Quarks and Compact Stars 2019

Effects of nuclear symmetry energy and equation of state on neutron star properties

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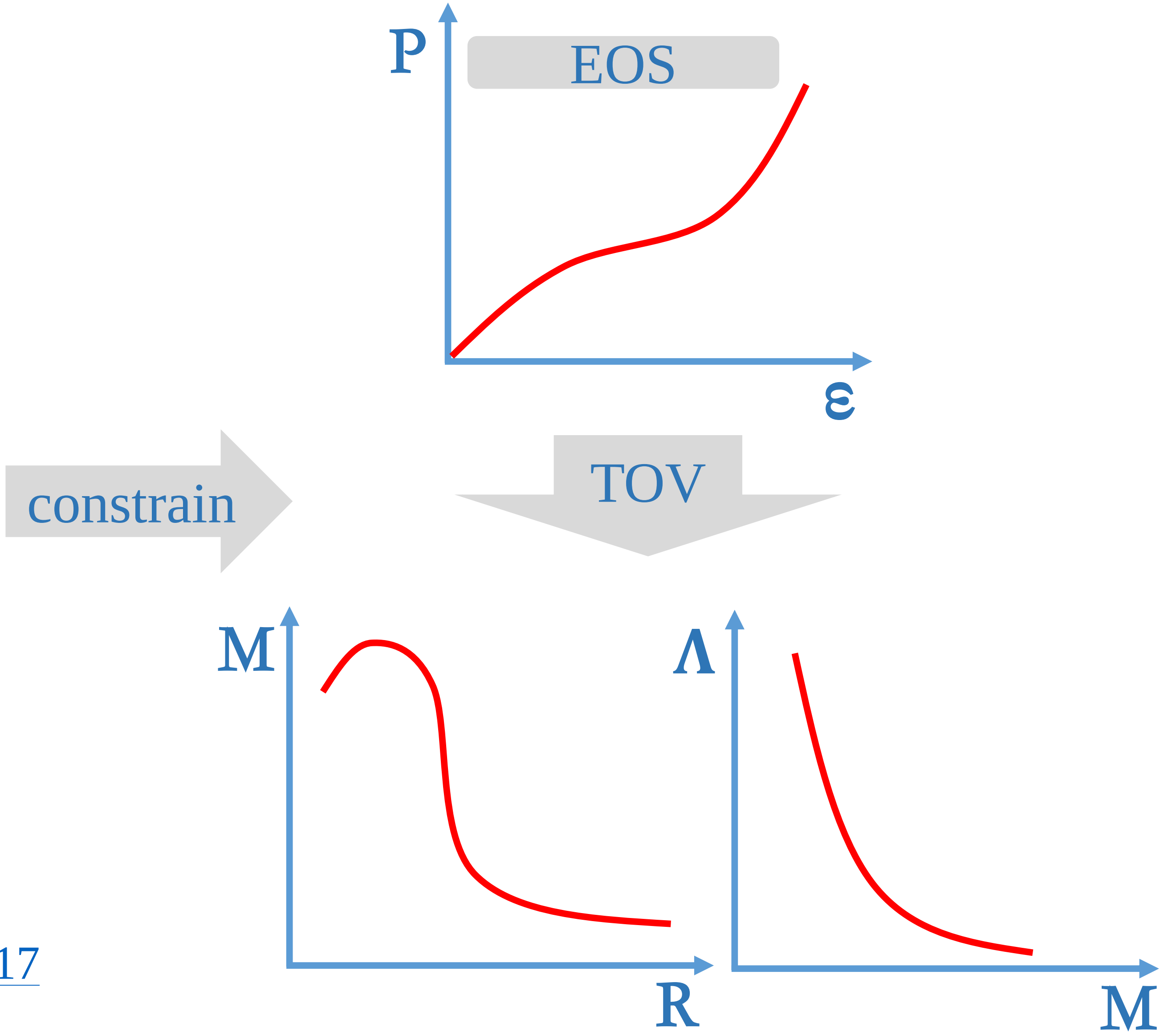
Outline

- Background
- Model and Method
- Results
- Conclusions

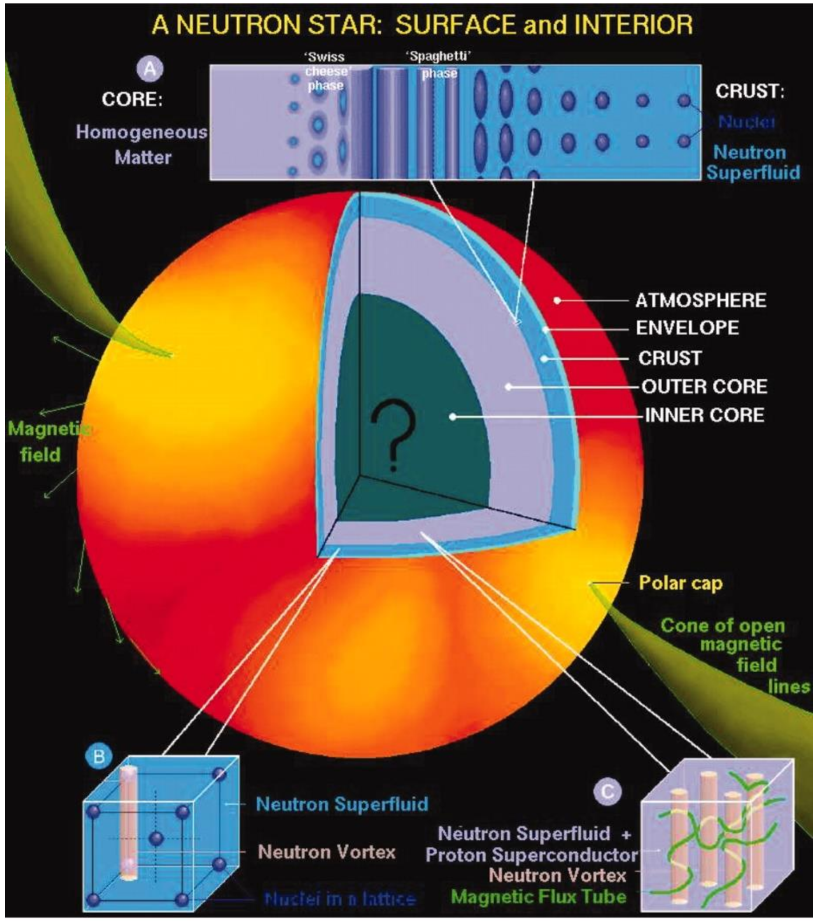
Binary neutron-star merger

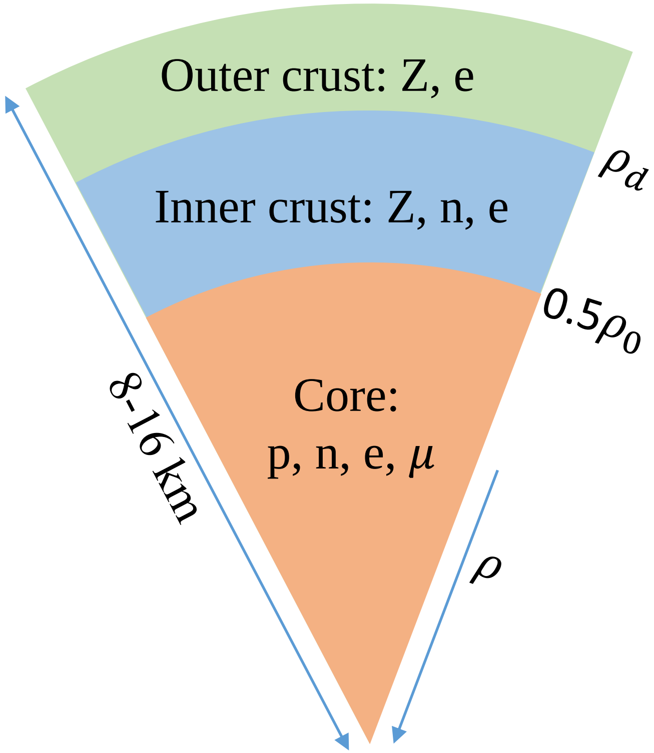
https://www.ligo.caltech.edu/page/press-release-gw170817



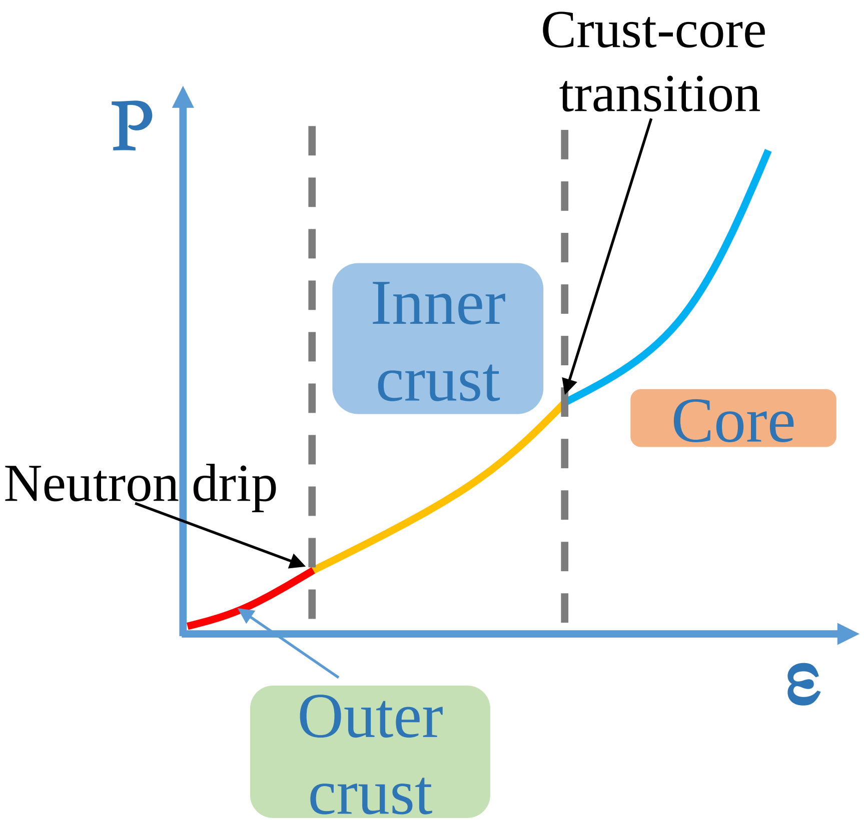
1 Background

Structure of neutron star





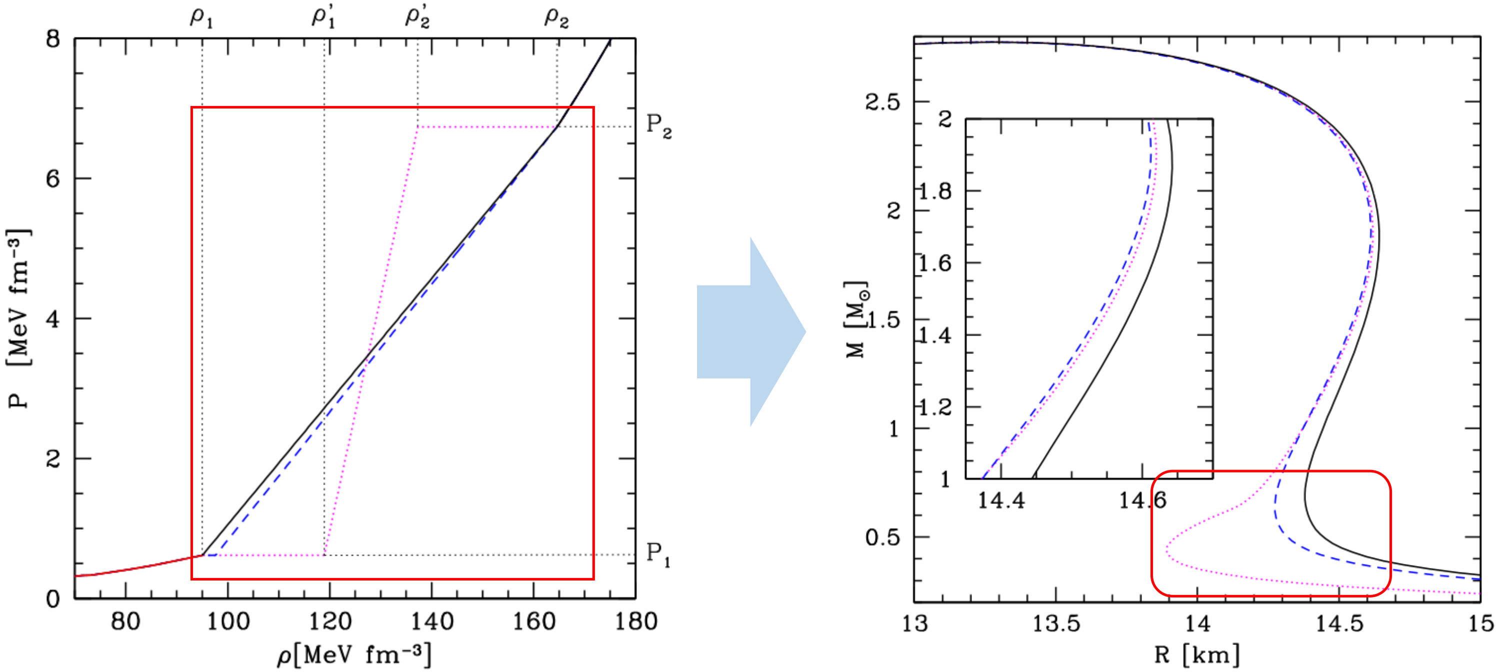
EOS



J. M. Lattimer and M. Prakash, Science 304, 536 (2004)

Non-unified EOS

Matching EOS with different models



M. Fortin, C. Providencia, Ad. R. Raduta, F. Gulminelli, J. L. Zdunik, P. Haensel, and M. Bejger, Phys. Rev. C94, 035804 (2016).

Unified EOS

Outer crust EOS: BPS EOS

G. Baym, C. Pethick, and P. Sutherland, Astrophys. J.**170**, 299 (1971).

+

Inner crust EOS: TM1 models

S. S. Bao and H. Shen, Phys. Rev. C 91, 015807 (2015).

+

Core EOS: TM1 models

2 Model and method

Lagrangian density

$$\begin{aligned}\mathcal{L}_{\mathrm{RMF}} = & \sum_{b=p,n} \bar{\psi}_b \{ i\gamma_\mu \partial^\mu - (M + g_\sigma \sigma) \\ & - \gamma_\mu \left[g_\omega \omega^\mu + \frac{g_\rho}{2} \tau_a \rho^{a\mu} + \frac{e}{2}(1+\tau_3) A^\mu \right] \} \psi_b \\ & + \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma - \frac{1}{2} m_\sigma^2 \sigma^2 - \frac{1}{3} g_2 \sigma^3 - \frac{1}{4} g_3 \sigma^4 \\ & - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu + \frac{1}{4} c_3 (\omega_\mu \omega^\mu)^2 \\ & - \frac{1}{4} R^a_{\mu\nu} R^{a\mu\nu} + \frac{1}{2} m_\rho^2 \rho^a_\mu \rho^{a\mu} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + \Lambda_{\mathrm{v}} (g_\omega^2 \omega_\mu \omega^\mu)(g_\rho^2 \rho^a_\mu \rho^{a\mu}) \\ & + \sum_{l=e,\mu} \bar{\psi}_l (i\gamma_\mu \partial^\mu - m_l + e\gamma_\mu A^\mu) \psi_l ,\end{aligned}$$

Symmetry energy slope

$$L = 3n_0 \left[\frac{\partial E_{\mathrm{sym}}(n_b)}{\partial n_b} \right]_{n_b=n_0}$$

TM1 parametrization

Model	TM1(L=40)	TM1(L=60)	TM1(L=80)	TM1(L=111)
g_σ	10.0289	10.0289	10.0289	10.0289
g_ω	12.6139	12.6139	12.6139	12.6139
g_2 (fm^{-1})	-7.2325	-7.2325	-7.2325	-7.2325
g_3	0.6183	0.6183	0.6183	0.6183
c_3	71.3075	71.3075	71.3075	71.3075
g_ρ	**13.9714**	**11.2610**	**10.1484**	**9.2644**
Λ_{v}	**0.0429**	**0.0248**	**0.0128**	**0.0000**
n_0 (fm^{-3})	0.145	0.145	0.145	0.145
E_0 (MeV)	-16.3	-16.3	-16.3	-16.3
K (MeV)	281	281	281	281
E_{sym} (MeV)	**31.38**	**33.29**	**34.86**	**36.89**
L (MeV)	**40**	**60**	**80**	**111**
$\triangle r_{\mathrm{np}}$ (^{208}Pb) (fm)	**0.16**	**0.21**	**0.24**	**0.27**
r_c (^{208}Pb) (fm)	**5.56**	**5.55**	**5.54**	**5.54**
E/A (^{208}Pb) (MeV)	7.88	7.88	7.88	7.88

Self-consistent Thomas-Fermi

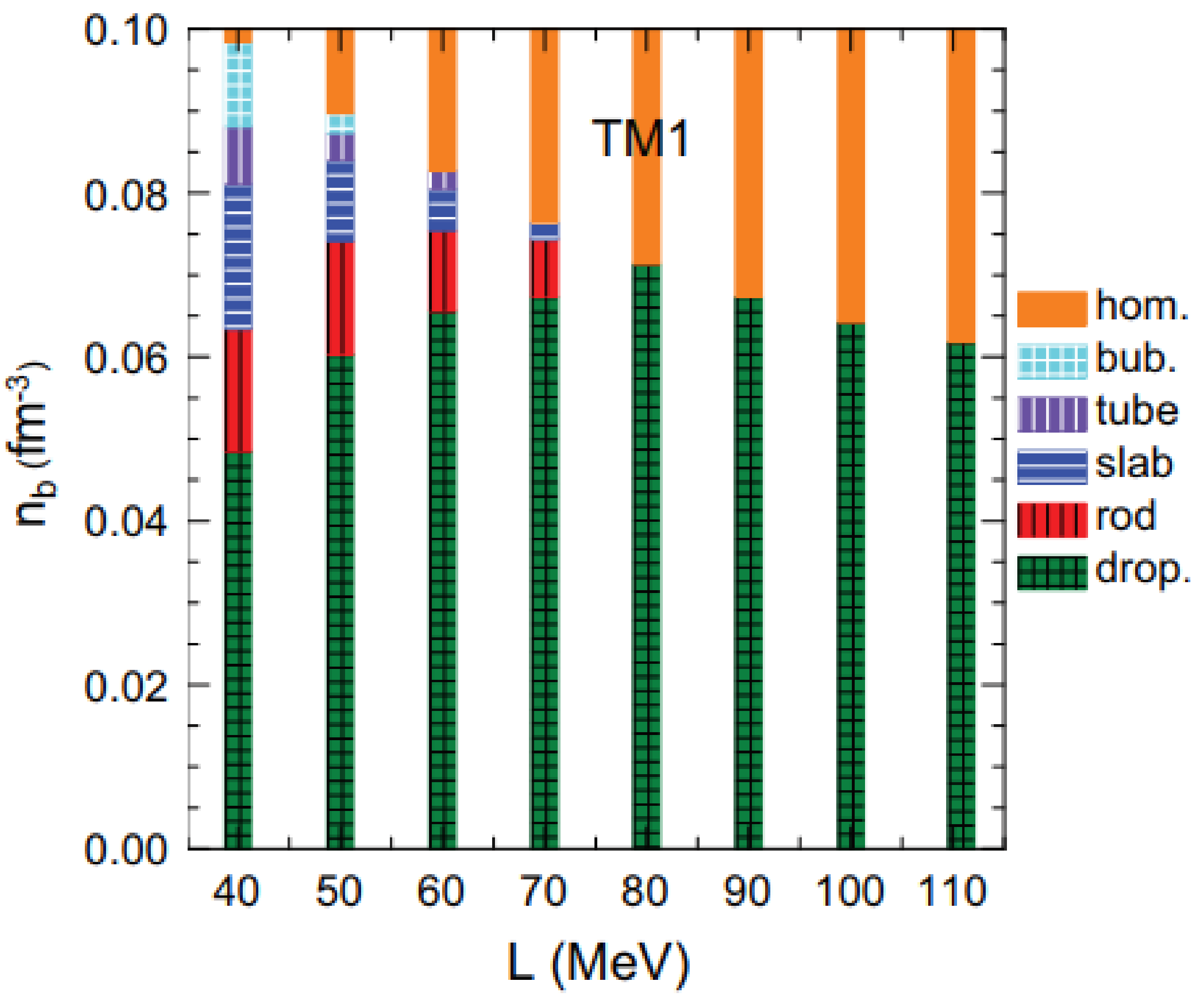
↓

Non-uniform matter

↓

Pasta phases

Model	rod	slab	tube	bubble	HM
TM1(L=40)	0.049	0.064	0.082	0.089	0.099
TM1(L=60)	0.066	0.076	0.081	–	0.083
TM1(L=80)	–	–	–	–	0.072
TM1(L=111)	–	–	–	–	0.062



S. S. Bao and H. Shen, Phys. Rev. C 89, 045807 (2014)

3 Results—Neutron-star properties with unified EOSs

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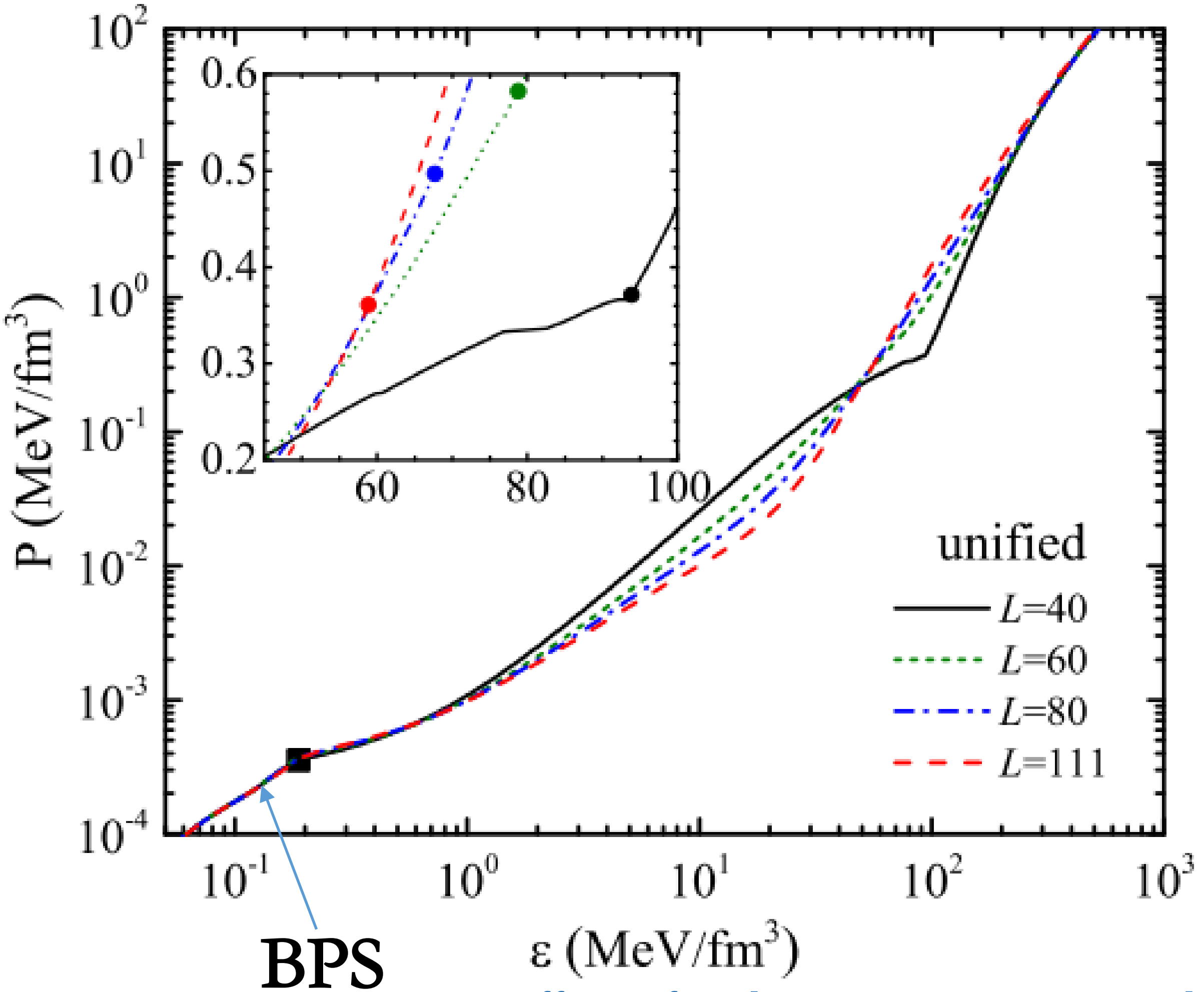
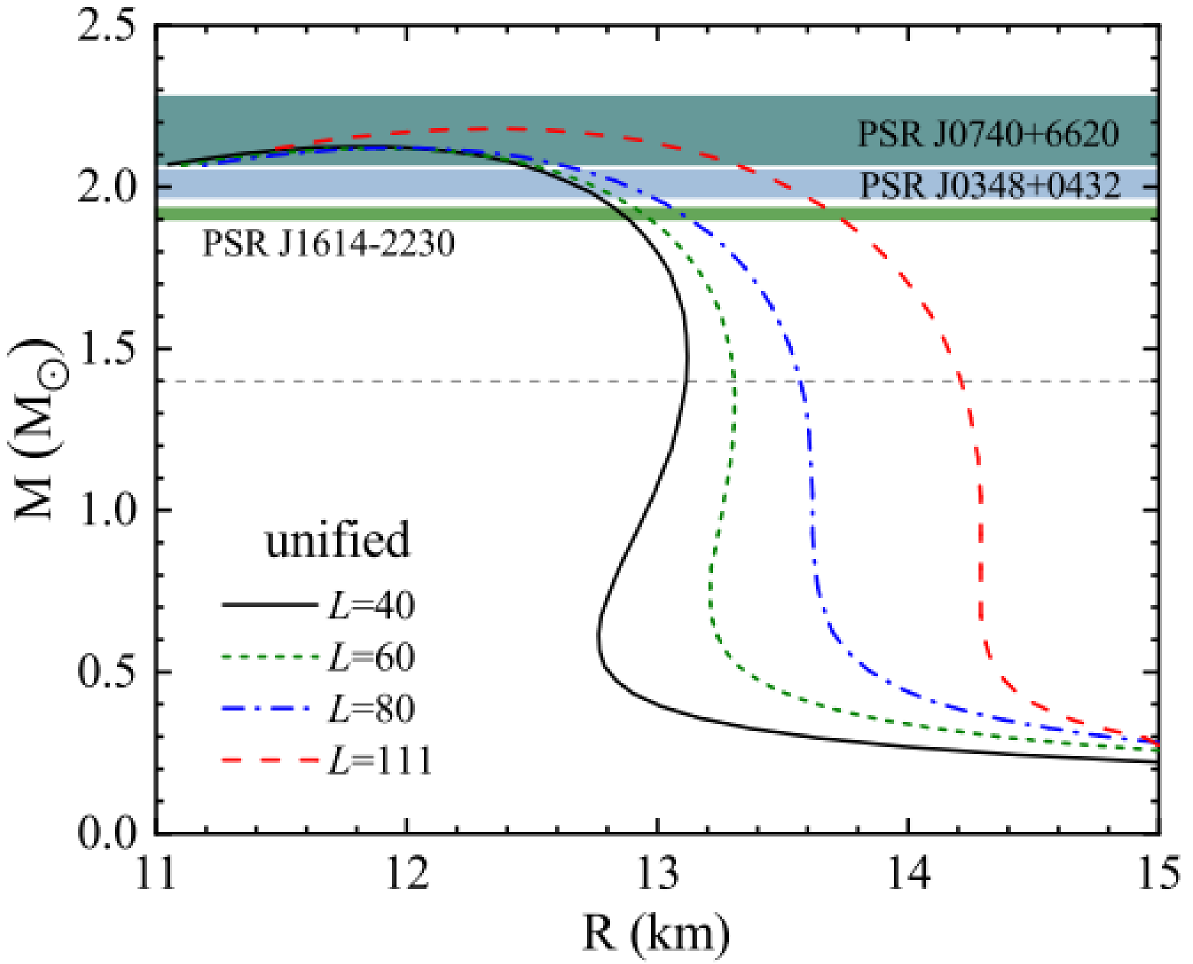
EOSs



Mass-radius relations



Effects of nuclear symmetry energy and equation of state on neutron star properties,
Fan Ji, Jinniu Hu, S. S. Bao and H. Shen, Phys. Rev. C (accepted) .

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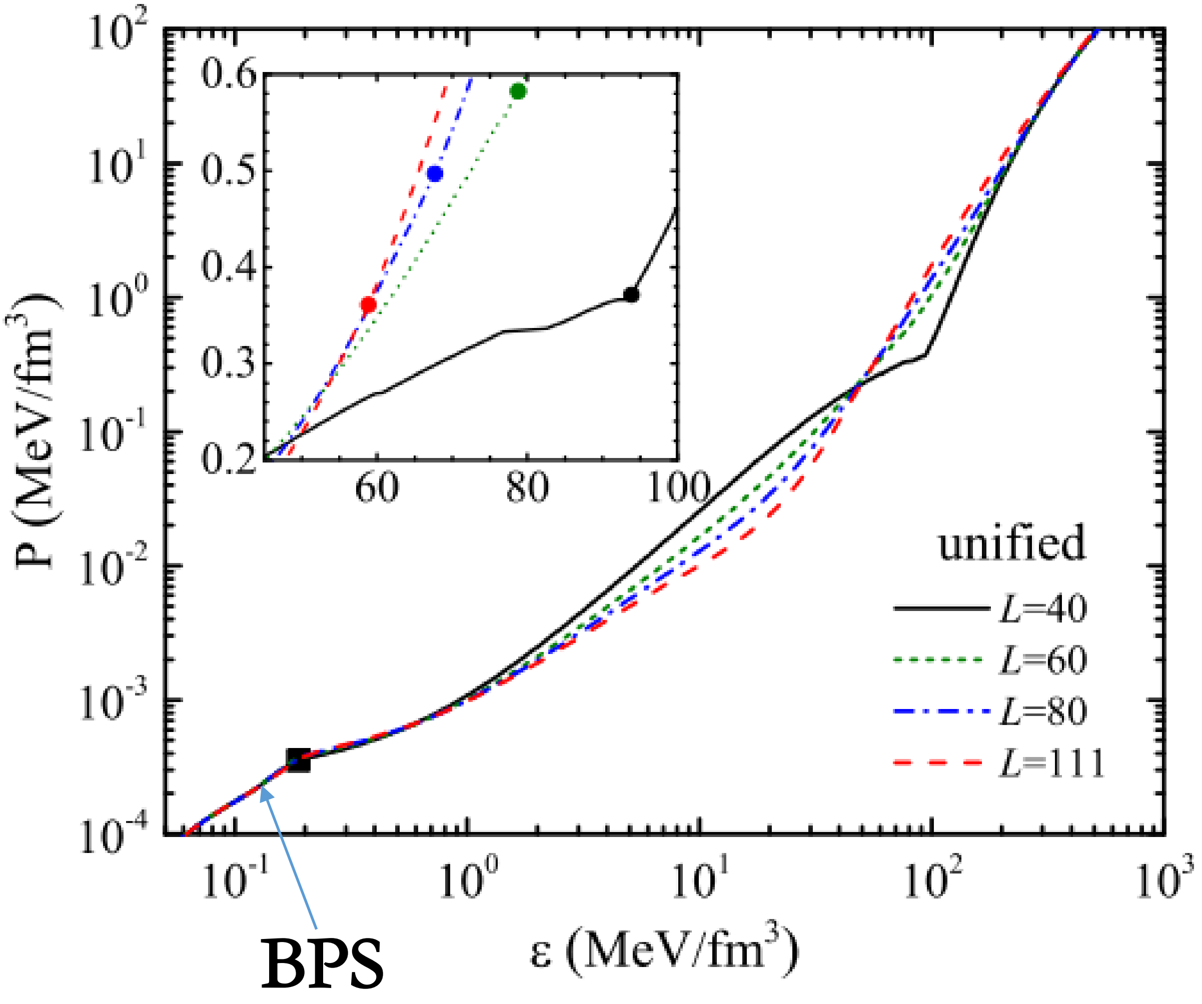
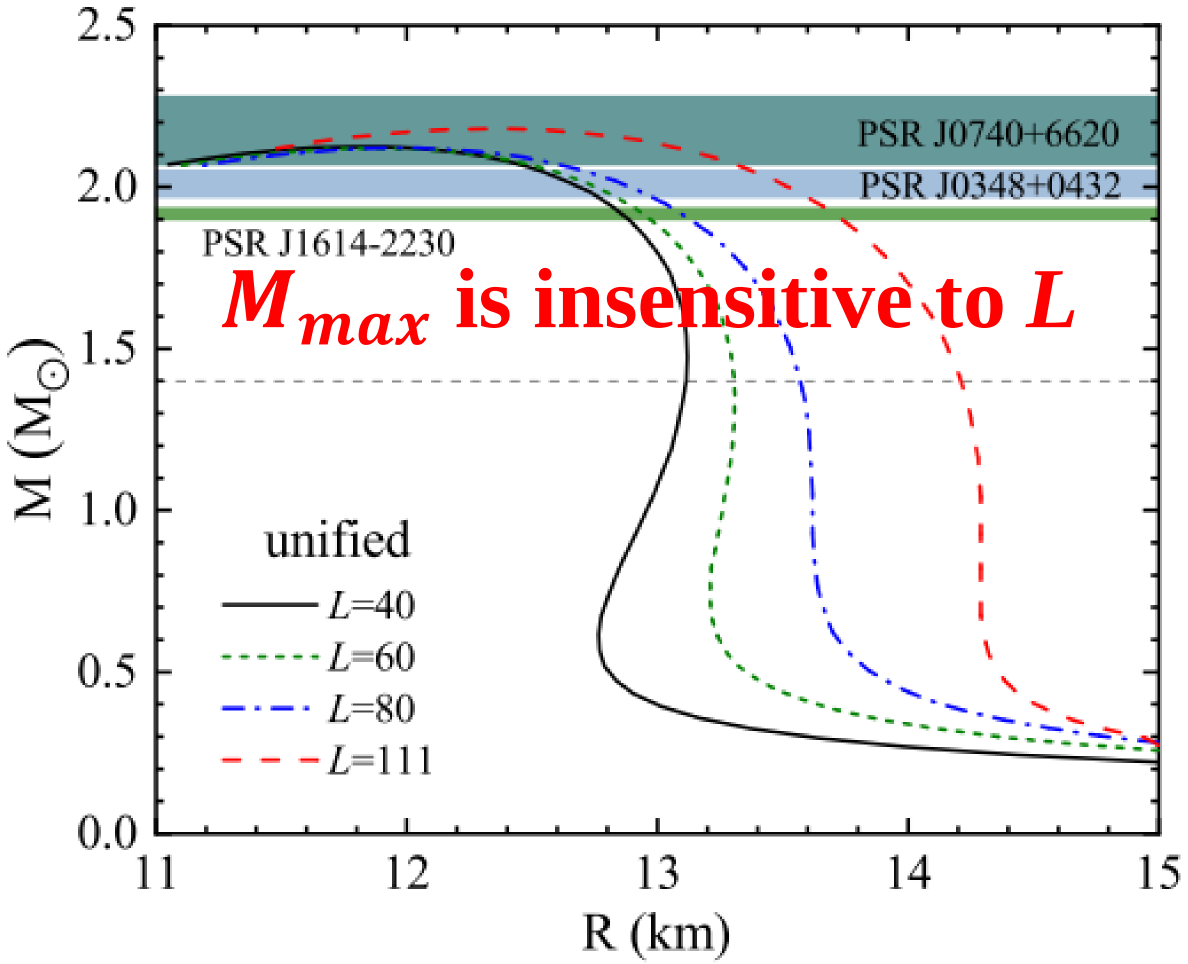
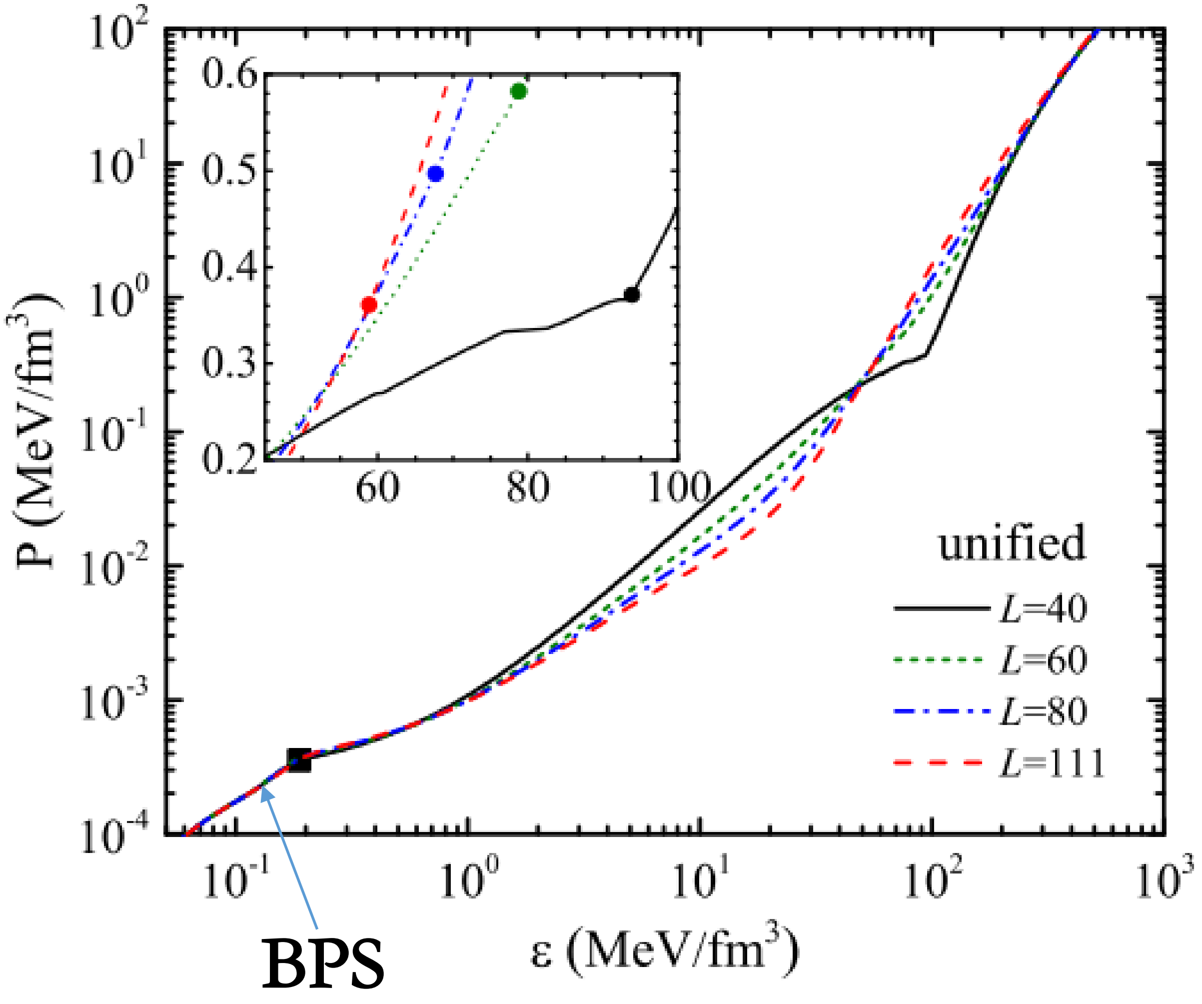


Mass-radius relations



3 Results—Neutron-star properties with unified EOSs

EOSs



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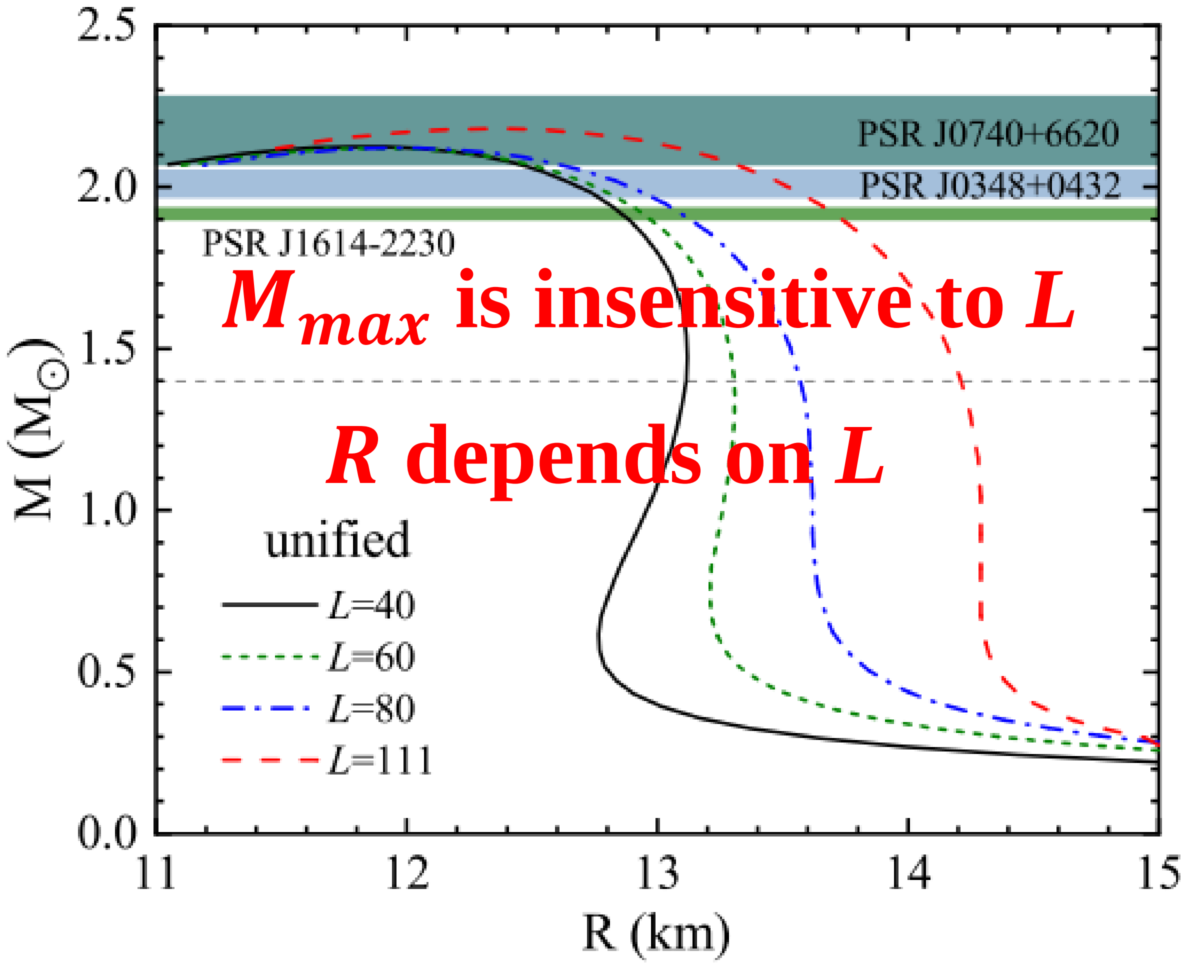
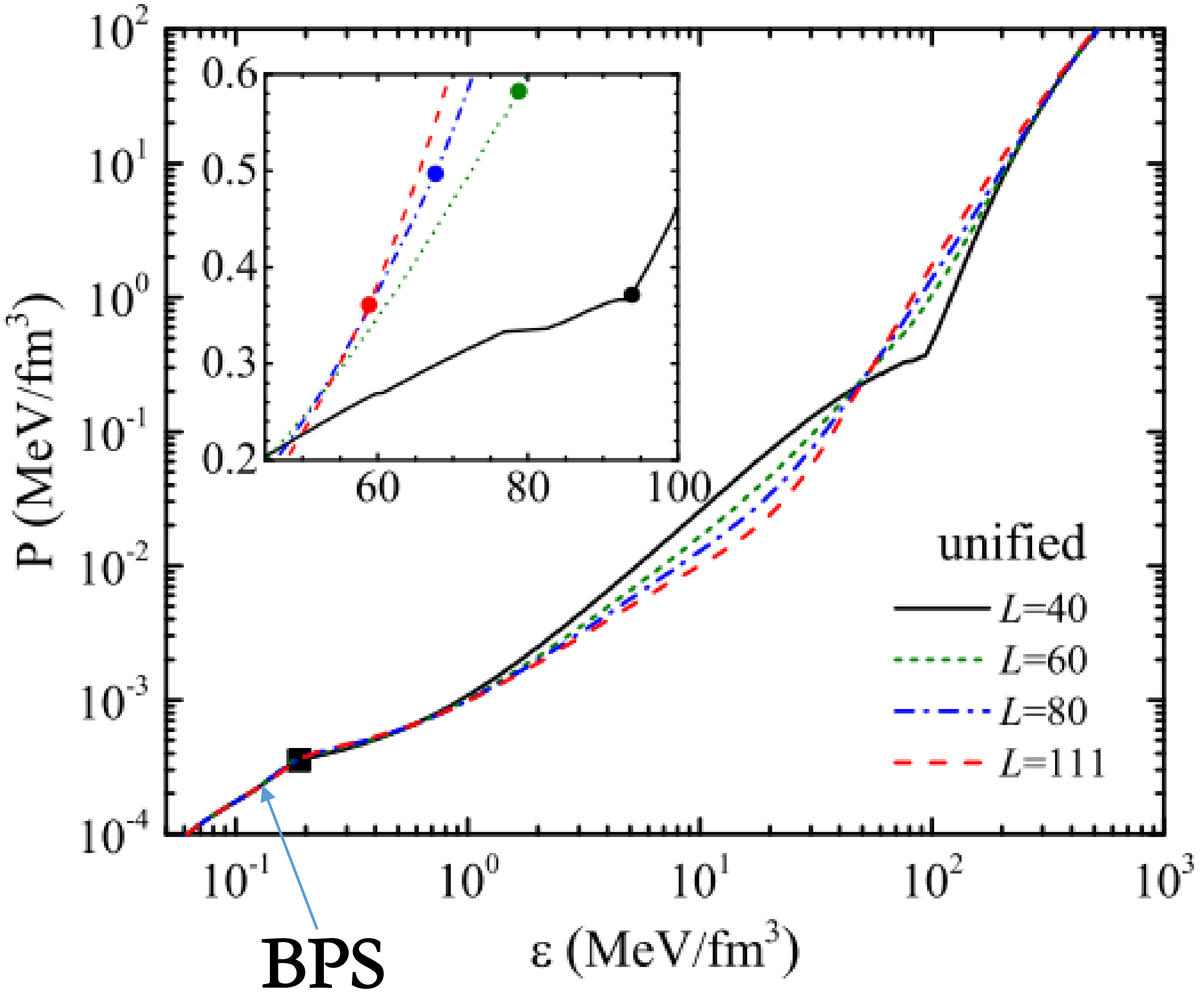
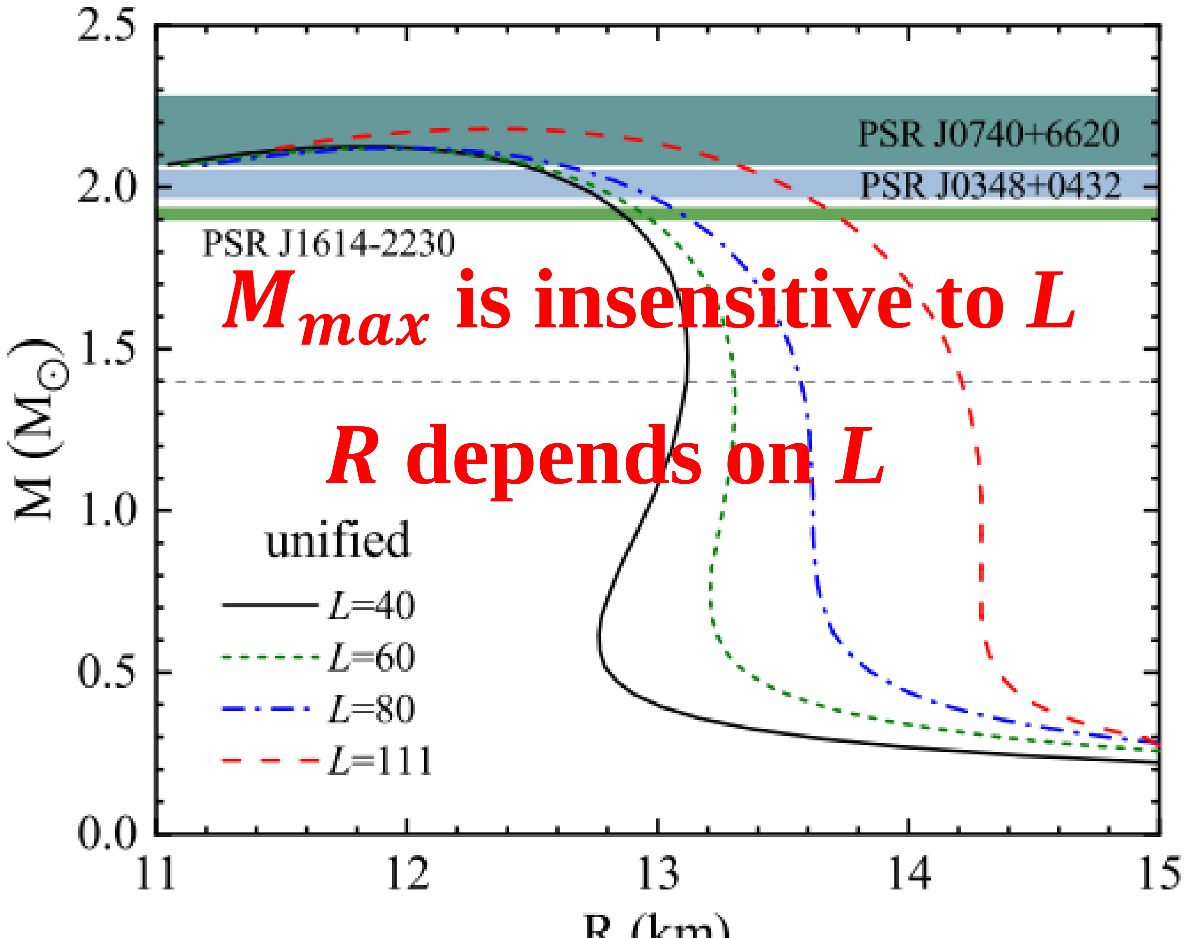


Results—Neutron-star properties with unified EOSs

EOSs



Mass-radius relations



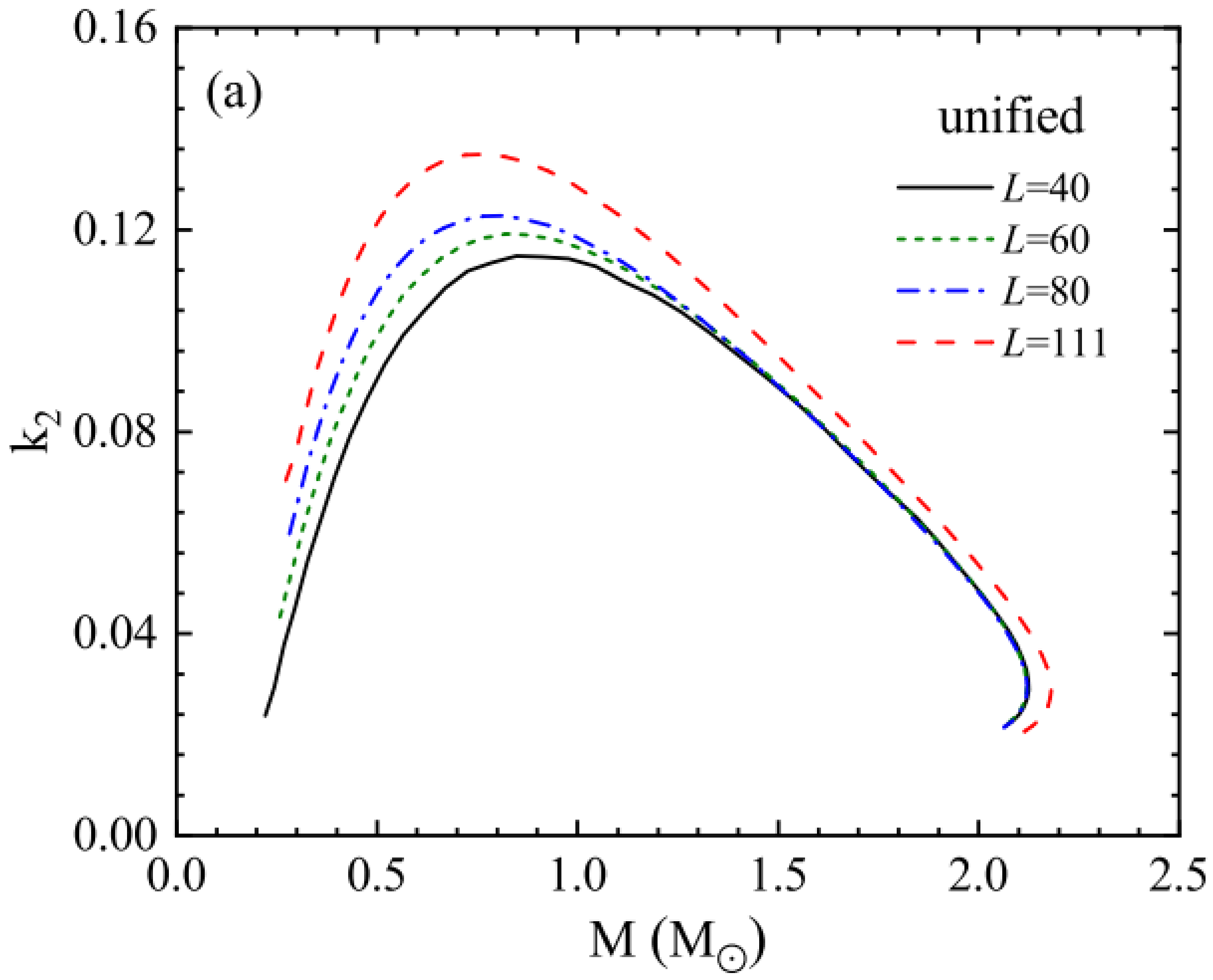
M_{max} is insensitive to L

R depends on L

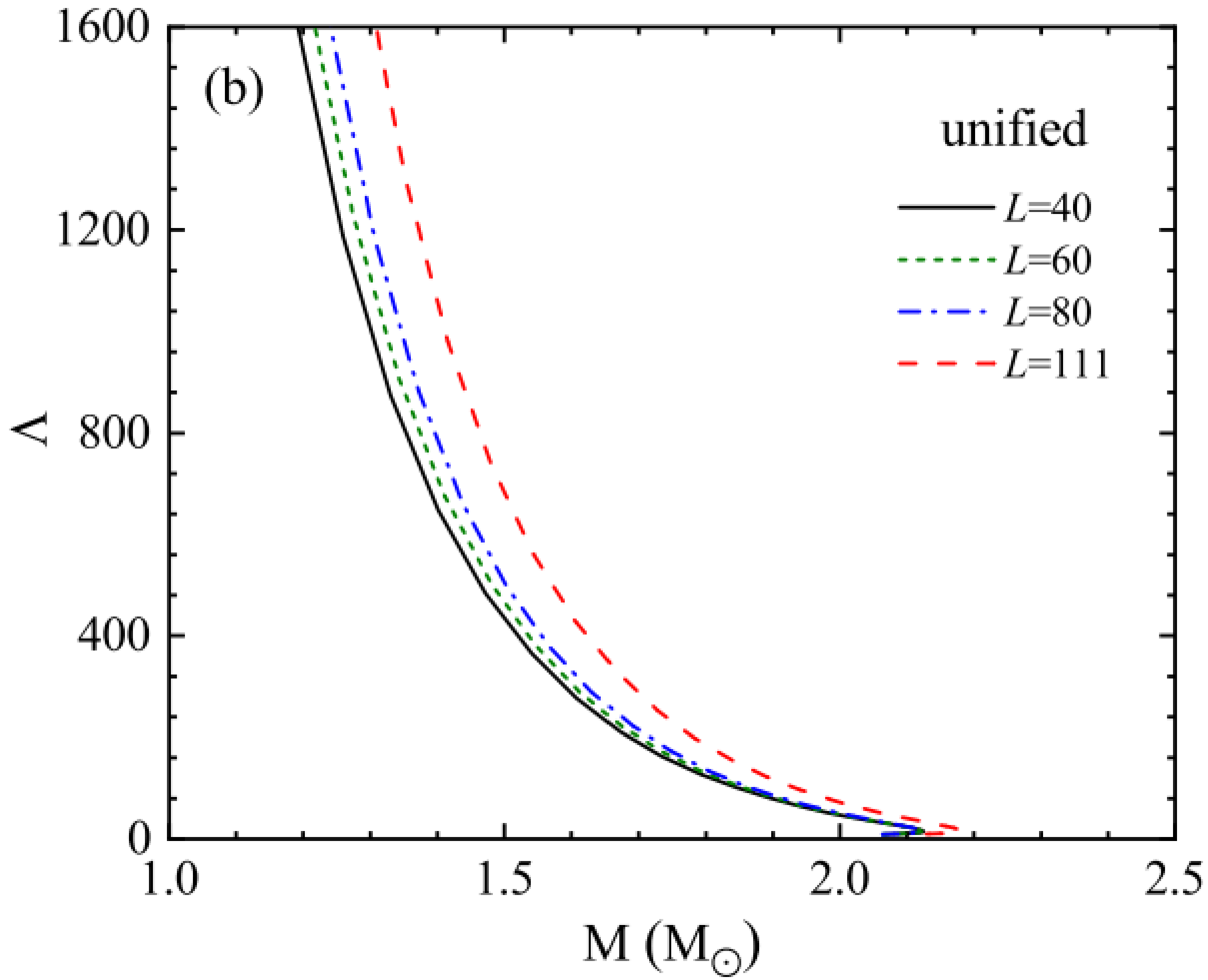
GW170817: $R_{1.4} < 13.6\ km$

B. P. Abbott et al. (Virgo, LIGO Scientific), Phys. Rev. Lett. 119, 161101 (2017).

Love number k_2



Tidal deformability Λ



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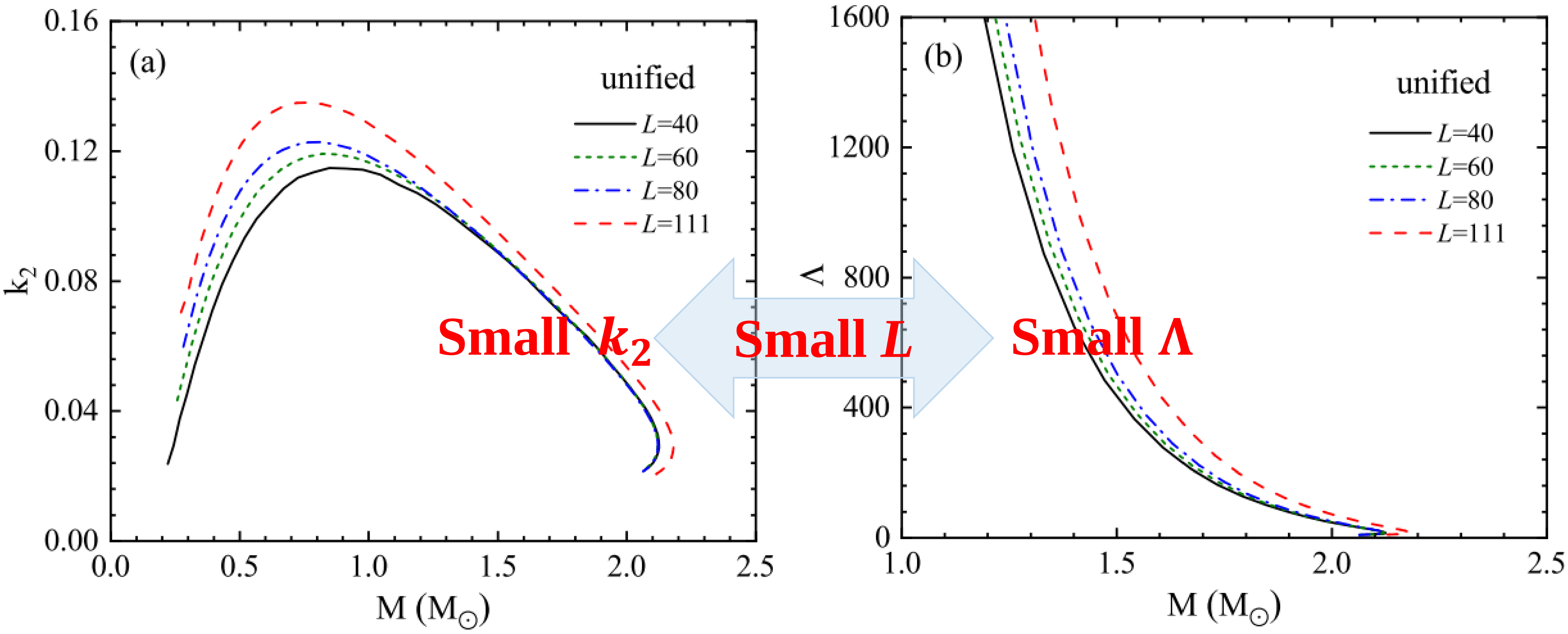
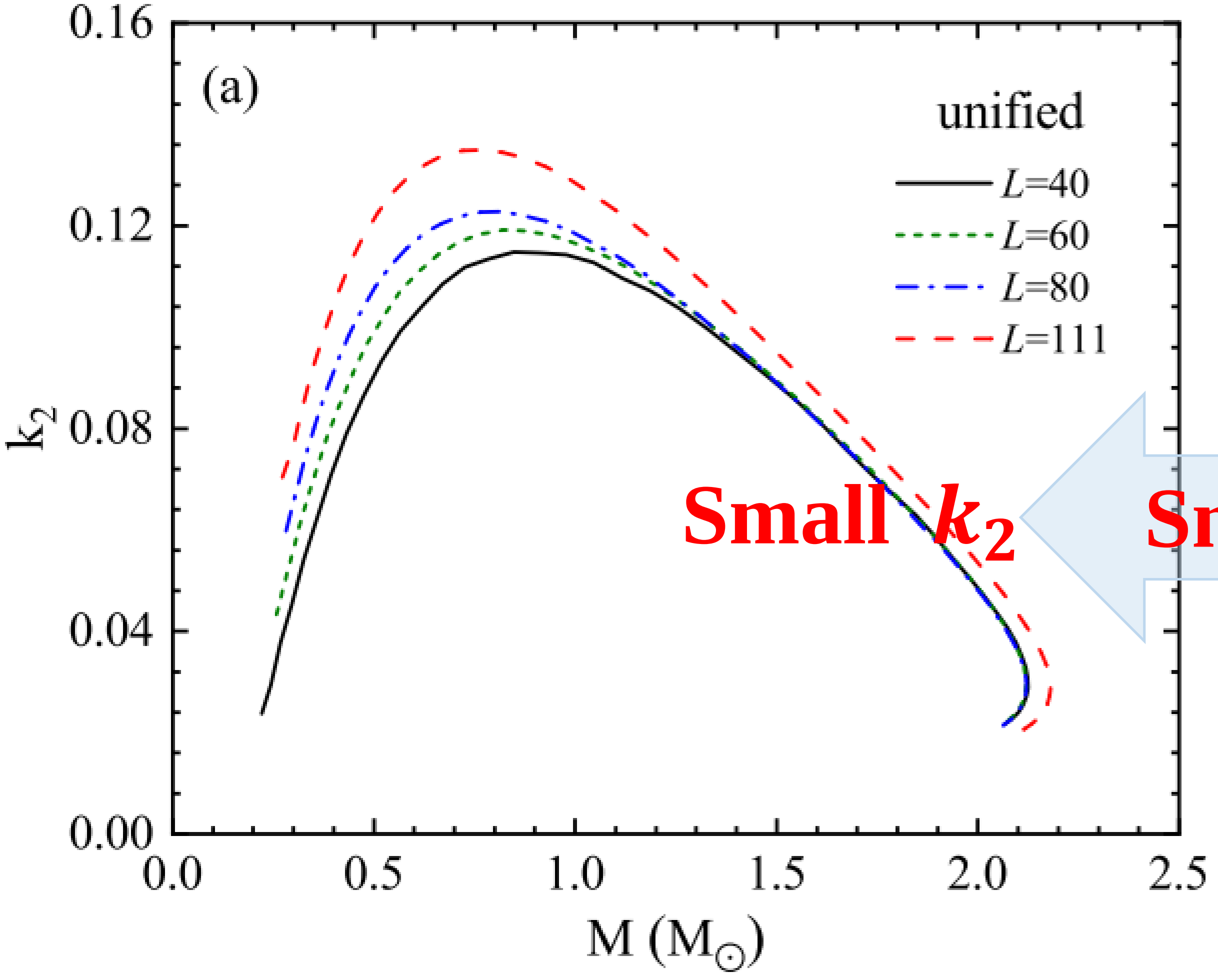
Love number k_2

Tidal deformability Λ

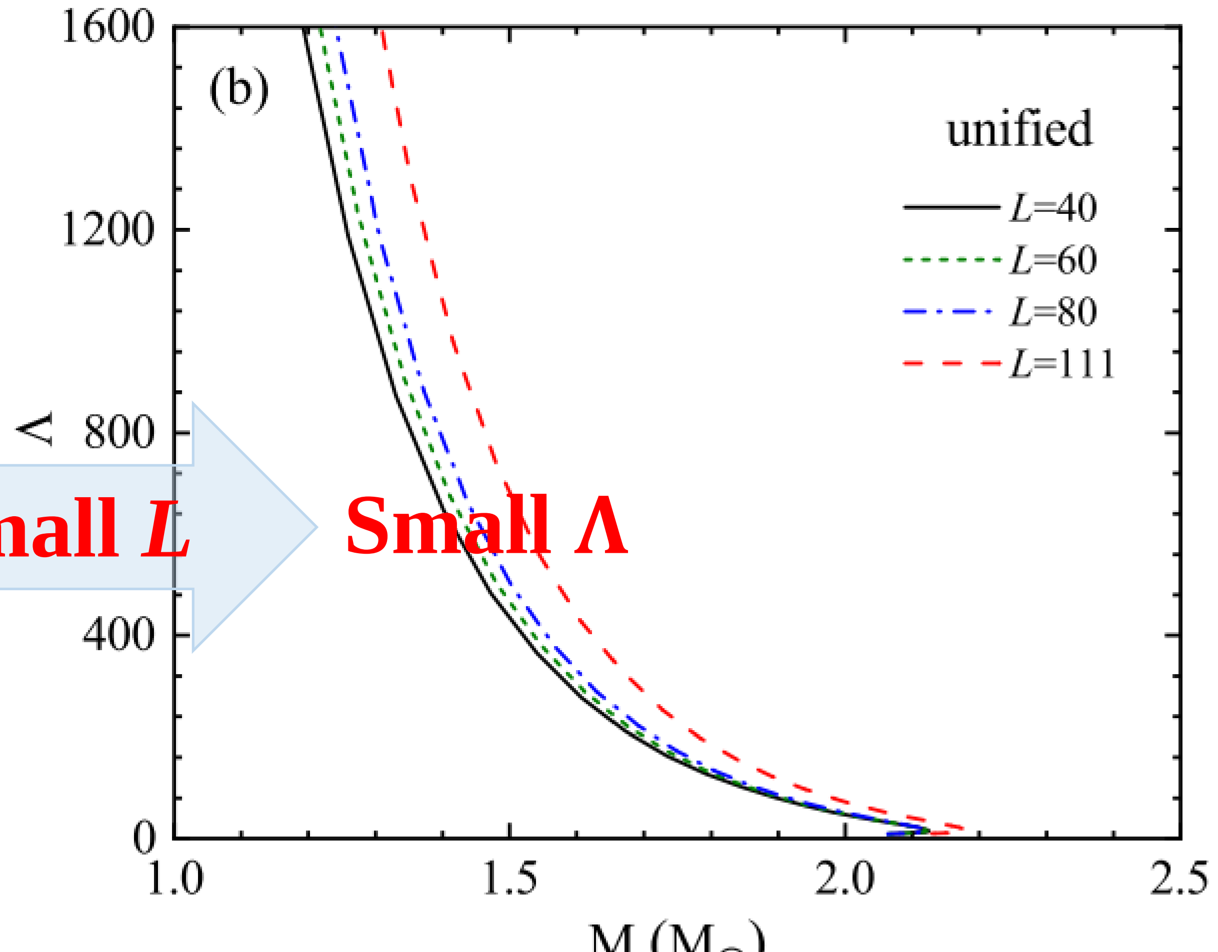


Results—Neutron-star properties with unified EOSs

Love number k_2



Tidal deformability Λ



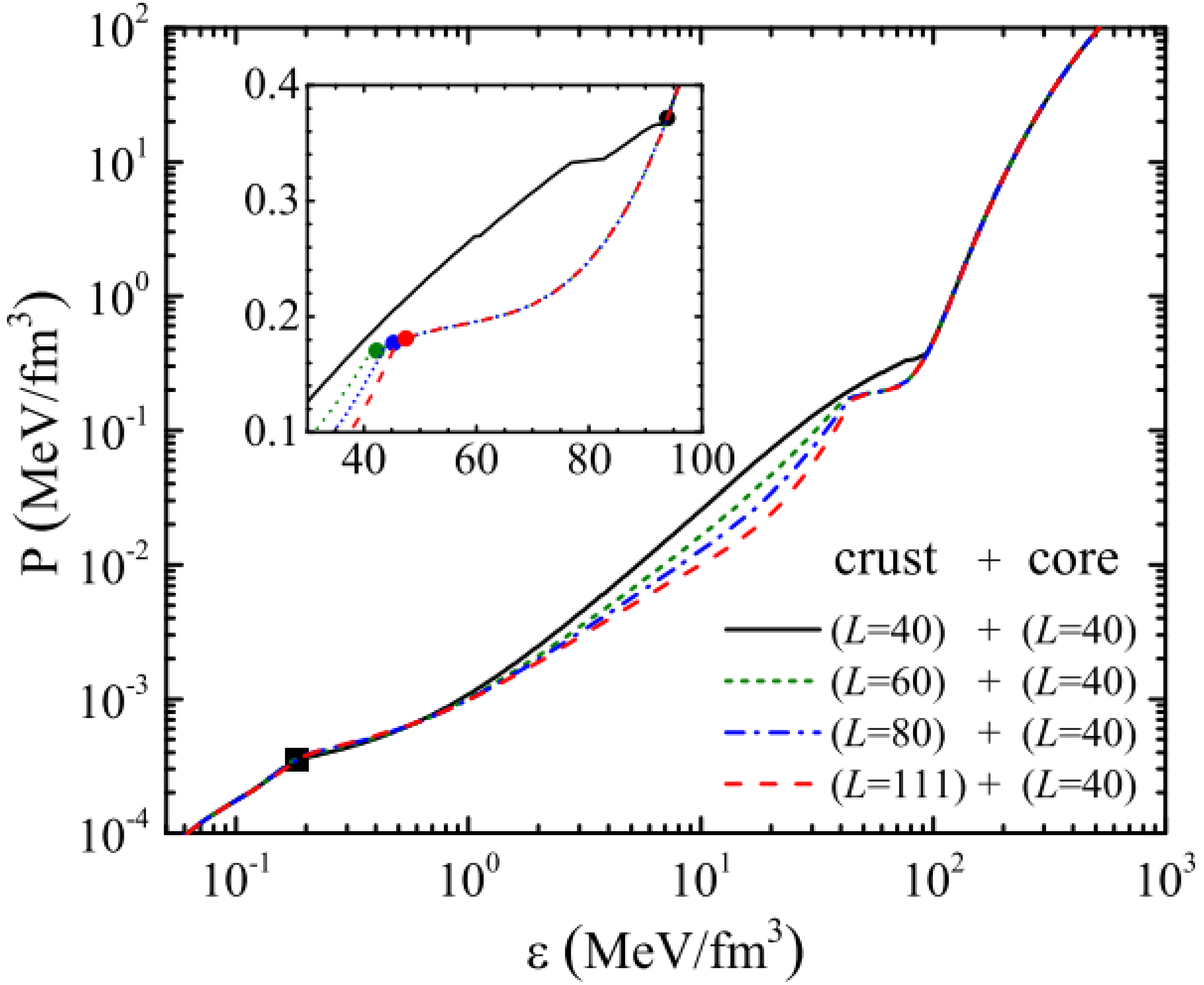
Small k_2 **Small L** **Small Λ**

GW170817: $\Lambda_{1.4} < 800$

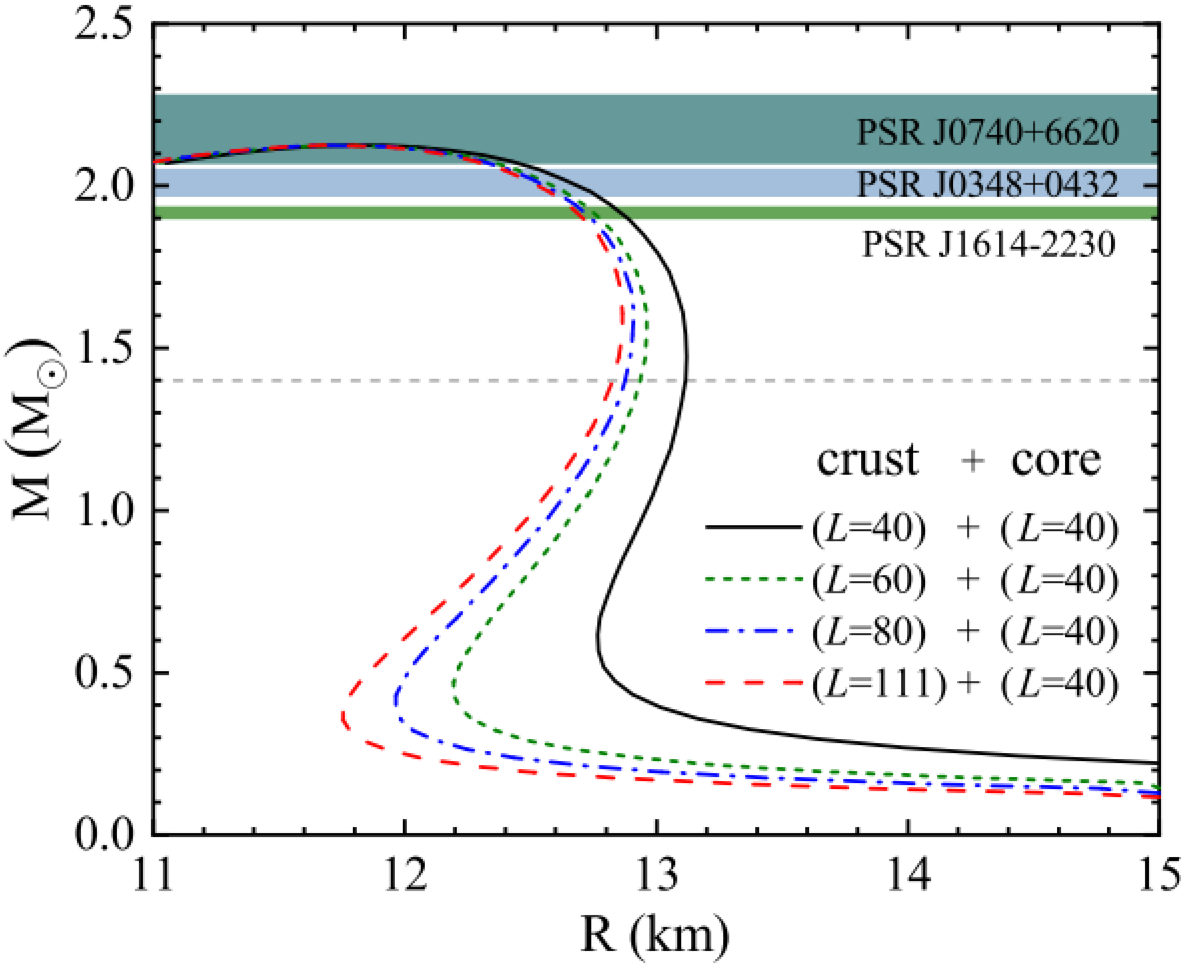
B. P. Abbott et al. (Virgo, LIGO Scientific), Phys. Rev. Lett. 119, 161101 (2017).

Results—Effects of the crust EOS

EOSs



Mass-radius relations



3 Results—Effects of the crust EOS

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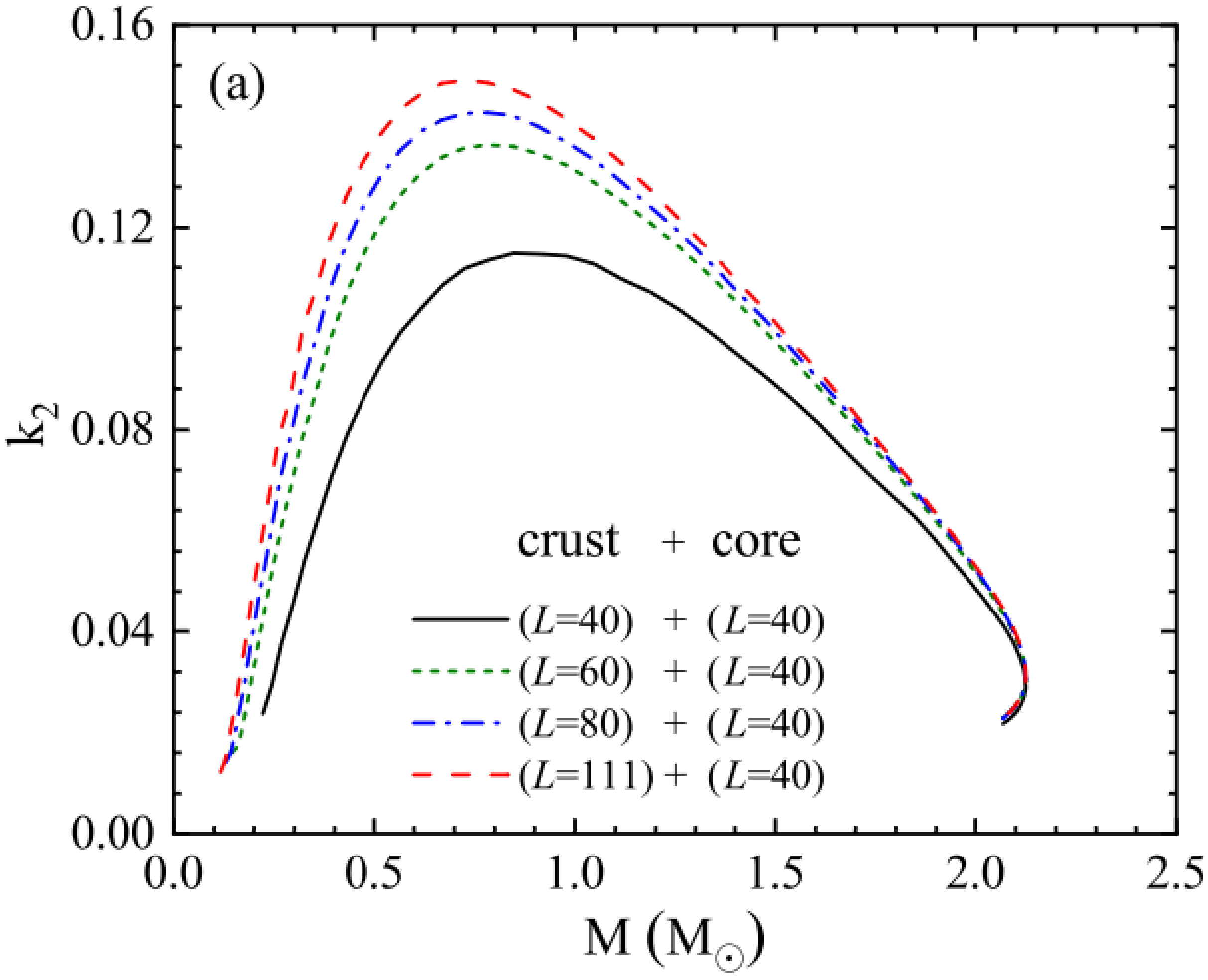
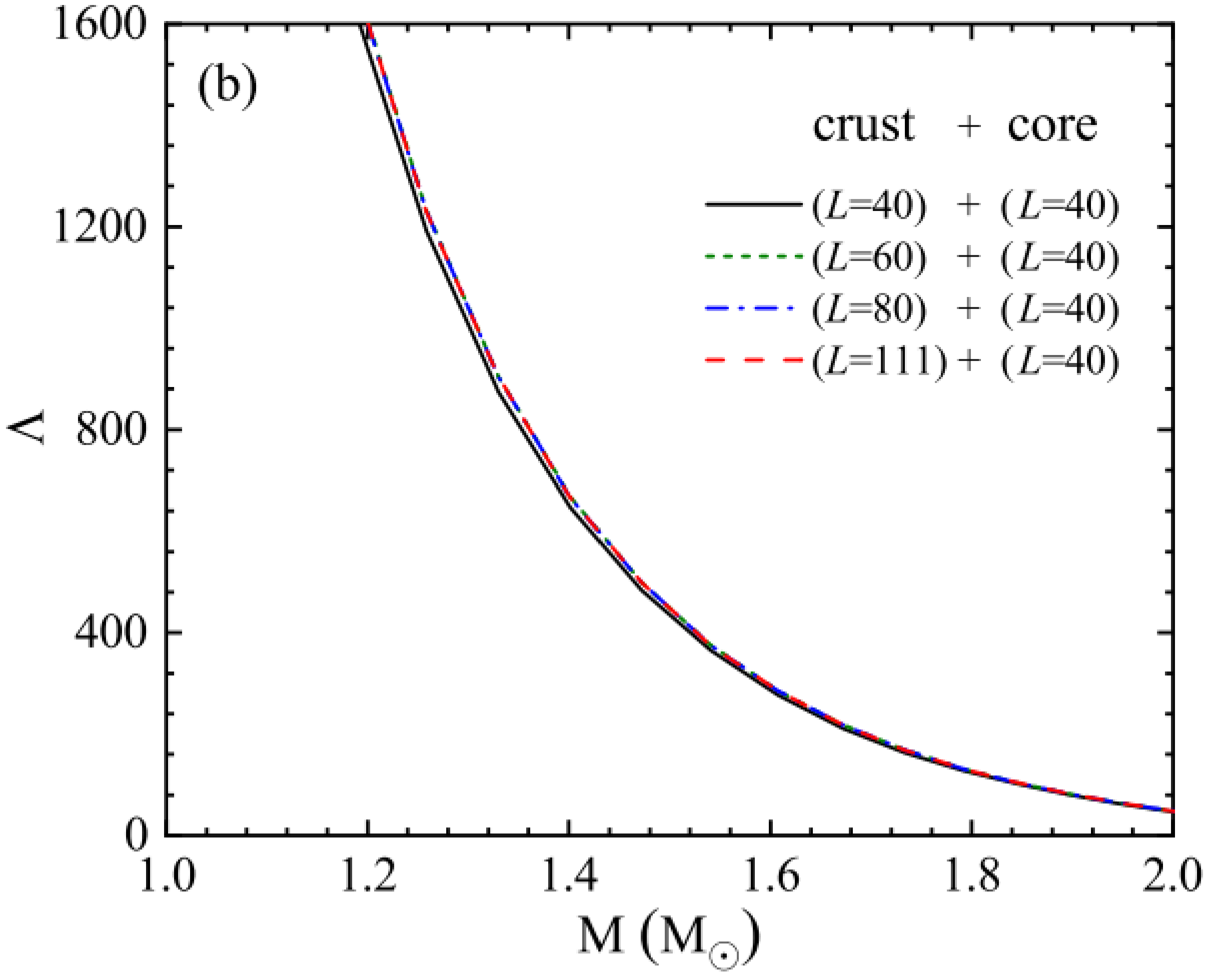
Love number k_2

Tidal deformability Λ





3 Results—Effects of the crust EOS

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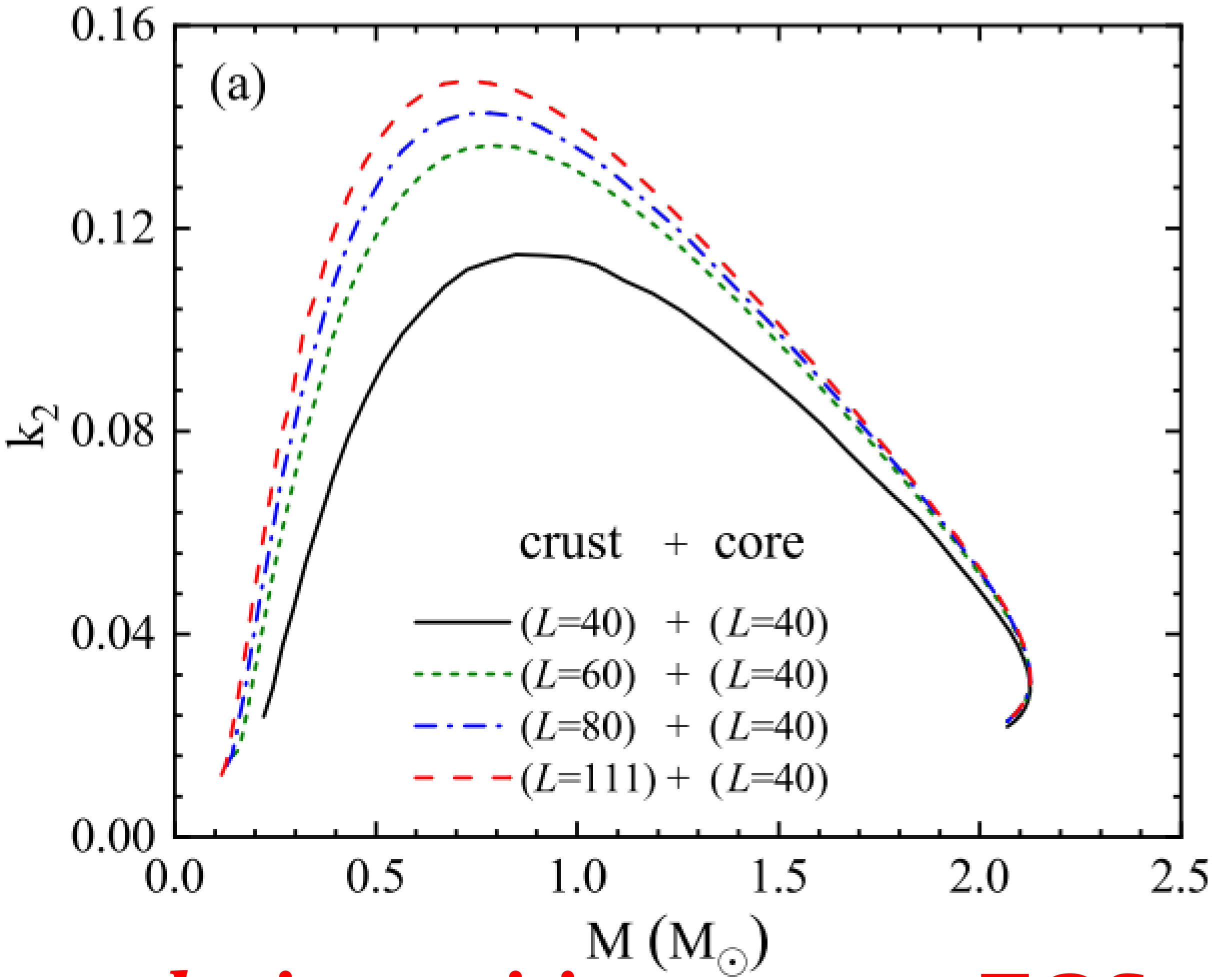
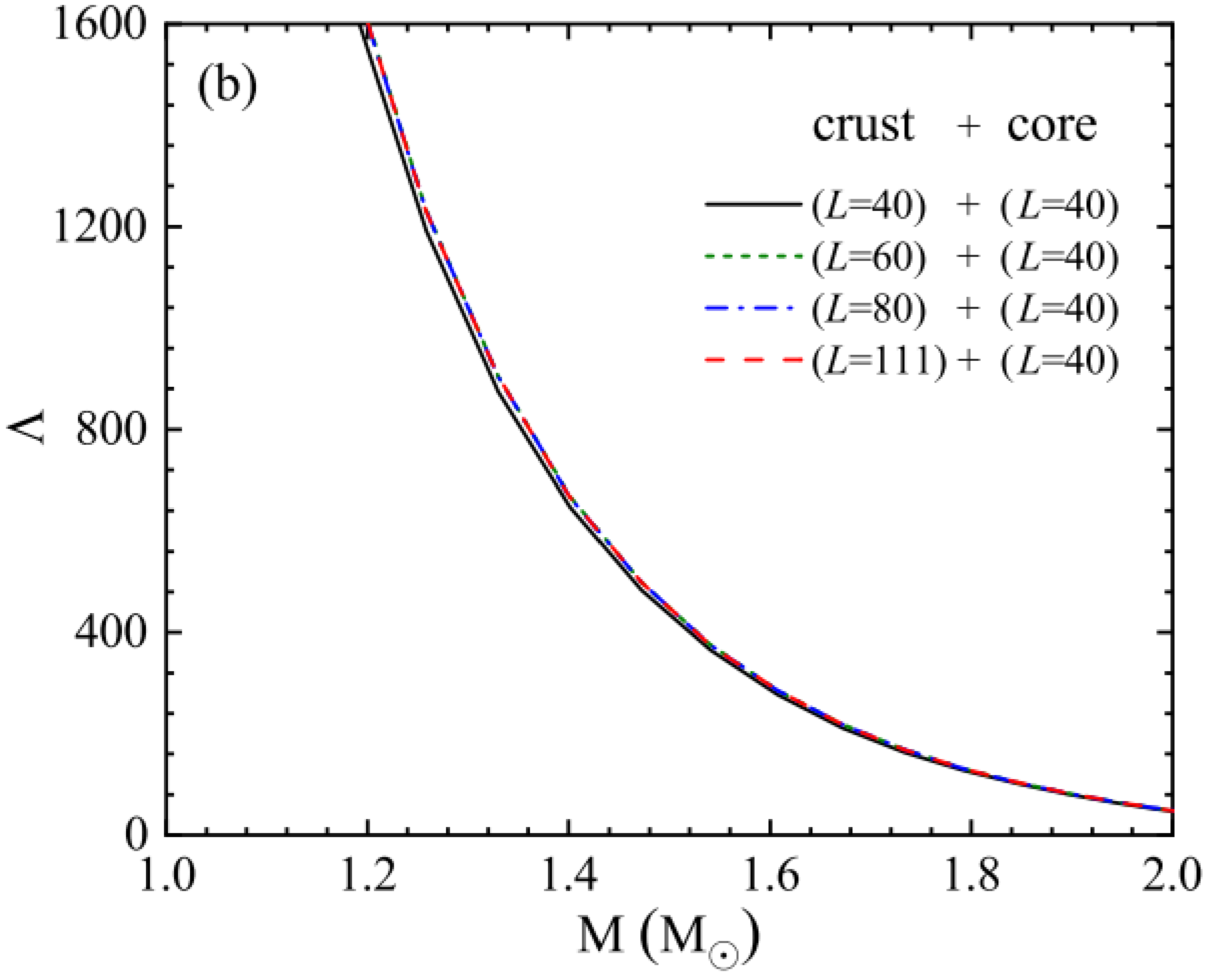
Love number k_2



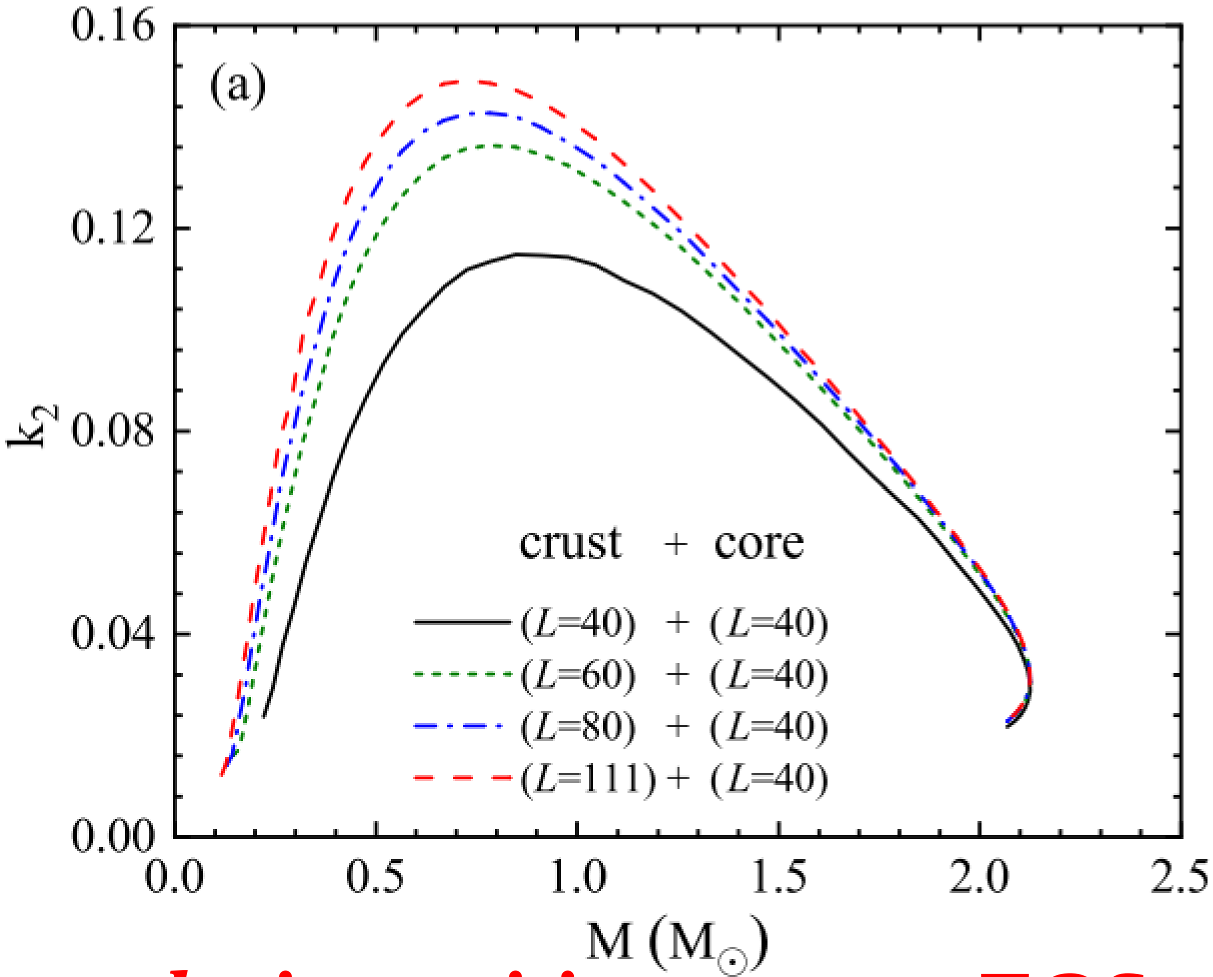
Tidal deformability Λ



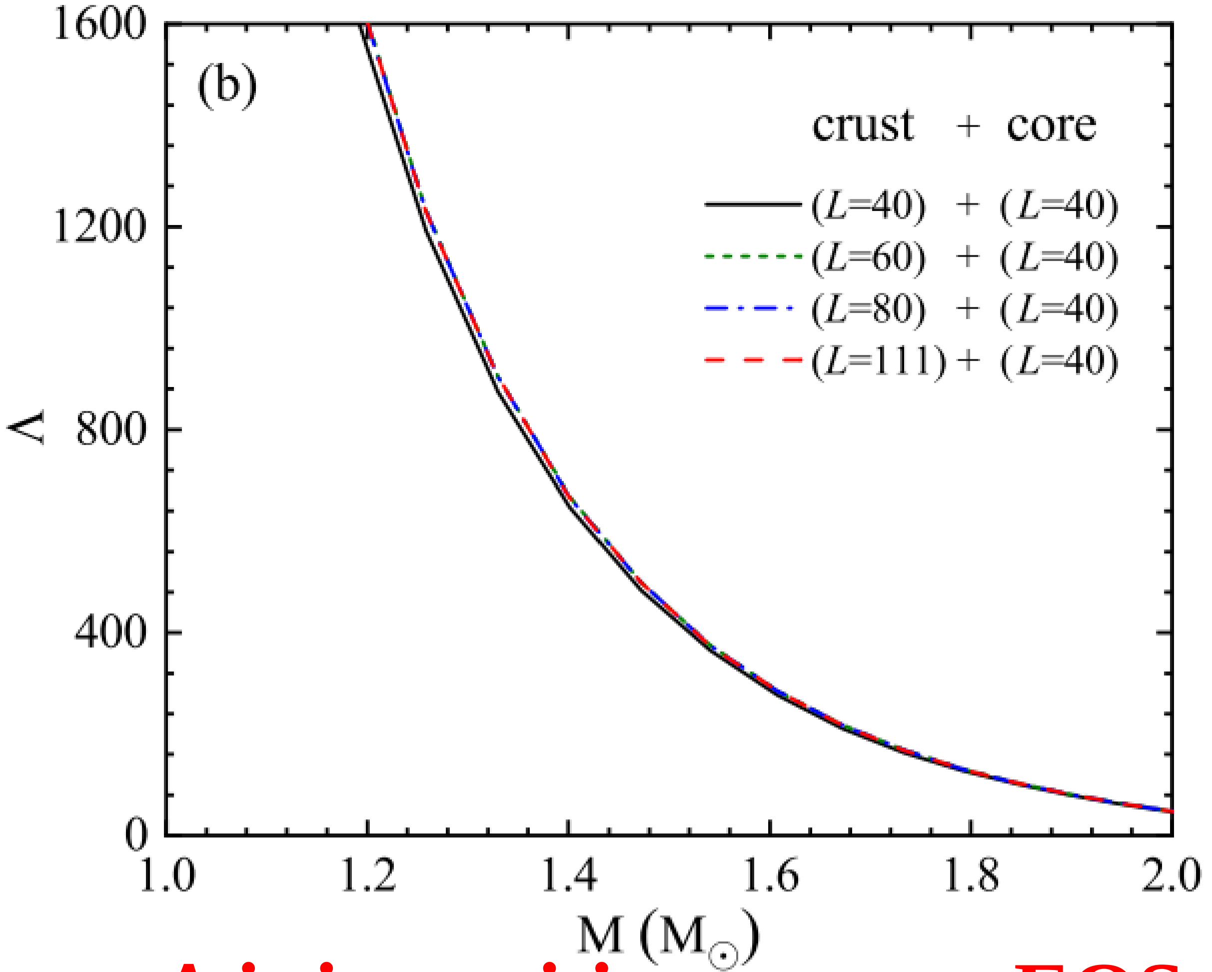
k_2 is sensitive to crust EOS

Results—Effects of the crust EOS

Love number k_2



Tidal deformability Λ



k_2 is sensitive to crust EOS

Λ is insensitive to crust EOS

3 Results—Effects of the core EOS

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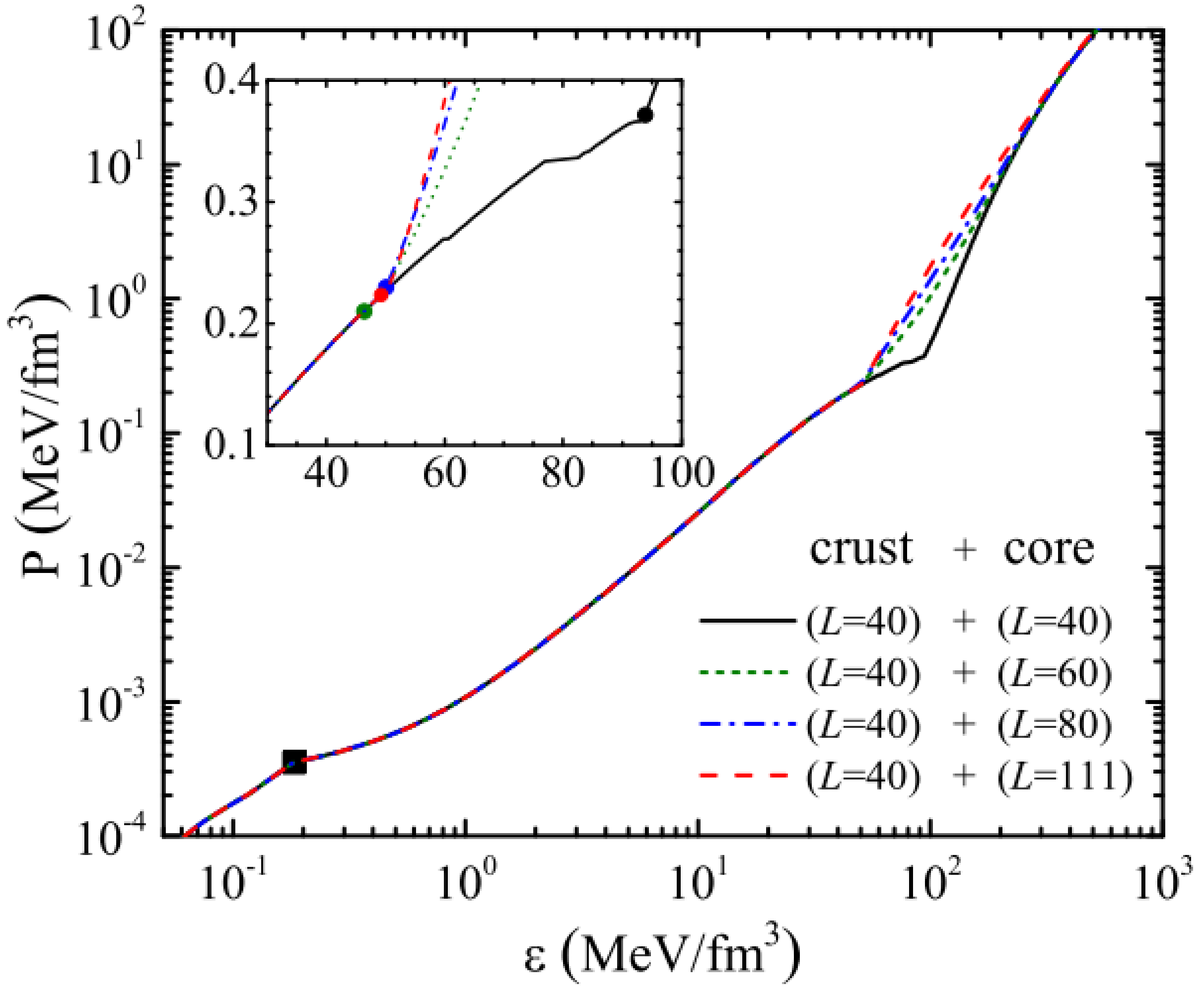
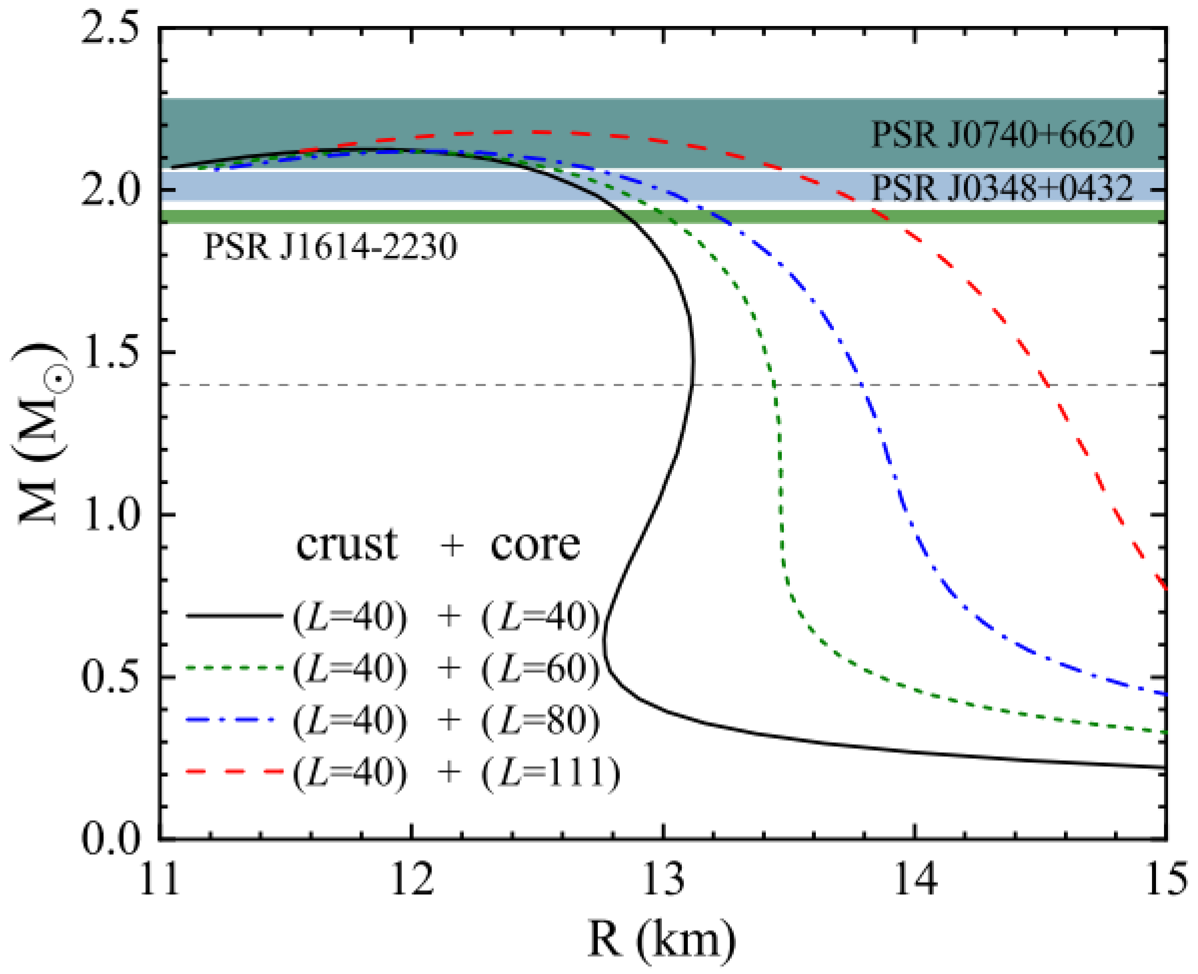
EOSs

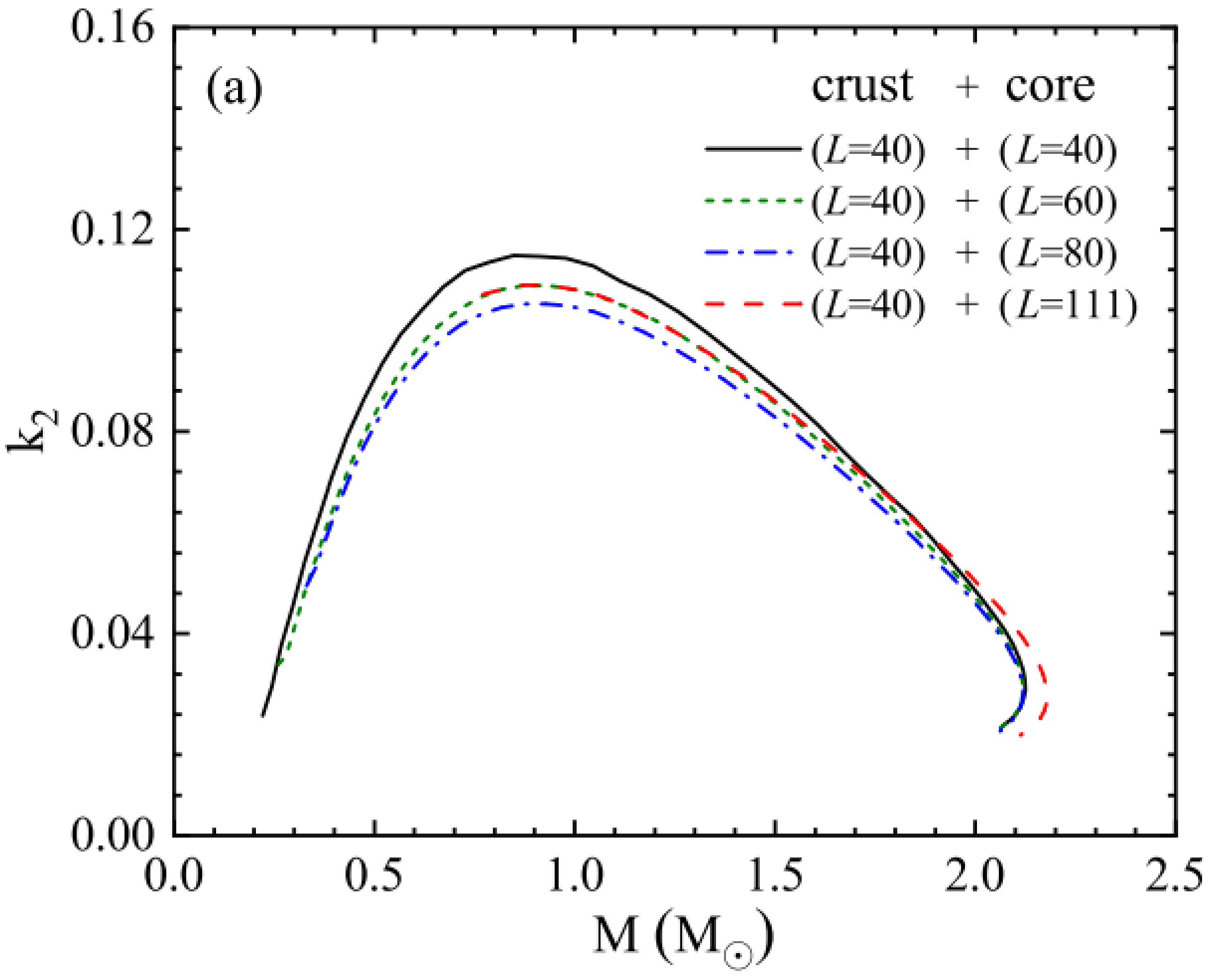


Mass-radius relations

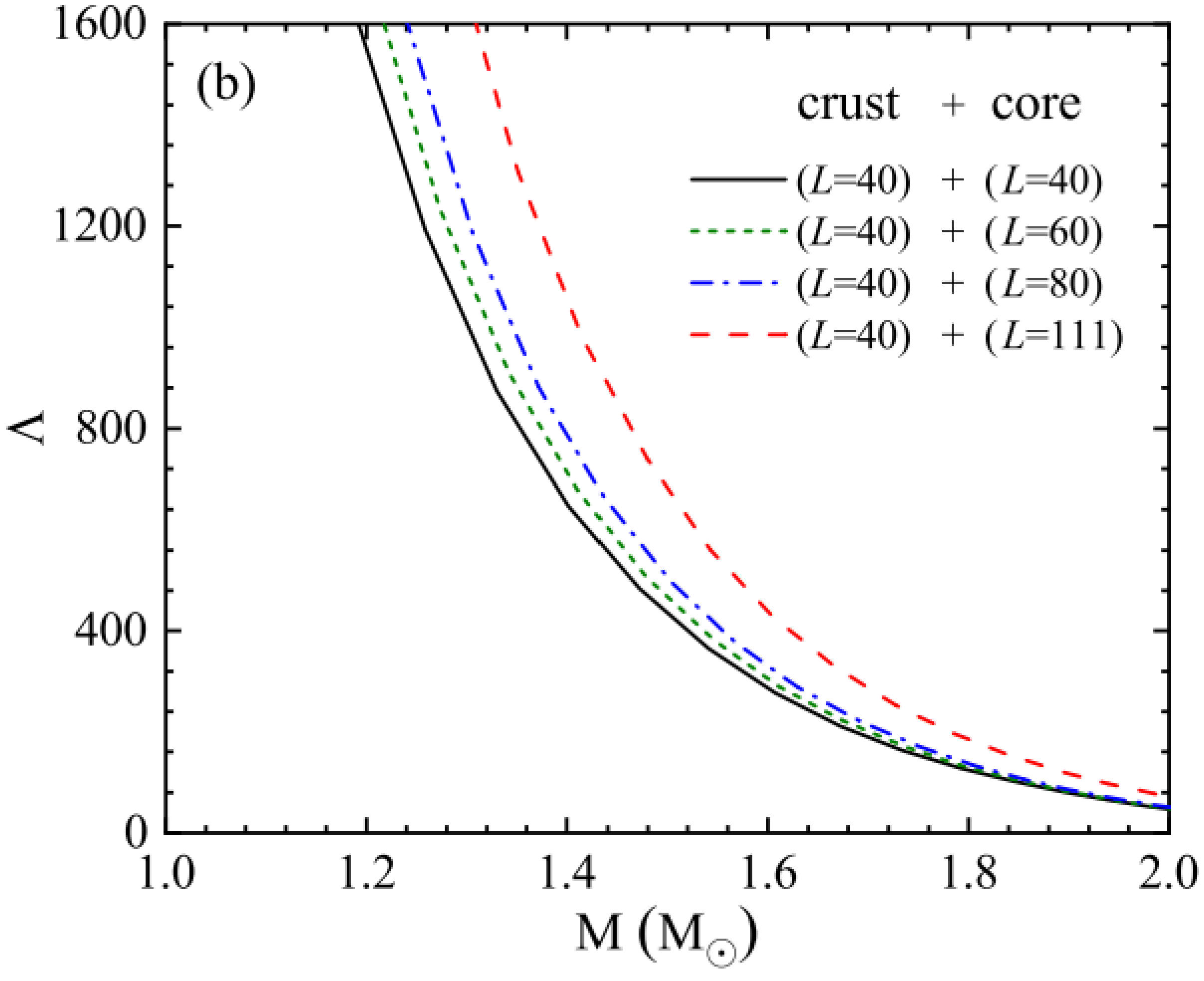


3 Results—Effects of the core EOS

Love number k_2



Tidal deformability Λ



4 Conclusions

- The model with a small *L* predicts a large crust-core transition density.
- A small *L* corresponds to a small neutron-star radius and a small tidal deformability.
- The effect of the core EOS on the tidal deformability Λ is more significant than the one of the crust EOS .
- Both the crust and core EOSs could significantly affect neutron star properties such as the radius and tidal deformability.

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