FAST/Future Pulsar Symposium 9
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The investigation of secondary compact object in GW190814 with DDRMF model

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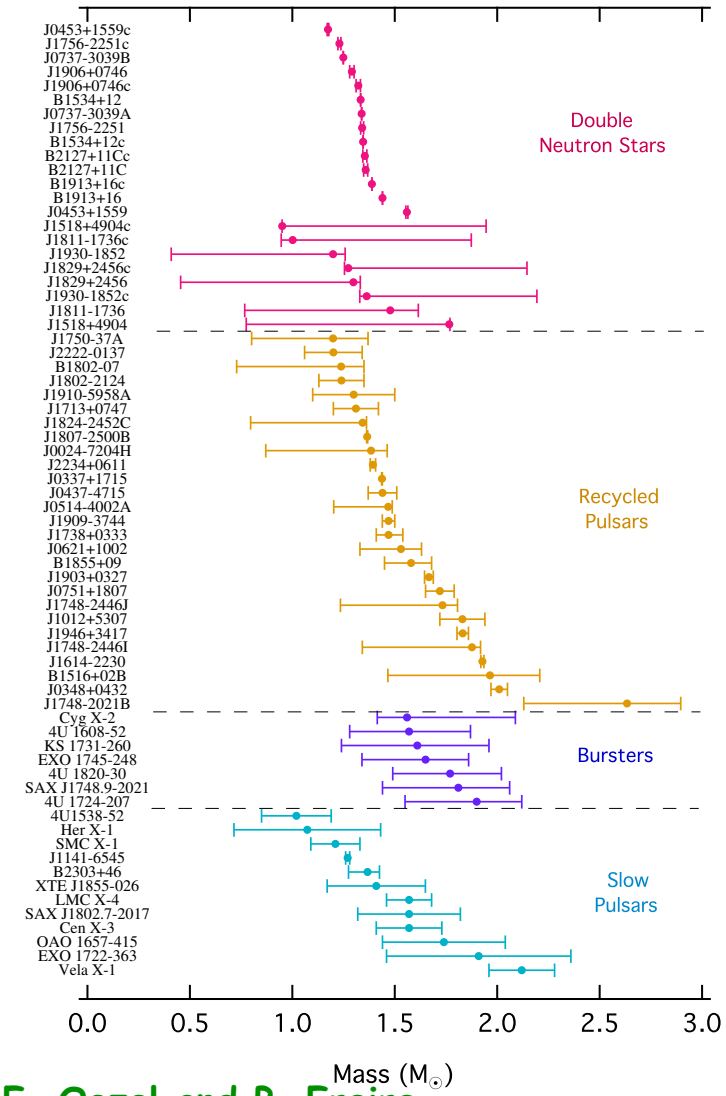
School of Physics, Nankai University

SNP, Nishina Center, RIKEN

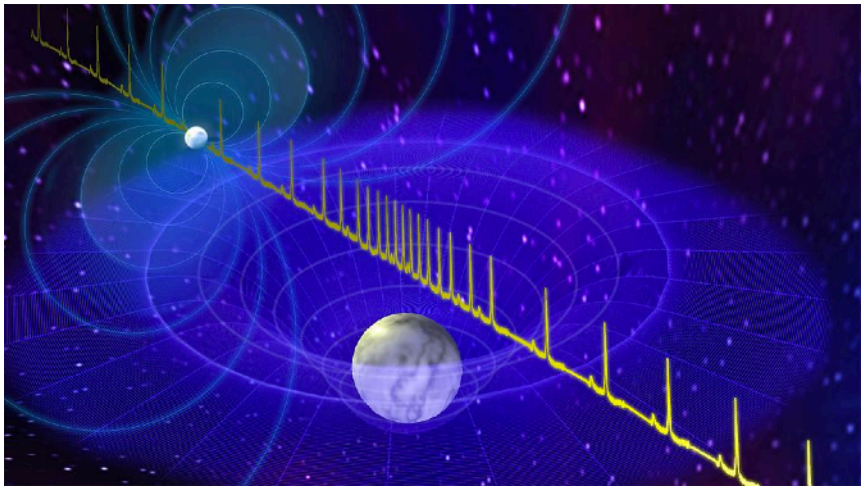
Kaixuan Huang, Jinniu Hu, Ying Zhang, and Hong Shen, arXiv: 2008.04491

Massive Neutron stars



F. Oezel and P. Freire

Annu. Rev. Astron. Astrophys. 54 (2016)401



PSR J1614-2230: 1.928±0.017 $M_\odot$

P. B. Demorest, et al., Nature. 467(2010)108

E. Fonseca et al., Astrophys. J. 832, 167 (2016).

PSR J0348+0432: 2.01±0.04 $M_\odot$

P. J. Antoniadis et al., Science 340, 1233232 (2013).

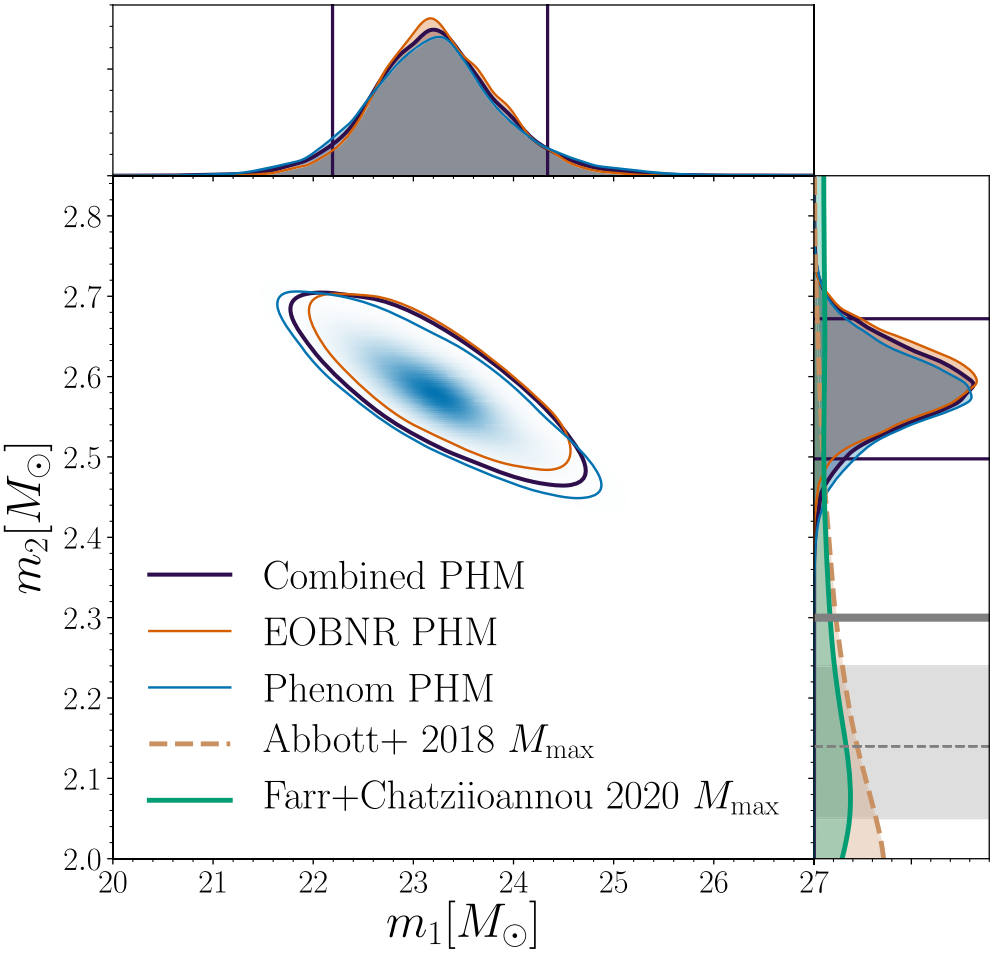
PSR J0740+6620: 2.14±0.10 $M_\odot$

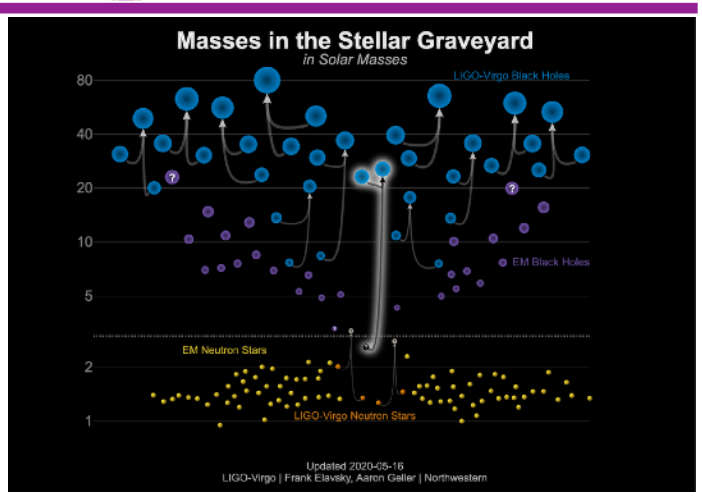
H. T. Cromartie et al., Nat. Astron. 4, 72 (2020)

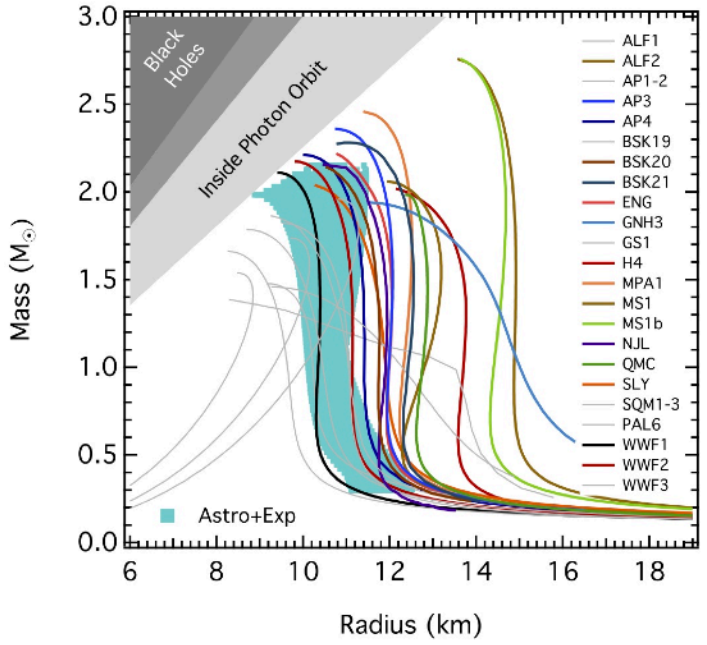
The GW190814-2.6$M_\odot$ object

The Astrophysical Journal Letters, 896:L44 (20pp), 2020 June 20
https://doi.org/10.3847/2041-8213/ab960f

GW190814: Gravitational Waves from the Coalescence of a 23 Solar Mass Black Hole with a 2.6 Solar Mass Compact Object







F. Oezel and P. Freire Annu. Rev. Astron. Astrophys. 54 (2016)401

The possibilities of GW190814

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A heavy neutron star including the deconfined QCD matter

H. Tan, J. Noronha-Hostler, and N. Yunes, (2020), arXiv:2006.16296

V. Dexheimer, R.O. Gomes, T. Klähn, S. Han and M. Salinas, (2020), arXiv:2007.08493

A super-fast pulsar

N. B. Zhang and B.-A. Li, (2020), arXiv:2007.02513

V. Dexheimer, R.O. Gomes, T. Klähn, S. Han and M. Salinas, (2020), arXiv:2007.08493

A normal neutron star

Y. Lim, A. Bhattacharya, J. W. Holt, and D. Pati, (2020), arXiv:2007.0652

A black hole

I. Tews, et al.,(2020), arXiv:2007.06057

F. Fattoyev, C. Horowitz, J. Piekarewicz, and B. Reed, (2020), arXiv:2007.03799

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Density-dependent CDFT

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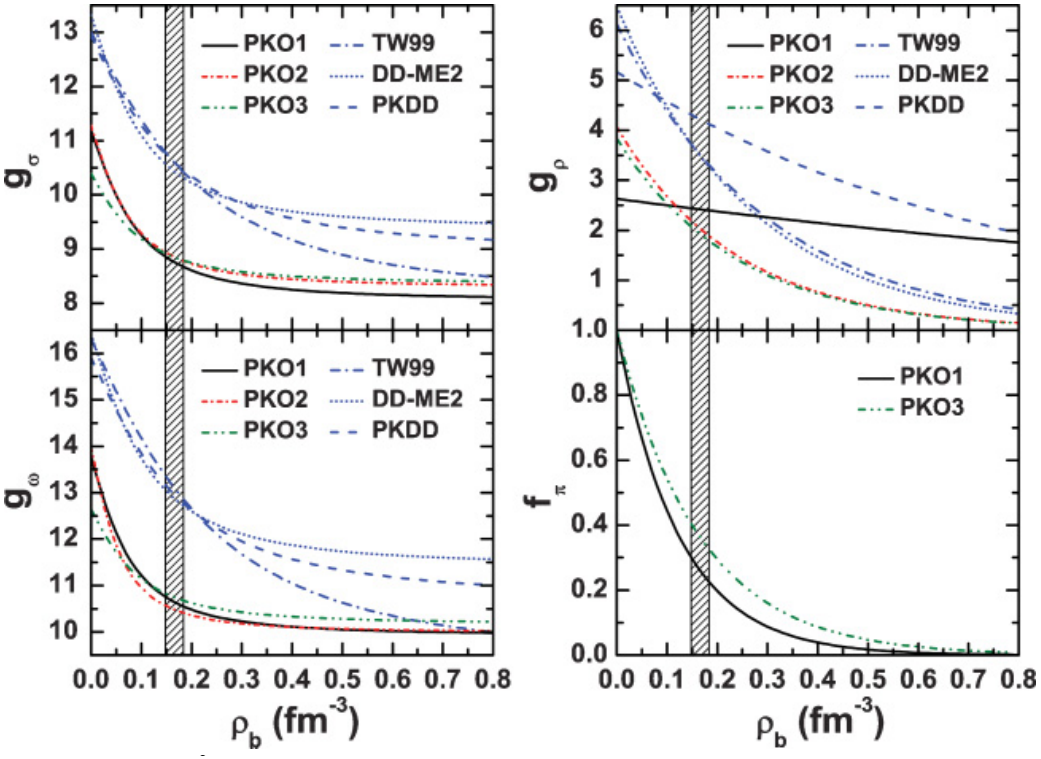
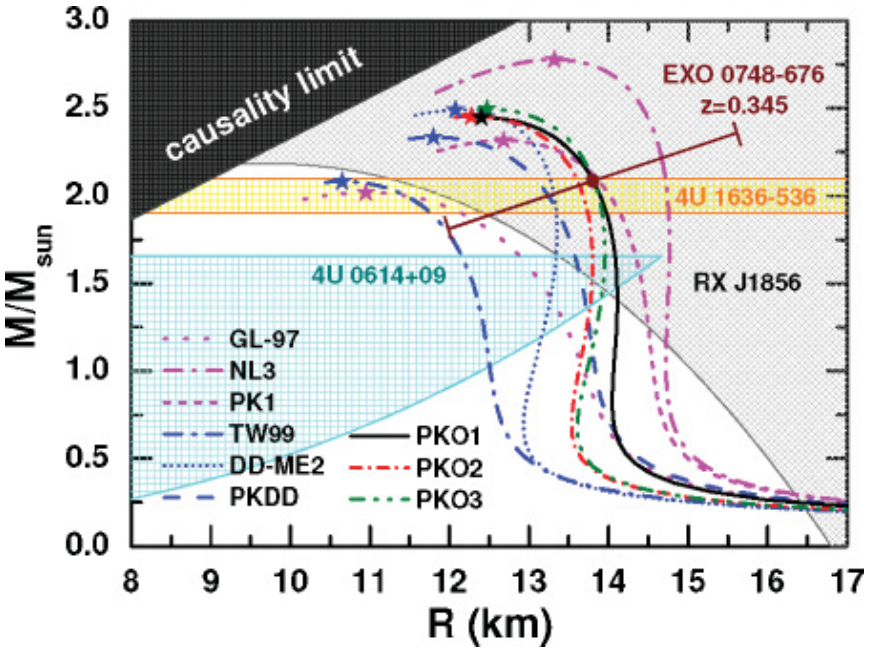
B. Sun, W. H. Long, J. Meng, and U. Lombardo, Phys. Rev. C 78, 065805 (2008)

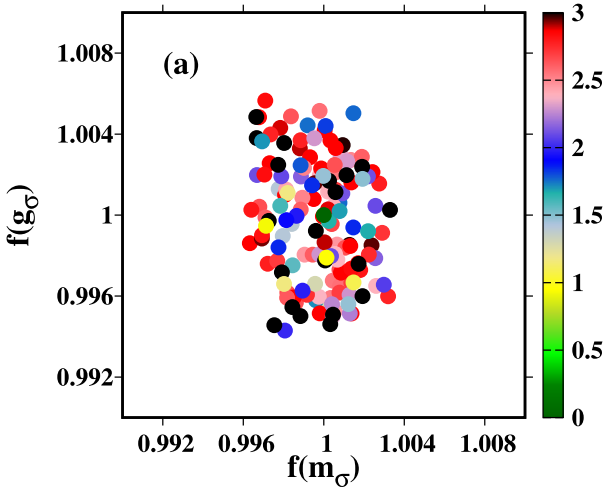




	PKO1	PKO2	PKO3	GL-97	NL1	NL3	NLSH	TM1	PK1	TW99	DD-ME1	DD-ME2	PKDD
$M_{\max}$	2.45	2.45	2.49	2.02	2.81	2.78	2.80	2.18	2.32	2.08	2.45	2.49	2.33
$\rho_{\max}(0)$	0.80	0.81	0.78	1.09	0.66	0.67	0.65	0.85	0.80	1.10	0.84	0.82	0.89
$R(M_{\max})$	12.4	12.3	12.5	10.9	13.4	13.3	13.5	12.4	12.7	10.7	11.9	12.1	11.8
$R(1.4M_\odot)$	14.1	13.8	13.9	13.3	14.7	14.7	14.9	14.4	14.5	12.4	13.2	13.3	13.7

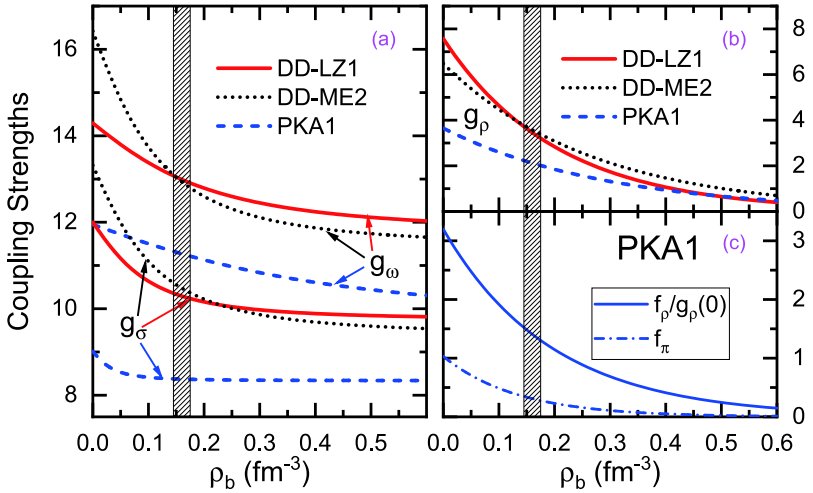
New DDRMF parameterizations

DD-MEX



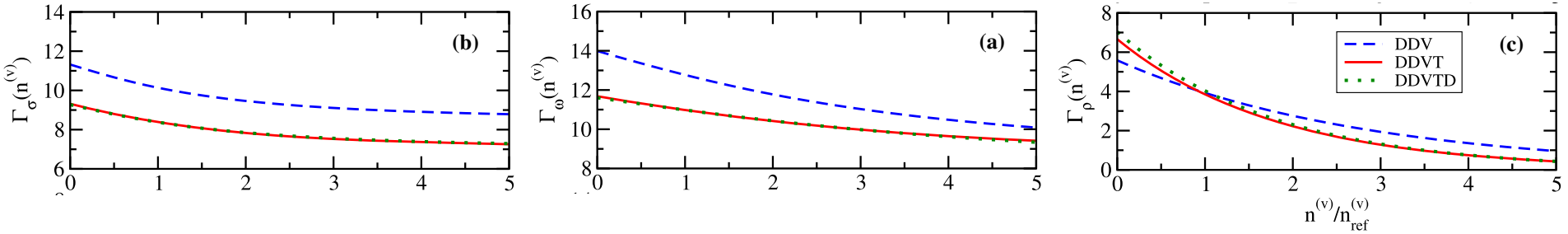
A. Taninah, et al. Phys. Lett. B 800,135065(2020)

DD-LZ1



B. Wei, et al. Chin. Phys. C 44, 074107 (2020)

DDV, DDVT, DDVTD



S. Typel and D. A. Terrero, Eur. Phys. J. A 56, 160 (2020)

Density-dependent RMF model

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The Lagrangian of DDRMF model

$$\mathcal{L}_{DD} = \sum_{i=p,\ n} \overline{\psi}_i \left[\gamma^\mu \left(i\partial_\mu - \Gamma_\omega(\rho_B)\omega_\mu - \frac{\Gamma_\rho(\rho_B)}{2}\gamma^\mu \vec{\rho}_\mu \vec{\tau} \right) - \left(M - \Gamma_\sigma(\rho_B)\sigma - \Gamma_\delta(\rho_B)\vec{\delta}\vec{\tau} \right) \right] \psi_i$$
$$+ \frac{1}{2}\left(\partial^\mu \sigma \partial_\mu \sigma - m_\sigma^2 \sigma^2\right) + \frac{1}{2}\left(\partial^\mu \vec{\delta} \partial_\mu \vec{\delta} - m_\delta^2 \vec{\delta}^2\right)$$
$$- \frac{1}{4} W^{\mu\nu} W_{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu - \frac{1}{4} \vec{R}^{\mu\nu} \vec{R}_{\mu\nu} + \frac{1}{2} m_\rho^2 \vec{\rho}_\mu \vec{\rho}^\mu,$$

The density dependent coupling constants

for σ and ω mesons

$$\Gamma_i(\rho_B) = \Gamma_i(\rho_{B0}) f_i(x), \quad \text{with} \quad f_i(x) = a_i \frac{1 + b_i(x + d_i)^2}{1 + c_i(x + d_i)^2}, \ x = \rho_B/\rho_{B0},$$

for ρ and δ mesons

$$\Gamma_i(\rho_B) = \Gamma_i(\rho_{B0}) \exp[-a_i(x-1)].$$

Density-dependent coupling constants

DD2

DD-ME1

DD-ME2

DD-MEX

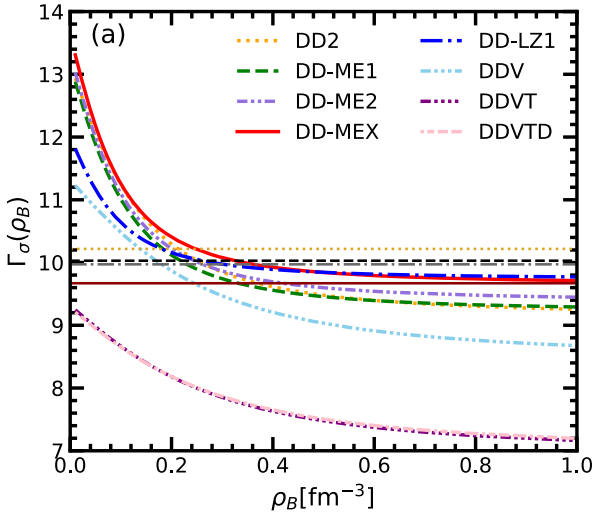
DD-LZ1

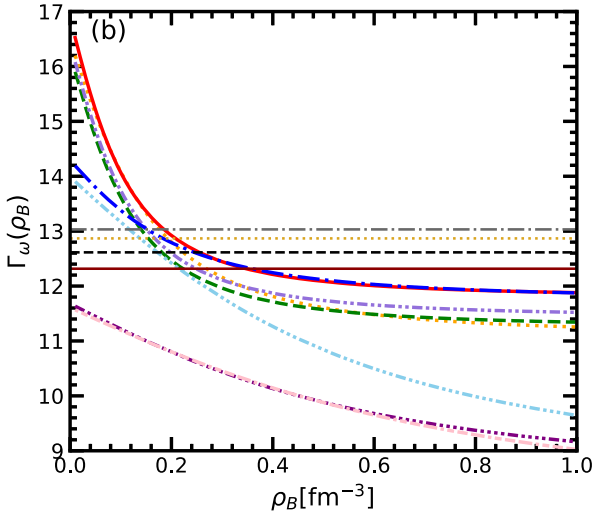
DDV

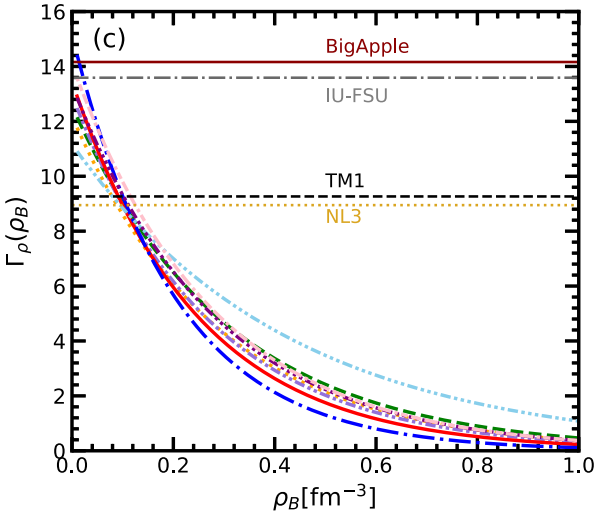
DDVT

DDVTD

	DD-LZ1		DD2	DD-ME1	DD-ME2	DD-MEX	DDV	DDVT	DDVTD
m_n[MeV]	938.900000	m_n	939.56536	939.0000	939.0000	939.0000	939.565413	939.565413	939.565413
m_p[MeV]	938.900000	m_p	938.27203	939.0000	939.0000	939.0000	938.272081	938.272081	938.272081
m_σ[MeV]	538.619216	m_σ	546.212459	549.5255	550.1238	547.3327	537.600098	502.598602	502.619843
m_ω[MeV]	783.0000	m_ω	783.0000	783.0000	783.0000	783.0000	783.0000	783.0000	783.0000
m_ρ[MeV]	769.0000	m_ρ	763.0000	763.0000	763.0000	763.0000	763.0000	763.0000	763.0000
m_δ[MeV]	—	m_δ	—	—	—	—	—	—	980.0000
$\Gamma_\sigma(0)$	12.001429	$\Gamma_\sigma(\rho_{B0})$	10.686681	10.4434	10.5396	10.7067	10.136960	8.382863	8.379269
$\Gamma_\omega(0)$	14.292525	$\Gamma_\omega(\rho_{B0})$	13.342362	12.8939	13.0189	13.3388	12.770450	10.987106	10.980433
$\Gamma_\rho(0)$	15.150934	$\Gamma_\rho(\rho_{B0})$	7.25388	7.6106	7.3672	7.2380	7.84833	7.697112	8.06038
$\Gamma_\delta(0)$	—	$\Gamma_\delta(\rho_{B0})$	—	—	—	—	—	—	0.8487420
ρ_{B0}[fm^{-3}]	0.158100	ρ_{B0}	0.149	0.152	0.152	0.153	0.1511	0.1536	0.1536
a_σ	1.062748	a_σ	1.357630	1.3854	1.3881	1.3970	1.20993	1.20397	1.19643
b_σ	1.763627	b_σ	0.634442	0.9781	1.0943	1.3350	0.21286844	0.19210314	0.19171263
c_σ	2.308928	c_σ	1.005358	1.5342	1.7057	2.0671	0.30798197	0.27773566	0.27376859
d_σ	0.379957	d_σ	0.575810	0.4661	0.4421	0.4016	1.04034342	1.09552817	1.10343705
a_ω	1.059181	a_ω	1.369718	1.3879	1.3892	1.3936	1.23746	1.16084	1.16693
b_ω	0.418273	b_ω	0.496475	0.8525	0.9240	1.0191	0.03911422	0.04459850	0.02640016
c_ω	0.538663	c_ω	0.817753	1.3566	1.4620	1.6060	0.07239939	0.06721759	0.04233010
d_ω	0.786649	d_ω	0.638452	0.4957	0.4775	0.4556	2.14571442	2.22688558	2.80617483
a_ρ	0.776095	a_ρ	0.518903	0.5008	0.5647	0.6202	0.35265899	0.54870200	0.55795902
a_δ	—	a_δ	—	—	—	—	—	—	0.55795902

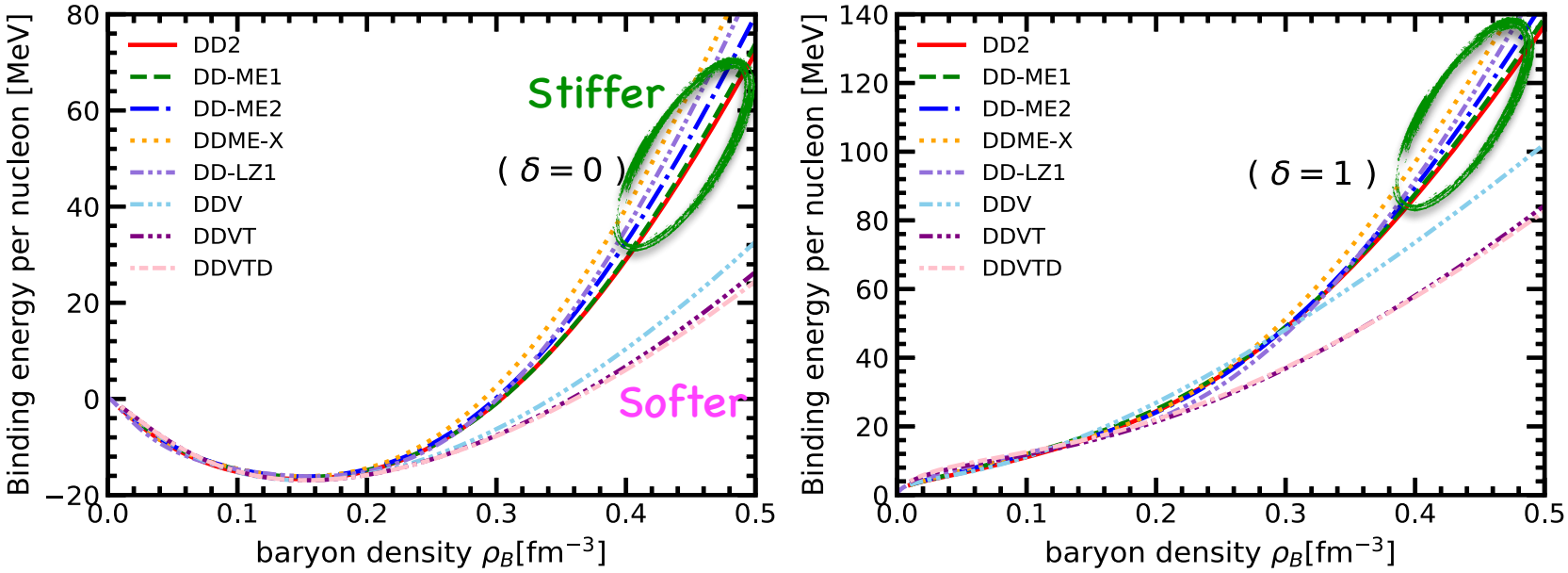




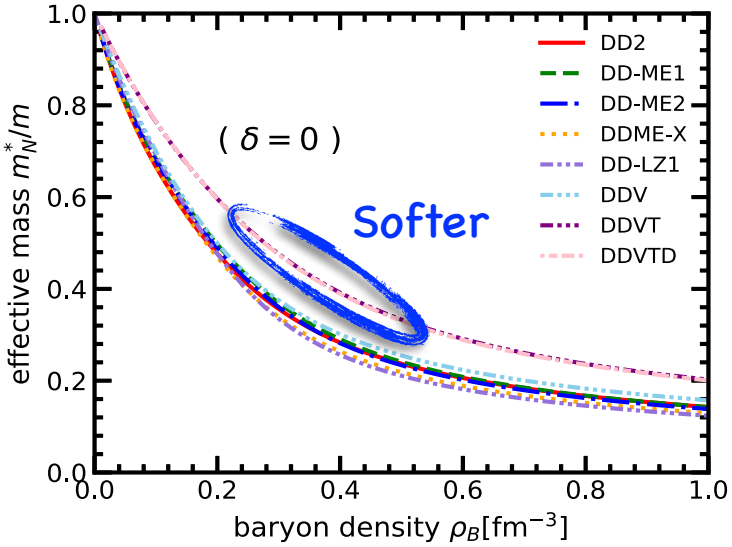


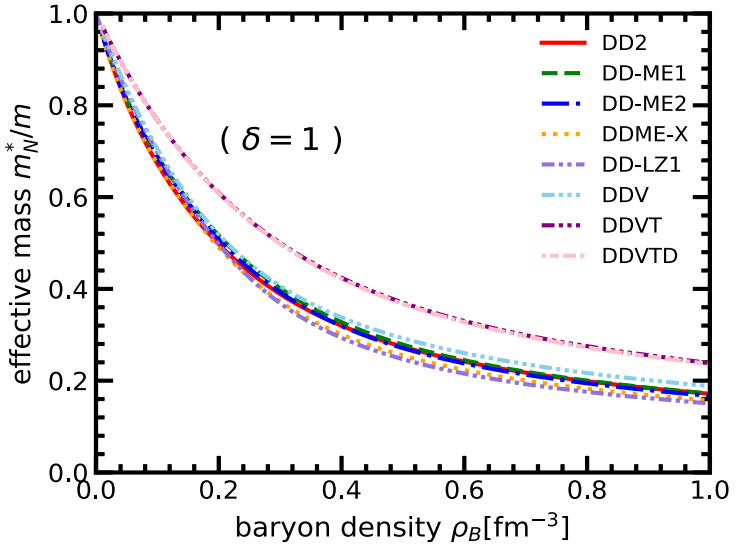
The saturation properties of SNM

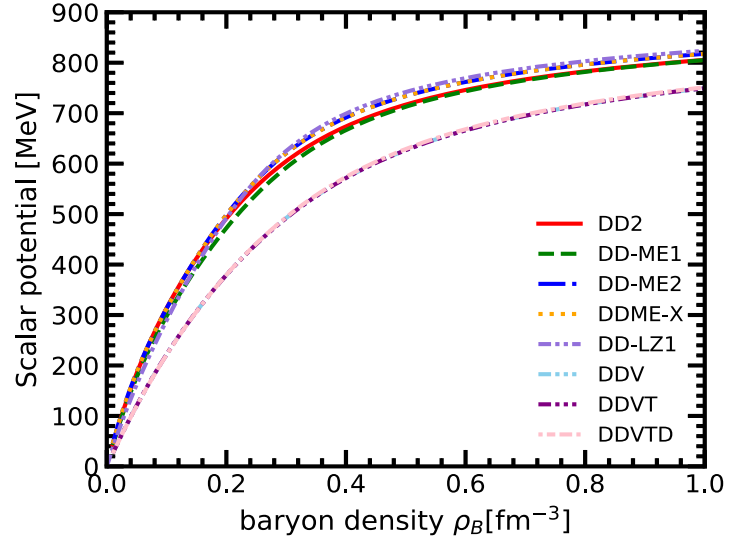
	DD-LZ1	DD2	DD-ME1	DD-ME2	DD-MEX	DDV	DDVT	DDVTD
$\rho_{B0}[\mathrm{fm}^{-3}]$	0.1585	0.149	0.152	0.152	0.1518	0.1511	0.1536	0.1536
$E/A[\mathrm{MeV}]$	-16.126	-16.916	-16.668	-16.233	-16.14	-16.097	-16.924	-16.915
$K_0[\mathrm{MeV}]$	231.237	241.990	243.881	251.306	267.059	239.499	239.999	239.914
$E_{\mathrm{sym}}[\mathrm{MeV}]$	32.016	31.635	33.060	32.31	32.269	33.589	31.558	31.817
$L[\mathrm{MeV}]$	42.467	54.933	55.428	51.265	49.692	69.646	42.348	42.583
M_n^*/M	0.558	0.563	0.578	0.572	0.556	0.586	0.667	0.667
M_p^*/M	0.558	0.562	0.578	0.572	0.556	0.585	0.666	0.666

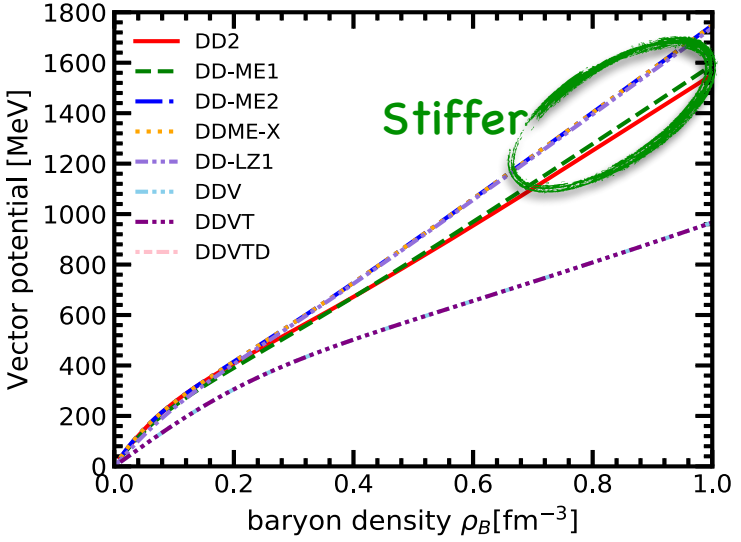


The Strong vector potentials









The equations of state of neutron star

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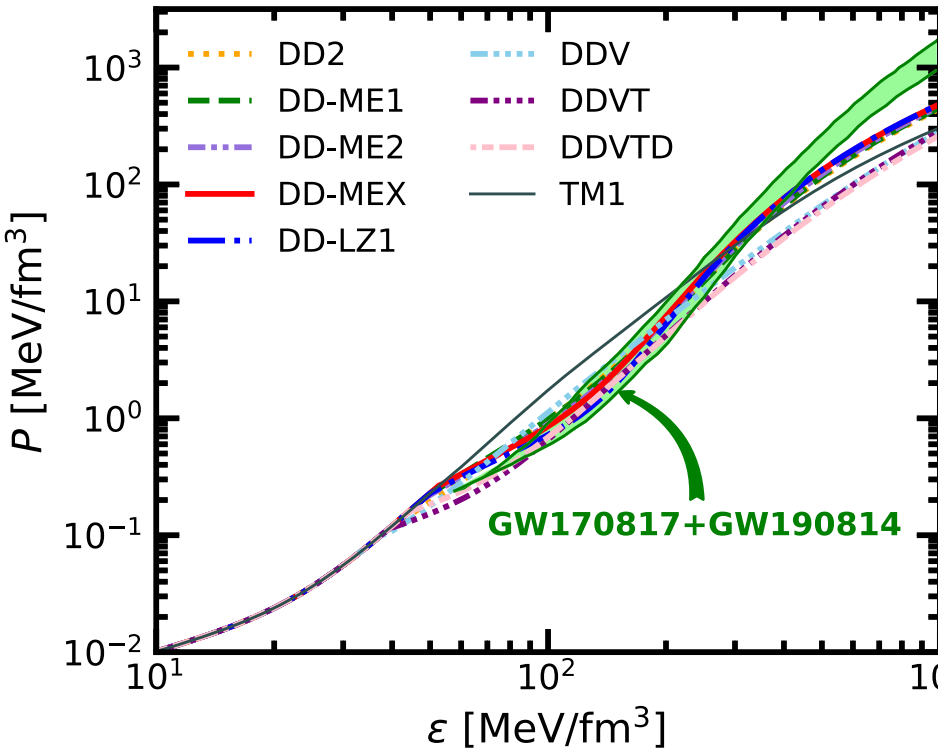
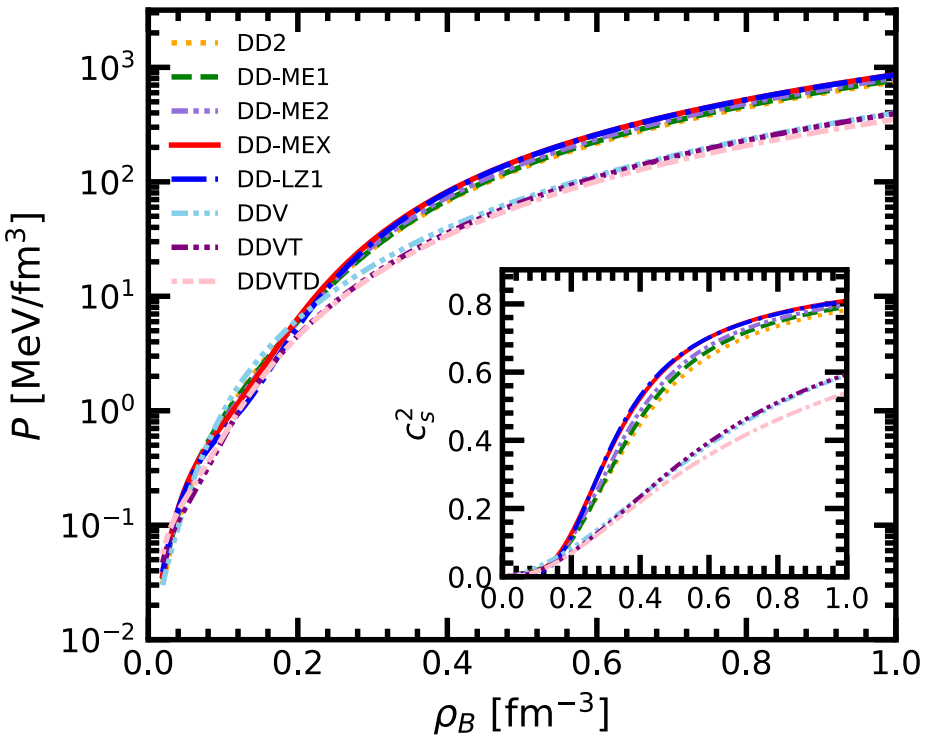
Pressure vs. energy



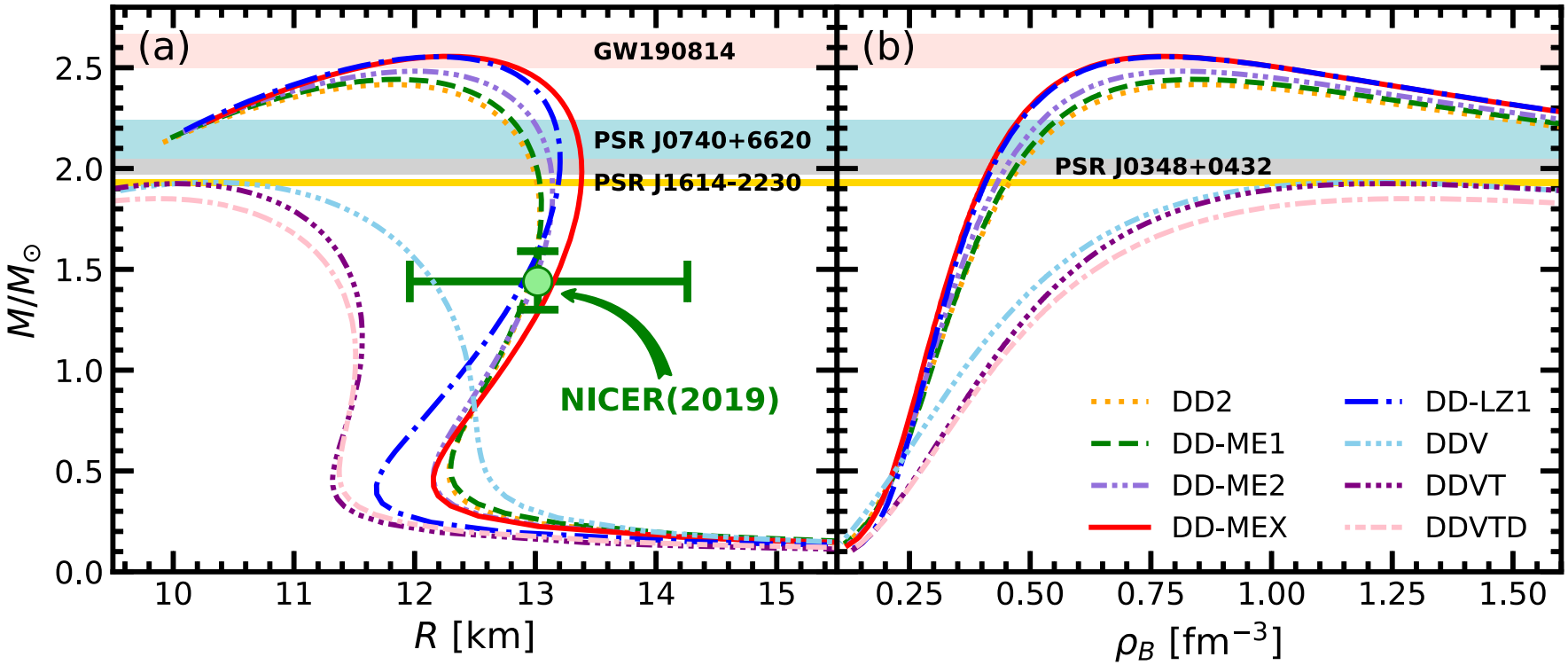
Pressure vs. density



The stiffer EOSs will generate larger speeds of sound

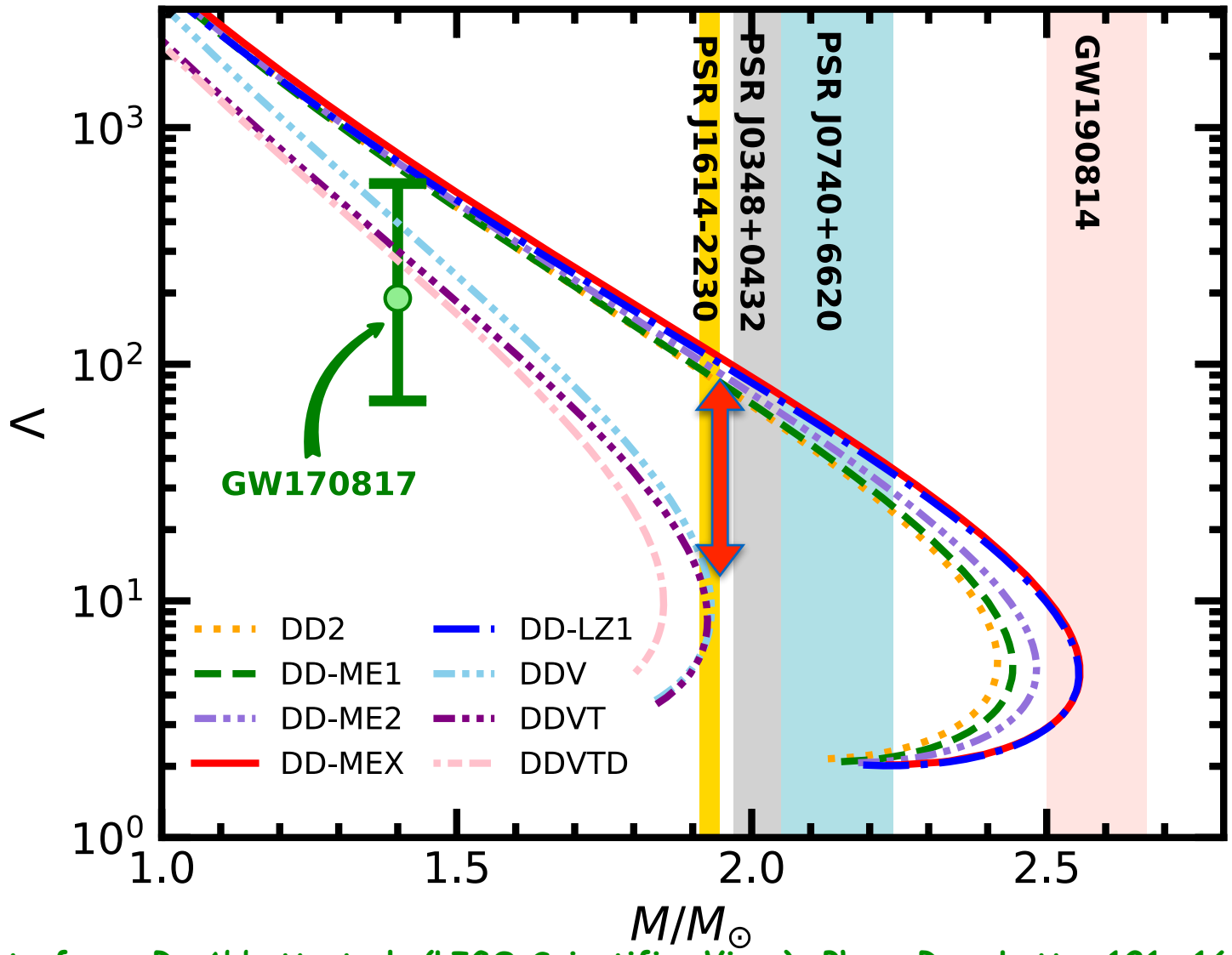
data from: R. Abbott et al. (LIGO Scientific, Virgo), Astrophys. J. 896, L44 (2020)

The mass, radius, density relations



	DD-LZ1	DD2	DD-ME1	DD-ME2	DD-MEX	DDV	DDVT	DDVTD
$M_{\max}/M_\odot$	2.5545	2.4168	2.4426	2.4829	2.5566	1.9317	1.9251	1.8507
$R_{\max}$[km]	12.178	11.826	11.885	12.012	12.274	10.336	10.023	9.850
$\rho_{\max}$[fm^{-3}]	0.786	0.845	0.832	0.813	0.777	1.188	1.237	1.306
$R_{1.4}$[km]	12.864	12.938	12.931	12.961	13.118	12.195	11.511	11.396
$\Lambda_{1.4}$	727.071	639.032	686.786	730.737	790.051	390.005	301.388	274.908

The tidal deformabilities of neutron star



data from: R. Abbott et al. (LIGO Scientific, Virgo), Phys. Rev. Lett., 121, 161101 (2018)

Summary

The properties of neutron star were investigated with DDRMF parameterizations.

The second object of GW190817 cannot be excluded as a neutron star consisting of hadron matter.

The precision measurements of tidal deformabilities of $2.0M_{\odot}$ neutron star will be much helpful to constrain the EOSs

The exotic phases in the core of neutron star will be further studied.