FAST/Future Pulsar Symposium 13

Properties of the mixed phase core in maximum mass neutron stars

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arXiv 2312.16843

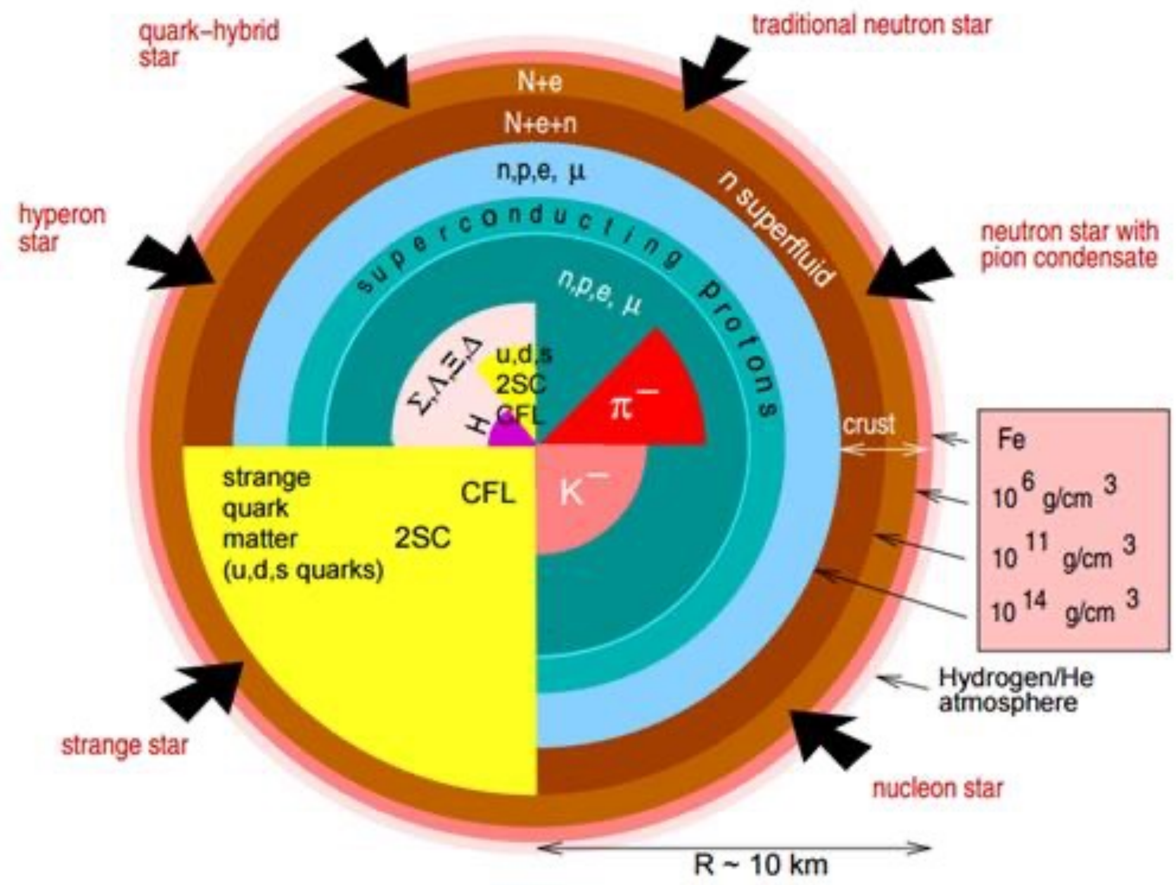
July 16th, 2024, 昆明

Outline

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

Introduction

Pulsar structures



Weber 2005

Observations and Constraints:

PSR J0740+6620

$M=2.08 \pm 0.07\, M_{\odot}$; Fonseca 2021

$M=2.14^{+0.10}_{-0.09} M_{\odot}$; Cromartie 2019

PSR J0348+0432

$M=2.01 \pm 0.04\, M_{\odot}$; Antoniadis 2013

PSR J1614−2230

$M=1.908 \pm 0.016\, M_{\odot}$; Arzoumanian2018

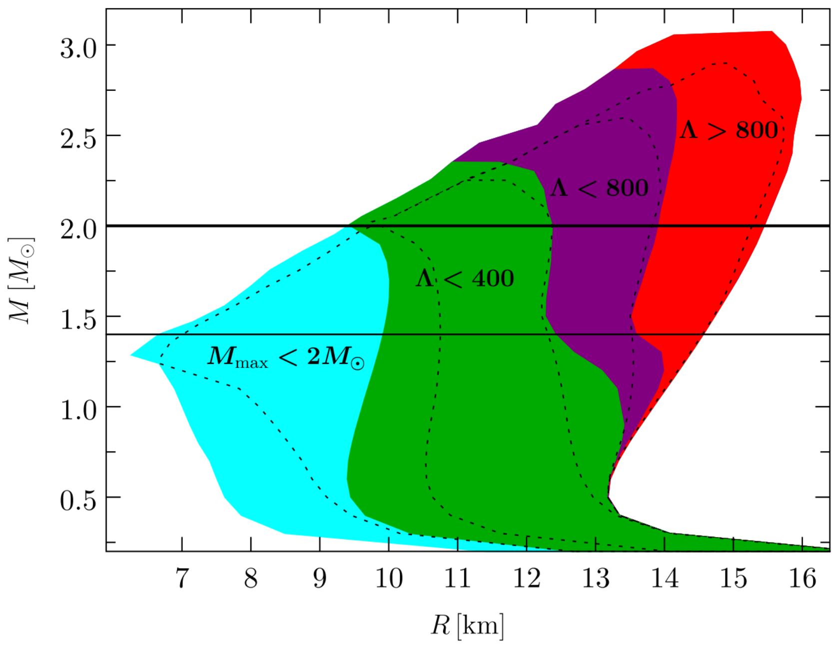
PSR J2215+5135

$M=2.27^{+0.17}_{-0.15} M_{\odot}$; Linares 2018

PSR J0952+0607

$M=2.35 \pm 0.17\, M_{\odot}$; Romani 2022

Introduction



Annala 2018

- **Mass-radius measurements by NICER:**

PSR J0740+6620

$$R = 12.39^{+1.3}_{-1.5}\ \text{km},\ M = 2.072^{+0.067}_{-0.066} M_\odot$$

$$R = 13.70^{+2.7}_{-1.5}\ \text{km},\ M = 2.08 M_\odot$$

M. C. Miller et al., Astrophys. J. Lett., 887, L24 (2019).
T. E. Riley et al., Astrophys. J. Lett., 887, L21 (2019).

PSR J0030+0451

$$R = 12.71^{+1.14}_{-1.19}\ \text{km},\ M = 1.34^{+0.15}_{-0.16} M_\odot$$

$$R = 13.02^{+1.24}_{-1.06}\ \text{km},\ M = 1.44^{+0.15}_{-0.14} M_\odot$$

M. C. Miller et al., Astrophys. J. Lett., 918, L28 (2021).
T. E. Riley et al., Astrophys. J. Lett., 918, L27 (2021).

GW170817

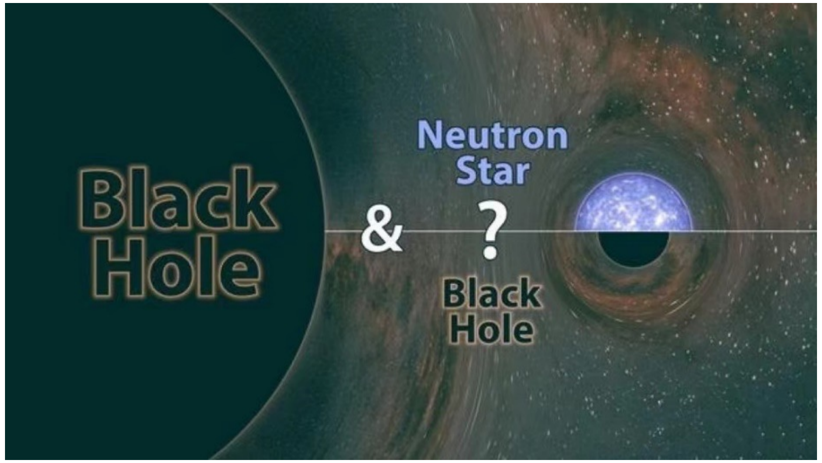
$\Lambda_{1.4} \lesssim 800$ ~ $R_{1.4} \lesssim 13.6$ km

$70 \lesssim \Lambda_{1.4} \lesssim 580$

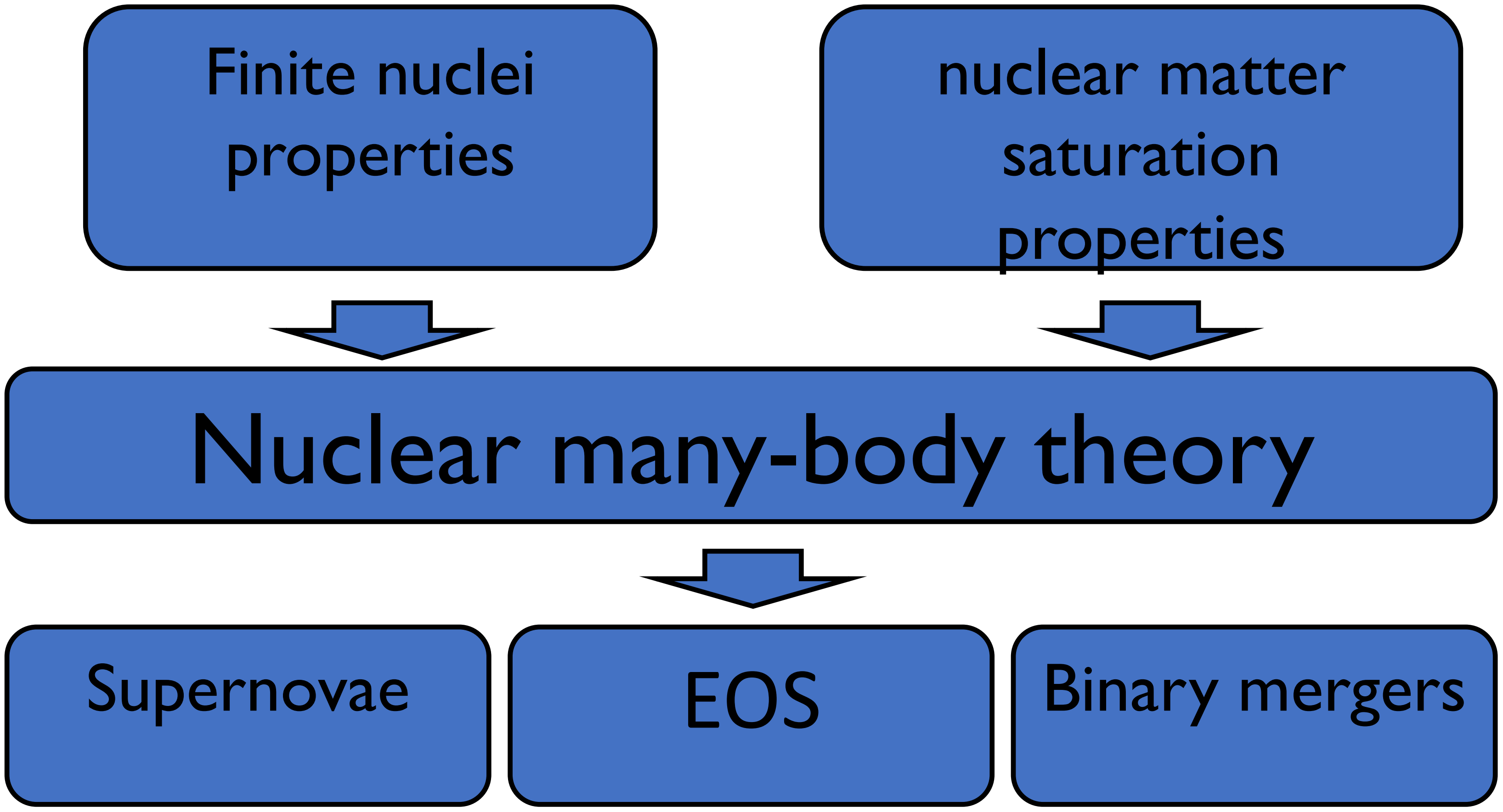
Abbott 2017, 2018

GW190814

$M = 2.6\ M_\odot$?



Introduction

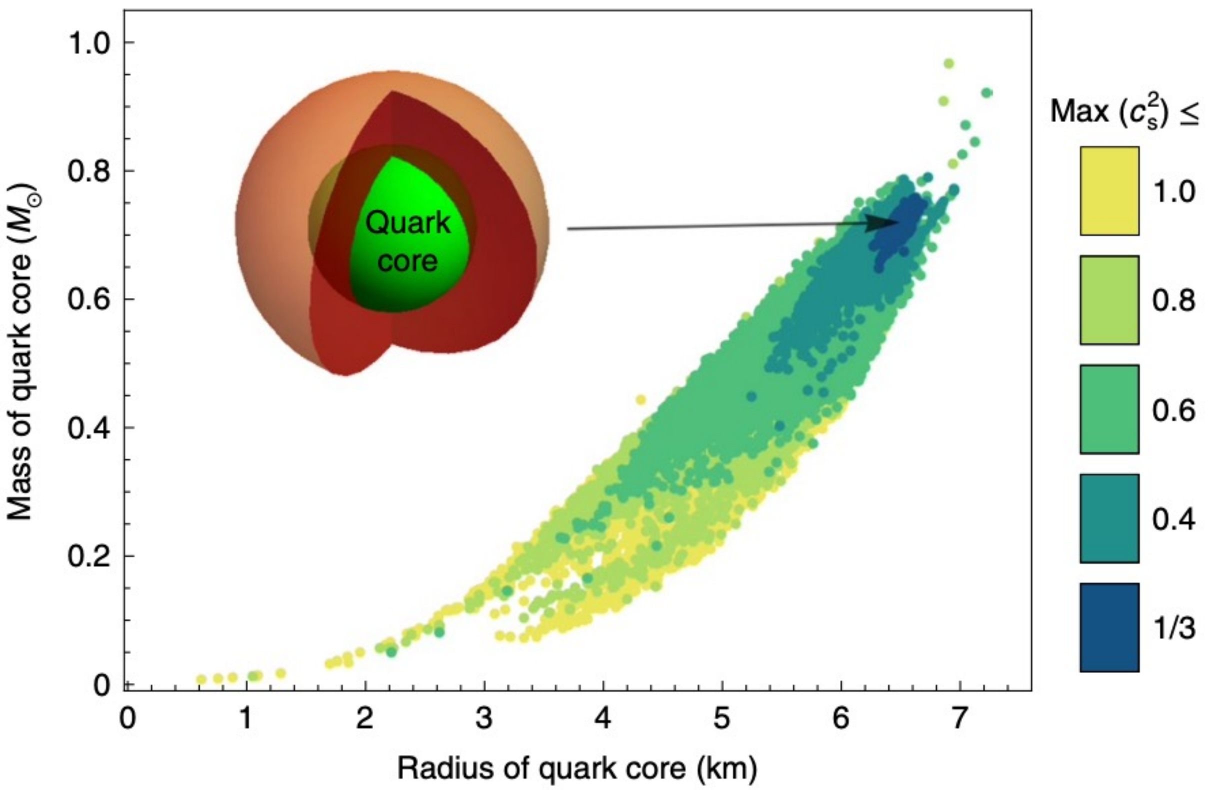


Introduction

nature physics
LETTERS
https://doi.org/10.1038/s41567-020-0914-9
Check for updates
OPEN

Evidence for quark-matter cores in massive neutron stars

Eemeli Annala[1], Tyler Gorda[2], Aleksi Kurkela[3,4], Joonas Nättilä[5,6,7] and Aleksi Vuorinen[1]



New speed-of-sound interpolation.

$$c_s^2(\mu) = \frac{(\mu_{i+1} - \mu)c_{s,i}^2 + (\mu - \mu_i)c_{s,i+1}^2}{\mu_{i+1} - \mu_i}$$

CET and pQCD EoSs

Theoretical Framework

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

$$
\begin{aligned}
\mathcal{L}_{\mathrm{NJL}} = & \bar{q} (i\gamma_\mu \partial^\mu - m^0) q \\
& + G_S \sum_{a=0}^{8} \left[(\bar{q} \lambda_a q)^2 + (\bar{q} i\gamma_5 \lambda_a q)^2 \right] \\
& - K \{ \det [\bar{q} (1+\gamma_5) q] + \det [\bar{q} (1-\gamma_5) q] \} \\
& - G_V \sum_{a=0}^{8} \left[(\bar{q} \gamma^\mu \lambda_a q)^2 + (\bar{q} \gamma^\mu \gamma_5 \lambda_a q)^2 \right],
\end{aligned}
$$

Gibbs Construction（GC）

$$T^H = T^Q$$

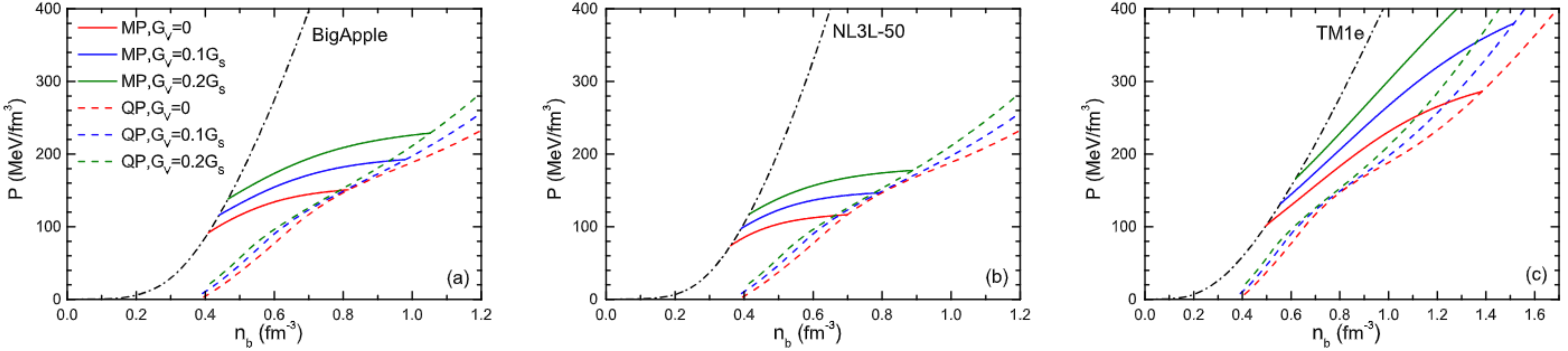
$$\mu_{\mathrm{b}}^H = \mu_{\mathrm{b}}^Q, \quad \mu_{\mathrm{e}}^H = \mu_e^Q$$

$$P^H = P^Q$$

Results

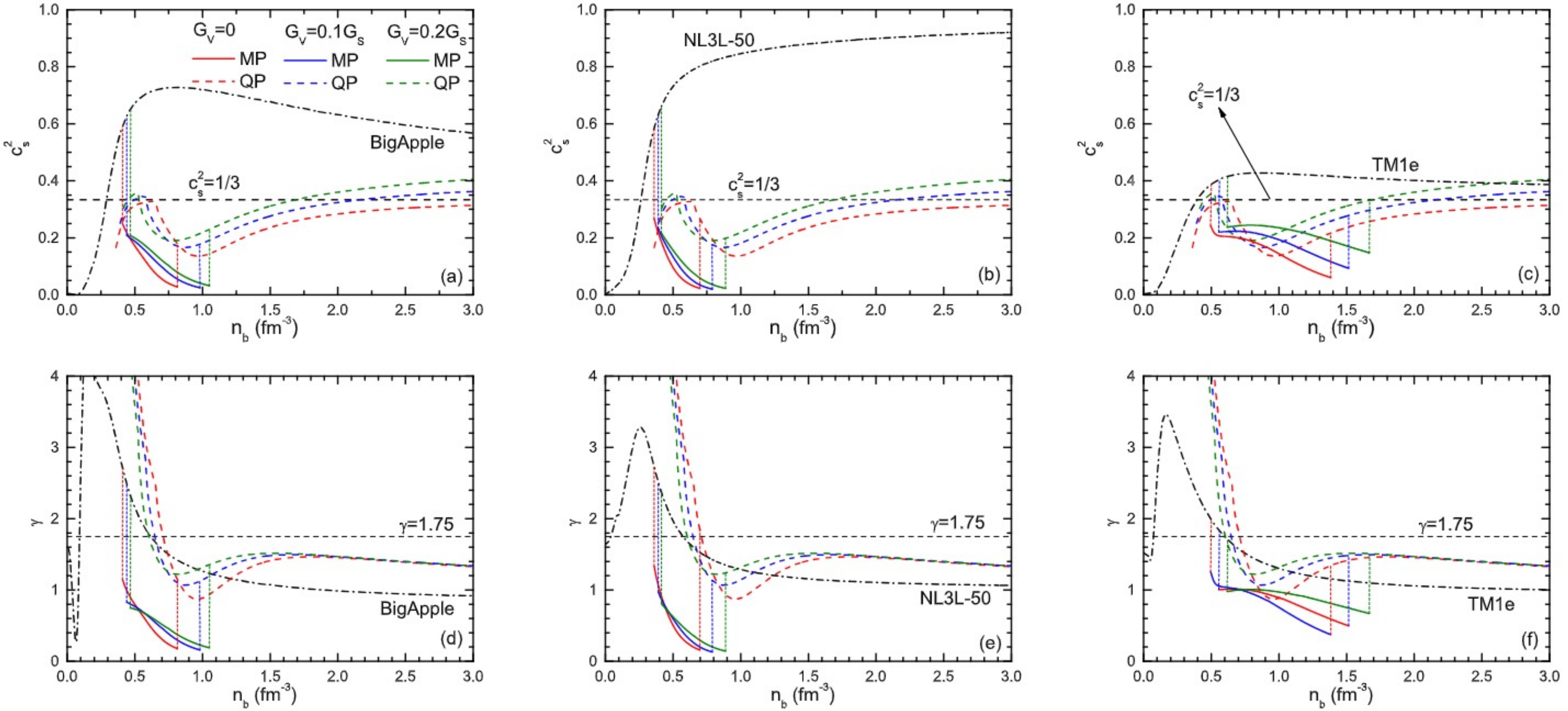
The EOSs

Model	n_0 (fm^{-3})	E_0 (MeV)	K (MeV)	$E_{\rm sym}$ (MeV)	L (MeV)
BigApple	0.155	−16.34	227.0	31.3	39.8
NL3L-50	0.148	−16.24	272.3	37.4	50
TM1e	0.145	−16.26	281.0	32.4	50
NL3	0.148	−16.24	272.3	37.4	118.5



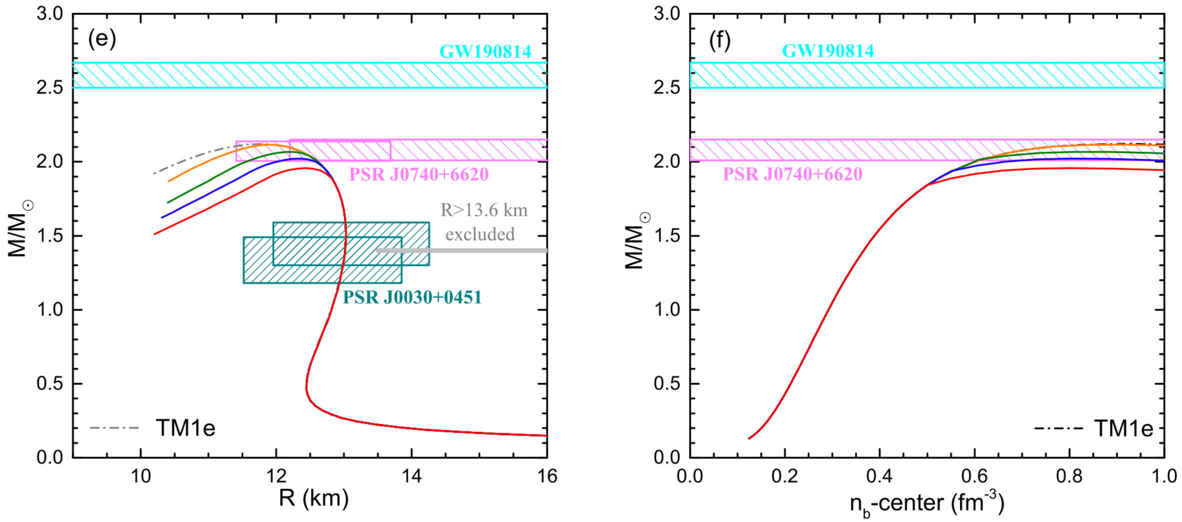
Results

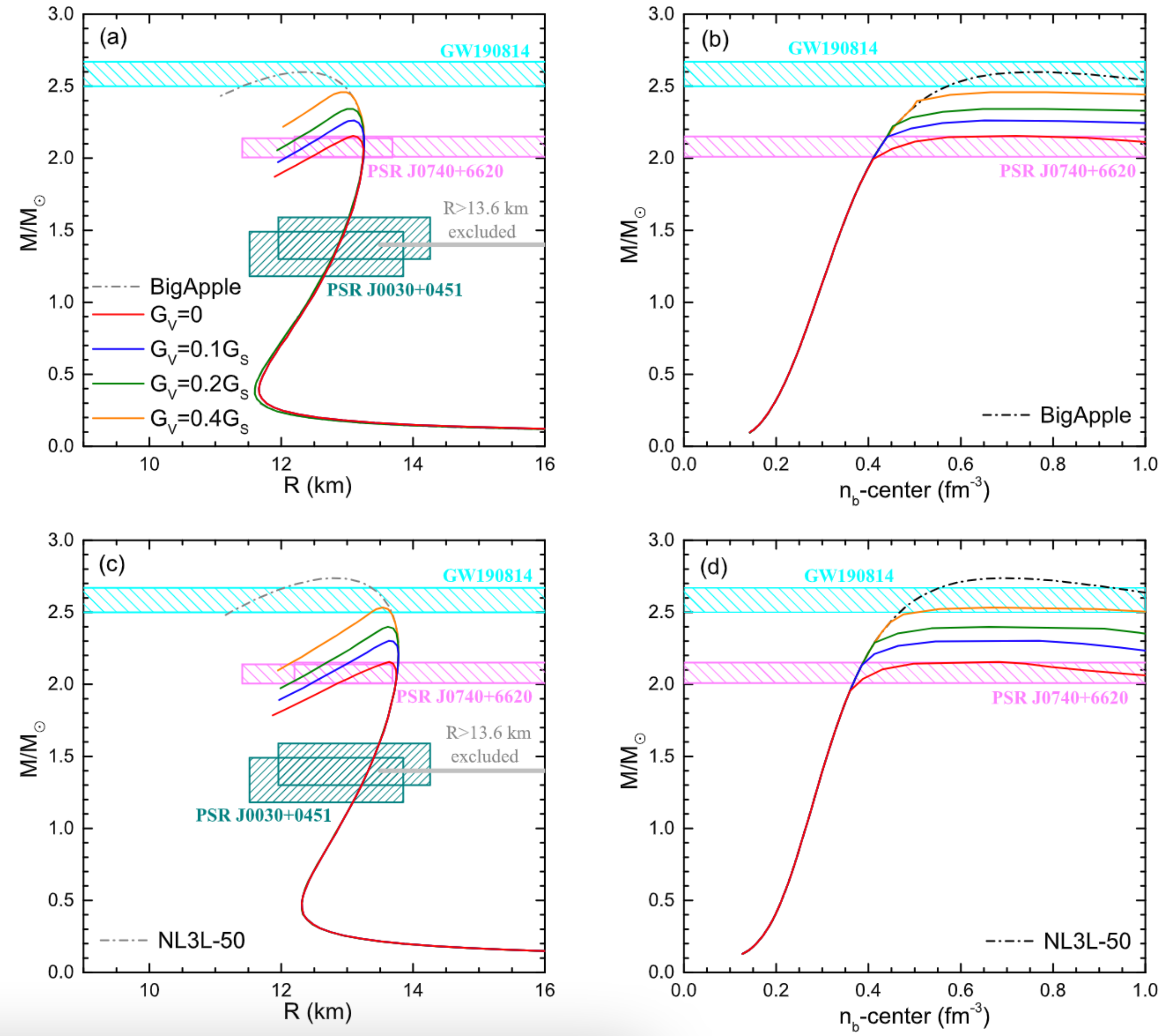
The EOS stiffness



Results

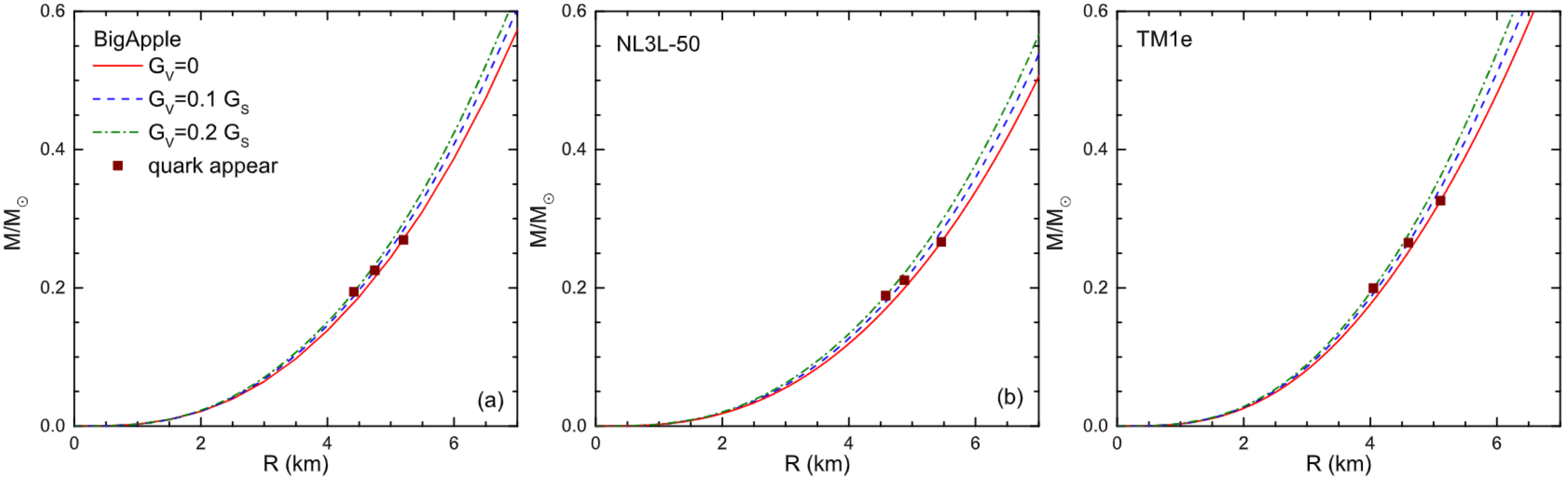
The mass-radius relation





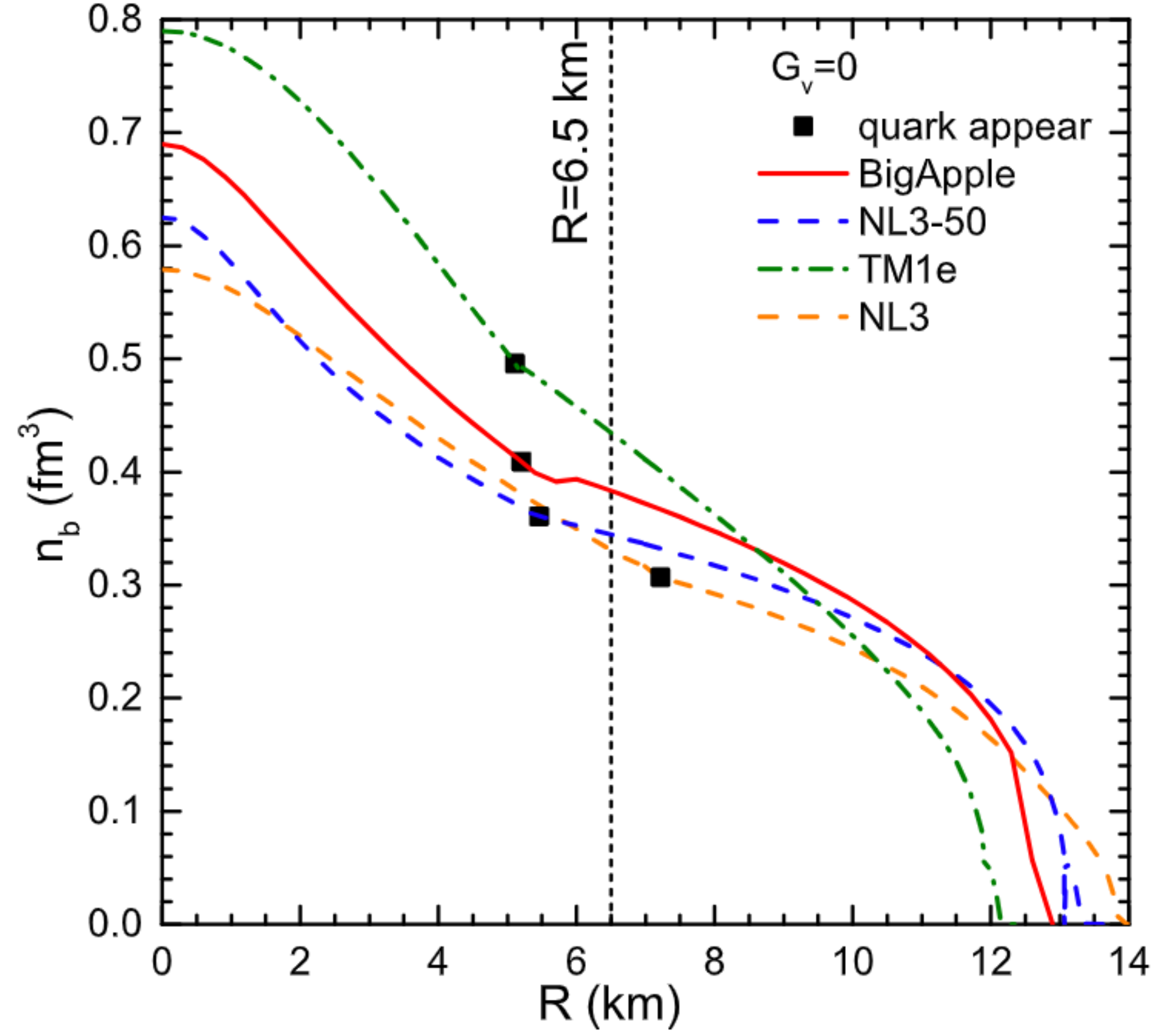
Results

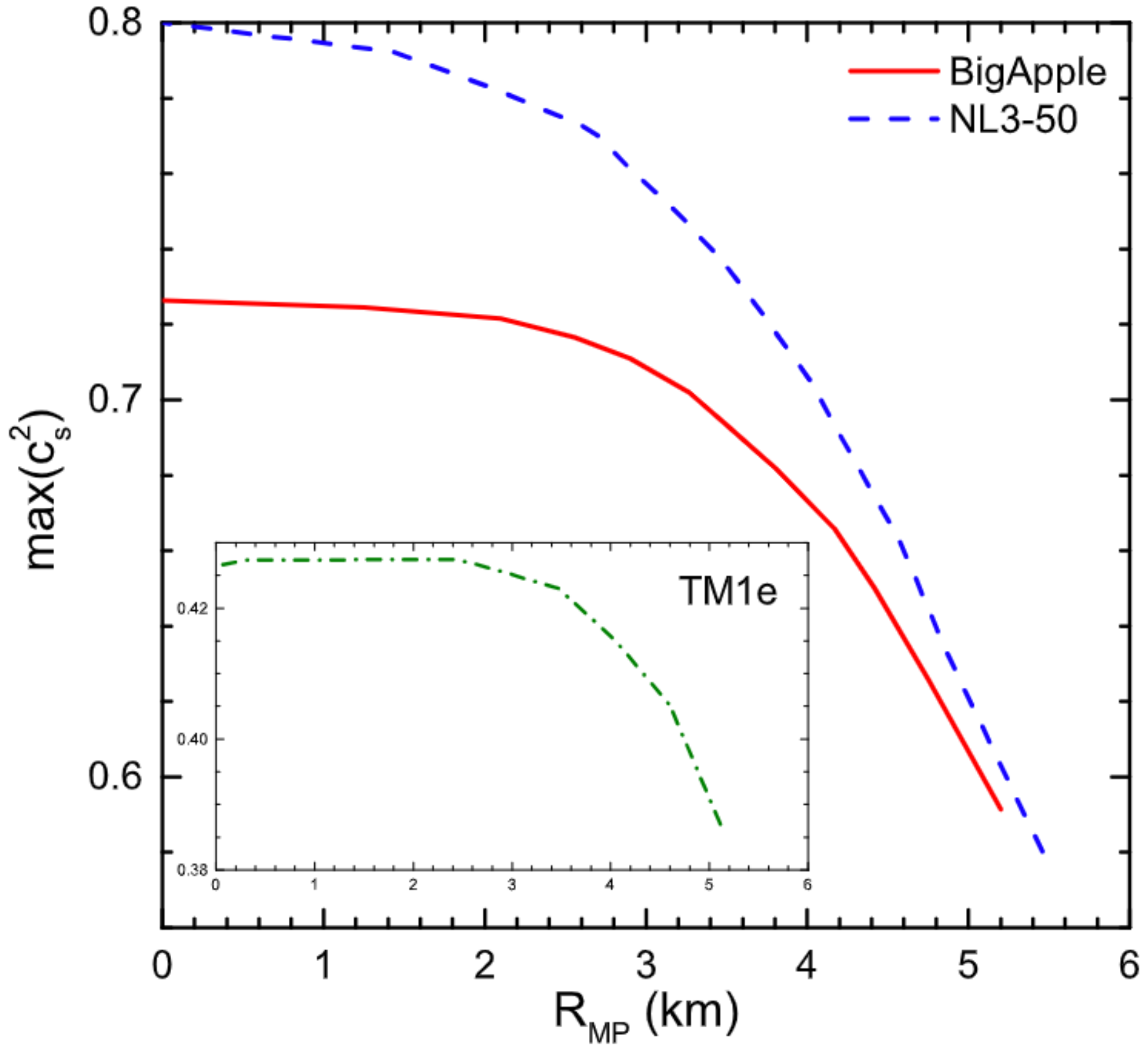
Mass-radius



Results

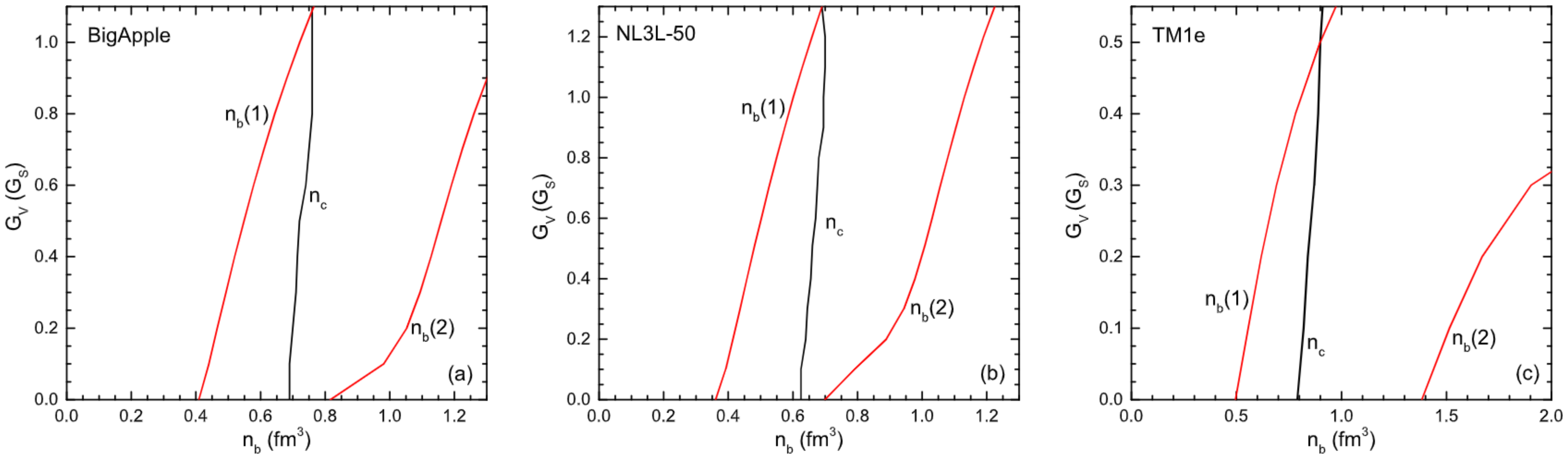
Maximum mass NS mixed phase Radius





Results

G_V dependence of phase transition density and central density of NS



Summary

- The global properties of maximum mass NSs are sensitive to the strength of the maximum sound velocity of the EOS;
- It is possible for a relatively large radius of the mixed phase to exist in the core of maximum mass NSs,
- G_V exhibit a slight correlation with the NS central density.

Thanks!