Rho meson effect in hadron-quark phase transition

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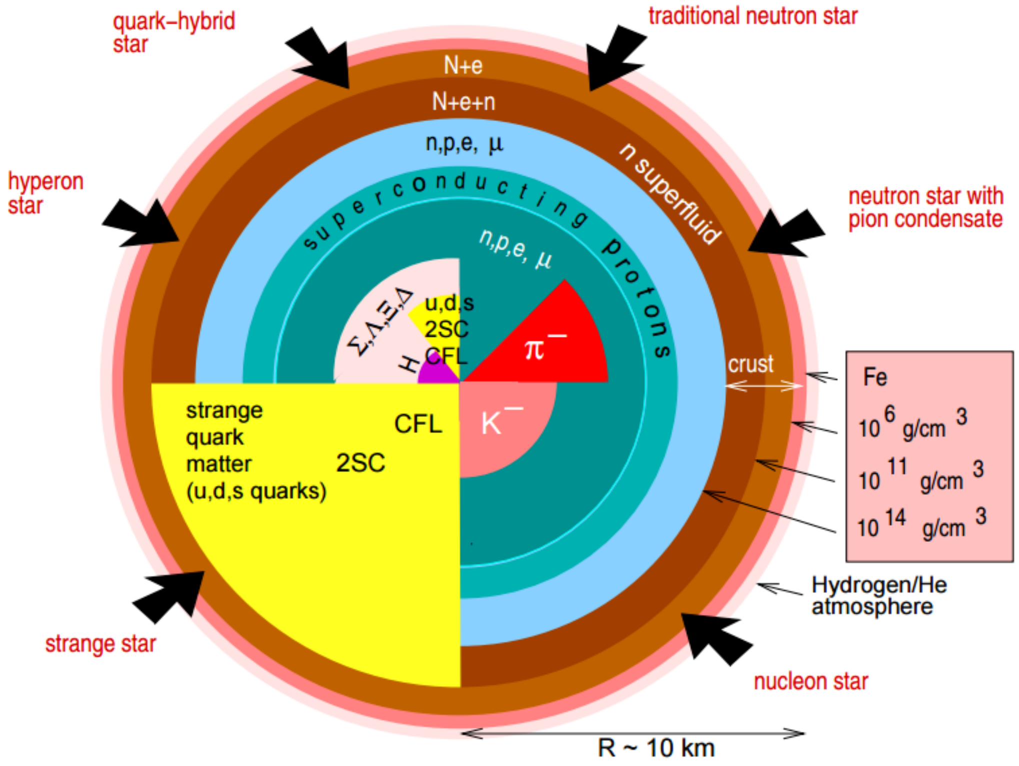
Outline

- *Introduction*
- *Theoretical framework*
- *Numerical results*
- *Summary*

Introduction



F. Weber, Prog. Part. Nucl. Phys. 54 (2005) 193-288.

Hadronic matter

↓ **Phase transition**

Quark matter

PSR J1614-2230 [1,2]: $1.928 \pm 0.017 M_\odot$

PSR J3048+0432 [3]: $2.01 \pm 0.04 M_\odot$

[1] P. B. Demorest, T. Pennucci, S. M. Ransom, et al., Nature 467, 1081 (2010).
[2] E. Fonseca, T. T. Pennucci, J. A. Ellis, I. H. Stairs, D. J. Nice, S. M. Ransom, P. B. Demorest, Z. Arzoumanian, K. Crowter, T. Dolch et al., Astrophys. J. 832, 167 (2016).
[3] J. Antoniadis1, P. C. C. Freire1, N. Wex1, et al., Science 340, 6131 (2013).

Introduction

What do we want to know?

Symmetry energy slope L dependence?

Phase transition densities	EoS	Neutron star properties

Isovector-vector coupling G_R dependence?

binding energy per nucleon	Symmetric	Neutron star properties

Theoretical framework

Hadronic matter: (RMF)

$$\mathcal{L}_{\rm RMF} = \sum_{i=p,n} \bar{\psi}_i \left\{ i\gamma_\mu \partial^\mu - (M + g_\sigma \sigma) - \gamma_\mu \left[g_\omega \omega^\mu + \frac{g_\rho}{2} \tau_a \rho^{a\mu} \right] \right\} \psi_i$$
$$+\frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma - \frac{1}{2} m_\sigma^2 \sigma^2 - \frac{1}{3} g_2 \sigma^3 - \frac{1}{4} g_3 \sigma^4$$
$$-\frac{1}{4} W_{\mu\nu} W^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu + \frac{1}{4} c_3 (\omega_\mu \omega^\mu)^2$$
$$-\frac{1}{4} R^a_{\mu\nu} R^{a\mu\nu} + \frac{1}{2} m_\rho^2 \rho^a_\mu \rho^{a\mu} + \Lambda_{\rm v} (g_\omega^2 \omega_\mu \omega^\mu)(g_\rho^2 \rho^a_\mu \rho^{a\mu})$$
$$+ \sum_{l=e,\mu} \bar{\psi}_l (i\gamma_\mu \partial^\mu - m_l) \psi_l,$$

Quark matter:

(NJL)

$$\mathcal{L}_{\rm NJL} = \bar{q}\left(i\gamma_\mu \partial^\mu - m^0\right) q + G_S \sum_{a=0}^{8} \left[(\bar{q}\lambda_a q)^2 + (\bar{q} i\gamma_5 \lambda_a q)^2 \right]$$
$$- K \left\{ \det\left[\bar{q}(1+\gamma_5) q\right] + \det\left[\bar{q}(1-\gamma_5) q\right] \right\}$$
$$+ \mathcal{L}_{\rm vector}$$

$$\mathcal{L}_V = -G_0 (\bar{q}\gamma^\mu q)^2 - G_3 \left[(\bar{q}\gamma^\mu \lambda_3 q)^2 + (\bar{q} i\gamma^\mu \gamma_5 \lambda_3 q)^2 \right]$$
$$-G_8 \left[(\bar{q}\gamma^\mu \lambda_8 q)^2 + (\bar{q} i\gamma^\mu \gamma_5 \lambda_8 q)^2 \right]$$

$$\mathcal{L}_{\rm vector} = \begin{cases} 1. \quad -g_V (\bar{q}\gamma^\mu q)^2 \\ 2. \quad -G_V \sum_{a=0}^{8} \left[(\bar{q}\gamma^\mu \lambda_a q)^2 + (\bar{q}\gamma^\mu \gamma_5 \lambda_a q)^2 \right] \\ \quad \overset{\rm MF}{=} -\frac{2}{3} G_V (\bar{q}\gamma^\mu q)^2 - G_V \sum_{a=1}^{8} \left[(\bar{q}\gamma^\mu \gamma_5 \lambda_a q)^2 \right] \\ 3. \quad -G_R \sum_{a=1}^{3} \left[(\bar{q}\gamma^\mu \lambda_a q)^2 + (\bar{q}\gamma^\mu \gamma_5 \lambda_a q)^2 \right] \end{cases}$$

Results

Parameter set

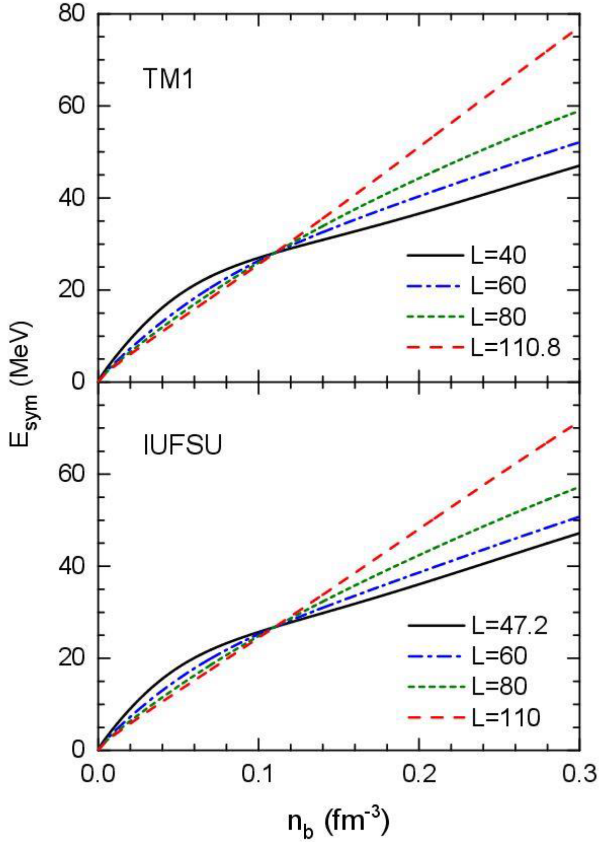
$$n_{\rm fix} = 0.11 \text{ fm}^{-3}$$

TM1 parameter set

L (MeV)	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.8
g_ρ	13.9714	12.2413	11.2610	10.6142	10.1484	9.7933	9.5114	9.2644
$\Lambda_{\rm v}$	0.0429	0.0327	0.0248	0.0182	0.0128	0.0080	0.0039	0.0000
$E_{\rm sym}(n_0)$ (MeV)	31.38	32.39	33.29	34.11	34.86	35.56	36.22	36.89

IUFSU parameter set

L (MeV)	47.2	50.0	60.0	70.0	80.0	90.0	100.0	110.0
g_ρ	13.5900	12.8202	11.1893	10.3150	9.7537	9.3559	9.0558	8.8192
$\Lambda_{\rm v}$	0.0460	0.0420	0.0305	0.0220	0.0153	0.0098	0.0051	0.0011
$E_{\rm sym}(n_0)$ (MeV)	31.30	31.68	32.89	33.94	34.88	35.74	36.53	37.27



S. S. Bao, J. N. Hu, Z. W. Zhang, and H. Shen, Phys. Rev. C 90, 045802 (2014).

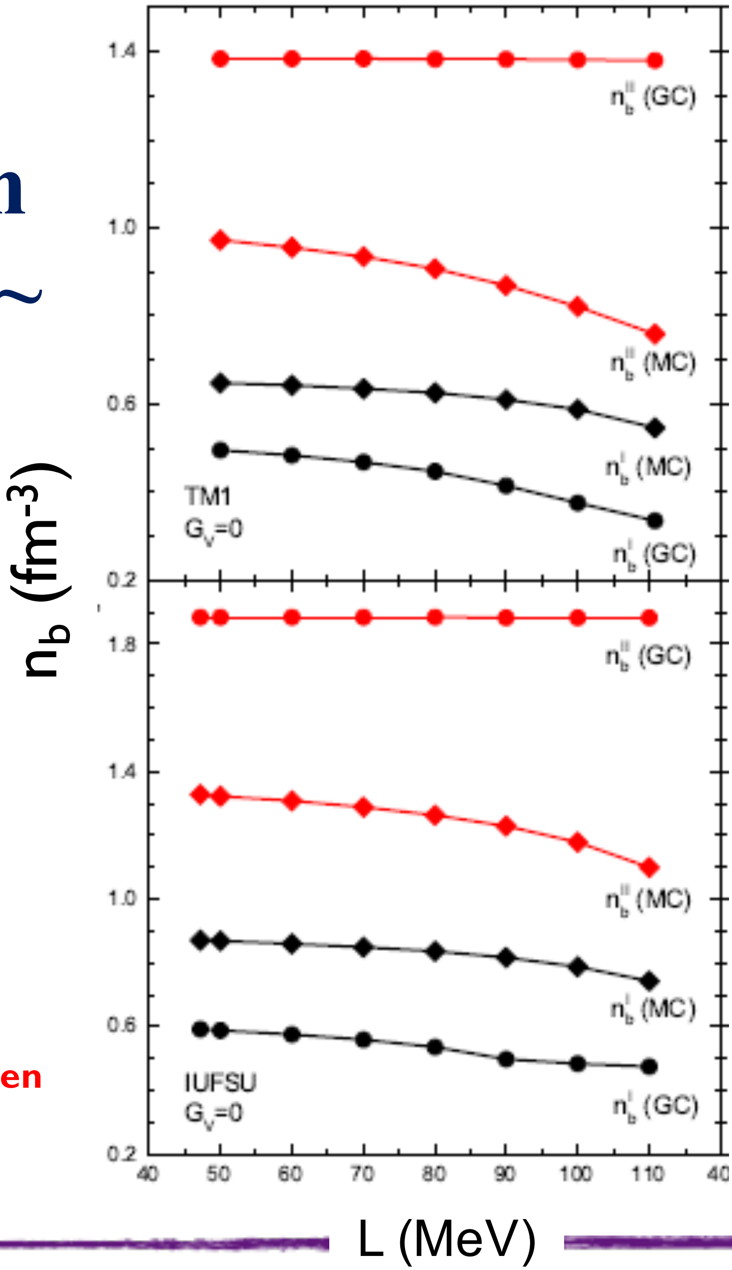
Results (L dependence)

Phase transition densities ~ slope L

$n_b^i \searrow \sim L \nearrow$

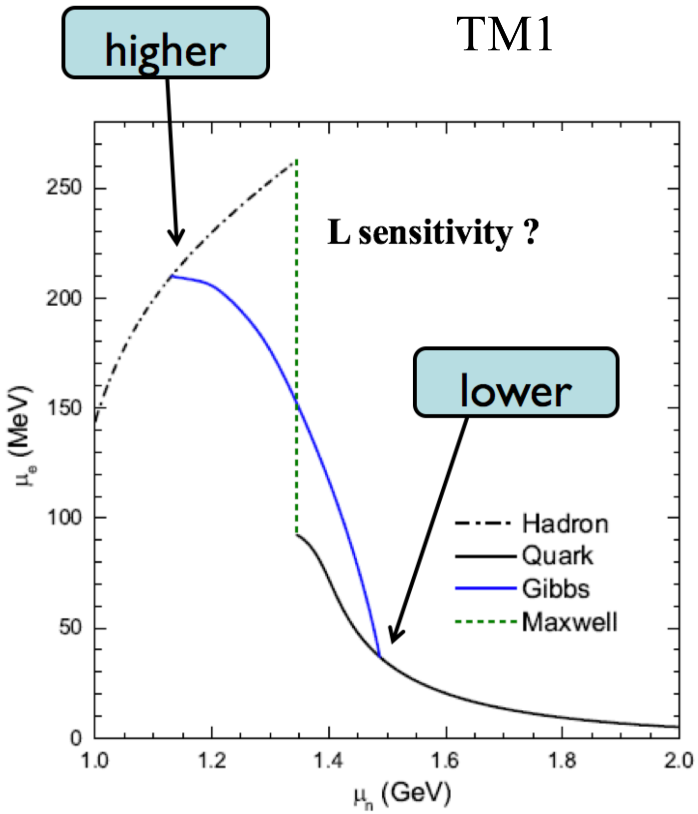
$G_0 = 0$

X. H. Wu and H. Shen (in prep.)



$$\mu_e = \mu_n - \mu_p$$

$$\mu_e = \mu_d - \mu_u$$



Results (L dependence)

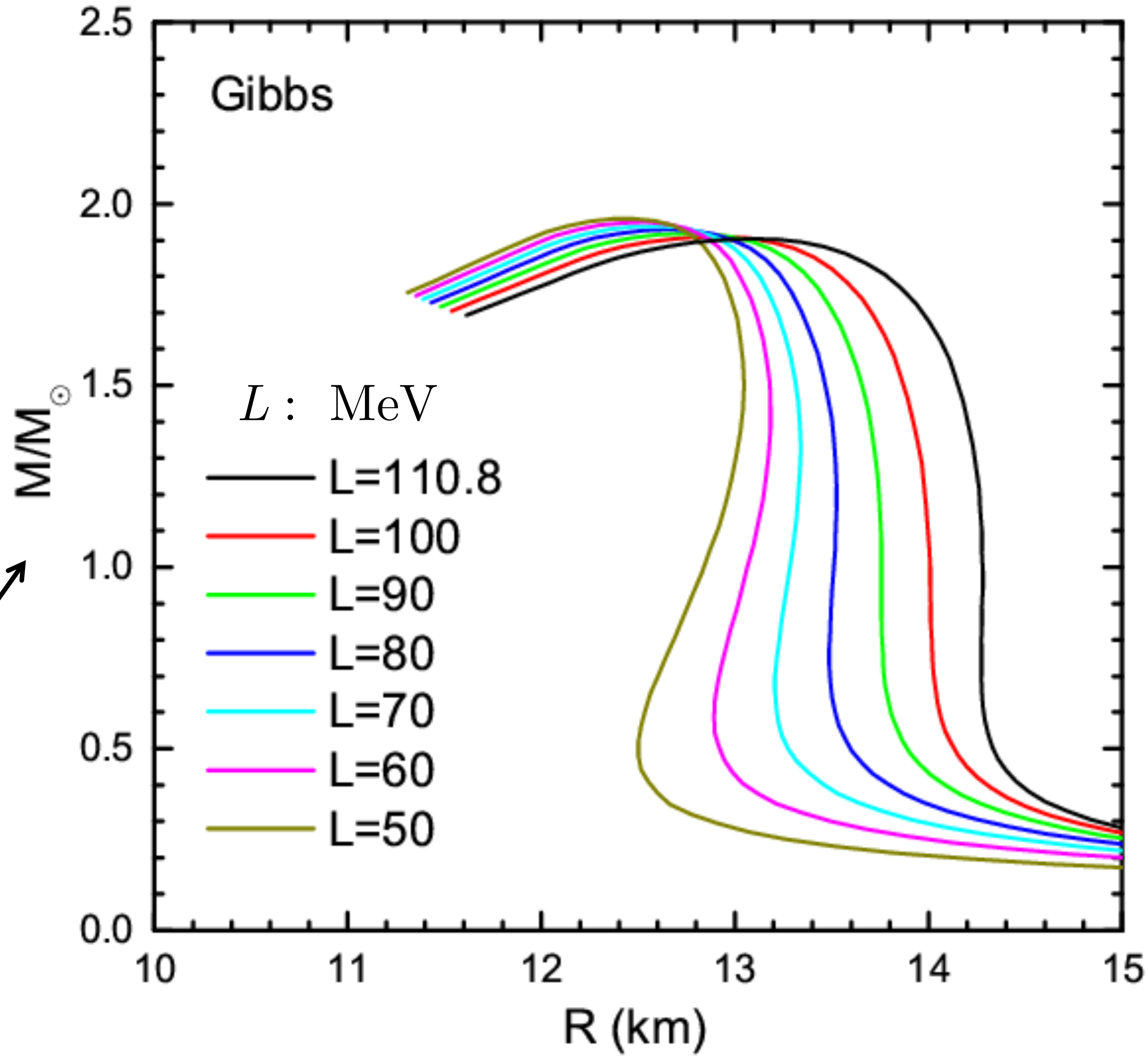
Mass-radius relations under Gibbs condition

$R \nearrow \sim L \nearrow$

TM1

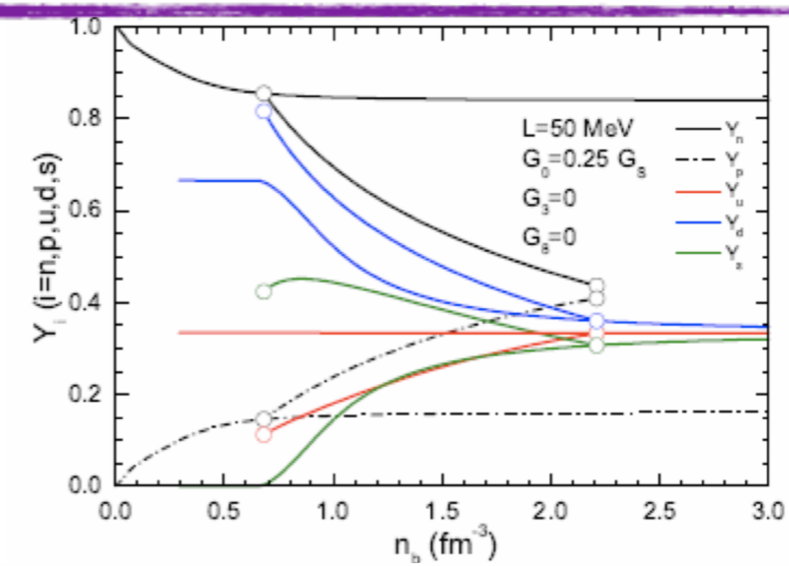
$G_0 = 0$

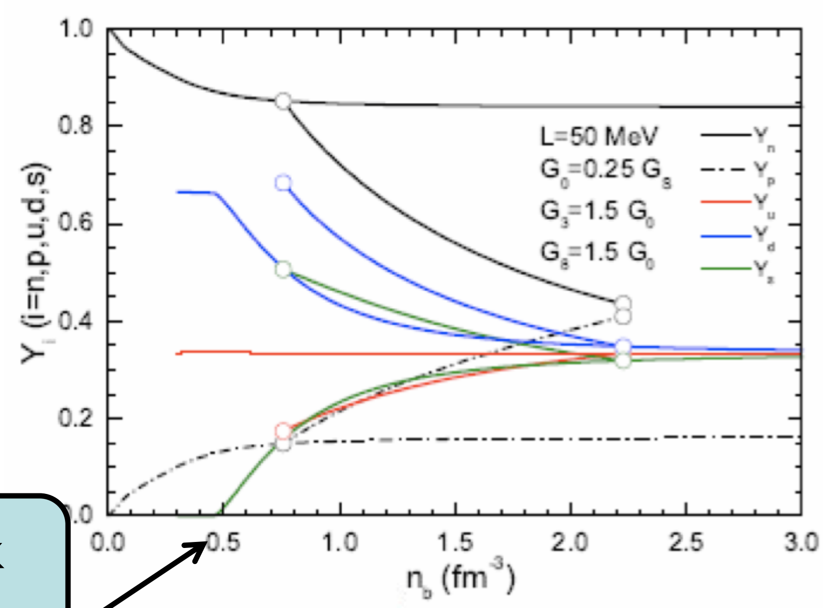
X. H. Wu and H. Shen (in prep.)

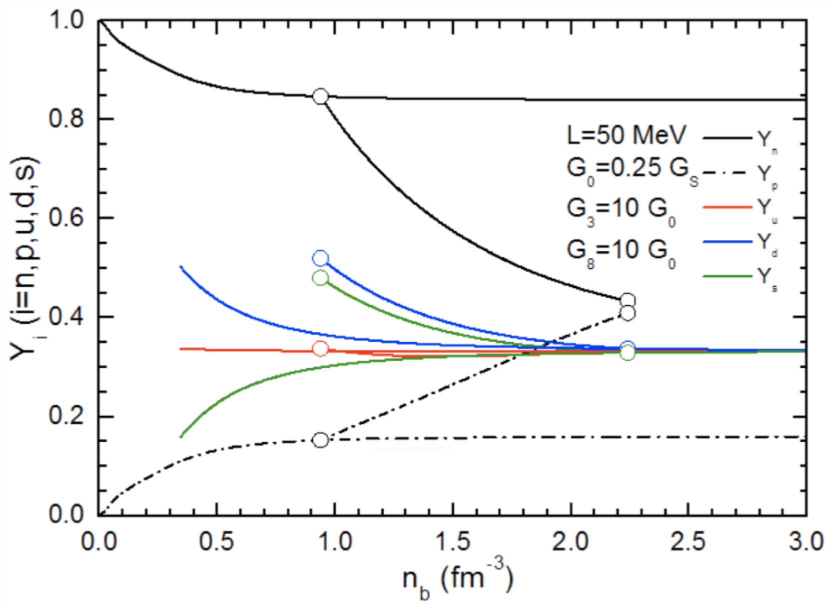


Results (sym in QM)

Particle number fraction







s quark appears

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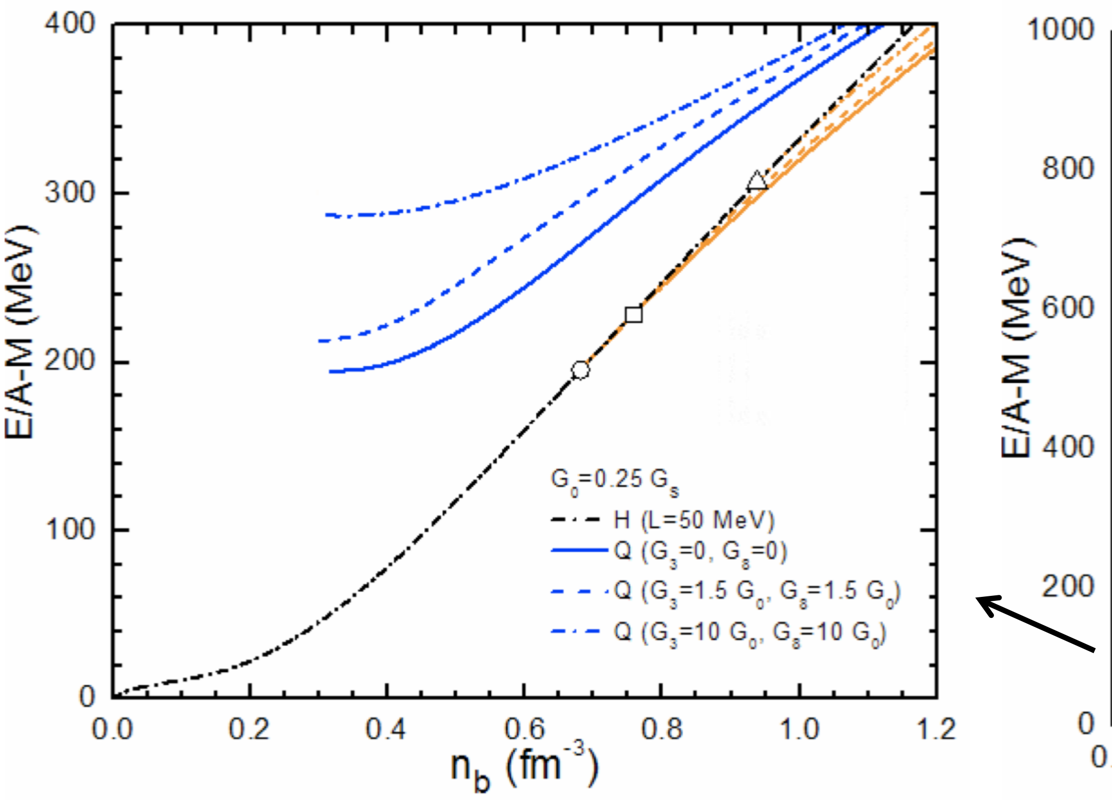
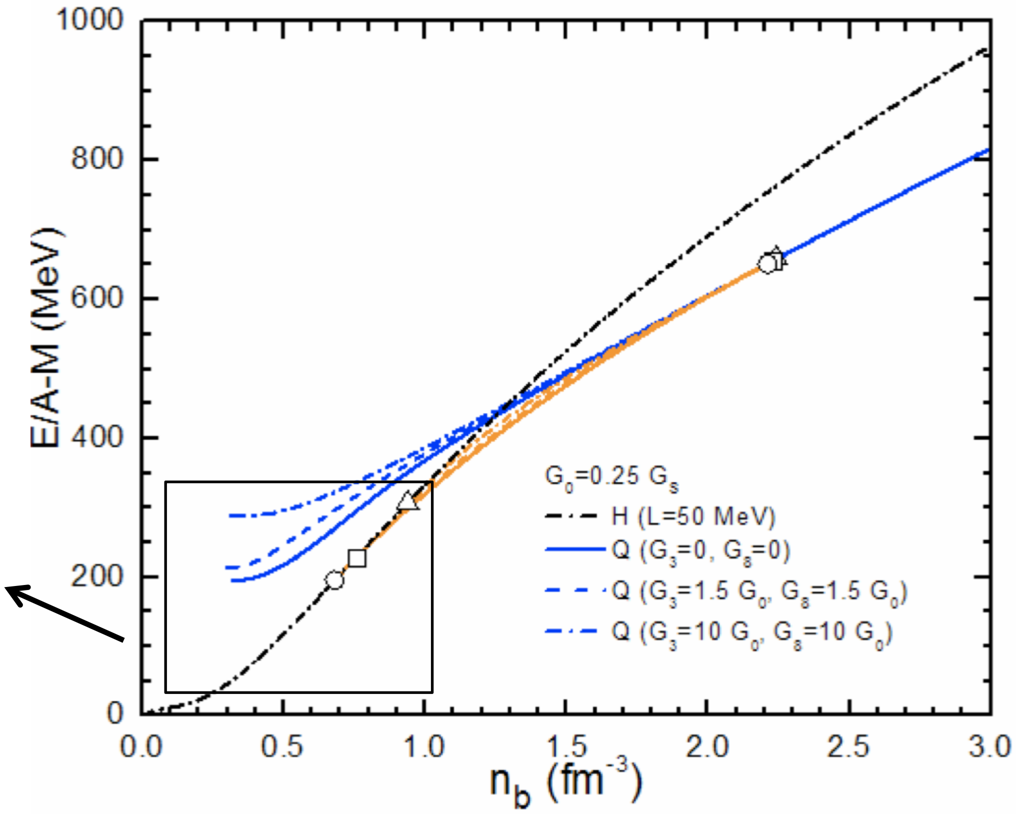
Results (sym in QM)

Energy density per baryon





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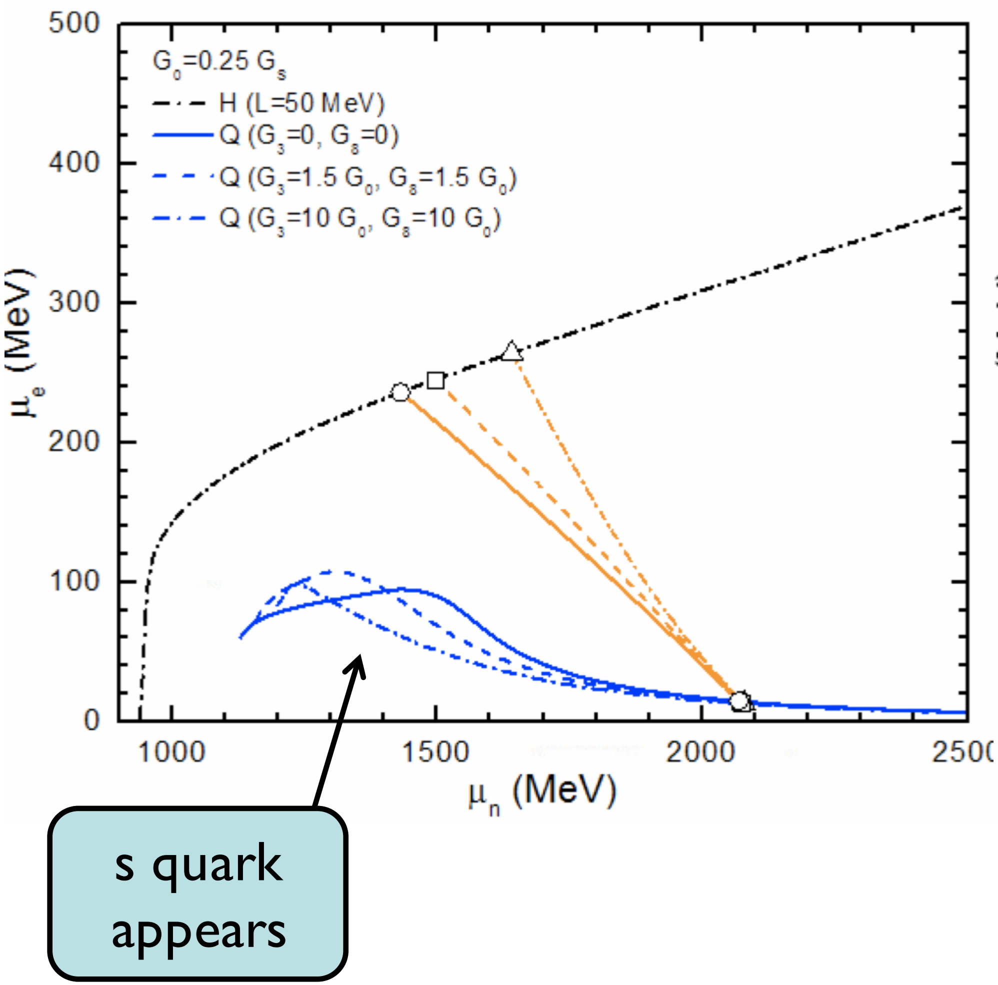
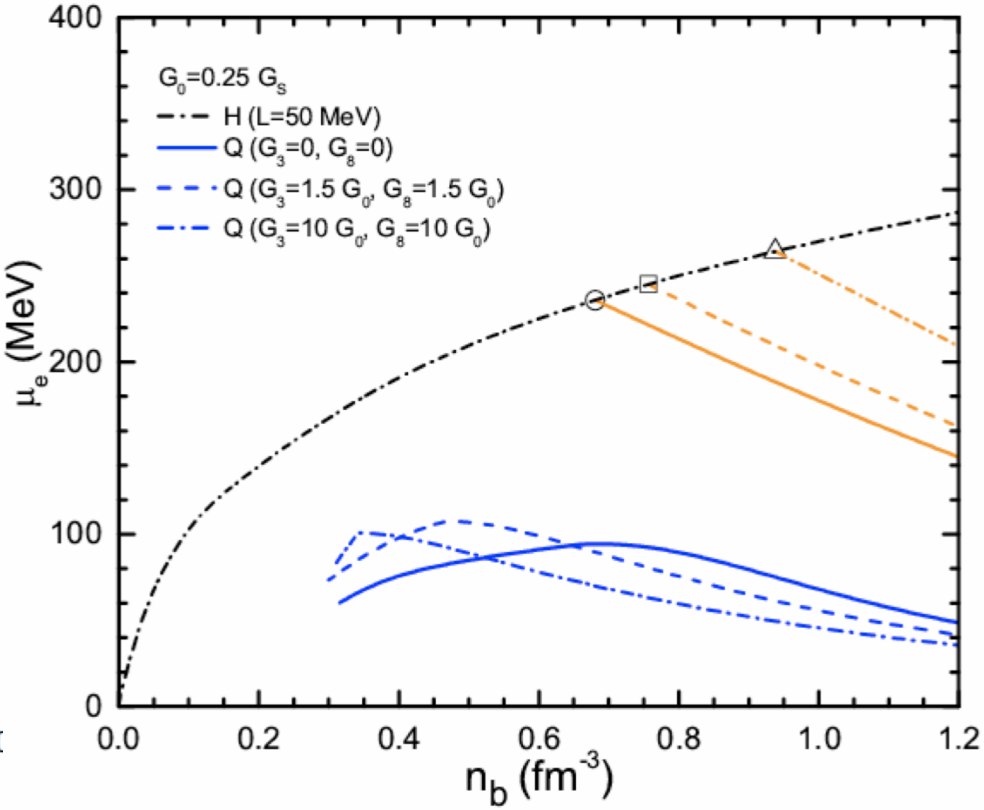
Results (sym in QM)

Electron chemical potential

$$\mu_e = \mu_n - \mu_p$$

$$\mu_e = \mu_d - \mu_u$$





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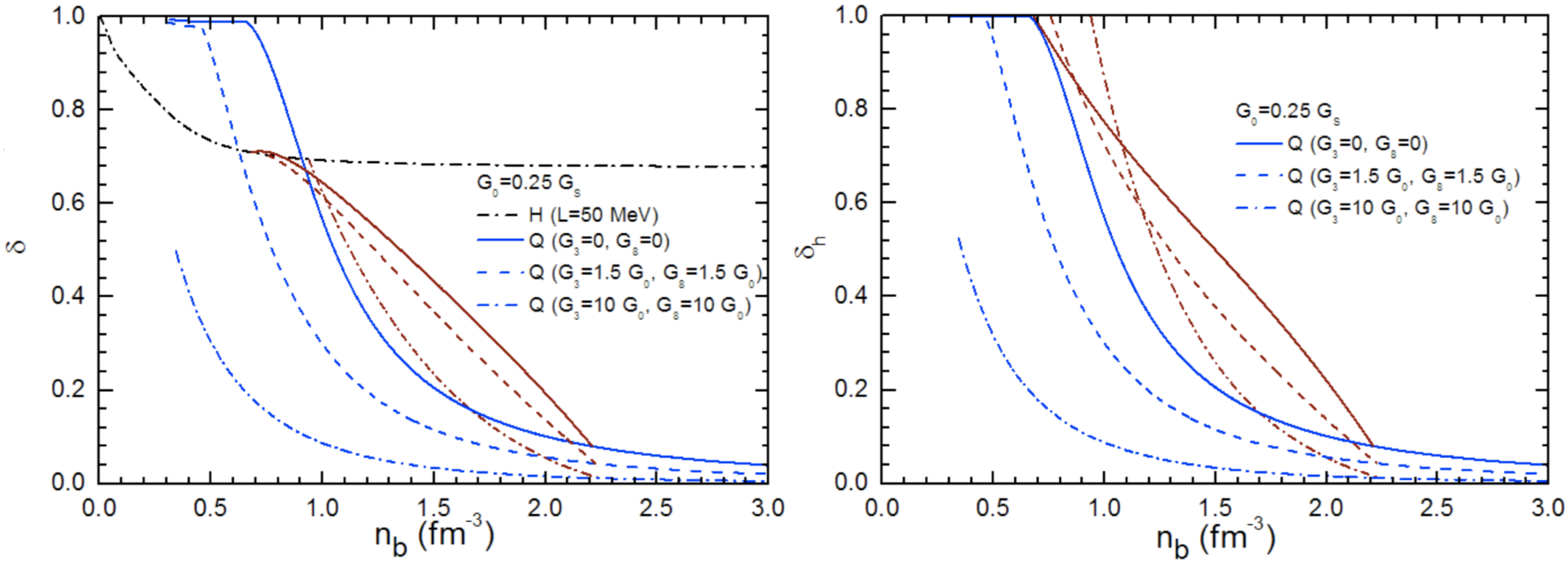
Results (sym in QM)

$n_u = n_d = n_s$

Charge neutrality

Isospin asymmetry
Hypercharge asymmetry



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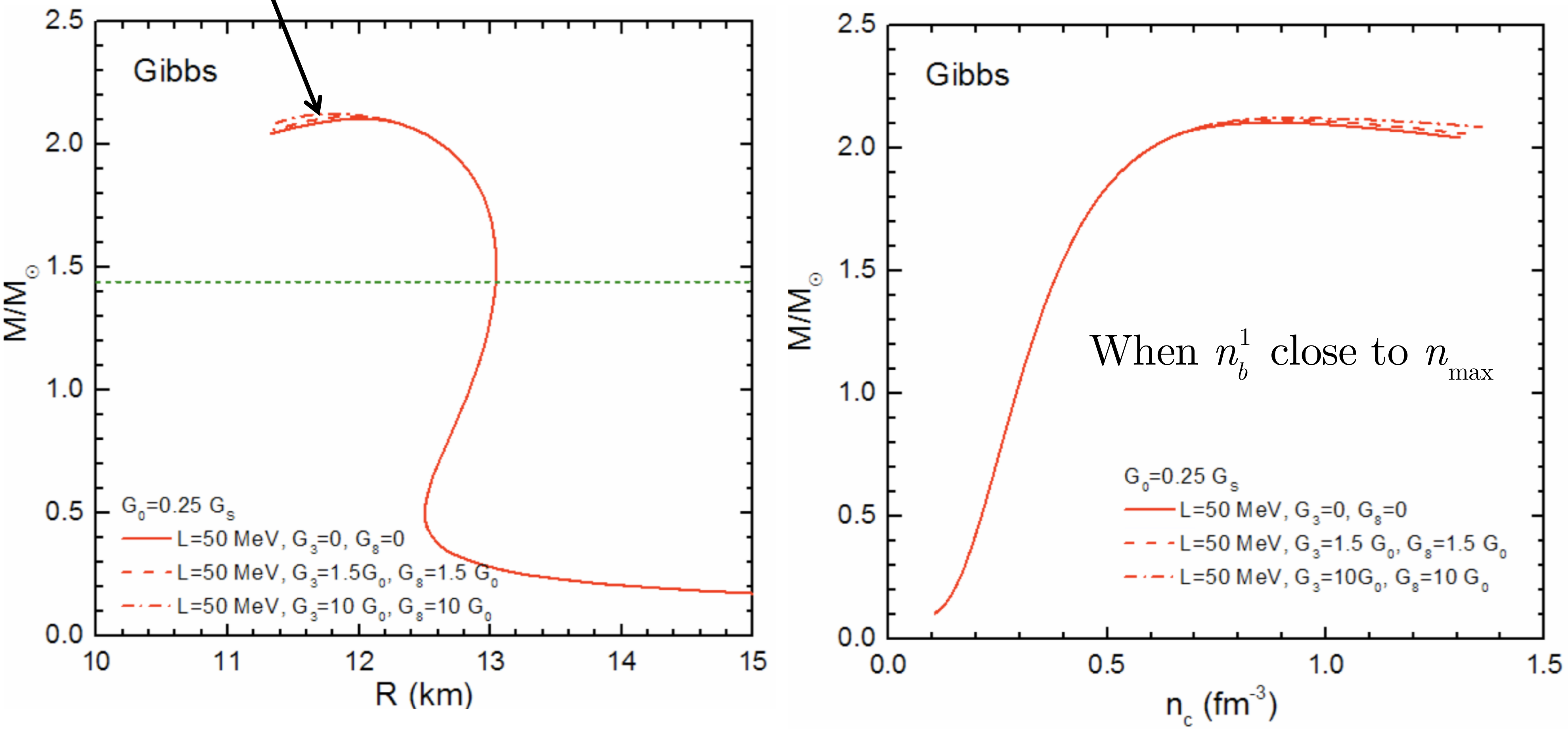
Results (sym in QM)

slighter increase

Mass-radius relations



X. H. Wu, A. Ohnishi, H. Shen (in prep.)

Summary

1. The hadron-quark phase transition densities decrease with slope L grow.

2. The isovector-vector coupling G_3 and hyper-charge coupling G_8 in the NJL model can support higher neutron star mass.

3. The phase transition point close to the hadron phase are more sensitive to rho meson effect (slope L and couplings G_3 , G_8).


Thank you very much
for your attention!
INFORMATION
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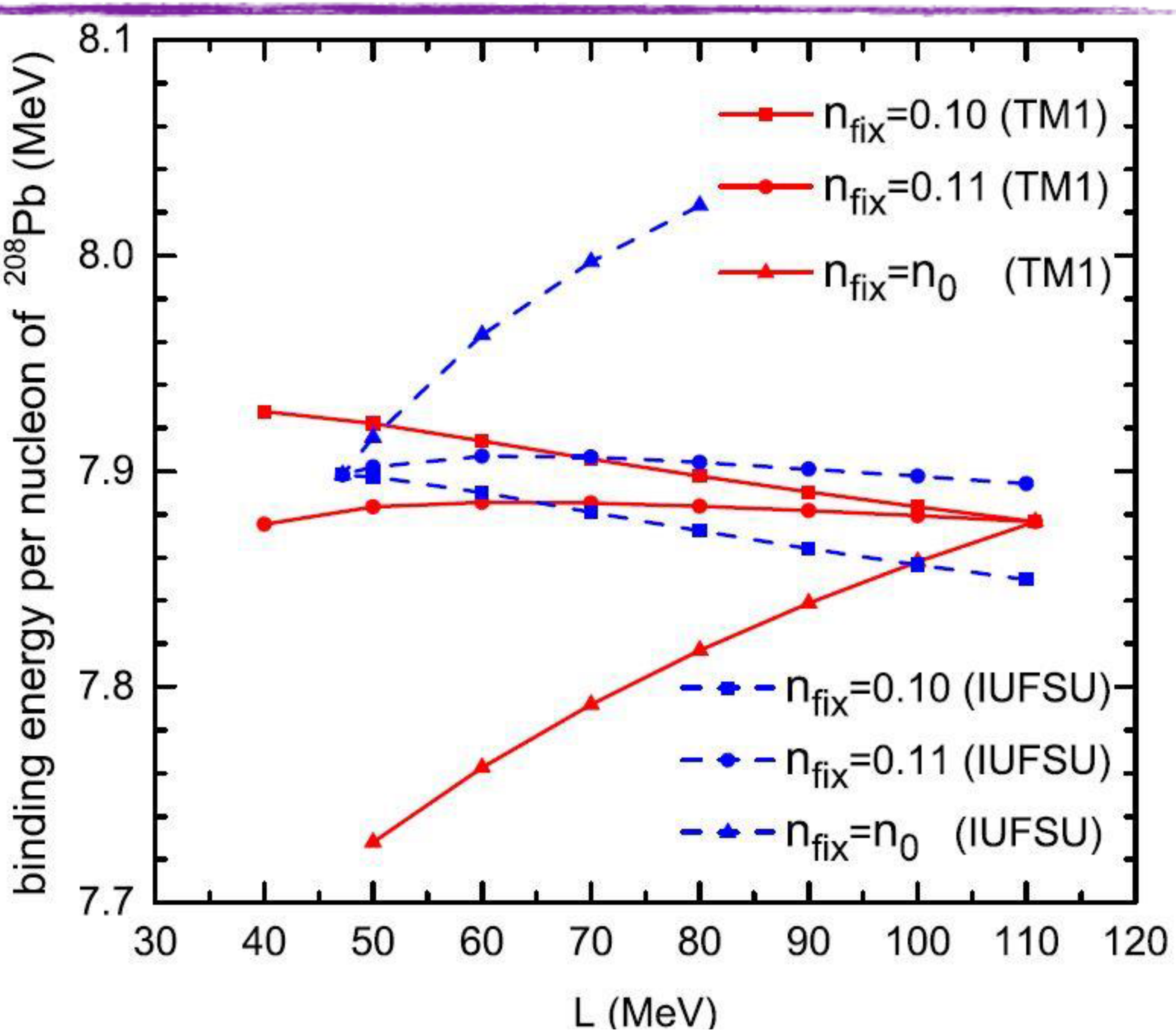
KYOTO UNIVERSITY

Appendix

$n_{\text{fix}} = 0.11\ \text{fm}^{-3}$

Why？



S. S. Bao, J. N. Hu, Z. W. Zhang, and H. Shen, Phys. Rev. C 90, 045802 (2014).