Constraining the EoS and compact stars structure with multi-messenger data

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H. Güven, K. Bozkurt, E. Khan, J. Margueron, PRC102(2020)015805
H. Güven, J. Margueron, K. Bozkurt, E. Khan, PRC108(2023)035810

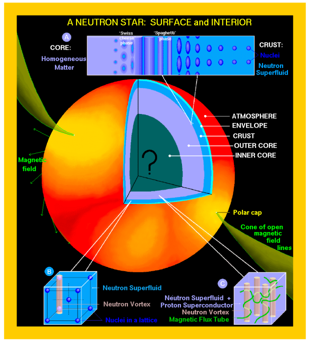
Outline

- GW constraints on the EoS
- Compact stars: from neutron stars to hybrid stars
- A couple of discussions items

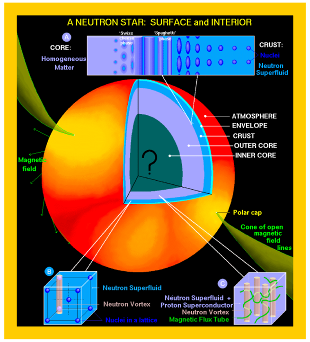
I could help on

- GW constraints on the EoS
- Nuclear excitations for r-process nucleosynthesis
- Collective excitations in the crust of neutron stars
- Hypernuclei
- Electron capture in supernovae
- Propagation of Ultra-High Energy Cosmic Rays
- Incompressibility of the EoS

GW, EoS and compact stars



2 NS merging



Open questions:

- GW vs multimessenger vs nuclear phys. constraints
- EoS quantities: L_{sym}, K_{sym} etc.
- Neutron stars vs hybrid stars

Method (1/2): EoS

- TOV eq: R, M with either (metamodel EoS or 2 EoS) + crust ~ SLy4 in CLDM

$$v(n_0, n_1) = \sum_{a \geqslant 0}^{N} \frac{1}{a!}(c_a^{\text{sat}} + c_a^{\text{sym}}\delta^2)x^a u_a(x)$$

$$c_{a=1}^{\text{sym}} = L_{\text{sym}} - \tfrac{5}{9}t_{\text{sat}}^{\text{FG}}[2 + 5(\kappa_{\text{sat}} + 3\kappa_{\text{sym}})],$$

$$c_{a=2}^{\text{sym}} = K_{\text{sym}} - \tfrac{10}{9}t_{\text{sat}}^{\text{FG}}[-1 + 5(\kappa_{\text{sat}} + 3\kappa_{\text{sym}})]$$

$x=(\rho-\rho_{sat})/3\rho_{sat}$

	Sly5	PKDD
L_{sym}=	48 MeV	80 MeV

- If Hybrid Star: quark phase

$$\varepsilon(p) = \begin{cases} \varepsilon_{\text{NM}}(p) & p < p_{\text{PT}} \\ \varepsilon_{\text{NM}}(p_{\text{PT}}) + \Delta\varepsilon_{\text{PT}} + (p - p_{\text{PT}})/\alpha & p \geqslant p_{\text{PT}} \end{cases}$$

MIT bag model

$$\Delta\varepsilon_{\text{PT}} = \frac{p_{\text{PT}}}{\alpha}\left[\frac{1+\alpha}{\left[\frac{\mu_{\text{NM}}(p_{\text{PT}})}{\mu^*}\right]^{\frac{1+\alpha}{\alpha}} - 1} + 1\right] - \varepsilon_{\text{NM}}(p_{\text{PT}})$$

Parameters variation:

$\mu^* = 925 \pm 75$ MeV

$\alpha=c_s^2=1/3$ or $2/3$ or 1

p_{PT} from 6 to 500 MeV fm^{-3}

Method (2/2): polarizability and analysis

- Tidal polarizability calculation

$$\Lambda = \frac{2k_2}{3C^5}$$

$$k_2 = \frac{8C^5}{5}(1-2C)^2[2+2C(Y-1)-Y] \times \{2C[6-3Y+3C(5Y-8)] + 4C^3[13-11Y+C(3Y-2)+2C^2(1+Y)] + 3(1-2C)^2[2-Y+2C(Y-1)]\ln(1-2C)\}^{-1}$$

Y=y(R)

$$r\frac{dy(r)}{dr} + y(r)^2 + y(r)F(r) + Q(r) = 0$$

$$F(r) = \frac{1}{r-2Gm/c^2}\left(\frac{r+4\pi G r^3}{P-\rho c^2}\right),$$

$$Q(r) = \frac{4\pi G r^3/c^2}{r-2Gm/c^2}\left(5\rho + \frac{9P}{c^2} + \frac{P+\rho c^2}{\rho c_s}\right) - \frac{4\pi G r^3/c^2}{r-2Gm/c^2}\left(\frac{6}{4\pi G r^2/c^2}\right) - \left(\frac{2G^2 r}{c^4}\right) \times \left(\frac{m+4\pi r^3 P/c^2}{r-2Gm/c^2}\right)^2,$$

$M_1 + M_2 = 2.73M_\odot$

$$\tilde{\Lambda} = \frac{16}{13}\frac{(M_1+12M_2)M_1^4\Lambda_1 + (M_2+12M_1)M_2^4\Lambda_2}{(M_1+M_2)^5}$$

- Bayesian analysis

$$P(\{a_i\}|\text{data}) \sim P(\text{data}|\{a_i\}) \times P(\{a_i\})$$

posterior — prior

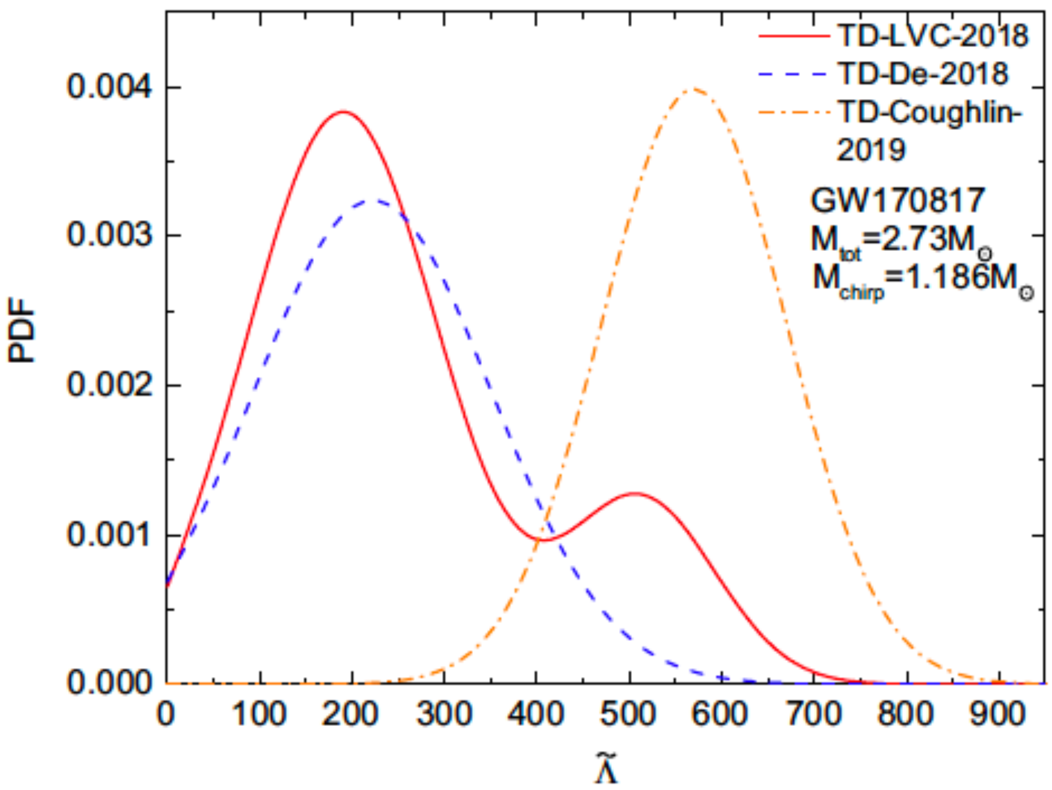
with $P(\text{data} \mid \{a_i\}) = w_{\text{filter}}\, p_{\tilde{\Lambda}}\, p_{\chi\text{EFT}}\, p_{\text{ISGMR}}$

w_{filter}: viable models: $M_{max} > 2M_\odot$ etc.

$p_{\chi\text{EFT}}$: Drischler et al.

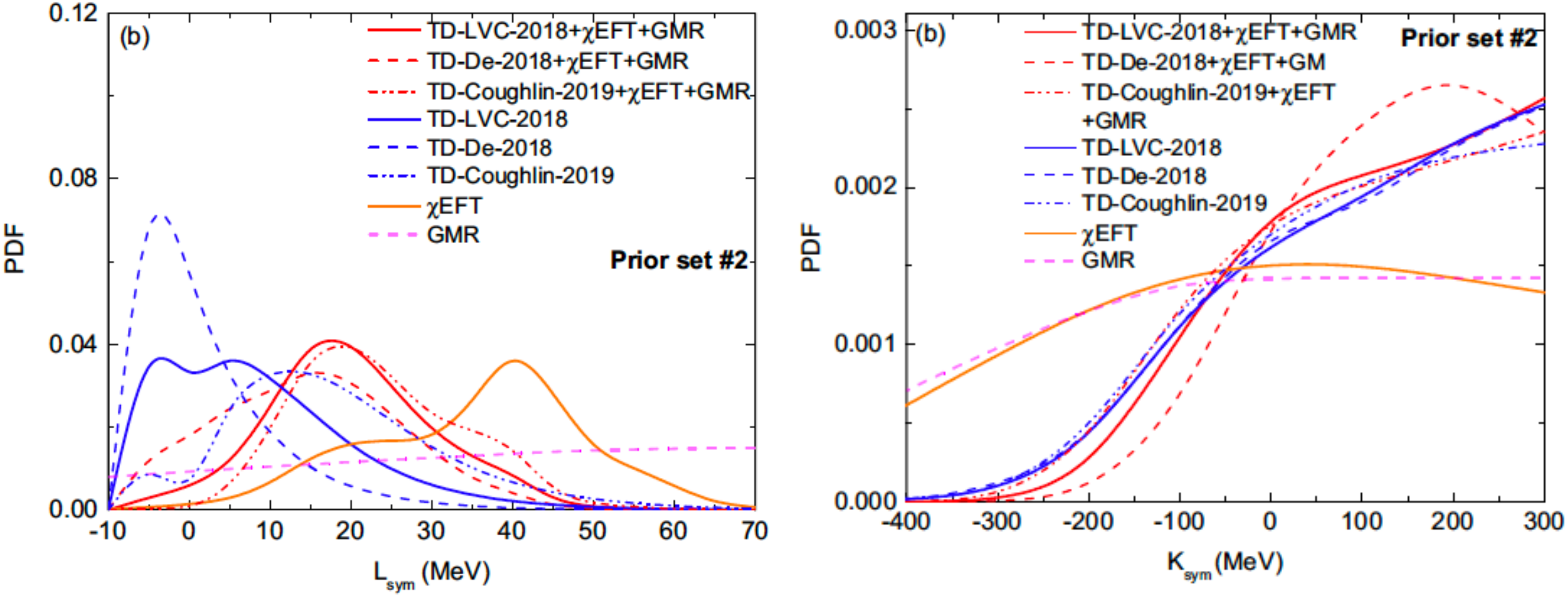
p_{ISGMR}: GMR (M_c)

What about the GW170817 data ?



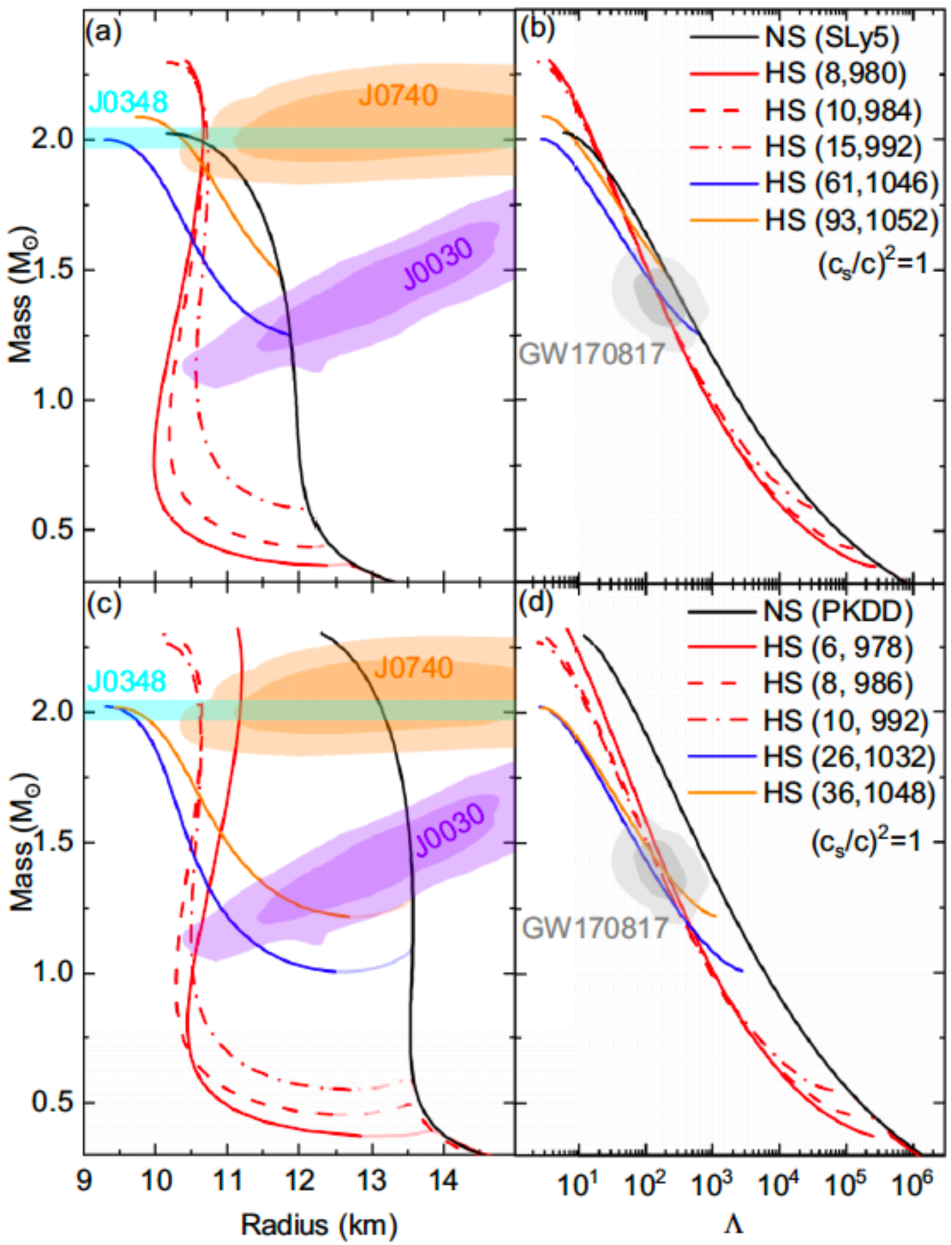
Results

Constraints on the EoS in NS from GW



NS: low L_{sym} value favored wrt nuclear phys. cons.

Tension between GW and other multimessenger data



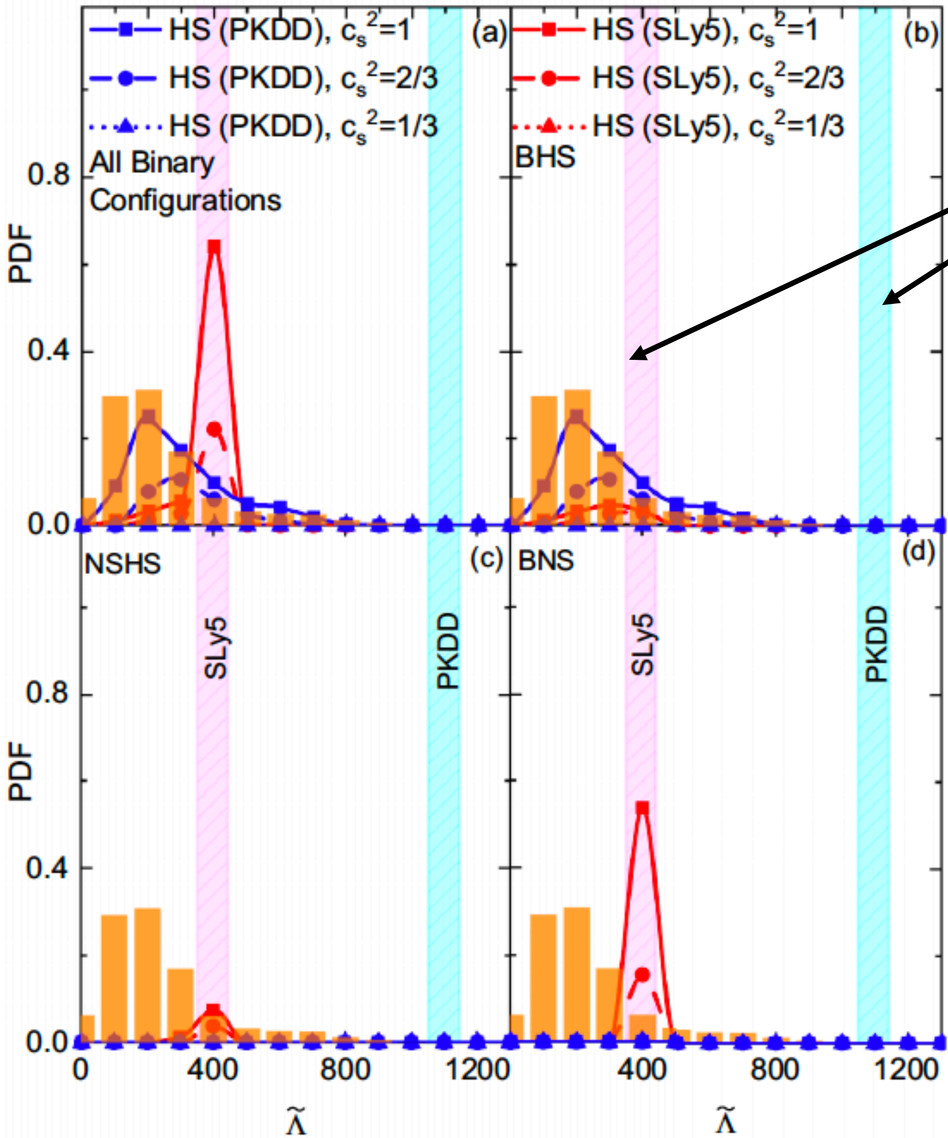
Sly5
L_{sym}= 48 MeV

PKDD
L_{sym}= 80 MeV

Hybrid star: solving the puzzle ?

- HS helps to solve this last one with large Lsym, and stiff q EoS (large sound speed)

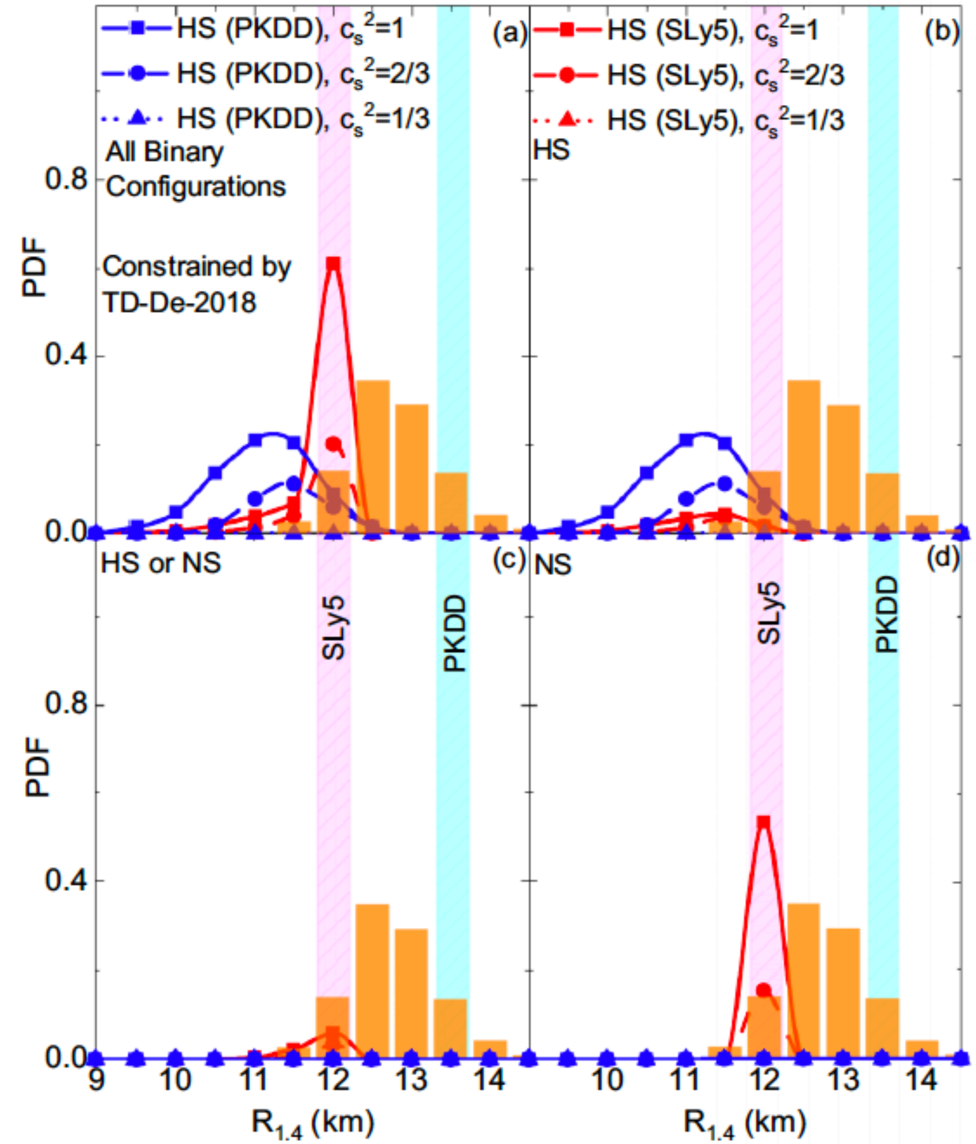
GW170817 data



No q phase

Determination of the radius of the HS

Nicer data



- $R_{1.4}$=12.22(45) km using GW170817 and Nicer data

For the discussion

- Hybrid stars: to be or not to be ?

- Nucleosynthesis in kilonovae: who ?

Thank you !