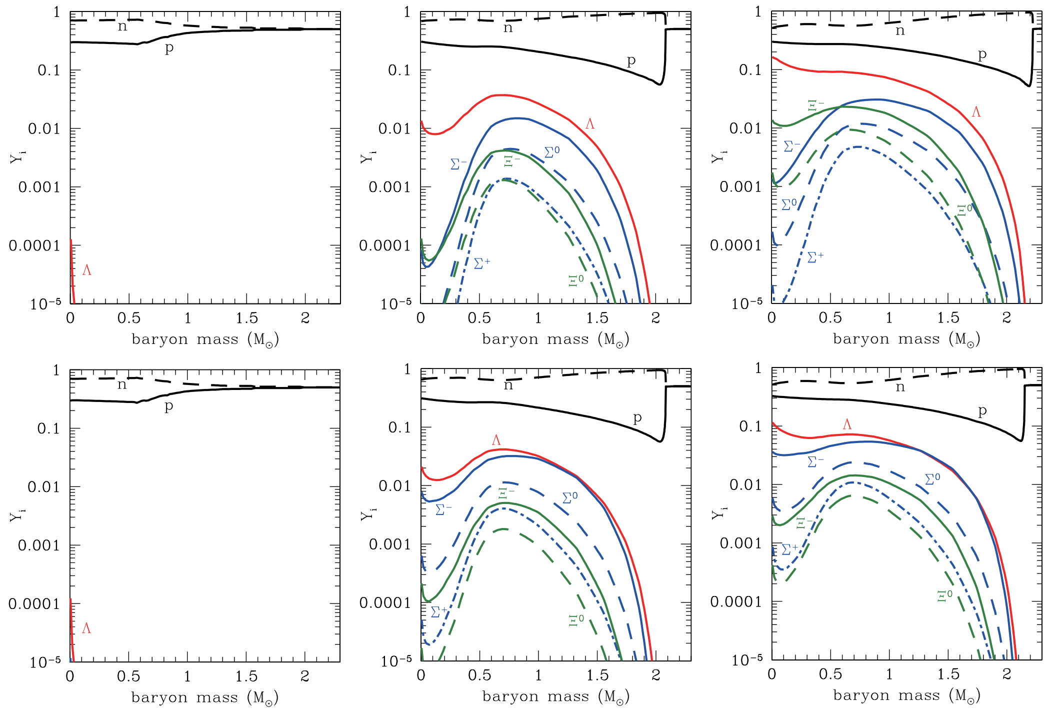


Fig. 4.— Profiles of the particle fractions at bounce (left), 500 msec after bounce (center) and 2 msec before black hole formation (right). The upper and lower panels show results for EOS's R and A, respectively.

Ishizuka EOS = Shen EOS + hyperons

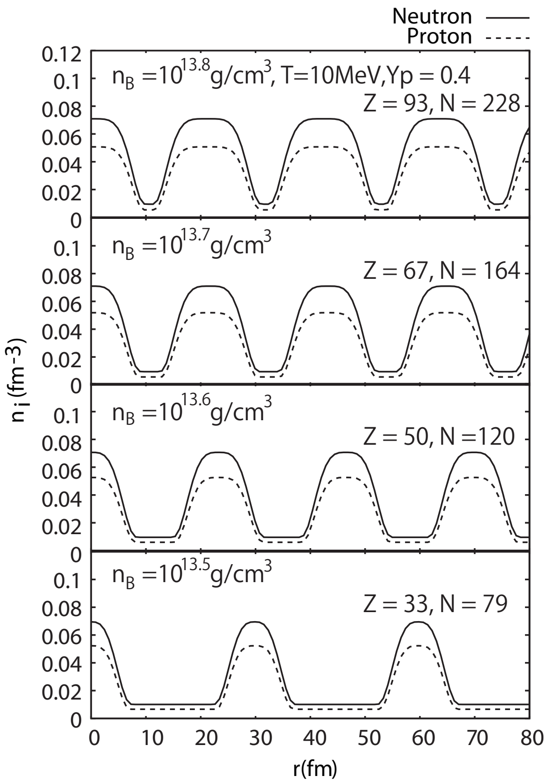
Upper: EOS R $U_\Sigma = +30\text{MeV}$,

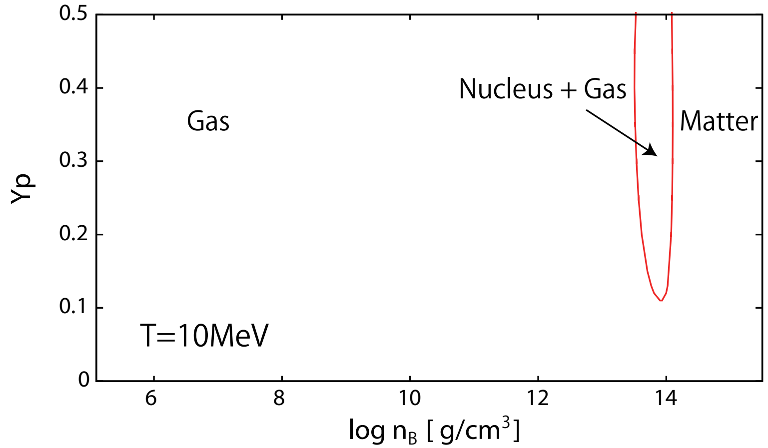
Lower: EOS A $U_\Sigma = -30\text{MeV}$

Toward a new EOS of supernova matter
Collaboration with A02 group (Togashi and Takano)

EOS for uniform matter using the cluster variational method with AV18+UXI potentials

EOS for non-uniform matter (single nuclei + free nucleons) using Thomas-Fermi calculation (following a strategy of H. Shen EOS with RMF)





nucleon distribution($T = 10$MeV, $Y_P = 0.4$)

phase diagram ($T = 10$MeV)

Yamamuro *et al.* in progress

from EOS with single representative nuclei to EOS with multicomponent in Nuclear Statistical Equilibrium

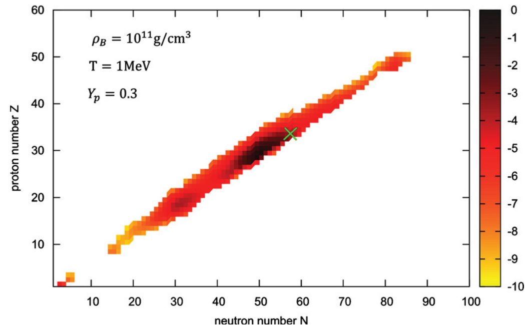


Figure 1. Mass fractions in $\log_{10}$ of nuclei in the (N, Z) plane for $\rho_B = 10^{11}$ g cm^{-3}, $T = 1$ MeV, and $Y_p = 0.3$. The cross indicates the representative nucleus for the H. Shen EOS under the same condition.

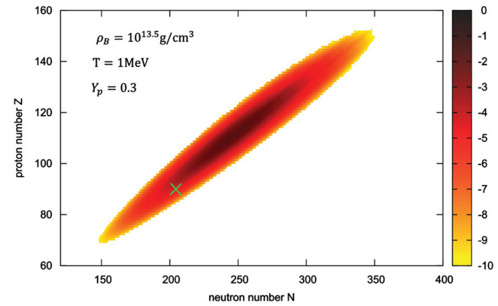


Figure 2. Mass fractions in $\log_{10}$ of nuclei in the (N, Z) plane for $\rho_B = 10^{13.5}$ g cm^{-3}, $T = 1$ MeV, and $Y_p = 0.3$. The cross indicates the representative nucleus for the H. Shen EOS under the same condition.

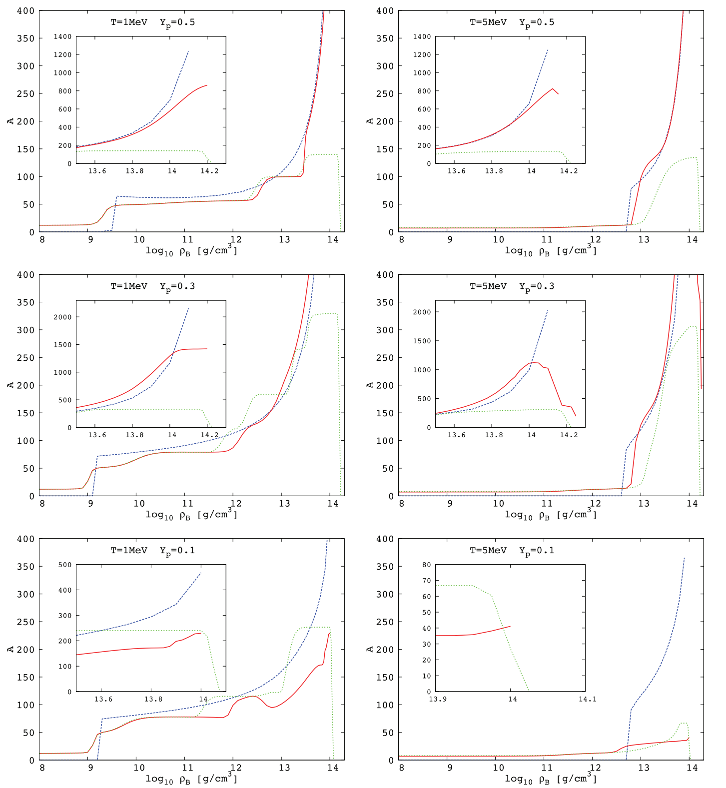


Figure 5. Average mass number, $\bar{A}$, of heavy nuclei with $Z \geqslant 6$ for our EOS (solid red lines) and Hempel's EOS (dotted green lines) together with the mass number of representative nucleus for H. Shen's EOS (dashed blue liens) as a function of density for $T = 1$ MeV and $Y_p = 0.1, 0.3, 0.5$. The insets are the close-ups of the high density regimes.

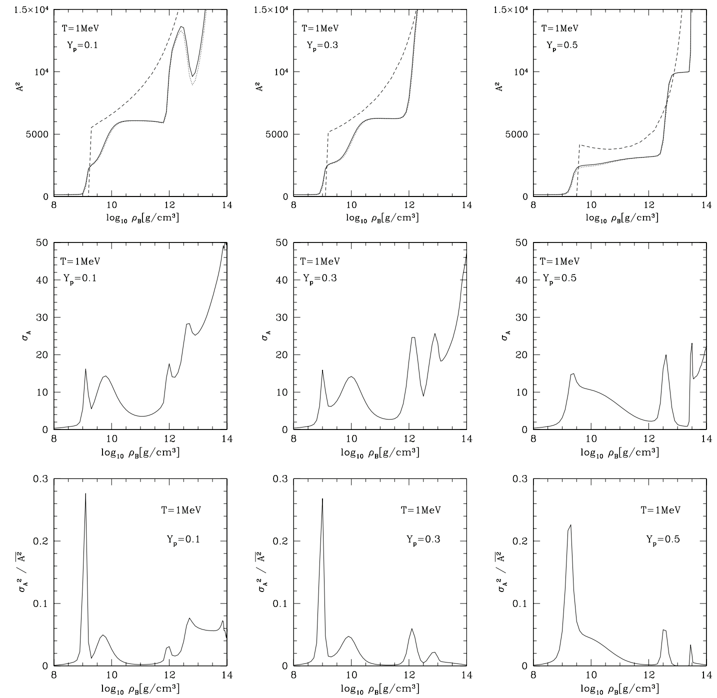
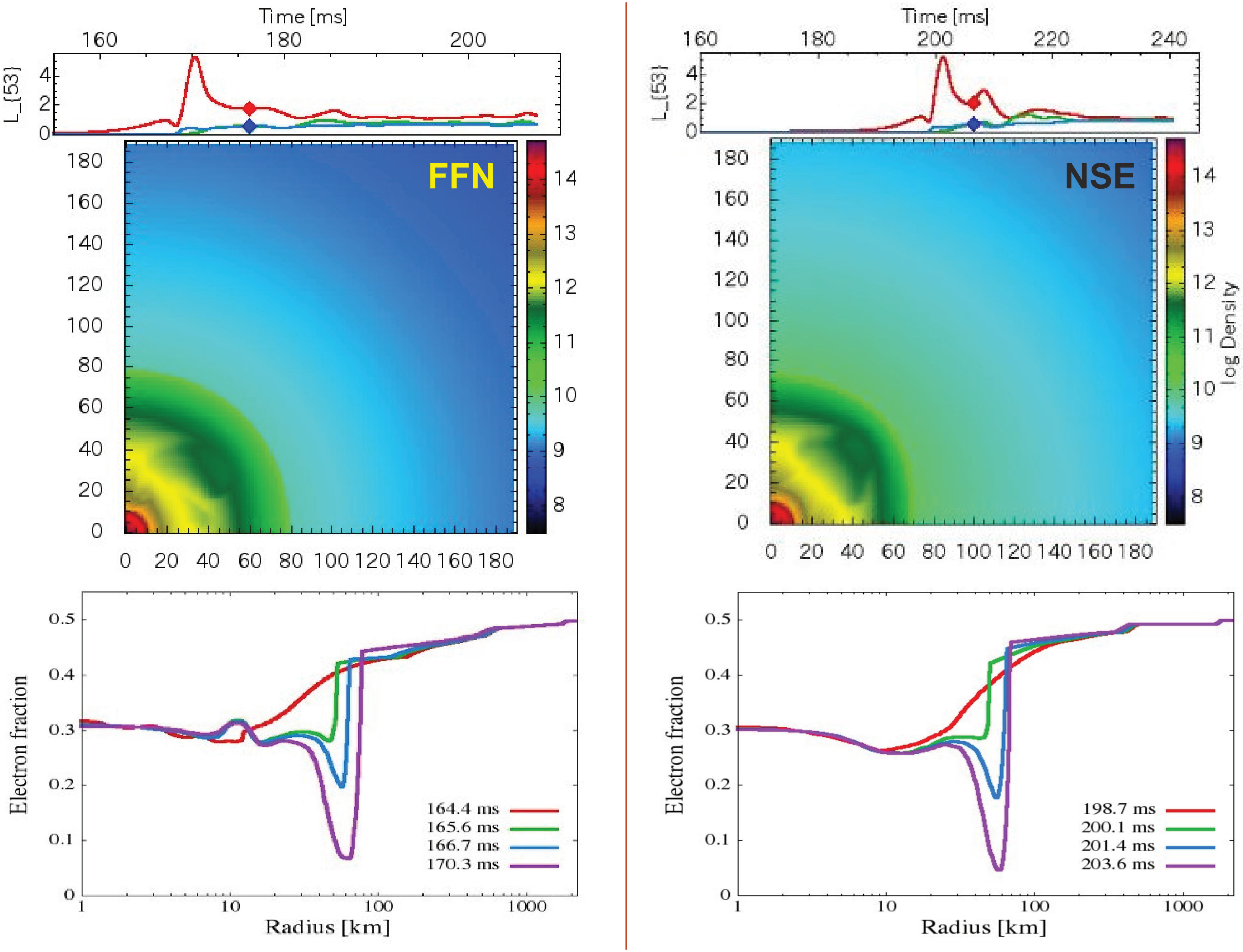


Figure 6. Square of mass numbers (top), the standard deviation of mass number, $\sigma_A = \sqrt{\overline{A^2} - \bar{A}^2}$ (middle), and the dispersion normalized by the average mass number squared, $\sigma_A^2/\bar{A}^2$ (bottom), of heavy nuclei with $Z \geqslant 6$ for $T = 1$ MeV and $Y_p = 0.1$ (left), 0.3 (middle), and 0.5 (right). In the top panels, the solid and dotted lines show the average mass number squared, $\overline{A^2}$, and the square of average mass number, $\bar{A}^2$, in our EOS, respectively, whereas the dashed lines display the mass number squared of the representative nucleus for the H. Shen EOS.

neutrino coherent scattering off nuclei depends strongly on mass number A

Furusawa *et al.*, ApJ 738 (2011) 178

electron capture rates in NSE should be compiled with NSE EOS
shell blocking + single nuclei scheme underestimates the e-cap. rate.



Sekiguchi *et al.* in progress

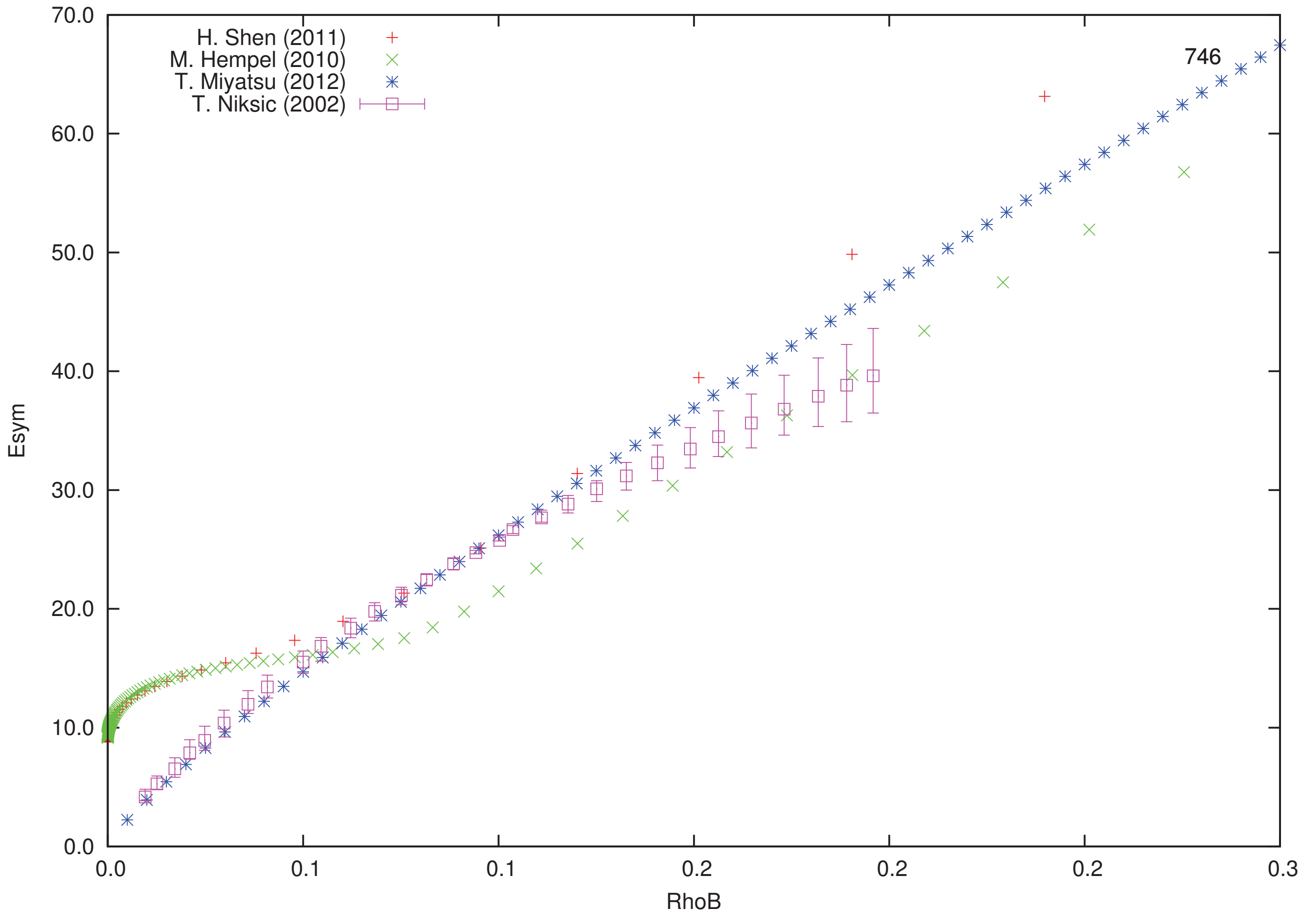
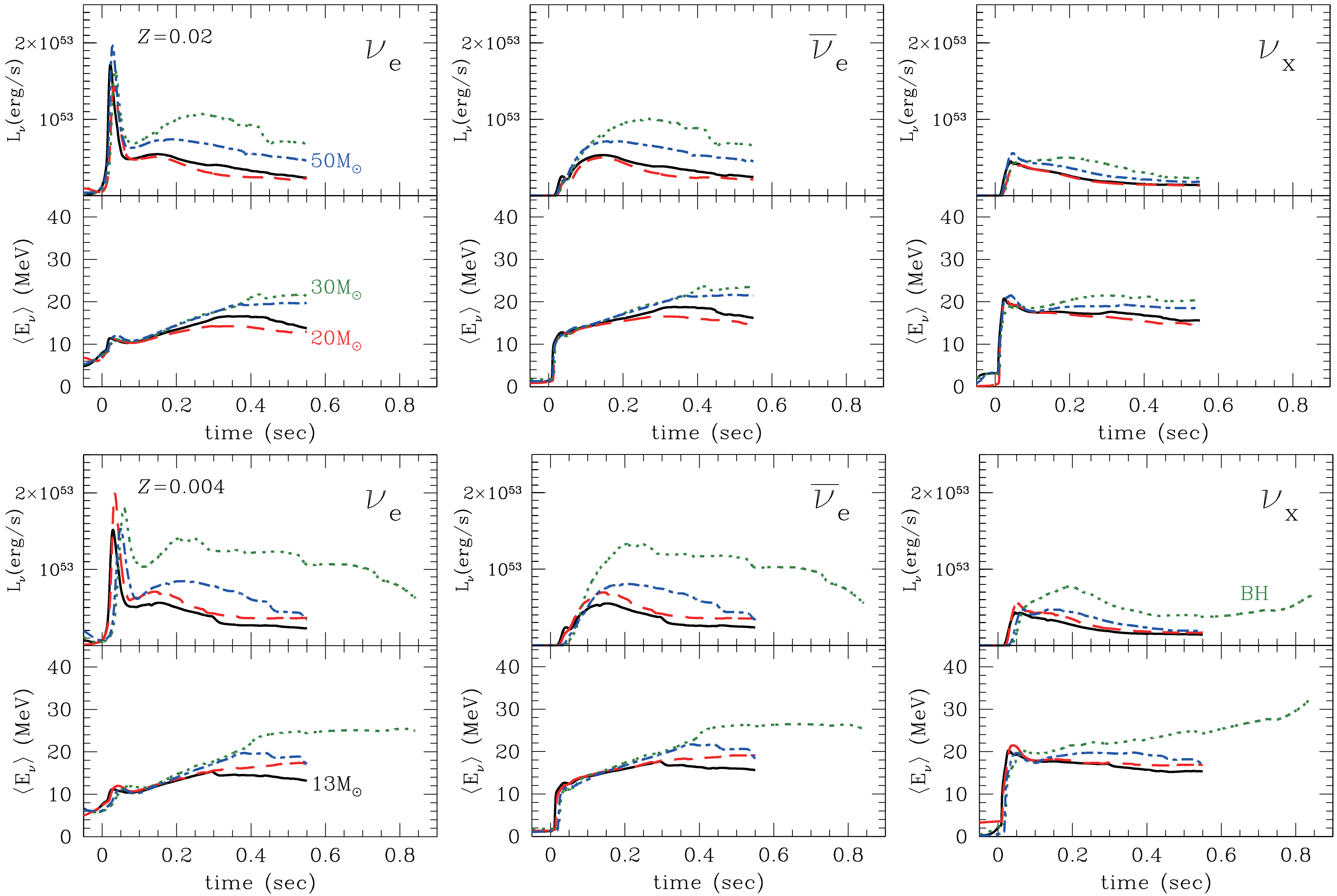
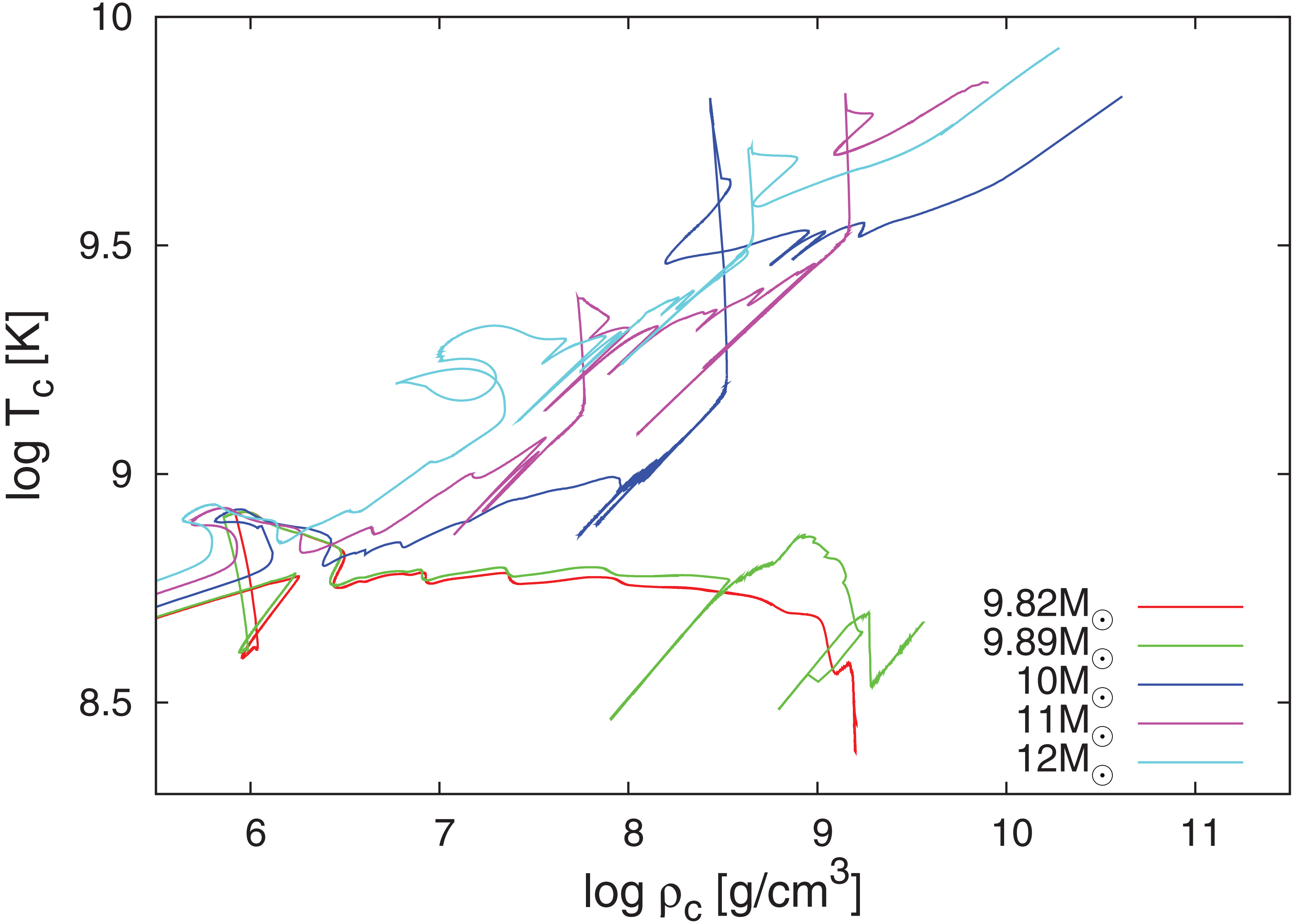


Figure 2: Figure made by the EOSDB, saved online as a eps file and downloaded. Symmetric energy of recent three Relativistic Mean Field models [10, 11, 12] and its constraint citeNiksic2002 shown in Fig.1.

Supernova Neutrino Database (various progenitors)
(1D hydro simulation + protoneutron star cooling, connected by a parameter corresponding to the shock revival time)



Nakazato *et al.*, arXiv:1210.0684



Umeda, Yoshida and Takahashi, 2012

neutrino-related nucleosynthesis

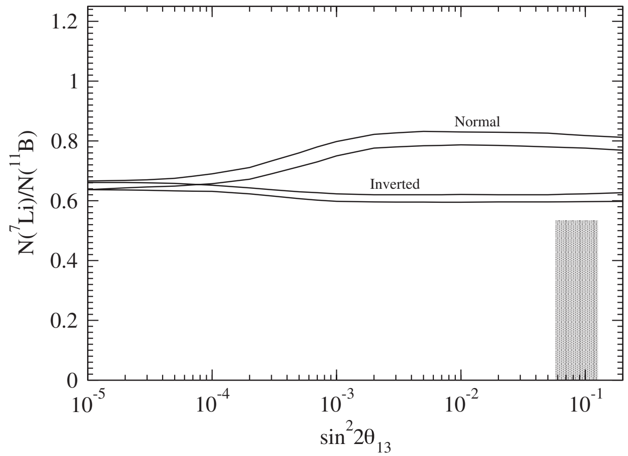
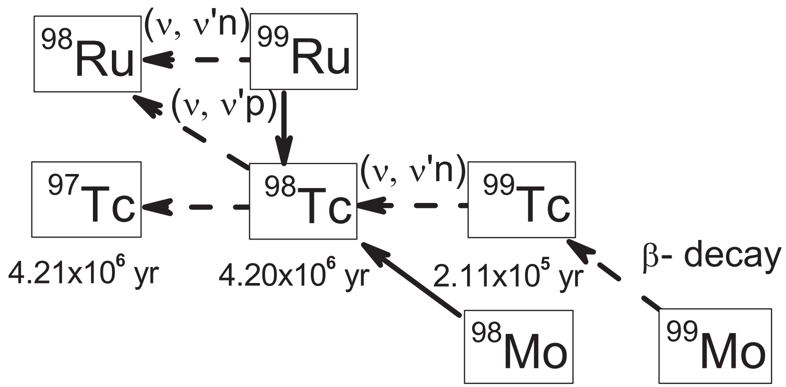


FIG. 1. Produced ^{7}Li/^{11}B abundance [15] as a function of mixing angle for both a normal and inverted neutrino mass hierarchy. This ratio varies in models with different neutrino temperatures in the range indicated by the lower and upper solid lines. The width of the shaded region indicates the 2σ confidence limits to $\sin^2(2\theta_{13})$ from the Daya Bay result [7]. The top of the shaded region is the 2σ upper limit on the observed ν-process ^{7}Li/^{11}B ratio as deduced here from the SiC *X* grains.

G. J. Mathews, T. Kajino, *et al.*, PRD85 (2012), 105023

Neutrino induced reactions related to the ν-process nucleosynthesis of ^{98}Tc M-

K.Cheoun *et al.*, 2011



Summary

- Systematic studies on EOSs and progenitor models with 1D simulations of core collapse and neutrino signal
- Appreciable progress toward 3D simulations with GR + ν transfer (well connected to HPCI)
- Good collaborations with A02 (Nuclear Physics) and A04 (Computational Science)

  still in progress: new SN EOSs, electron capture rates

  wish: hyperonic EOS from Lattice QCD in near future
- Development of stellar evolution codes and databases (EOSs, SN neutrino spectra)
- Nucleosynthesis (explosive process, r-process, ν-process)