Evolution from Hot Neutron Stars with Hadron-Quark Crossover

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Abstract

Using the idea of smooth crossover from hadronic matter to quark matter, it was already shown by the authors that 2 solarmass neutron star can be sustained by strongly interacting quark matter. In this poster, we extend this idea to finite temperature and consider neutron star evolution with crossover. We show

(I) temperature profile has a peak due to the existence of quark matter inside neutron stars, and

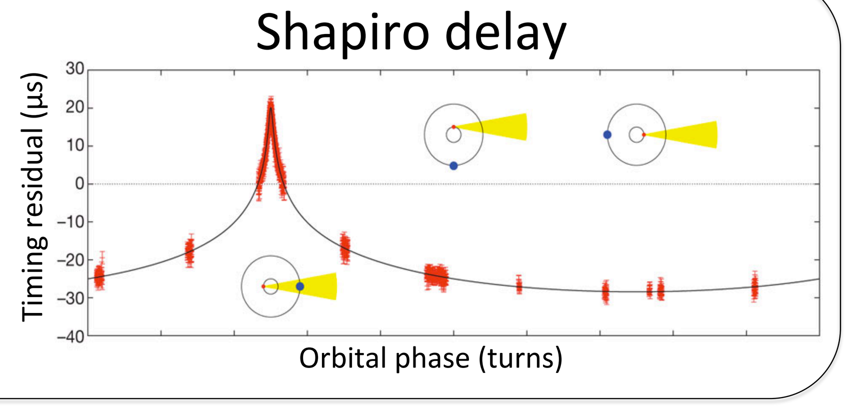
(II) vector interaction plays an important role for determining whether neutron stars become black hole through evolution.

Introduction [1,2,3]

•Recent discovery [1]

In 2010, NS(PSRJ1614-2230) with (1.97±0.04) $M_\odot$ was found through Shapiro delay .

Shapiro delay



•Key questions

We can study high dense matter through NSs.

Observations	Theory
Mass	EOS through TOV equation
Cooling	Superfluid / conductivity

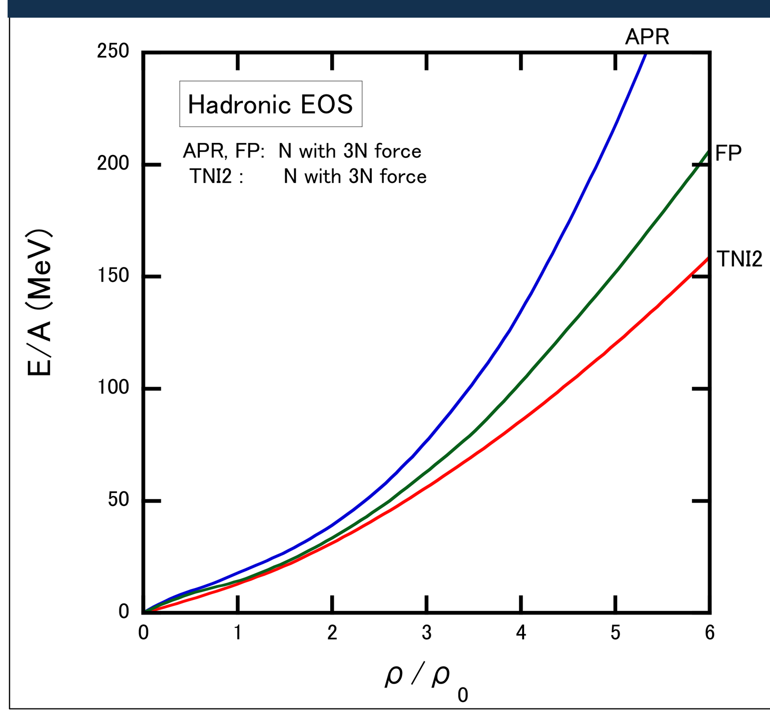
At T=0 MeV [2,3]

- Are there any EOS which can explain $2M_\odot$ NS?

At T≠0 MeV

- How do hot NSs impose new constraints on dense matter ?

Hadronic EOS [4]



	TNI2	APR
method	G-matrix	Variational
2-body force	Reid	AV18
3-body force	✔	✔
nuclear incompressibility κ	250	269
maximum mass	1.62	2.20

Quark EOS [5]

We use (2+1)-flavor NJL with β-equilibrium and charge neutrality.

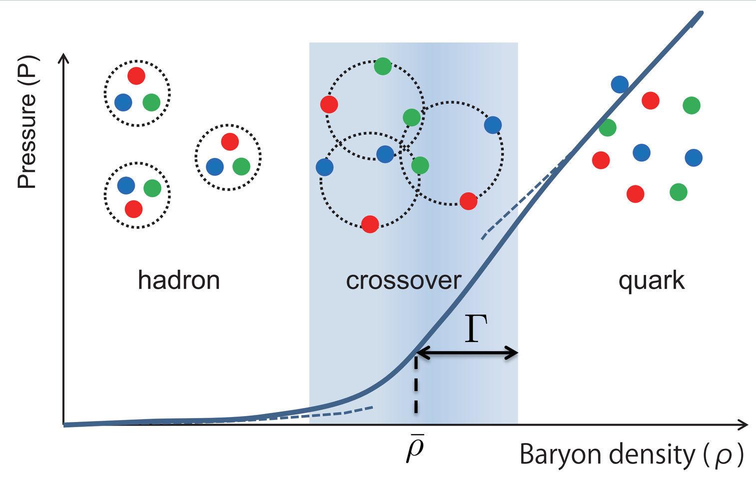
$$L_{NJL} = \bar{q}(i\partial - m)q + \frac{G_s}{2}\sum_{a=0}^{8}[(\bar{q}\lambda^a q)^2 + (\bar{q}i\gamma_5\lambda^a q)^2] - \frac{g_v}{2}[(\bar{q}\gamma_\mu q)^2]$$
$$+G_D[\det\bar{q}(1+\gamma_5)q + \mathrm{h.c}]$$

mean field approximation

parameter [5]	$\Lambda(\mathrm{MeV})$	$G_s\Lambda^2$	$G_D\Lambda^5$	$m_{u,d}(\mathrm{MeV})$	$m_s(\mathrm{MeV})$
	631.4	3.67	9.29	5.5	135.7

Hadron-quark crossover for finite T

Hot NSs are composed of ``supernova matter" characterized by constant entropy per baryon S and lepton fraction Y.



•Definition of EOS for supernova matter

we hypothesis $\bar{\rho}$ and Γ do not depend on T.

$$P(\rho,T) = P_H(\rho,T)\times\frac{1-\tanh\left(\frac{\rho-\bar{\rho}}{\Gamma}\right)}{2} + P_Q(\rho,T)\times\frac{1+\tanh\left(\frac{\rho-\bar{\rho}}{\Gamma}\right)}{2}$$

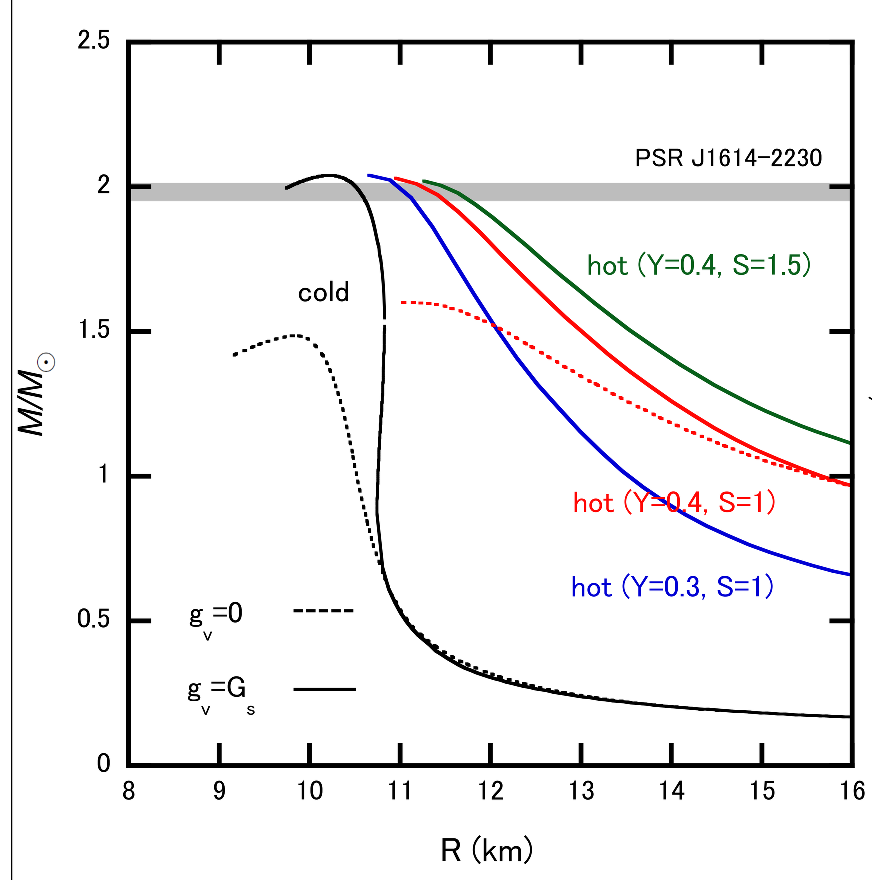
thermodynamic relation

$$s(\rho,T) = s_H(\rho,T)\times\frac{1-\tanh\left(\frac{\rho-\bar{\rho}}{\Gamma}\right)}{2} + s_Q(\rho,T)\times\frac{1+\tanh\left(\frac{\rho-\bar{\rho}}{\Gamma}\right)}{2}$$

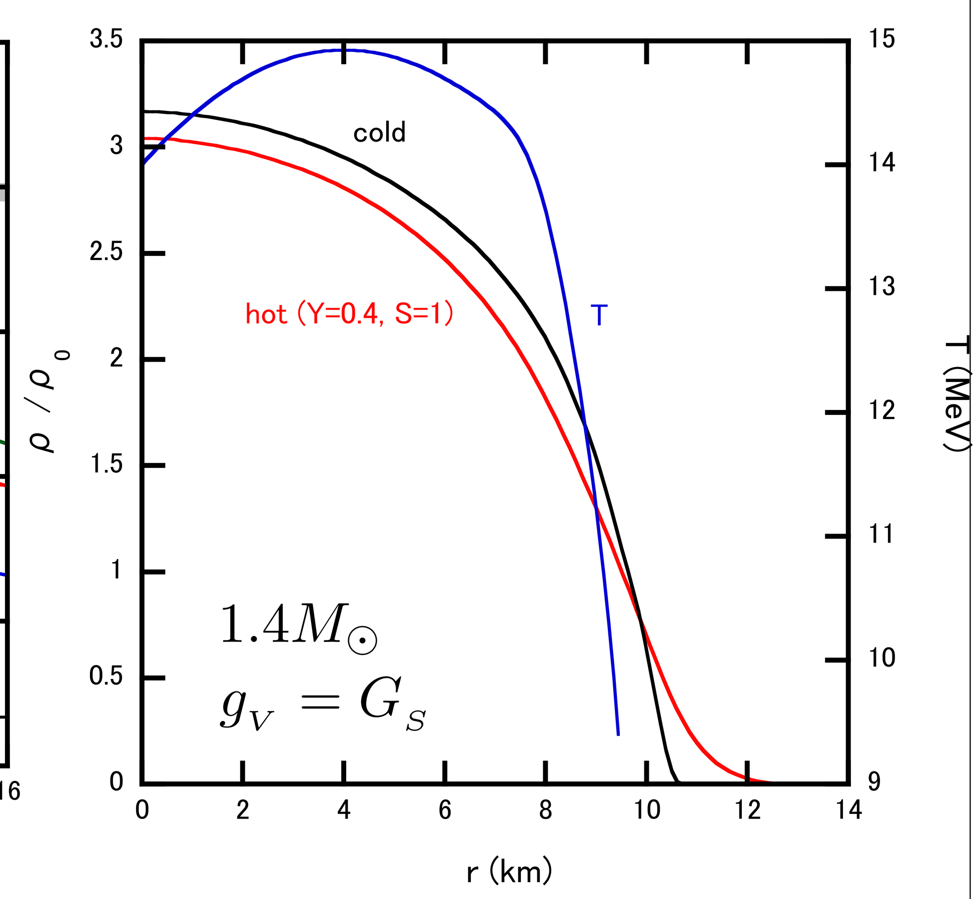
Results

1. Effects of crossover H-EOS: TNI2 $(\bar{\rho},\Gamma) = (3\rho_0,\rho_0)$

M-R relation



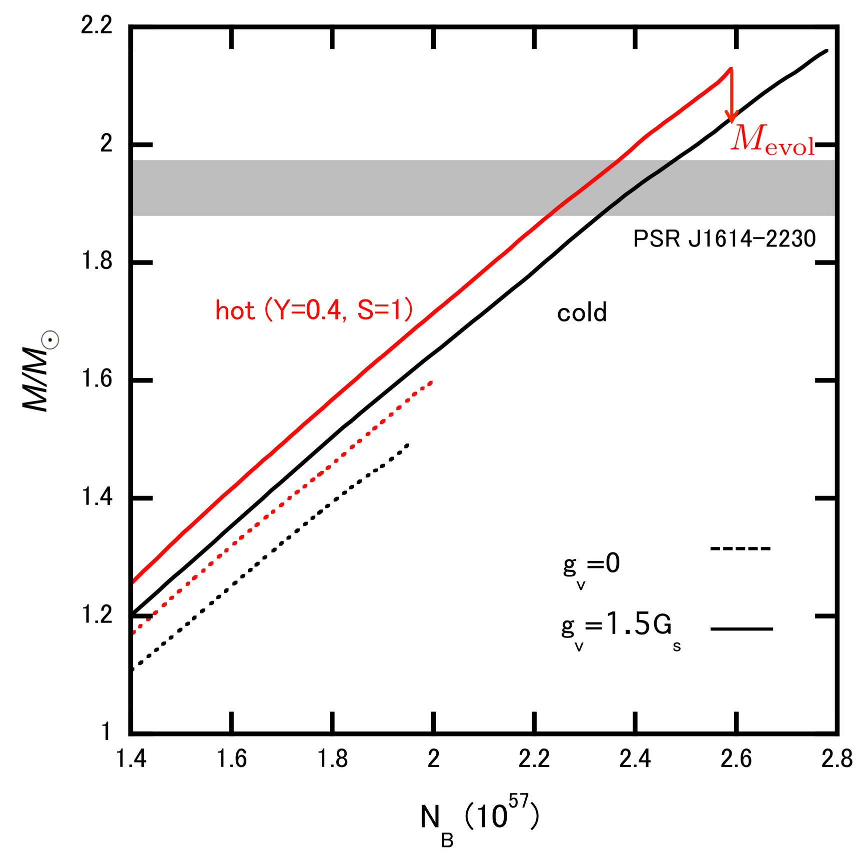
ρ-r, T-r relation



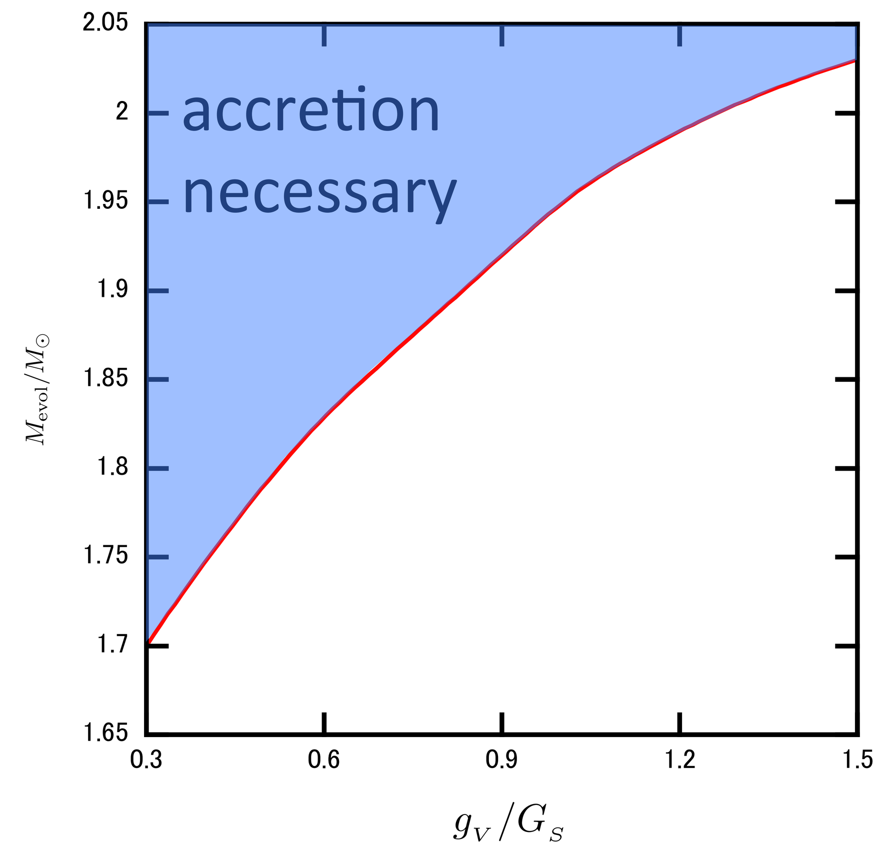
At the density where the effect of quark phase emerges, temperature profile has a peak.

2. Effects of vector interaction $(\bar{\rho},\Gamma) = (3\rho_0,\rho_0)$

M-N$_B$ relation



$M_{\mathrm{evol}} - g_V$ relation



- Universal repulsion among different flavors of vector interaction makes the effects of temperature and neutrino trapping on maximum mass smaller.

Summary

- By using crossover picture, EOS can become hard due to strongly interacting quark matter.
- Due to the color degree of freedom of quarks, temperature profile has a peak.
- The strength of vector interaction determines whether NSs becomes BH and whether accretion occurs partially.

Future works

1. Cooling from our crossover model.
2. Constraints on EOS from other observables. (Radius etc.)

References

[1]P. B. Demorest et al., Nature **467** (2004), 1081-1083
[2]K. Masuda, T. Hatsuda and T. Takatsuka, ApJ **764**, 12 (2013)
[3]K. Masuda, T. Hatsuda and T. Takatsuka, PTEP 073D01 (2013)
[4]T. Takatsuka, S. Nishizaki and J. Hiura, Prog. Theor. Phys. **92** (1994), 4.
[5]T. Hatsuda and T. Kunihiro, Physics Reports , **247** (1994), 221-367