

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

Chiranjib Mondal & Francesca Gulminelli



PhyNuBE
December 9, 2021

What do we have?

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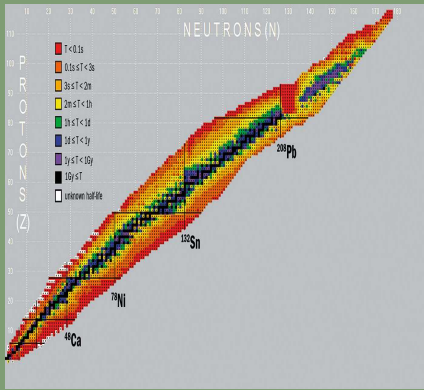
Low energy Nuclear Physics

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Low energy Nuclear Physics

We have knowledge from Nuclear Physics in the laboratory

Finite nuclear properties

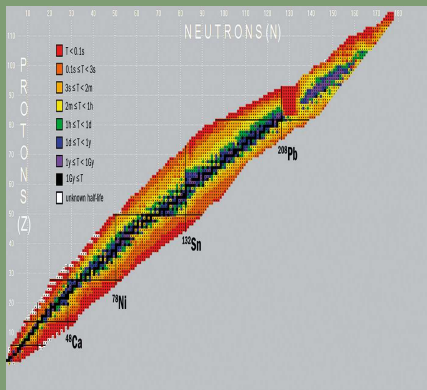


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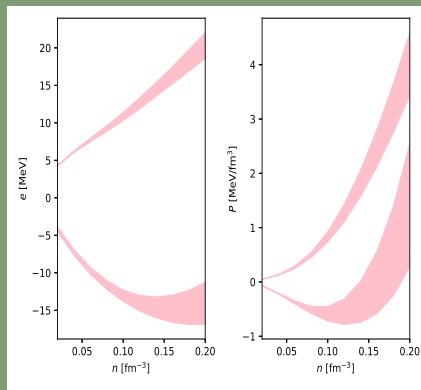
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Finite nuclear properties



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

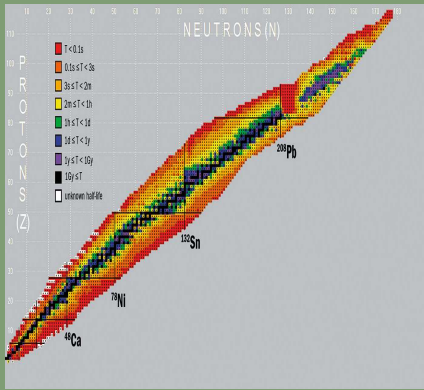


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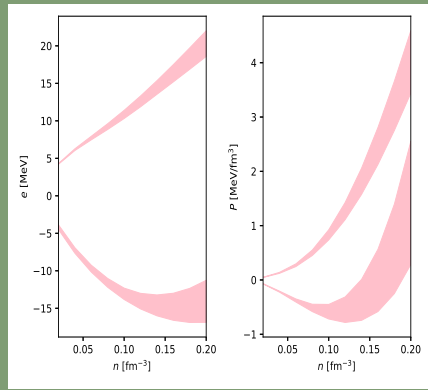
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We can build models for nuclear interaction. (!!!!)

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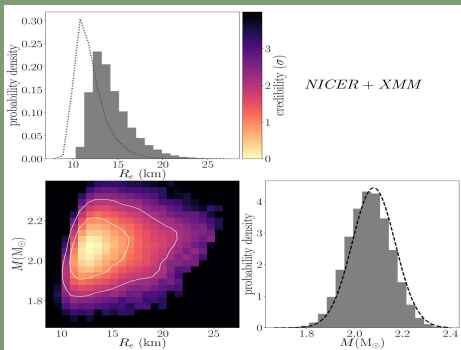
Static properties of the Neutron Star

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Mass-Radius M-R measurements from NICER, Radio astronomy (M)

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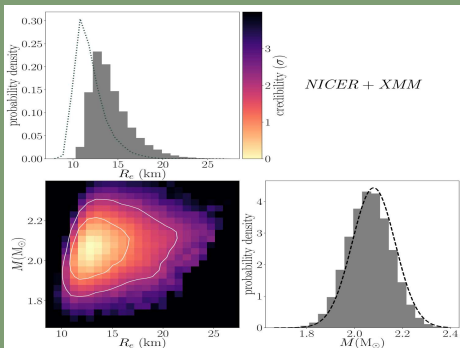


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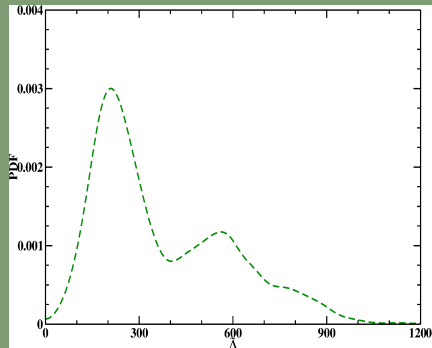
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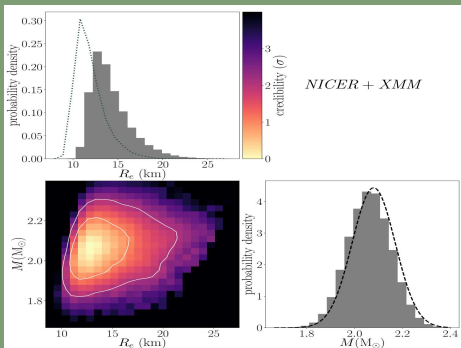


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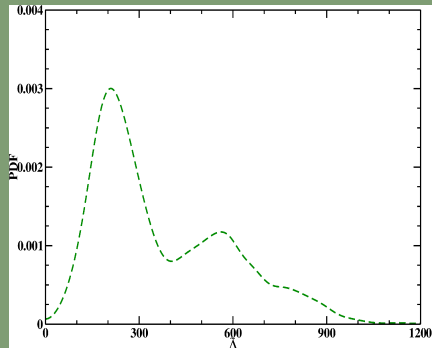
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We can construct equation of state (EoS) with nuclear models.

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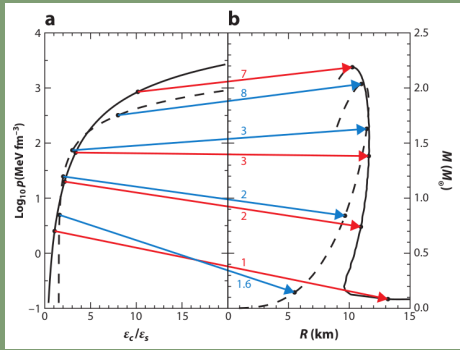
EoS in β -equilibrium and static properties of NS

What do we have?

EoS in β -equilibrium and static properties of NS

Solve Tolman-Oppenheimer-Volkoff (TOV) equations, we can construct the unique M-R or Λ -M(R) relations.

J. Lattimer, ARNPS 62, 485–515 (2012)

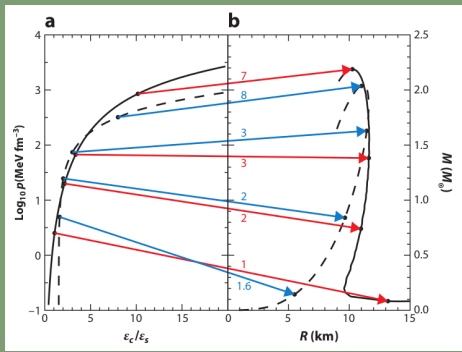


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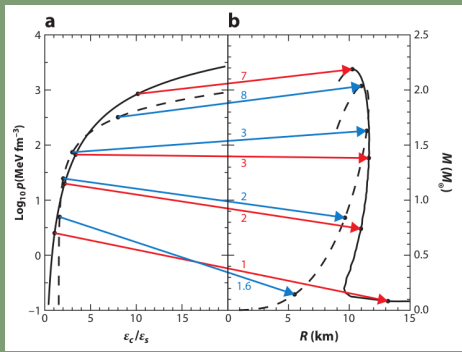
- Can we predict the composition of the Neutron star matter?

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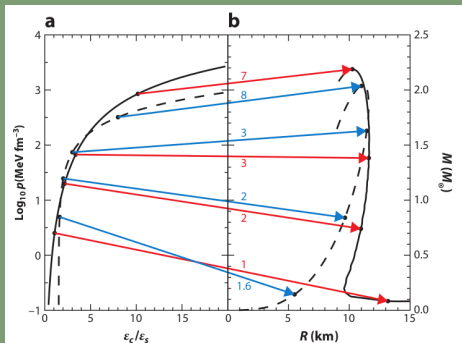
- Can we predict the composition of the Neutron star matter?
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What do we want to know?

- Can we predict the composition of the Neutron star matter?
- 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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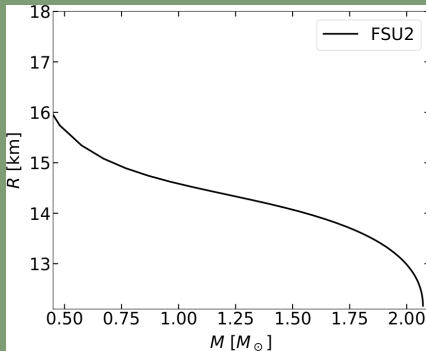
A demonstration with FSU2 [Chen *et. al.* PRC 90, 044305]

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A demonstration with FSU2 [Chen *et. al.* PRC 90, 044305]

Mass-Radius relation

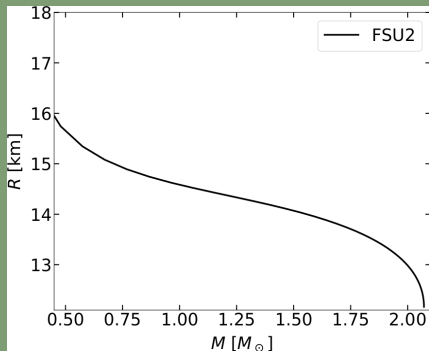


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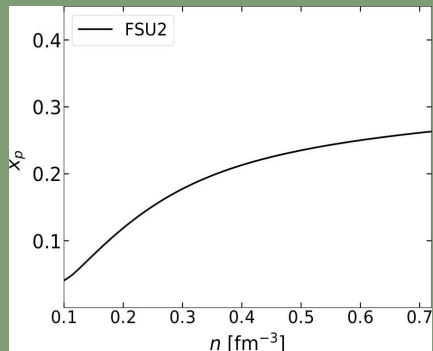
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Mass-Radius relation



Proton fraction x_p

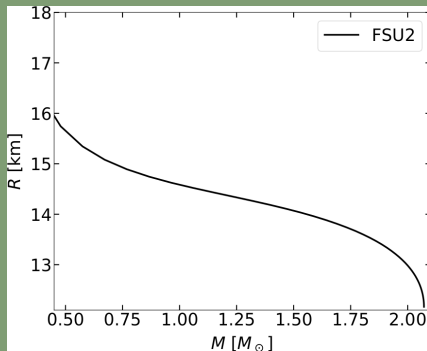


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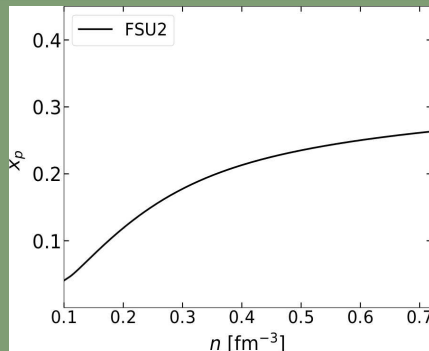
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We need an efficient mechanism to explore the M-R plane

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. \vec{X} .
- β -equilibrium!!!

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- The energy per particle is given by ($x = \frac{n-n_{\text{sat}}}{3n_{\text{sat}}}$, $n = n_n + n_p$, $x_p = \frac{n_p}{n}$)

$$e(n_n, n_p) \simeq e_{\text{SNM}}(n, 0) + e_{\text{sym}}(n)(1 - 2x_p)^2$$

$$e_{\text{SNM}}(n) \simeq E_{\text{sat}} + \frac{1}{2}K_{\text{sat}}x^2 + \frac{1}{6}Q_{\text{sat}}x^3 + \frac{1}{24}Z_{\text{sat}}x^4$$

$$e_{\text{sym}}(n) \simeq J_{\text{sym}} + Lx + \frac{1}{2}K_{\text{sym}}x^2 + \frac{1}{6}Q_{\text{sym}}x^3 + \frac{1}{24}Z_{\text{sym}}x^4.$$

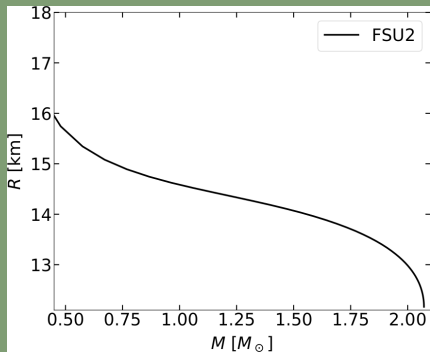
Problem at hand with FSU2

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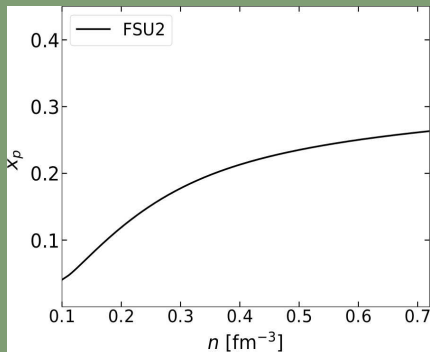
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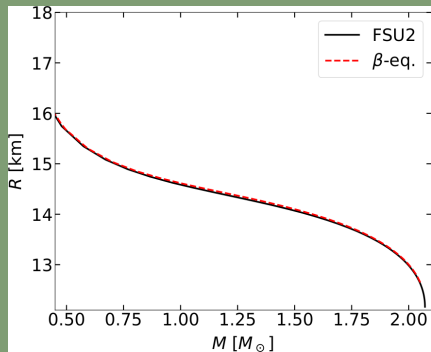
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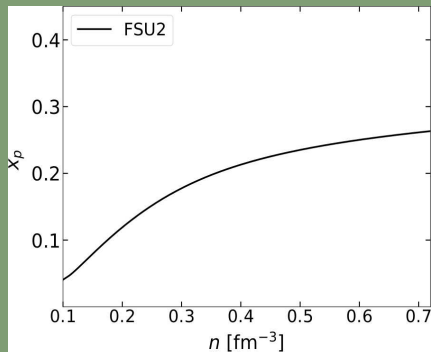
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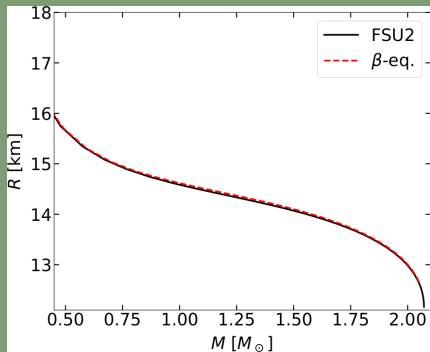
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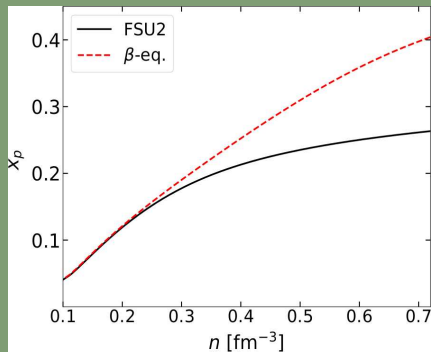
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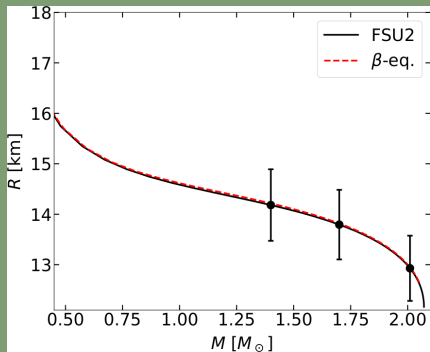
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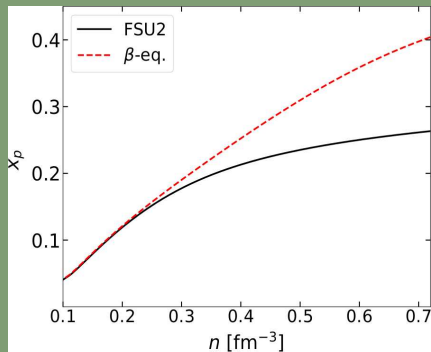
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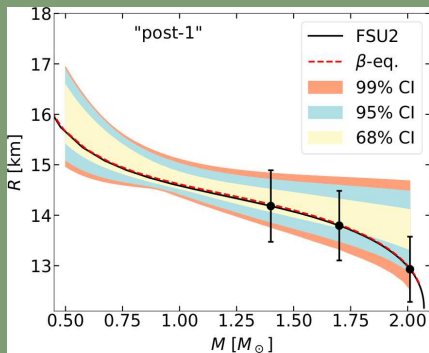
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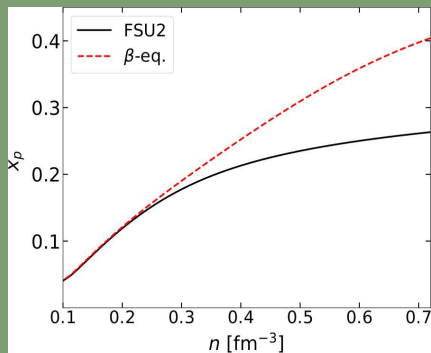
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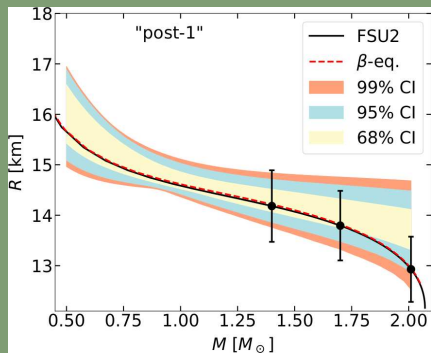
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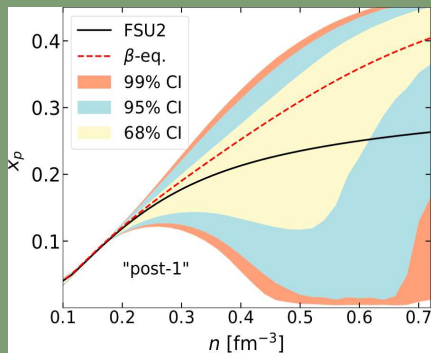
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CM & F. Gulminelli, arXiv:2111.04520

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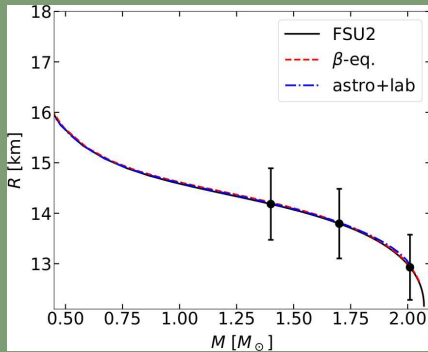
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Can high density constraint on nuclear matter from
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Problem at hand with FSU2

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

M-R relation +SNM



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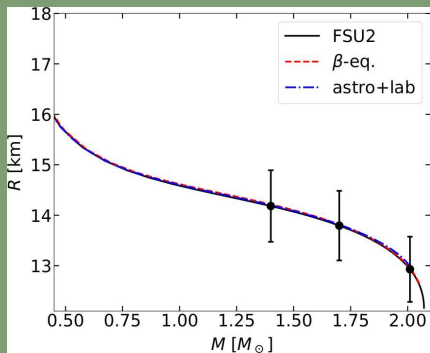
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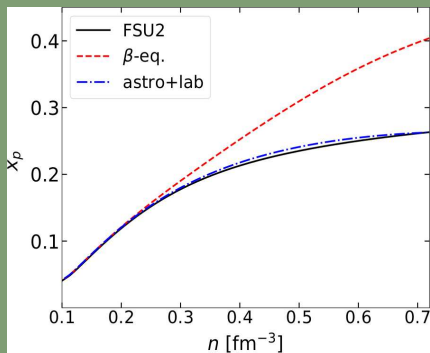
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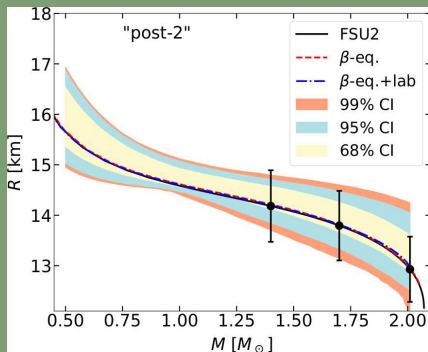
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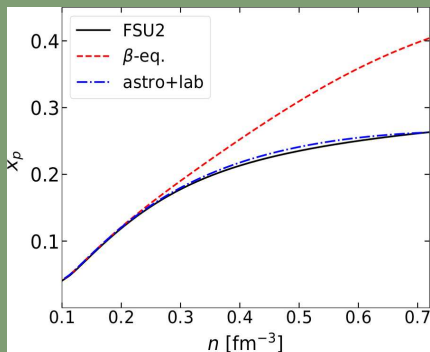
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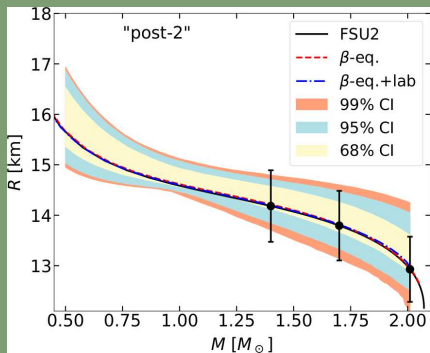
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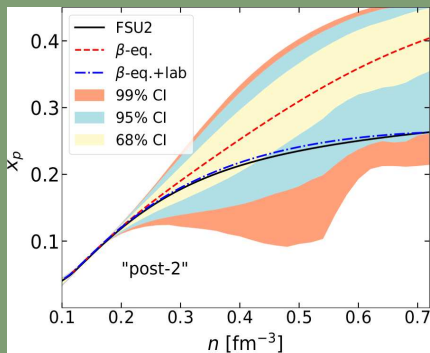
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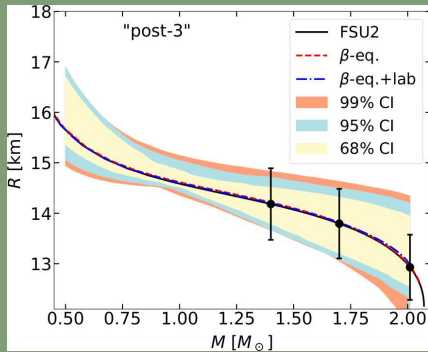
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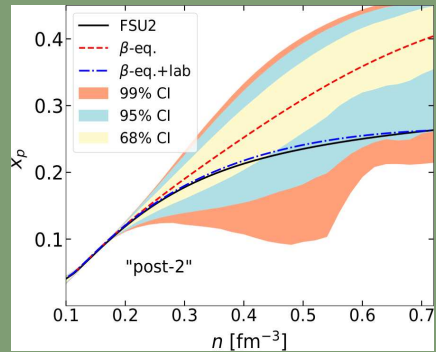
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M-R relation +SNM +Symm Ener



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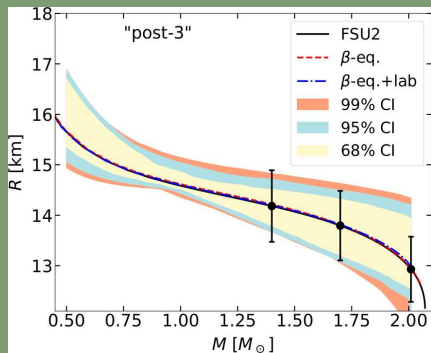
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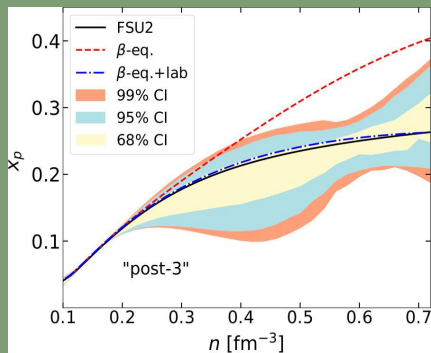
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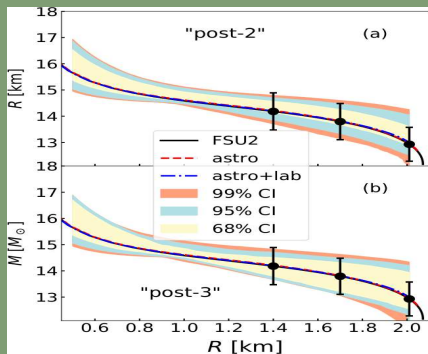
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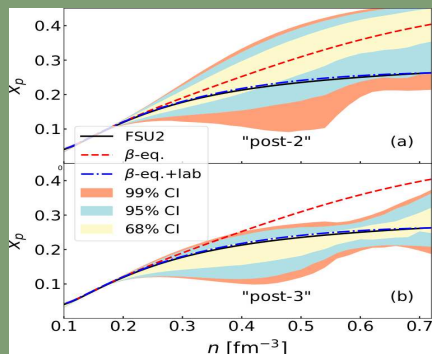
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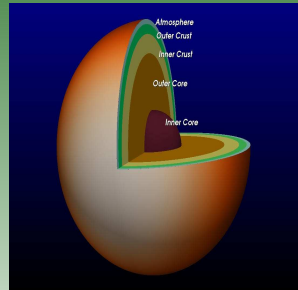
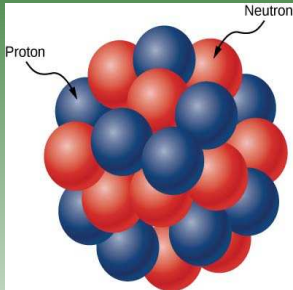


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Can high density constraint on nuclear matter from
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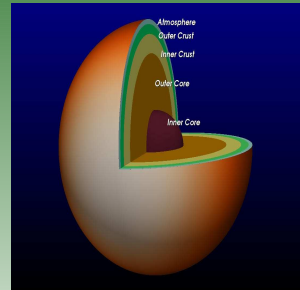
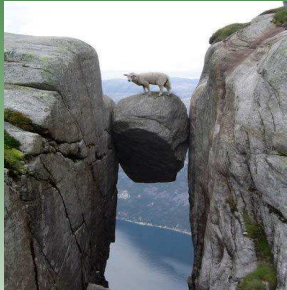
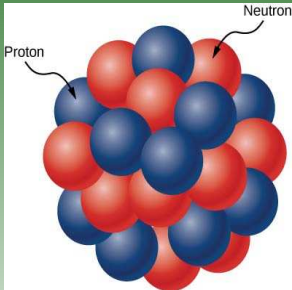
What did we learn?

Ab-initio model

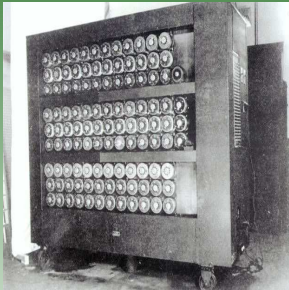


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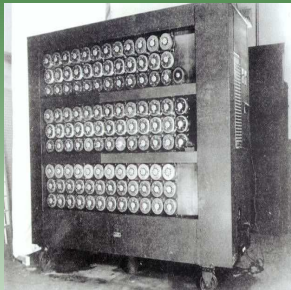
Meta-model



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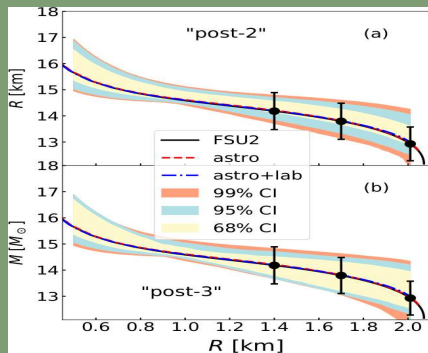
What did we learn?



Back up

Why symm energy is more sensitive?

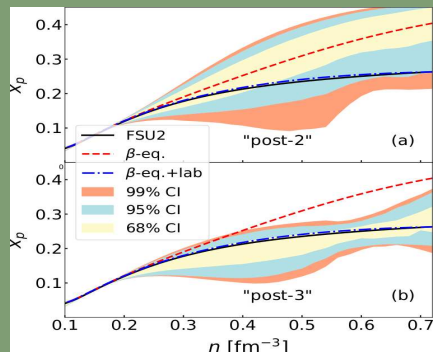
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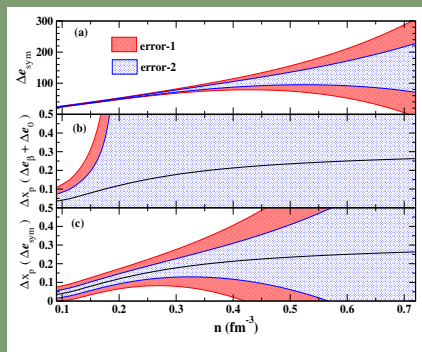
Back up

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M-R relation +SNM +Symm Ener



Analytical error



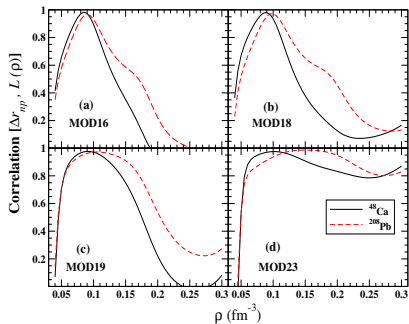
$$\Delta x_p = \frac{12x_p(\Delta e_\beta + \Delta e_0)}{\mu_e|1 - 8x_p|} = \frac{12(1 - 2x_p)^2 x_p \Delta e_{\text{sym}}}{\mu_e(4x_p + 1)}.$$

CM & F. Gulminelli, arXiv:2111.04520

Back up

What we can do from theoretical side?

Δr_{np} - L correlation

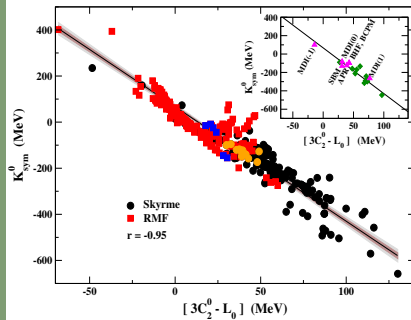


CM, arXiv:2111.05743

Back up

What we can do from theoretical side?

Decoding physical correlation(s)



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