EOS of hyperonic matter for core collapse supernovae

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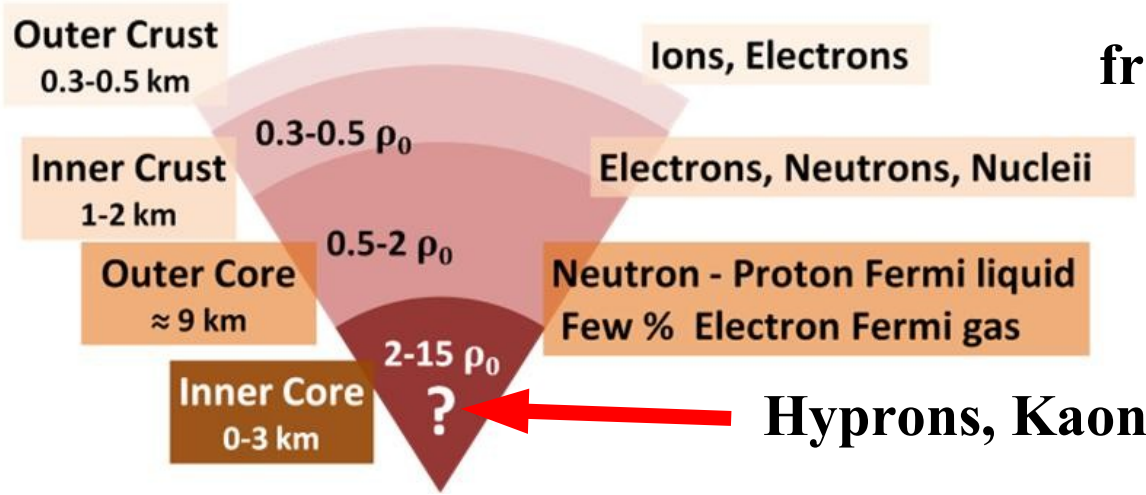
- **Introduction**
- **EOS table of hyperonic matter**
  C.Ishizuka, AO, K.Tsubakihara, K.Sumiyoshi, S.Yamada, JPG35(08)085201.
- **Hyperons in Compact Stars**
  K. Sumiyoshi, C. Ishizuka, AO, S. Yamada, H. Suzuki, ApJ690(09)L43.
- **Summary**

Where do we find strangeness in the universe ?

- **Hyperons appear in Neutron stars at $\rho_B > (2\text{-}3)\ \rho_0$!**
  - **Cold, dense (~ 5 ρ_0), static, ν-less → Large μ_B and μ_e**
    (Senger, Schulze, Muto, Vidana, Hyun, Schaffner-Bielich, ...)



from Wikipedia

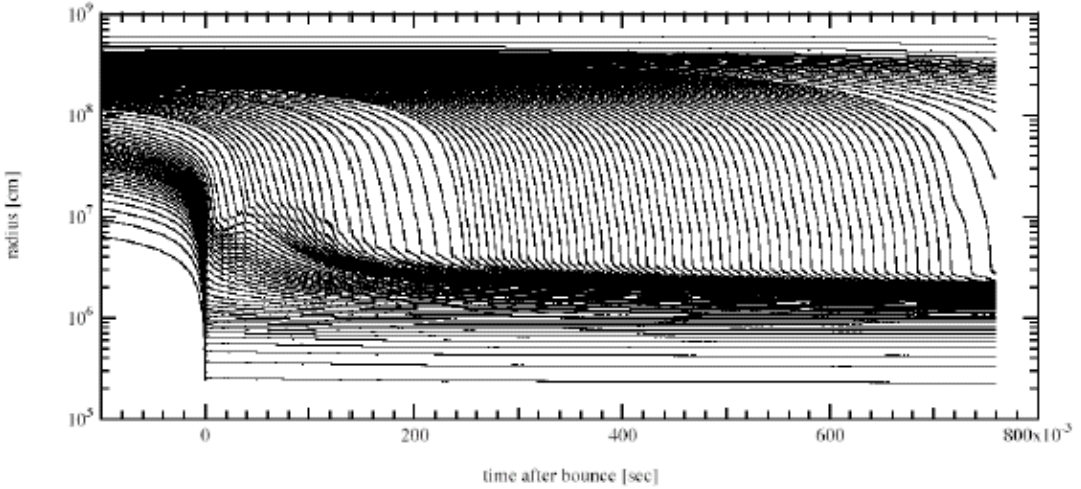
Hyprons, Kaons, Quarks, CSC

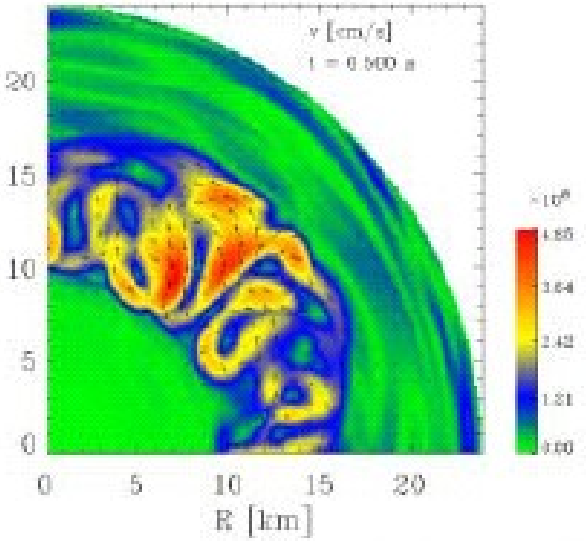
How about dynamical processes ?

- ***Supernovae: Warm (T~20 MeV) and Dense (ρ_B~1.6 ρ_0)***
- ***Black Hole Formation: Hot (T~70 MeV) and Dense (ρ_B~4 ρ_0)***
- ***NS-NS merger: Extremely Dense***

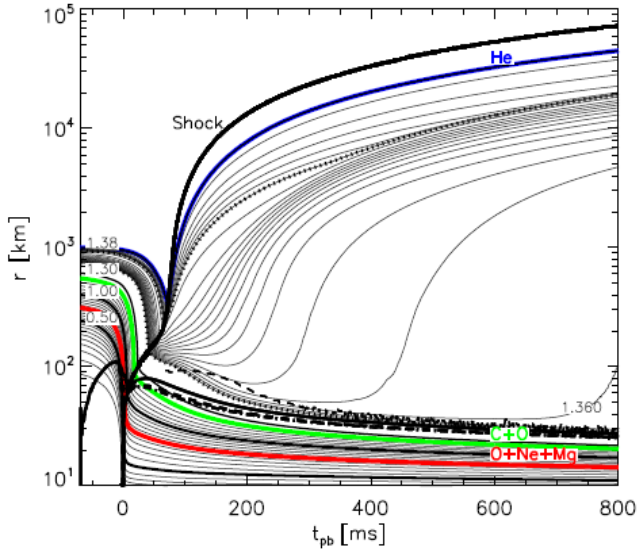
→ We study Hyperon Effects in "Hot Compact Star" processes

Numerical Simulation of Supernova Explosion

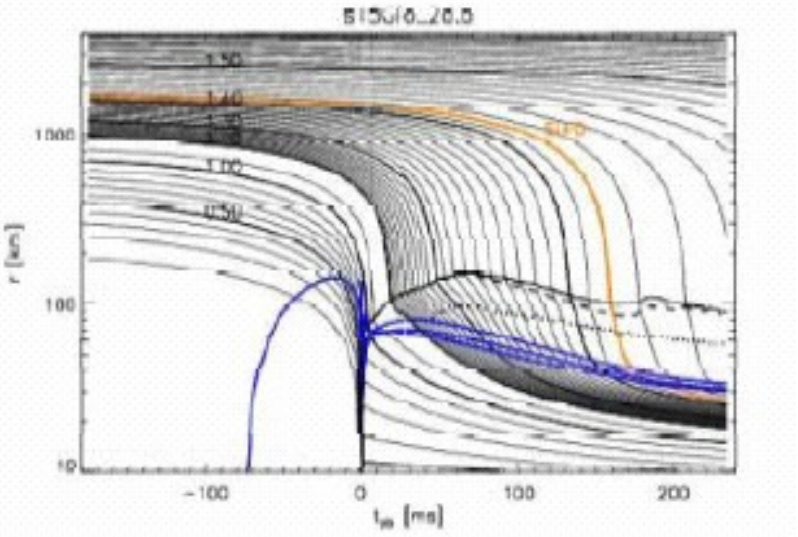




Sumiyoshi et al., 2005



Kitaura, Janka, Hillebrandt, 2006



（Janka et al., 2002)

Nuclear EOS table for Core-Collapse Processes

- **Numerical Simulation of Supernova Explosion**
  - **Time-scale ~ a few 100 msec → Equilibrium except for ν**
    →Hydro (Nuclear EOS) + ν transpport.
- **EOS for Core-Collapse Supernova**
  → Wide (T, ρ_B, Y_e) range must be covered.

  $\rho_B = (10^5 \text{ -- } 10^{15})$ g/cc ~ $(10^{-10} \text{ -- } 10)\ \rho_0$ ($\rho_0 \sim 2.5 \times 10^{14}$ g/cc)

  $T = (0.1 \text{ -- } 100)$ MeV, $Y_e = \rho_e / \rho_B = 0 – 0.6$

  - **Lattimer-Swesty (LS) EOS** ***(J.M.Lattimer, F.D.Swesty, NPA535(91)331)***
    Non-Rel. (Skyrme) + Liquid-Drop
  - **Relativistic (Shen) EOS**
    (H.Shen, H.Toki, K. Oyamatsu, K.Sumiyoshi, NPA637(98)435; PTP100(98)1013)
    RMF (TM1) +Thomas-Fermi Approx. +α

  → Hyperons are not included in these EOS !

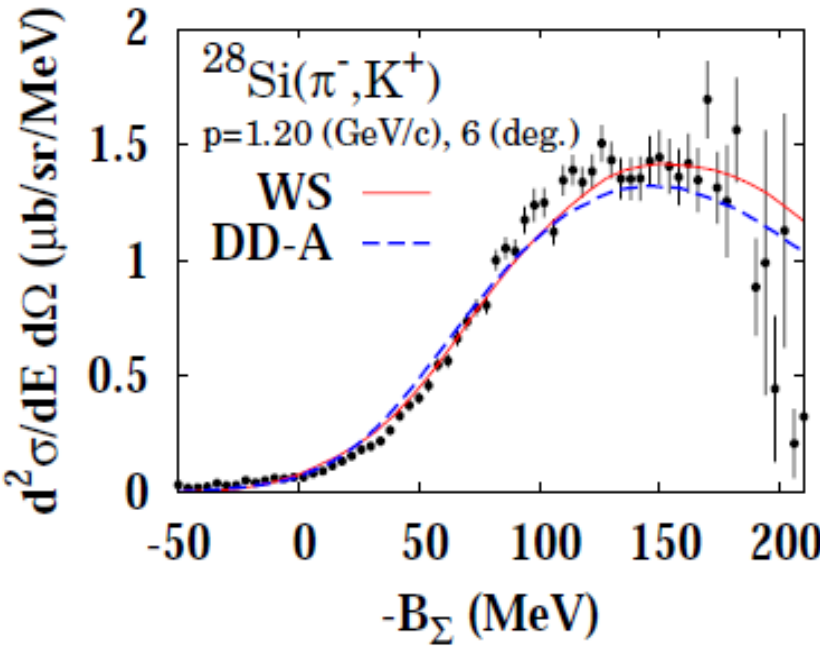
Hyperons should be included in EOS for Core-Collapse Supernvae !

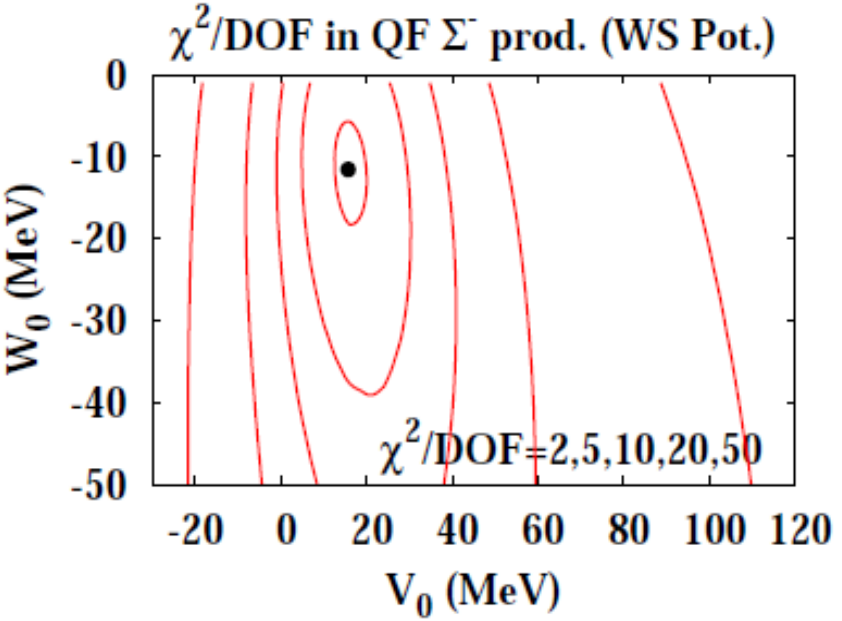
EOS table of Hyperonic Matter

- **Relativistic EOS table with Hyperons for Core Collapse Supernovae**
  (C.Ishizuka, AO, K.Tsubakihara, K.Sumiyoshi, S.Yamada, JPG35(08)085201.)
  http://nucl.sci.hokudai.ac.jp/~chikako/EOS/index.html
  - **Shen EOS + Hyperons**
  - **Hyperon Potential: U_Λ = -30 MeV, U_Σ = +30 MeV, U_Ξ = -15 MeV**

    U_Σ = +30 MeV (Noumi et al.02, Friedmann et al. 84,Mares et al.95, Harada-Hirabayashi 06, Kohno et al. 06, Maekawa et al. 07)

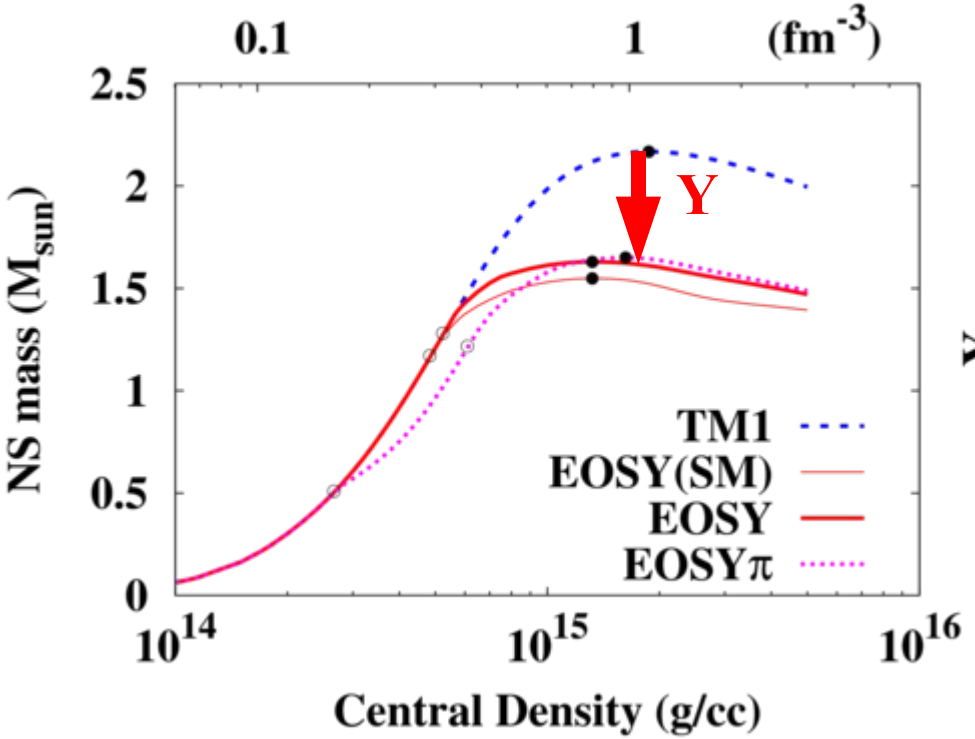
    U_Ξ ~ -15 MeV (Fukuda et al.98, Khaustov et al. 00, Maekawa et al. 07)

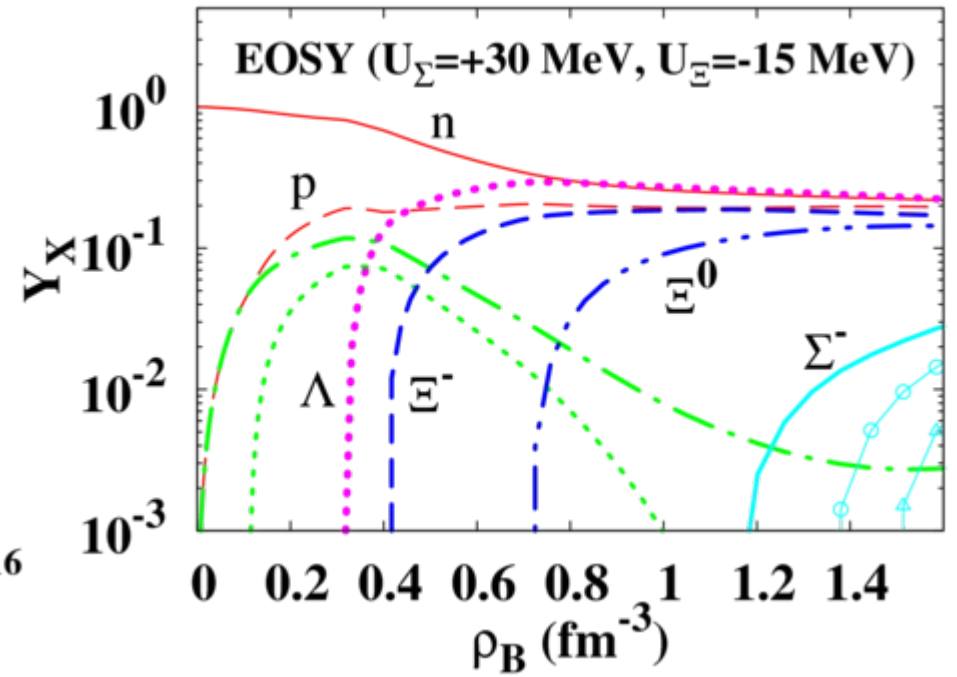




Neutron Stars

- **Neutron Star: (ρ_B,T,Y_e) ~ ($5\rho_0$, 0 MeV, 0.2) → Hyperon fraction ~ 50 %**
  - **Reduction of max. mass of NS**
  - **Repulsive Σ pot. → Ξ will be the next hyperon to Λ ! (c.f. Talk by Schaffner-Bielich)**





Neutron Star can be understood as Hyperon Star !

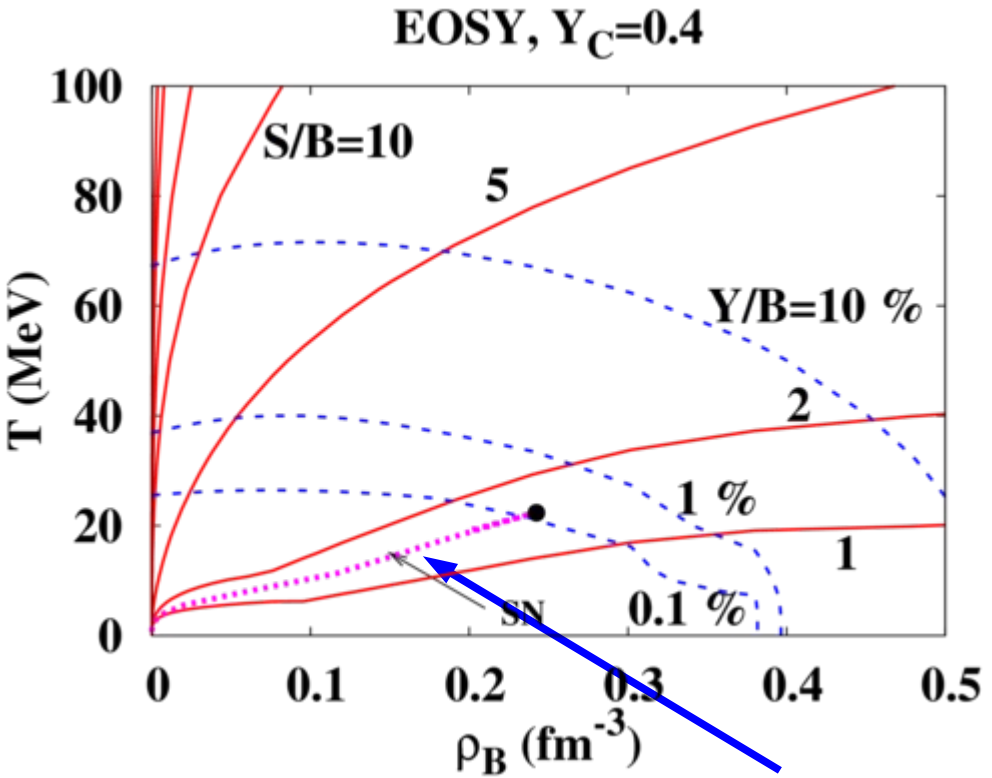
Supernovae

(C.Ishizuka, AO, K.Tsubakihara, K.Sumiyoshi, S.Yamada, JPG35(08)085201.)

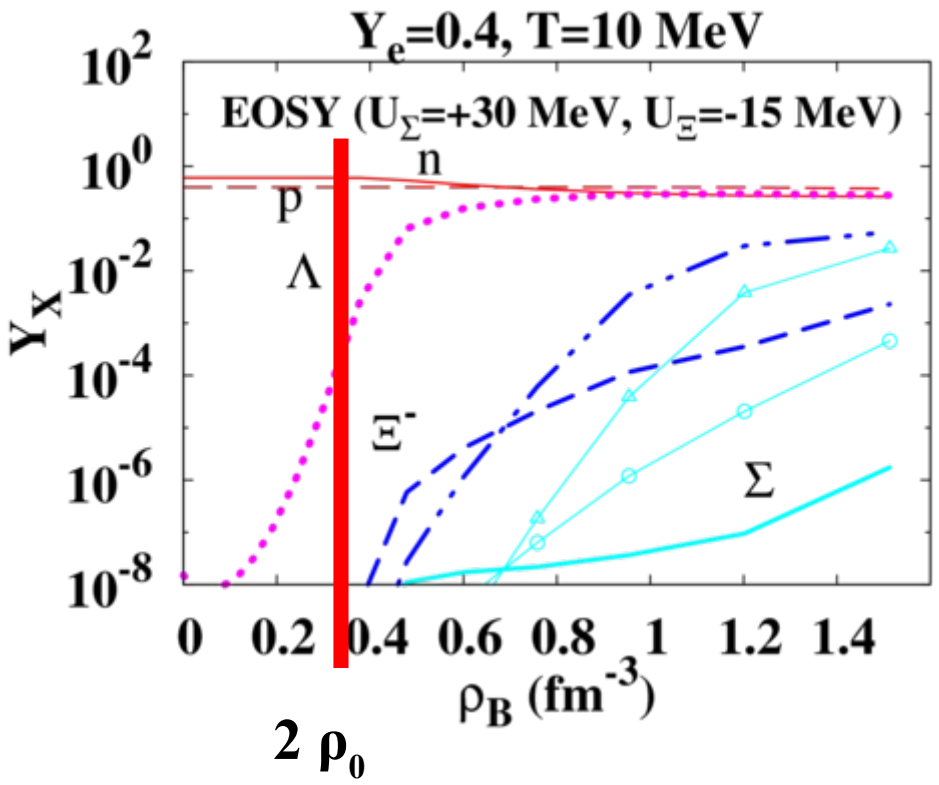
- **Supernova (Early stage): (ρ_B, T, Y_e) ~ (1.6 ρ_0, 20 MeV, 0.4)**

  → Hyperon fraction ~ 0.1 %

  (Density and/or Temperature are not enough at Y_e ~ 0.4)



Prompt Expl. (15 Msun)

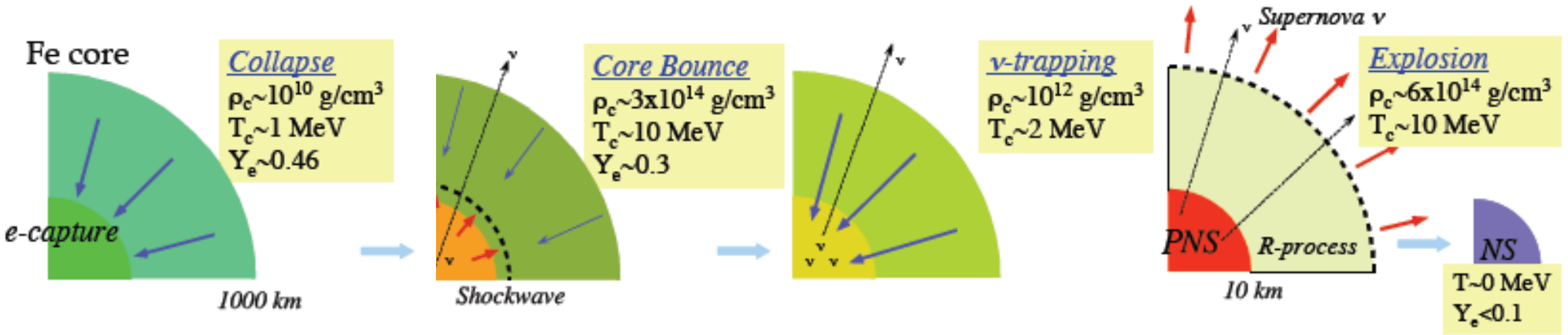


2 ρ_0

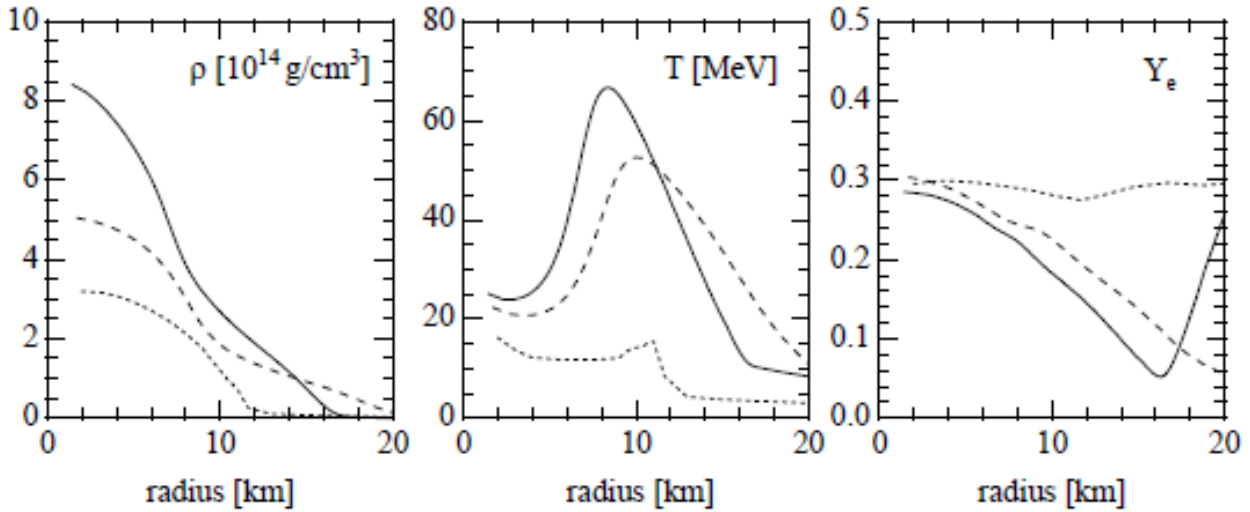
Hyperon effects are small in supernovae in the early stage !

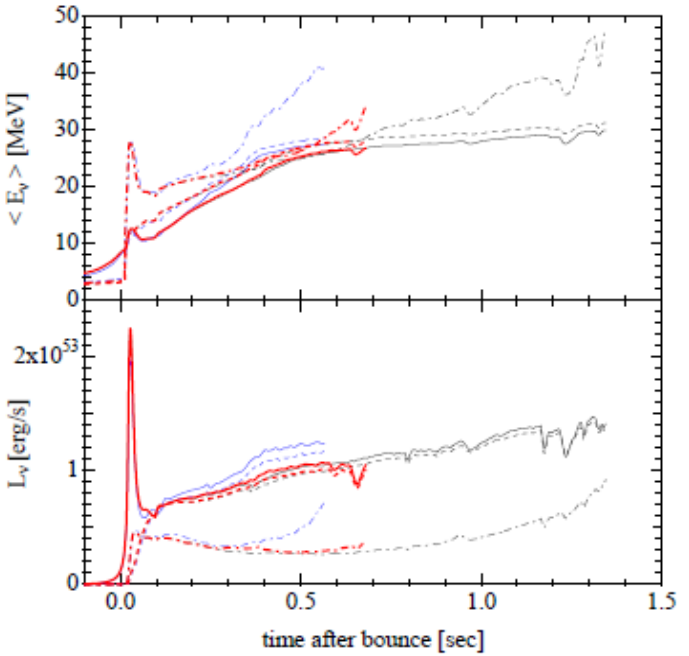
Black Hole Formation (Failed Supernova)

Details will be discussed in Sumiyoshi's talk on Friday.



At bounce, 500 ms 680 ms (at BH formation)

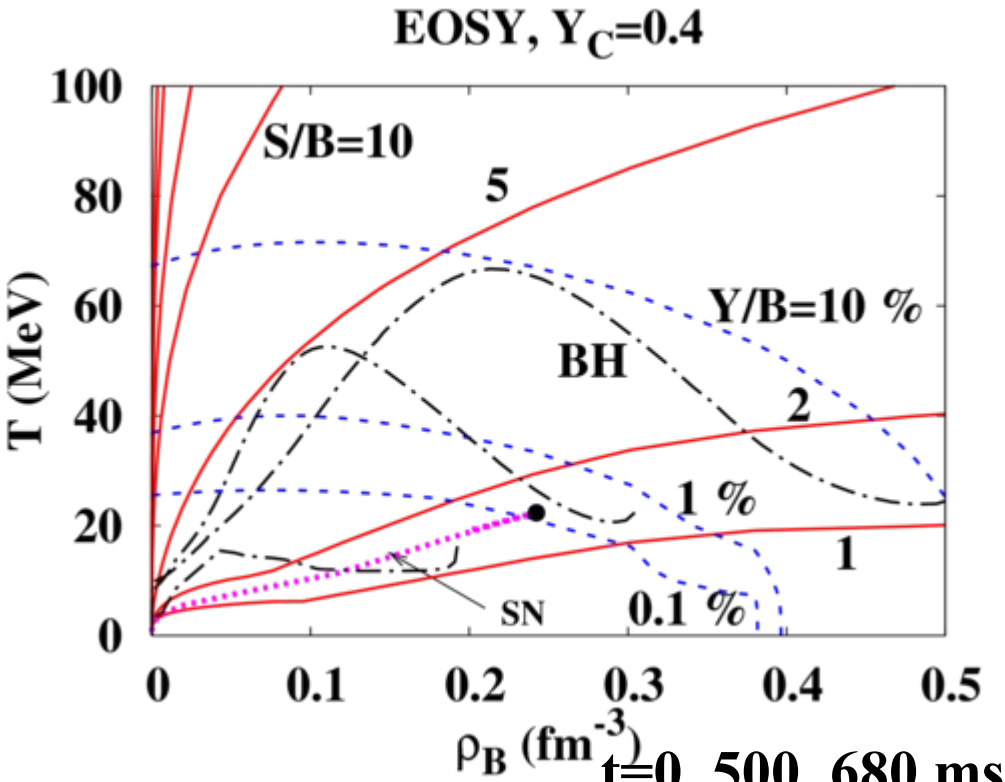




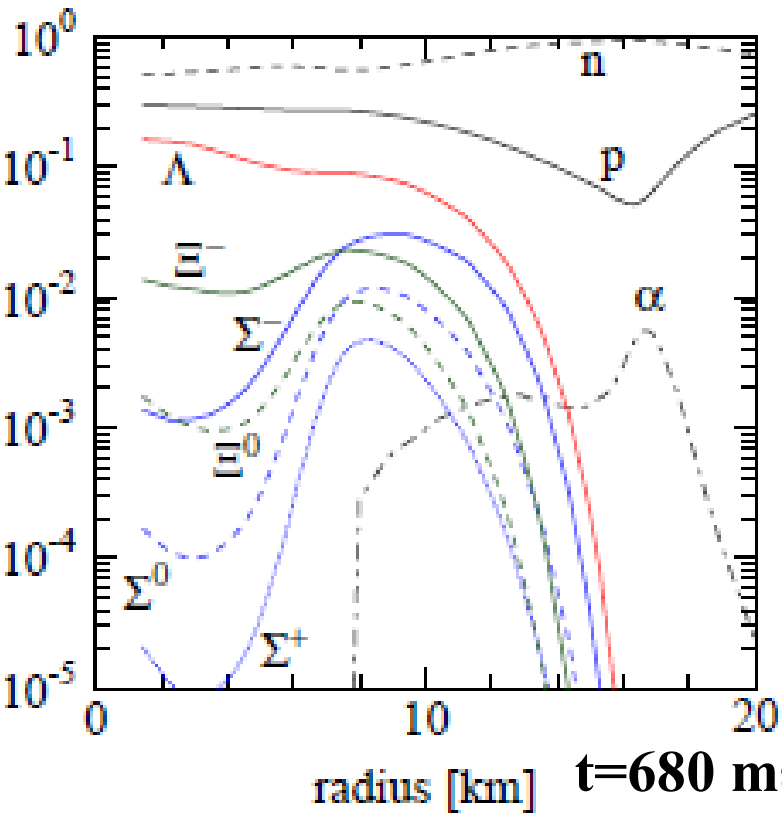
Sumiyoshi, Ishizuka, AO, Yamada, Suzuki, 2009

Black Hole Formation

- **Black Hole Formation: (ρ_B, T, Y_e) ~ (4 ρ_0, 70 MeV, 0.2)**
  → Hyperon fraction ~ 10 %
  (K. Sumiyoshi, C. Ishizuka, AO, S. Yamada, H. Suzuki, ApJ690(09)L43)



t=0, 500, 680 msec



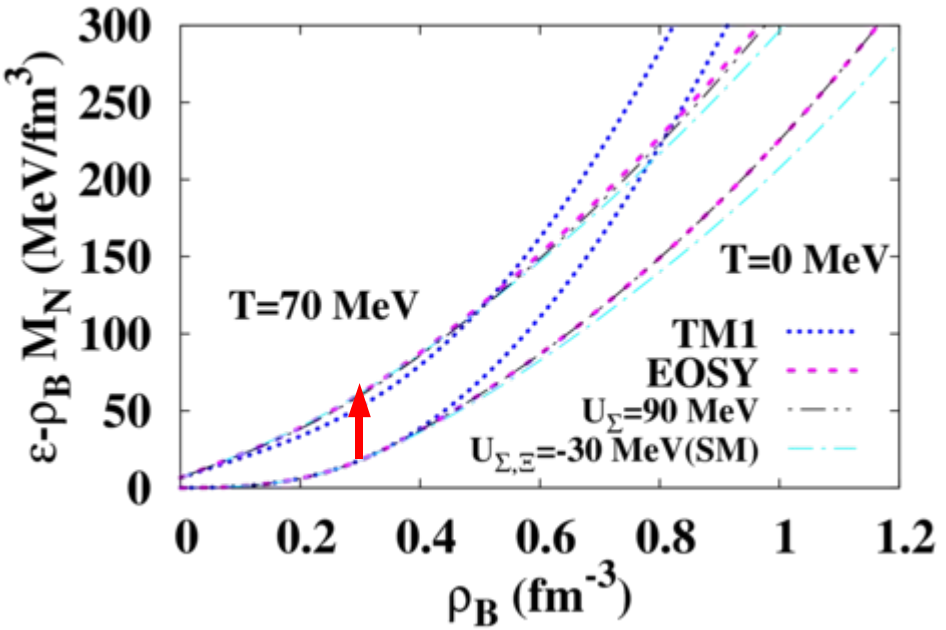
t=680 msec

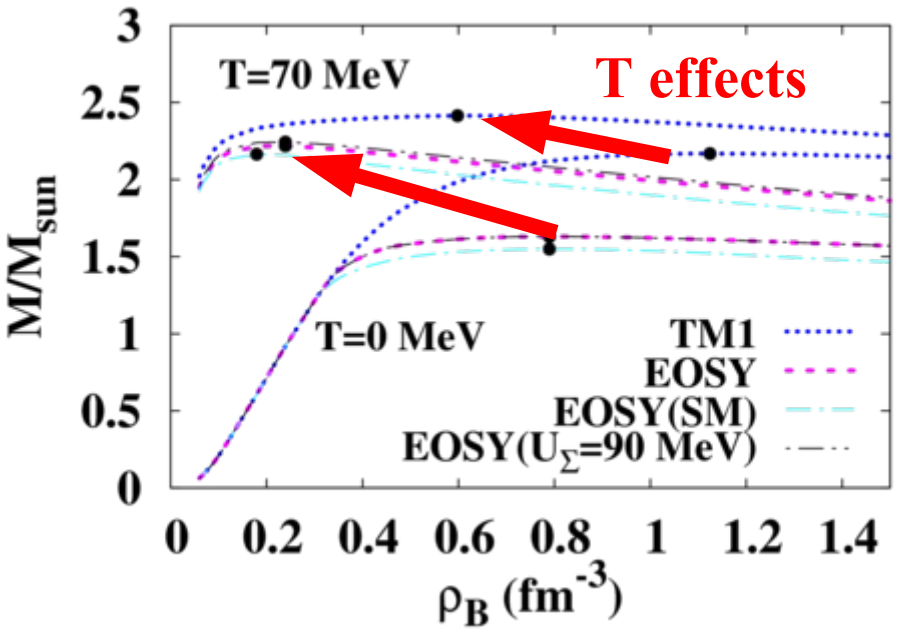
Hyperons are abundantly formed during BH formation !
→ EOS softening, Early collapse, Short ν duration

EOS of Hot Hyperonic Matter

- **Earlier BH formation with Y**
  - **Shen: 2.4 Msun at t=1342 msec**
  - **EOSY: 2.1 Msun at t=682 msec**

  → Larger than max. mass at T=0
- **TOV equation at constant T**
  - **Larger pressure even at low ρ_B**
  - **Larger max. mass**
    Shen: 2.17 Msun → 2.41 Msun
    EOSY: 1.63 Msun → 2.22 Msun
  - **Max. mass is supported at SMALLER center density**
    Shen: 1.12 fm^{-3} → 0.60 fm^{-3}
    EOSY: 0.79 fm^{-3} → 0.24 fm^{-3}





Smaller ρ_B for max. mass with Y may be cause earlier formation of BH. (conjecture)

Summary

- **EOS with hyperons for core collapse supernovae is tabulated and opened to public, as an extension of the relativistic EOS by Shen et al.**
  http://nucl.sci.hokudai.ac.jp/~chikako/EOS/index.html
  Hyperon potentials are chosen to be
  U_Λ = -30 MeV, U_Σ = +30 MeV, U_Ξ = -15 MeV
  according to recent hypernuclear physics implications.

- **Hyperons are produced not only in neutron stars but also during black hole formation, where the temperature can be as high as T=70 MeV. With hyperons, BH is formed at an earlier time, which may be observable via short ν duration time in failed supernovae.**
  By the temperature effects, Σ can be more abundant than Ξ.
  (c.f. Sumiyoshi's talk on Friday.)

- **Earlier BH formation may be caused by the lower ρ_B with hyperons, which support the max. mass of hot neutron star. Hyperon potential dependence would be smaller (a few % difference) in BH formation.**

- **EOS should be improved !**
  Hyperon pot., Chiral Sym., Mesons, Quarks, ...

- **Collaborators**

EOS and Astrophysical applications

C. Ishizuka, K. Tsubakihara (Poster on Tuesday), K. Sumiyoshi (Talk on Friday), S. Yamada, H. Suzuki

Hypernuclear production and structure

H. Maekawa, H. Matsumiya (Poster on Tuesday), K. Tsubakihara, M. Kimura (Talk on Tuesday), M. Isaka (Poster on Tuesday), A. Dote

Mesons in Dense Matter

D. Jido (Talk on Monday), T. Sekihara (Talk on Thursday), K. Tsubakihara

Thank You for Your Attention !