中性子星における
Σハイペロン混合の効果について

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Introduction

- Our interest: dense matter EOS including Y

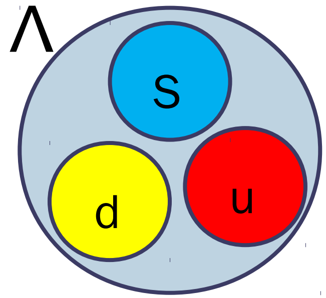
NS matter, SN

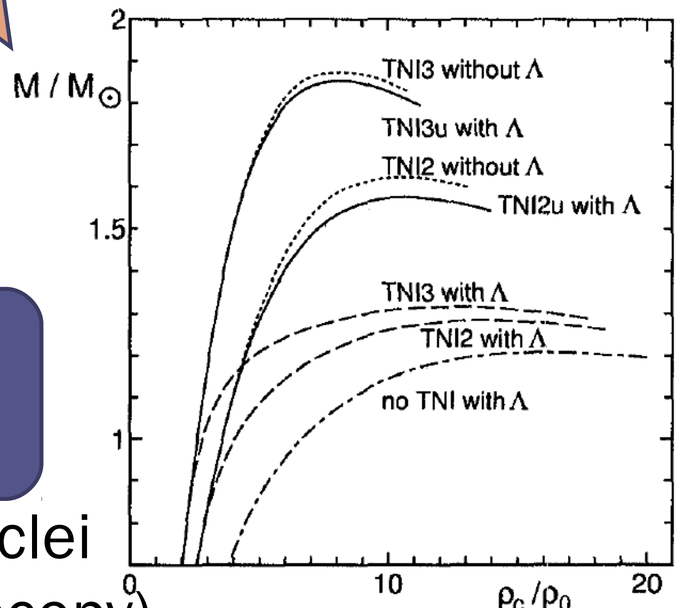
Dense matter EOS

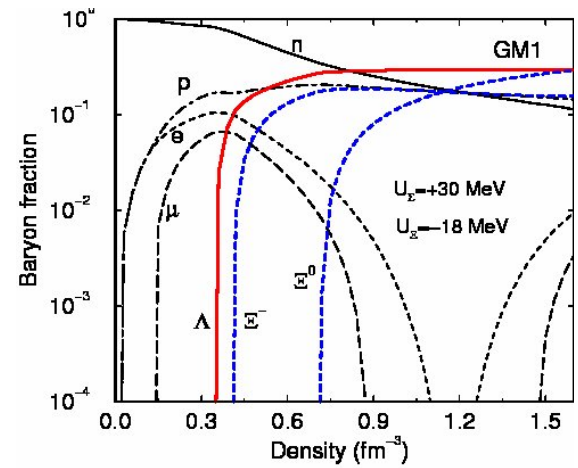
Finite system and nuclear matter

Hyperon potential

Λ, Σ and Ξ hypernuclei
(bound state spectroscopy)



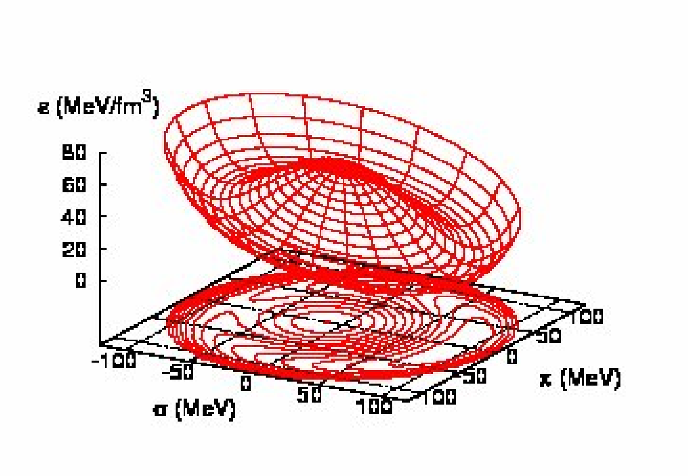


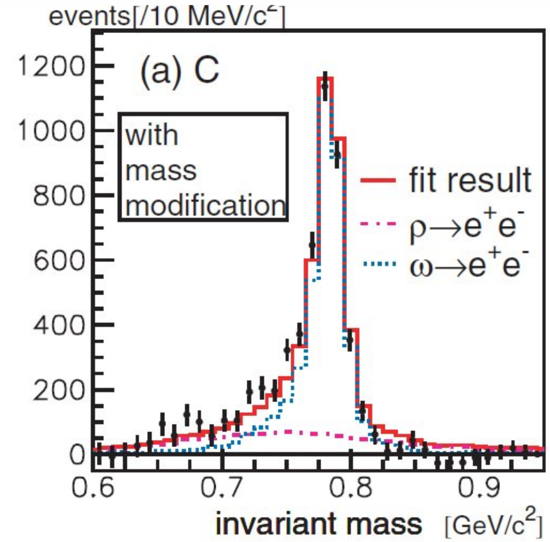


[1] Lattimer and Swesty, NPA 535 (1991) 331. [2] Shen et al., PTP 100 1013. [3] Yamamoto, Nishizaki and Takatsuka, NPA 691 (2001) 432c.
[4] Schaffner and Mishustin PRC **53** (1996) 1416. [5] Schaffner-Bielich, NPA **804** (2008) 309..

Chiral symmetry in hadron phase

- Chiral symmetry in hadron: π as Nambu-Goldstone boson and its chiral partner, σ
- Chiral potential in RMF model: suggested from QCD (c.f. NJL m corresponding to chiral restoratic medium
- ω and ρ mass modification[12]
  - Evidences of partial chiral symmetry restoration in nuclear medium?
  - Theoretical model overestimates mass modification compared to [13] where all of vector meson mass is gene condensate.

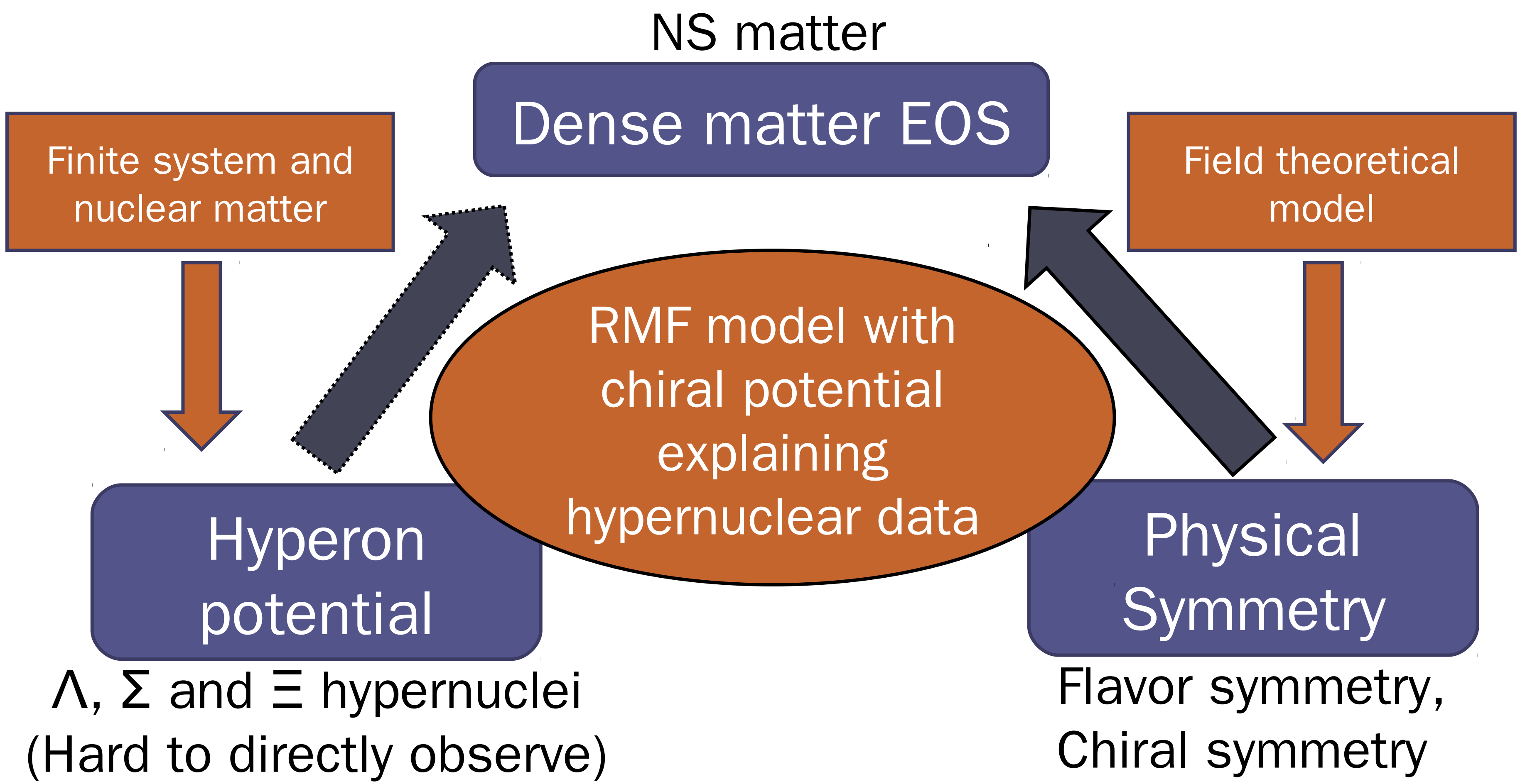




[6] Naruki et al., PRL 96 (2006) 092301. [7] Brown and Rho, PR 363 (2002) 85; Hatsuda and Lee, PRC **46** (1992) R34.

Motivation

- Our interest: dense matter EOS with Y



[1] Lattimer and Swesty, NPA 535 (1991) 331. [2] Shen et al., PTP 100 1013. [3] Yamamoto, Nishizaki and Takatsuka, NPA 691 (2001) 432c.

Model description

- RMF Lagrangian

Scalar mesons: Attractive part of baryon interaction

Vector mesons: Repulsive part of baryon interaction

$$\mathcal{L} = \sum_i \bar{\psi}_i \left[g_{\sigma i}\varphi_\sigma + g_{\zeta i}\varphi_\zeta - \gamma_0 \left(g_{\omega i}\,\omega^0 + g_{\rho i}\,\rho^0 + g_{\phi i}\,\phi^0 + \frac{1+\tau_3}{2} e A^0 \right) \right] \psi_i$$

$$- \left\{ (\nabla\varphi_\sigma)^2 + m_\sigma^2 \varphi_\sigma^2 \right\} - \left\{ (\nabla\varphi_\zeta)^2 + m_\zeta^2 \varphi_\zeta^2 \right\} - V_{\sigma\zeta}$$

$$+ \left\{ (\nabla\omega^0)^2 + m_\omega^2 (\omega^0)^2 \right\} + \left\{ (\nabla\rho^0)^2 + m_\rho^2 (\rho^0)^2 \right\} + \left\{ (\nabla\phi^0)^2 + m_\phi^2 (\phi^0)^2 \right\} + \frac{c_\omega}{4}\omega^4$$

Kinetic part of mesons

Effective potential of mesons

- Long standing problems: Too early chiral restoration, very stiff EOS, instability on chiral potential

What form should the meson potential have?
$\Rightarrow$ Constrained by chiral symmetry, derived from SCL-LQCD

Chiral potential derived from SCL

- Start point: Action of gluon and fermion on strong coupling limit of Lattice QCD (g→∞) at T = 0

$$S = S_G + S_F + m_0 \bar{\chi}\chi$$

- After bosonizing fermion pair and integrating fermion

$$U = -\frac{a}{2}\log(\sigma) + b\sigma^2 \rightarrow -\frac{a}{2}\log(\det MM^\dagger) + b\,\mathrm{tr}(MM^\dagger)$$

SU$_f$(2) case

$$U = -\frac{a}{2}\log(\det MM^\dagger) + b\,\mathrm{tr}(MM^\dagger) - c_\sigma \sigma$$

$$-a\left[\log(f_\pi + \phi) - \phi + \frac{1}{2}\left(\frac{\phi}{f_\pi}\right)^2\right]$$

$$+\frac{1}{2}m_{\sigma^2}\phi^2 + \frac{1}{2}m_{\pi^2}\pi^2$$

SU$_f$(3) case

$$U = -\frac{a}{2}\log(\det MM^\dagger) + b\,\mathrm{tr}(MM^\dagger) - c_\sigma \sigma - c_\zeta \zeta$$

$$+d(\det M + \det M^\dagger)$$

$$-a\left[\log(f_\pi + \phi_\pi) - \left(\frac{\phi_\pi}{f_\pi}\right) + \frac{1}{2}\left(\frac{\phi_\pi}{f_\pi}\right)^2\right] + \frac{1}{2}m_{\sigma^2}\phi_{\sigma^2} + \frac{1}{2}m_{\pi^2}\pi^2$$

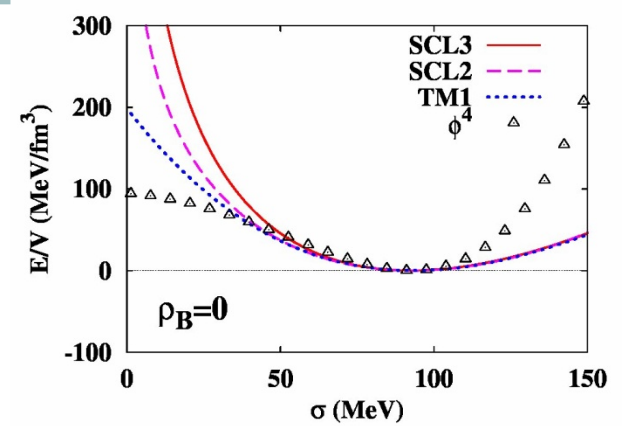
$$-\frac{a}{2}\left[\log(f_\zeta + \phi_\zeta) - \phi_\zeta + \frac{1}{2}\left(\frac{\phi_\zeta}{f_\zeta}\right)^2\right] + \frac{1}{2}m_{\zeta^2}\phi_{\zeta^2} + \frac{1}{2}m_{K^2}K^2$$

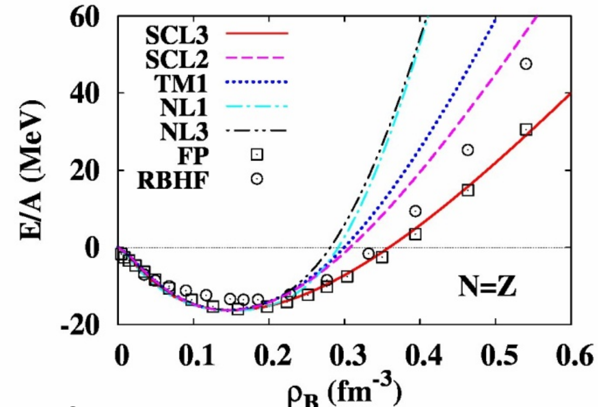
$$+\xi_{\sigma\zeta}\phi_\sigma\phi_\zeta$$

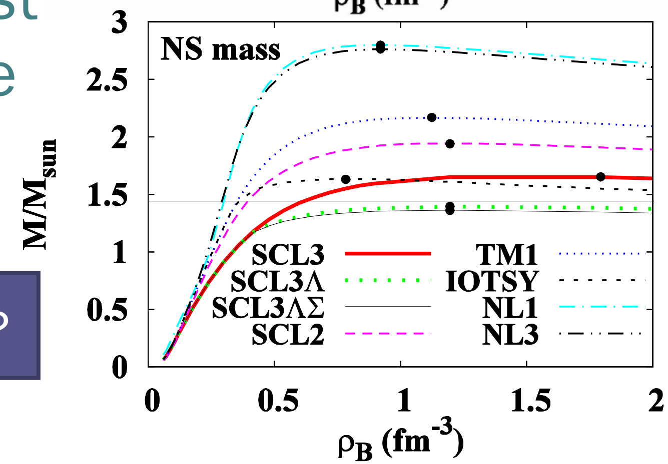
[8] Kawamoto and Smit, NPB 190 (1981) 100. [9] Kawamoto, Miura, Ohnishi and Ohnuma PRD **75** (2007) 014502.

SCL3 RMF model

- Logarithmic SCL Chiral Potential
  - Property of chiral potential: Neither instability nor abnormal vacuum
  - Consistent with reproducing *BE* of normal nuclei, S_Λ of single Λ nuclei, $\Delta B_{\Lambda\Lambda}$ of ${}^{6}_{\Lambda\Lambda}$He and FP EOS ($K \sim 210$MeV softened by hidden strange condensate $\zeta = \bar{s}s$
  - Calculated NS mass underlies the most reliable observation, 1.44 $M_\odot$ when we include hyperon degrees of freedom





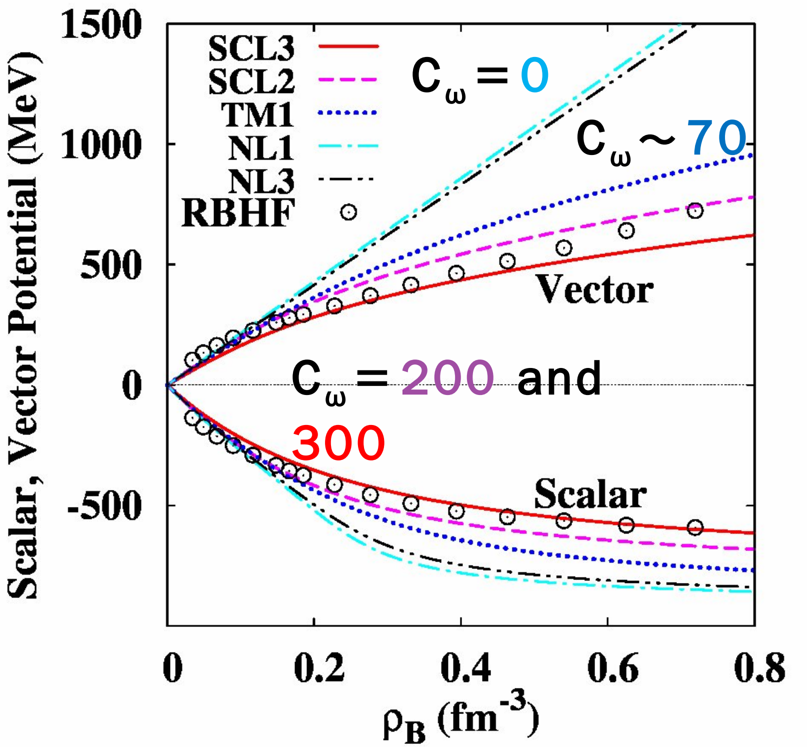


What are key ingredients which are efficient to refine ?

[10] KT, Maekawa, Matsumiya and Ohnishi, arXiv:0909.5058

Scalar and vector potential in matter

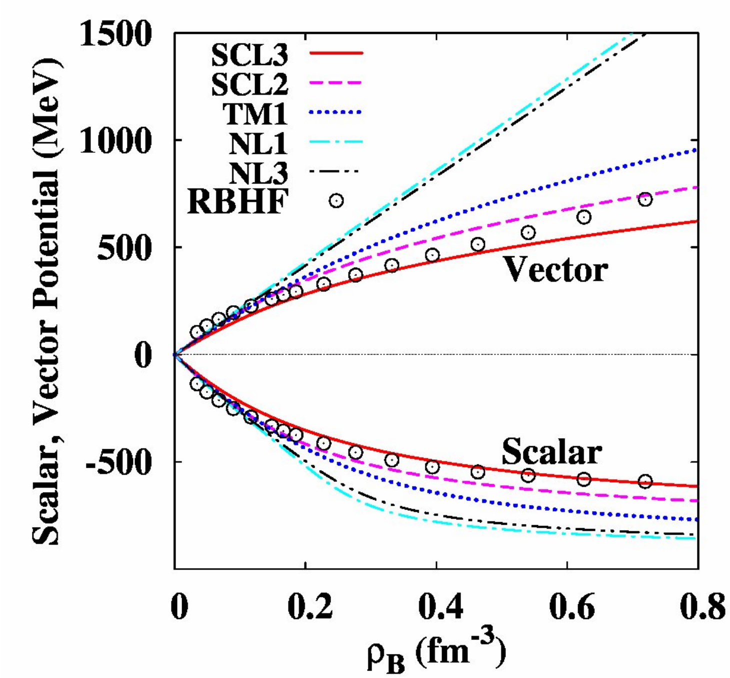
- Repulsive potential from ω: Good agreement with DBHF result by $3\rho_0$ but seems to be insufficient from higher ρ_B
- C_ω: Strength of ω meson potential and known as the suppresser of vector meson field



To reduce this strength, we would like to suggest "Density dependent type coupling (σωN)"

Density dependent type coupling

- May be derived from NLO calculation on SCL-LQCD
- Scalar potential(∝ σ)⇒saturate
  Vector potential (∝ ω) ⇒increase linearly
- σωN coupling: effective around ρ_0 and not important in high ρ_B



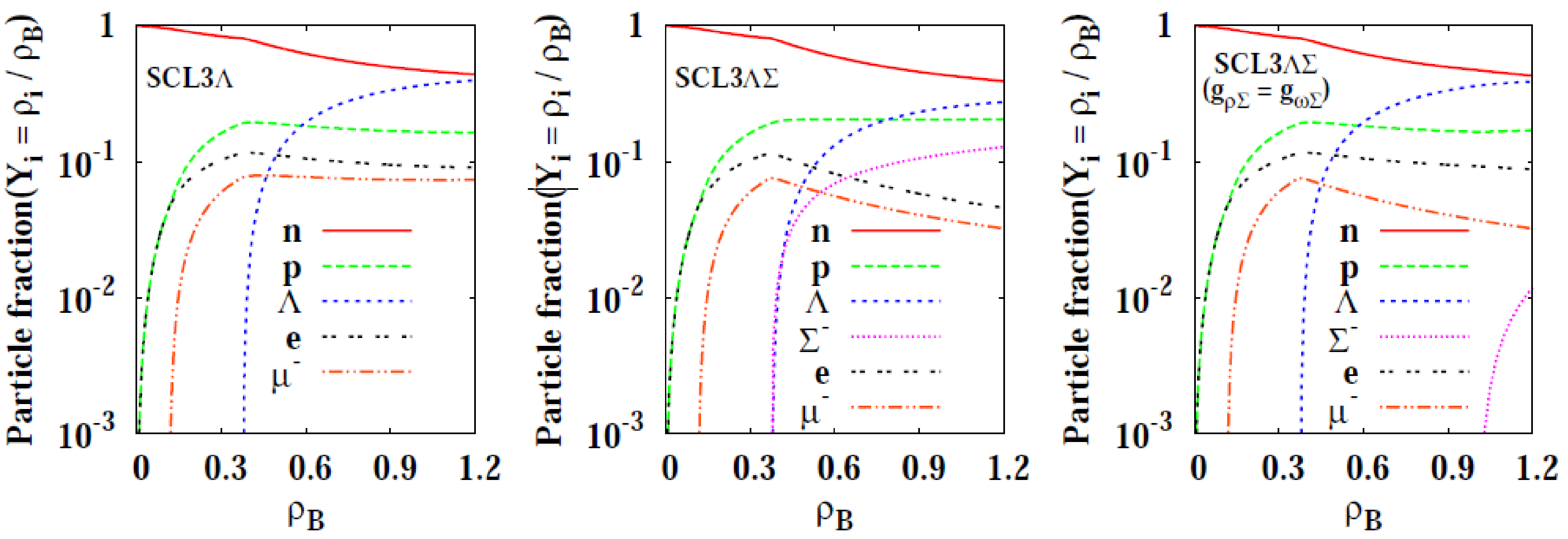
Here, we introduce σωN coupling

$$g_\omega = g_{\omega 0} + g_{\sigma\omega N}\phi_\sigma$$

and we examine its effect to the property of sym. nuclear matter and NS matter

Interesting feature

- Is the ratio of hyperon fraction in NS changed by Σ hyperon potential?
  - Determined by $SU_f(3)$ symmety and the atomic shifts(AS) of Σ^-
  - Repulsive but weak vector-isovector meson coupling: Σ hyperon may appear on NS



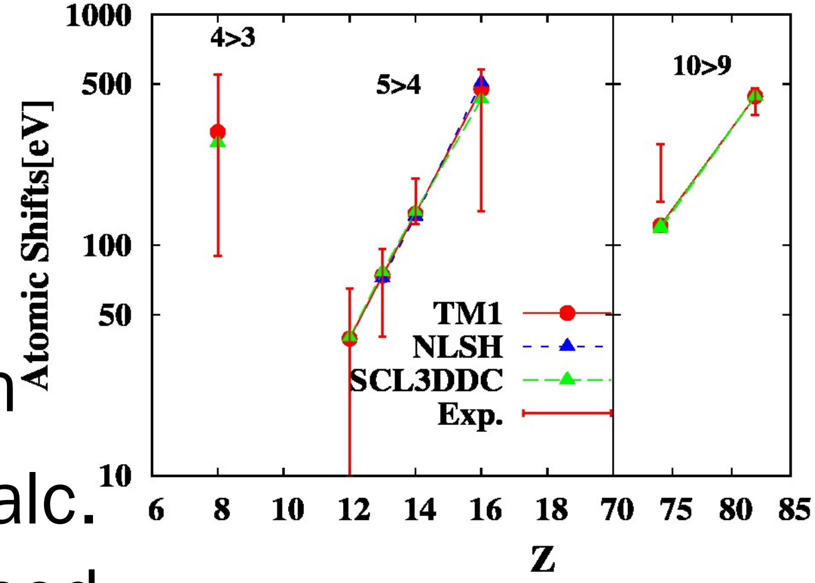
Aim of this study

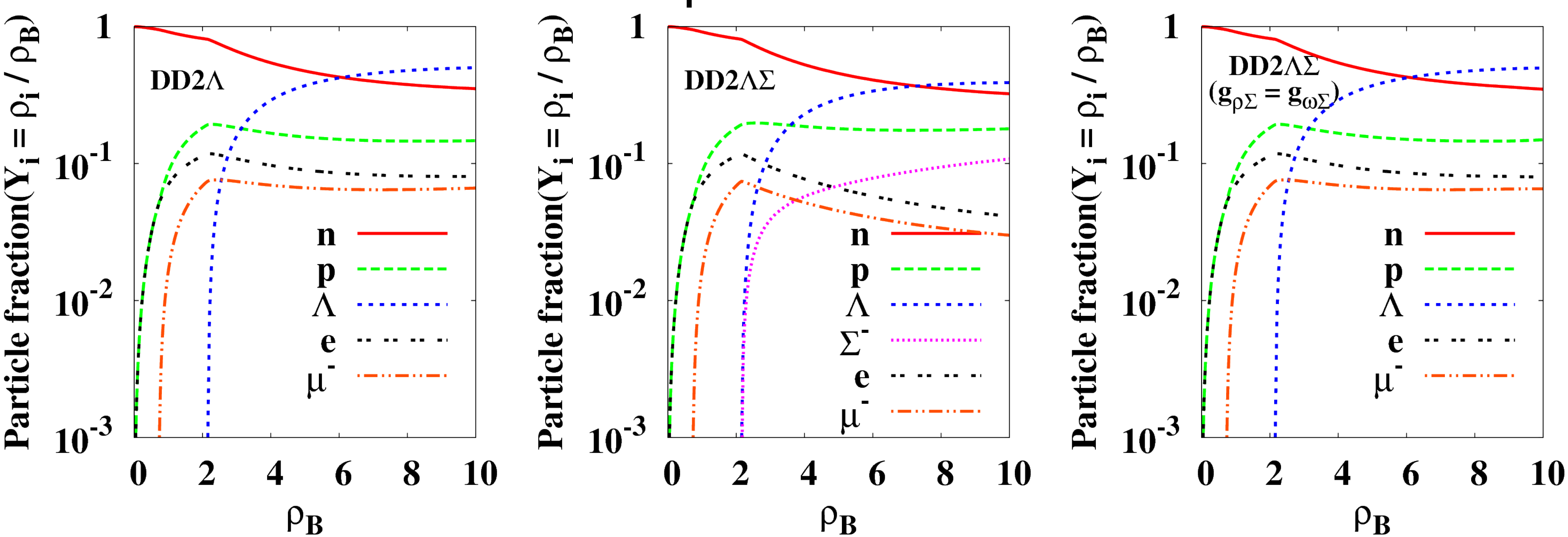
- Is SCL3 RMF model be able to support maximum mass of neutron star?
  - Can density dependent type coupling resolve this problem?

- On another RMF model, is the ratio of hyperon fraction in NS also changed by Σ hyperon potential determined by the atomic shifts(AS) of Σ^-?

Result(1)

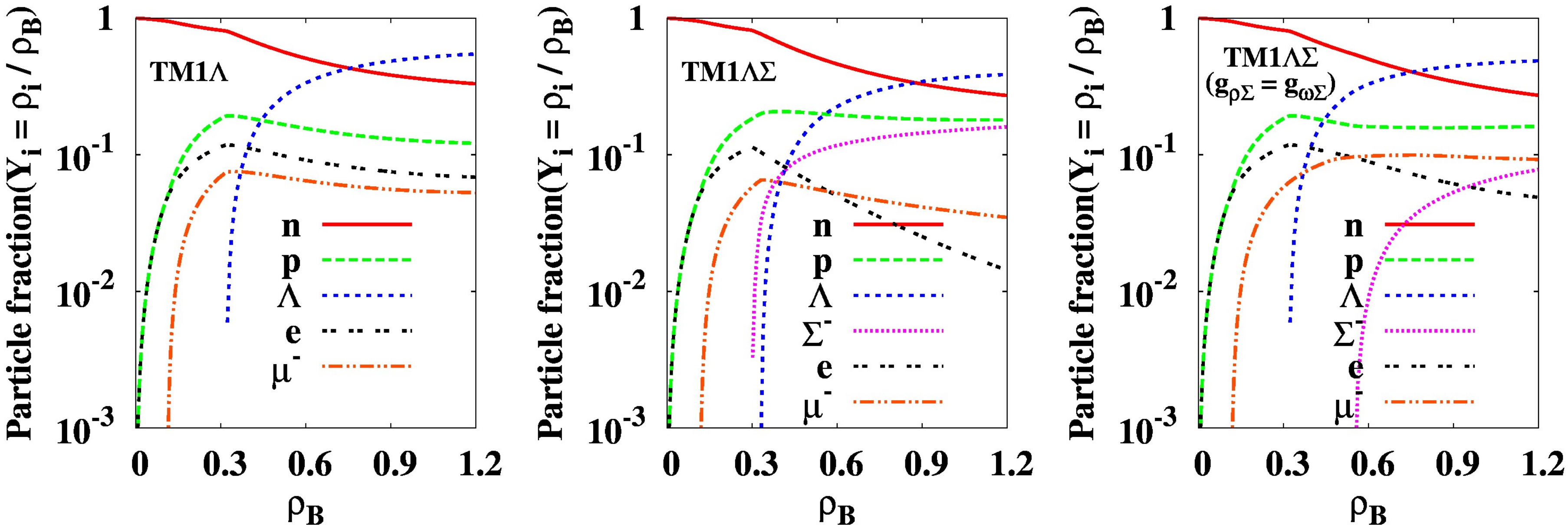
- Σ hyperon potential: determined by the atomic shifts(AS) of Σ^-
- Σ^- appear at lower ρ_B than Λ → contradict to other calc. where AS are not reproduced.





Result(2)

- To confirm this situation, we also use the phenomenological RMF model with non-linear potential(TM1)

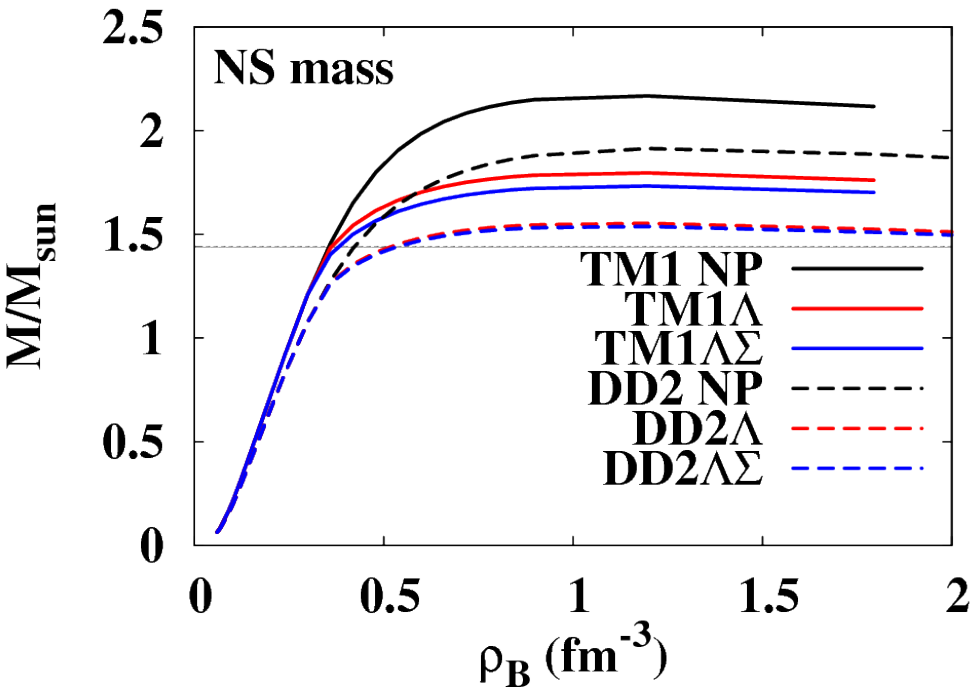


- We can find the same situation occurred in this calculation and Σ can appear in NS matter even if it has a repulsive potential

Results(3)

Maximum mass of Neutron Star

- Neutron Star EOS with Hyperon effect:
  - →Inclusion of Hyperon make NS EOS softened at high density phase
- Recent observation may confirm heavier maximum mass of neutron star, $1.7M_{\odot}$
- New SCL3 DDC RMF model seems not to be enough to explain this observation.



Summary

- RMF model with chiral SU(3) potential (SCL3)
  - Saturation property, incompressibility, BE, S_Λ, and $\Delta B_{\Lambda\Lambda}$ are well reproduced in appropriate parameter range.
  - Calculated NS matter EOS underestimates observed NS mass.
- Key for the property in high ρ_B phase: C_ω
  - Density dependent type coupling (σωN type coupling)
    ⇒This needs not too large C_ω to reproduce nuclear property.
    Calculated results seems not to support 1.7 $M_\odot$ if hyperon effects are taken into account properly.
- Ordering of hyperon appearance
  - Atomic shifts of Σ^-: one of key ingredients of this topic
  - Ordering may be changed but that does not affect the final result so much so far.
- In future……
  - Finite temperature EOS for supernovae simulation

Thank you for listening!!