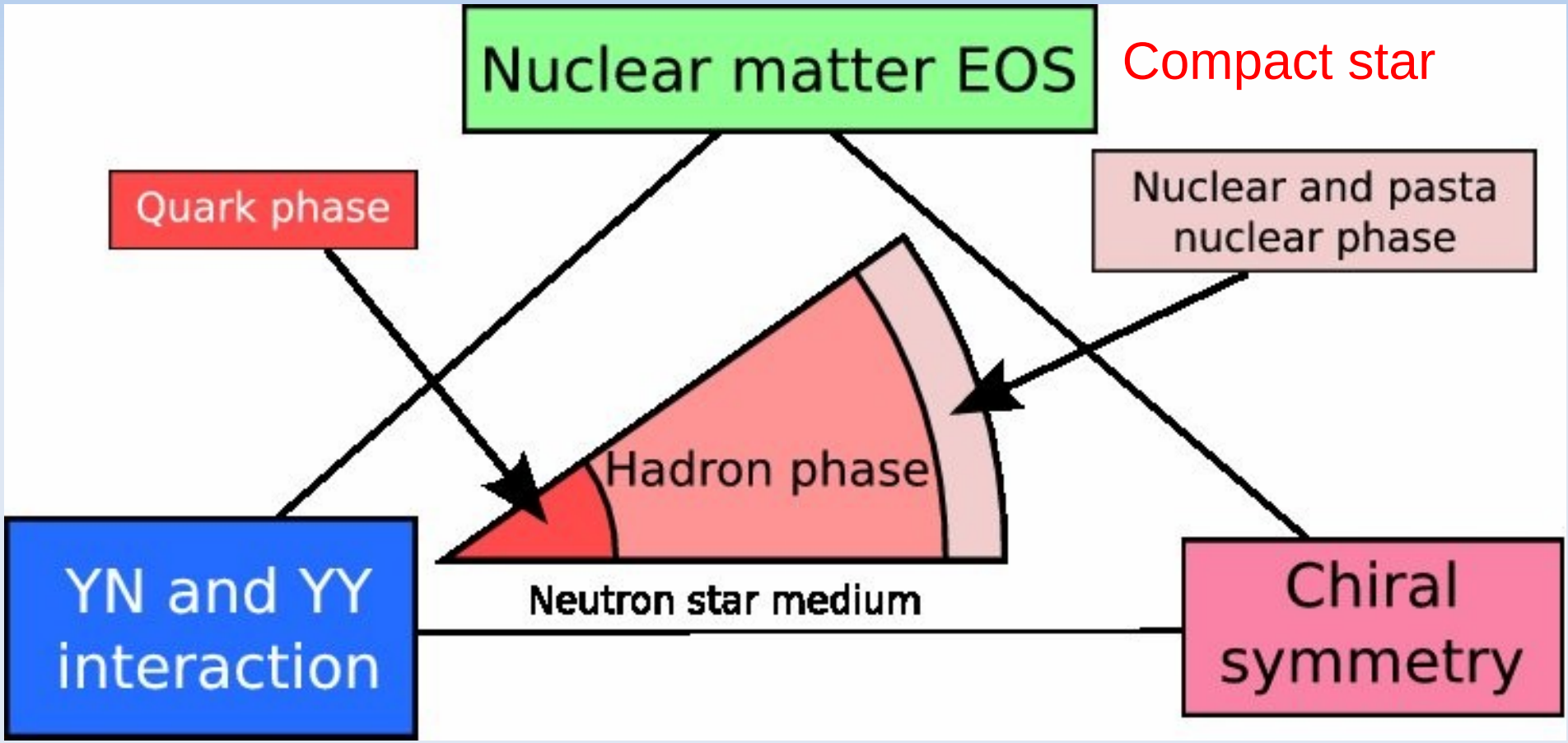
Vector meson mass modification and its effect to dense matter in RMF model

K. Tsubakihara, H. Matsumiya,

H. Maekawa and A. Ohnishi

Introduction

- Interest: dense matter EOS including hyperon



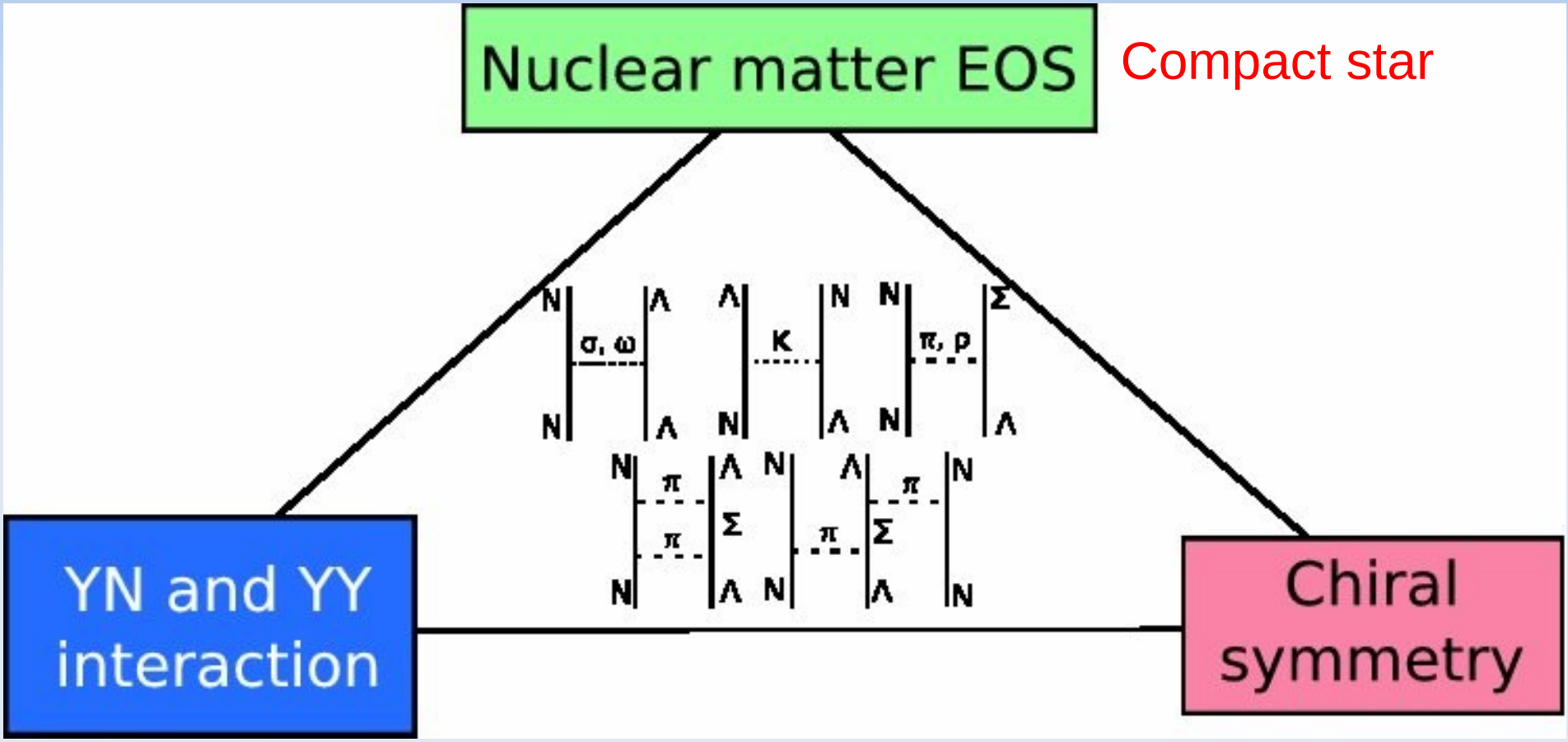
Flavor symmetry, Hypernuclei

Partitional restoration at high ρ_B

[1] Lattimer and Swesty, NPA 535 (1991) 331. [2] Shen et al., PTP 100 1013.
[3] Yamamoto, Nishizaki and Takatsuka, NPA 691 (2001) 432. [4] Ogawa et al., PTP 111 (2004) 75.

Introduction

- Interest: dense matter EOS including hyperon



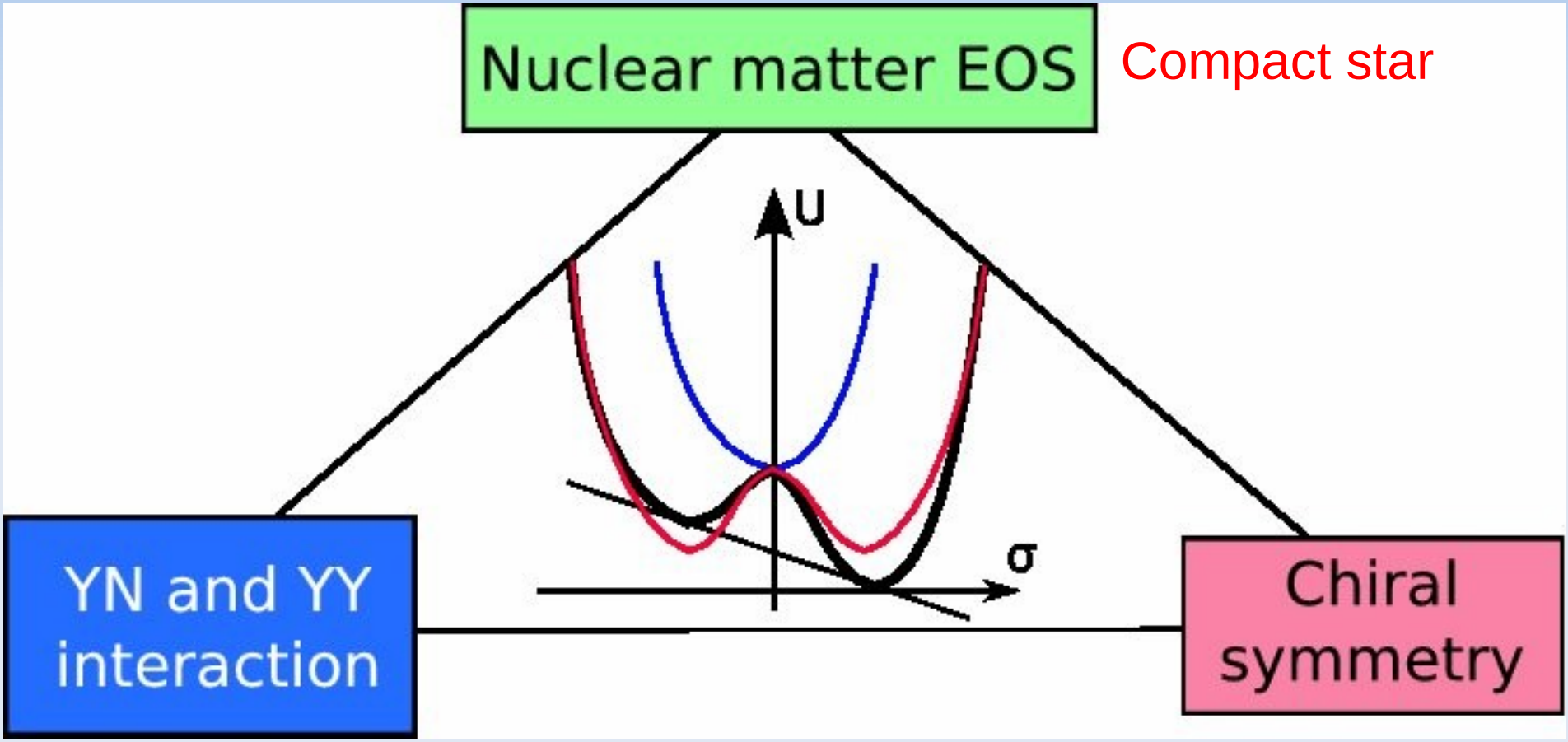
Flavor symmetry, Hypernuclei

Partitional restoration at high ρ_B

[1] Lattimer and Swesty, NPA 535 (1991) 331. [2] Shen et al., PTP 100 1013.
[3] Yamamoto, Nishizaki and Takatsuka, NPA 691 (2001) 432. [4] Ogawa et al., PTP 111 (2004) 75.

Introduction

- Interest: dense matter EOS including hyperon



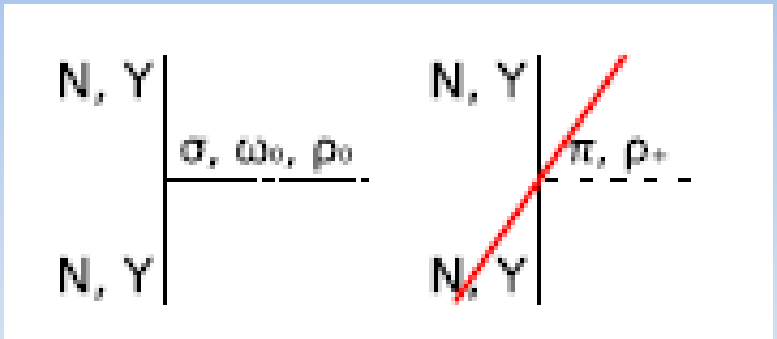
Flavor symmetry, Hypernuclei

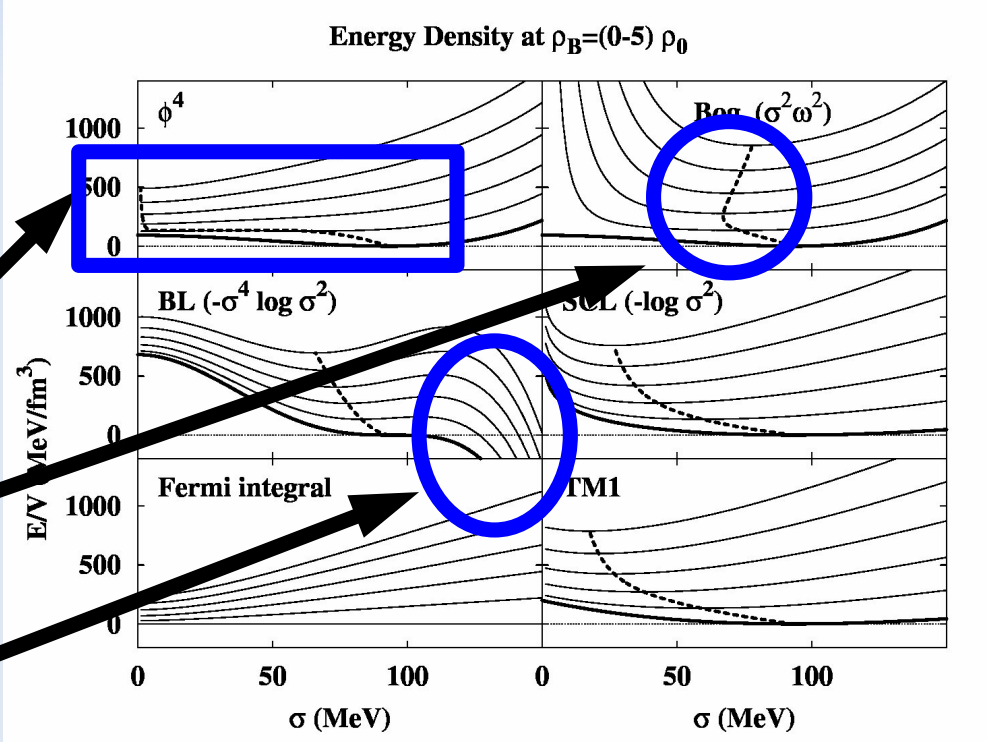
Partitional restoration at high ρ_B

[1] Lattimer and Swesty, NPA 535 (1991) 331. [2] Shen et al., PTP 100 1013.
[3] Yamamoto, Nishizaki and Takatsuka, NPA 691 (2001) 432. [4] Ogawa et al., PTP 111 (2004) 75.

Chiral symmetric RMF

- Strong point of RMF
  - Good description of Nuclei and Nuclear Matter
  - Symmetries are naturally included
- Problems in chiral RMF [5]
  1. Sudden chiral restoration below ρ_0 [6]
  2. Too stiff EOS [4, 7]
  3. Instability at large chiral condensate





[5] KT and Ohnishi, Prog. Theor. Phys. 117 (2007) 903. [6] Matsui and Serot, AP 144 (1982) 107.
[4] Ogawa et al, PTP 111 (2004) 75. [7] Boguta, PLB 120 (1983) 34.

Effective Potential in SCL-LQCD (Zero T)

- **QCD Lattice Action (Zero T treatment)**

Kawamoto, Smit, 1981

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

Strong Coupling Limit

$$\rightarrow -\frac{1}{2}(\bar{\chi}\chi) V_M (\bar{\chi}\chi) + m_0 \bar{\chi}\chi$$

One-link integral (1/d expansion*)

$$\rightarrow \frac{1}{2}\sigma V_M^{-1}\sigma + \bar{\chi}(\sigma + m_0)\chi$$

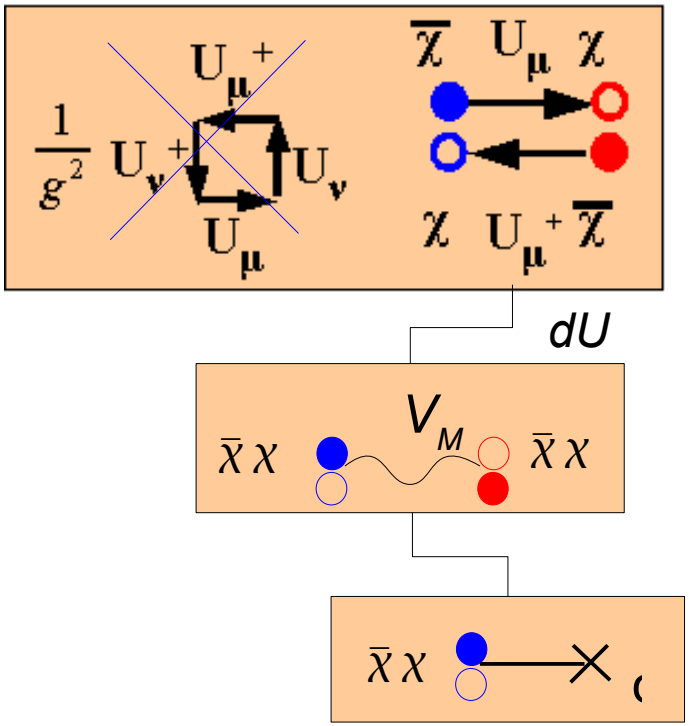
Bosonization

$$\rightarrow \frac{1}{2}\sigma V_M^{-1}\sigma - N_c \sum_x \log(\sigma(x) + m_0)$$

Fermion Integral

$$= L^d N_\tau \left[\frac{N_c}{d+1}\bar{\sigma}^2 - N_c \log(\bar{\sigma} + m_0) \right]$$

Effective Potential



* d = Spatial dim.

Fermion Matrix = Just a number
→ Simple Logarithmic Effective Potential for σ

$$V_\sigma = \frac{1}{2} a_\sigma \sigma^2 - b_\sigma \log \sigma$$

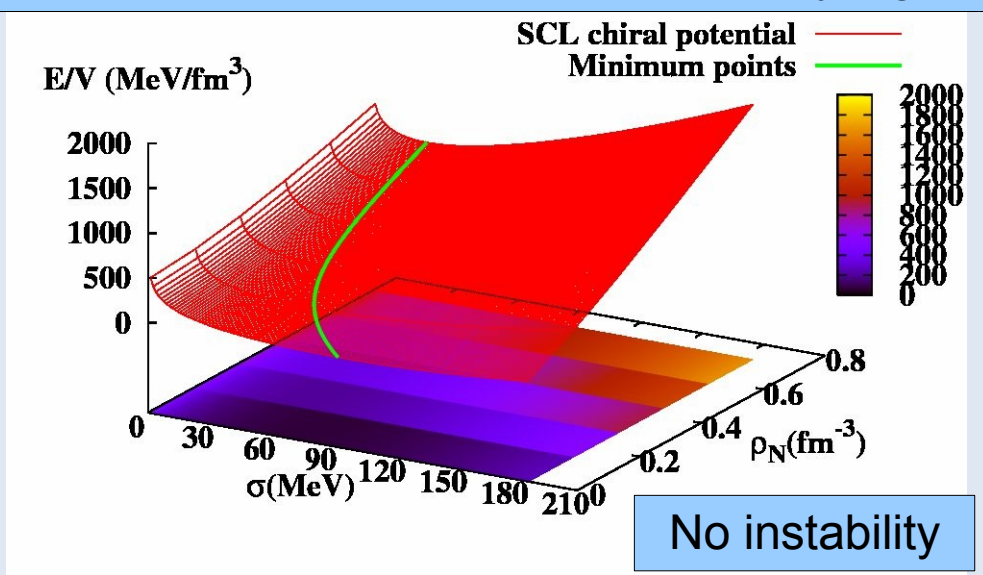
Chiral potential from SCL

- Chiral potential: derived from Strong Coupling Limit of lattice QCD [8,9]

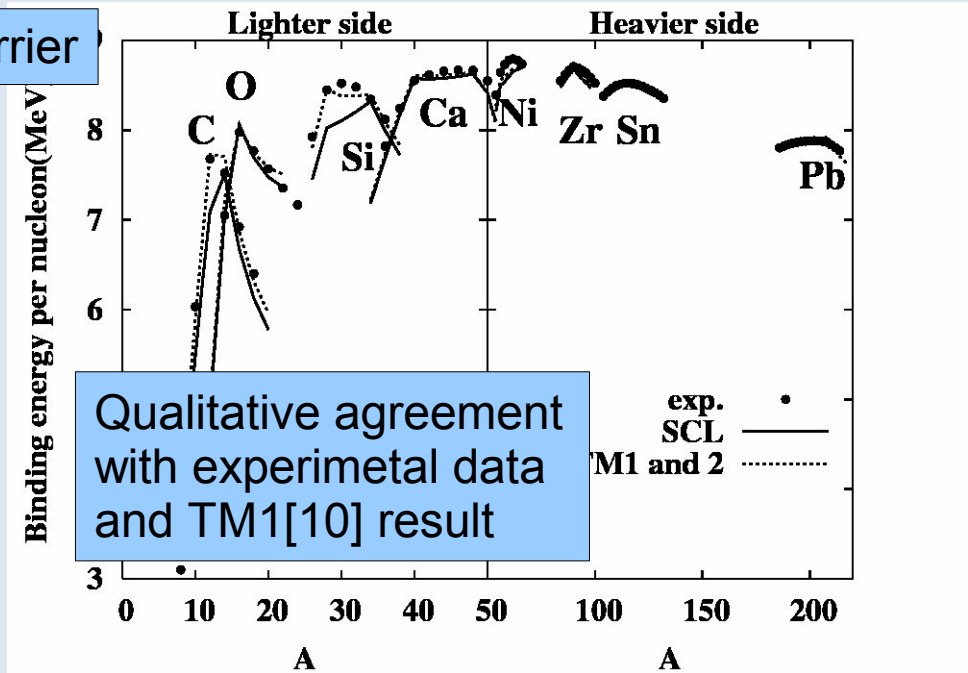
$$U_\sigma = -a\log(\det M_{\mathrm{SU(2)}} M^\dagger_{\mathrm{SU(2)}}) + b\,\mathrm{tr}(M_{\mathrm{SU(2)}} M^\dagger_{\mathrm{SU(2)}}) + c_\sigma \sigma$$

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

Sudden chiral resoration: surppressed by log barrier



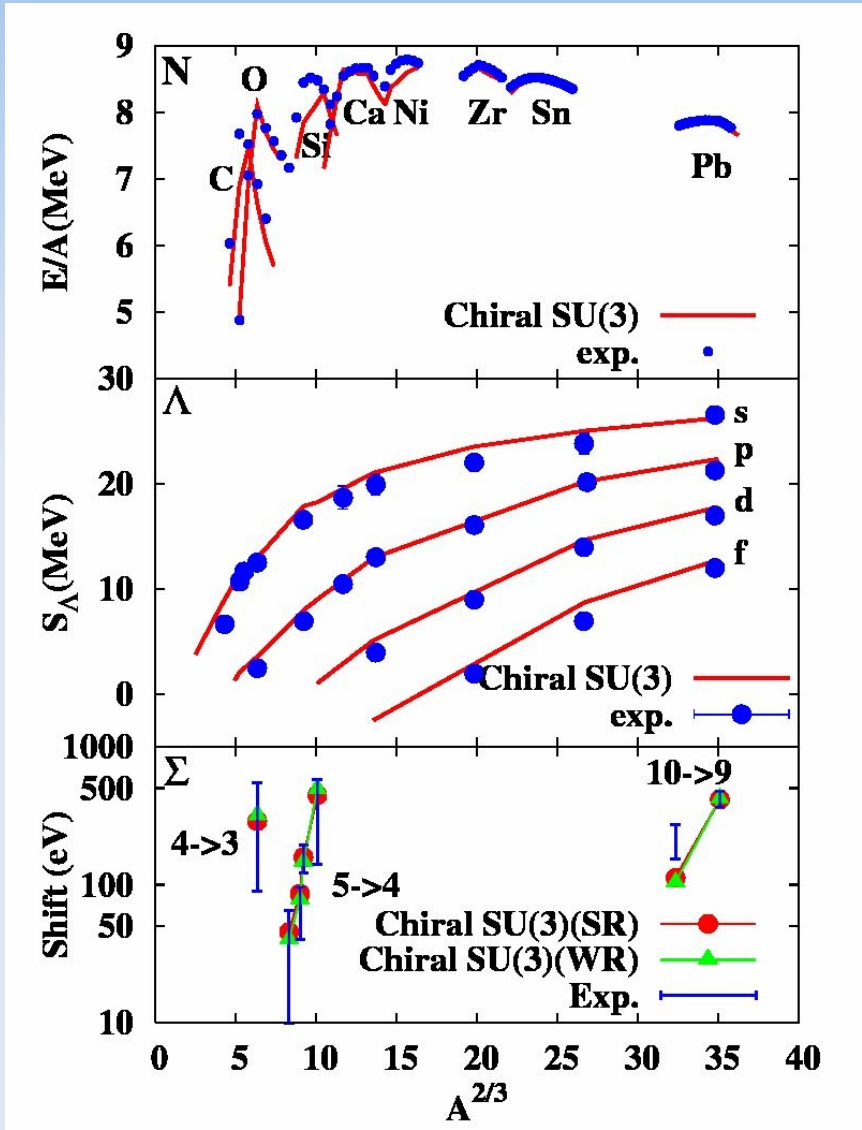
No instability



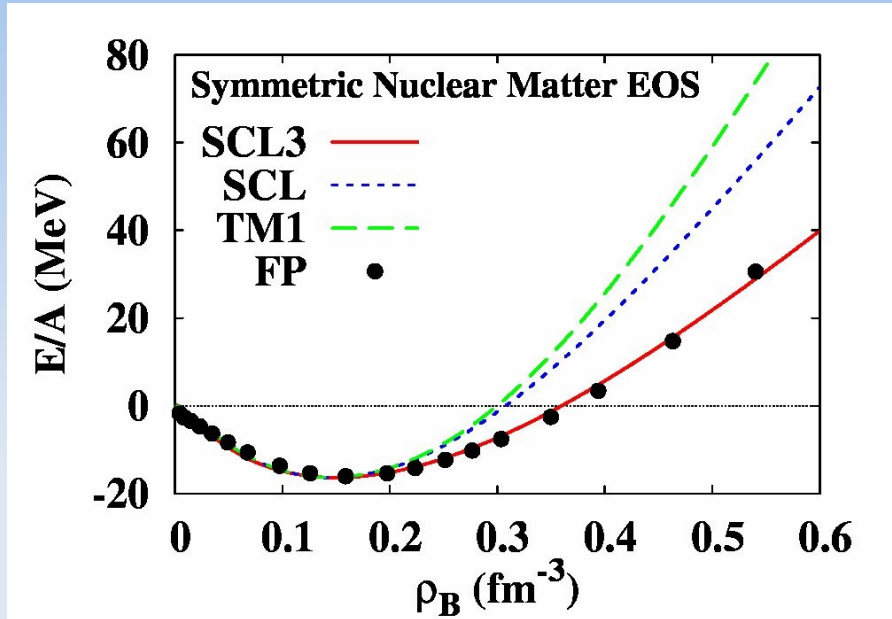
Qualitative agreement with experimetal data and TM1[10] result

[8] Kawamoto and Smit, NPB 192 (1981) 100. [9] KT and Ohnishi, PTP 117 (2007) 903.
[10] Sugahara and Toki, NPA 579 (1994) 557.

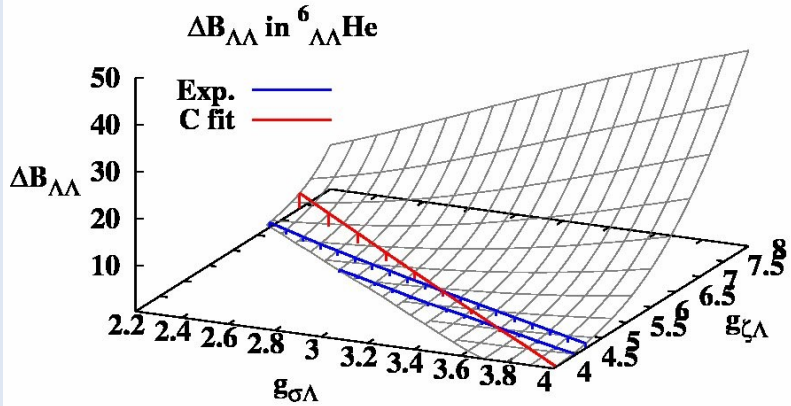
Λ and Σ hypernuclear results



B/A, S_Λ and Atomic Shift of Σ:
Reproduced in approapriate paramter set

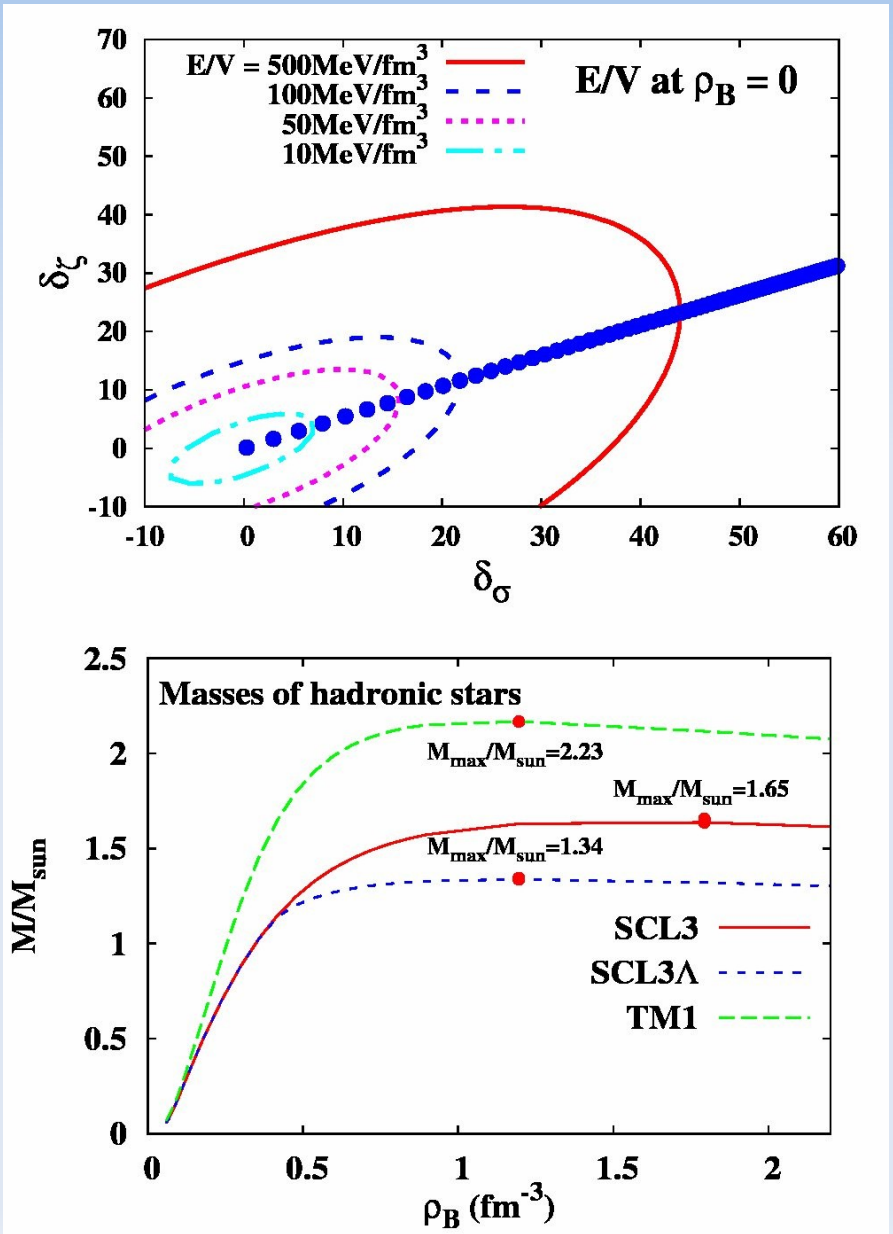


$K \sim 0.8K_{SU(2)} \sim 220MeV$



Coupling constatnt set of Λ($g_{\sigma\Lambda}$ and $g_{\zeta\Lambda}$):
fixed by double Λ hypernuclear data

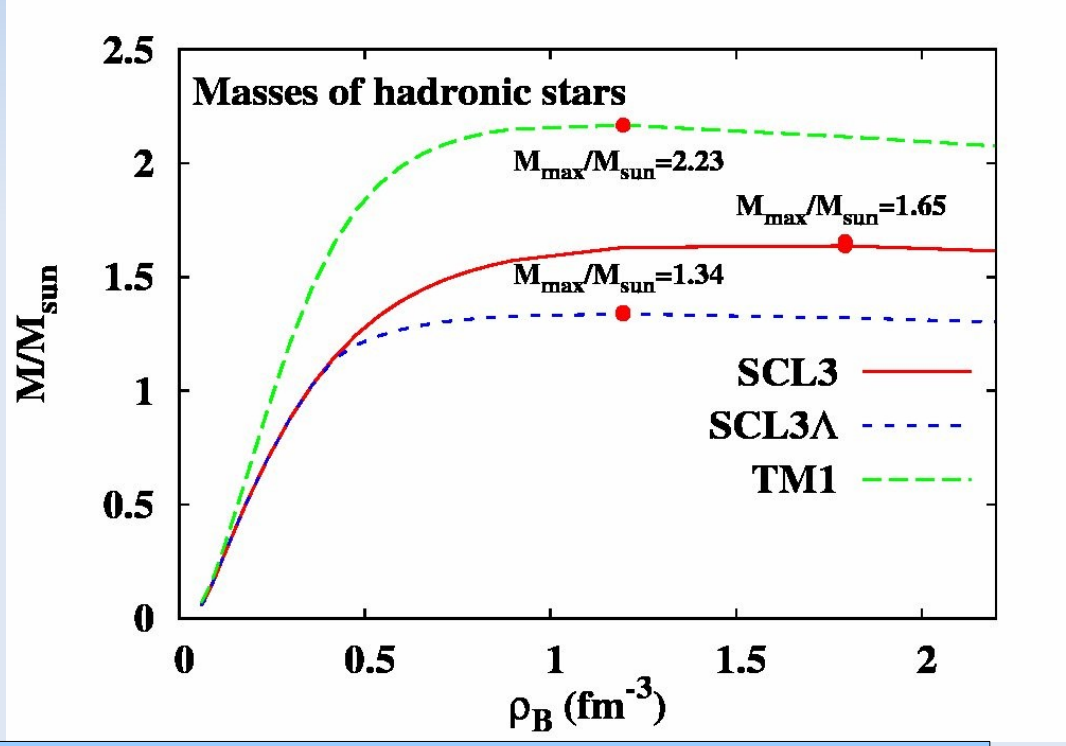
Results of NS matter (1)



- Extra degree of freedom: softening Sym. Matter EOS.
- Softer than TM model [8] or SU(2) version especially in high density.
- E/B in RMF is almost linear at high densities cf. ρ_B^2 in FP

Results of NS matter (2)

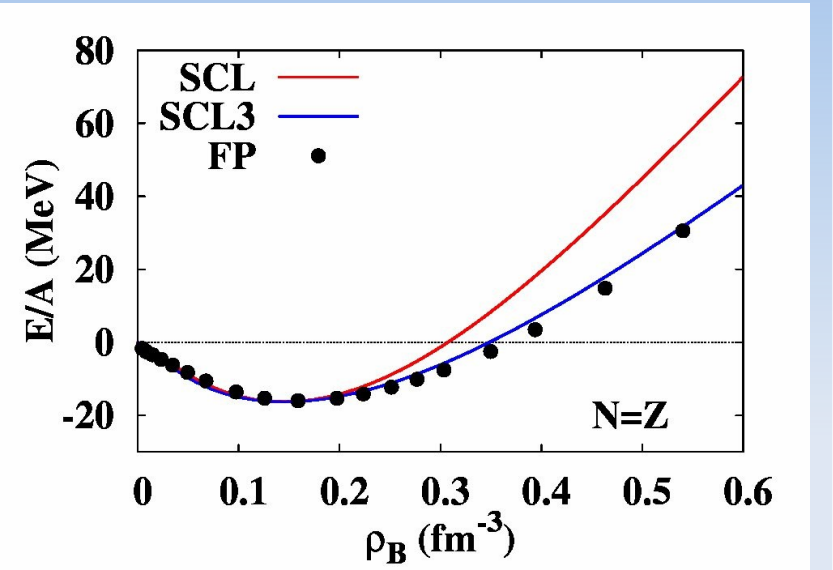
- Max Mass of NS in chiral RMF =1.3$M_\odot$ with parameter sets determined from hypernuclear data
  → Underestimate existing NS mass !

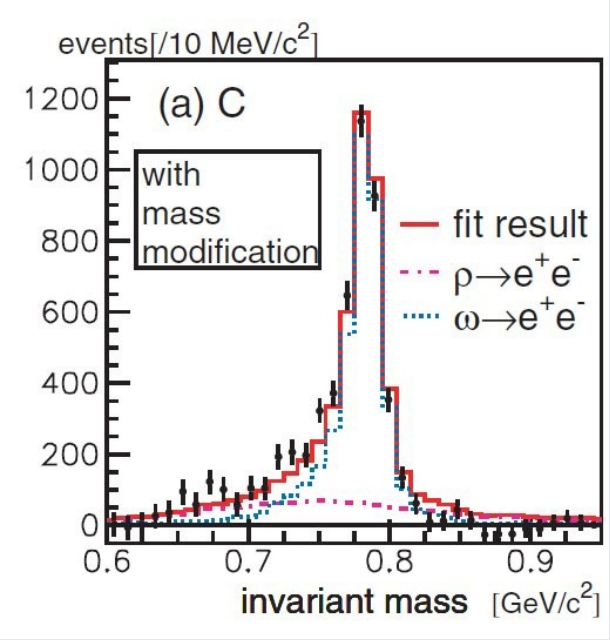


We need for extra repulsion at high ρ_B as pointed by Takatsuka

Mass modification

- Sym. nuclear matter EOS: good agreement with FP EOS around ρ_0
  - This EOS is too soft at high ρ_B to support NS mass.
  - Origin of repulsion: partitional σω coupling introduced to reproduce ω mass reduction[11]?



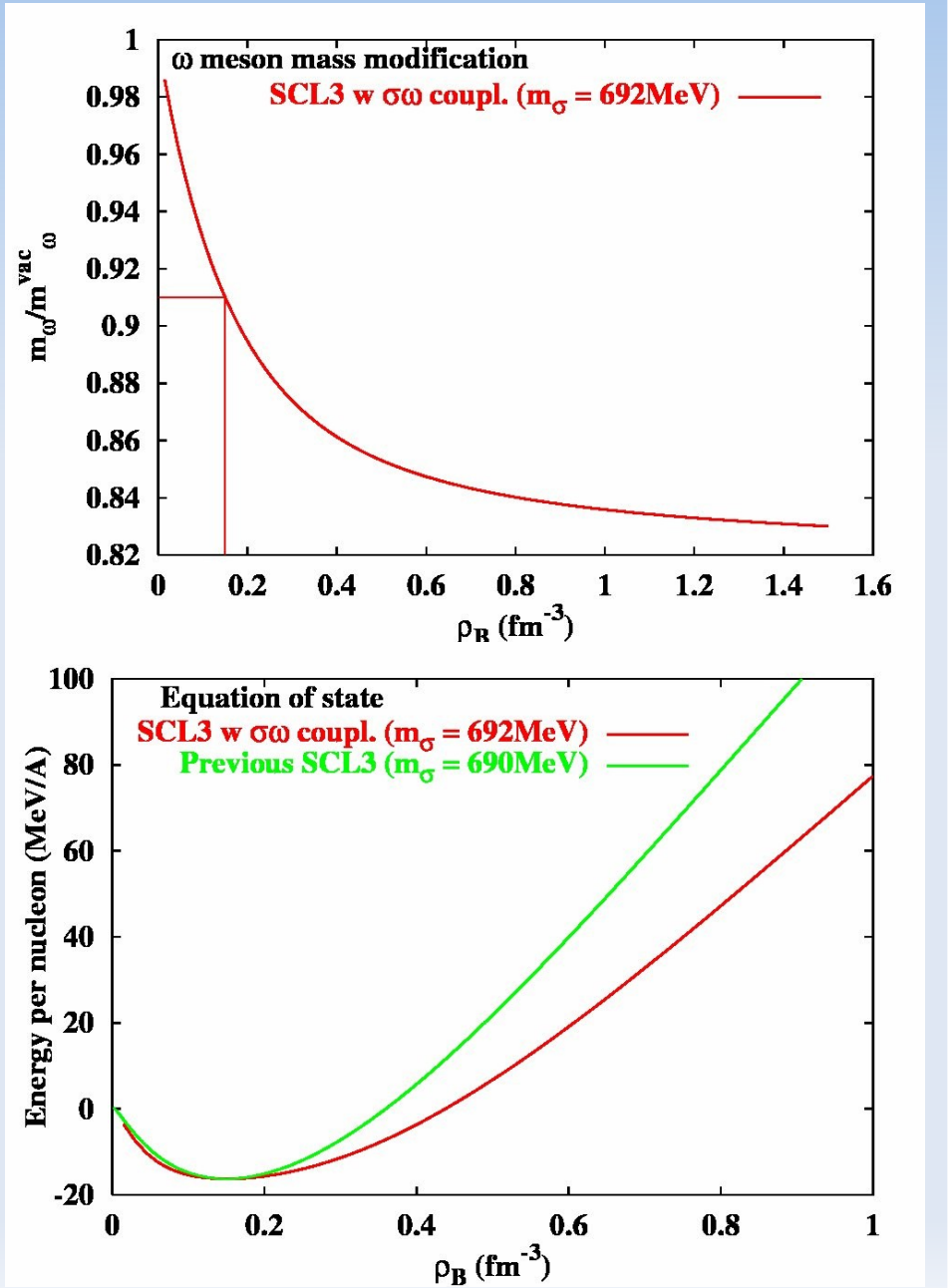


$$\frac{1}{2} m_\omega^2(\sigma)\omega^2 = \frac{1}{2}\left[(m_\omega^0)^2 + g_{\sigma\omega}(f_\pi - \sigma)^2\right]\omega^2$$

[11] Naruki et al., PRL 96 (2006) 092301.

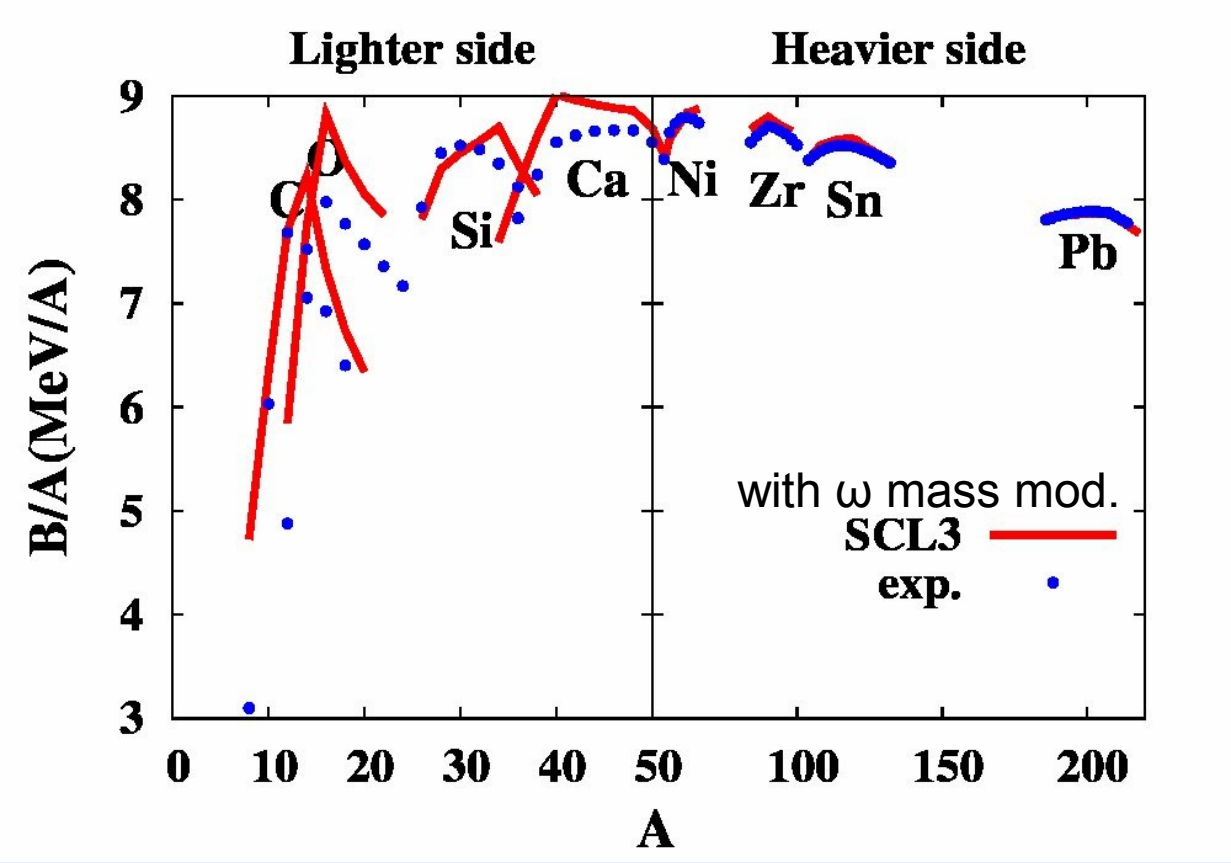
Effect of mass modification to dense matter in RMF model

- Suggested mass reduction of ω: 9%
- Sym. nuclear matter EOS becomes softer after fitting BE of nuclei !
- Why ?
  Smaller ω mass at ρ_0
  $\rightarrow$ smaller $g_{\omega N}$
  $\rightarrow$ softer EOS at high ρ_B
- Do we miss something ?



BE with modified meson mass

- With medium modification of vector meson mass, we cannot describe binding energies of light nuclei (<Ca).
- Similar results are obtained by Furnstahl et al. and Heide et al. with glueball field representing scale anomaly.



Summary

- We have invesitgated the properties of normal nuclei and hypernulei in chiral SU(3) RMF.
  - Energy density at $\rho_B=0 \rightarrow$ SCL-LQCD
  - Vector meson mass: Constant / Modified at finite ρ_B
- Properties of sym. nuclear matter, normal nuclei, Λ and Σ hypernuclear state are well reproduced with constant ω mass, but max. NS mass is calculated to be too small ($1.3M_\odot$).
- σω coupling: medium mod. of vector meson mass may not lead to the universal extra repulsion.

That' all.

Thank you for attention!!
and KT is so sorry not to be here!!

A short-cut from QCD to Nuclei

- **Density Functional Theory**

  Hohenberg, Kohn, Phys.Rev.136('64),B864
  Kohn, Sham, Phys.Rev.140('65),A1133

  There should have a unique Density Functional

$$E = E[\sigma = \langle \bar{q} q \rangle, \rho_B, \ldots]$$

  also in Quark/Hadron/Nuclear systems

- **DF in condensed matter**

  Exact Calc. of
  Uniform Electron Gas
  + Derivative terms
  → Exchange-Correlation Pot.

- **Density Functional from QCD**

  "Exact" Calc. of Unif. Matter
  + Finite range effects
  → Nuclear Density Functional