

A flexible model for neutron star equation of state: Implication of recent observations

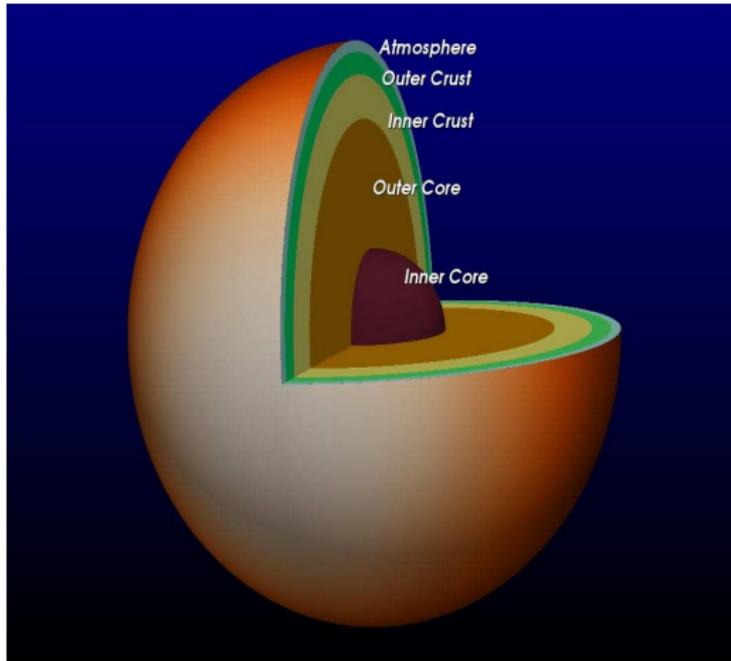
Chiranjib Mondal
Hoa Dinh Thi & Francesca Gulminelli



“Coimbra University”
September 15, 2021

Neutron star

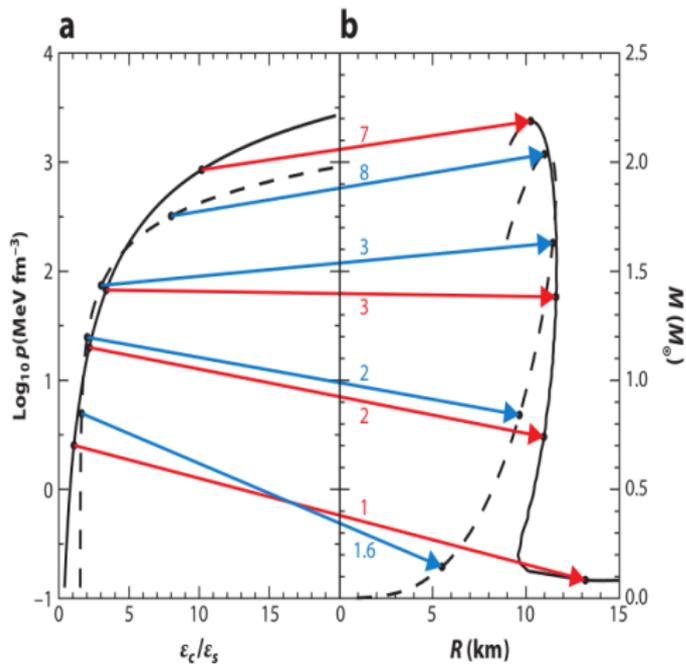
Structure



courtesy: C. Gonzalez-Boquera

Equation of State

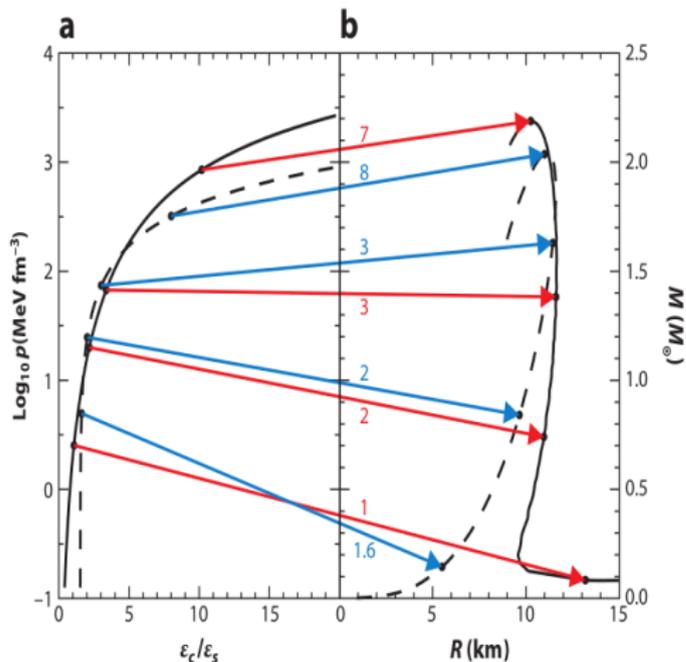
One-to-one correspondence



J. Lattimer, *Ann. Rev. Nucl. Part. Sci.* 62, 485–515 (2012)

Equation of State

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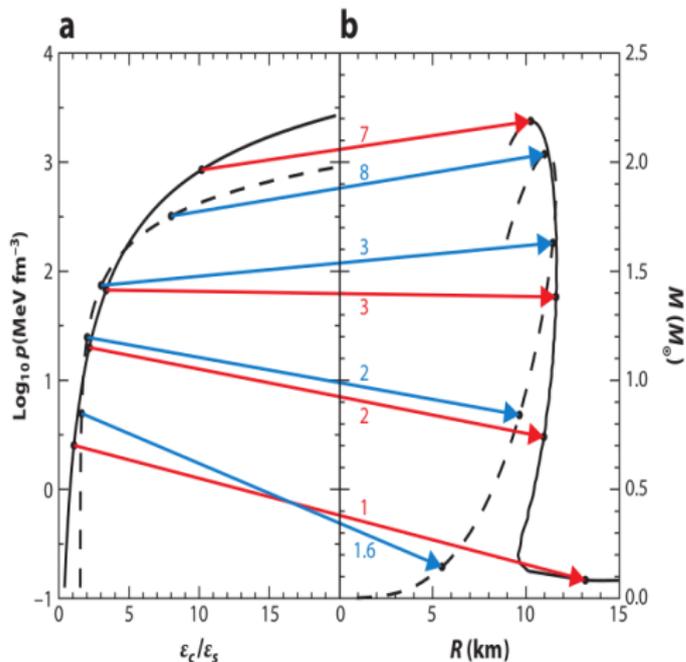


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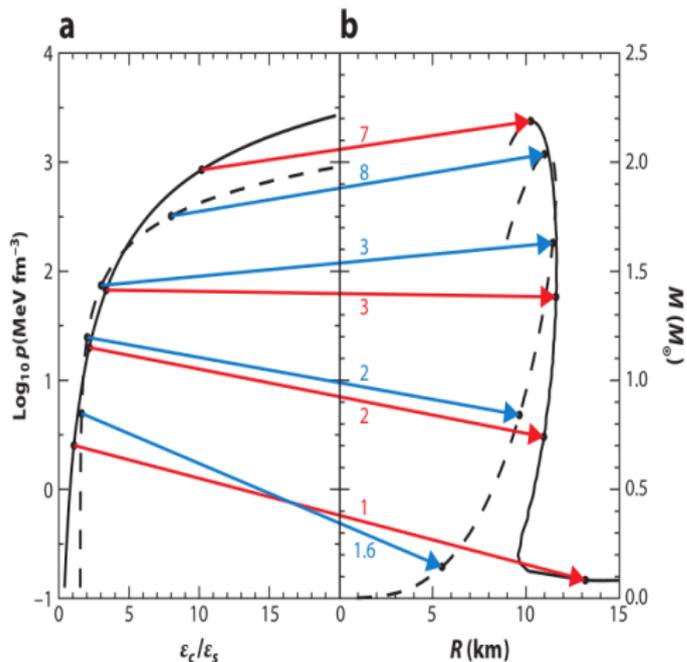


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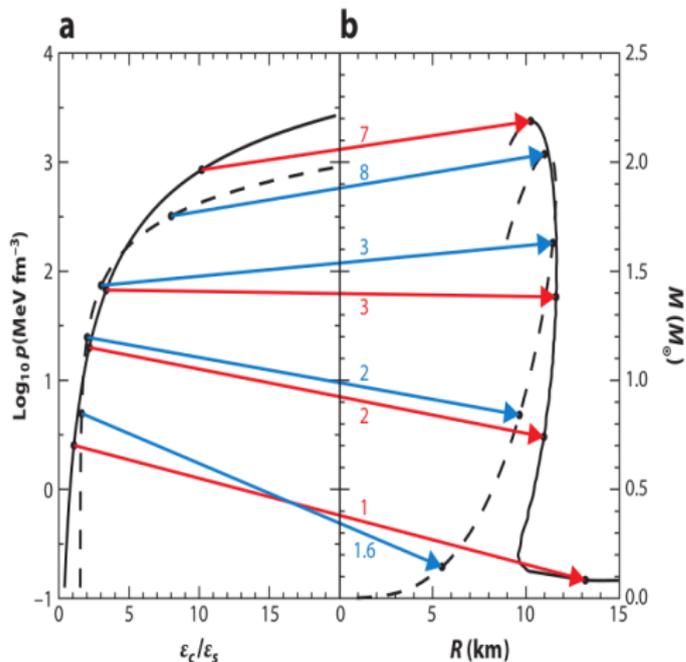


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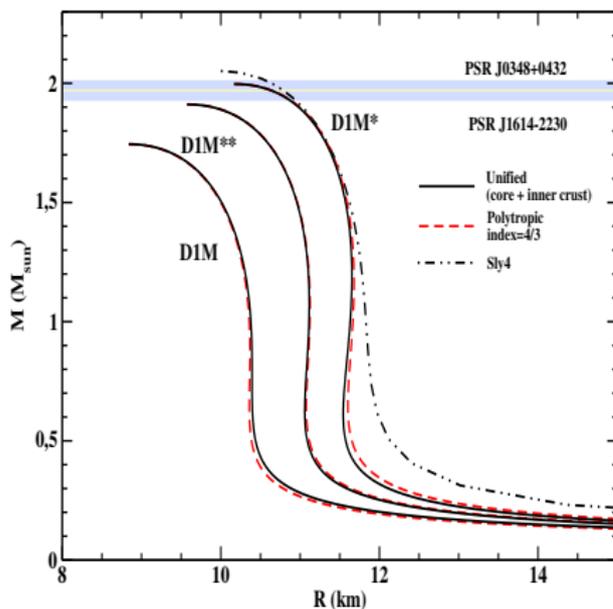


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- What about composition? Hyperons? Quarks?
- Reactions \Rightarrow nucleosynthesis \Rightarrow kilonova as well as cooling \Rightarrow X-ray spectra.

Unifying equation of state

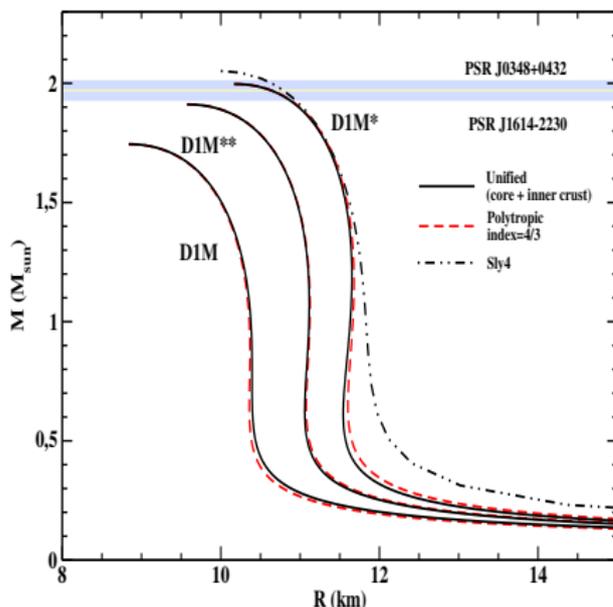
Gogny interaction



C. Gonzalez-Boquera, X. Viñas, M. Centelles, CM and L. M. Robledo, Symmetry 13 (2021) 9, 1613

Unifying equation of state

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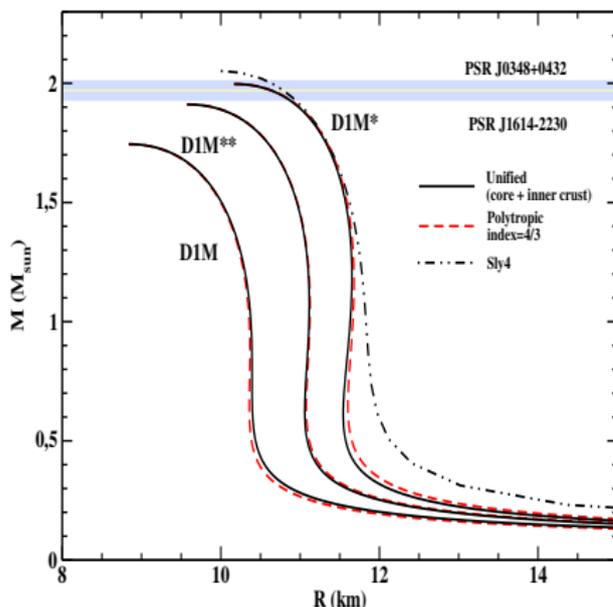


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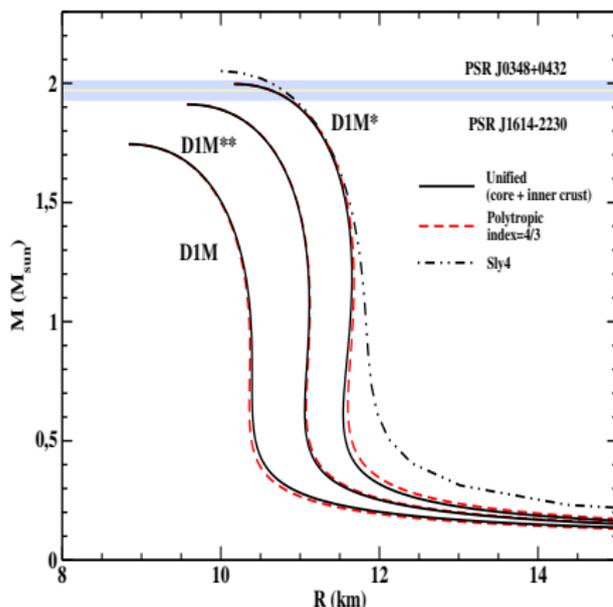


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- DIM* is the first Gogny interaction which can reach 2 solar mass neutron star. (Phys.Lett.B 779 (2018) 195)

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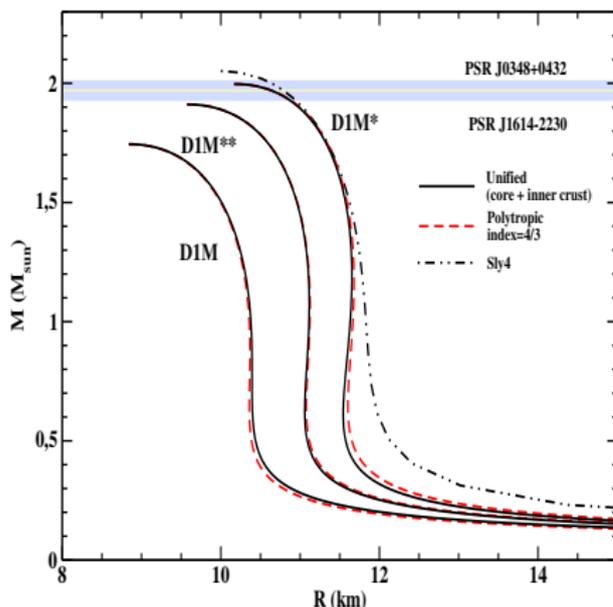


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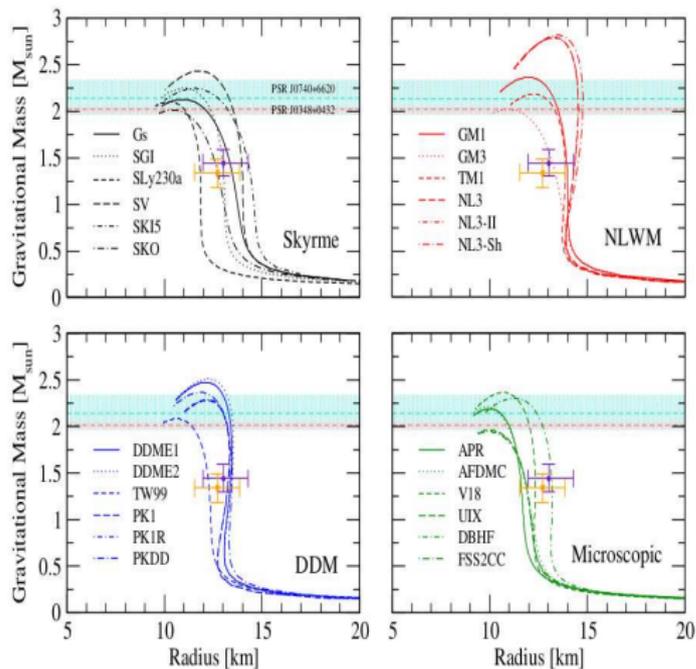


- Finite range interaction has the advantage of treating mean-field and pairing with the same interaction.
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- **Inner crust EoS based on Gogny interaction** (CM *et. al.*, PRC 102, 015802(2020))
- Not big differences in EoS. But composition is predicted.

C. Gonzalez-Boquera, X. Viñas, M. Centelles, CM and L. M. Robledo, Symmetry 13 (2021) 9, 1613

Equation of State

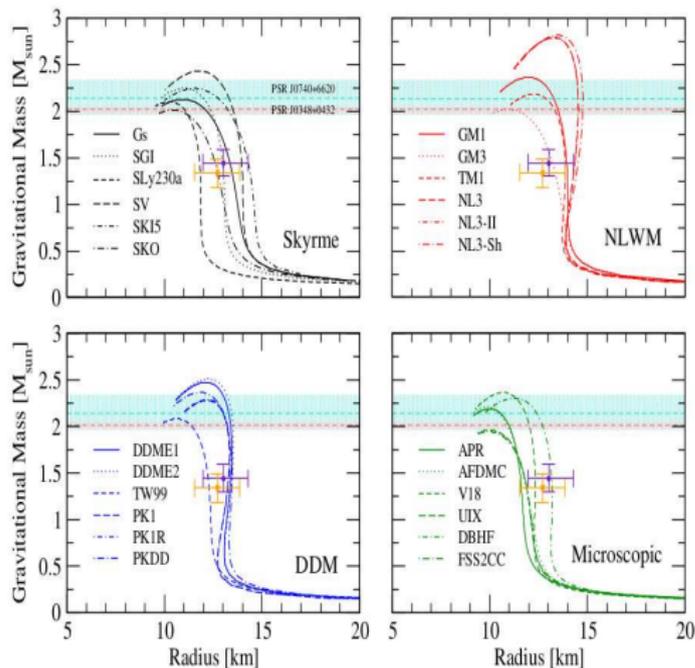
Nucleonic hypothesis



G. Burgio & I. Vidaña, Universe 6, 119 (2020)

Equation of State

Nucleonic hypothesis

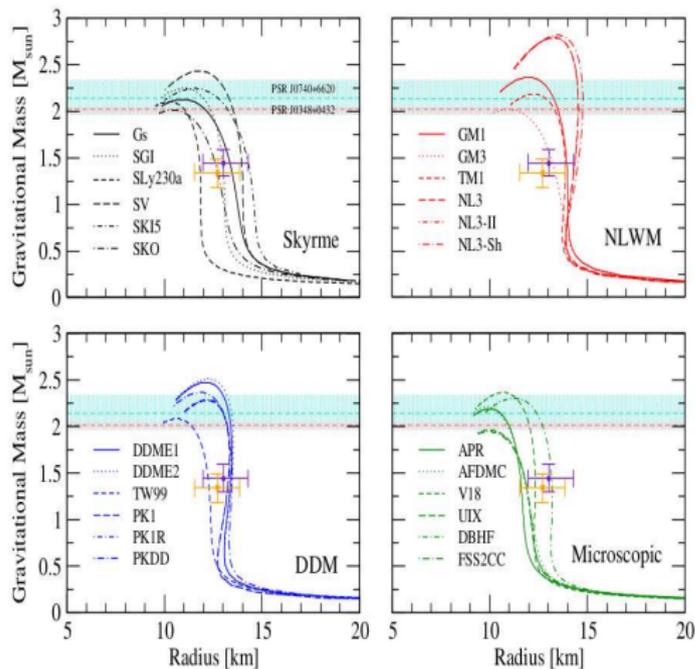


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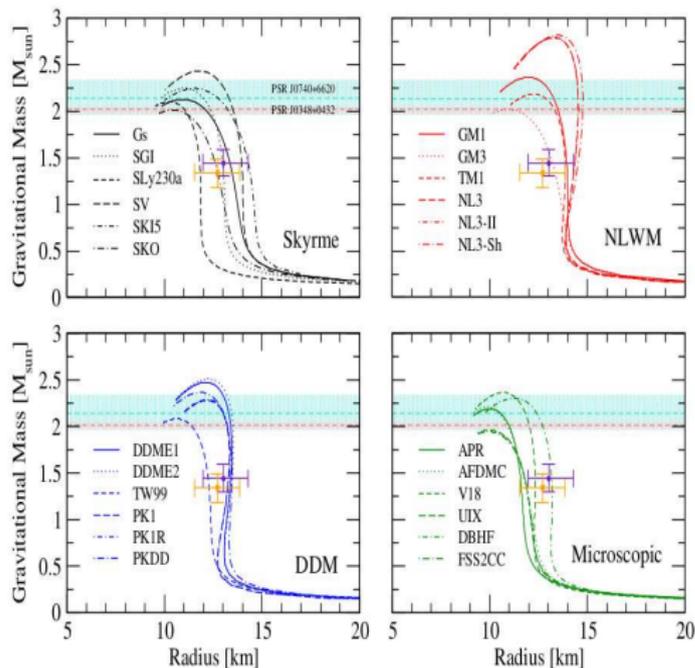


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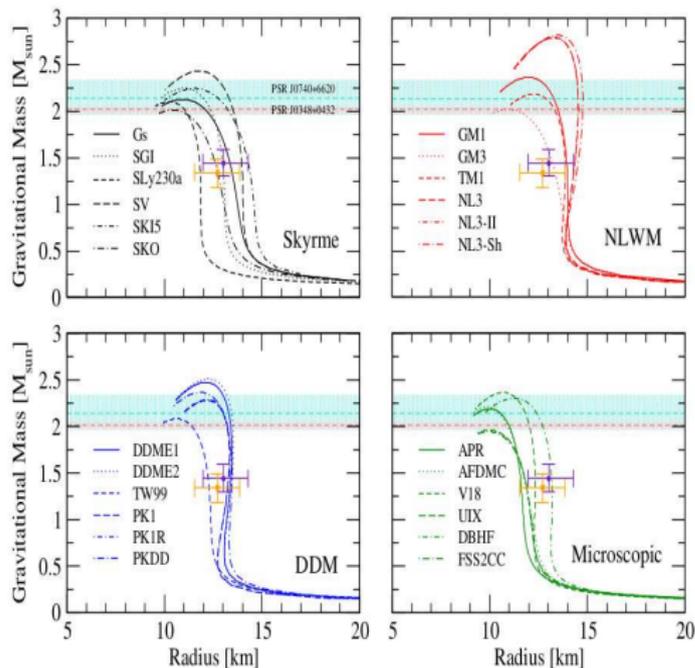


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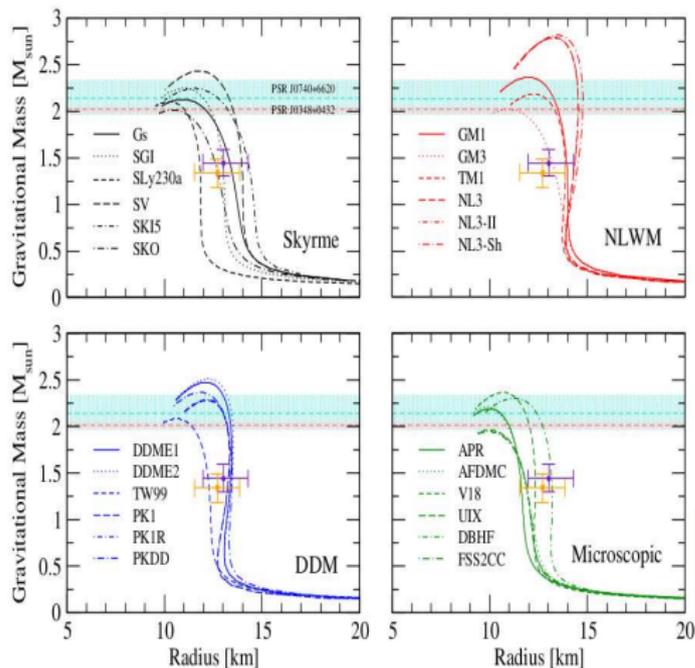


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● 1 model \Rightarrow 1 EoS
Similar EoS \Rightarrow similar model???
What impact the new measurements have?

G. Burgio & I. Vidaña, Universe 6, 119 (2020)

Nucleonic meta-modelling

Founding aspects (Based on J. Margueron *et. al.*, PRC 97, 025805 (2018))

Features

- Flexible functional $e(\rho_n, \rho_p)$ able to reproduce existing effective nucleonic models and interpolate between them.
- Expansion in powers of the Fermi momentum or of the density.
- Expansion around saturation: Parameter space = emp. par. \vec{X} .
- **Beta-equilibrium!!!**

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- The energy per particle is given by ($x = \frac{n_b - n_0}{3n_0}$, $n_b = \rho_n + \rho_p$,
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$$e(\rho_n, \rho_p) \simeq e_{\text{SNM}}(n_b, 0) + e_{\text{sym}}(n_b)\delta^2$$

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$$e_{\text{SNM}}(n_b) \simeq \mathcal{E}_0 + \frac{1}{2}K_0x^2 + \frac{1}{6}Q_0x^3 + \frac{1}{24}Z_0x^4$$

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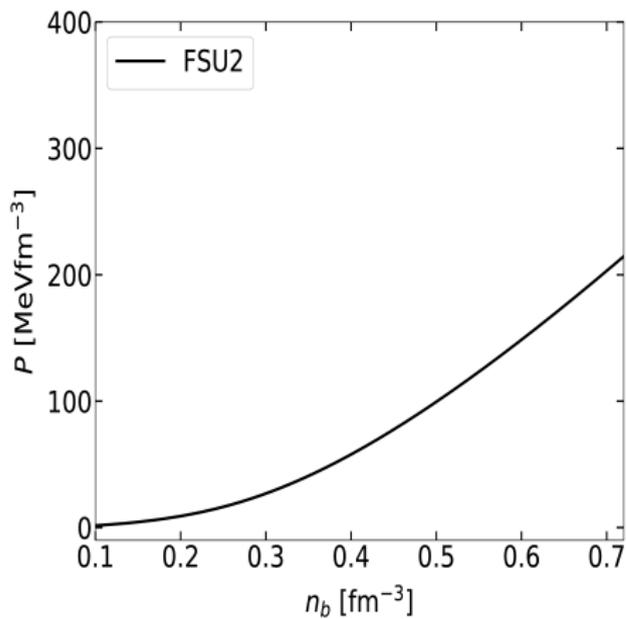
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$$e_{\text{Elf}}(\rho_n, \rho_p) = KE(\rho_n, \rho_p) + \sum_{\alpha \geq 0} \frac{1}{\alpha!} (v_{\alpha}^{is} + v_{\alpha}^{iv}\delta^2) x^{\alpha}.$$

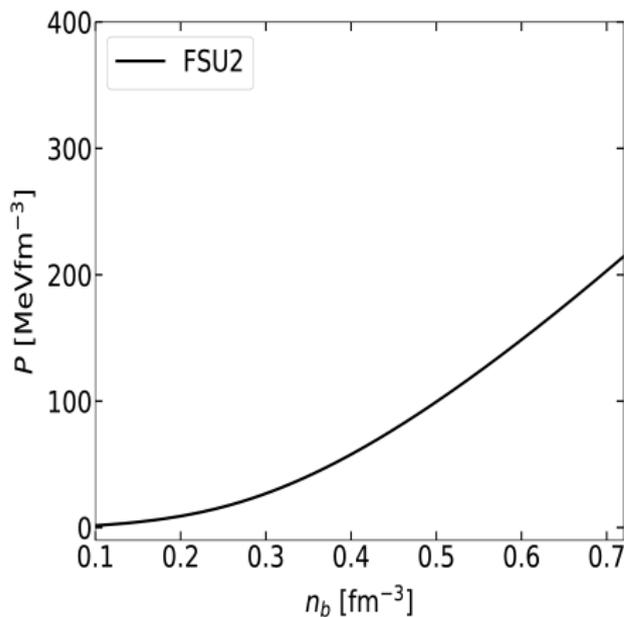
Obtaining static properties

fitting the pressure



Obtaining static properties

fitting the pressure

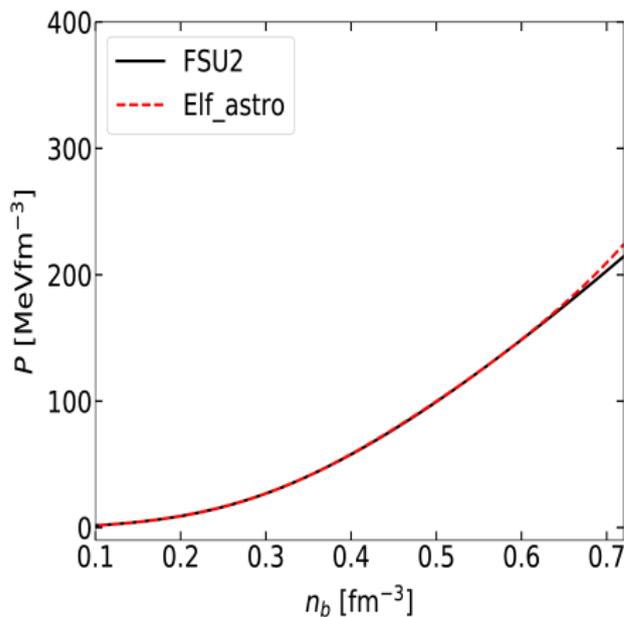


Elf-astro

- Optimize higher order parameters to obtain the beta equilibrium energy/pressure!!

Obtaining static properties

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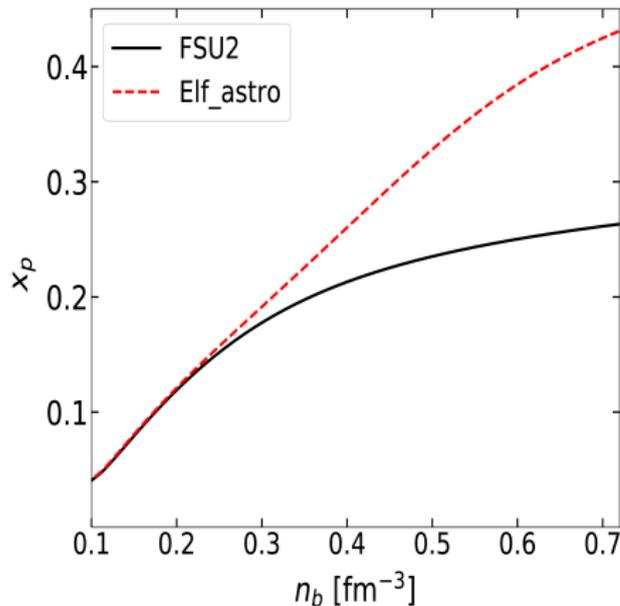


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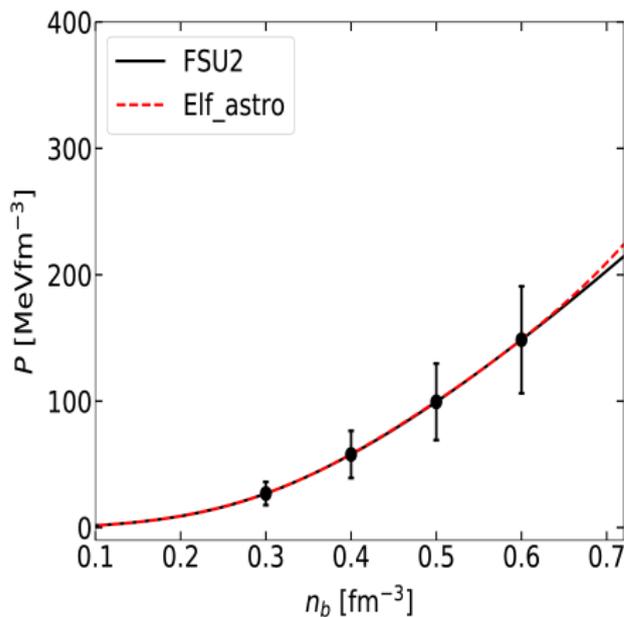


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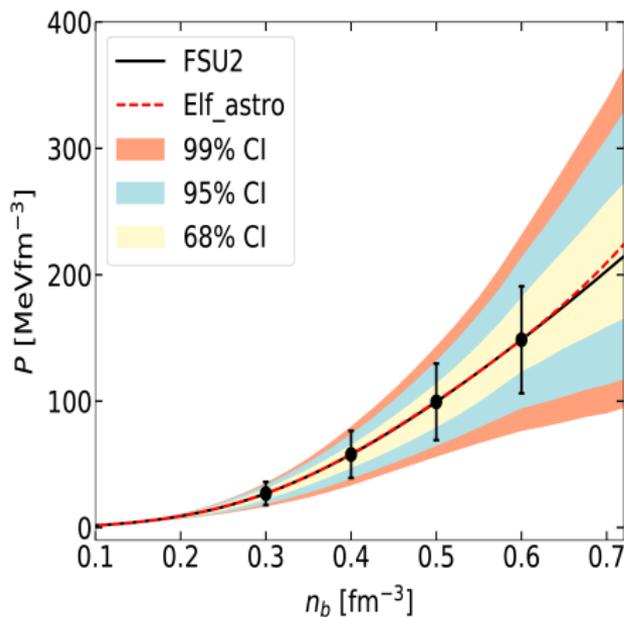


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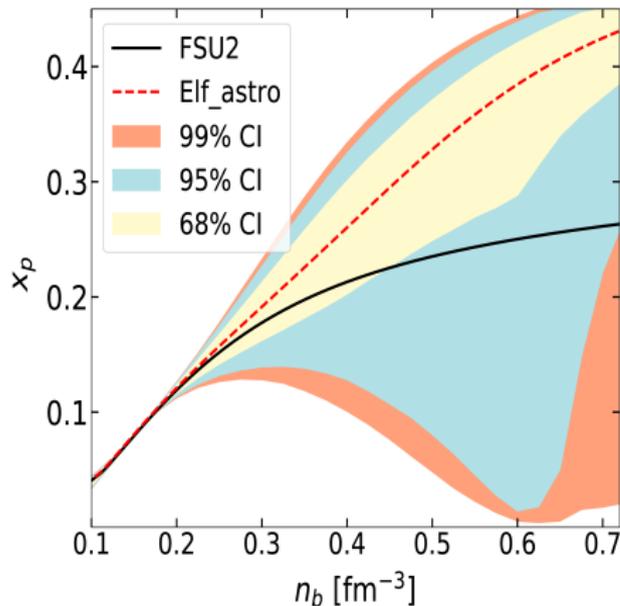


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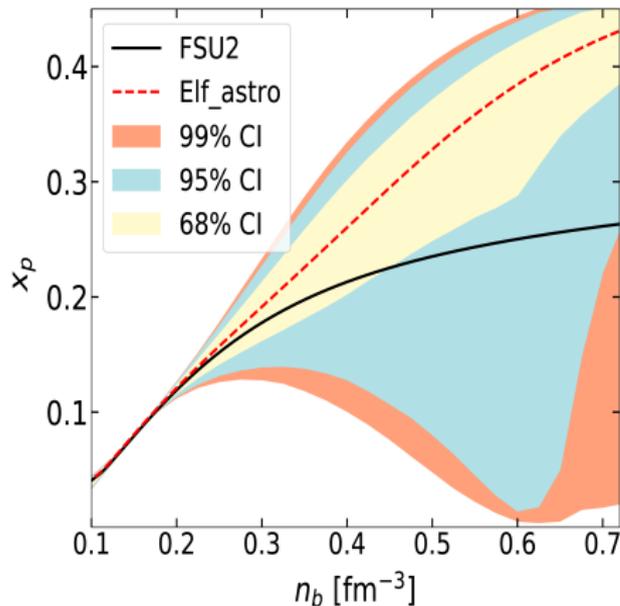


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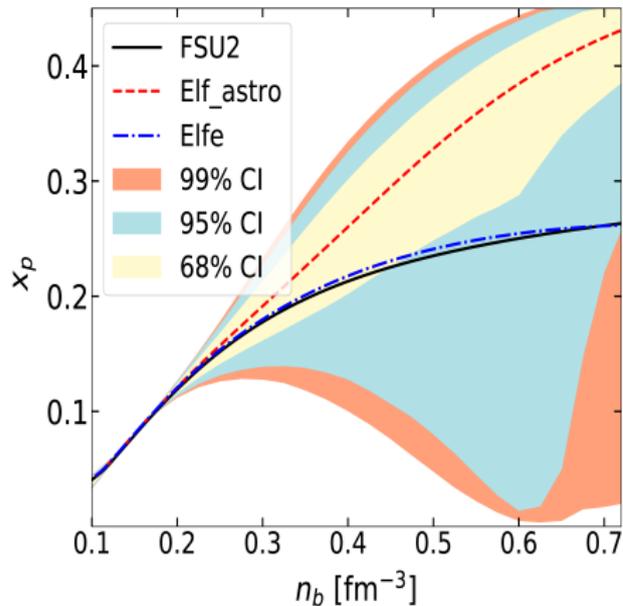
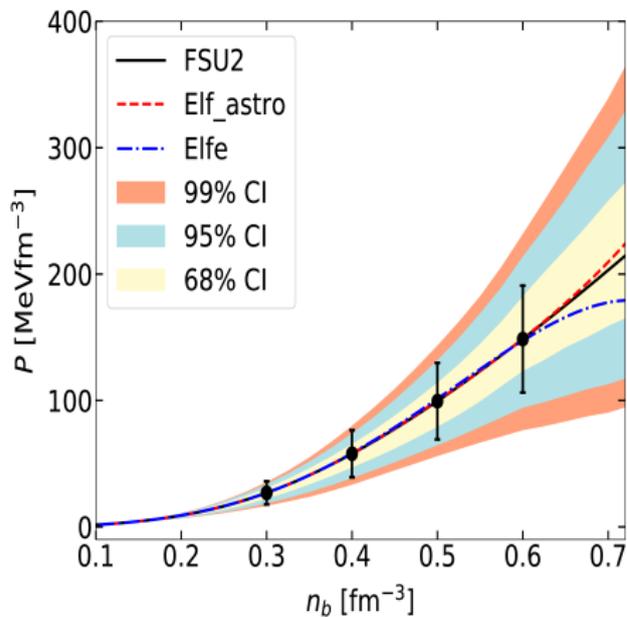
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A possible Remedy (Elfe)

- Fix higher order symmetric nuclear matter from Laboratory!

Obtaining static properties

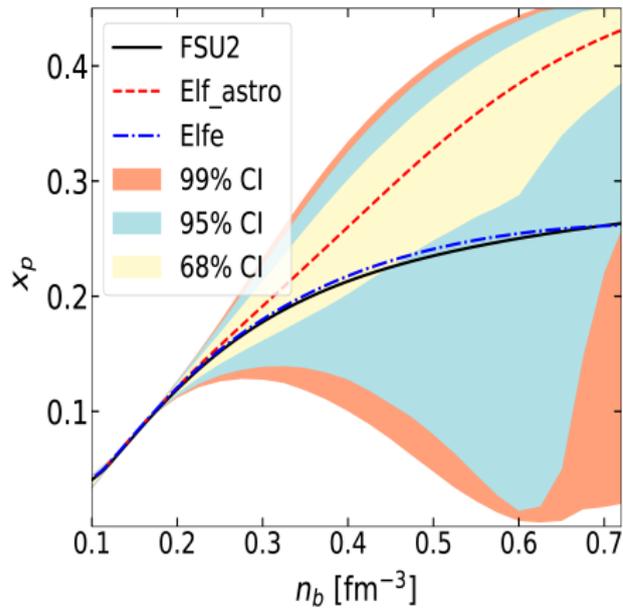
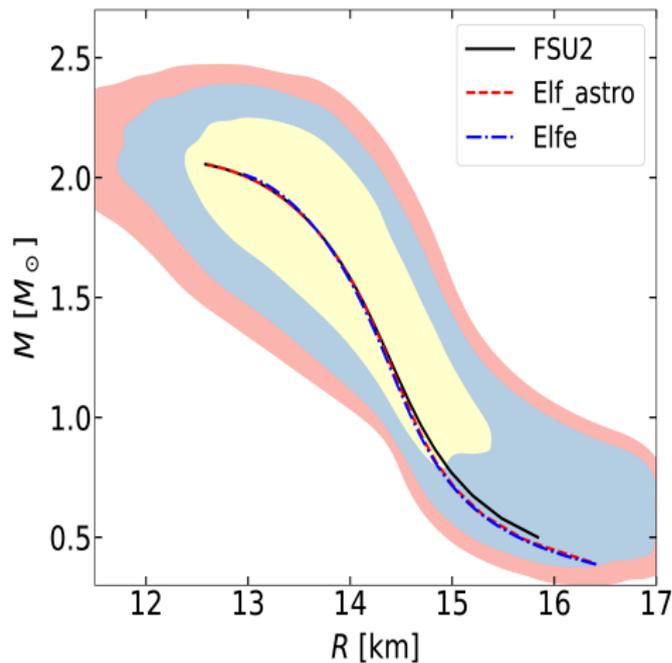
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C. Mondal & F. Gulminelli (in preparation)

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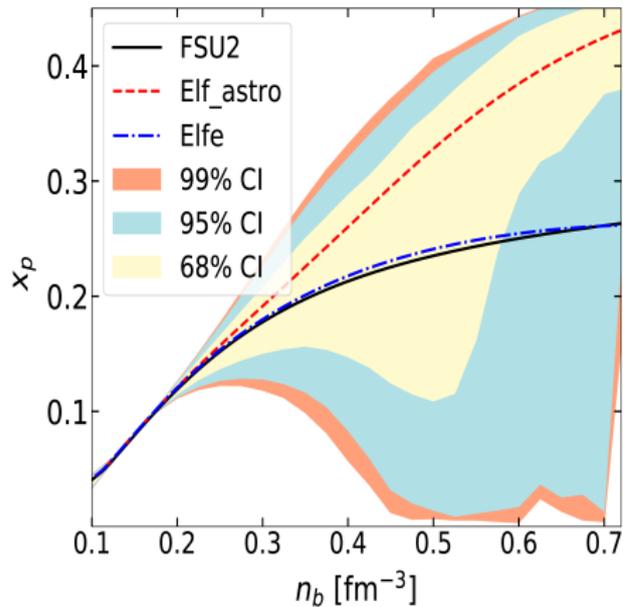
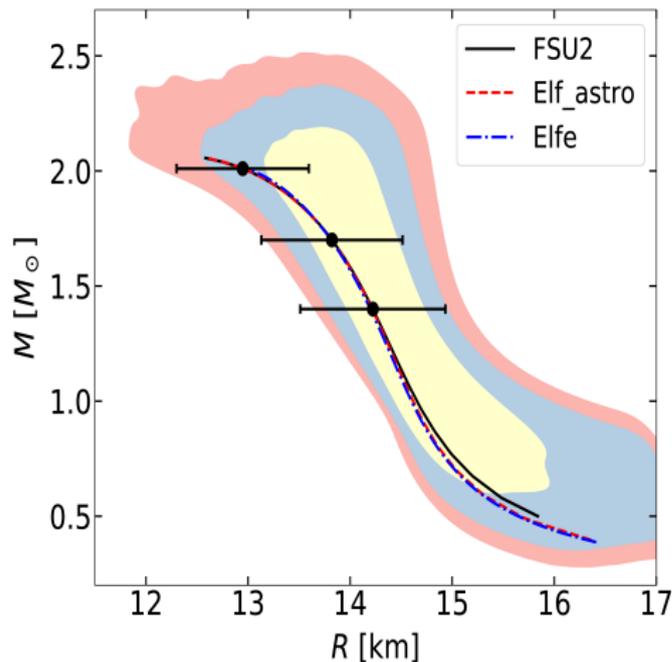
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Obtaining static properties

fitting the M-R



C. Mondal & F. Gulminelli (in preparation)

Impact of recent data on Meta-model

Obtaining the filters

Prior = Nuclear physics informed prior with AME2016 fit.

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Filters in Bayesian Analysis

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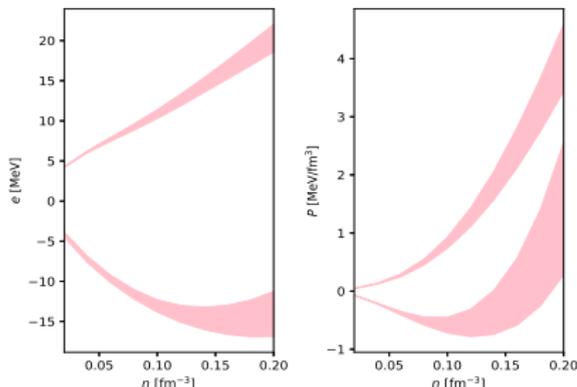
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Filters in Bayesian Analysis

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EFT



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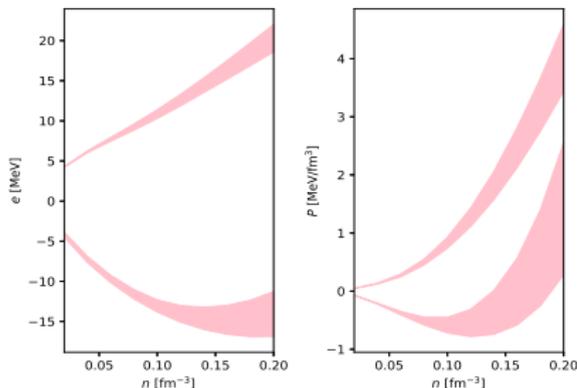
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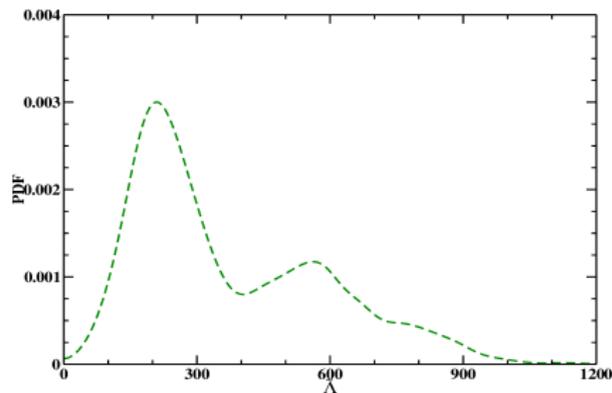
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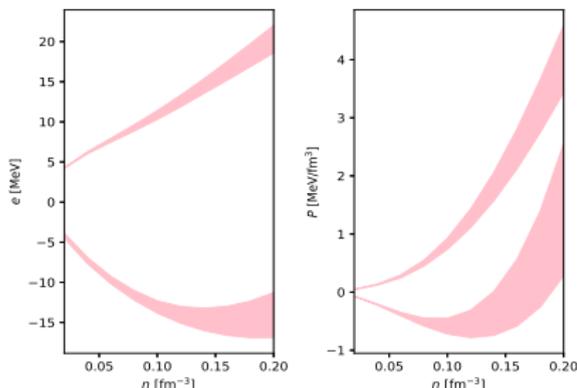
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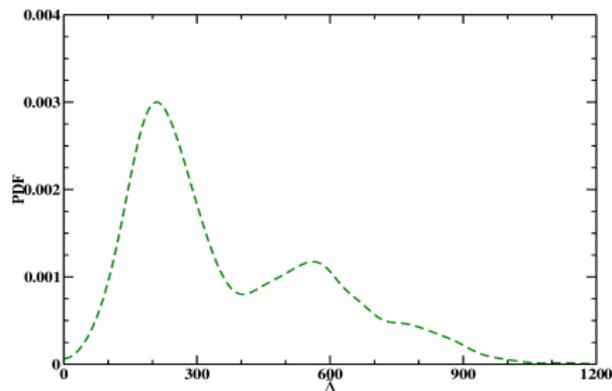
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- **All** = EFT + HD + LVC + NICER.

EFT



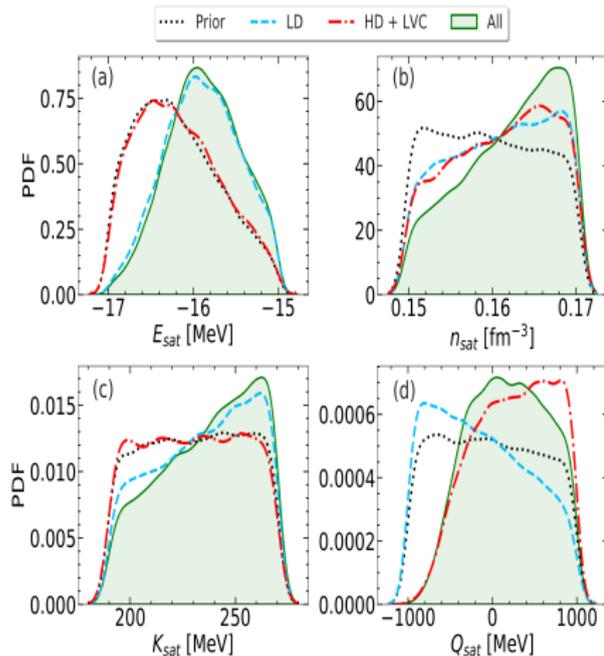
LVC



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Distribution of parameters

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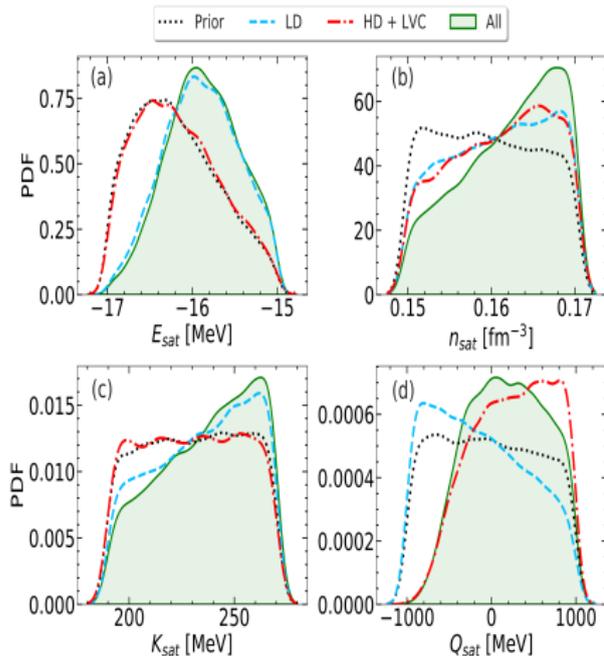


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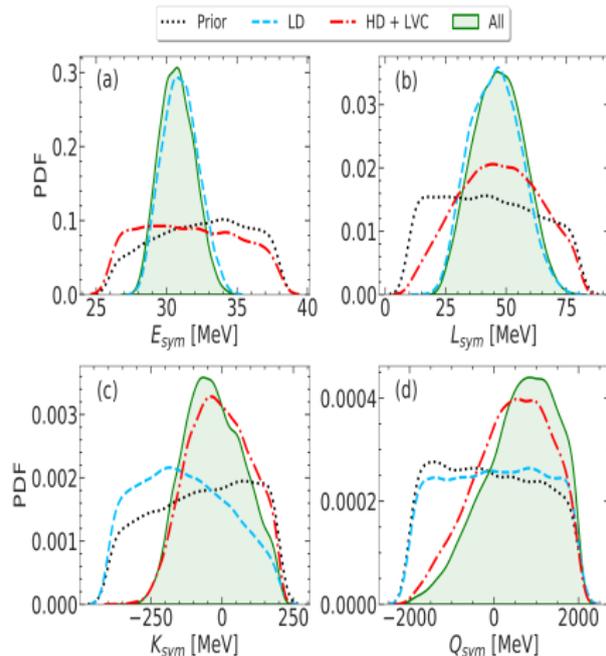
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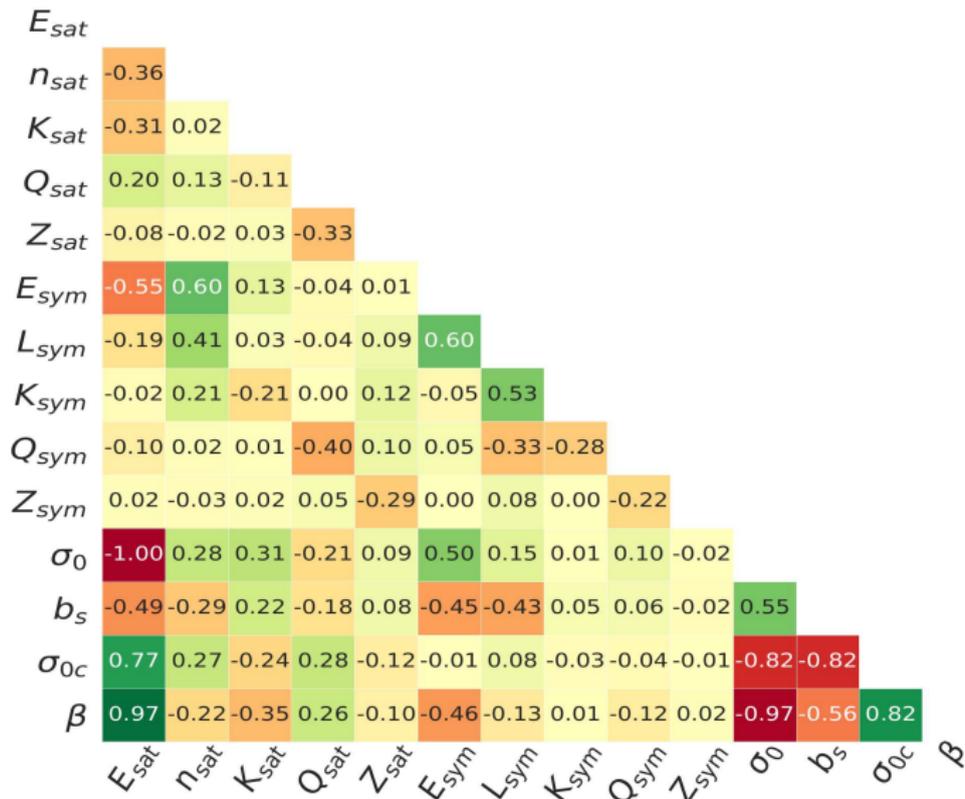
Isovector



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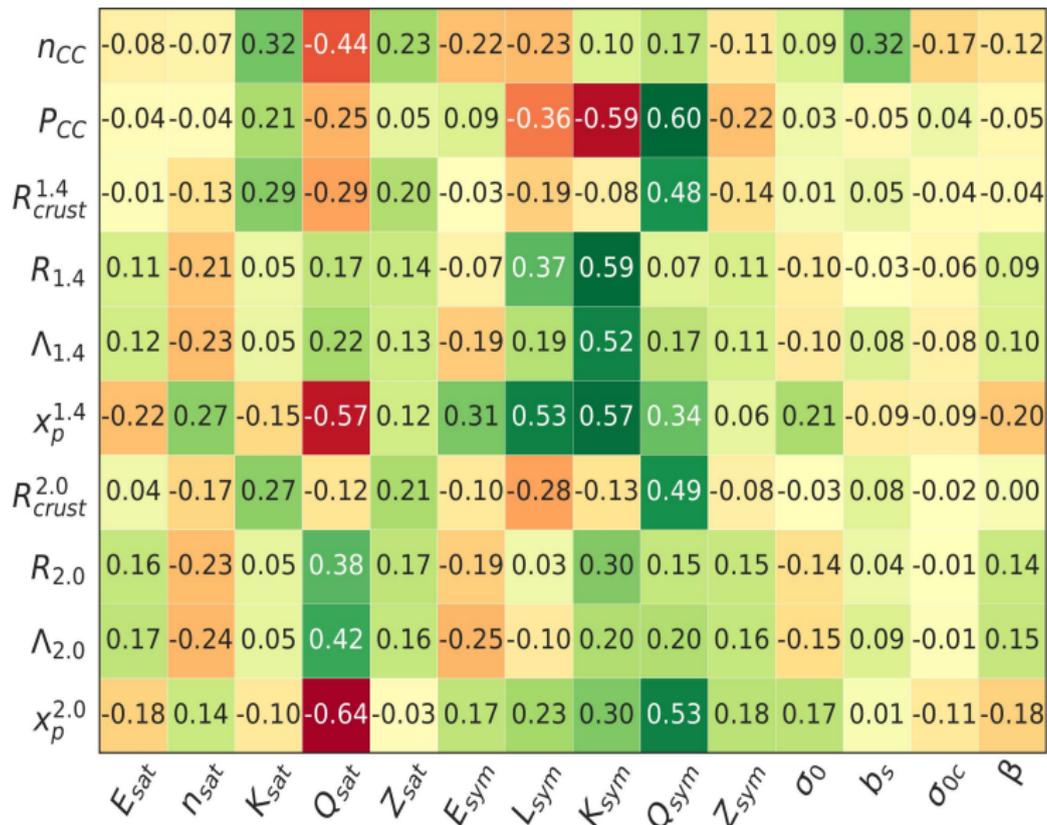
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Correlation among parameters



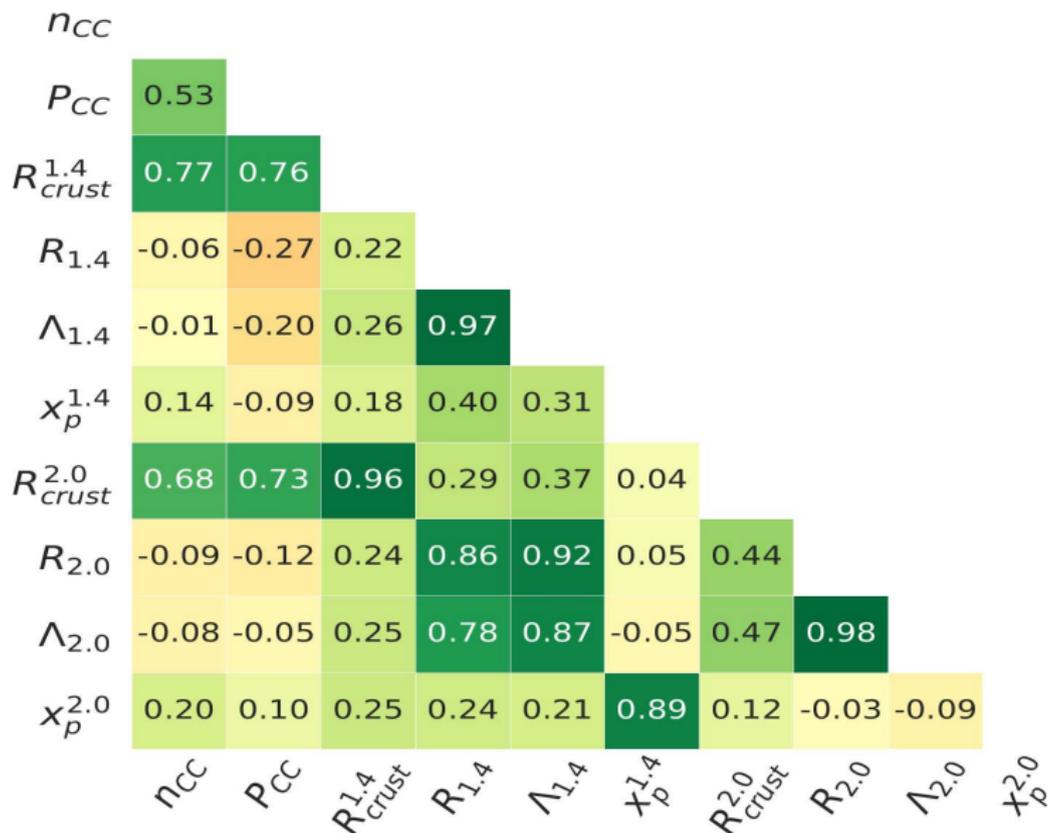
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Correlation between parameters and observables



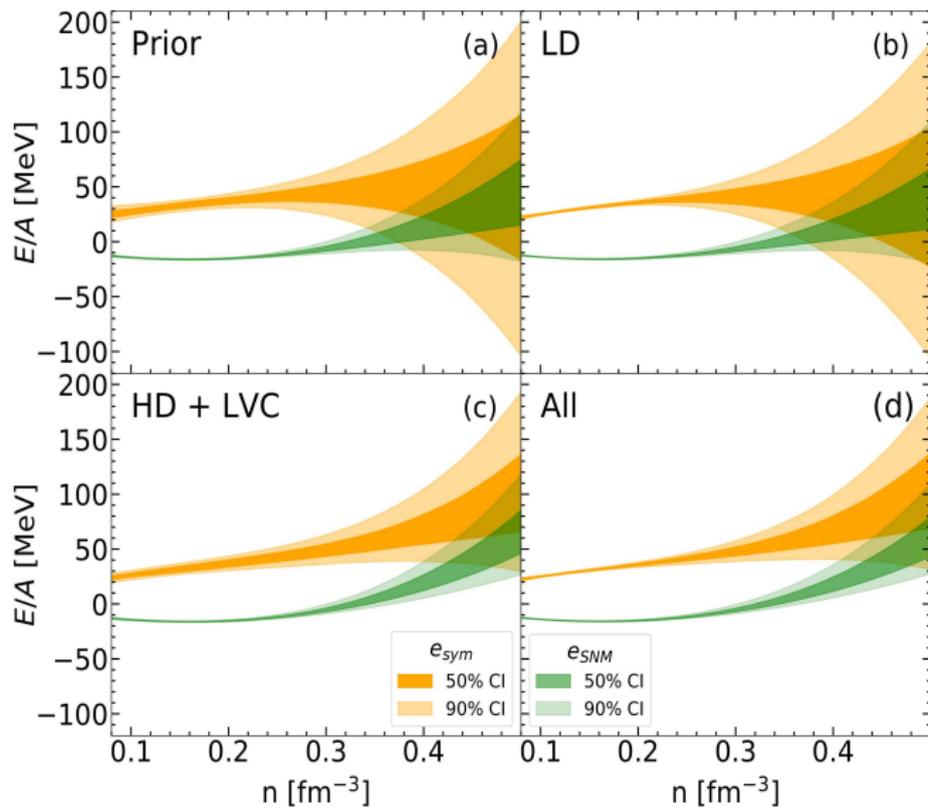
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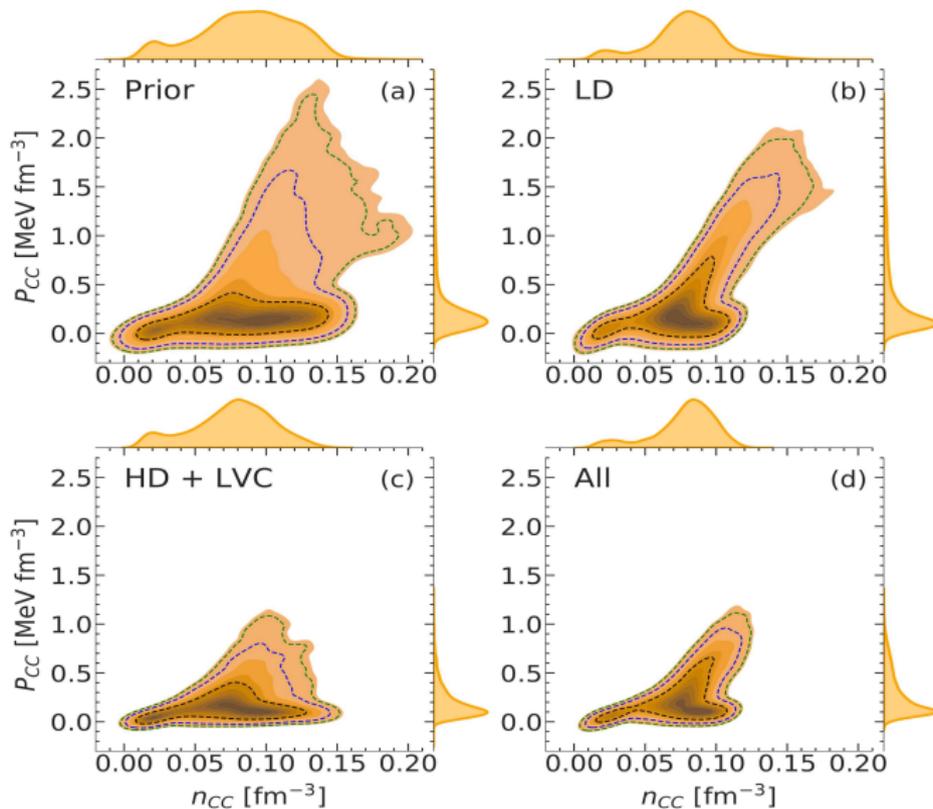
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SNM and symmetry energy



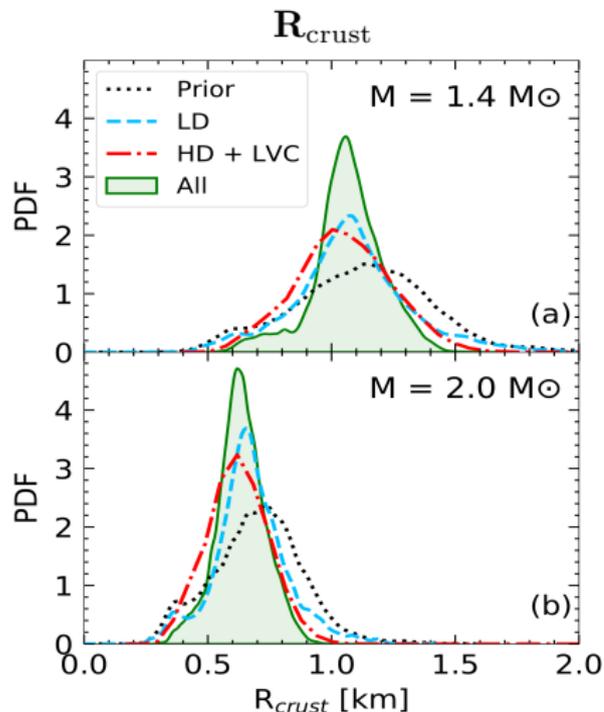
Impact of recent data on Meta-model

Transition properties



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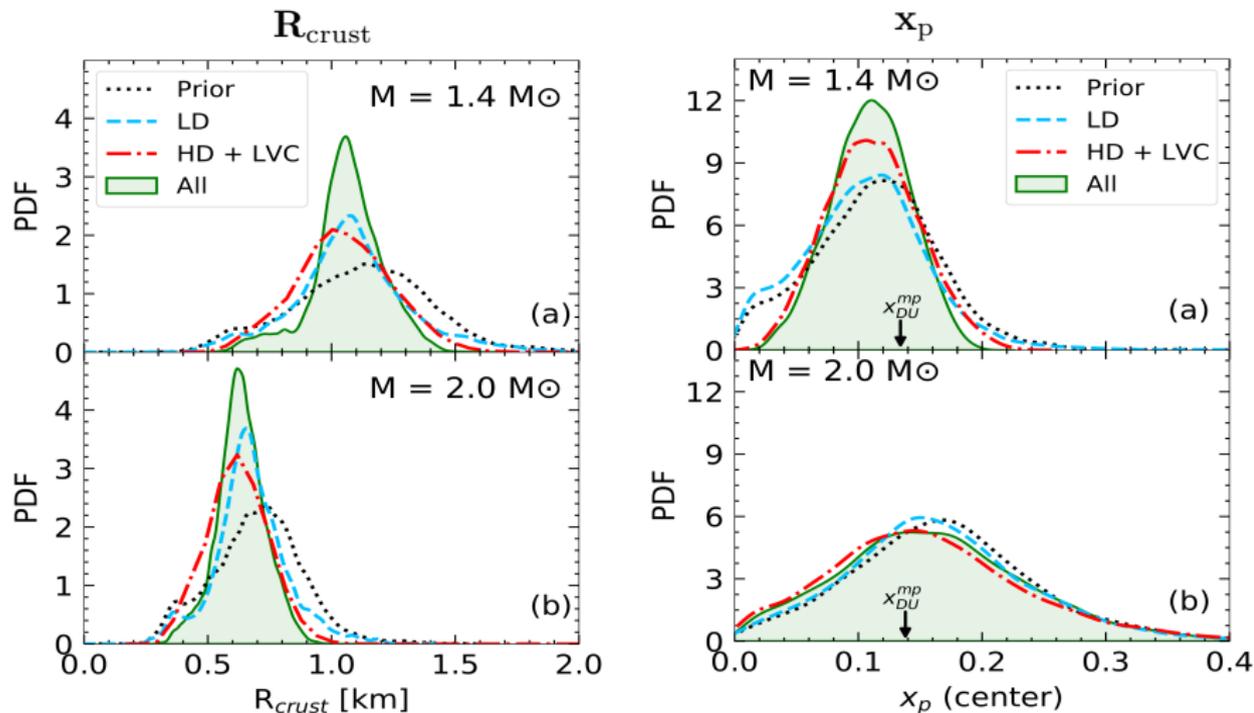
R_{crust} and x_{p}



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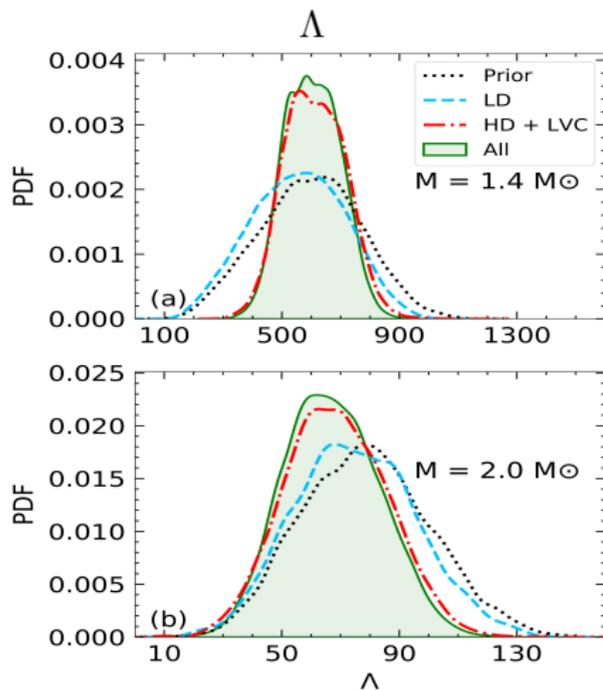
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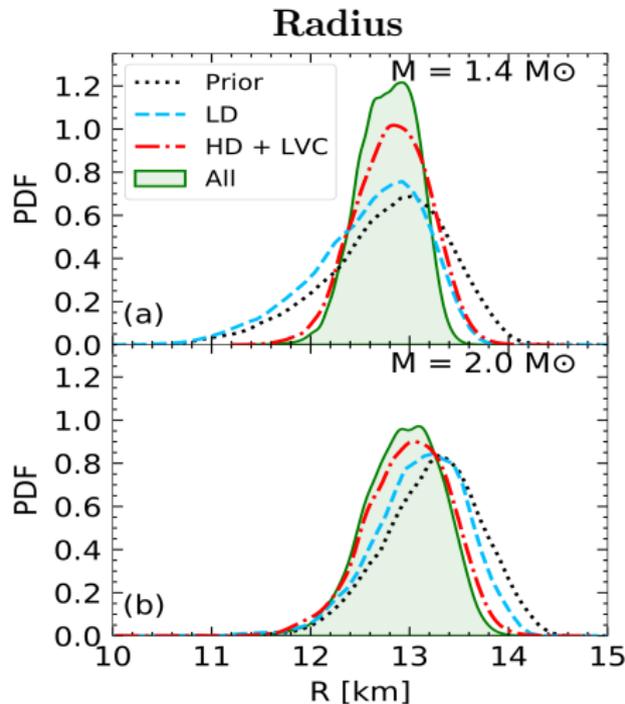
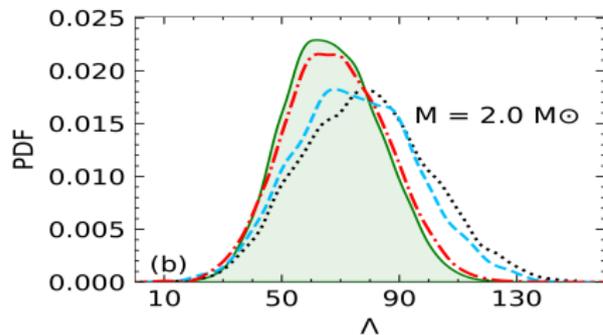
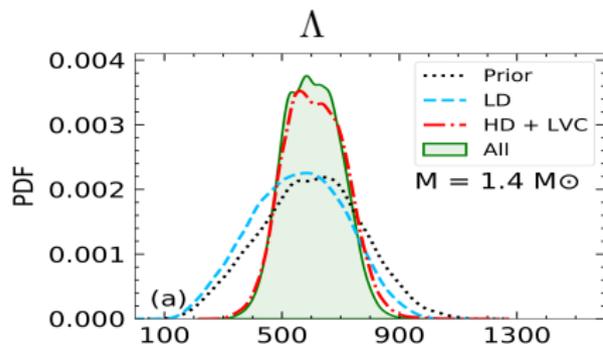
Λ and Radius



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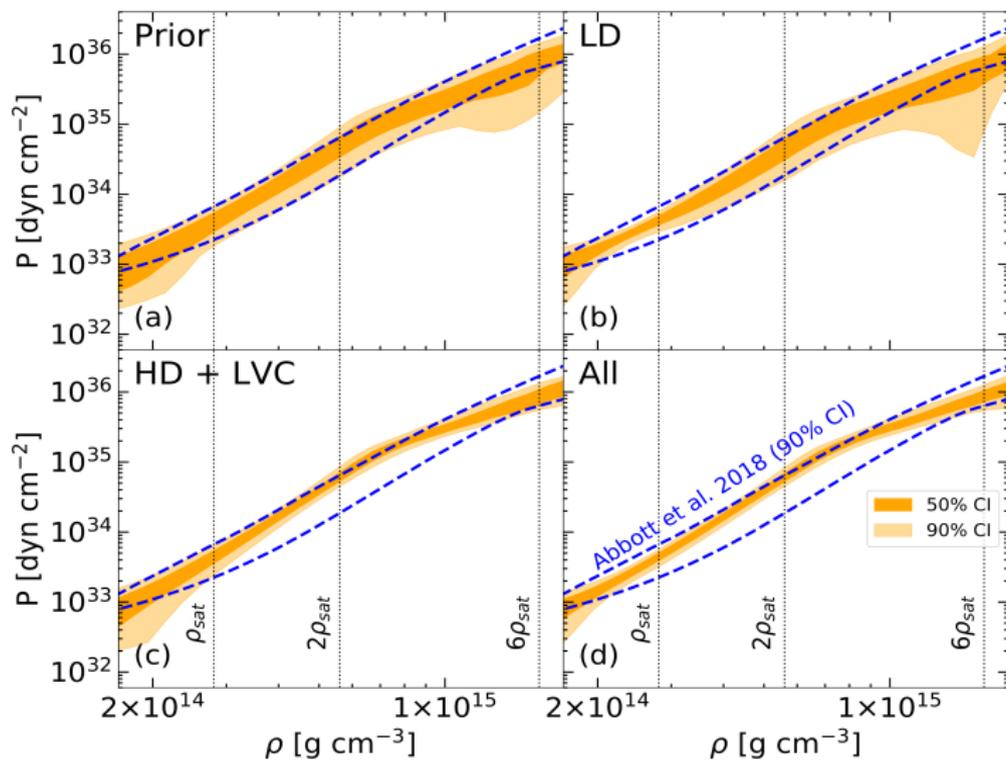
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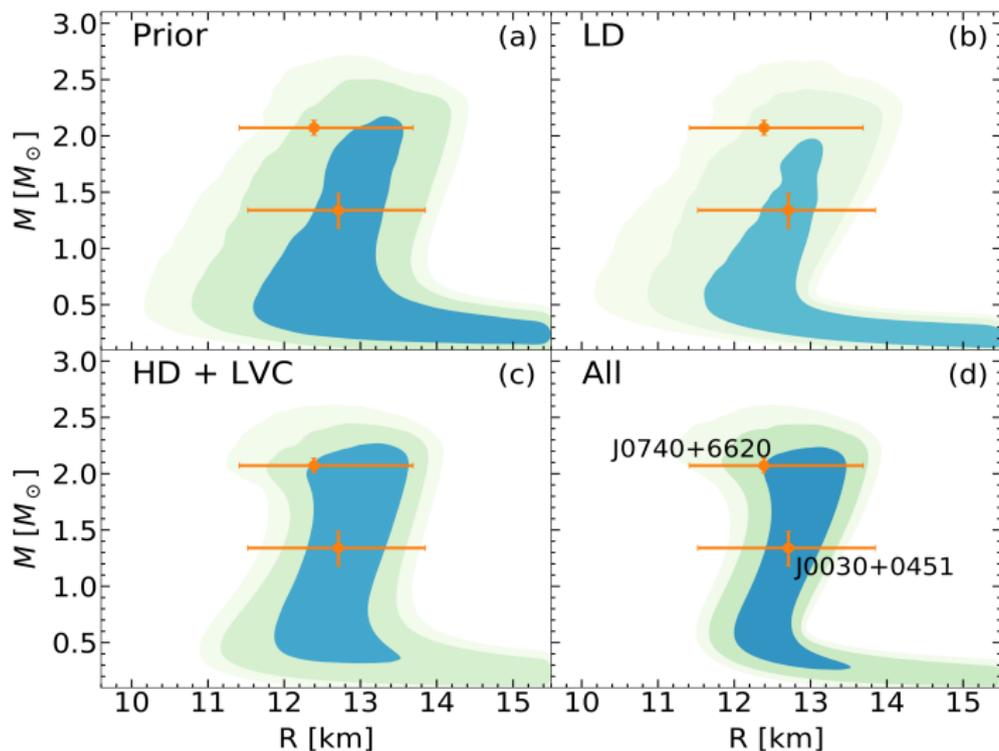
EoS



Hoa Dinh Thi, CM & F. Gulminelli (under review)

Impact of recent data on Meta-model

Mass-Radius



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Conclusions and outlook

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- The correspondence between beta-equilibrated matter and the physics of the nuclear energy functional is not precise.
- Within nucleonic hypothesis, static properties of the neutron stars are not enough to pin down the composition and behaviour of the high density matter!

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- The correspondence between beta-equilibrated matter and the physics of the nuclear energy functional is not precise.
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Conclusions and outlook

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- Nucleonic hypothesis is consistent with all the current data.
- Other degrees of freedom?? We need data with much less uncertainties.