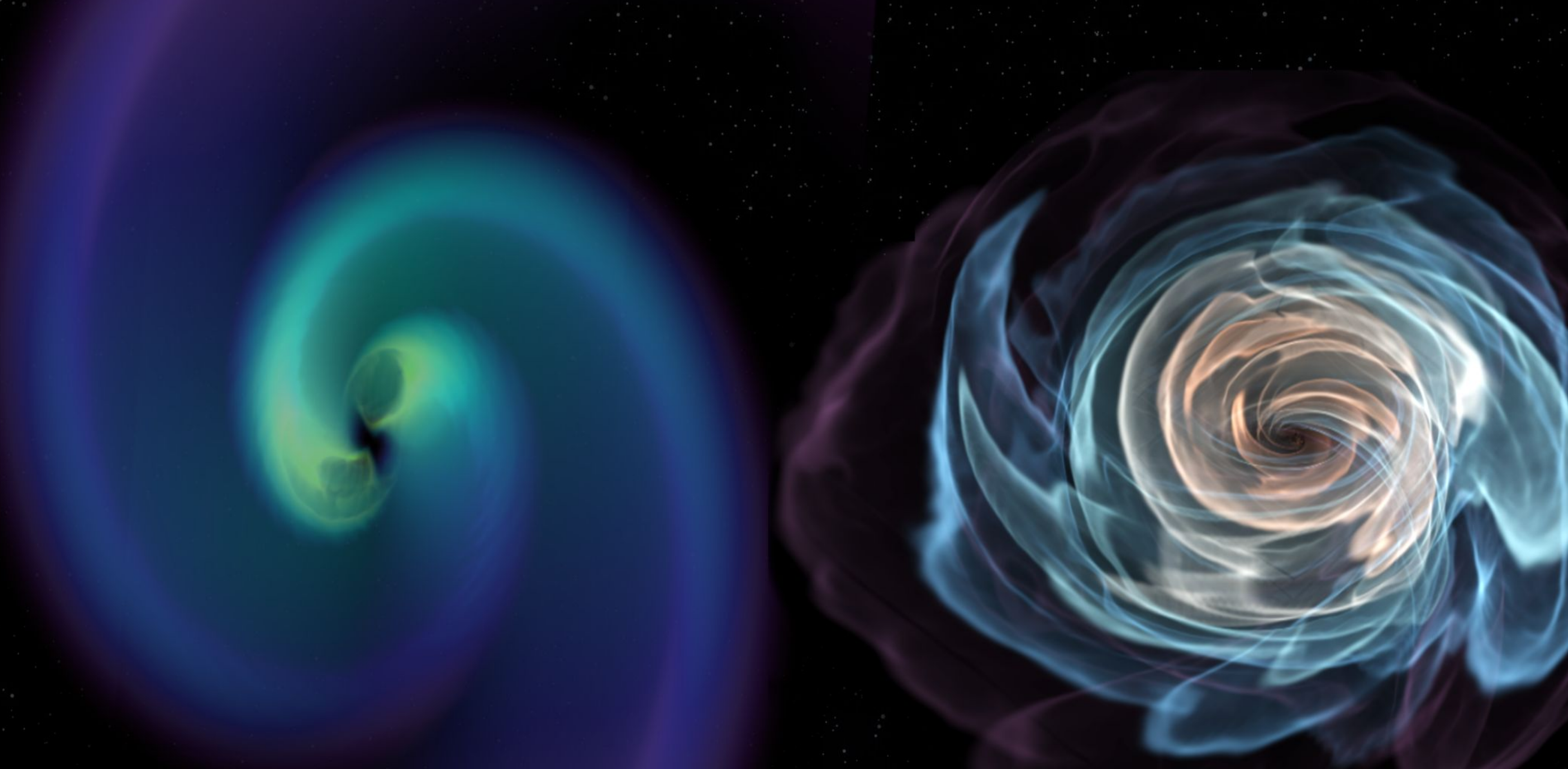
Dense matter EOS with GW170817

Ang Li
Xiamen Univ.
liang@xmu.edu.cn
http://astro.xmu.edu.cn/LiAng/

- Zhou, et al., 1711.04312, PRD accepted
- Ai, et al., 1802.00571, ApJL under review
- Zhu, et al., 1802.05510, ApJ under review

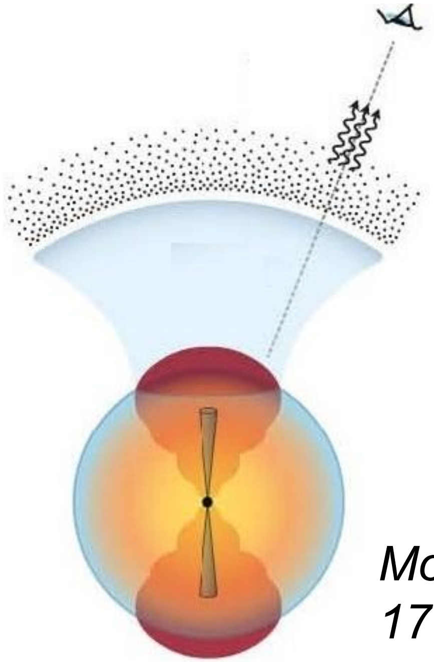
iHIC 2018

First Cosmic Event Observed in Gravitational Waves and Light



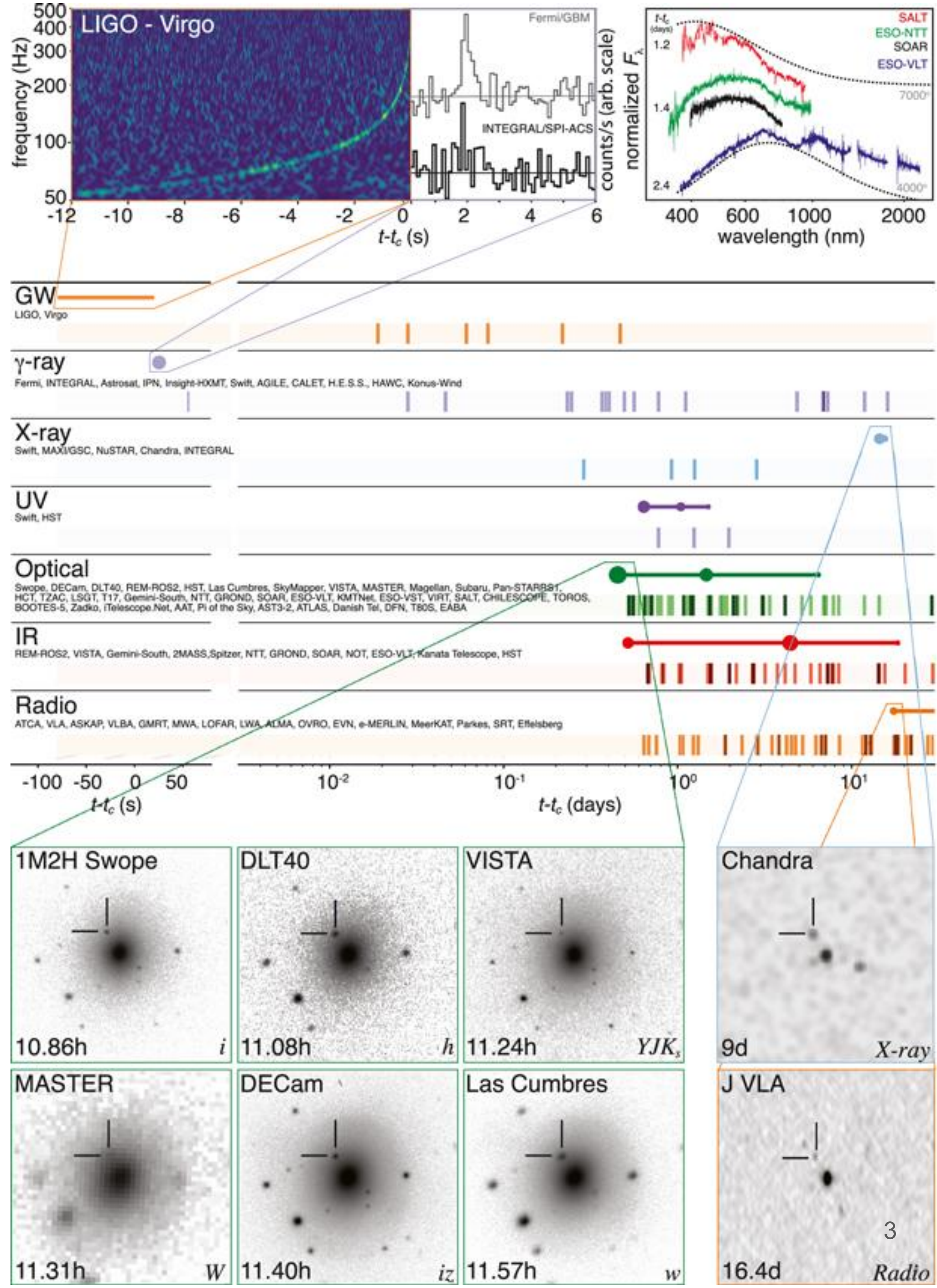
- Intro of GW170817
- EOS of NS/QS
- Summary

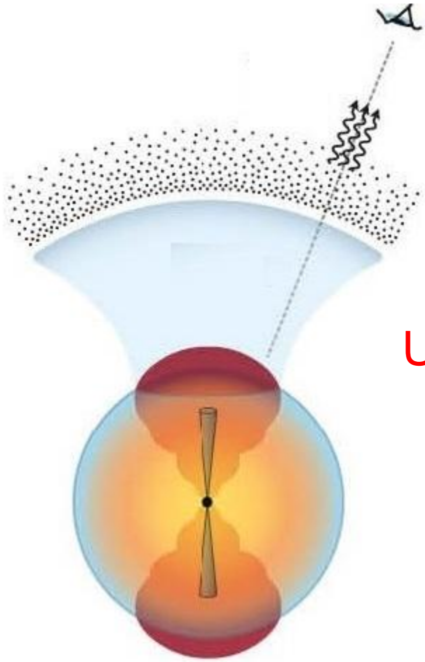
PRL : 1
Nature : 6
Science : 7
ApJL : 23
67 preprints:
http://blogs.cornell.edu/arxiv/2017/10/16/gw170817/



Mooley et al., 1711.11573

- GW
- Neutrino: none
- ***γ***-ray: 1.7 s
- X-ray: 9 days
- UV/Optical/IR: 2 days
- Radio:16 days





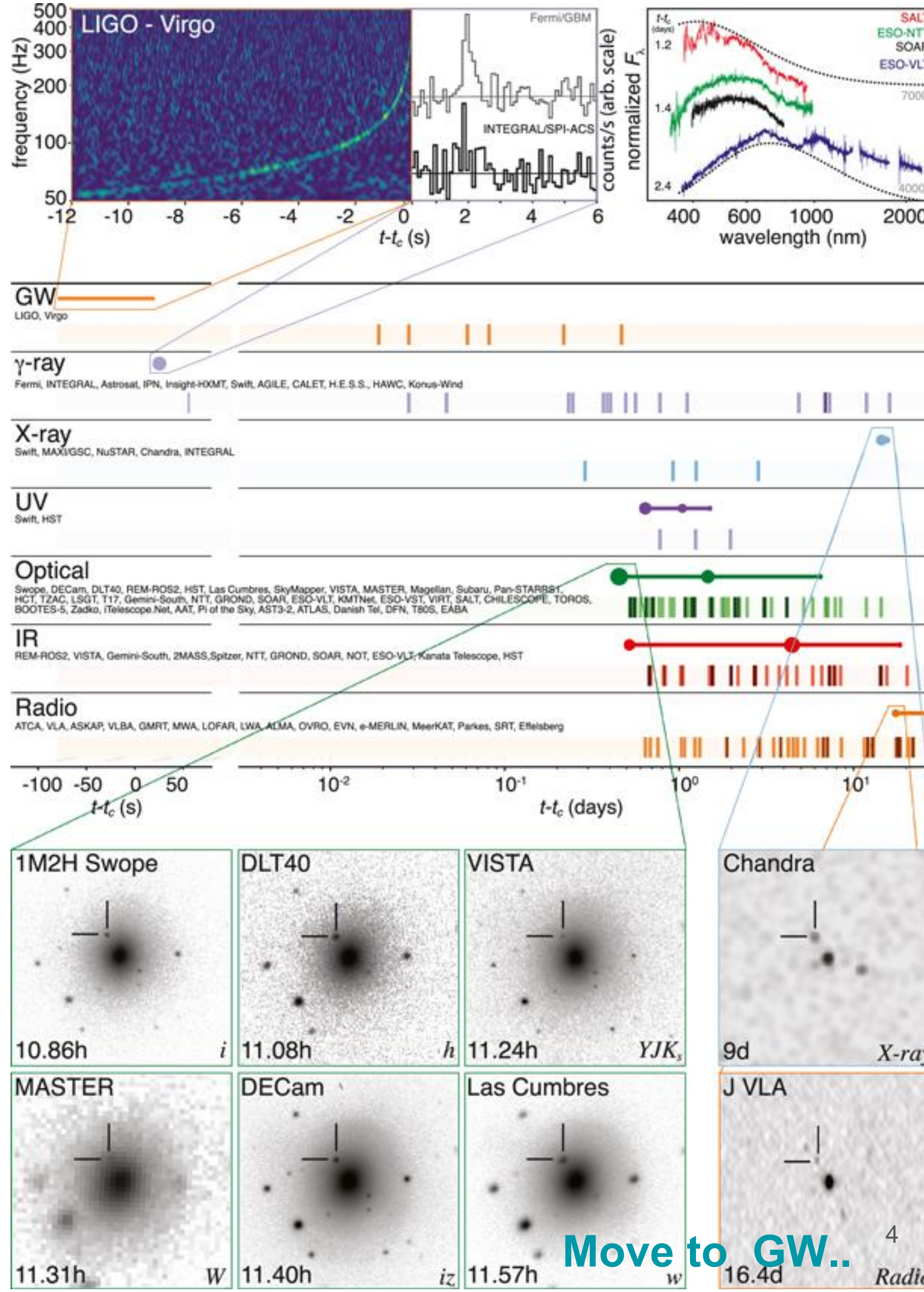
Uncertain:

- EOS
- Ejecta mass
- Mass ratio
- Jet sructure
- ...

Long-lived NS as remnant?

1. **Spin period**
2. **Magnetic field**
3. **Ellipticity**
4. **...**

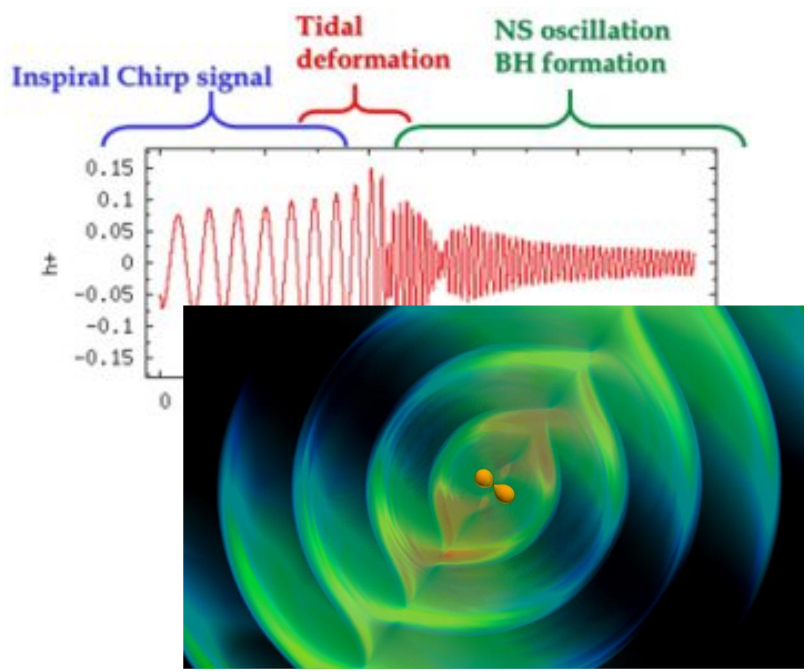
S.-K. Ai, H. Gao, Z.-G. Dai, X.-F. Wu, A. Li and B. Zhang,**1802.00571**
#The allowed parameter space of a long-lived neutron star as the merger remnant of GW170817



Move to GW..

TABLE I. Source properties for GW170817: we give ranges encompassing the 90% credible intervals for different assumptions of the waveform model to bound systematic uncertainty. The mass values are quoted in the frame of the source, accounting for uncertainty in the source redshift.

	Low-spin priors ($\lvert\chi\rvert \leq 0.05$)	High-spin priors ($\lvert\chi\rvert \leq 0.89$)
Primary mass m_1	1.36–1.60 $M_\odot$	1.36–2.26 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$	0.86–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc
Viewing angle Θ	$\leq 55°$	$\leq 56°$
Using NGC 4993 location	$\leq 28°$	$\leq 28°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	≤ 800	≤ 700
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	≤ 800	≤ 1400



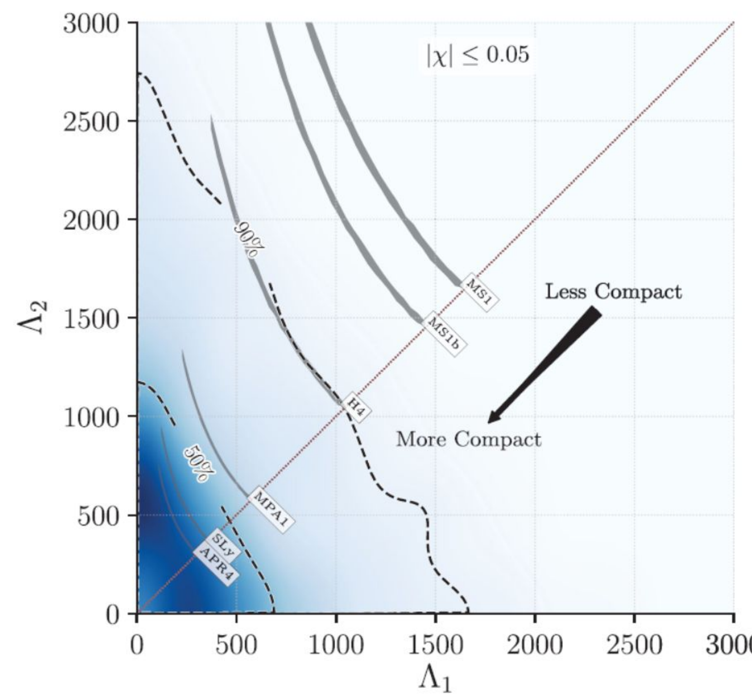
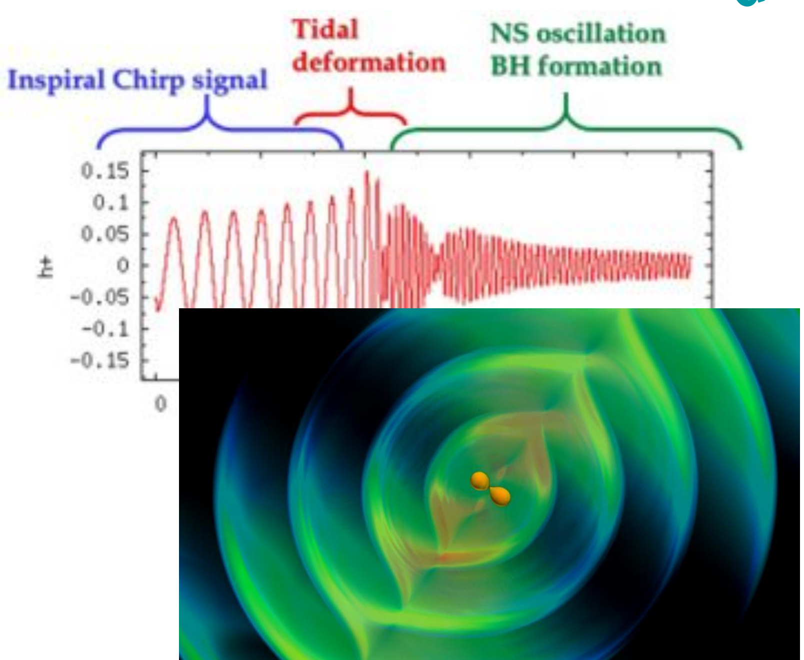
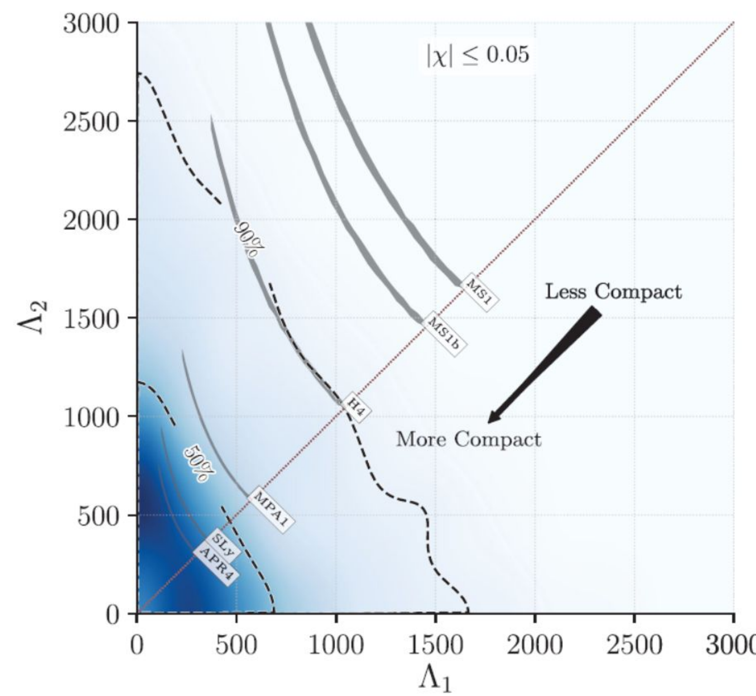


TABLE I. Source properties for GW170817: we give ranges encompassing the 90% credible intervals for different assumptions of the waveform model to bound systematic uncertainty. The mass values are quoted in the frame of the source, accounting for uncertainty in the source redshift.

	Low-spin priors ($\lvert\chi\rvert \le 0.05$)	High-spin priors ($\lvert\chi\rvert \le 0.89$)
Primary mass m_1	1.36–1.60 $M_\odot$	1.36–2.26 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$	0.86–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc
Viewing angle Θ	$\le 55°$	$\le 56°$
Using NGC 4993 location	$\le 28°$	$\le 28°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	≤ 800	≤ 700
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	≤ 800	≤ 1400

More reasonable considering magnetic braking during the binary evolution





▸ Low-spin spior ($\Lambda(1.4M_\odot) \leq 800$)

3-tropes	All EoSs	$2M_\odot$	$\Lambda < 800$
γ_1	0.2-8.5	0.7-8.5	0.7-6.6
$M_{\max}[M_\odot]$	<0.5-3.0	2.0-3.0	2.0-2.7
$R(1.4M_\odot)$[km]	7.1-14.6	10.7-14.6	10.7-13.6
4-tropes	**All EoSs**	**$2M_\odot$**	**$\Lambda < 800$**
γ_1	0.05-8.5	0.6-8.5	0.6-6.7
$M_{\max}[M_\odot]$	<0.5-3.2	2.0-3.2	2.0-3.0
$R(1.4M_\odot)$[km]	6.6-14.6	9.9-14.6	9.9-13.6

▸ NS EOS

#Gravitational-wave constraints on the neutron-star-matter Equation of State
Annala et al., **1711.02644** (17/11/7)**, PRL**

#GW170817: Joint Constraint on the Neutron Star Equation of State from Multimessenger Observations
Radice et al., **1711.03647, ApJL**

#Neutron skins and neutron stars in the multi-messenger era
Fattoyev, et al., **1711.06615, PRL**

#Imprints of the nuclear symmetry energy on the tidal deformability of neutron stars
Krastev & Li, **1801.04620**

▸ QS EOS

#Constraints on interquark interaction parameters with GW170817 in a binary strange star scenario
Zhou, Zhou & **AL**, **1711.04312** (17/11/12 in 4 weeks), **PRD**

- **QS** from Bodmer-Witten's conjecture
- Self-bound by strong interaction:
  - Finite surface density;
  - Fast increase of grav. mass with spin frenquency (40% vs. 20%,

    e.g., ***AL*** *et al. 2016 PRD 1606.02934; 2017 ApJ 1706.04720*)

…

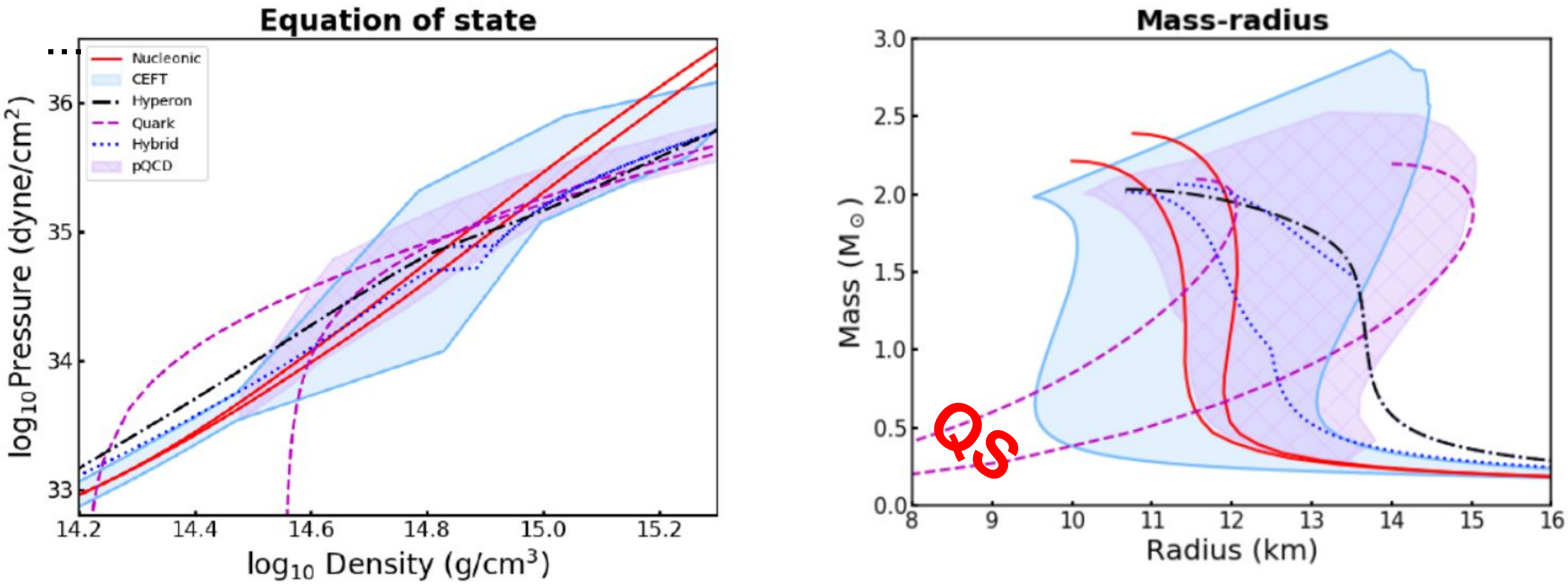
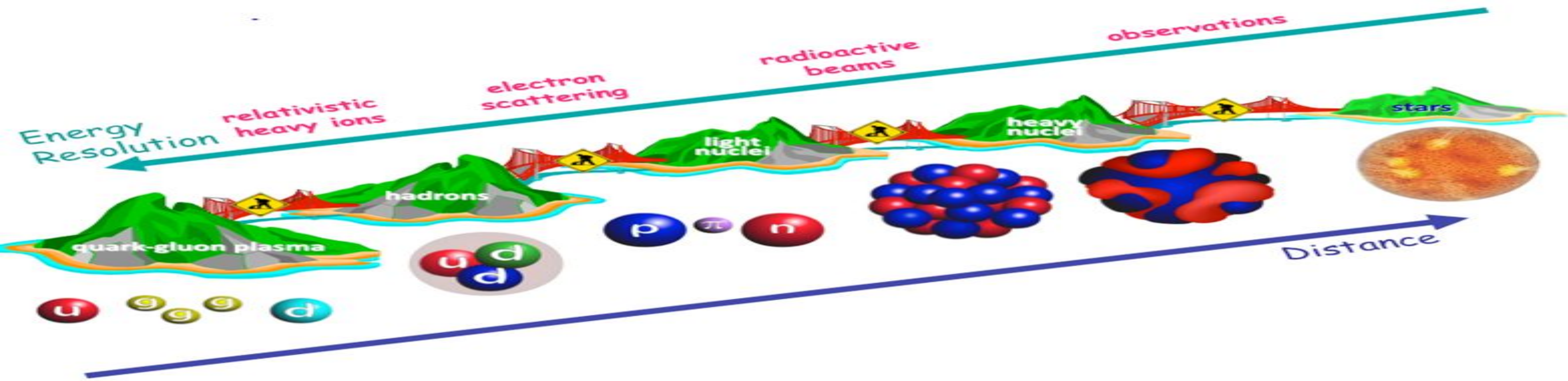
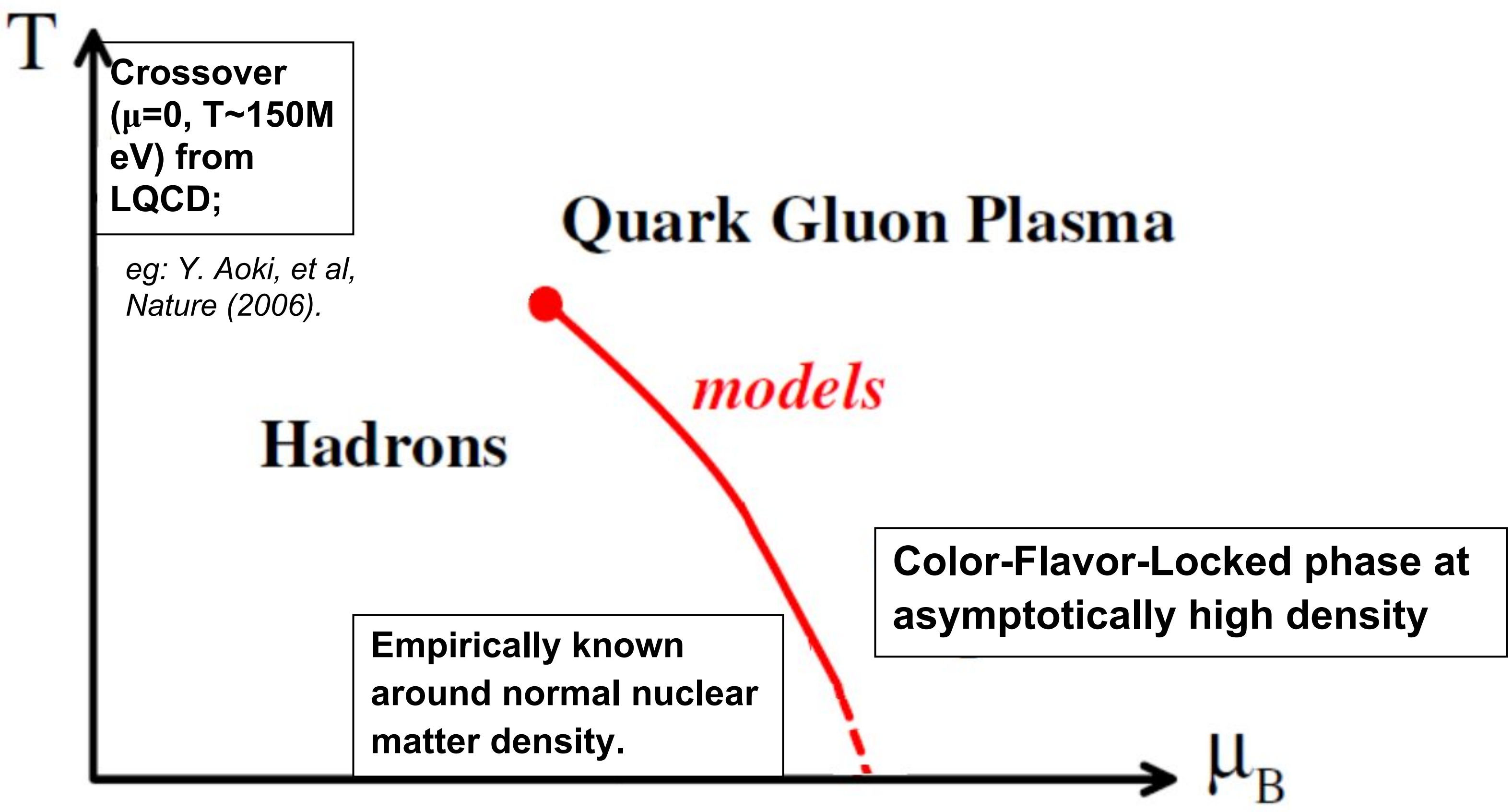


Figure 3 The pressure–density relation (EOS, left) and the corresponding M-R relation (right) for some example models with different microphysics. Nucleonic (neutrons, protons): models AP3 and AP4 from Akmal & Pandharipande (1997), also used in Lattimer & Prakash (2001). Quark (u, d, s quarks): models from Li et al. (2016) and Bhattacharyya et al. (2016). Hybrid (inner core of uds quarks, outer core of nucleonic matter): models from Zdunik & Haensel (2013). Hyperon (inner core of hyperons, outer core of nucleonic matter): Model from Bednarek et al. (2012). CEFT: range of nucleonic EOS based on Chiral Effective Field Theory (CEFT) from Hebeler et al. (2013). pQCD: range of nucleonic EOS from Kurkela et al. (2014) that interpolate from CEFT at low densities and match to perturbative QCD (pQCD) calculations at higher densities than shown in this figure. All of the EOS shown are compatible with the existence of ~ 2 $M_\odot$ NSs.

Dense matter with eXTP (White paper), Sci. China in press


Energy Resolution
relativistic heavy ions
electron scattering
radioactive beams
observations
quark-gluon plasma
hadrons
light nuclei
heavy nuclei
stars
u
g g g
d
u d d
p
π
n
Distance

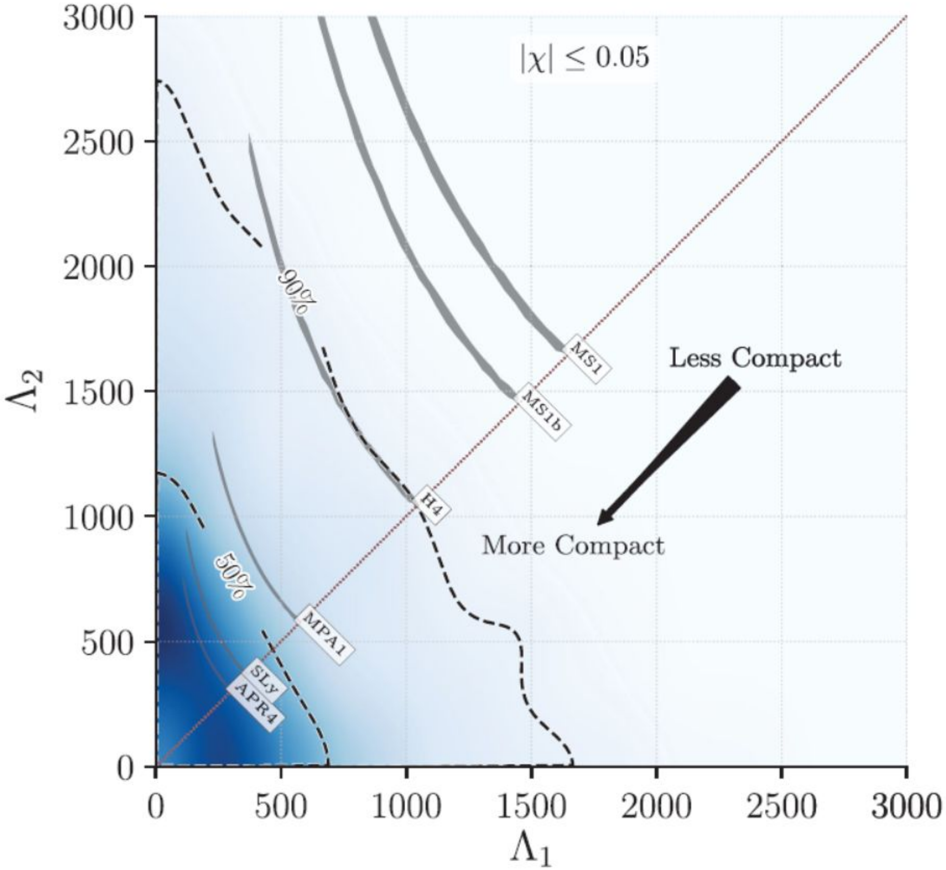

T
Crossover (μ=0, T~150MeV) from LQCD;
eg: Y. Aoki, et al, Nature (2006).
Quark Gluon Plasma
models
Hadrons
Color-Flavor-Locked phase at asymptotically high density
Empirically known around normal nuclear matter density.
μB

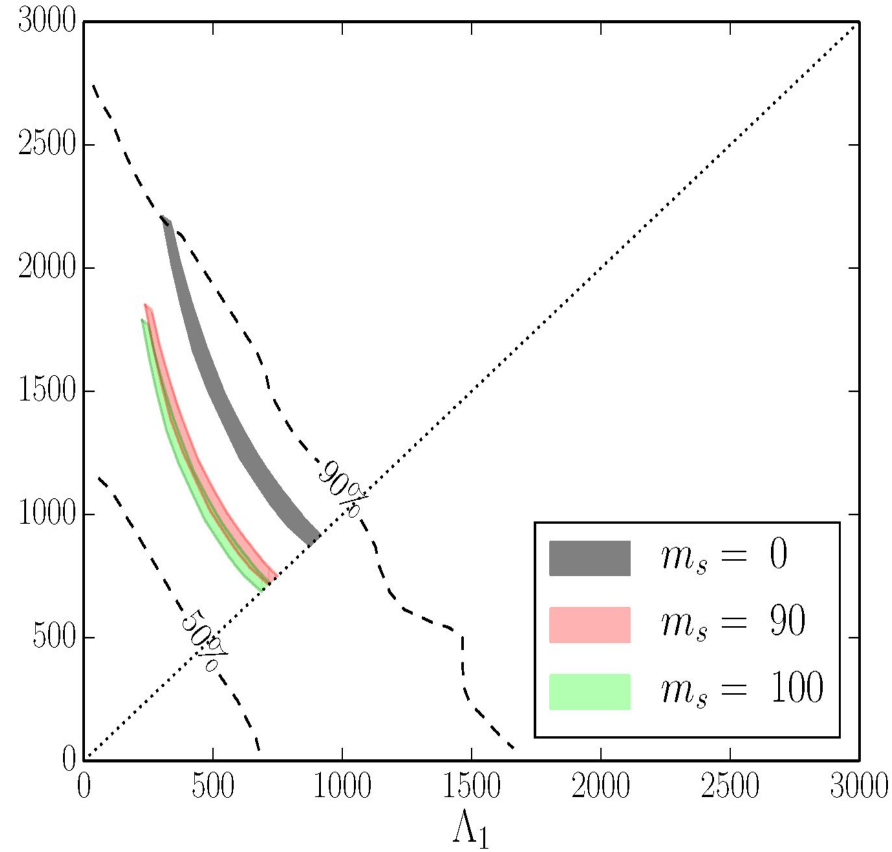
- MIT$\alpha_s^{\,2}$ bag model
  - interaction parametrized in ($B_{\rm eff}$, a_4)
  - superfluid parametrized in Δ

$$\Omega_{\rm free} = \sum_i \Omega_i^0 + \frac{3}{4\pi^2}(1-a_4)\left(\frac{\mu_b}{3}\right)^4 + B_{\rm eff}$$

$$\Omega_{\rm CFL} = \Omega_{\rm free} - \frac{3}{\pi^2}\Delta^2\mu_b^2$$

- Typical parameters ($B_{\rm eff}^{1/4}$, a_4)= (145, 0.61)
- **BQS merger justified**.



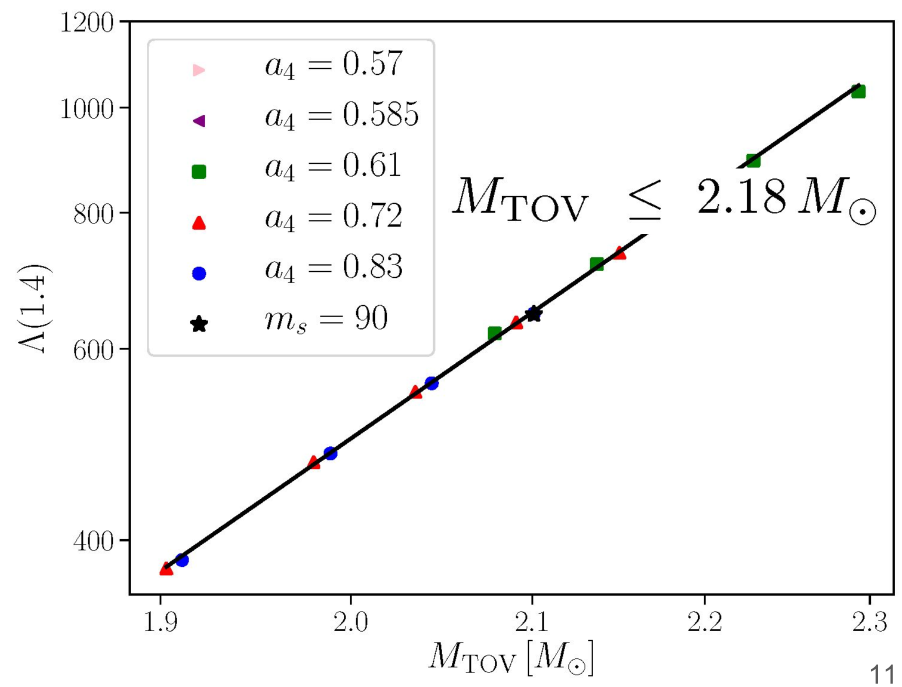


- **Normal QS**

a_4	$B_{\rm eff}^{1/4}$ [MeV]	R [km]	M/R	k_2	Λ
0.61	133	12.046	0.17166	0.19973	893.4
0.61	136	11.662	0.17731	0.18865	717.7
0.61	138	11.415	0.18115	0.18133	619.7
0.72	138	11.453	0.18055	0.18262	634.5
0.83	138	11.482	0.18008	0.18367	646.6

- Finite strange quark mass (m_s) soften EOS;
- Perturbative QCD correction (a_4) soften EOS;
- Effective bag constant ($B_{\rm eff}$) dominates the EOS stiffness;
- Strong Λ(1.4)-vs-$M_{\rm TOV}$ correlation:

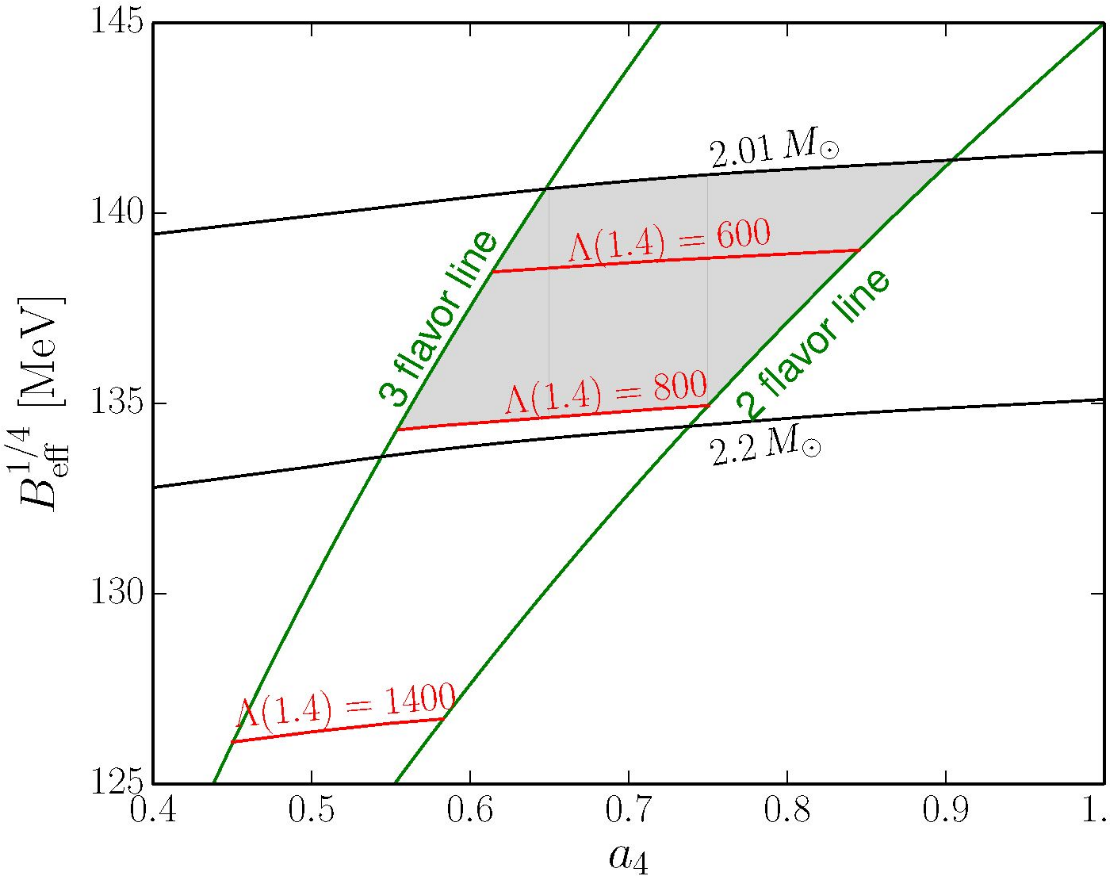
$$\Lambda(1.4) = 510.058 \times \left(\frac{M_{\rm TOV}}{2.01\,M_\odot}\right)^{5.457}$$



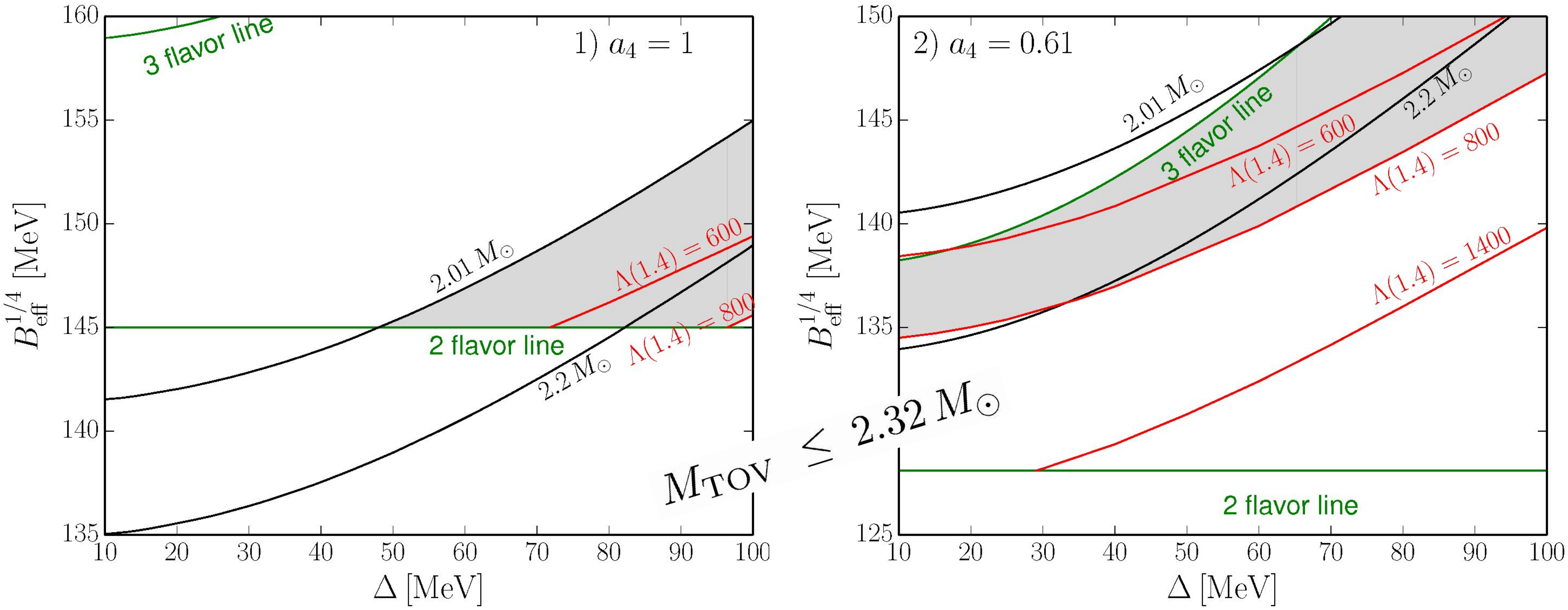
- NEW parameter ranges from GW170817: $B_{\text{eff}}^{1/4} \in (134.1, 141.4)\,\text{MeV}$
- Weak a_4 softening; $a_4 \in (0.56, 0.91)$
- QM stability window:
  - 2-flavor quark matter cannot be more stable than Fe nuclei;
  - 3-flavor quark matter is more stable than Fe nuclei.

Larger B_{eff} is required to bound the quark matter for larger a_4;

- **Possible future** observations of $\Lambda(1.4)=600$ & $M_{TOV}=2.2M_\odot$ can not reconcile in the model: **QS out?**

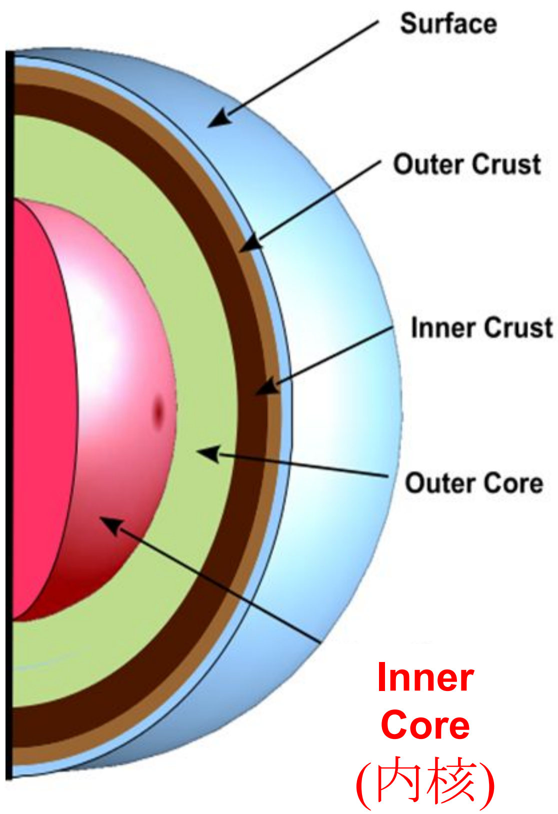


- **Superfluid QS**
- Gap parameter Δ very uncertain: (0,100/150 MeV);
- a_4=1: Two-solar mass constraint bounds the lower limit of at the order of 50MeV;
- a_4=0.61: No new lower limit is found for both the low-spin prior and the high-spin prior.



Move to NS...

NS structure

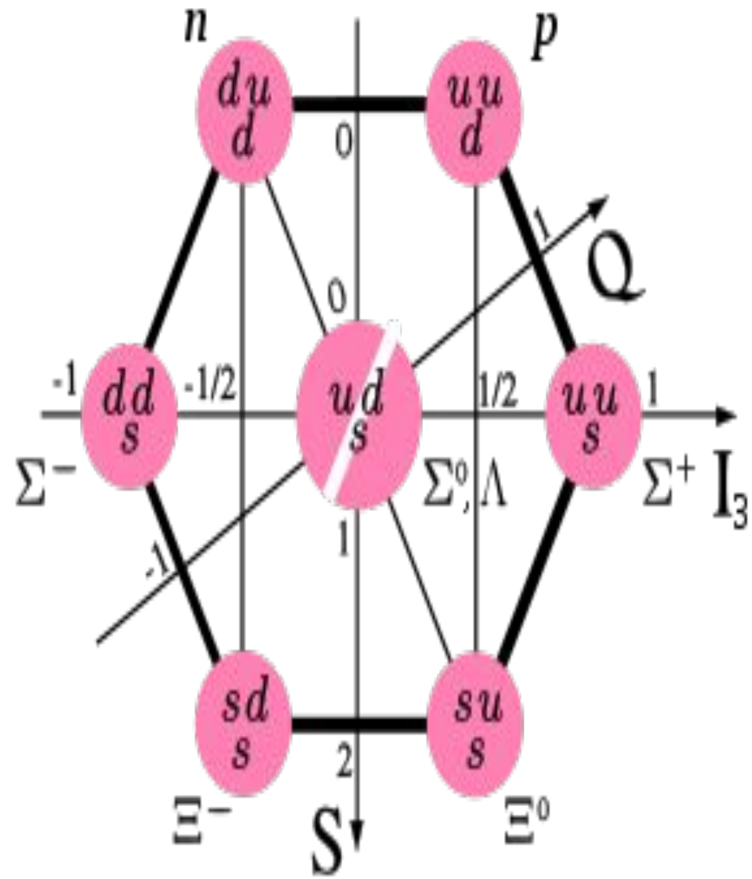


Dark matter-mixed

- **Li***, Liu, Gubler, Xu, 2015 Astropart. phys.
- **Li***, Huang, Xu, 2012 Astropart. phys.

- Nucleons
  - Zhu, **Li***, 2018 PRC
  - **Li***, Dong, Wang, Xu, 2016 ApJS
  - **Li***, Zhang, Zhang, Gao, Qi, Liu, 2016 PRD
  - **Li***, Hu, Shang, Zuo, 2016 PRC
  - **Li***, Liu, 2013 A&A
- **Excited nucleons (Δ-isobars)**
  - Zhu, **Li***, Hu, Sagawa, 2016 PRC
- **Kaon condensation**
  - **Li***, Zhou, Burgio, Schulze, 2010 PRC
  - **Li***, Burgio, Lombardo, Zuo, 2006 PRC
  - Zuo*, **Li**, Li, Lombardo, 2004 PRC
- **Free quarks**→ Hybrid star (混杂星)
  - **Li***, Peng, Zuo, 2015 PRC
  - Peng*, **Li**, Lombardo, 2008 PRC
- **Hyperons** (Λ^0, $\Sigma^{0,\pm,}$ $\Xi^{0,-}$)→ Hyperon star (超子星)
  - **Li***, Hiyama, Zhou, Sagawa, 2013 PRC
  - Hu, **Li***, Toki, Zuo, 2014 PRC
  - Burgio*, Schulze, **Li**, 2011 PRC

- Any strangeness phase transition leads to softer EOS (lower M_{TOV}) (Hyperon puzzle);
- Nucleonic EOS sufficiently stiff, or only weak soften (late appearance) of Delta/hyperon/Kaon/quark;
- Universal baryonic repulsive three-body force, or stiff quark core;
- Study of hyperon interaction (NY,YY,NNY,NYY,YYY) through hyperonnuclei/scattering experiments VERY IMPORTANT.



▸ Hyperon interaction (NY,YY,NNY,NYY,YYY) through hyperonnuclei/scattering experiments are VERY IMPORTANT 1/2

- **Microscopic** scheme, e.g., BHF;
- Nijmegen soft-core NY potentials (NSC89/ESC08...) model, fitted to the available experimental NY scattering data;
- Presently, 4233 NN data, 52 NY data, weak ΛΛ attraction (Nagara event, Takahashi et al., PRL 2001)

With these potentials, the various G-matrices are evaluated by solving numerically the Bethe-Goldstone equation, which can be written in operator form as

$$G_{ab}[W] = V_{ab} + \sum_c \sum_{p,p'} V_{ac}|pp'\rangle \frac{Q_c}{W - E_c + i\varepsilon} \langle pp'|G_{cb}[W], \quad (6)$$

where the indices a, b, c indicate pairs of baryons, and the Pauli operator Q_c and energy E_c characterize the propagation of intermediate baryon pairs. The pair energy in a given channel $c = (B_1 B_2)$ is

$$E_{(B_1B_2)} = T_{B_1}(k_{B_1}) + T_{B_2}(k_{B_2}) + U_{B_1}(k_{B_1}) + U_{B_2}(k_{B_2}), \quad (7)$$

with $T_B(k) = m_B + k^2/2m_B$, where the various s.p. potentials are given by

$$U_B(k) = \sum_{B'=n,p,\Lambda,\Sigma^-} U_B^{(B')}(k) \quad (8)$$

and are determined self-consistently from the G-matrices,

$$U_B^{(B')}(k) = \sum_{k'<k_F^{(B')}} \mathrm{Re}\langle kk'|G_{(BB')(BB')}[E_{(BB')}(k,k')]|kk'\rangle_A . \quad (9)$$

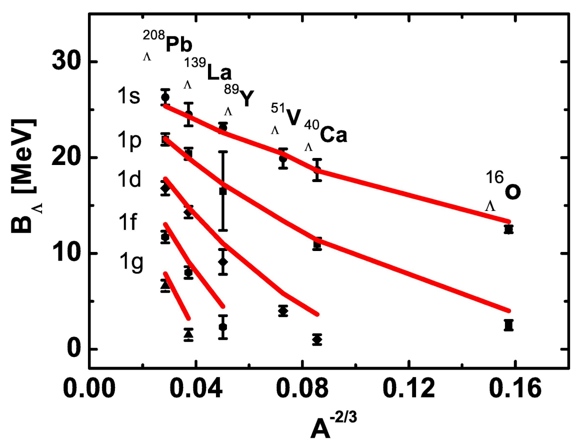
The coupled eqs. (6)–(9) define the BHF scheme with the

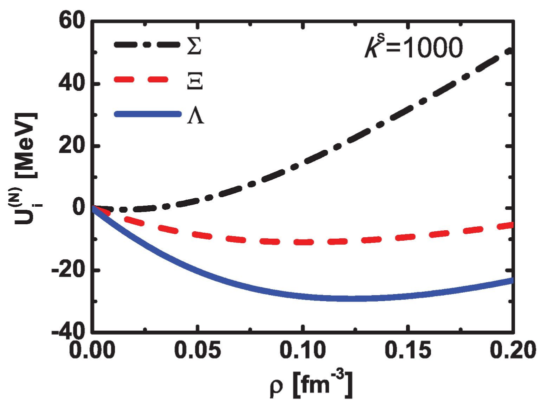
*e.g., Burgio, Schulze, **AL**, 1101.0726 PRC 2011*

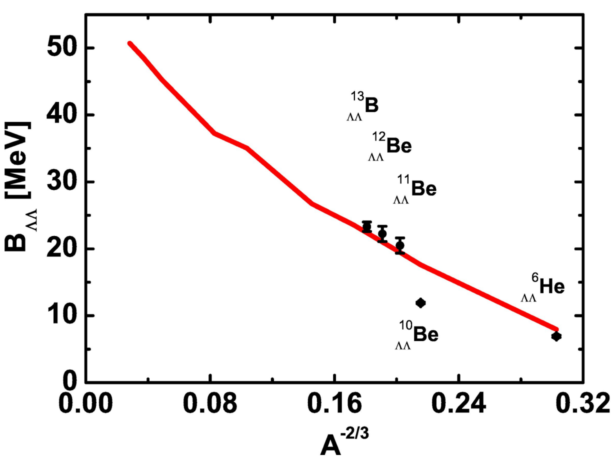
▸ Hyperon interaction (NY,YY,NNY,NYY,YYY) through hyperonnuclei/scattering experiments are VERY IMPORTANT 2/2

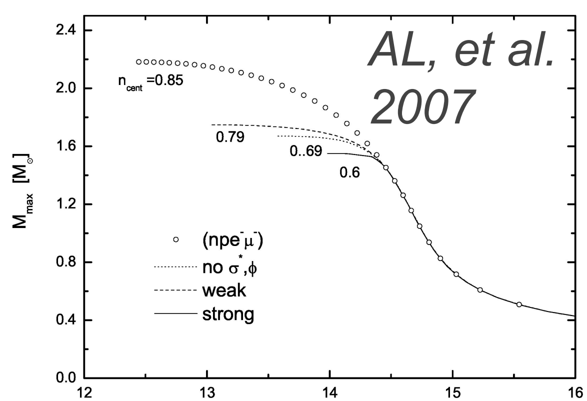
- **Phenomenological** scheme, e.g., RMF/QMF;
- Meson coupling constant ($\sigma\omega\varrho$...)

$$
\begin{aligned}
\mathcal{L} = \bar{\psi}\Big[& i\gamma_\mu\partial^\mu - M_N^* - g_\omega\omega\gamma^0 \\
& - g_\rho\rho\tau_3\gamma^0 - e\frac{(1+\tau_3)}{2}A\gamma^0\Big]\psi \\
& + \bar{\psi}_\Lambda\left[i\gamma_\mu\partial^\mu - M_\Lambda^* - g_\omega^\Lambda\omega\gamma^0\right]\psi_\Lambda \\
& - \frac{1}{2}(\nabla\sigma)^2 - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{4}g_3\sigma^4 \\
& + \frac{1}{2}(\nabla\omega)^2 + \frac{1}{2}m_\omega^2\omega^2 + \frac{1}{4}c_3\omega^4 \\
& + \frac{1}{2}(\nabla\rho)^2 + \frac{1}{2}m_\rho^2\rho^2 + \frac{1}{2}(\nabla A)^2
\end{aligned}
$$



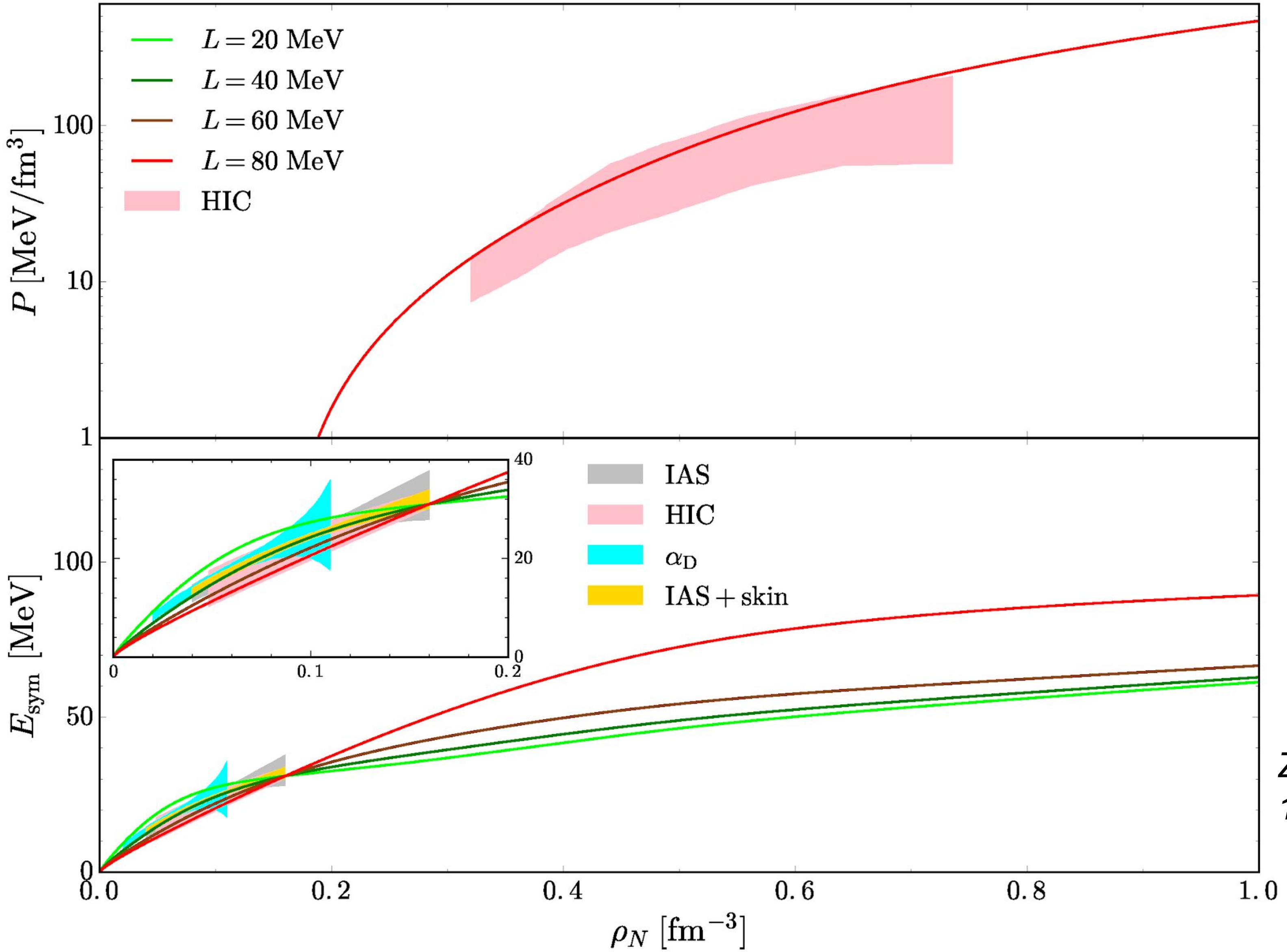






*e.g., J. N. Hu, **AL**, H. Shen and H. Toki, 1310.3602 PTEP 2014*

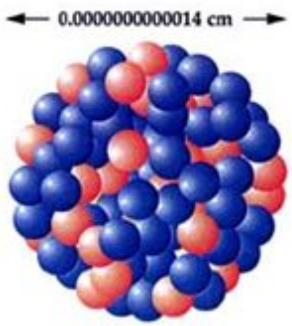
- Ignore strangeness for the moment
- EOS uncertain most in asymmetric part: *L*-vs-Λ?

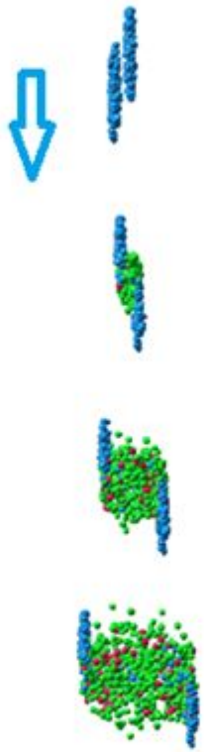


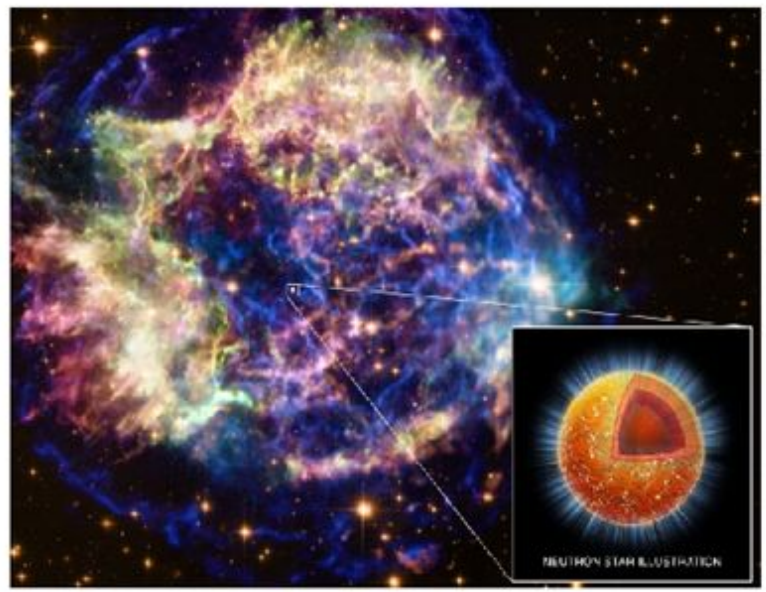
Zhu, Zhou & AL
1802.05510

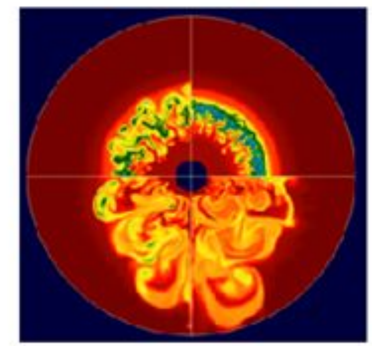
❑ Isobaric analog states (**IAS)** and from IAS and neutron skins (**IAS+skin**) *(Danielewicz & Lee 2014)*;

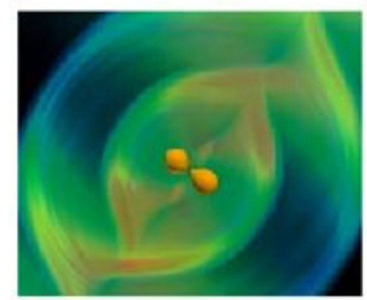
❑ Electric dipole polarizability in ^{208}Pb ($\boldsymbol{\alpha}_D$) *(Zhang & Chen 2015)*.









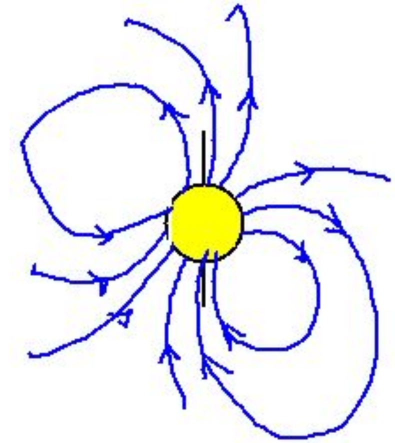


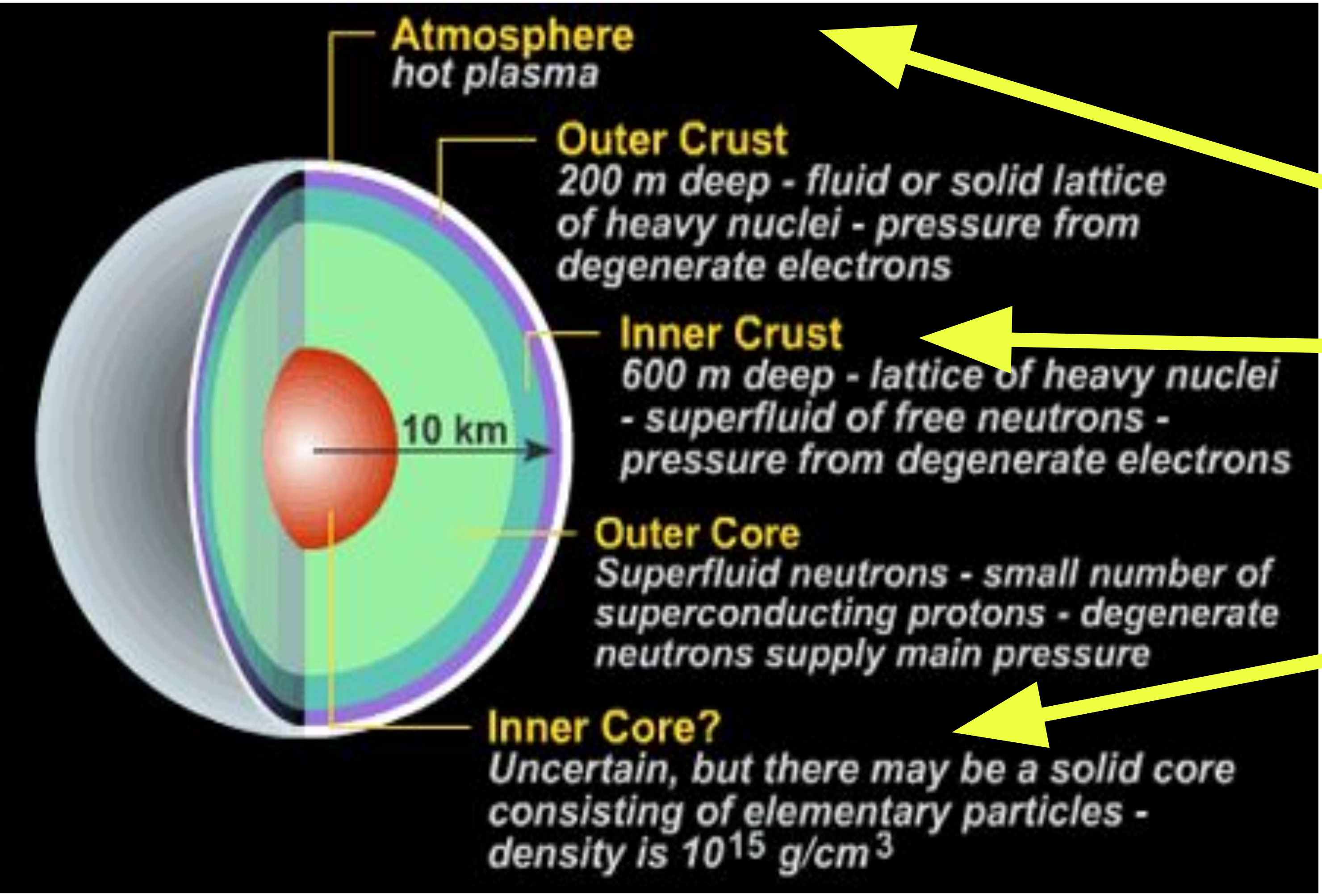
- Collective flow in **HIC** *(Danielewicz et al. 2002)*;
- Transport in **HIC** *(Tsang et al. 2009)*

★ PSR J1614-2230 *(Demorest et al. 2010; Fonseca et al. 2016)*;

★ PSR J0348+0432 *(Antoniadis et al. 2013)*.

- More astrophysical observations soon (NICER, Athena, eXTP, FAST, SKA, LIGO/VIRGO)





Hot X-ray

Glitch

*(e.g., **AL** et al. 2016 ApJS)*

Mass

▸ Many-body model

Green's Function Monte Carlo

Chiral Perturbation Theory (ChPT)

Variational Many-Body (VMB)

V_{lowk} + Renormalization Group

Brueckner-Hartree-Fock (BHF)

Dirac-Brueckner-Hartree-Fock (DBHF)

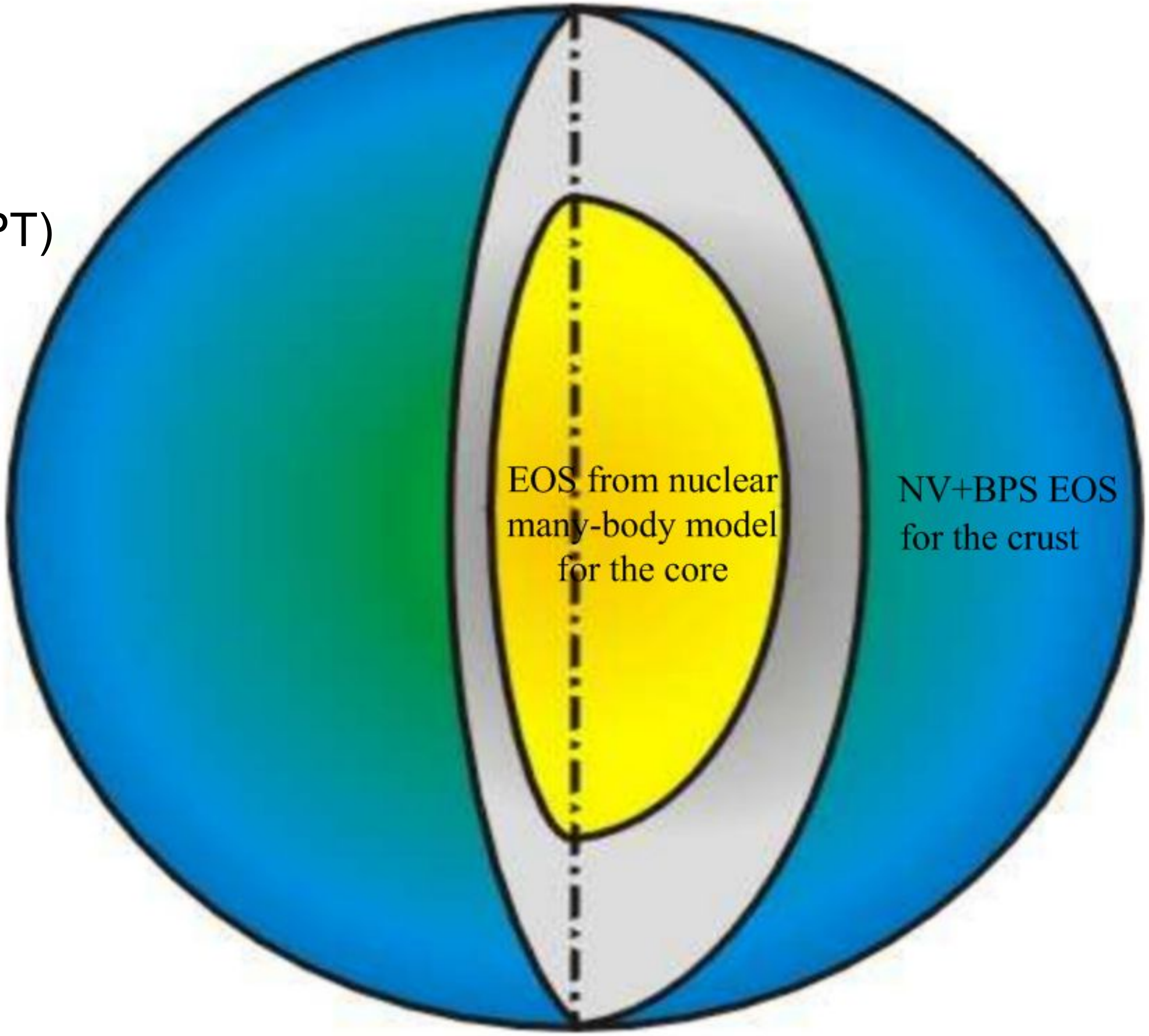
Quark mean-field (QMF)

Quark Meson Coupling (QMC)

Relativistic mean-field (RMF)

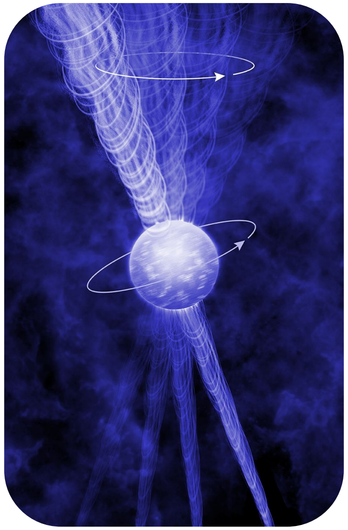
Skyrme energy density functional

…



Unless you are using unified NS EOS...
*(e.g., **AL** et al. 2016 PRD, ApJS)*

▸ Rotation



- **NS/QS structures are unique to the underlying EoS.**

❑ Static (TOV)

$$\frac{dP(r)}{dr} = -\frac{GM(r)\varepsilon(r)}{r^2}\frac{\left[1+\frac{P(r)}{\varepsilon(r)}\right]\left[1+\frac{4\pi r^3 P(r)}{M(r)}\right]}{1-\frac{2GM(r)}{r}}, \quad (1)$$

$$\frac{dM(r)}{dr} = 4\pi r^2 \varepsilon(r), \quad (2)$$

❑ Slow rotation $\Omega \ll \Omega_{\max} \approx \sqrt{GM/R^3}$

Spherical-symmetry metric + Axis-symmetry perturbation

Vela pulsar @ ***AL,*** *Dong, Wang, Xu, 2016* *ApJS* 1512.00340

❑ Fast rotation

Relativistic stars in general relativity from *rns* code (*www/gravity.phys.uwm.edu/rns*),

Komatsu H, Eriguchi Y and Hachisu I 1989 *Mon. Not. R. Astron. Soc.* **237** 355
Cook G B, Shapiro S L and Teukolsky S A 1994 *ApJ* **422** 227
Stergioulas N and Friedman J L 1995 *ApJ* **444** 306

AL, *Zhang, Zhang, Gao, Qi, Liu, 2016 PRD,* 1606.02934

▸ NS EOS model from the quark level within QMF (m_q~300MeV)

Step 1: Single nucleon

$$[\gamma^0(\epsilon_q - g_{\omega q}\omega - \tau_{3q} g_{\rho q}\rho) - \vec{\gamma}\cdot\vec{p} - (m_q - g_{\sigma q}\sigma) - U(r)]\psi_q(\vec{r}) = 0$$

$$U(r) = \frac{1}{2}(1+\gamma^0)(ar^2 + V_0) \qquad V_0 = -62.257187 \text{ MeV}, \quad a = 0.534296 \text{ fm}^{-3}$$

← $M_N = 939$ MeV, $r_N = 0.87$ fm.

Step 2: Nucleon many-body system

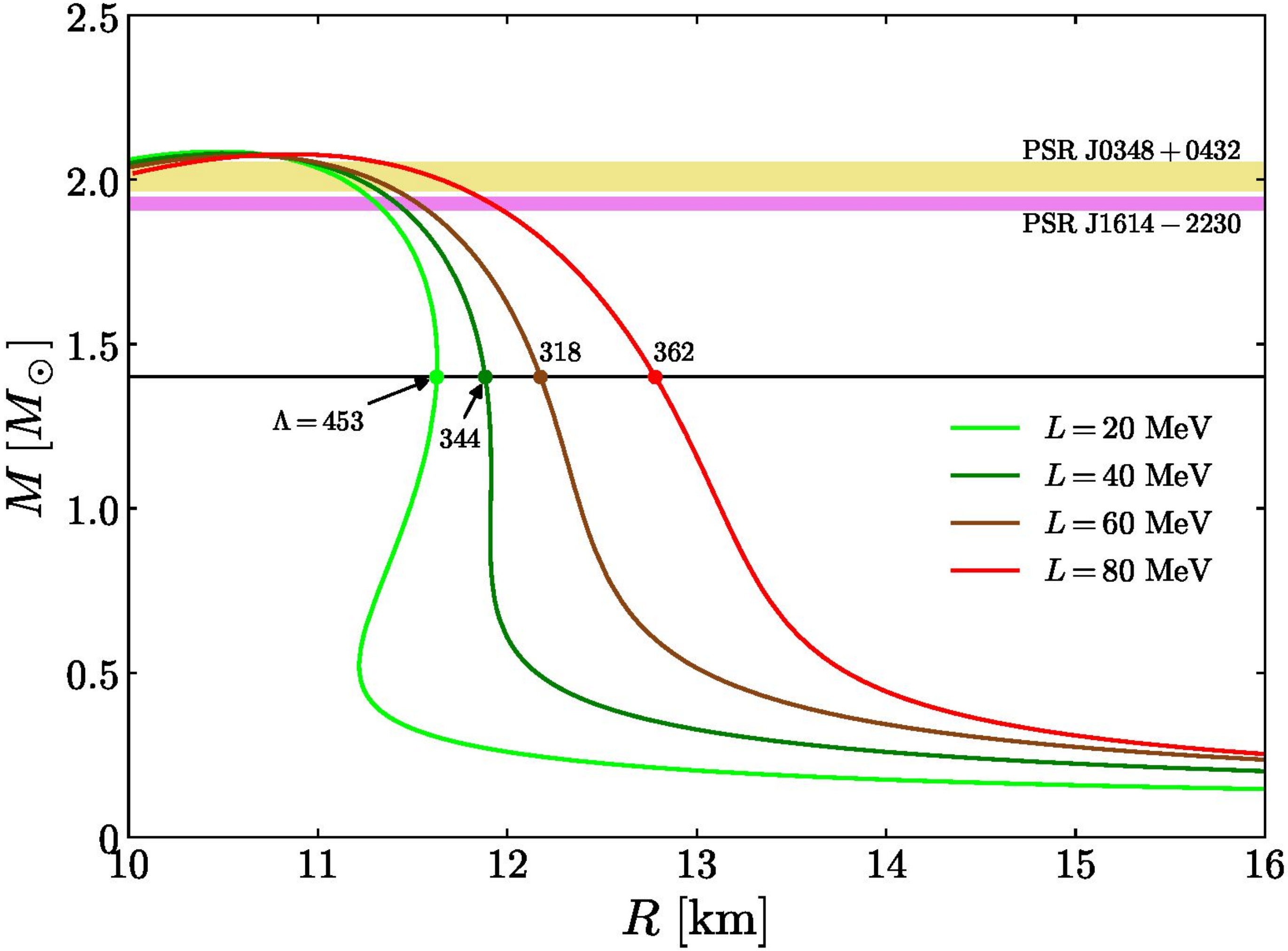
$$\mathcal{L} = \overline{\psi}\left(i\gamma_\mu\partial^\mu - M_N^* - g_{\omega N}\omega\gamma^0 - g_{\rho N}\rho\tau_3\gamma^0\right)\psi - \frac{1}{2}(\nabla\sigma)^2 - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4$$
$$+\frac{1}{2}(\nabla\rho)^2 + \frac{1}{2}m_\rho^2\rho^2 + \frac{1}{2}(\nabla\omega)^2 + \frac{1}{2}m_\omega^2\omega^2 + \frac{1}{2}g_{\rho N}^2\rho^2\Lambda_v g_{\omega N}^2\omega^2,$$

L [MeV]	$g_{\sigma q}$	$g_{\omega q}$	$g_{\rho q}$	g_2 [fm^{-1}]	g_3	Λ_v
20	3.8620366	2.9174838	6.9588083	14.6179599	-66.3442468	1.1080665
40	3.8620366	2.9174838	5.4129448	14.6179599	-66.3442468	0.7693664
60	3.8620366	2.9174838	4.5830609	14.6179599	-66.3442468	0.4306662
80	3.8620366	2.9174838	4.0459574	14.6179599	-66.3442468	0.0919661

ρ_0 [fm^{-3}]	E/A [MeV]	K [MeV]	E_{sym} [MeV]	L [MeV]	M_N^*/M_N /
0.16	-16	240	31	20/40/60/80	0.77

Li & Han (2013)

- All smaller than 800 limit of GW170817;
- Larger *L*, larger *R*, **NOT** monotonic dependence of Λ.



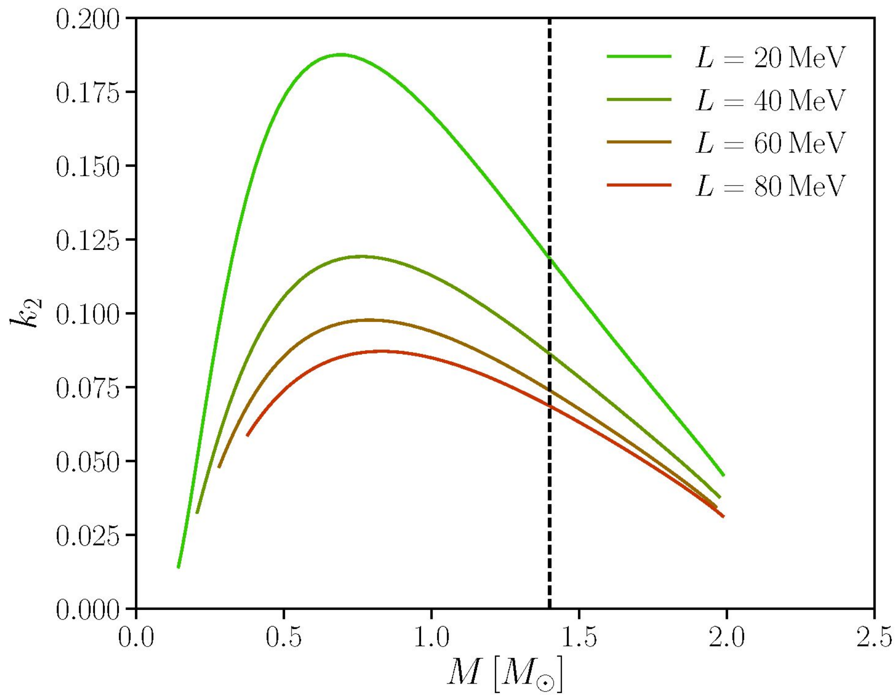
- Tidal deformability: $\Lambda = \frac{2}{3}k_2(M/R)^{-5}$

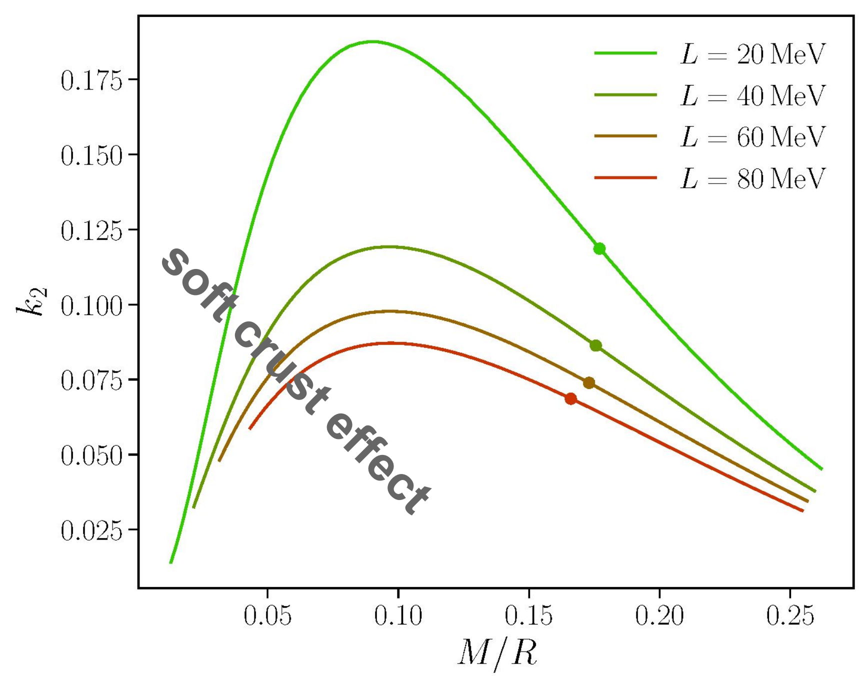
describes the amount of induced mass quadrupole moment when reacting to a certain external tidal field.

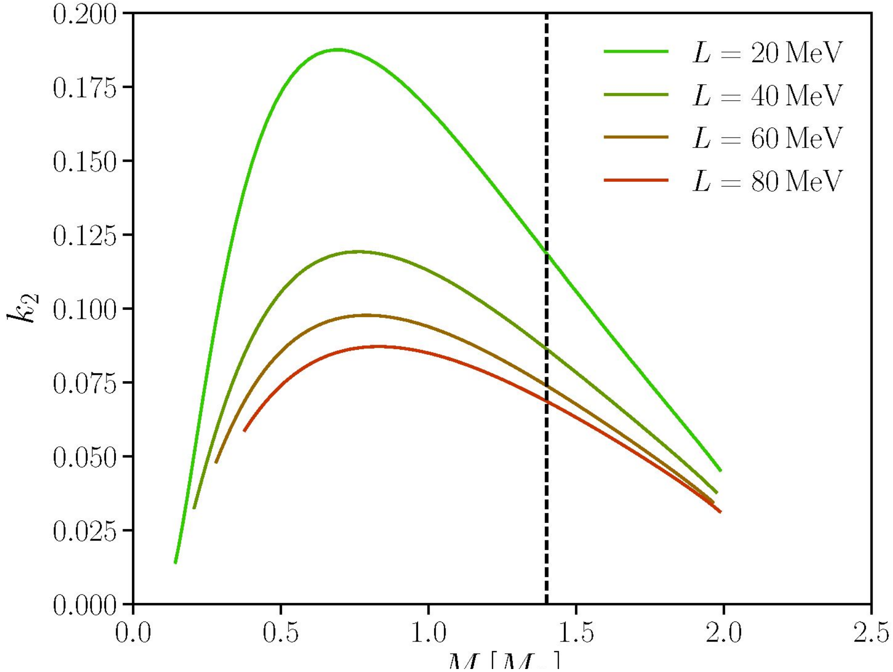
- Tidal 2nd Love number $\boldsymbol{k_2}$: $Q_{ij} = -k_2\frac{2R^5}{3G}E_{ij}$

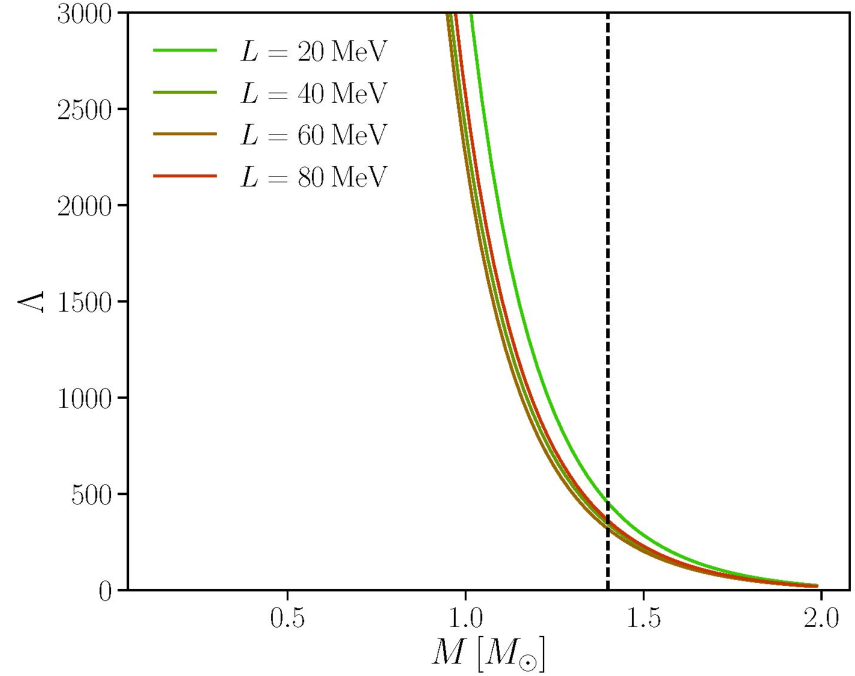
measures how easily the bulk of the matter in a star is deformed by an external tidal field.

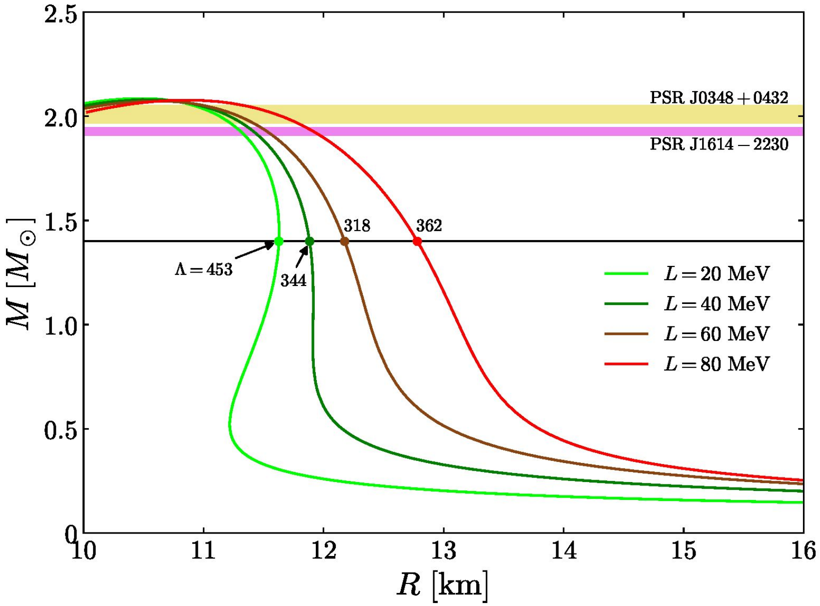
- Larger L leads to smaller k_2, for a star with certain amount of mass/compactness.











$$\Lambda = \frac{2}{3} k_2 (M/R)^{-5}$$

- Λ is normalized with a factor of R^5, from k_2
- Differences in radius scatter the dependence on L.

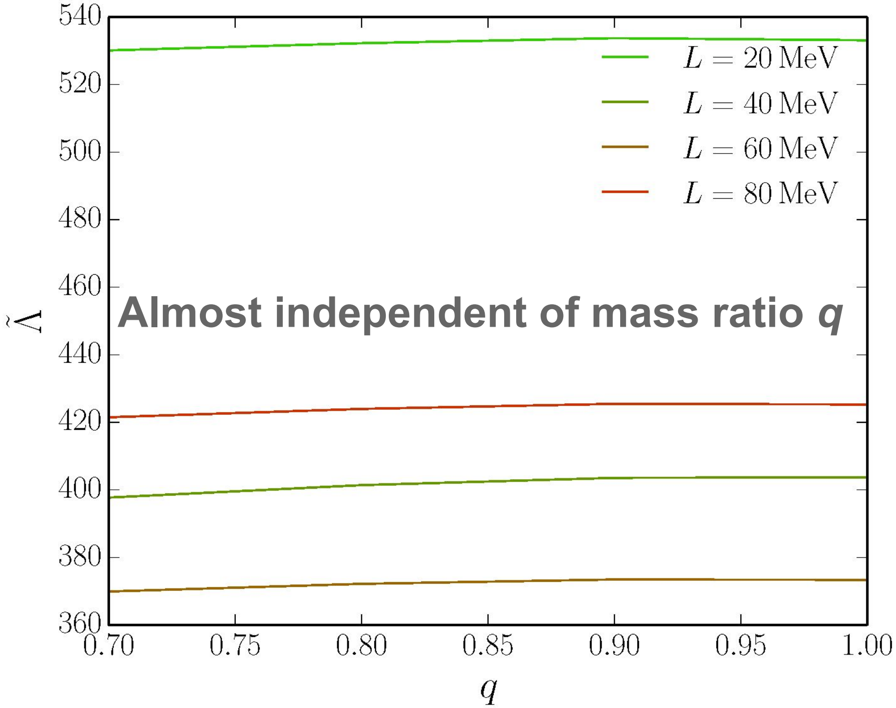
- Employing very well-constrained chirp mass of GW170817;

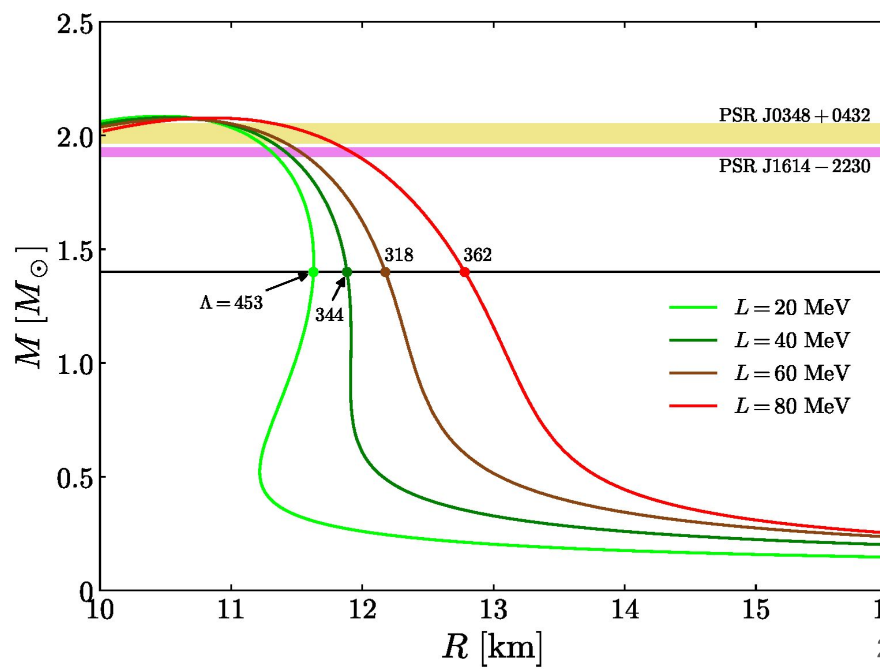
$$\mathcal{M} = (m_1 m_2)^{3/5}(m_1 + m_2)^{-1/5} = 1.188^{+0.004}_{-0.002} M_\odot$$

- Combined dimensionless tidal deformability **(Directly measured!)**

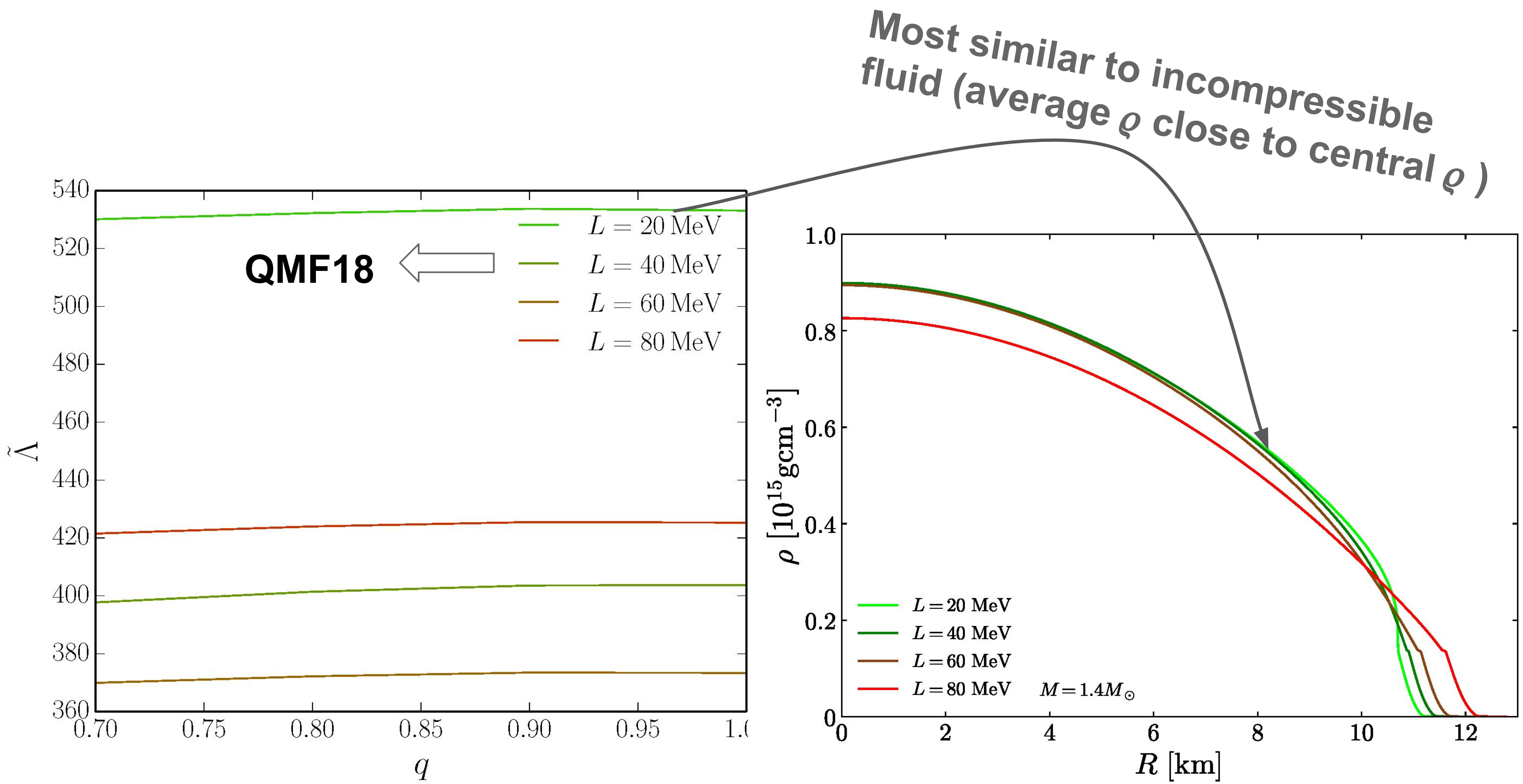
$$\tilde{\Lambda} = \frac{16}{13}\frac{(m_1 + 12m_2)m_1^4\Lambda_1 + (m_2 + 12m_1)m_2^4\Lambda_2}{(m_1 + m_2)^5}$$

- Violation of monotonic dependence: Maybe dangerous to probe R/L via Λ.





- To better understand the nonmonotonic behaviour



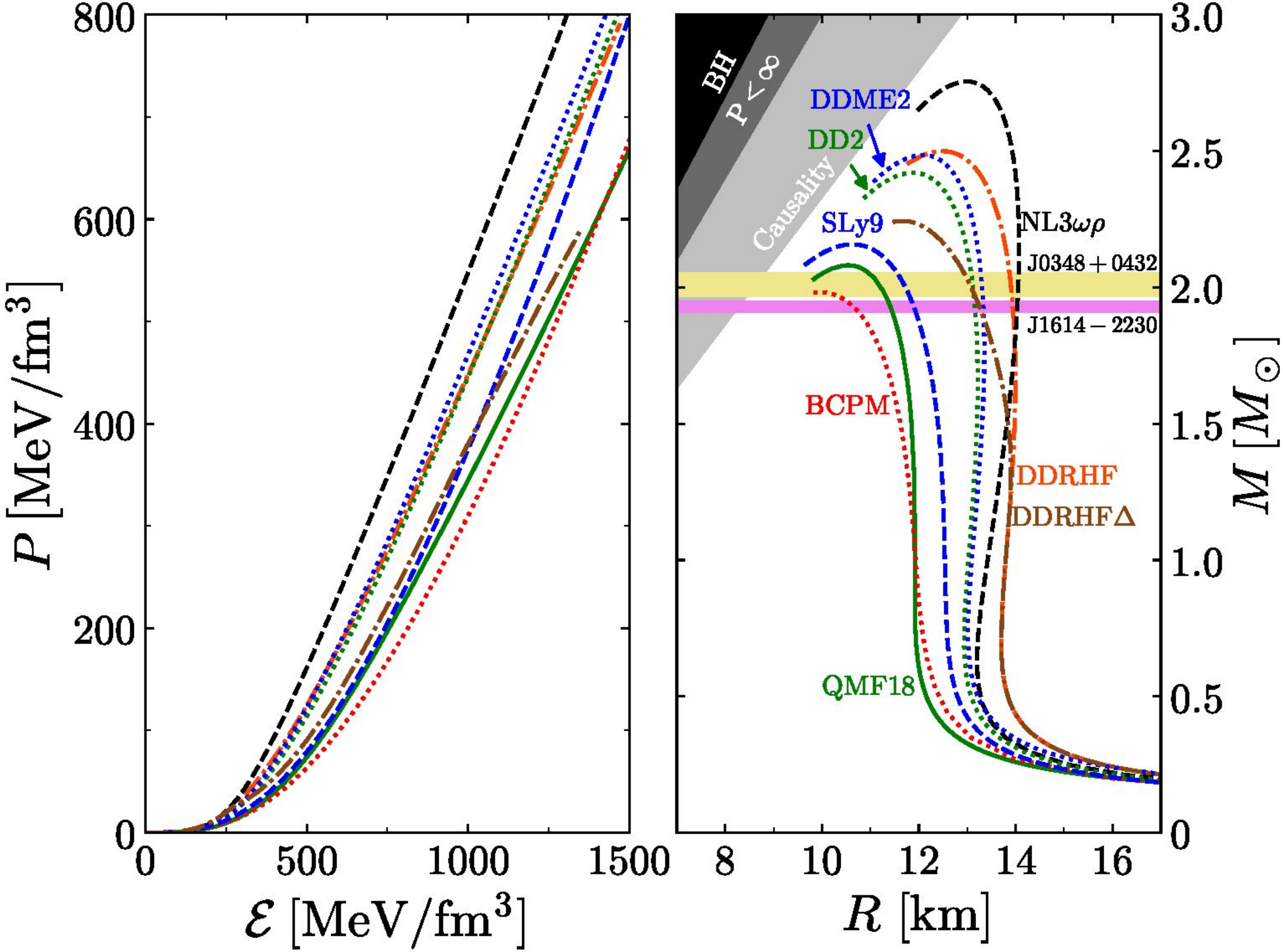
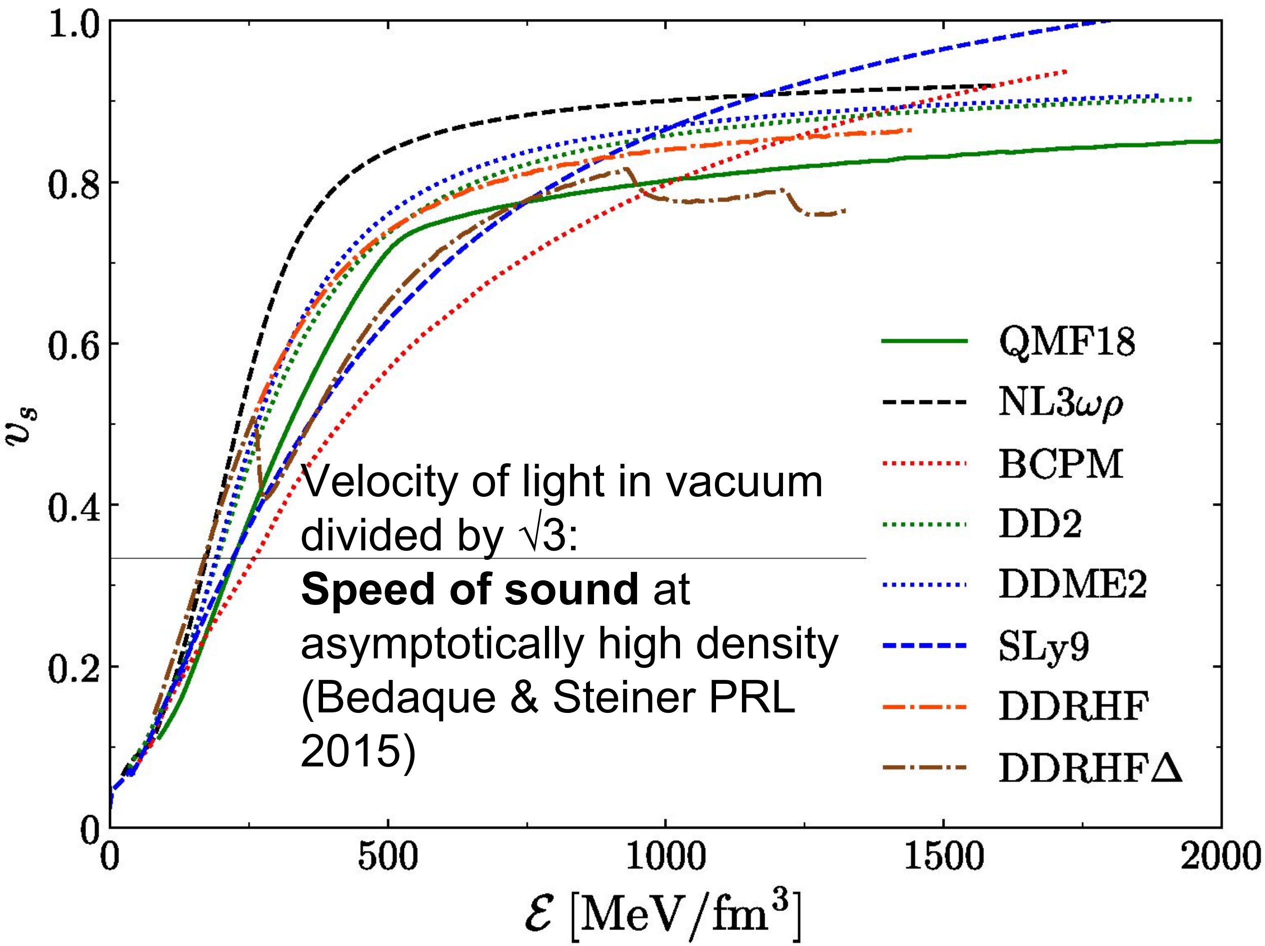

800
600
400
200
0
0
500
1000
1500
P [MeV/fm^3]
$\mathcal{E}$ [MeV/fm^3]
BH
P < ∞
Causality
DDME2
DD2
SLy9
NL3ωρ
J0348 + 0432
J1614 − 2230
BCPM
DDRHF
DDRHFΔ
QMF18
3.0
2.5
2.0
1.5
1.0
0.5
0
8
10
12
14
16
R [km]
M [$M_\odot$]

Table 4. Radius, compactness and tidal deformability for a 1.4 $M_\odot$ star are provided for various advanced NS EOSs, together with their maximum static gravitational mass $M_{\rm TOV}$ and the symmetry energy slope L.

	QMF18	DDRHF	DDRHFΔ	NL3ωρ	DDME2	DD2	Sly9	BCPM
$M_{\rm TOV}$ [$M_\odot$]	2.08	2.50	2.24	2.75	2.48	2.42	2.16	1.98
L [MeV]	40	82.99	82.99	55.5	51.2	55.0	54.9	52.96
$R(1.4)$ [km]	11.77	13.74	13.67	13.75	13.21	13.16	12.46	11.72
$M/R(1.4)$	0.1756	0.1505	0.1512	0.1503	0.1566	0.1571	0.1660	0.1765
$\Lambda(1.4)$	344	865	828	925	681	674	446	294

<13.6 km (Annala et al.,)



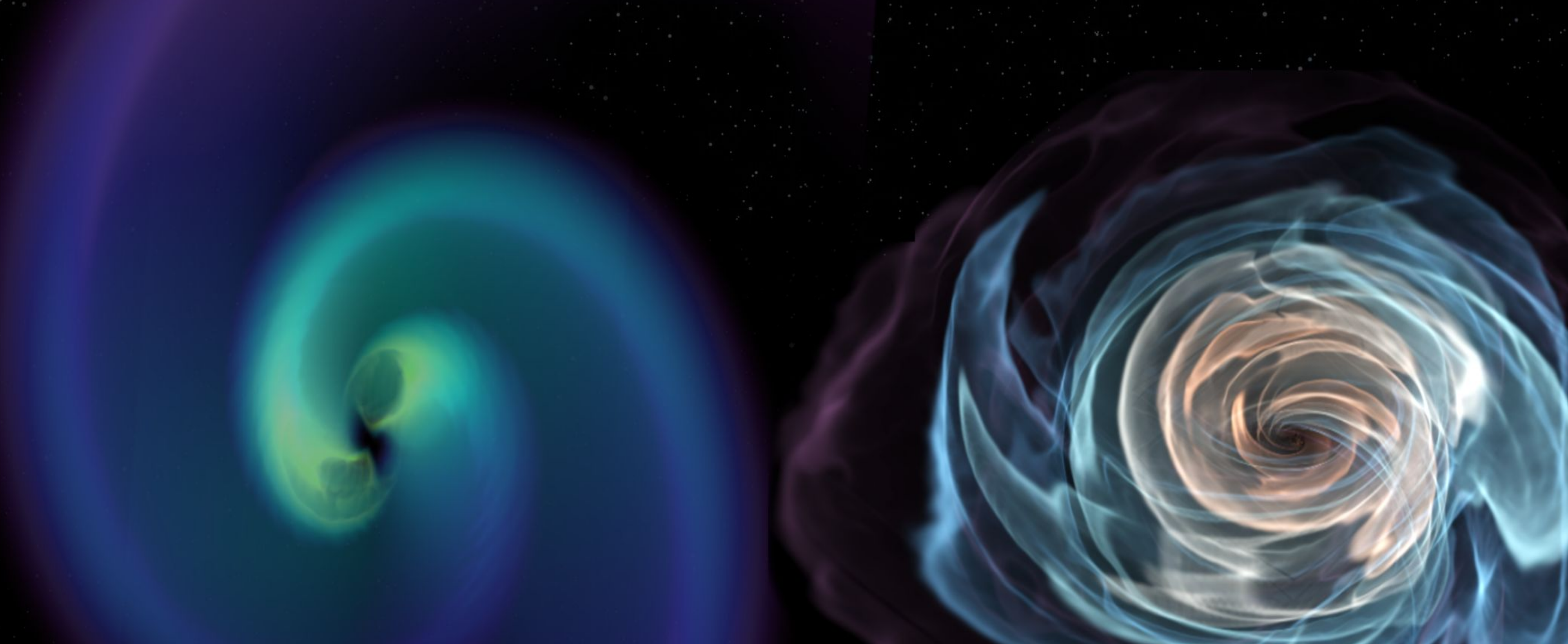
Details in Zhu, Zhou & AL 1802.05510

Table 3. NS EOS for the QMF18 model newly introduced in this work.

ϵ [g cm^{-3}]	P [erg cm^{-3}]	ρ_N [fm^{-3}]
0.13855E+15	0.79586E+33	0.082
0.14365E+15	0.85234E+33	0.085
0.15216E+15	0.95144E+33	0.090
0.16920E+15	0.11706E+34	0.100
0.18626E+15	0.14226E+34	0.110
0.20336E+15	0.17145E+34	0.120
0.22047E+15	0.20433E+34	0.130
0.27203E+15	0.33950E+34	0.160
0.32393E+15	0.55426E+34	0.190
0.37631E+15	0.87679E+34	0.220
0.42926E+15	0.13315E+35	0.250
0.48293E+15	0.19385E+35	0.280
0.53741E+15	0.27149E+35	0.310
0.59282E+15	0.36752E+35	0.340
0.64927E+15	0.48329E+35	0.370
0.70686E+15	0.62008E+35	0.400
0.76568E+15	0.77912E+35	0.430
0.82583E+15	0.96151E+35	0.460
0.88738E+15	0.11682E+36	0.490
0.95043E+15	0.13999E+36	0.520
0.10150E+16	0.16569E+36	0.550
0.10813E+16	0.19389E+36	0.580
0.11492E+16	0.22449E+36	0.610
0.12189E+16	0.25733E+36	0.640
0.12904E+16	0.29223E+36	0.670
0.13636E+16	0.32903E+36	0.700
0.14896E+16	0.39423E+36	0.750
0.16207E+16	0.46399E+36	0.800
0.17568E+16	0.53809E+36	0.850
0.18978E+16	0.61645E+36	0.900
0.20438E+16	0.69900E+36	0.950
0.21948E+16	0.78573E+36	1.000
0.25116E+16	0.97160E+36	1.100
0.28480E+16	0.11739E+37	1.200
0.32039E+16	0.13926E+37	1.300

"QMF18"
Welcome to use!

First Cosmic Event Observed in Gravitational Waves and Light



In this talk

- QS merger scenario for GW demonstrated;
- New interquark parameter range found;
- New NS EOS “QMF18” proposed.

Hurry for more calculations before O5!
Thank you for listening.
Ang