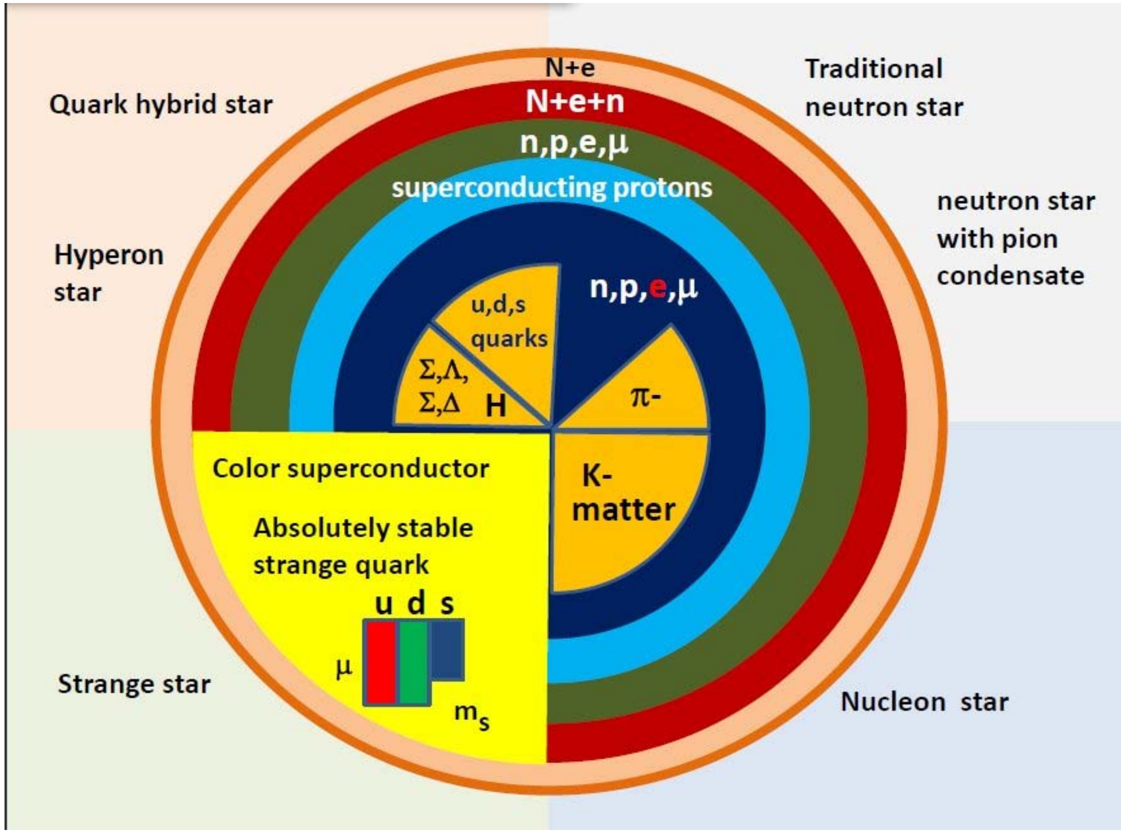
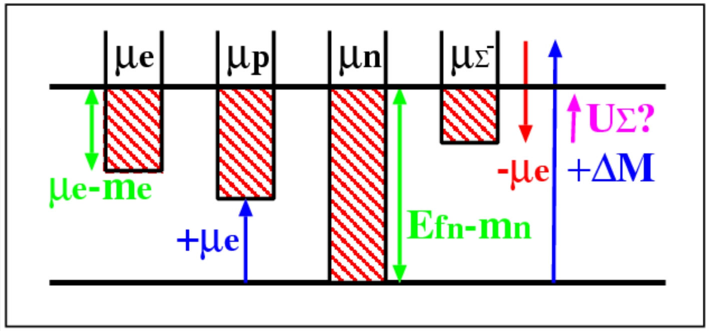
# 中性子星内におけるΣ⁻出現の可能性

KOHSUKE TSUBAKIHARA, TORU HARADA
*OSAKA ELECTRO-COMMUNICATION UNIVERSITY*
AKIRA OHNISHI
*YITP, KYOTO UNIVERSITY*

# Introduction

- Ambiguity in dense inner region of NS

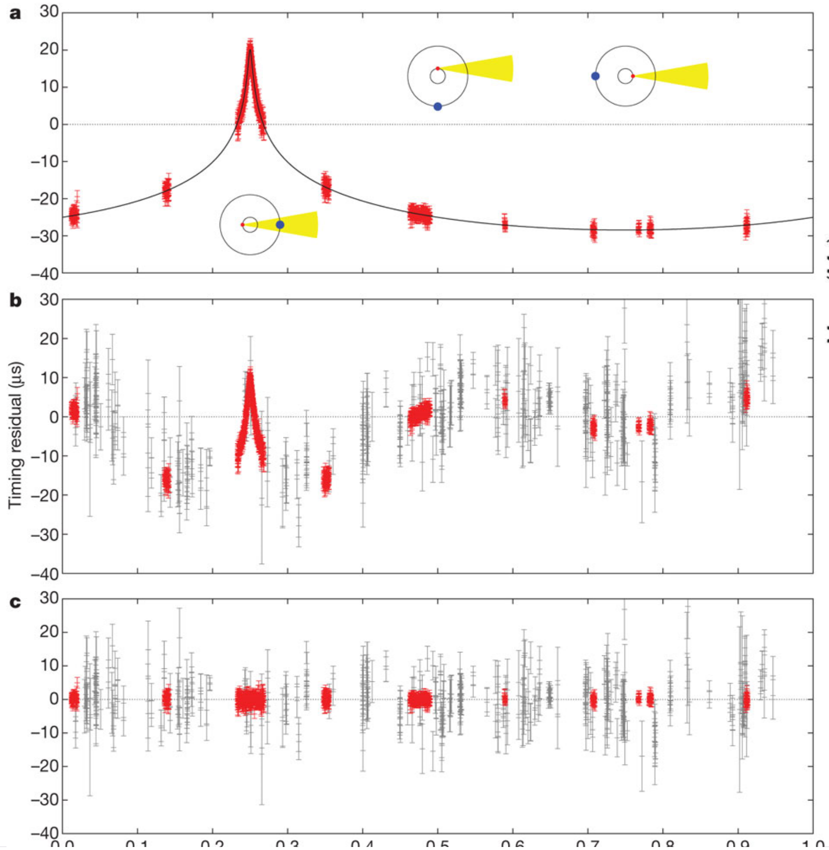


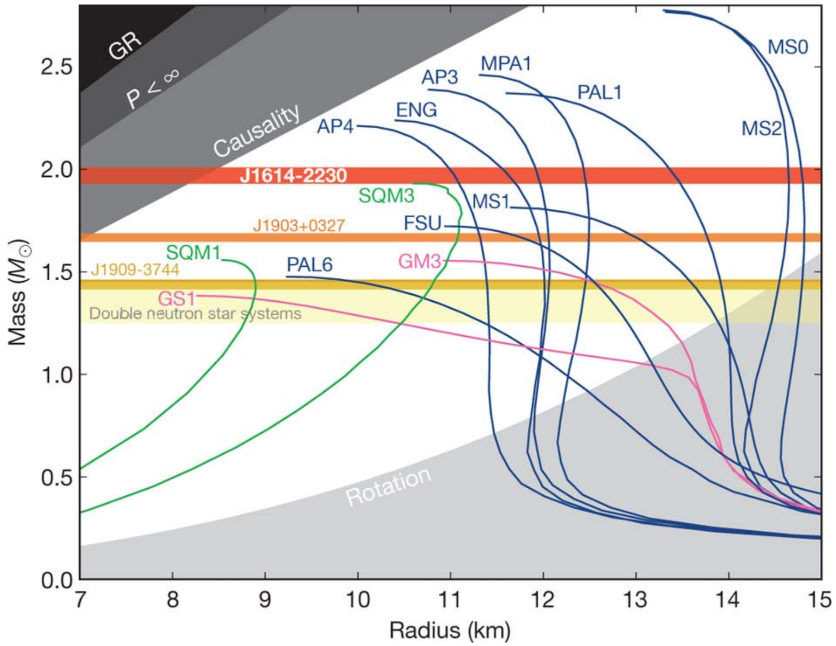




- New DOF such as Exotic particle soften NS EOS
- Emergence of hyperon: needs to treat "finite" hypernuclear systems in order to determine hyperon potential
- Framework which enable to treat finite/infinite system →RMF model

# Introduction

- Observation of massive neutron star

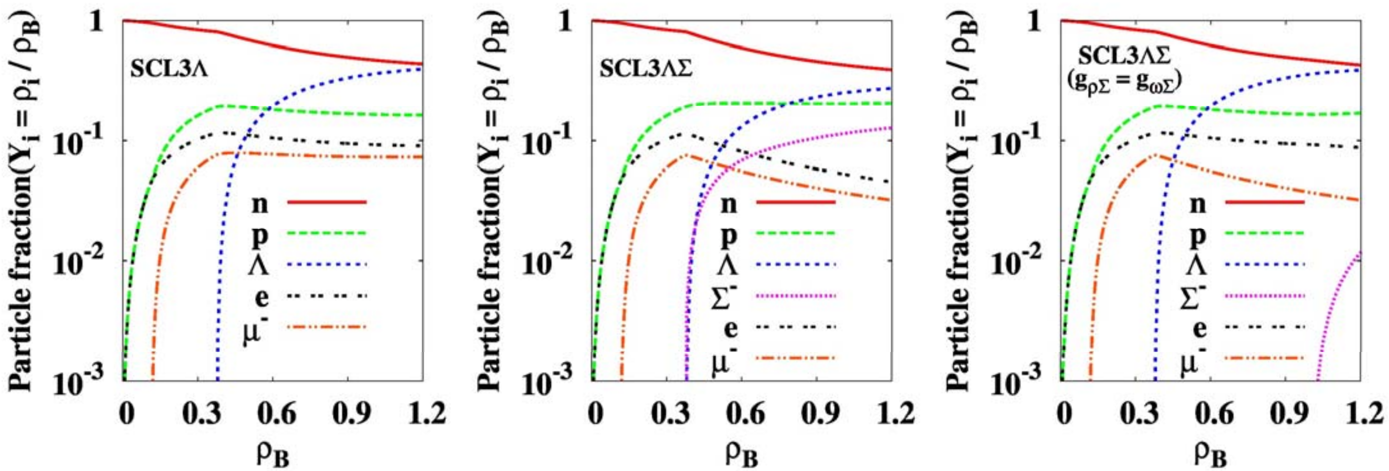


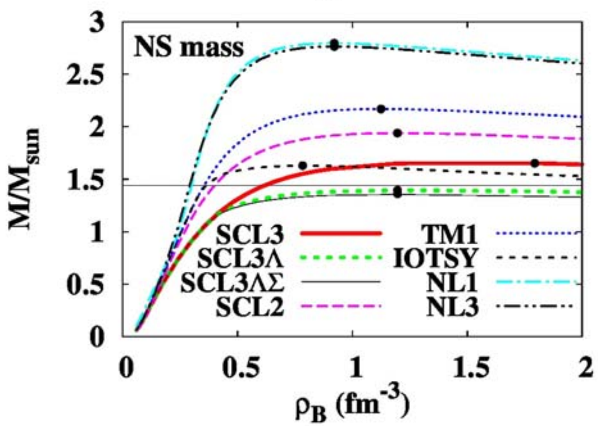




"Most EOS curves involving exotic matter, such as kaon condensates or hyperons tend to predict maximum masses, well below 2.0 $M_\odot$

# Personal motivation

- Previous works on SCL3 RMF model

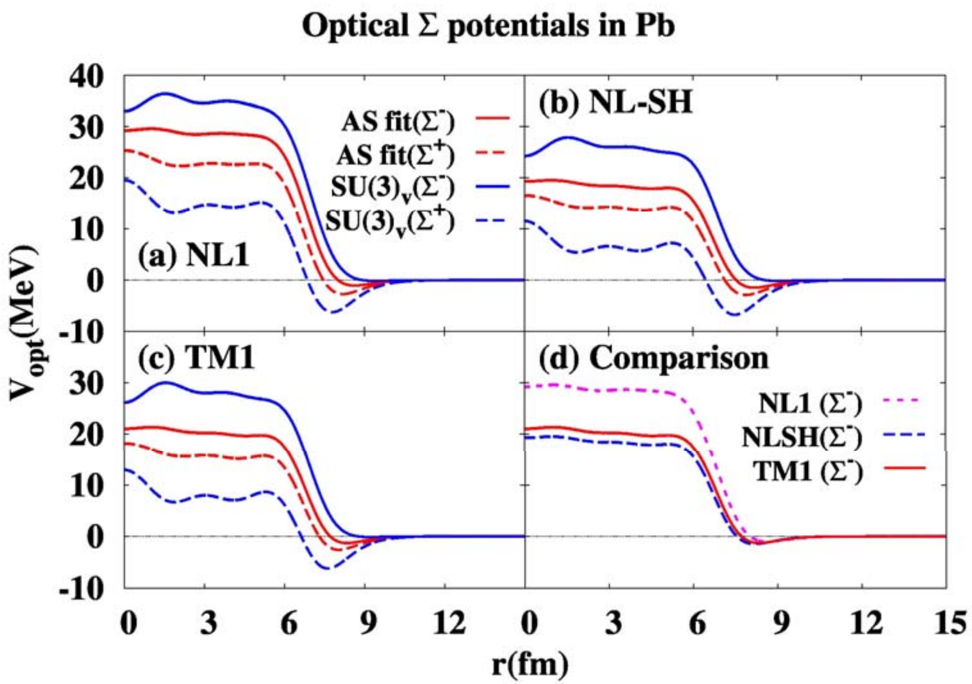


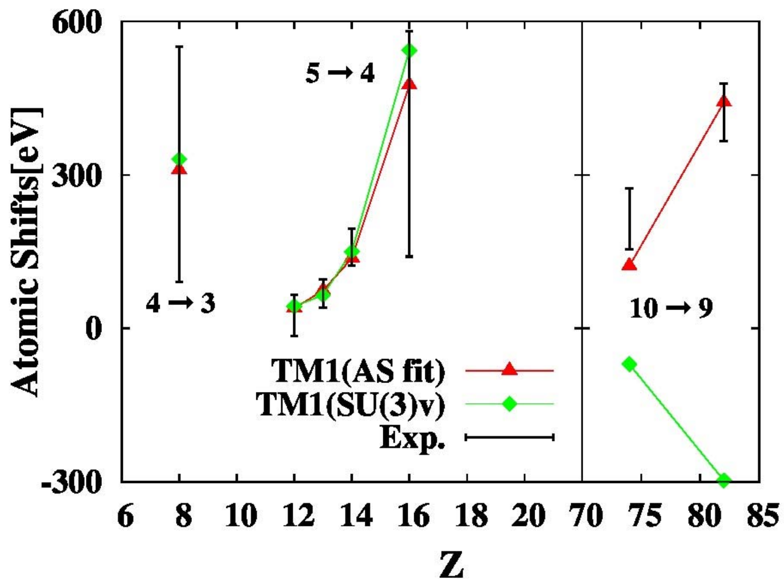




- Logarithmic meson potential derived from Strong Coupling Limit of lattice QCD
- Emergence of $\Sigma^-$: suggested from reduced IV potential of $\Sigma$
- Smaller NS mass: requirement of many-body interaction in RMF?

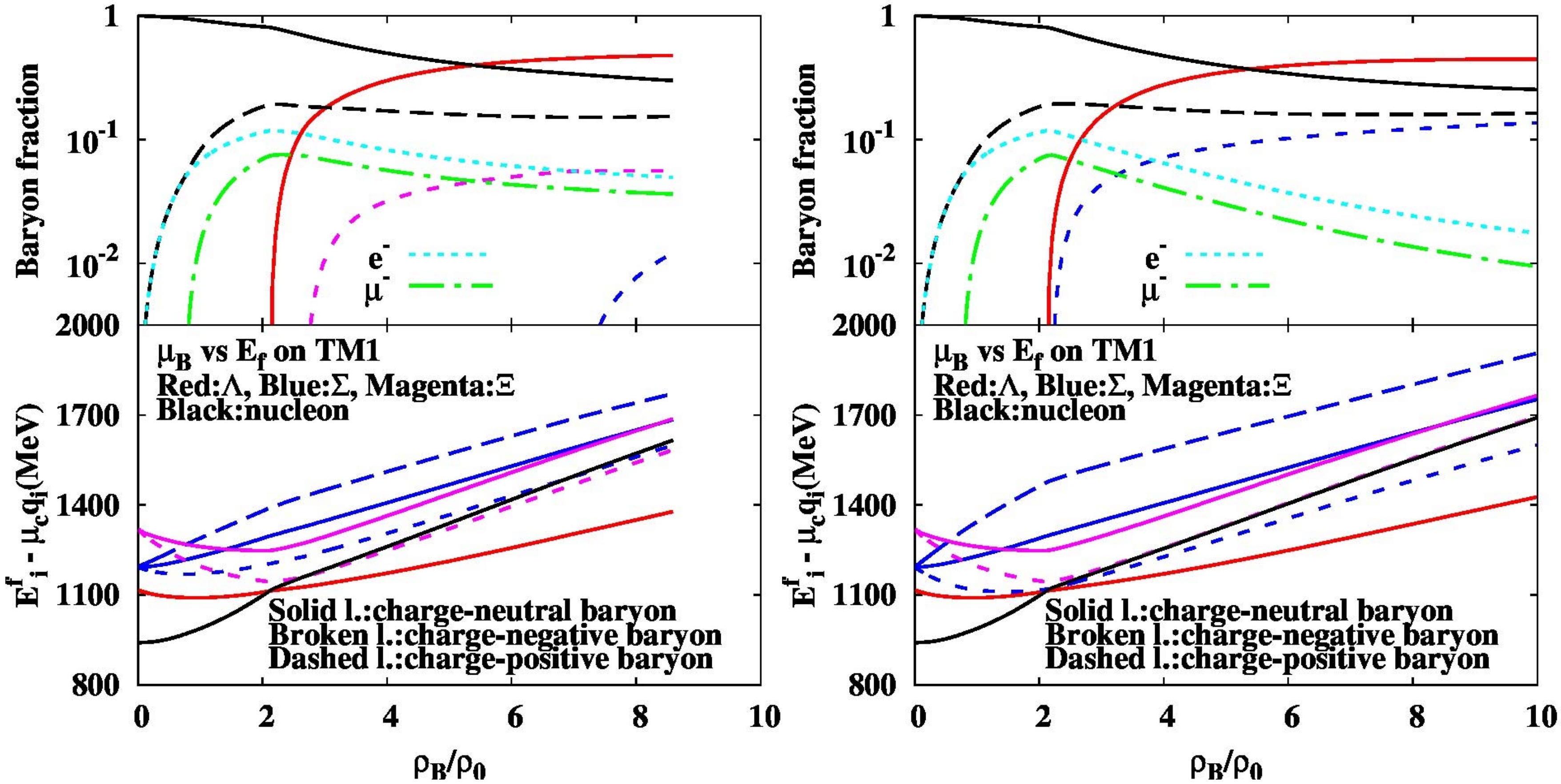
# Hypernulcer Symmetry Energy

- Atomic shift of $\Sigma^-$: Attractive potential around surface
- Difference between $\Sigma^+$ and $\Sigma^-$ potentials→ proportional to "Hypernulcear" symmetry energy: 15MeV(SU(3))→5MeV(fit)



# Baryon Fraction




$\Sigma^-$ may survive in NS matter even if $\Xi^-$ is taken into account ($U_{\Xi}$(12C-$\Xi^-$)=-14MeV).

# Physical motivation

- More massive NS than $2M_{\odot}$:
  How can be explained in RMF model?
  → n=3 meson-baryon couplings

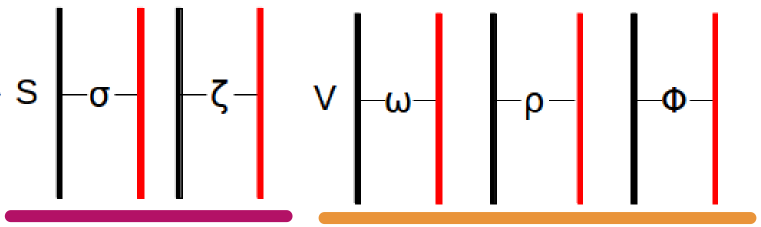
- Can $\Sigma^-$ survive in NS EOS in case we consider above n= 3 couplings and how large effects does $\Sigma^-$ take from those couplings

# RMF model

- n=B/2+M+D=2 RMF Lagrangian + meson potentials

$$\mathcal{L} = \sum_i \bar{\psi}\left[i\partial\!\!\!/ - M_i^* - \gamma_\mu V^\mu\right]\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$
$$+\frac{1}{2}\partial_\mu\varphi_\sigma\partial^\mu\varphi_\sigma - \frac{m_\sigma^2}{2}\varphi_\sigma^2 + \frac{1}{2}\partial_\mu\varphi_\zeta\partial^\mu\varphi_\zeta - \frac{m_\sigma^2}{2}\varphi_\zeta^2 - V_{\sigma\zeta}$$
$$-\frac{1}{4}W_{\mu\nu}W^{\mu\nu} + \frac{m_\omega^2}{2}\omega_\mu\omega^\nu - \frac{1}{4}R_{\mu\nu}R^{\mu\nu} + \frac{m_\rho^2}{2}\rho_\mu\rho^\nu - \frac{1}{4}\phi_{\mu\nu}\phi^{\mu\nu} + \frac{m_\phi^2}{2}\phi_\mu\phi^\nu + \frac{C_{\omega 4}}{4}\left(\omega_\nu\omega^\nu\right)^2$$

$$\bar{\Psi}_B g_{mB} m \Psi_B \Longleftrightarrow$$

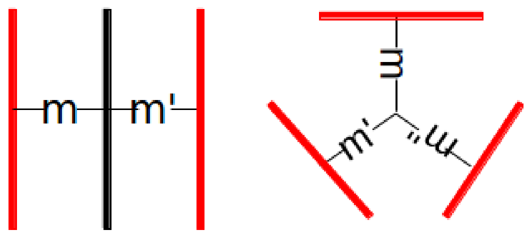



- Non-linear meson potentials
  - Interactions among mesons in finite/infinite system
  - Higher order terms than n=3 meson-baryon couplings

# n=3 coupling in RMF

- n=B/2+m+D=3 couplings

$$\bar{\Psi}_B m m' \Psi_B, \; m m' m''$$




  - Number n corresponds to the number of baryons participating in each interaction

- Isoscalar type couplings

$$\bar{\Psi}_B \left(g_{\sigma\sigma B}\varphi_\sigma^2/f_\pi\right)\Psi_B, \; \bar{\Psi}_B \left(g_{\sigma\omega B}\varphi_\sigma\omega/f_\pi\right)\Psi_B, \; \bar{\Psi}_B \left(g_{\omega\omega B}\omega^2/f_\pi\right)\Psi_B, \; \frac{C_{\sigma\omega 2}}{2} f_\pi \varphi_\sigma \omega^2$$

- Isovector type couplings

$$\bar{\Psi}_B \left(g_{\rho\sigma B}\rho\varphi_\sigma/f_\pi\right)\Psi_B, \; \bar{\Psi}_B \left(g_{\omega\rho B}\omega\rho/f_\pi\right)\Psi_B, \; \bar{\Psi}_B \left(g_{\rho\rho B}\rho^2/f_\pi\right)\Psi_B, \; \frac{C_{\sigma\rho 2}}{2} f_\pi \varphi_\sigma \rho^2$$

それぞれscalar、vector型結合

# Saturation parameters in RMF

- L,Kの具体的な表式

$$L \propto \frac{dE}{d\rho_B} = \sum_i \frac{d\rho_{Bi}}{d\rho_B}\frac{dE}{d\rho_{Bi}} = \frac{1}{\rho_B}\left[\frac{1}{2}\sum_i \left\{V_i^0 + \sqrt{k_{Fi}^2 + (M_i^*)^2}\right\} - E\right]$$

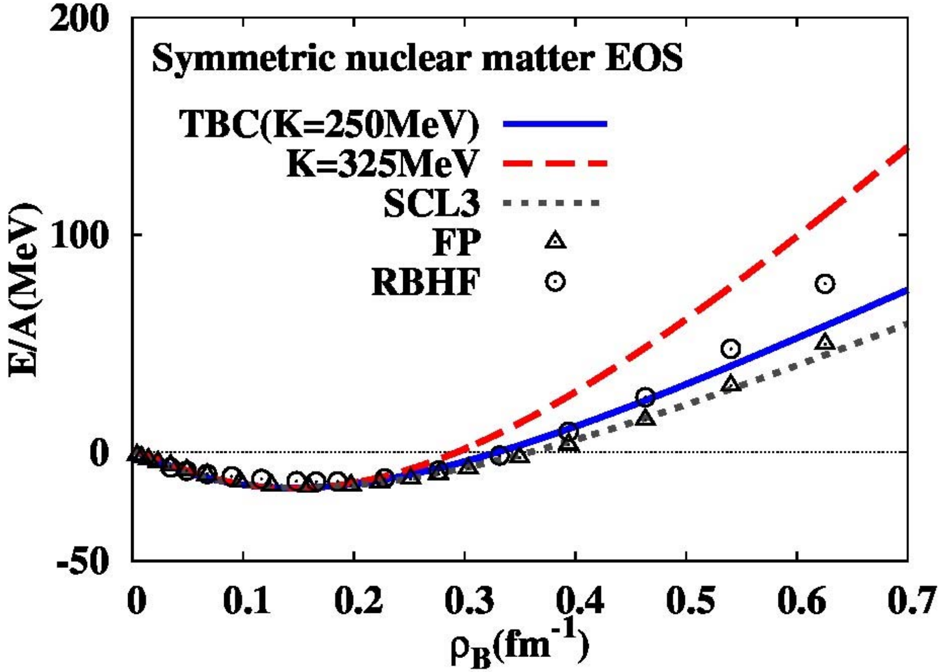
$$K_\infty = \frac{9\rho_0}{4}\sum_j \left\{\frac{\pi^2}{k_{Fj}}\frac{1}{\sqrt{k_{Fj}^2 + (M_j^*)^2}} + \sum_i \sum_m \frac{\partial f_m}{\partial \rho_{Bj}}\frac{\partial}{\partial f_m}\left(V_i^0 + \sqrt{k_{Fi}^2 + (M_i^*)^2}\right)\right\}$$

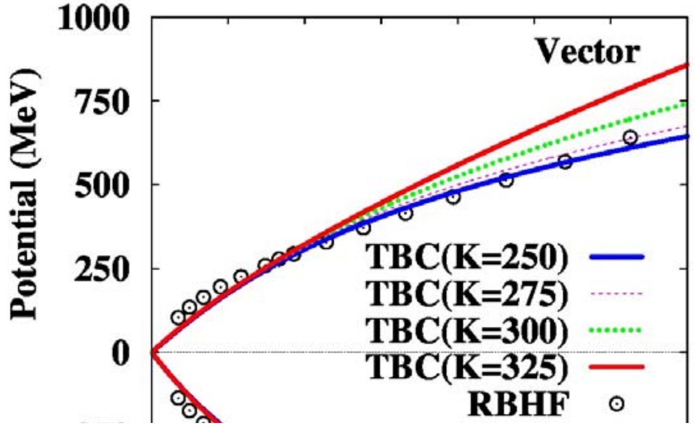
$$= \frac{9\rho_0}{4}\sum_j \left[\frac{\pi^2}{k_{Fi}}\frac{1}{\sqrt{k_{Fi}^2 + (M_i^*)^2}} + \frac{d\omega}{d\rho_{Bj}}\sum_i \frac{1}{f_\pi}\left(g_{\omega i} f_\pi - g_{\sigma\omega i}\varphi_\sigma + \frac{2g_{\omega\omega i}\omega M_i^*}{\sqrt{k_{Fi}^2 + (M_i^*)^2}}\right)\right.$$

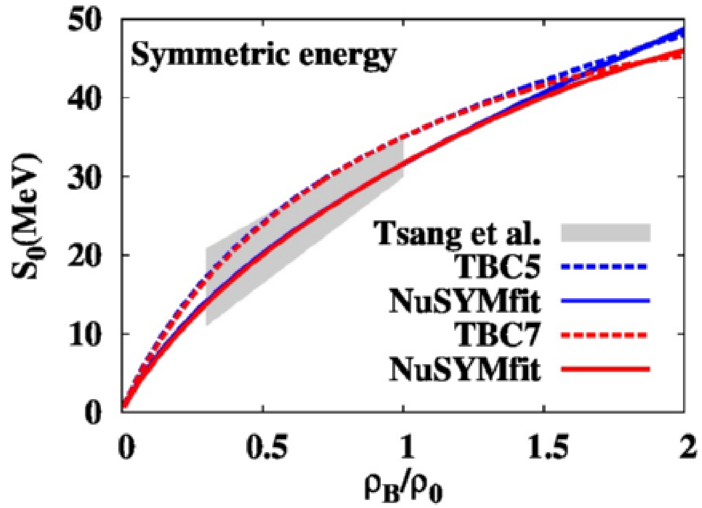
$$\left. + \frac{d\varphi_\sigma}{d\rho_{Bj}}\sum_i \frac{1}{f_\pi}\left\{-g_{\sigma\omega i}\omega + \frac{(-g_{\sigma i} f_\pi + 2g_{\sigma\sigma i}\varphi_\sigma)M_i^*}{\sqrt{k_{Fi}^2 + (M_i^*)^2}}\right\}\right]$$

- L,K can be constraints to n=3 coupling parameters
- Coupling strengths: Decidable based on also B/E and charge rms radii

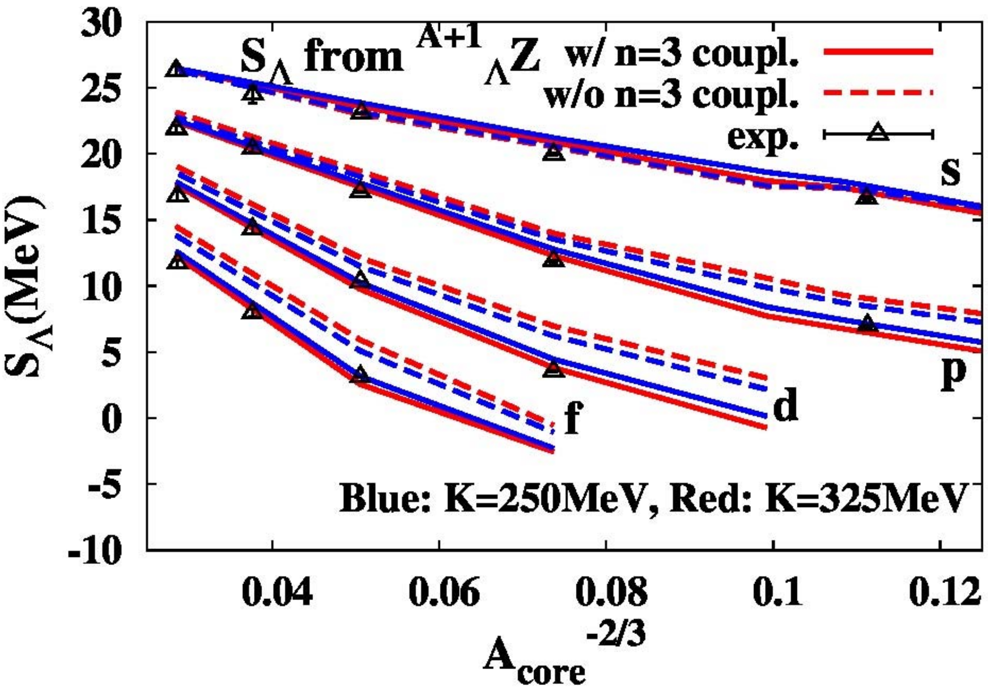
# Parameter setting



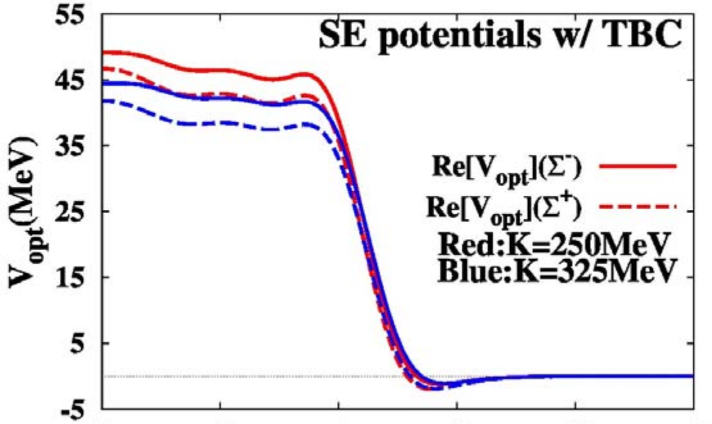



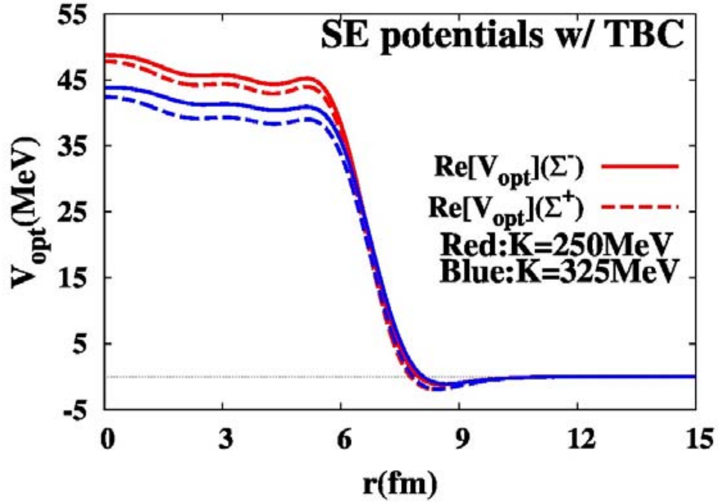
# Results: $S_\Lambda$ from single Λ hypernuclei

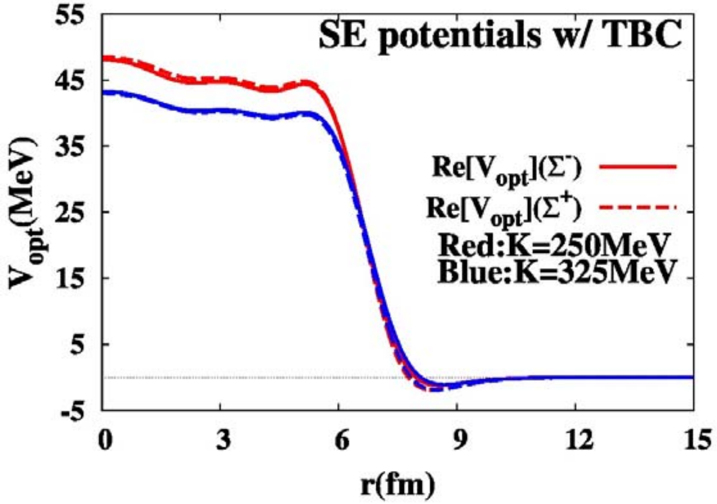



- Role of incompressibility to $S_\Lambda$⇒Almost free if we decide n=3 couplings where Λ participate
  ⇔ We can determine the strengths of n=3 couplings of Λ enough to each parameter set characterized by the incompressibility.

# Results: $\Sigma^-$ optical potential

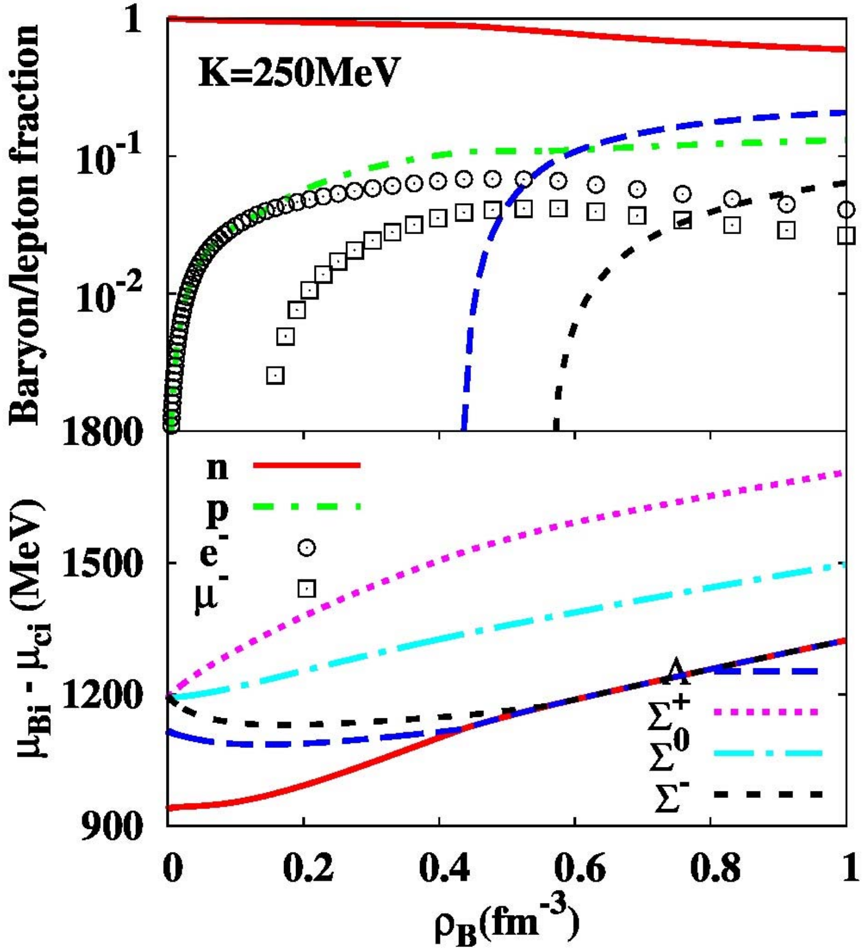


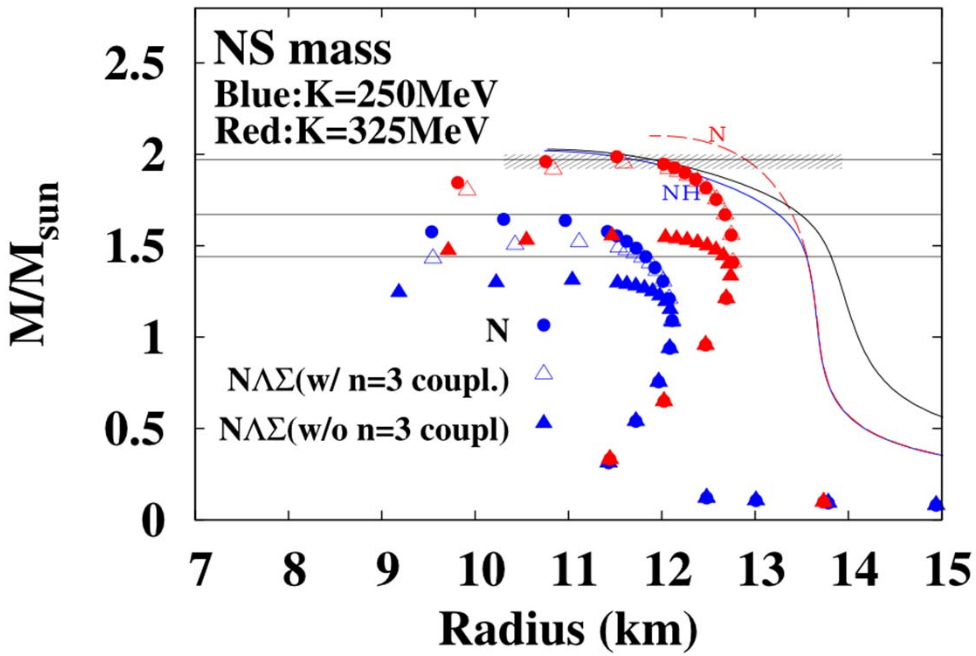




Smaller hypernuclear symmetry energy: 5～0MeV suggested from factorized n=3 coupling of $\Sigma^-$

# Baryon Fraction plot with $\mu$




- Emergence of hyperons is pushed to higher $\rho_B$ region.
- Calculated NS mass can excess $2M_\odot$ although hyperons are taken into account.(K=325MeV)

# Summary

- $\Sigma^-$ may allow to emerge in NS matter EOS if we respect the experimental results of $\Sigma-$ atomic shifts.
- Emergence of $\Xi^-$ may suppressed if we apply SU(3)v symmetry to coupling constants.
- n=3 couplings in RMF model:
  well characterized by incompressibility and constrained by reproducing experimental/
  values of nuclear/hypernuclear systems.
- Calculated NS mass excess $2M_{\odot}$(K=325MeV).
- Even if we introduced n=3 coupling to $\Sigma-$, $\Sigma-$ may appear in NS EOS as substitute of negative particles.

# Thank you
# for your listening.

THAT'S ALL.

# Introduction