Can we decipher the composition of the core of a neutron star?

Chiranjib Mondal

Ruβbach school
March 15, 2022

What do we need to have?

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```
while(noSuccess)
{
        tryAgain();

        if(Dead)
                break;
}
```

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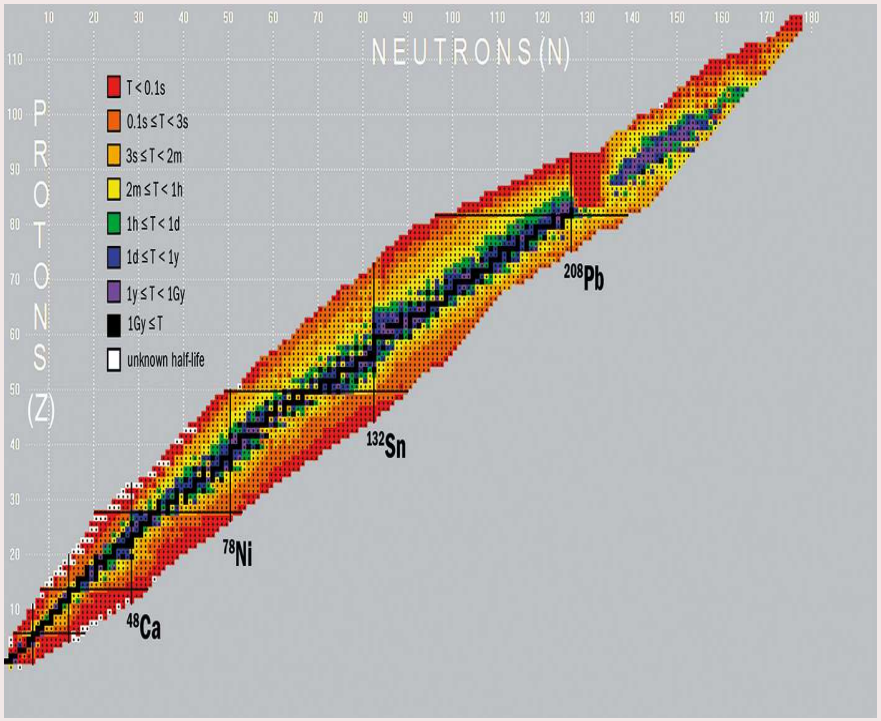
Low energy Nuclear Physics

We have knowledge from Nuclear Physics in the laboratory

Finite nuclear properties



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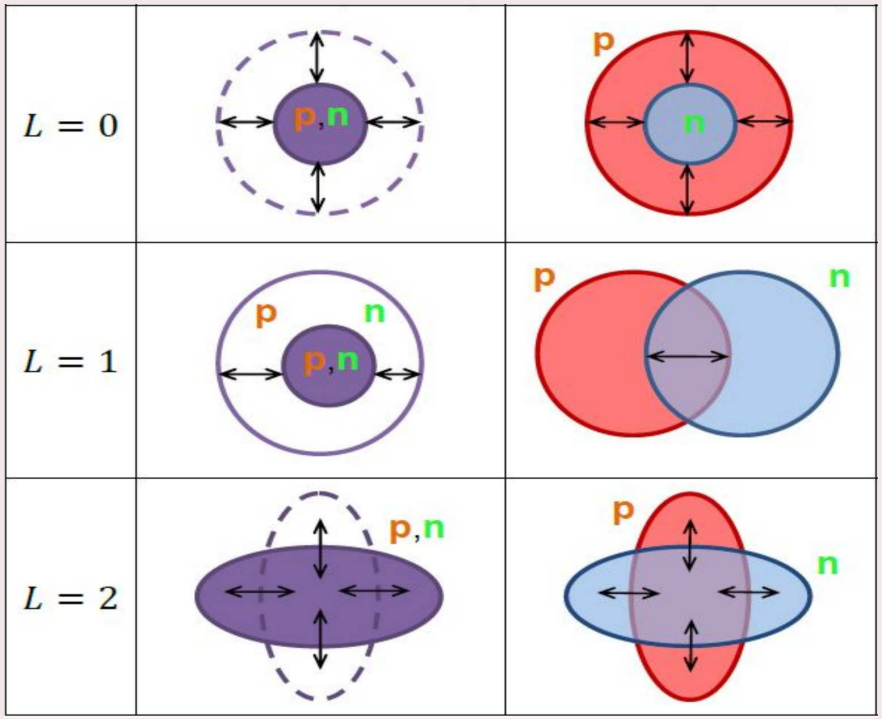

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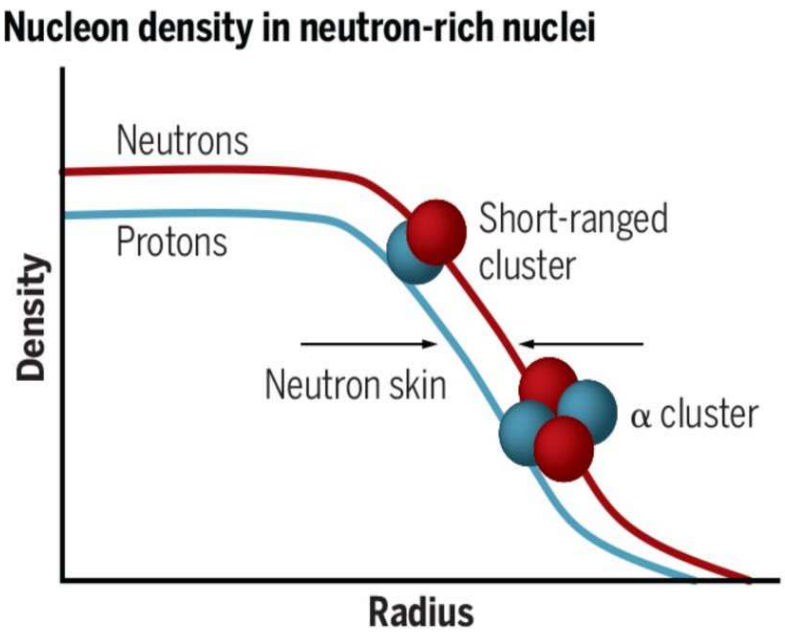

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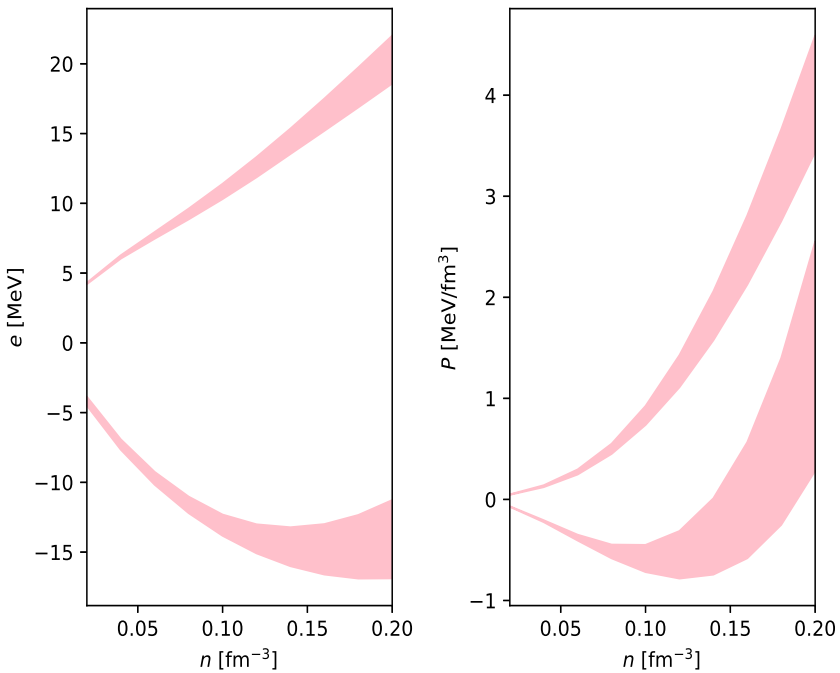

Drischler *et. al.* PRC 93, 05431 (2016)

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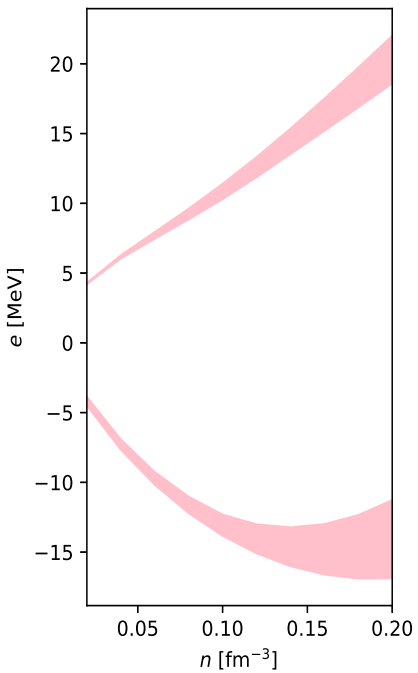

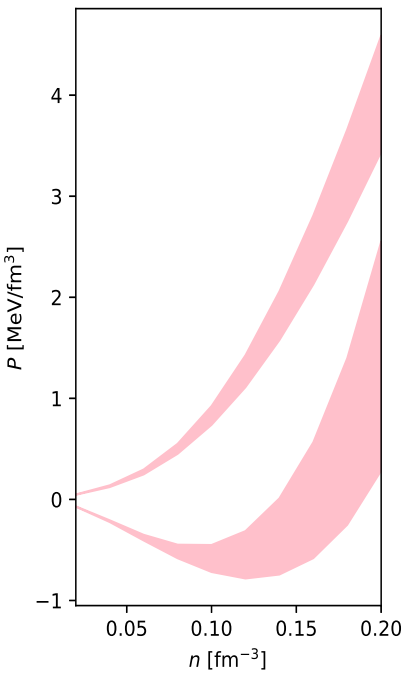

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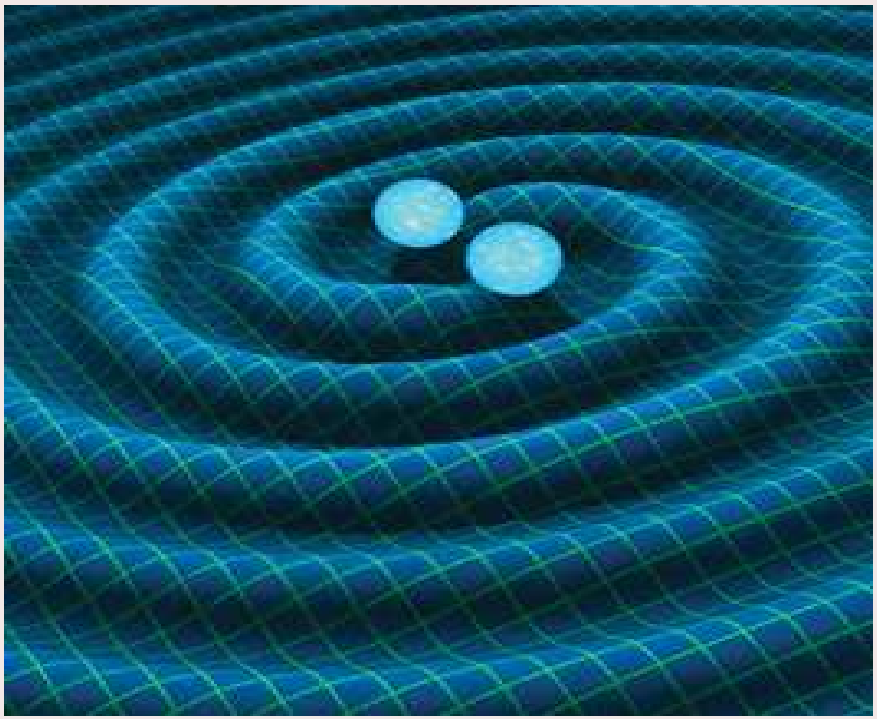

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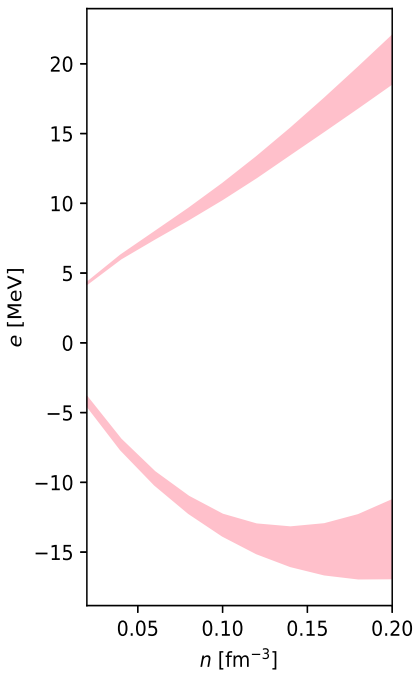

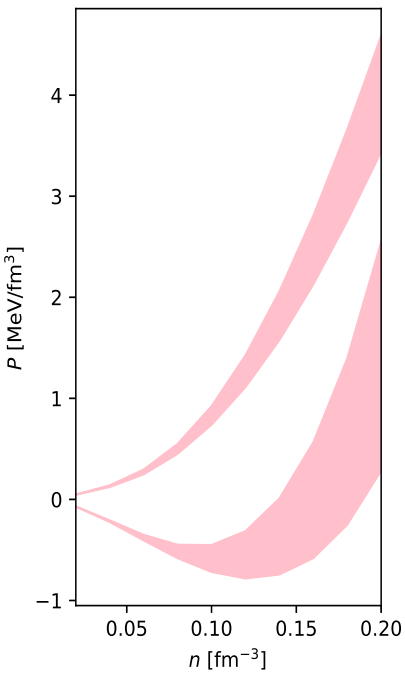

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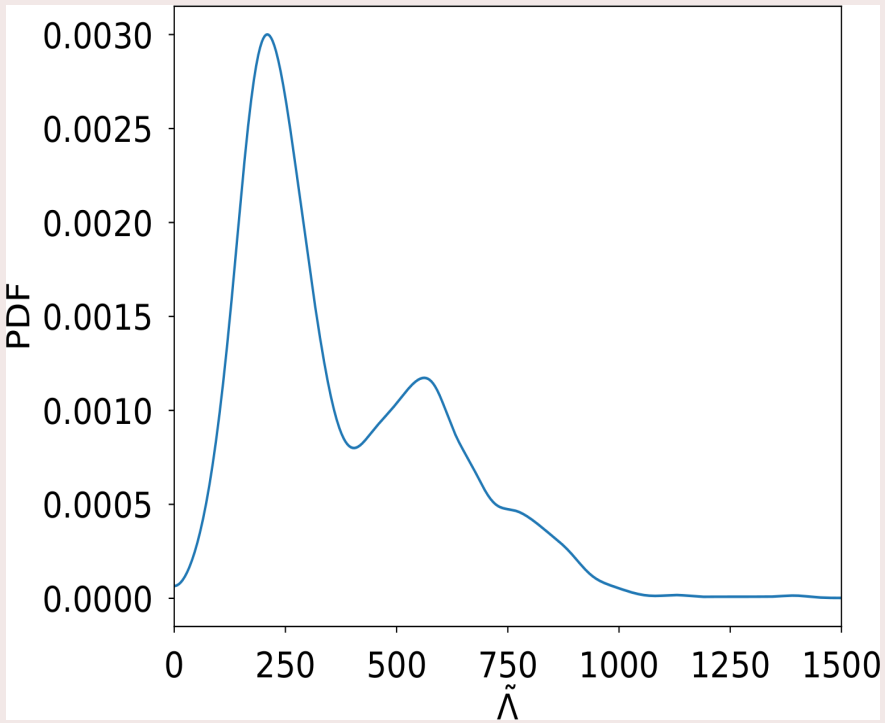

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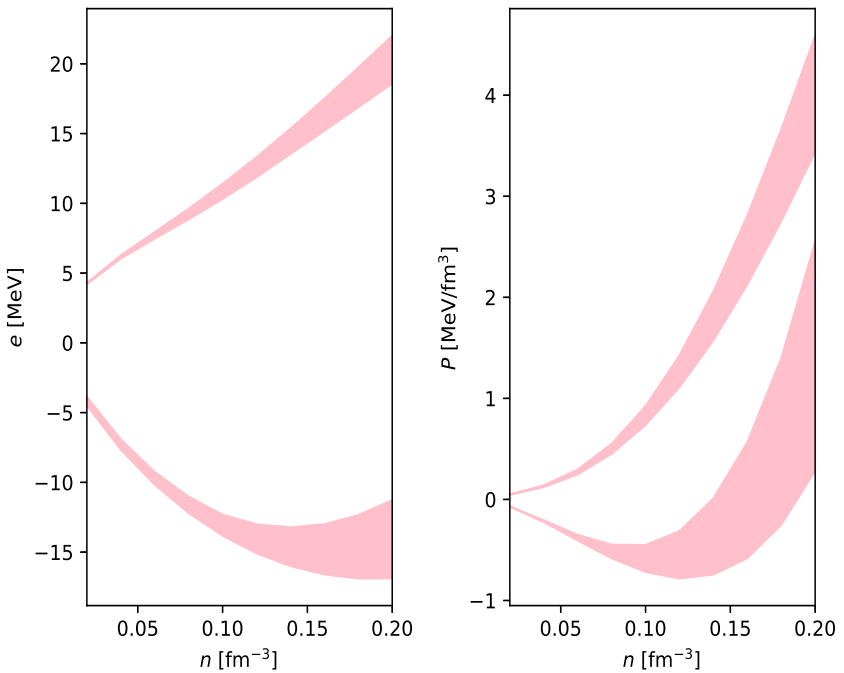

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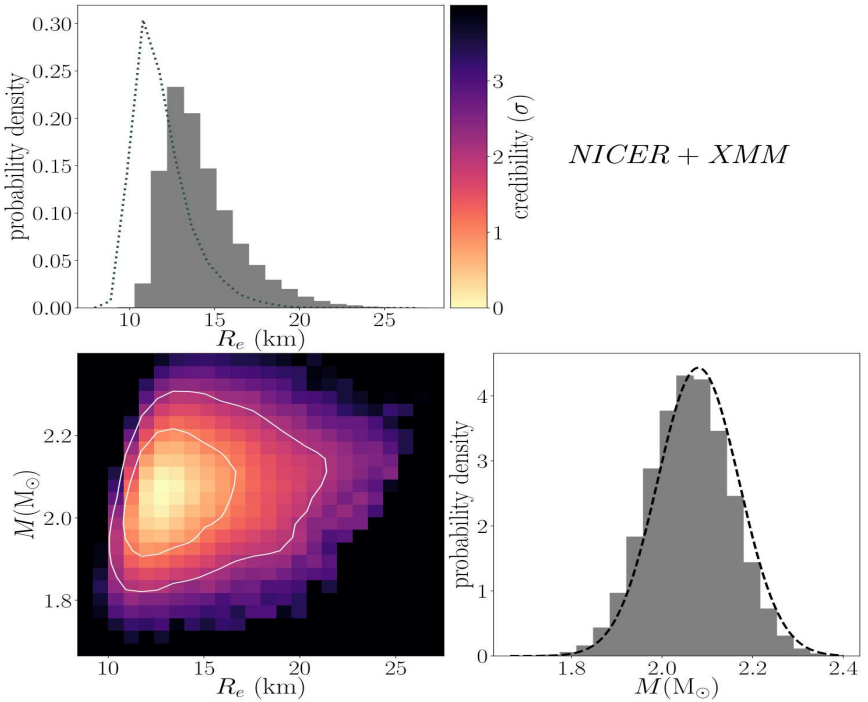

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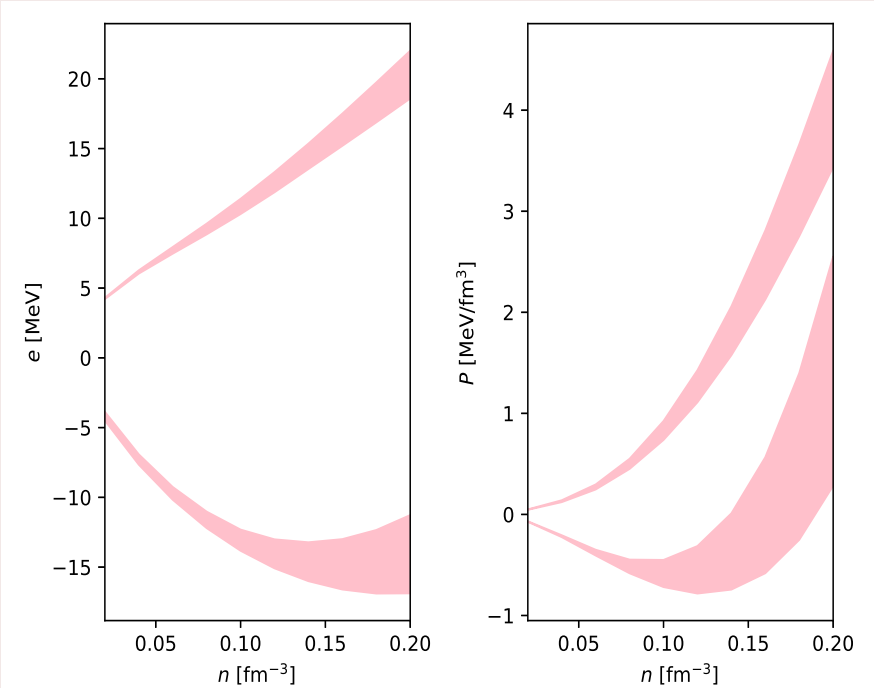

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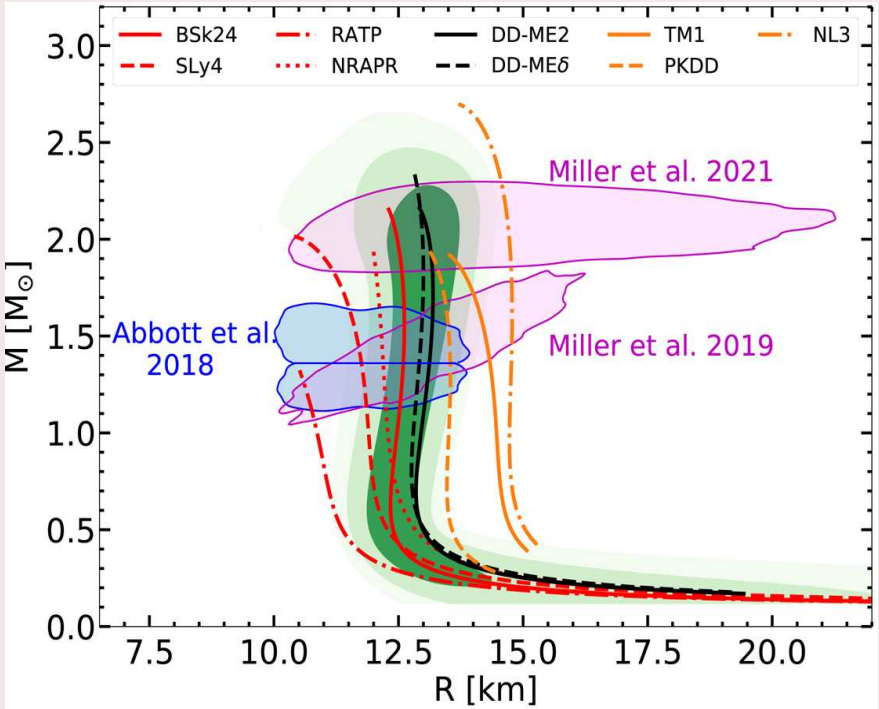

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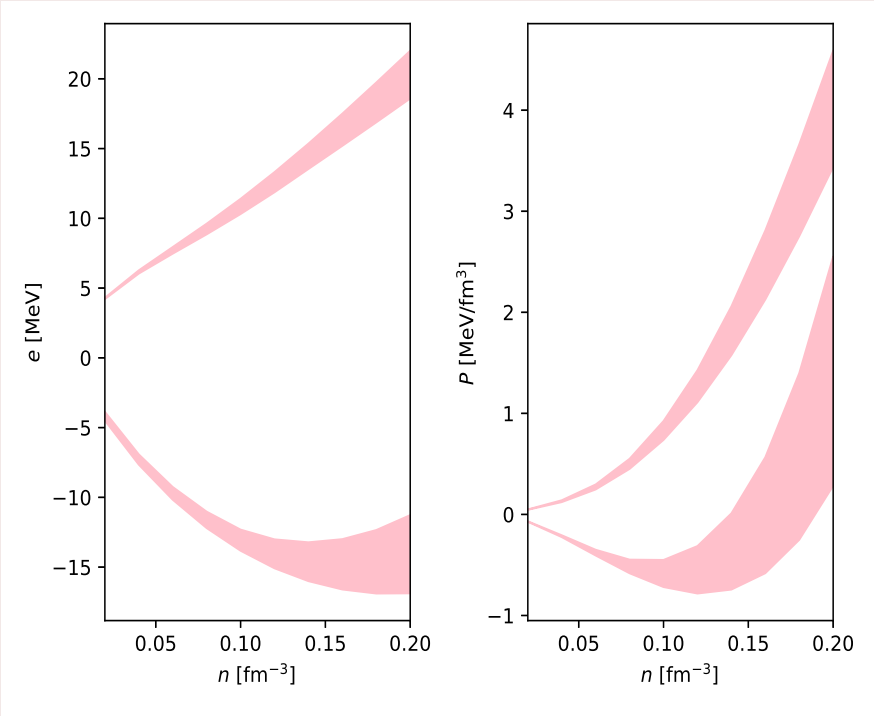

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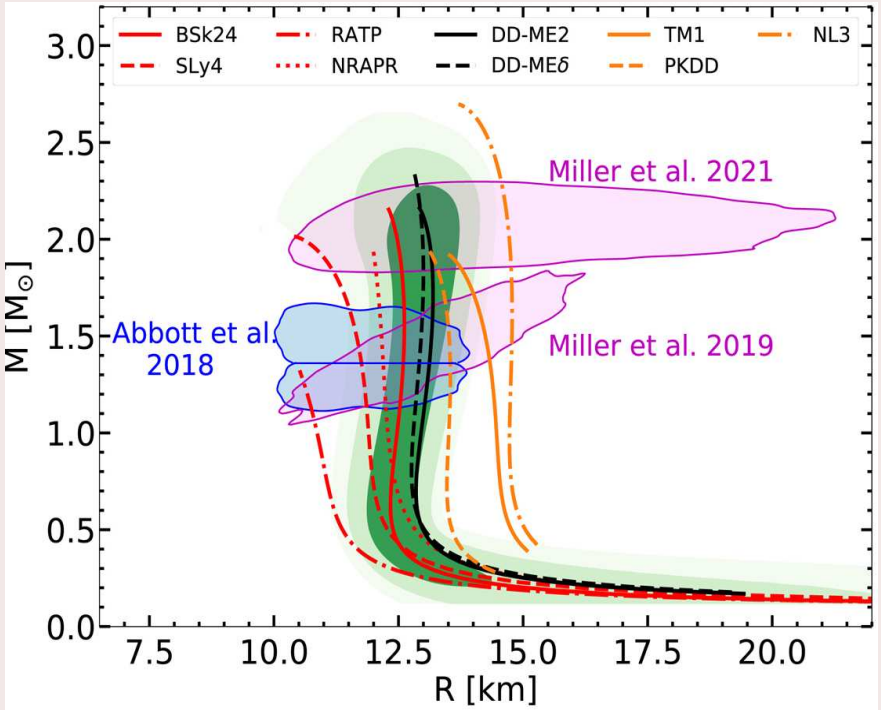

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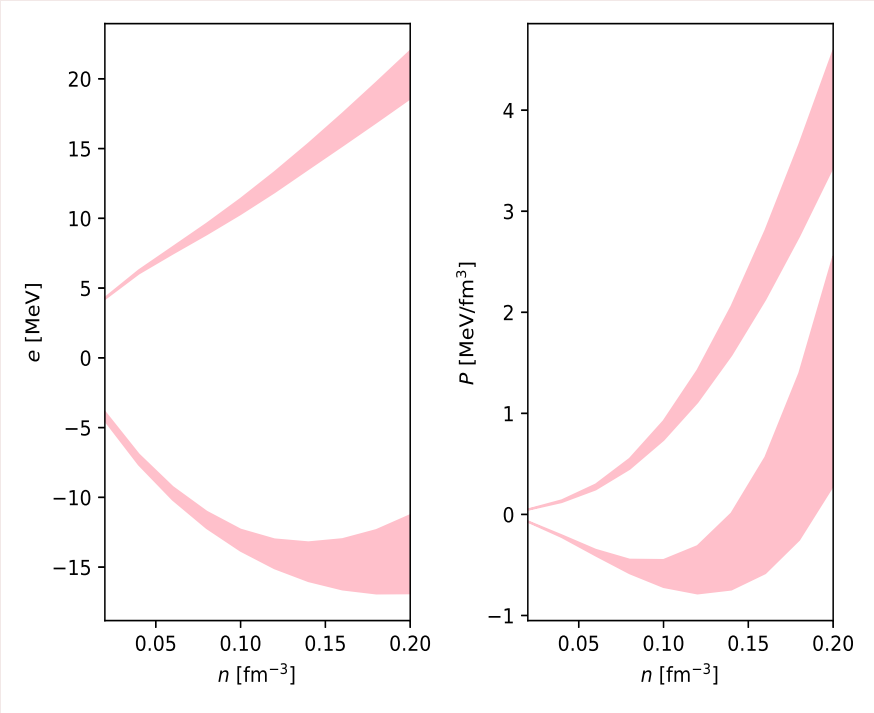

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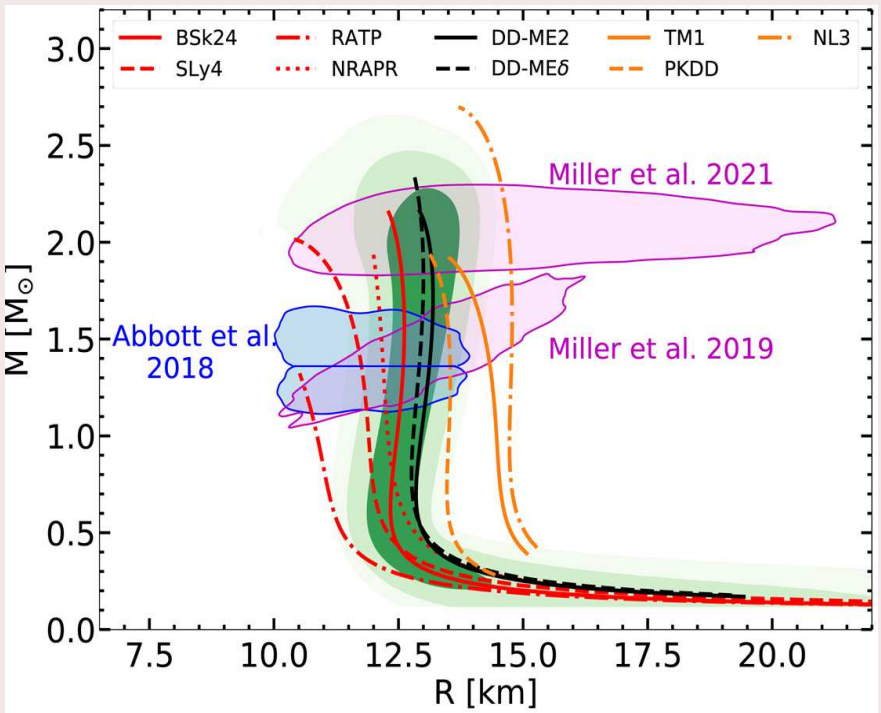

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We can construct equation of state (EoS) with nuclear models. (!!!!)

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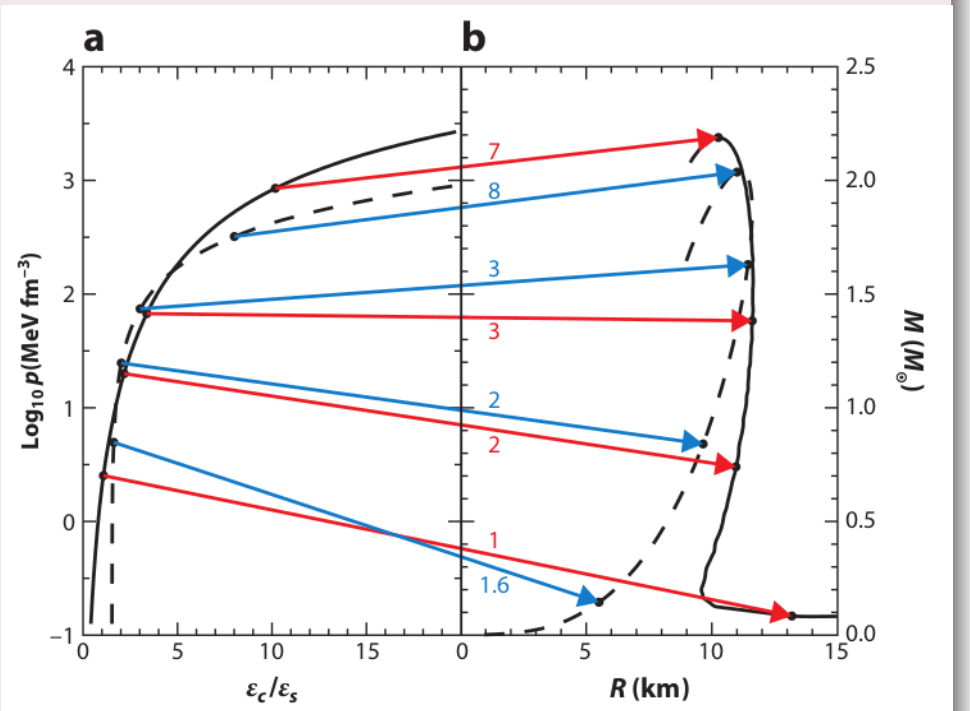

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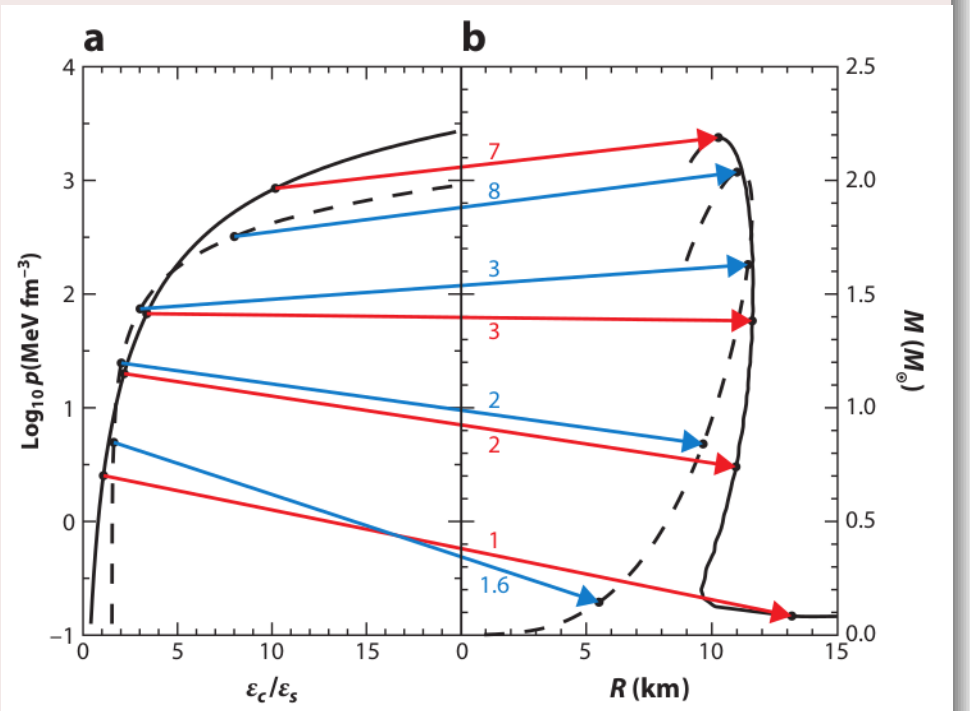

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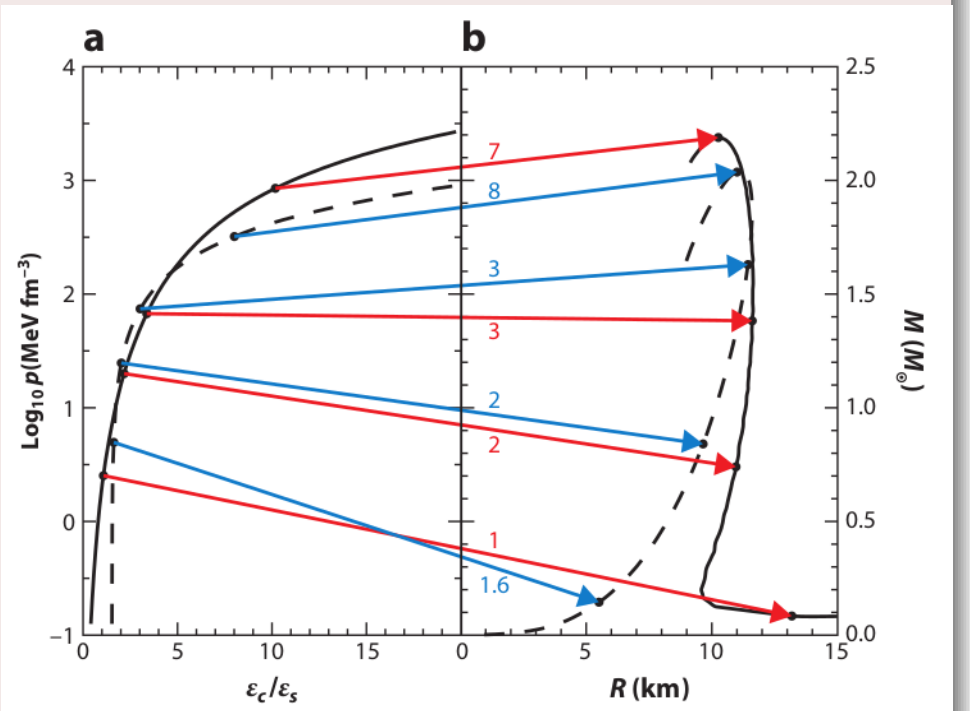

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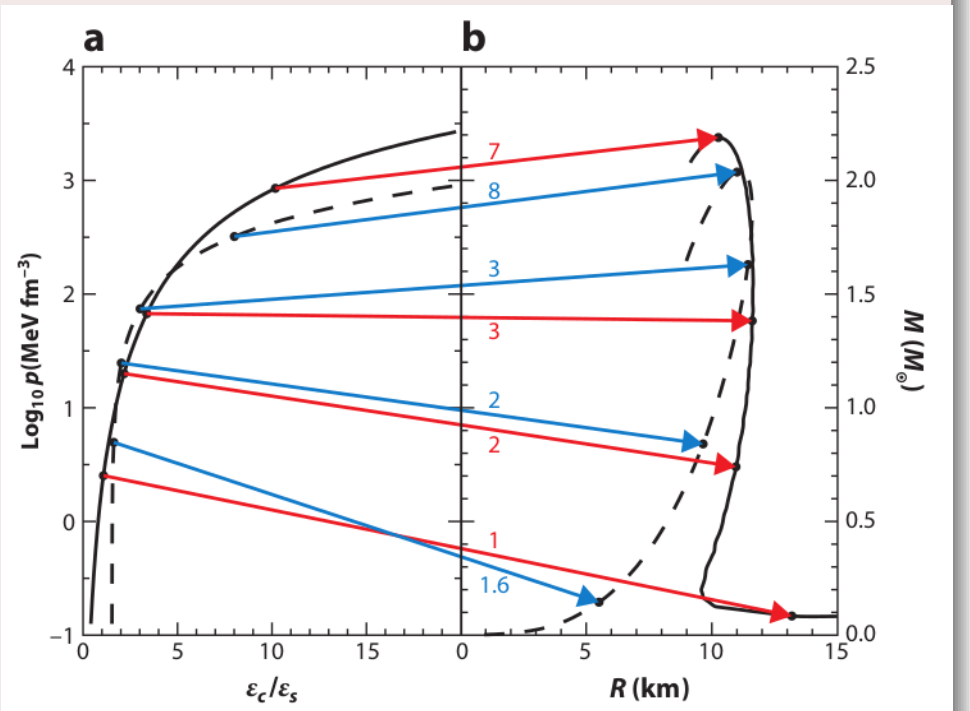

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- **Unfortunately, there is no direct way to infer/verify about the core of NS from observation, YET.**
- We propose a problem of reverse engineering!!

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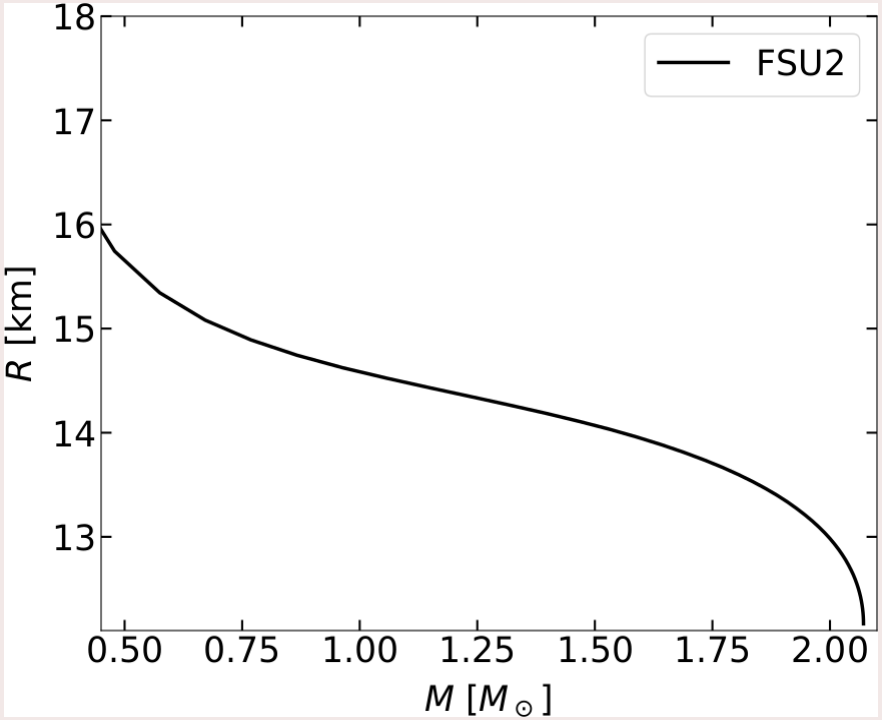

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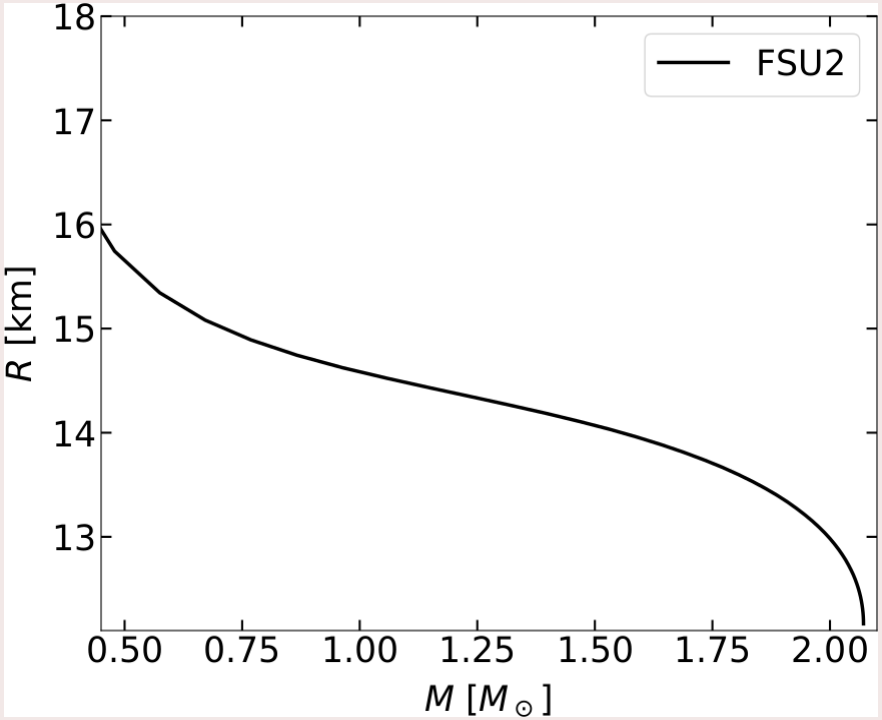
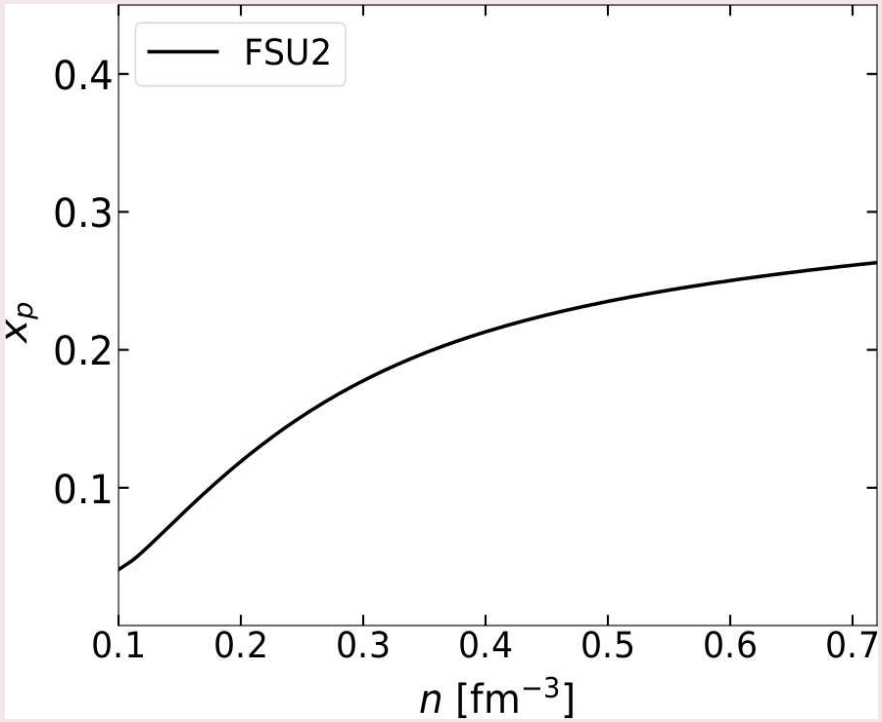


Proton fraction x_p



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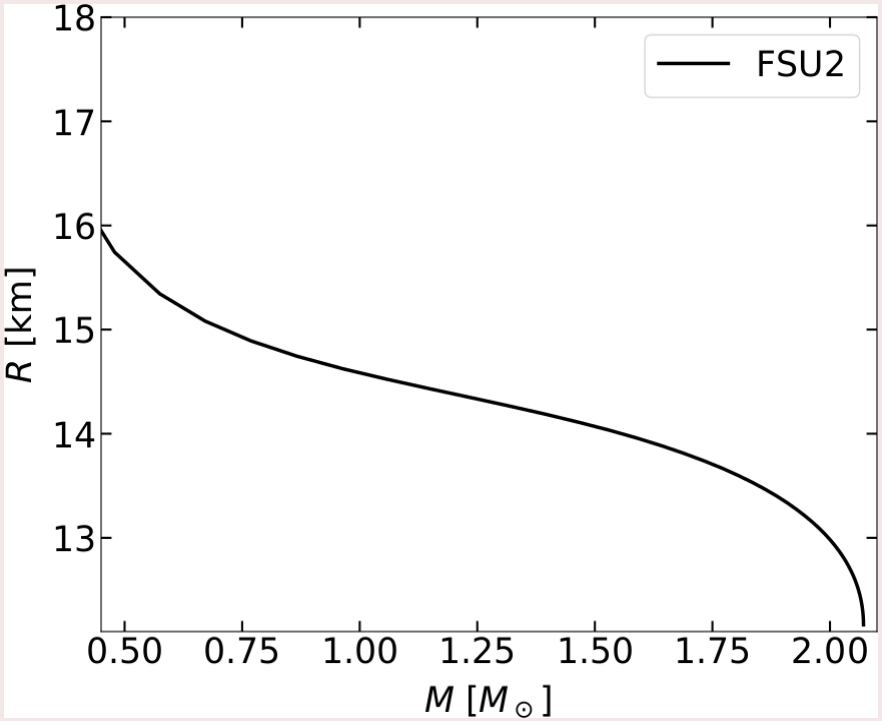

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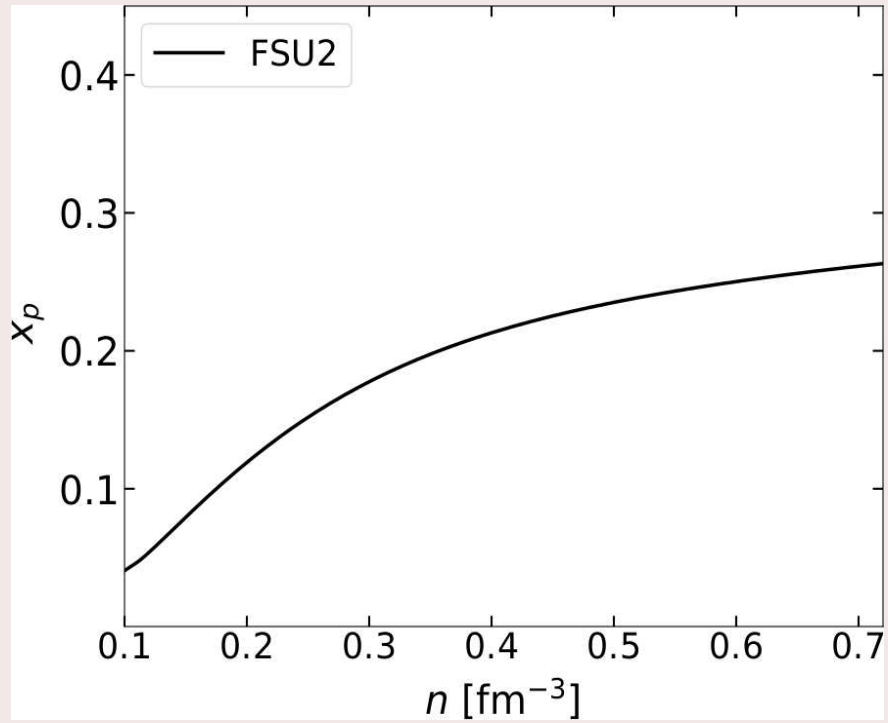

We need an efficient mechanism to explore the M-R plane

Meta-Model

Nucleonic meta-modelling

Founding aspects [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. $\overrightarrow{X}$.**
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- **The energy per particle is given by ($x = \frac{n-n_{\rm sat}}{3n_{\rm sat}}$, $n = n_n + n_p$, $x_p = \frac{n_p}{n}$)**

$$
\begin{aligned}
e(n_n, n_p) &\simeq e_{\rm SNM}(n, 0) + e_{\rm sym}(n)(1-2x_p)^2 \\
e_{\rm SNM}(n) &\simeq E_{\rm sat} + \frac{1}{2}K_{\rm sat}x^2 + \frac{1}{6}Q_{\rm sat}x^3 + \frac{1}{24}Z_{\rm sat}x^4 \\
e_{\rm sym}(n) &\simeq J_{\rm sym} + Lx + \frac{1}{2}K_{\rm sym}x^2 + \frac{1}{6}Q_{\rm sym}x^3 + \frac{1}{24}Z_{\rm sym}x^4.
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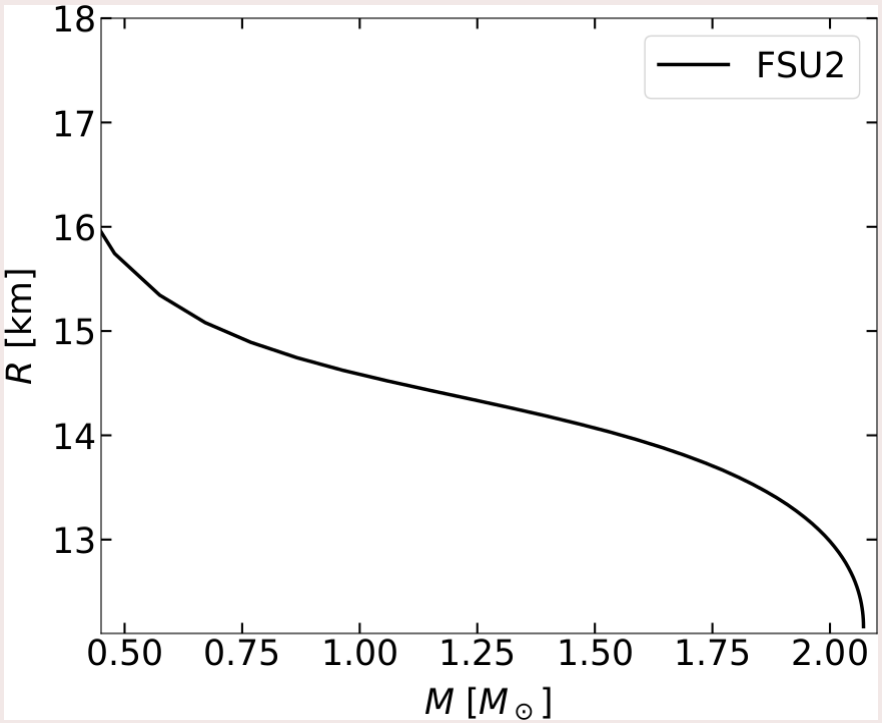

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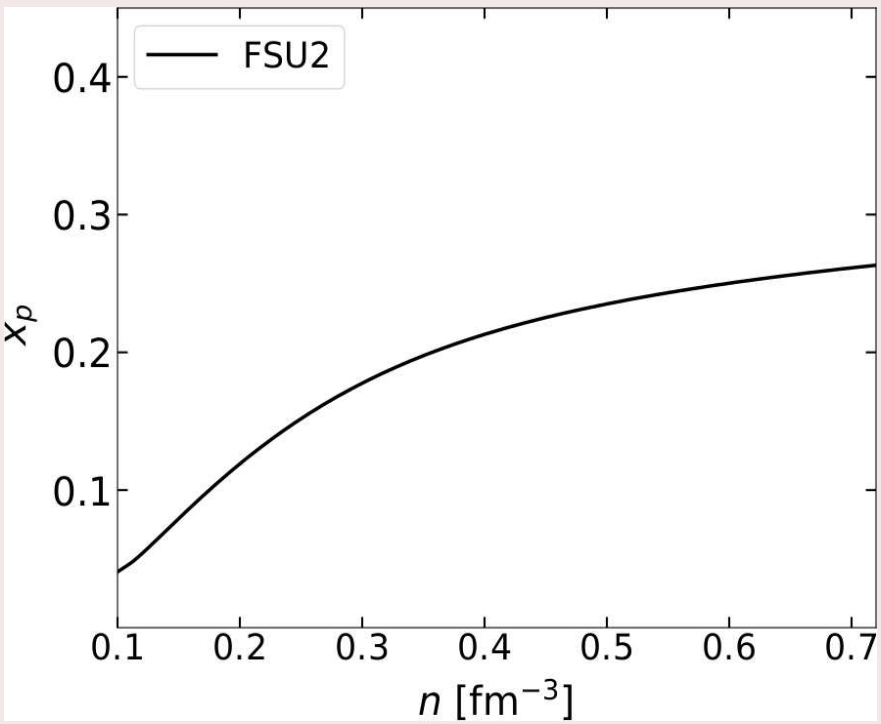

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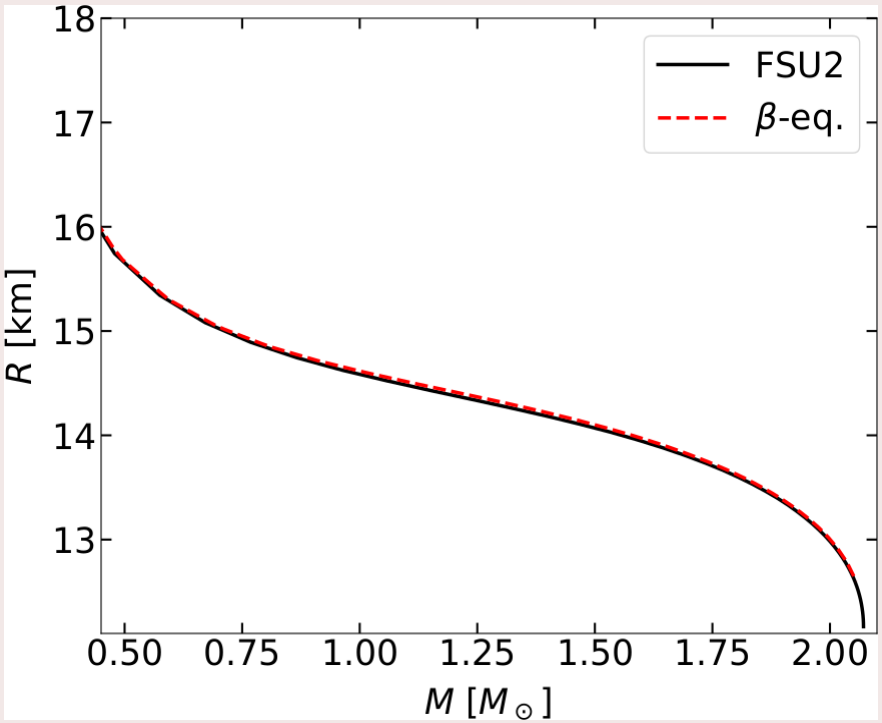

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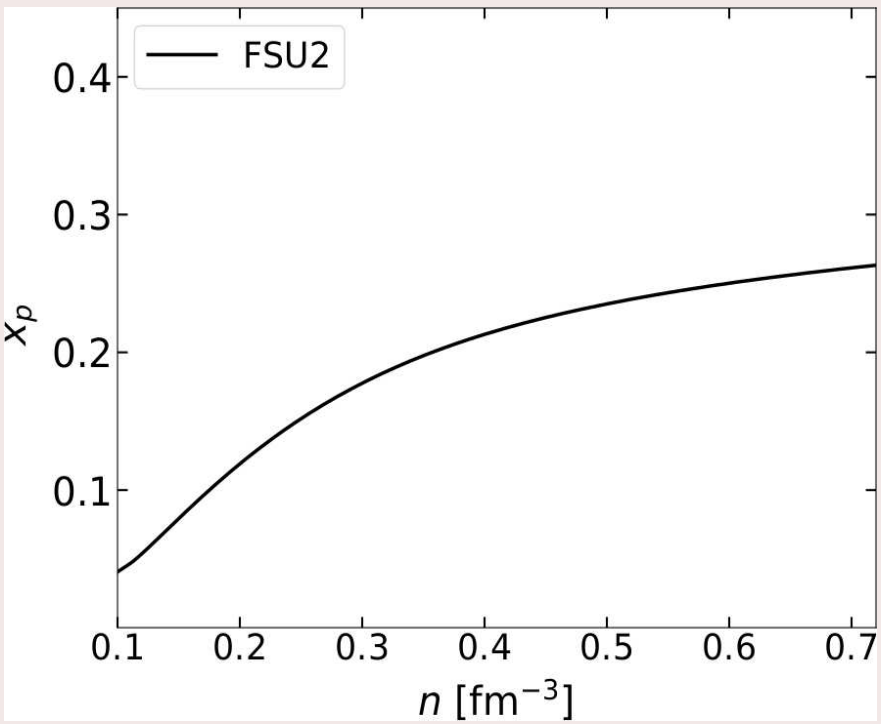

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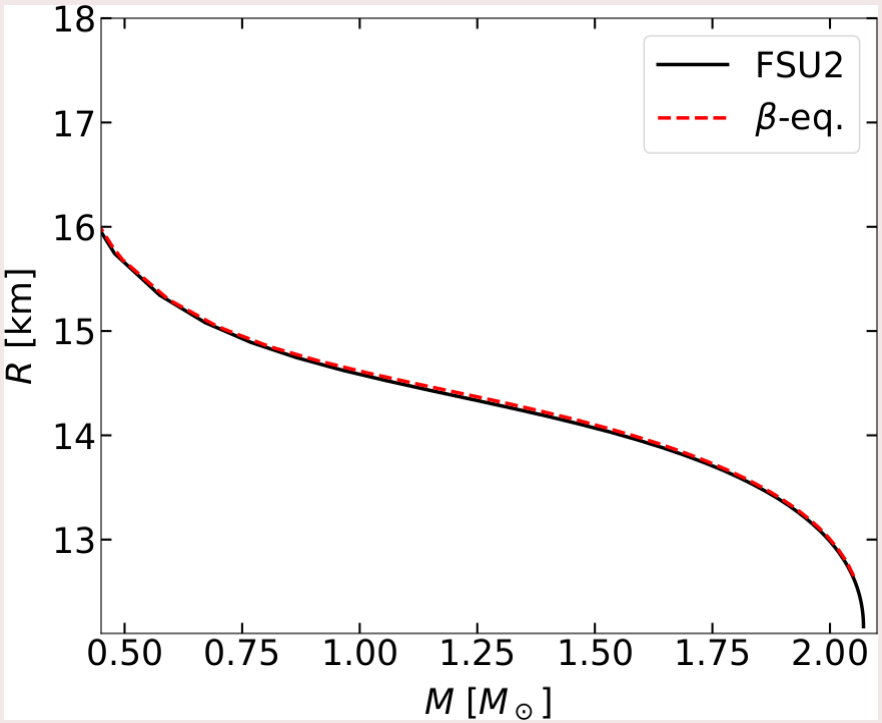

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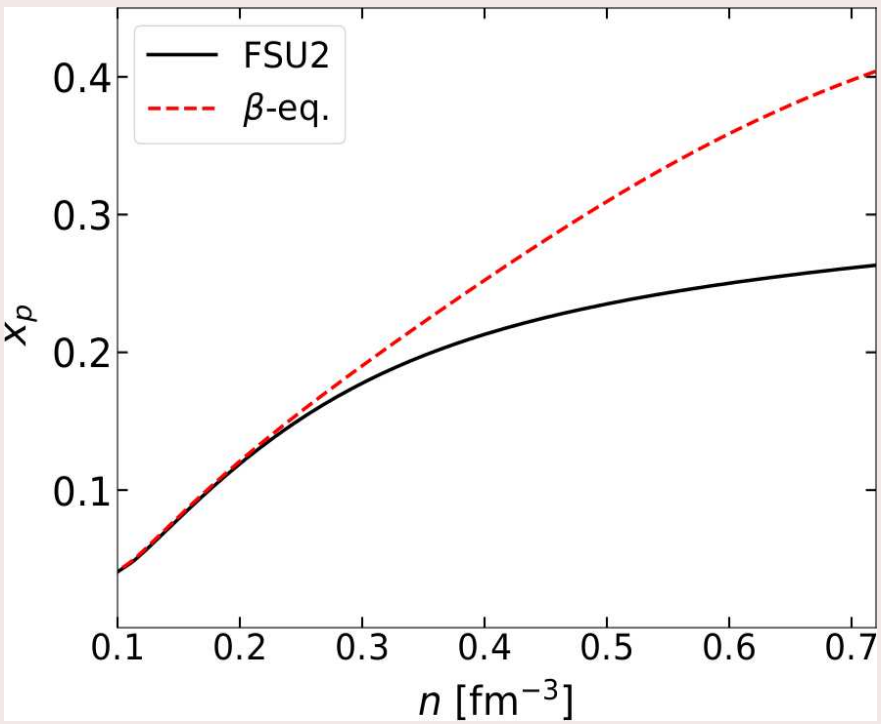

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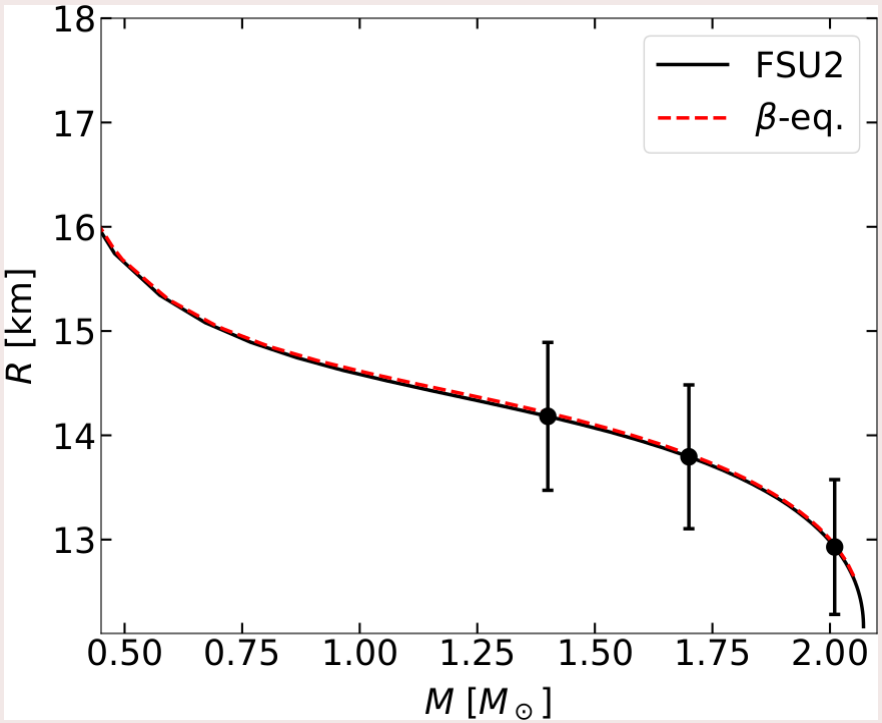

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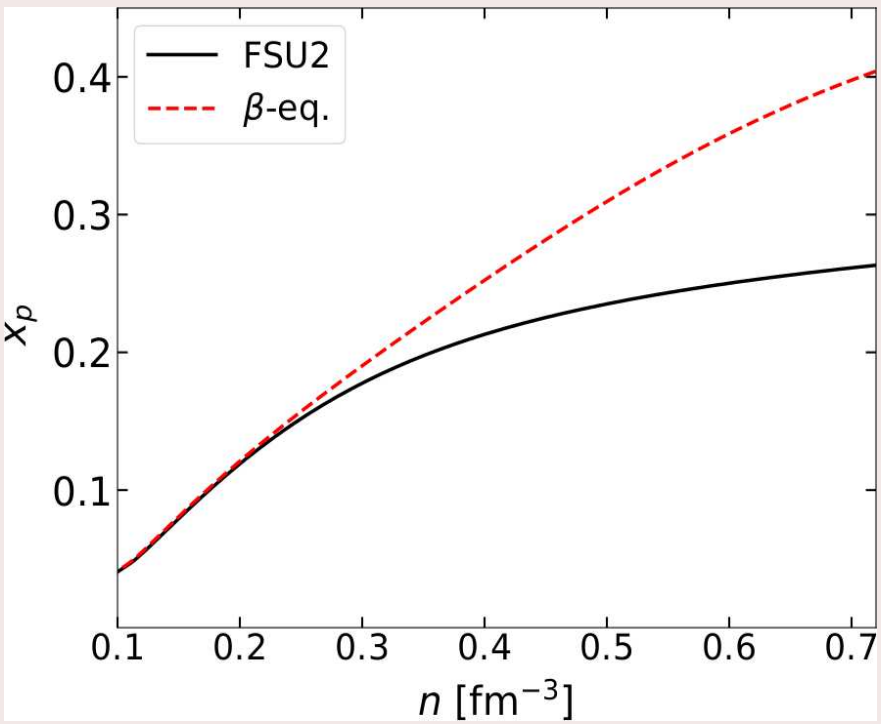

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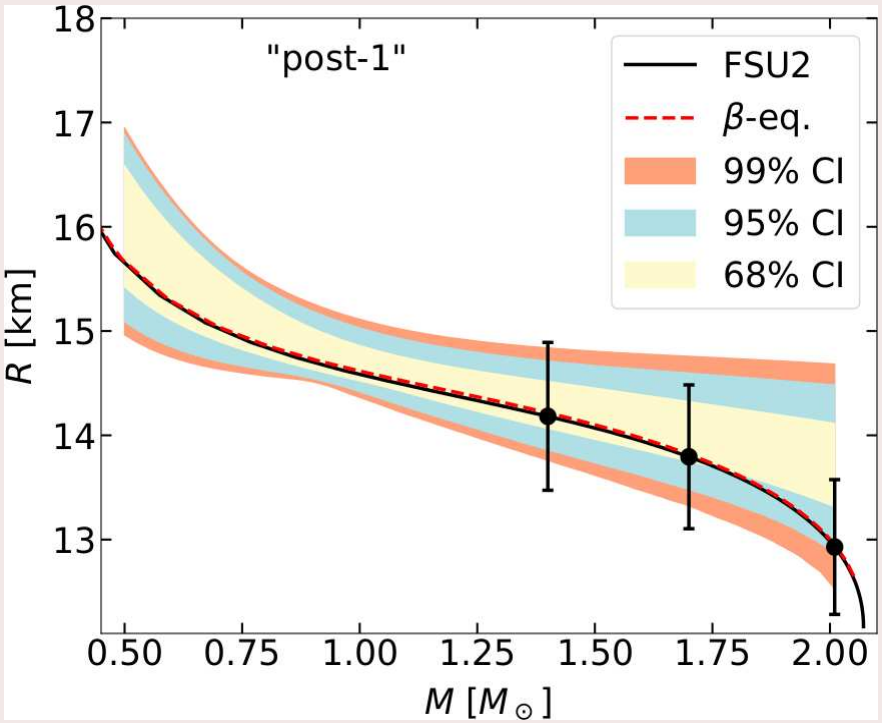

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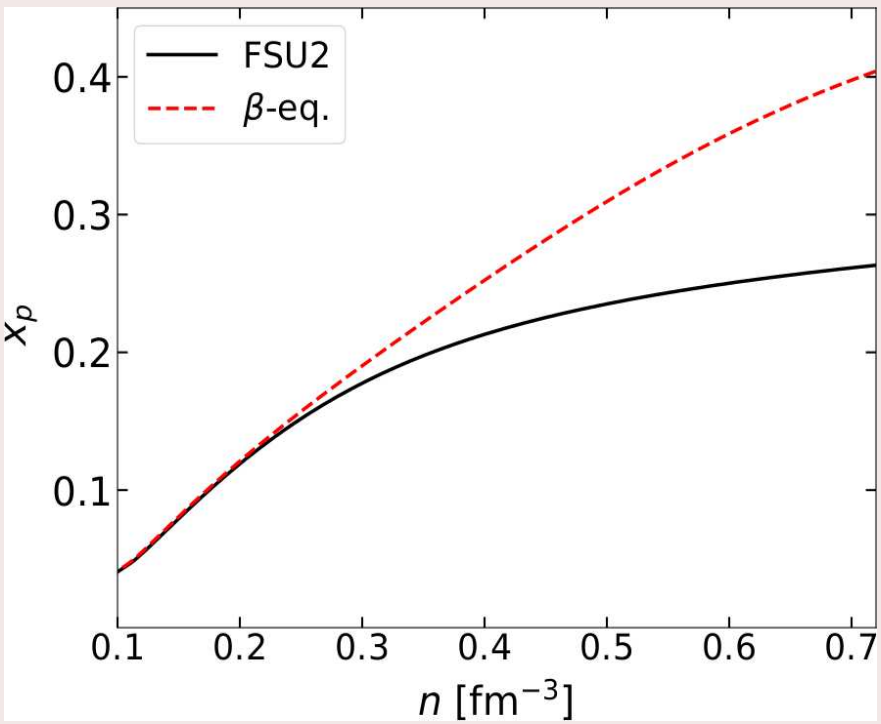

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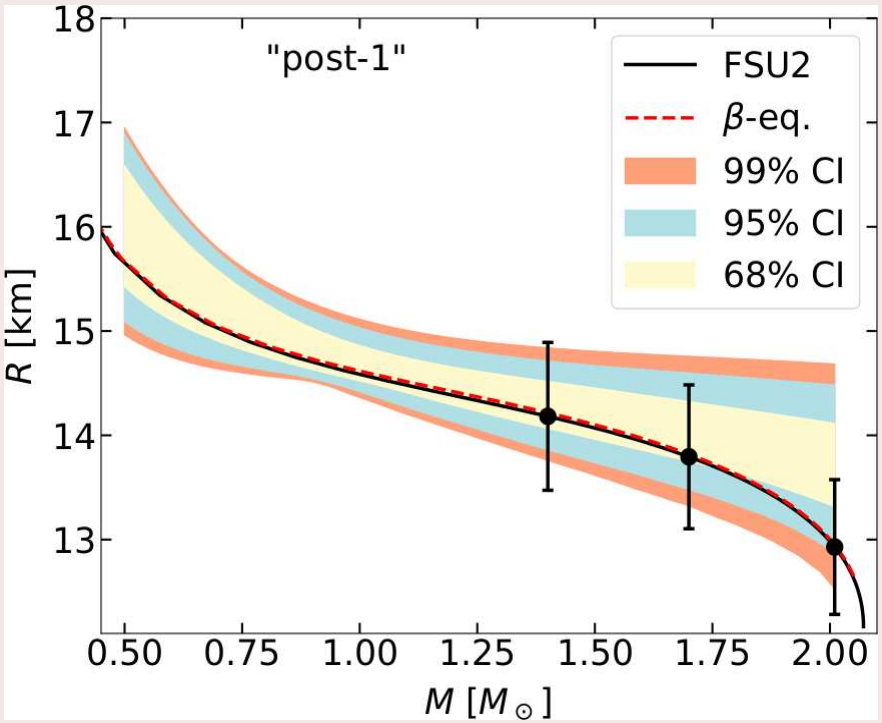

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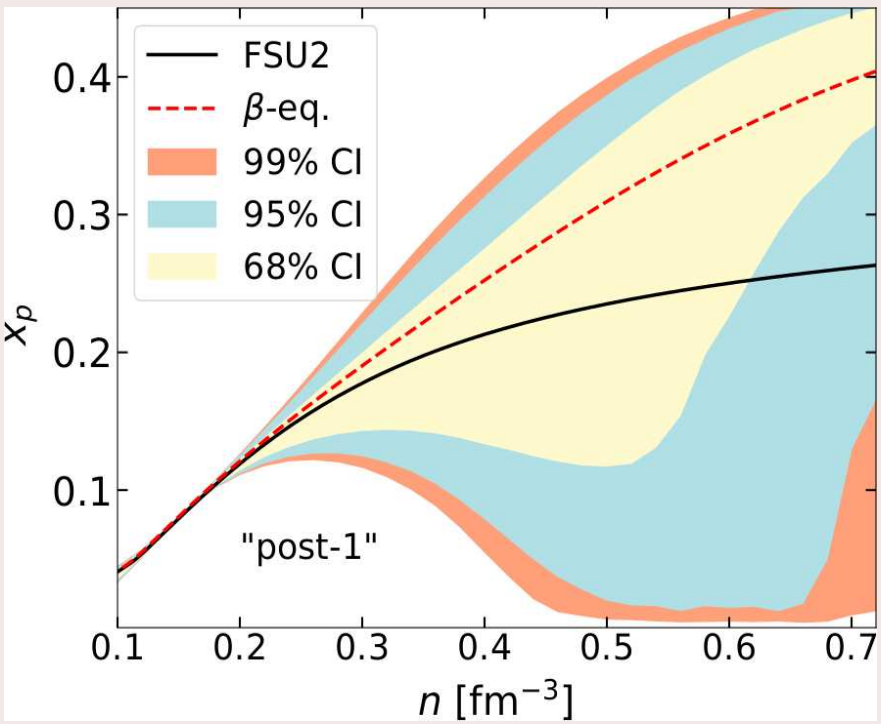

CM & F. Gulminelli, arXiv:2111.04520

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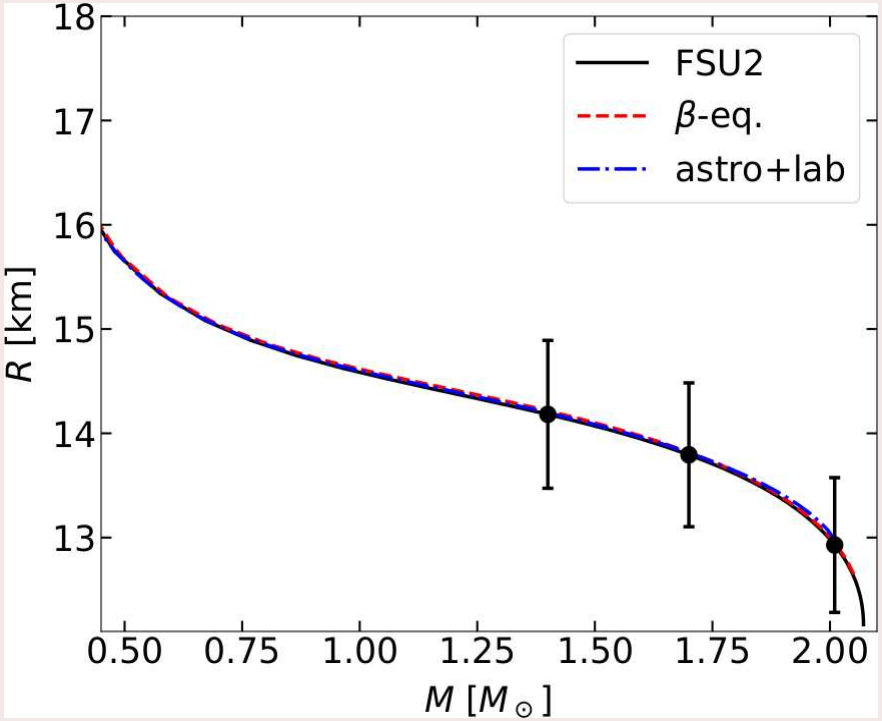

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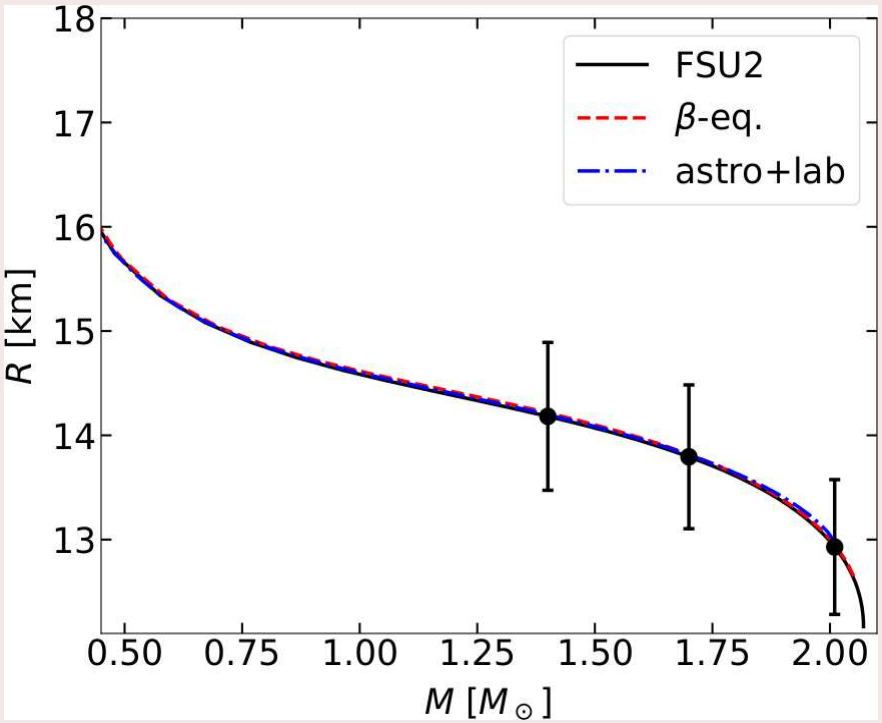

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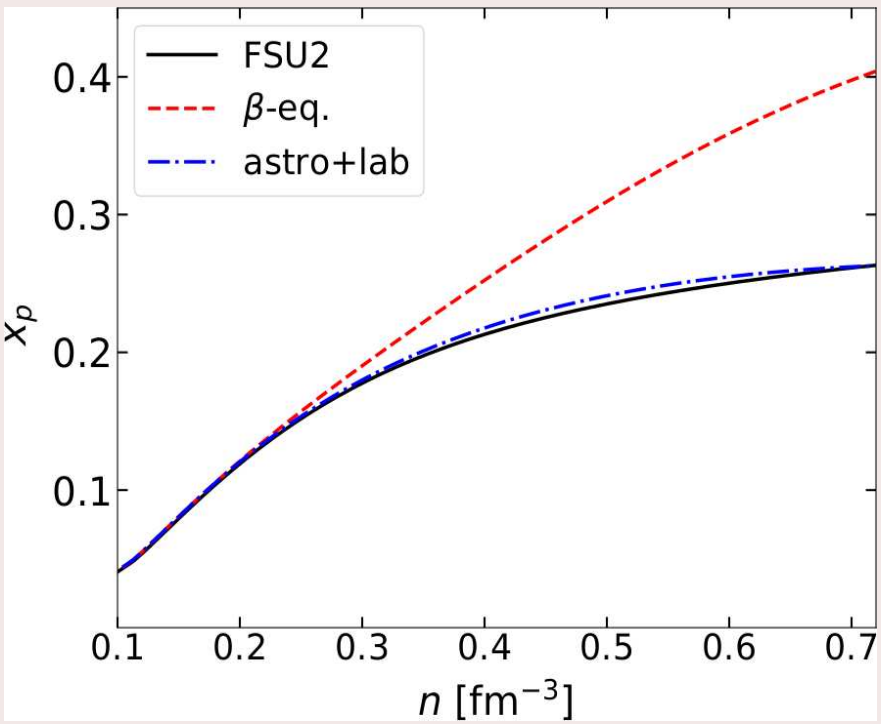

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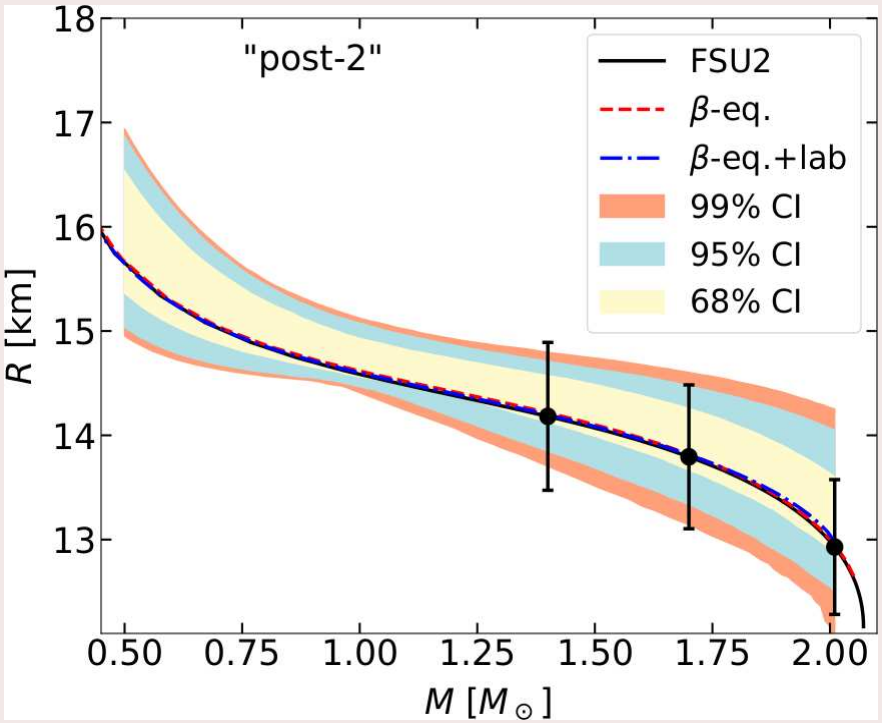

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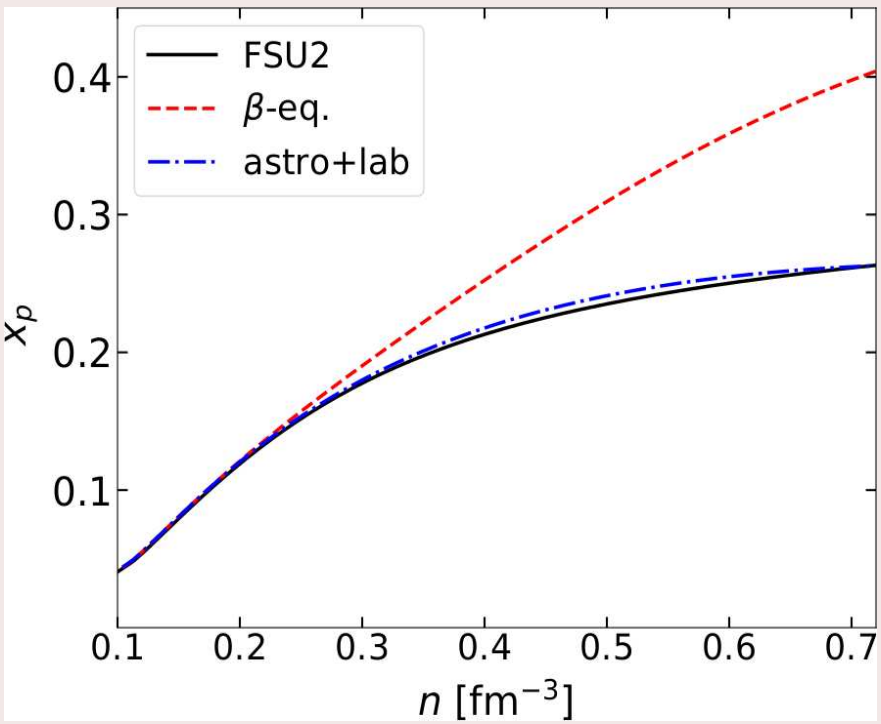

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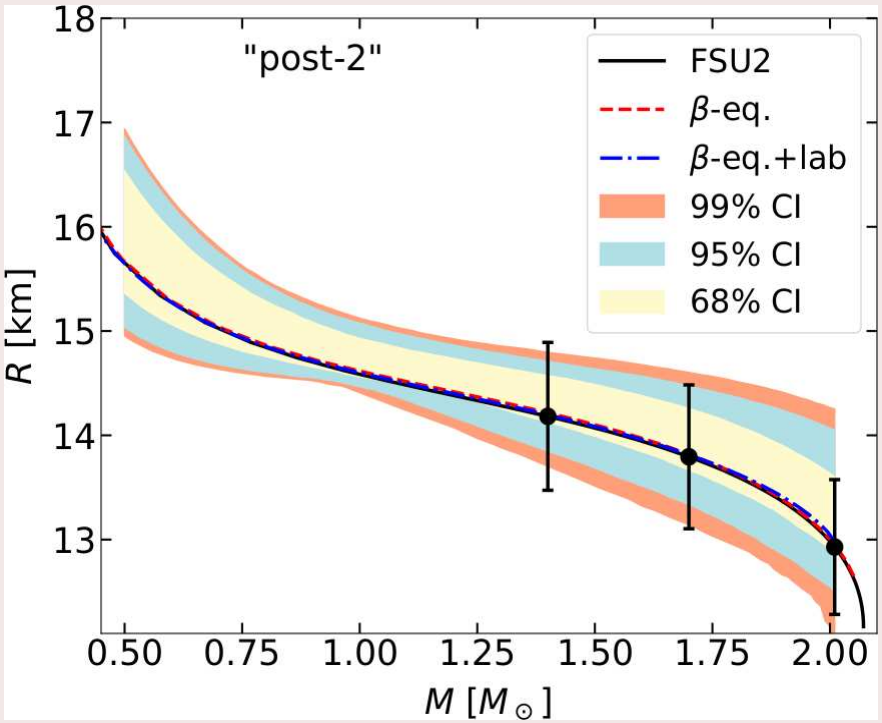
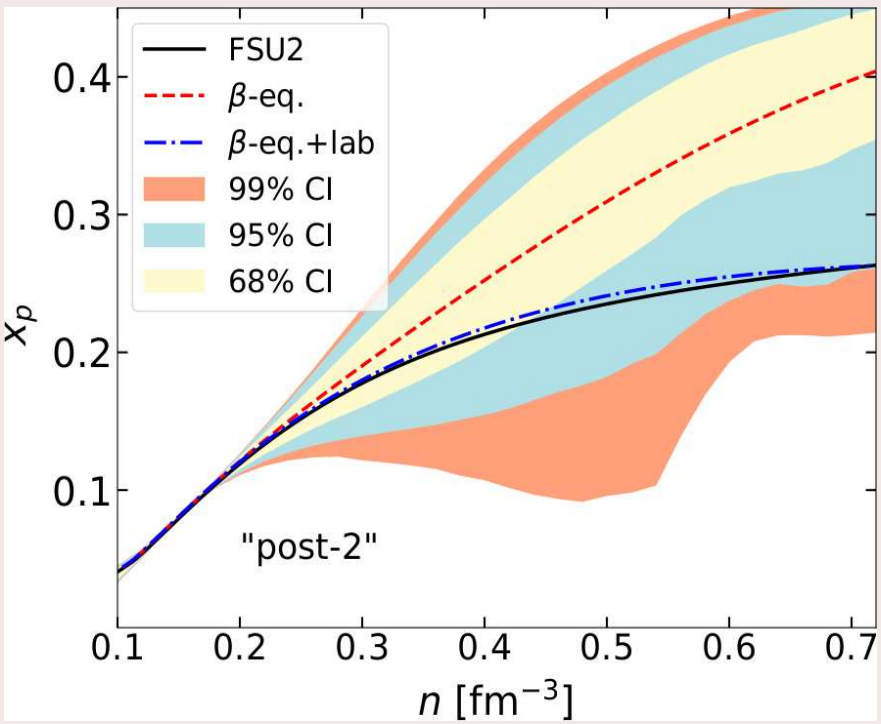
If we are given M-R, can we predict composition?

M-R relation +SNM



Proton fraction x_p



CM & F. Gulminelli, arXiv:2111.04520

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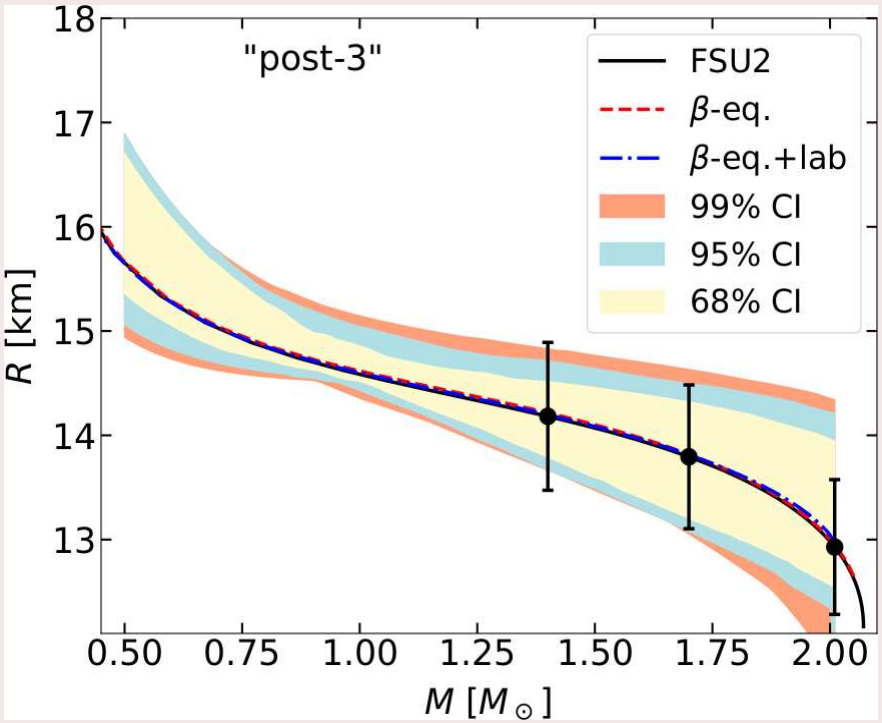

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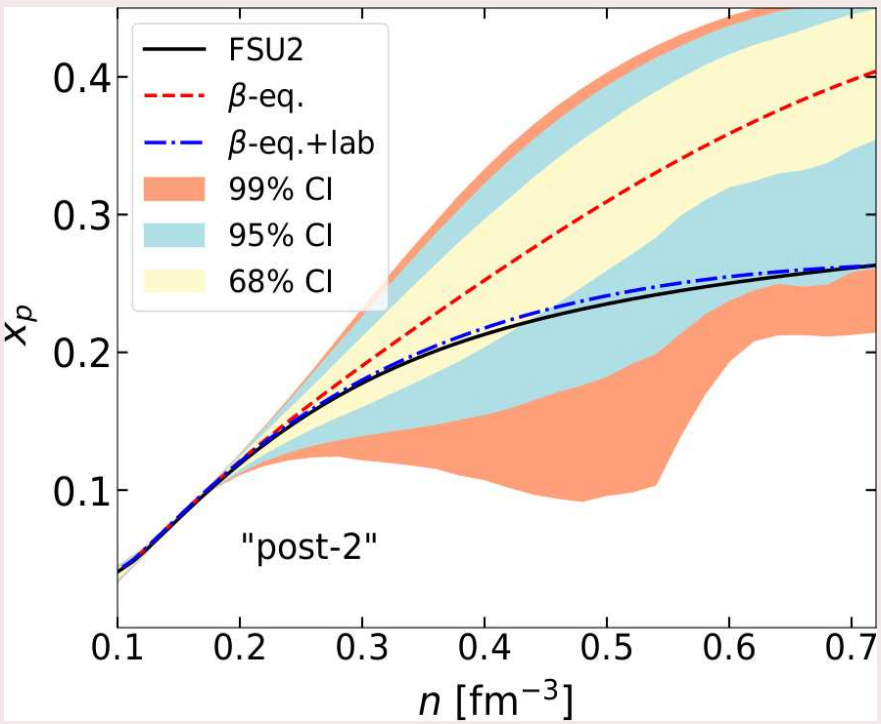

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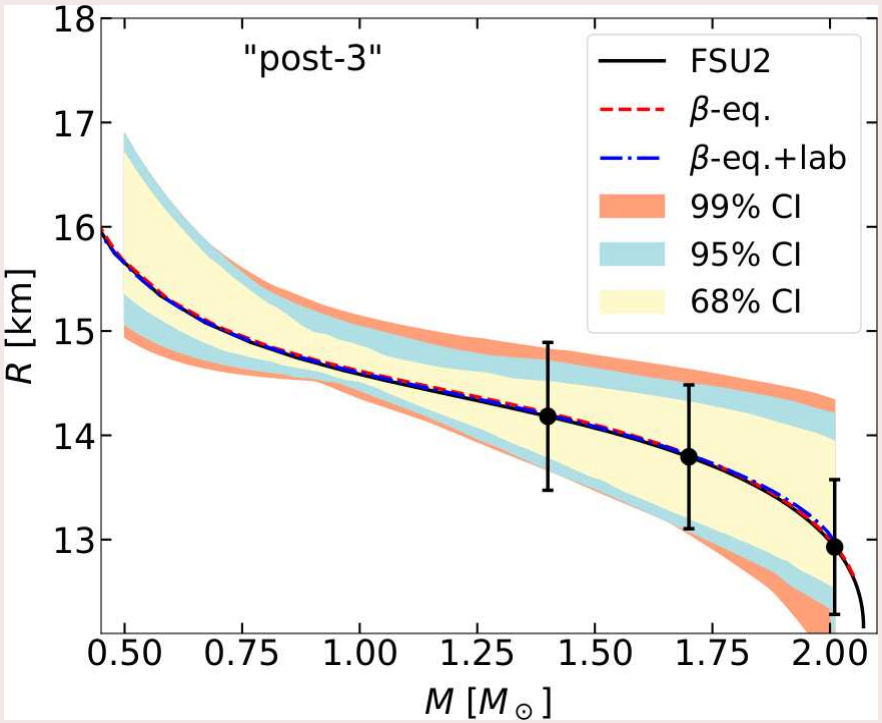

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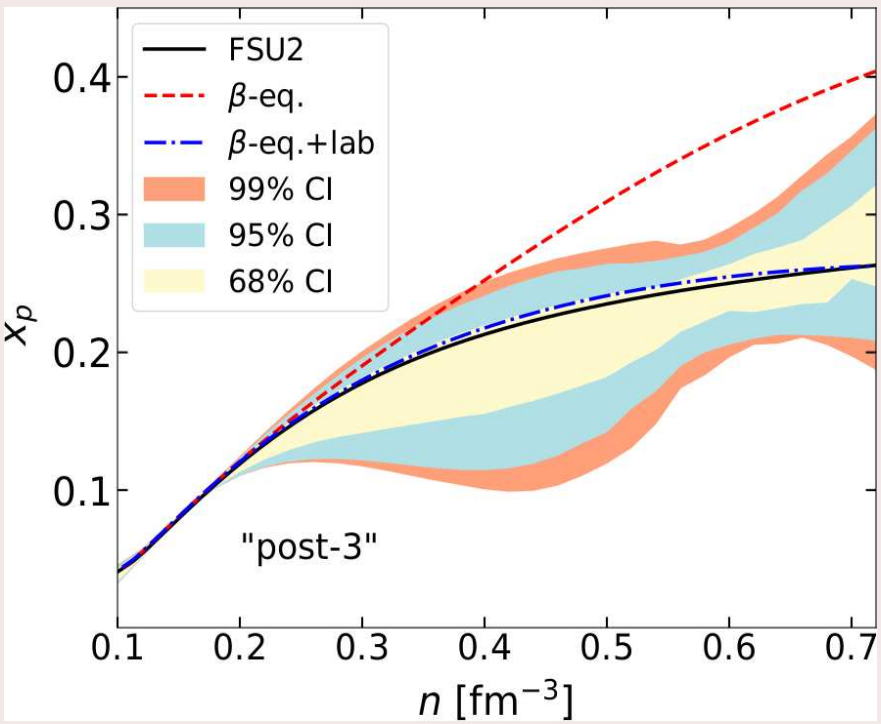

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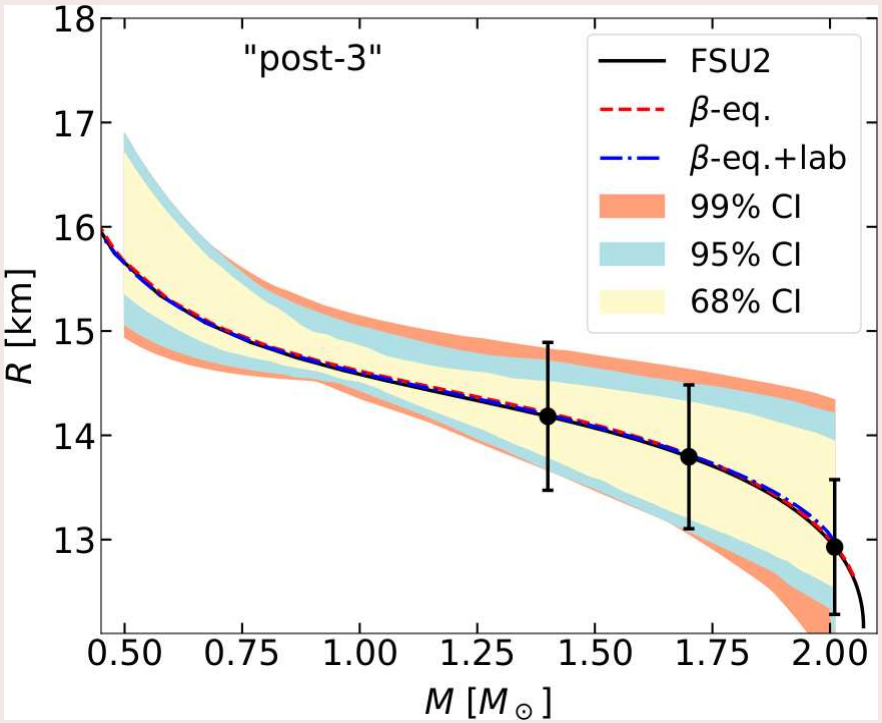

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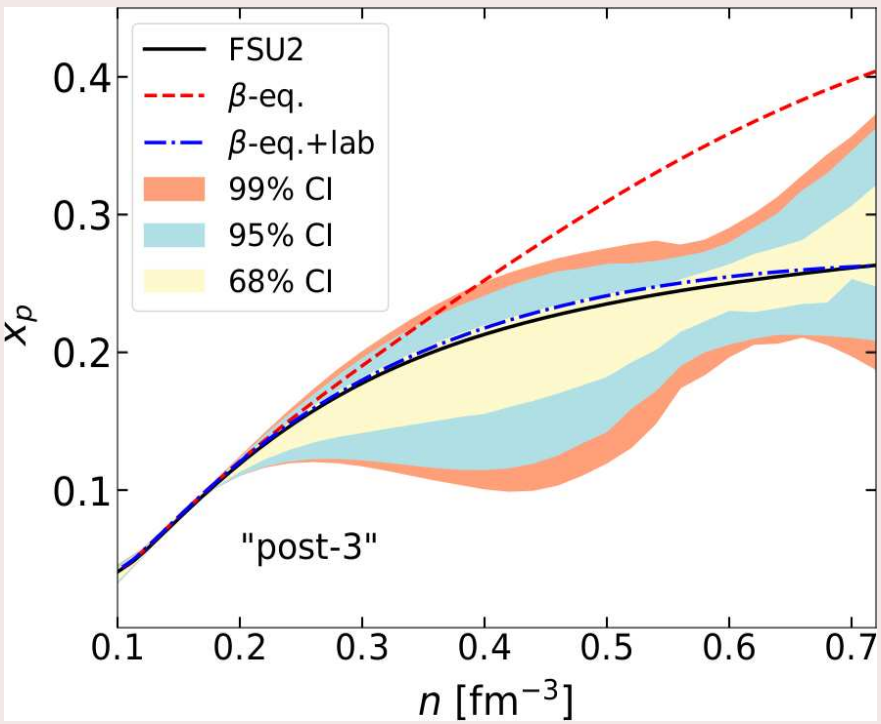
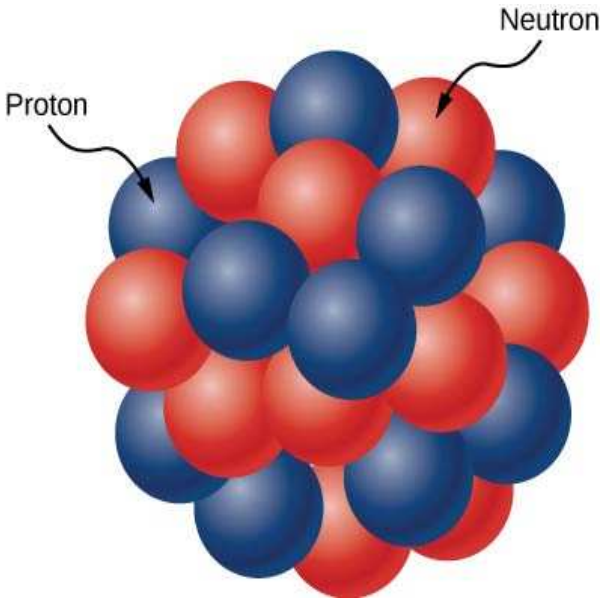


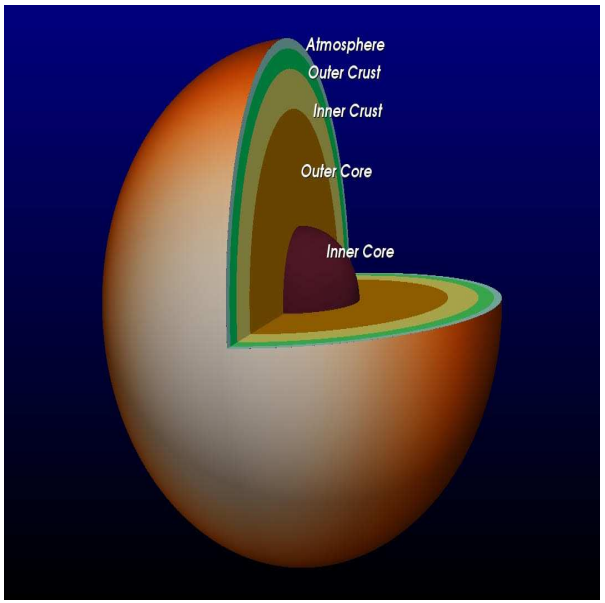
CM & F. Gulminelli, arXiv:2111.04520

Can high density constraint on nuclear matter from experiment help? YES

What can we learn?

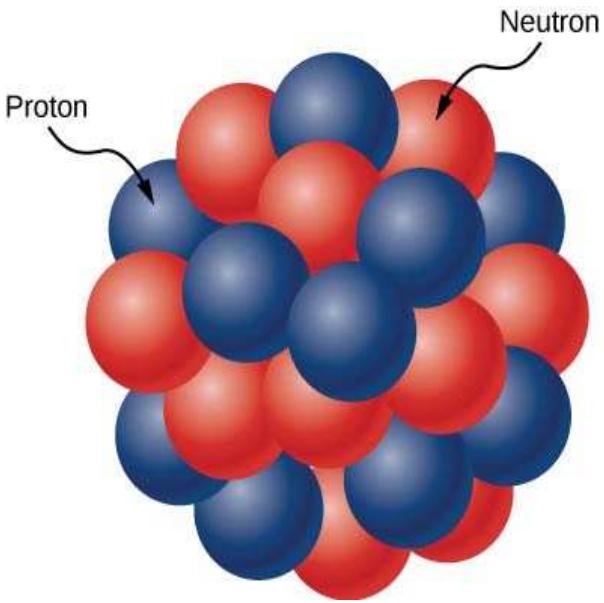
***Ab-initio* model**

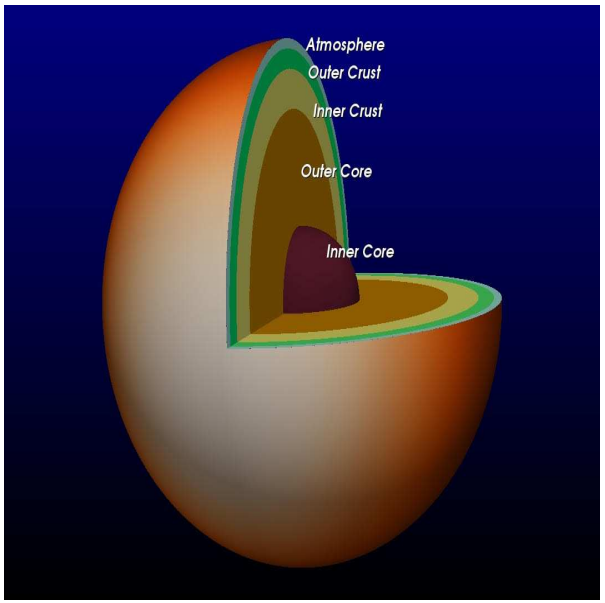




What can we learn?

Meta-model



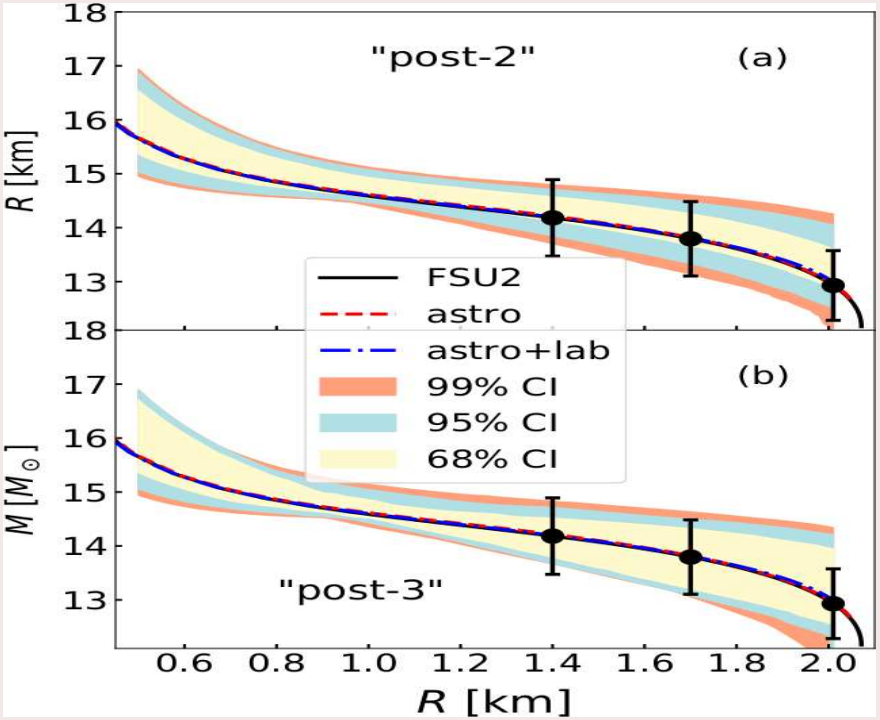


What can we learn?

Back up

Why symm energy is more sensitive?

M-R relation +SNM +Symm Ener



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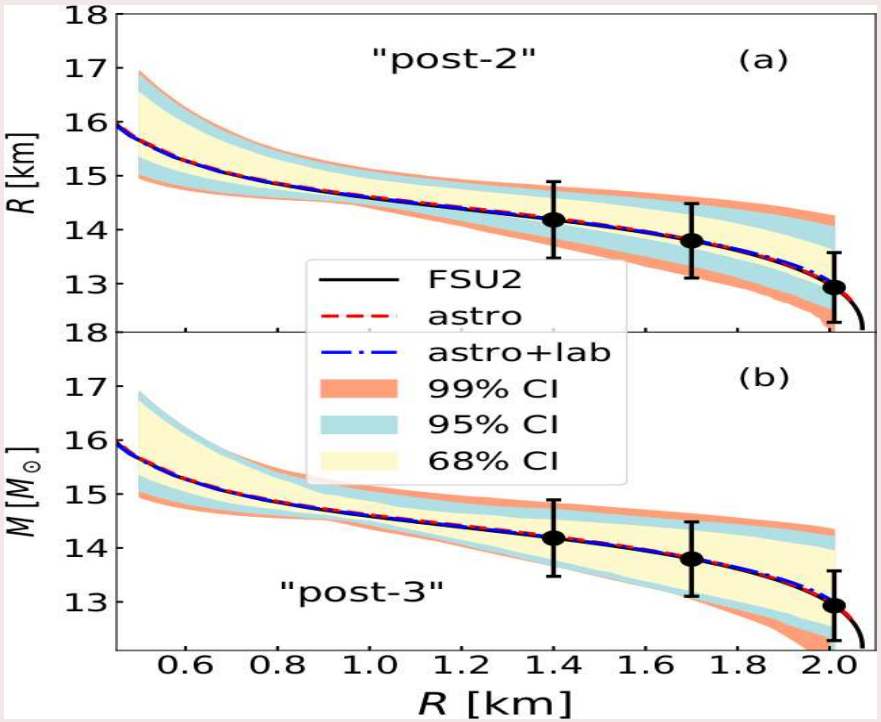
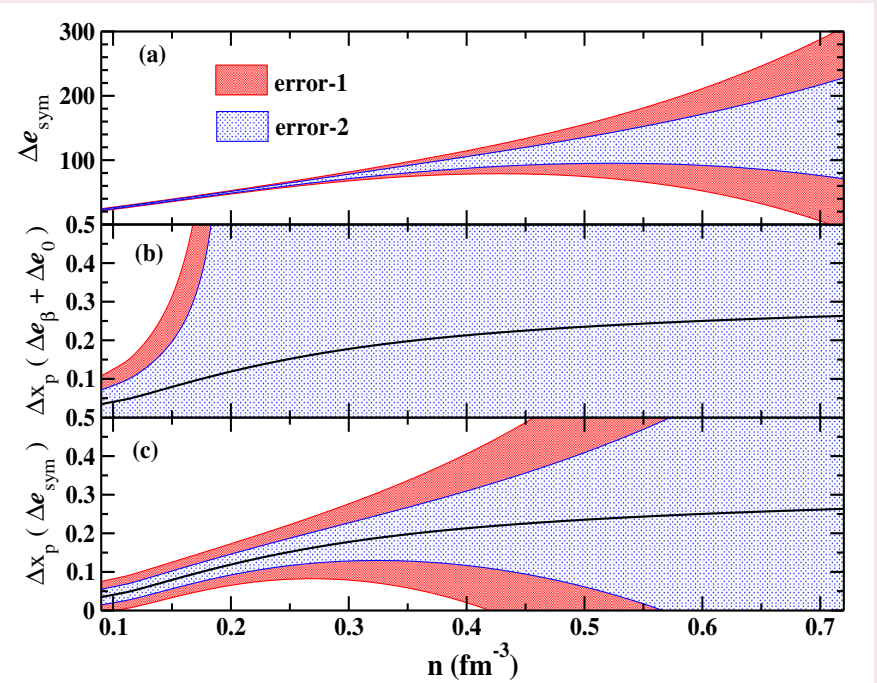


Analytical error



$$\Delta x_p = \frac{12 x_p (\Delta e_\beta + \Delta e_0)}{\mu_e |1 - 8 x_p|} = \frac{12 (1 - 2 x_p)^2 x_p \Delta e_{sym}}{\mu_e (4 x_p + 1)}.$$

CM & F. Gulminelli, arXiv:2111.04520

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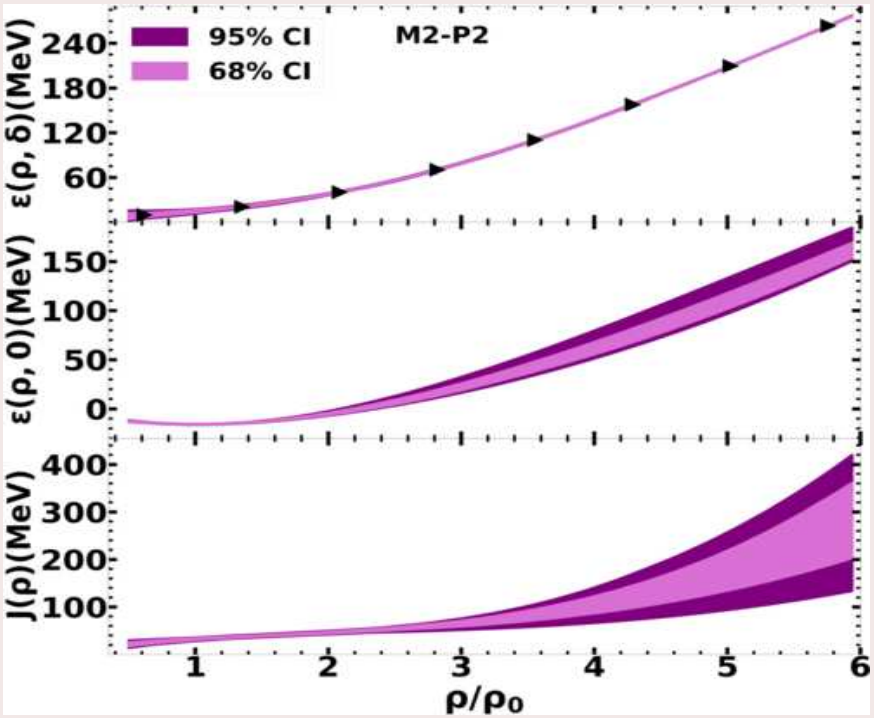
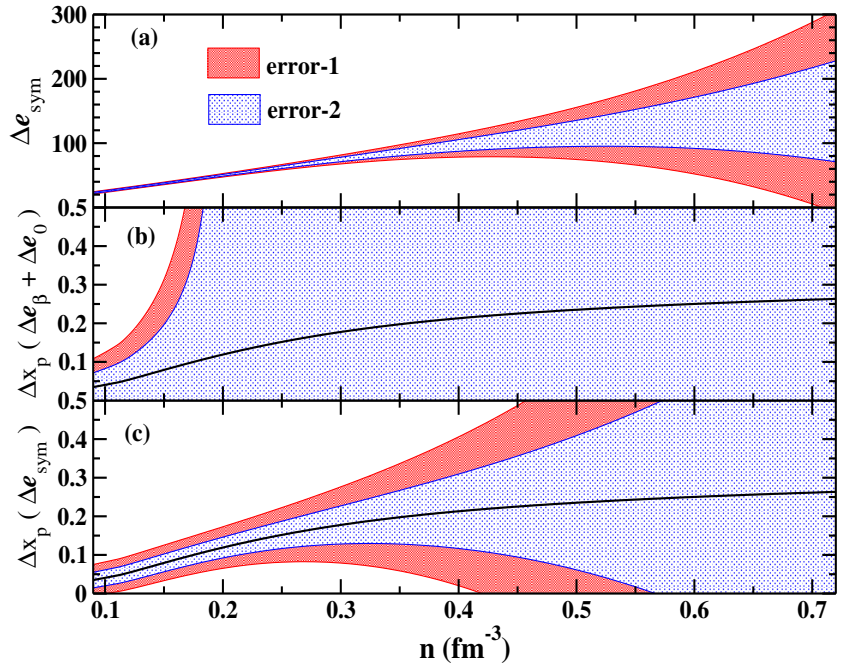


A. Imam *et. al.*, PRC 105, 015806 (2022)

Analytical error



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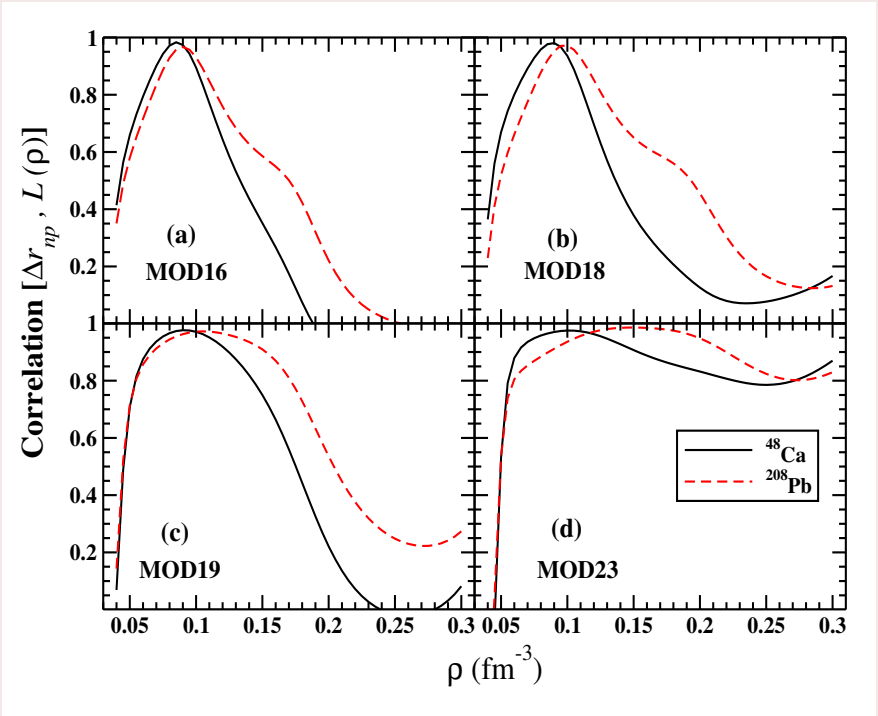
CM & F. Gulminelli, arXiv:2111.04520

Back up

What we can do from theoretical side?

Δr_{np} - L correlation



CM, Phys.Rev.C 105, 034305 (2022).

Back up

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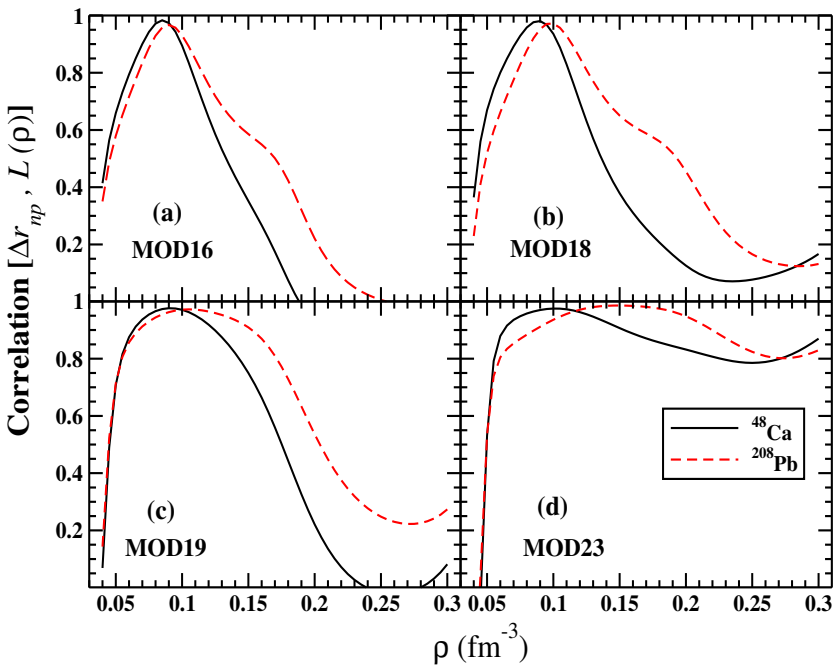
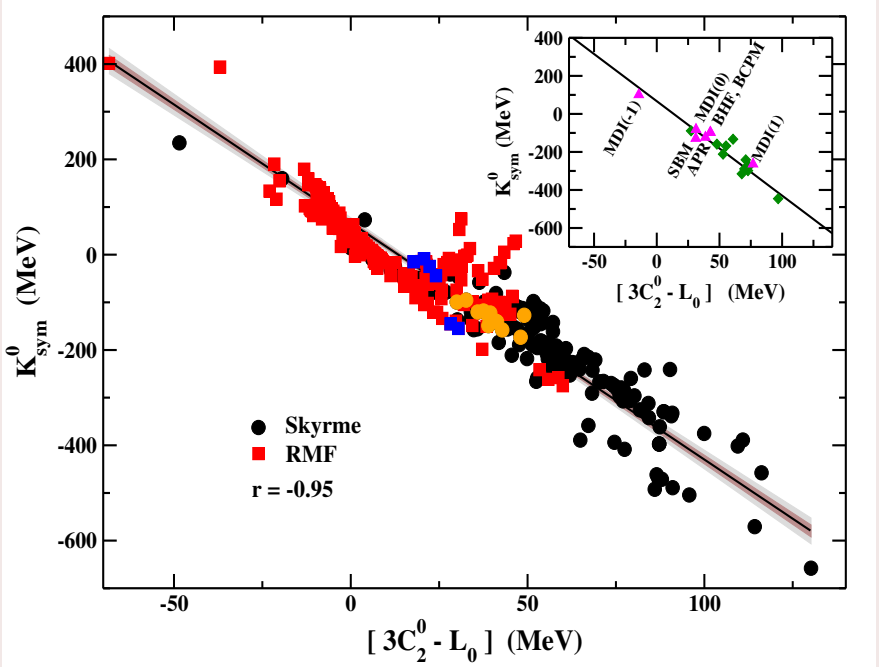


CM, Phys.Rev.C 105, 034305 (2022).

Decoding physical correlation(s)



CM *et. al.*, PRC 96, 021302 (2017)