

Effective field theories for neutron stars physics

Jose Manuel Alarcón



Universidad
de Alcalá

Introduction

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- **NS as laboratories of extreme dense matter**

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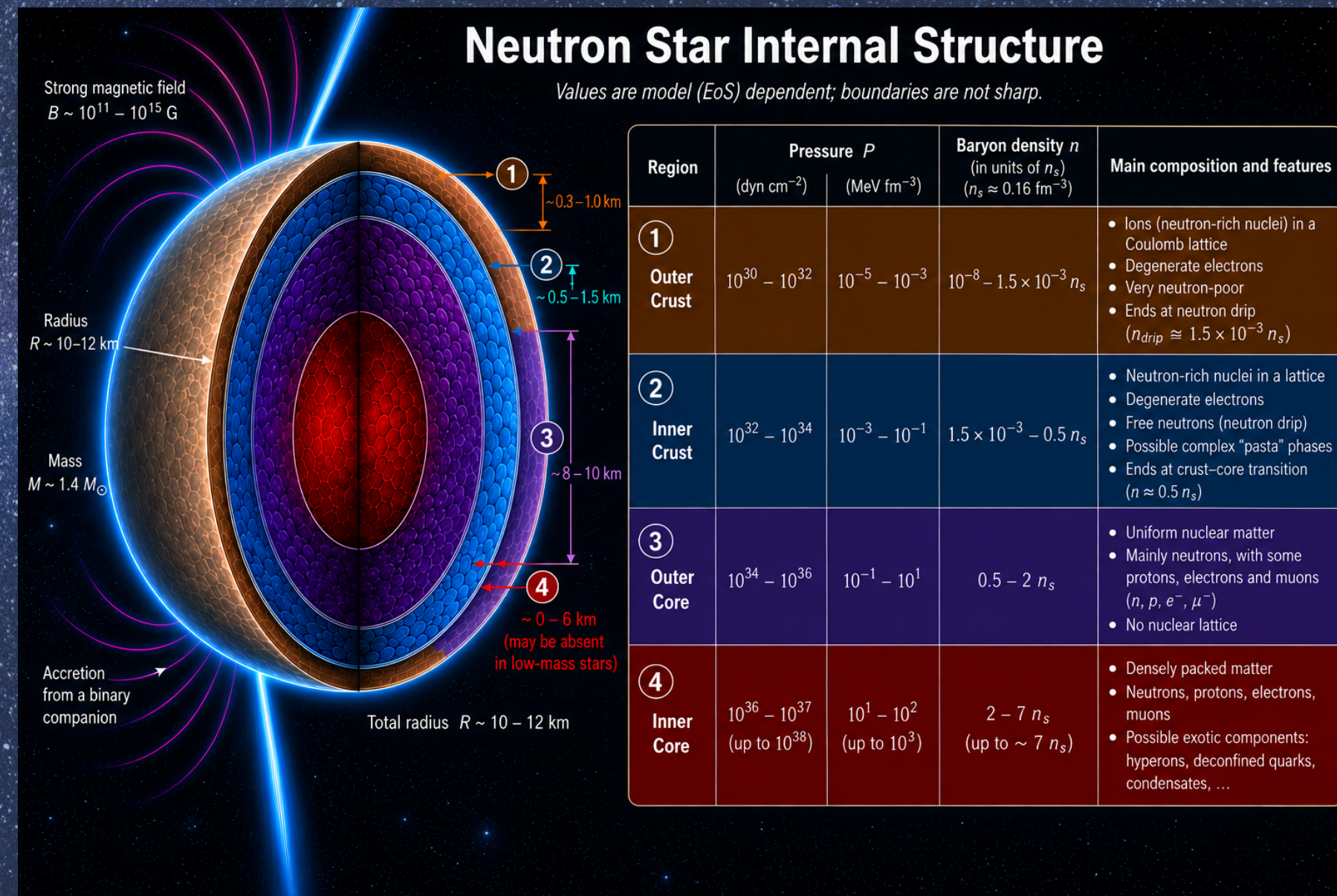
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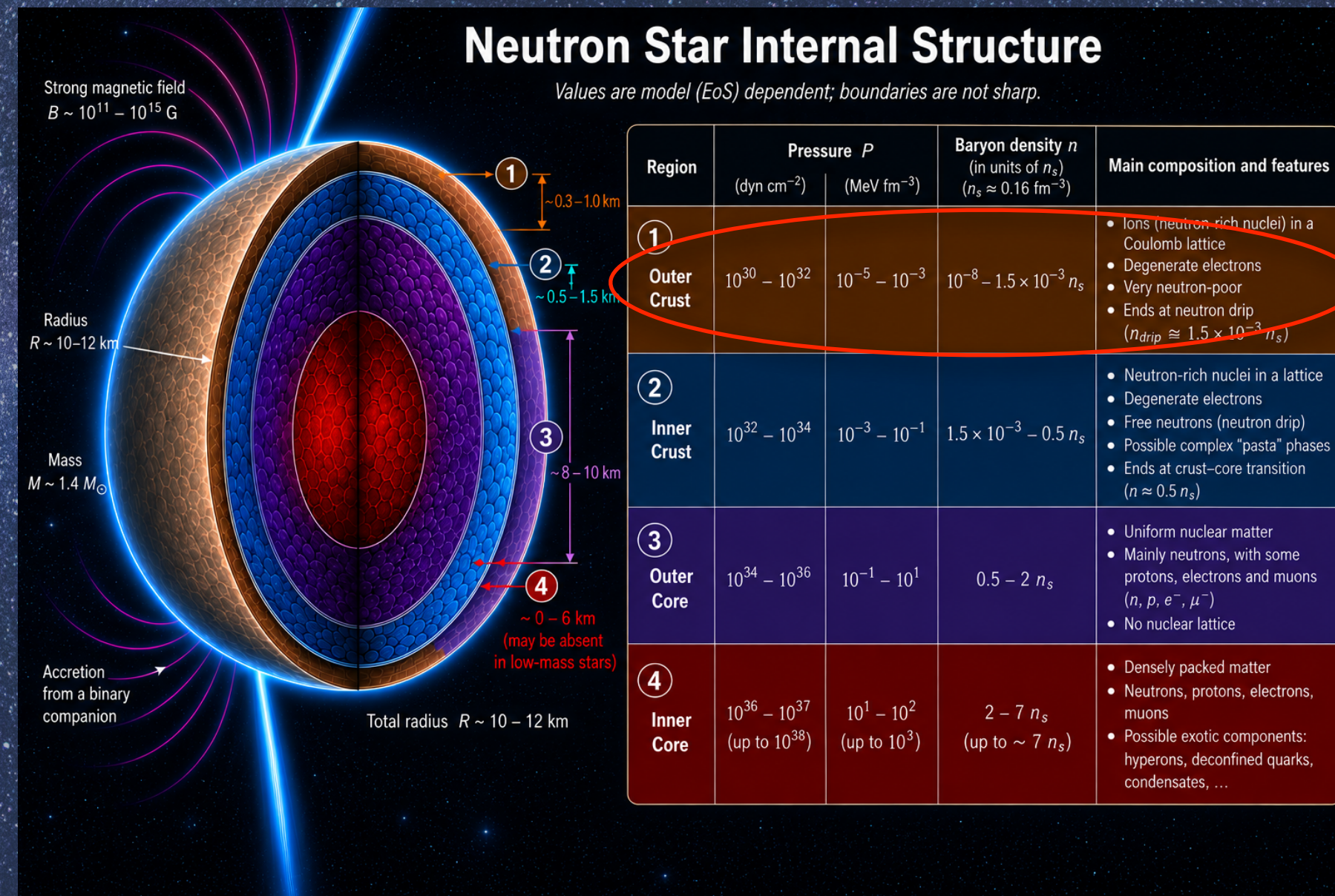
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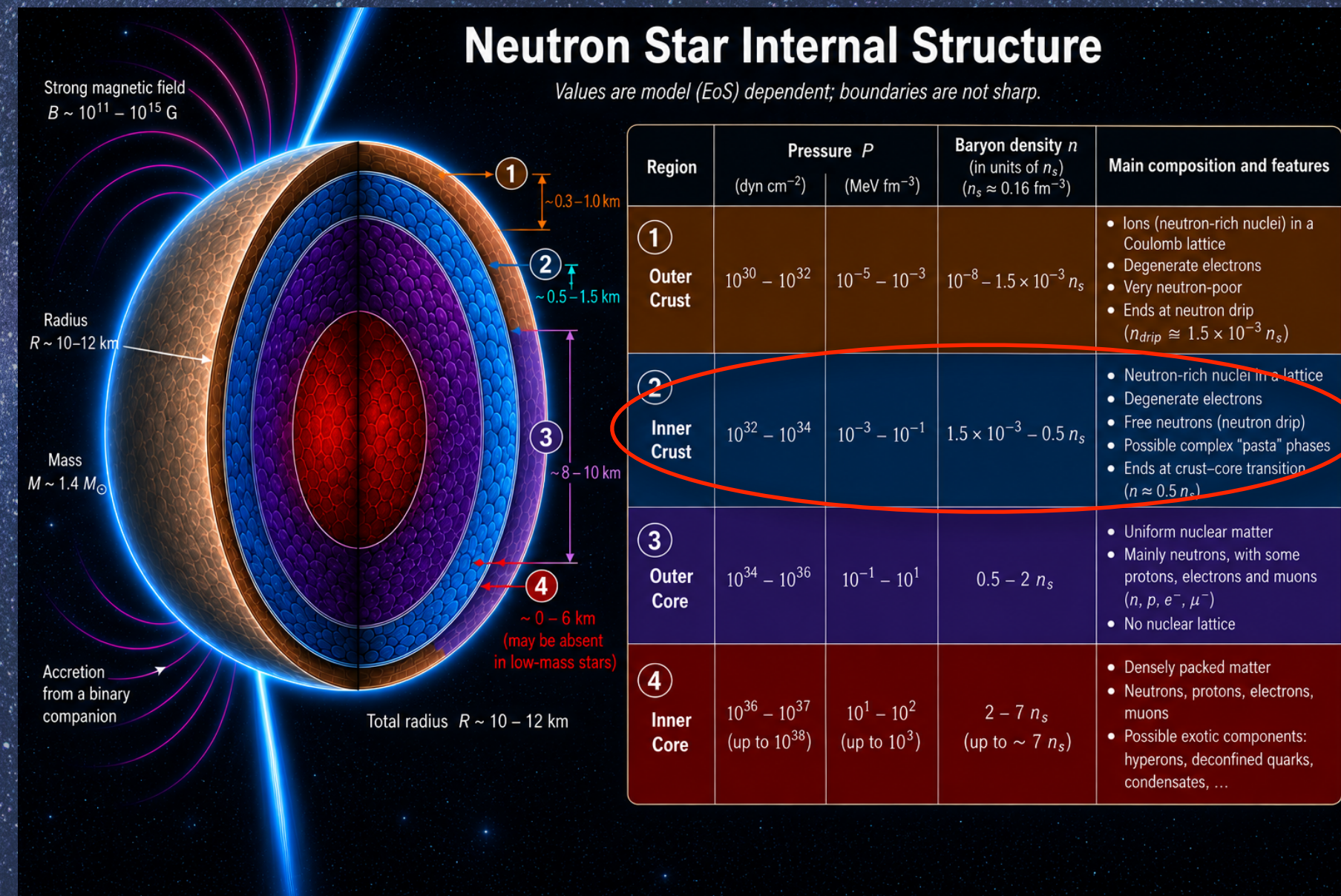
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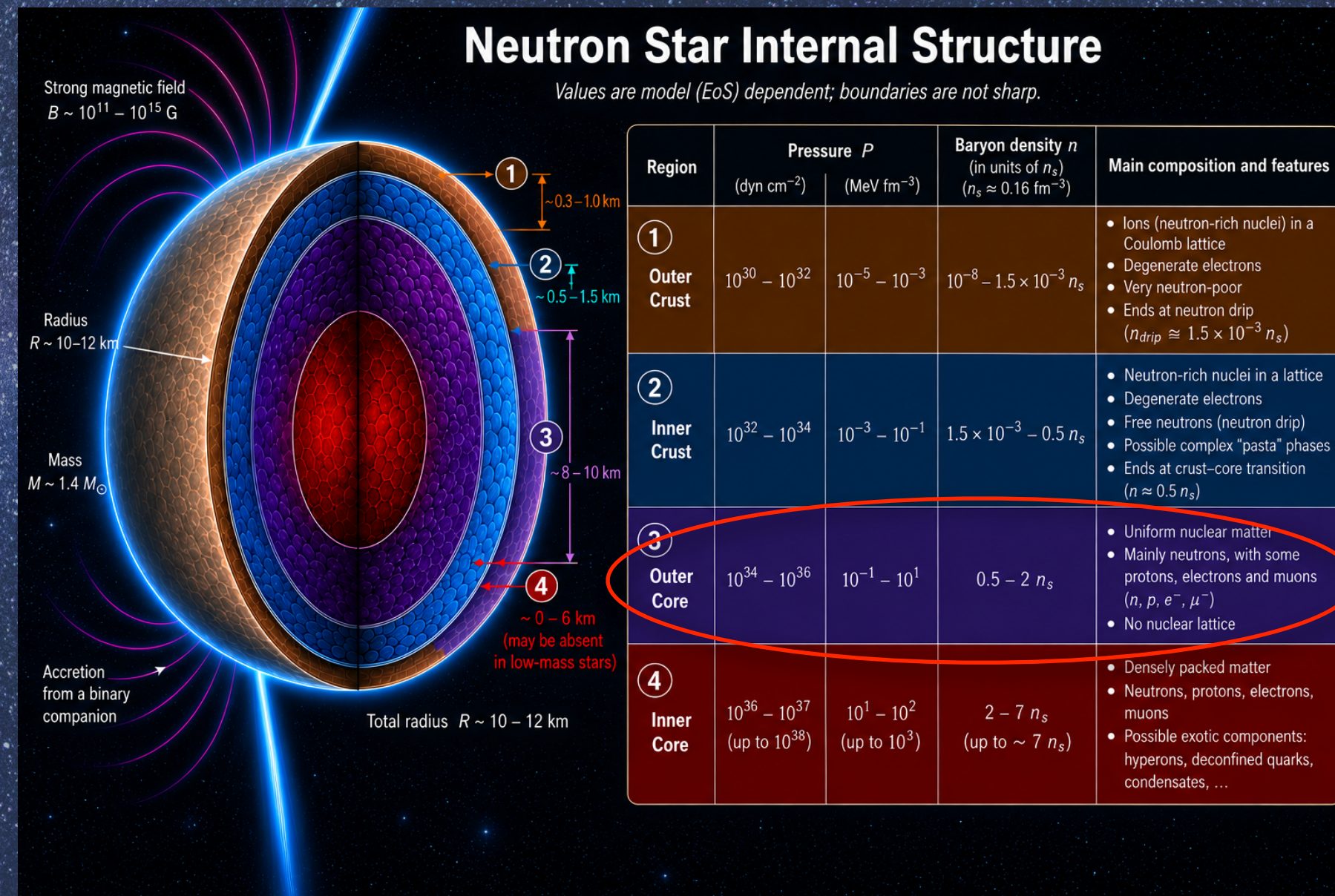
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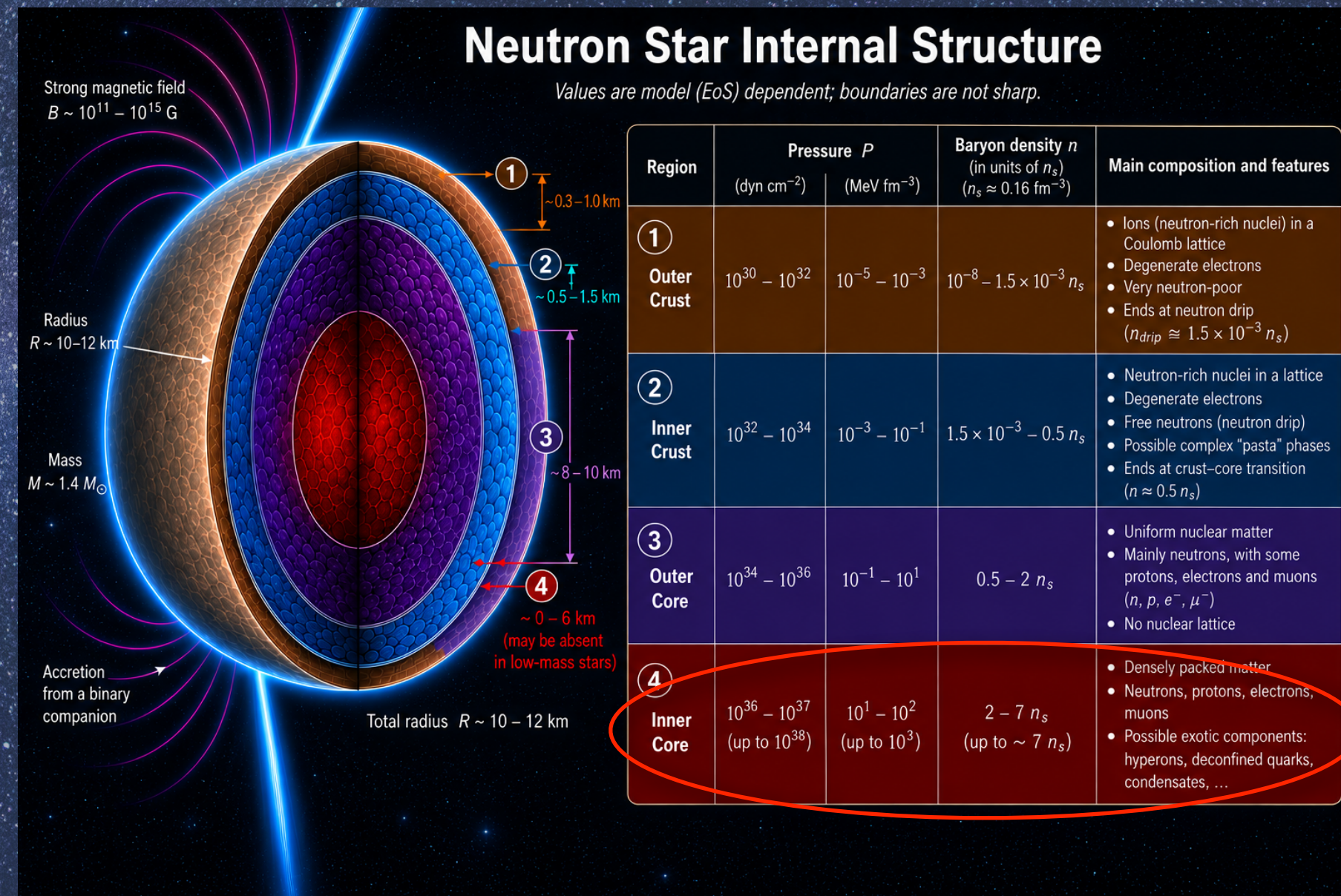
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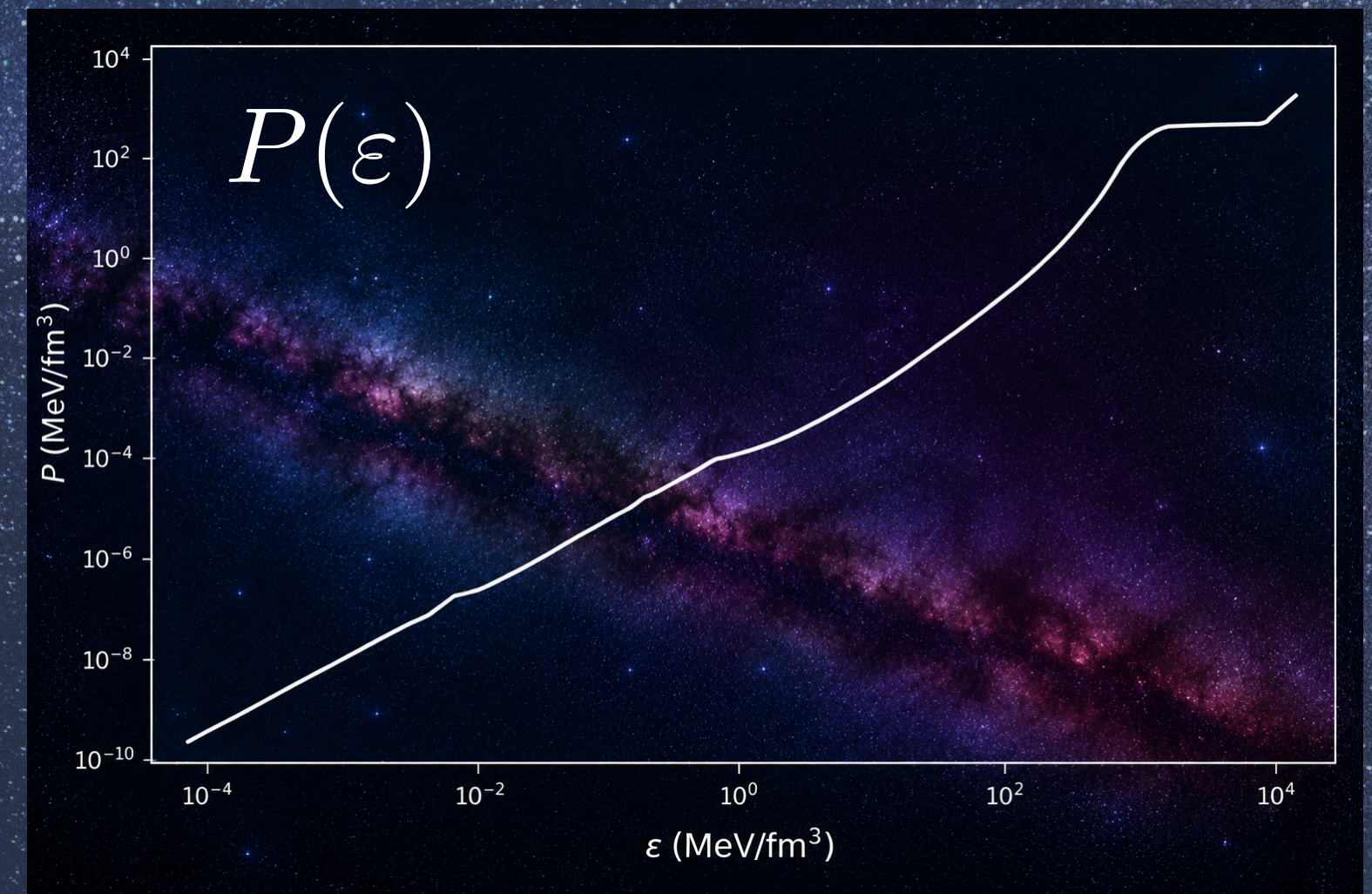
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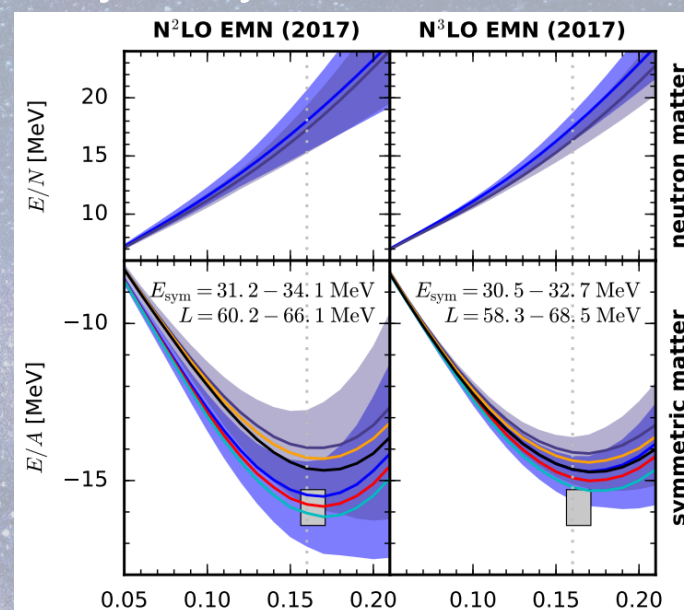
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Many-Body Methods

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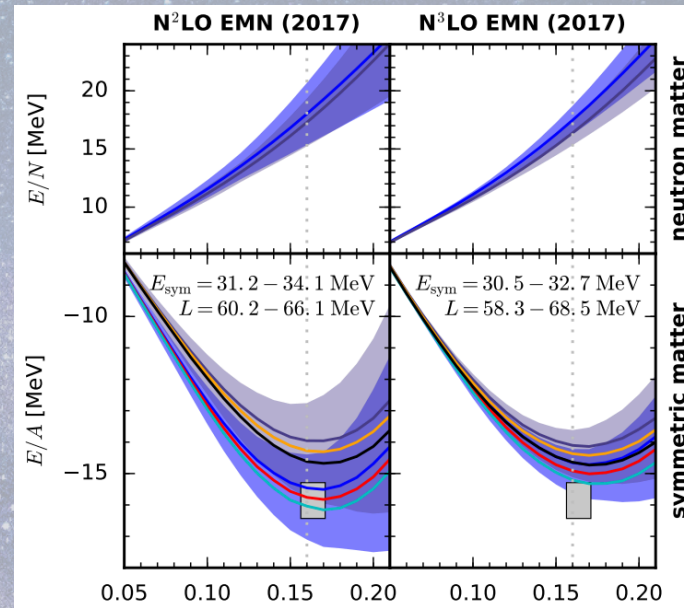
Many-Body Perturbation Theory



[C. Drischler, et al. PRL 122 (2019)]

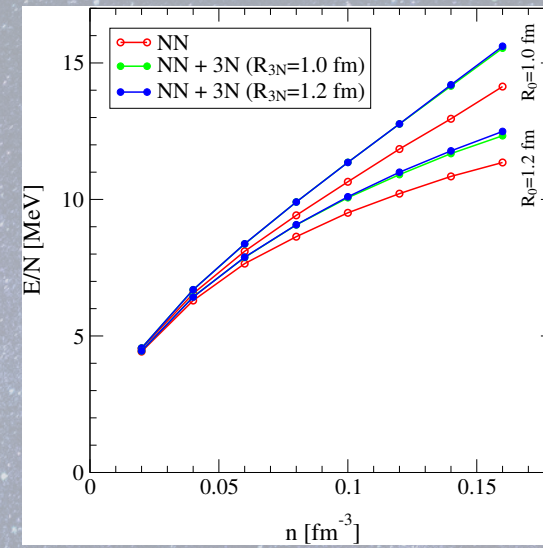
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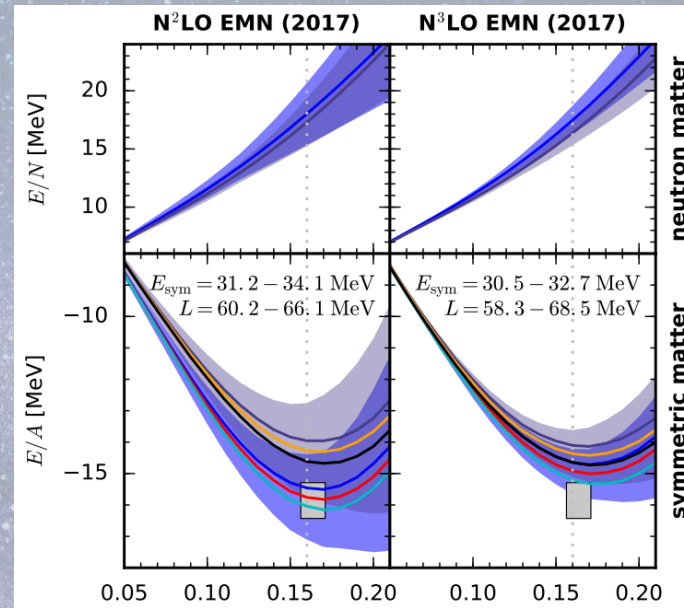
Quantum Monte Carlo



[J. Tews, et al. PRC 93 (2016)]

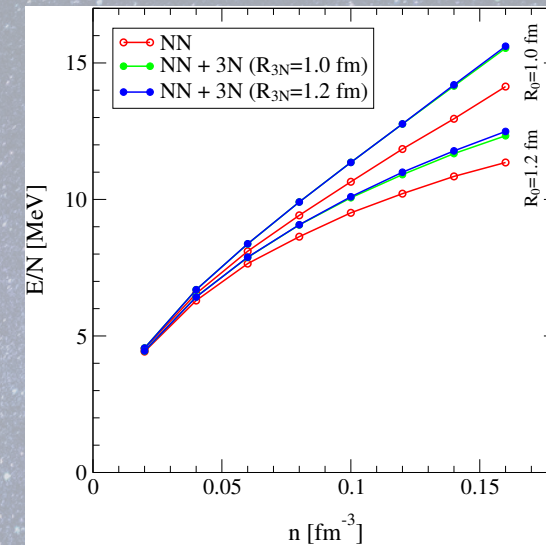
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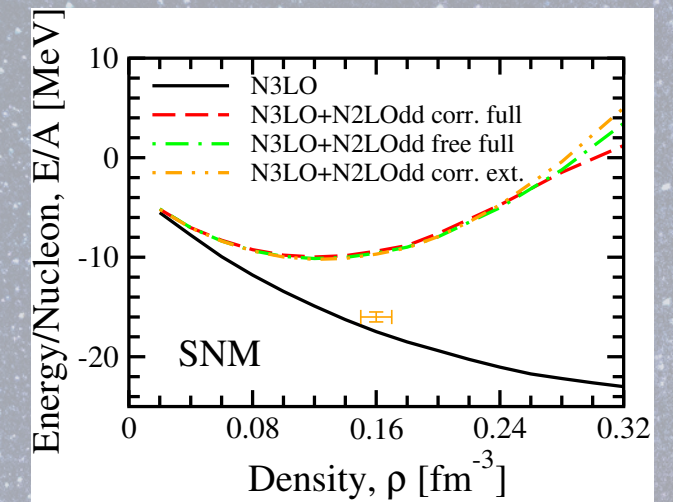
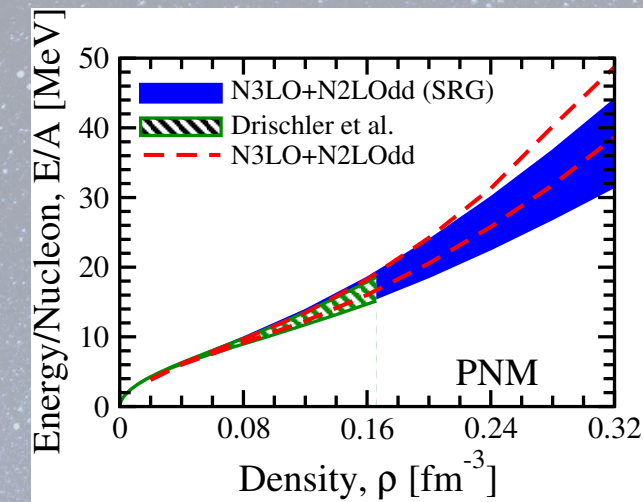
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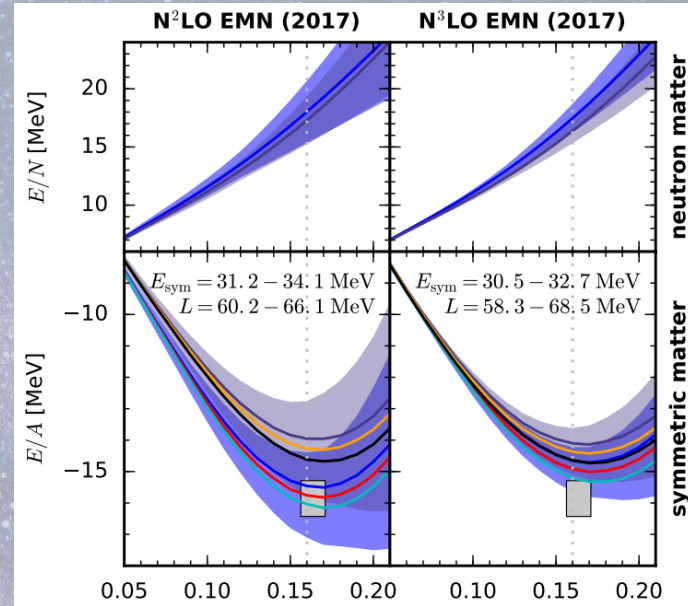
Self Consistent Green Function Method



[A. Carbone, et al. PRC 90 (2014)]

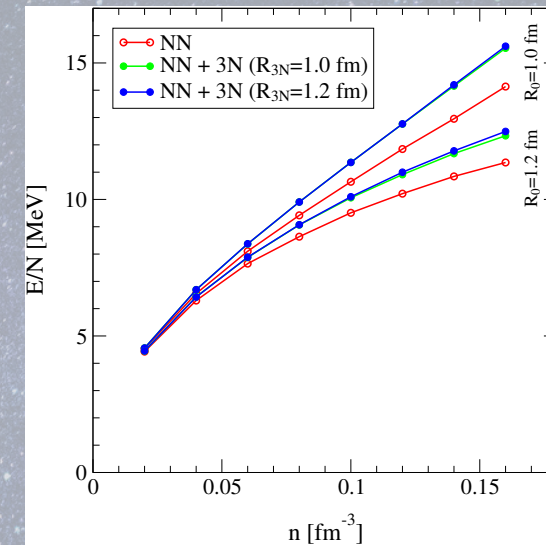
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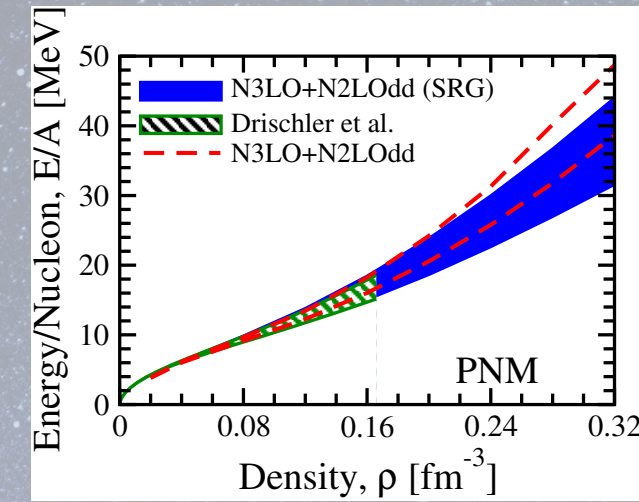
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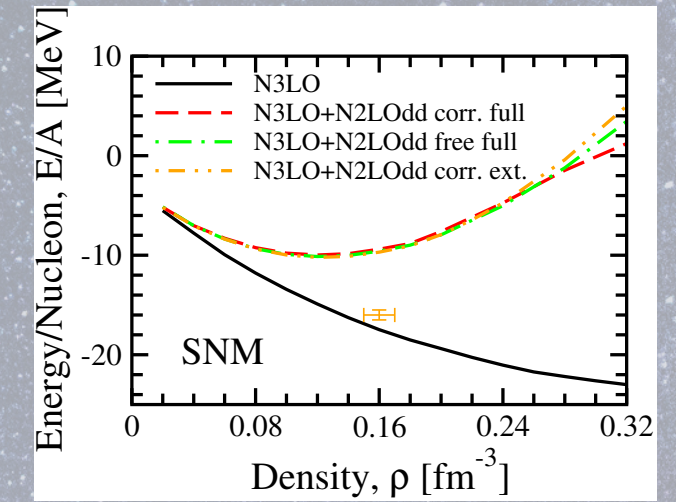


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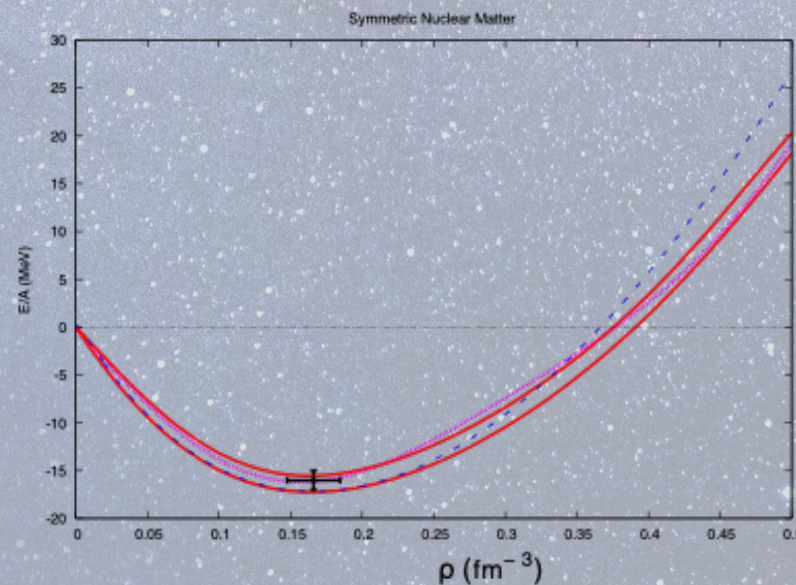
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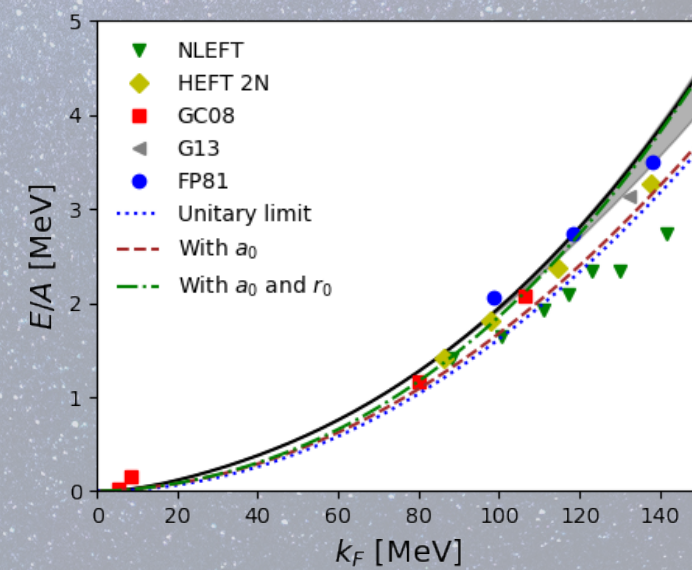
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In-medium Chiral Effective Field Theory



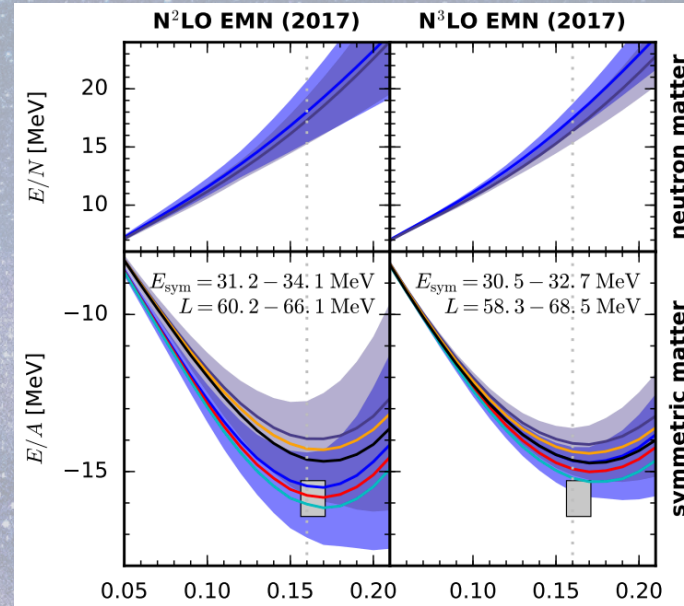
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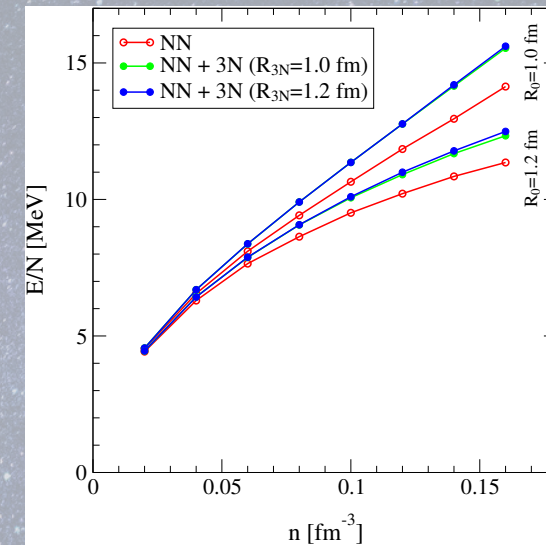
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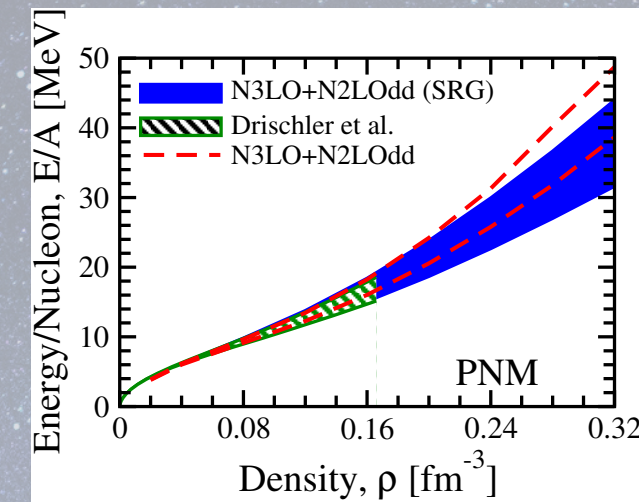
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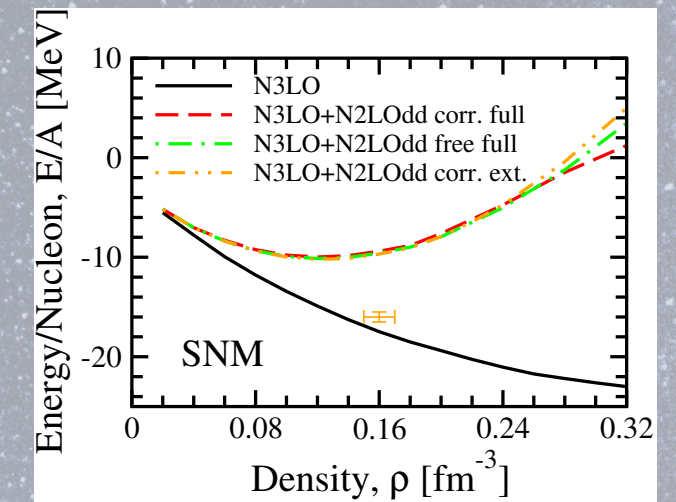


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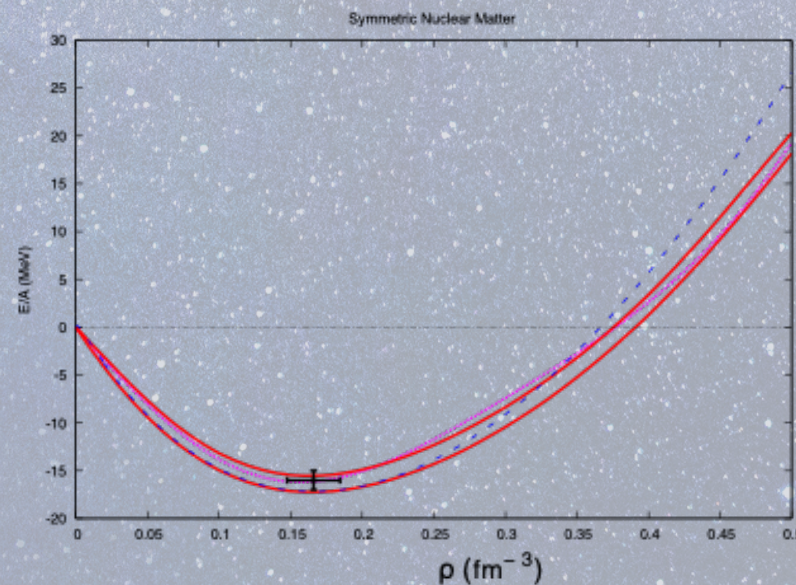
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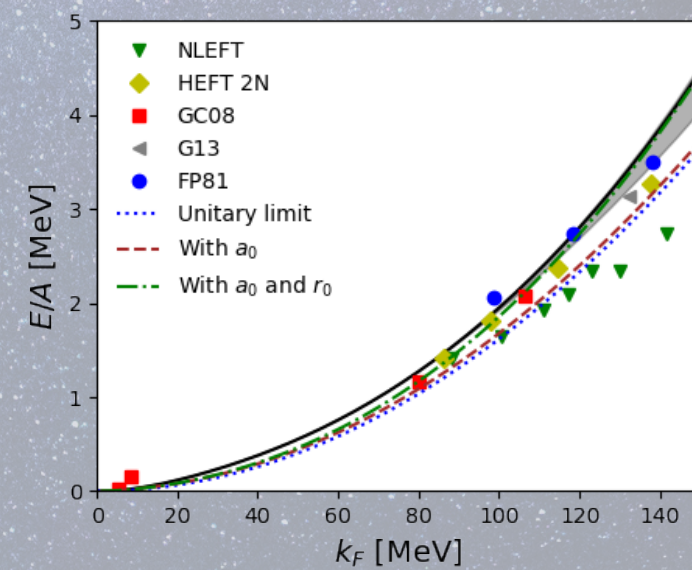
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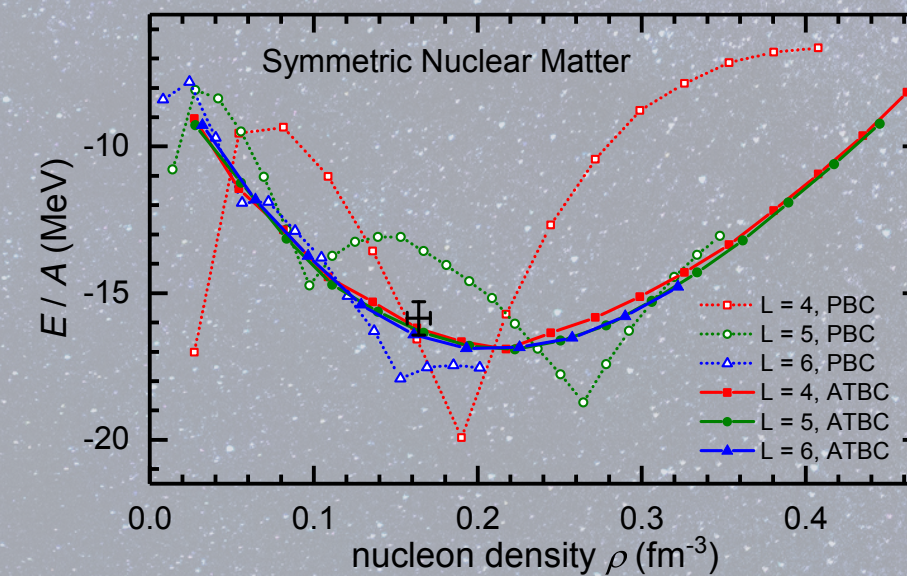


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Nuclear Lattice Effective Field Theory



[B. N. Lu, et al. PRL 125 (2020)]

Observables

The background of the slide is a high-resolution photograph of a starry night sky. A prominent horizontal band of the Milky Way galaxy stretches across the middle of the image, showing a dense concentration of stars and interstellar dust. The upper and lower portions of the image are filled with a field of stars of varying brightness against a dark, deep blue-black background.

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$$\frac{dP}{dr} = -\frac{G_N}{r^2} \frac{(\varepsilon(r) + P(r))(M(r) + 4\pi r^3 P(r))}{1 - \frac{2G_N M(r)}{r}}$$
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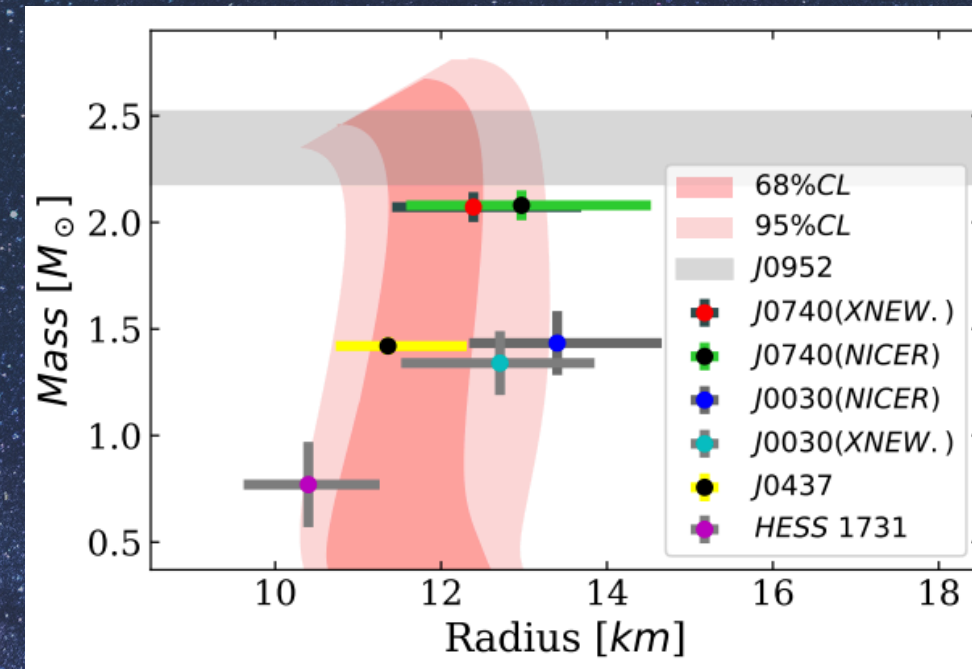
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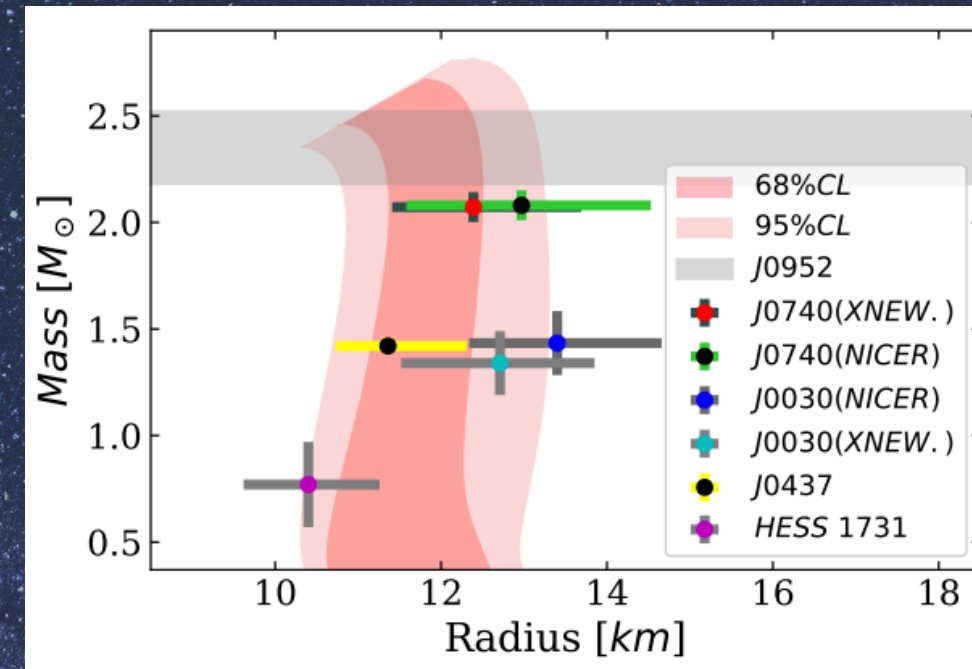


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- Tidal deformability

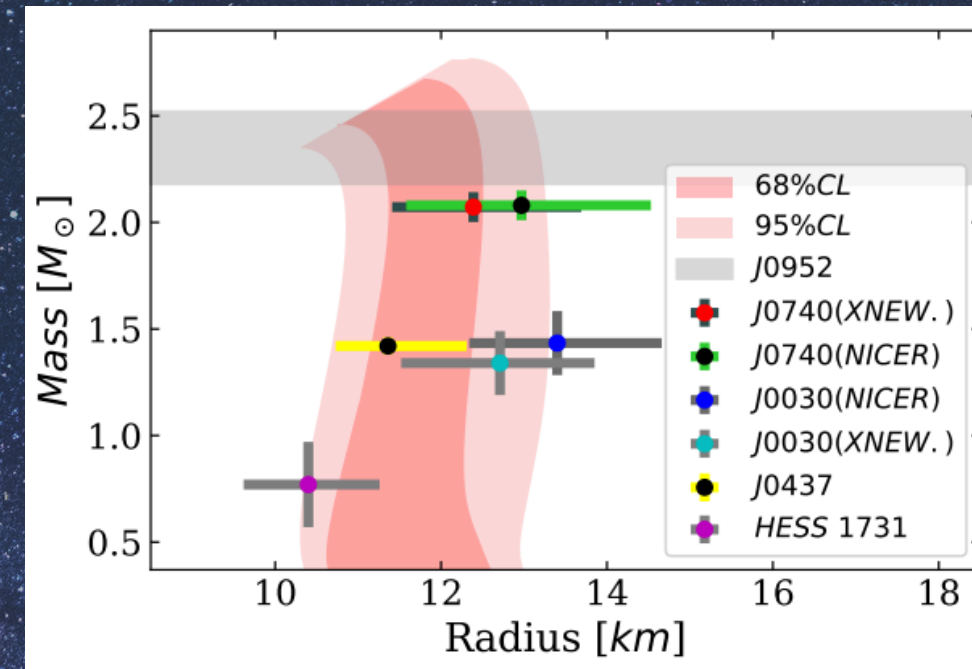


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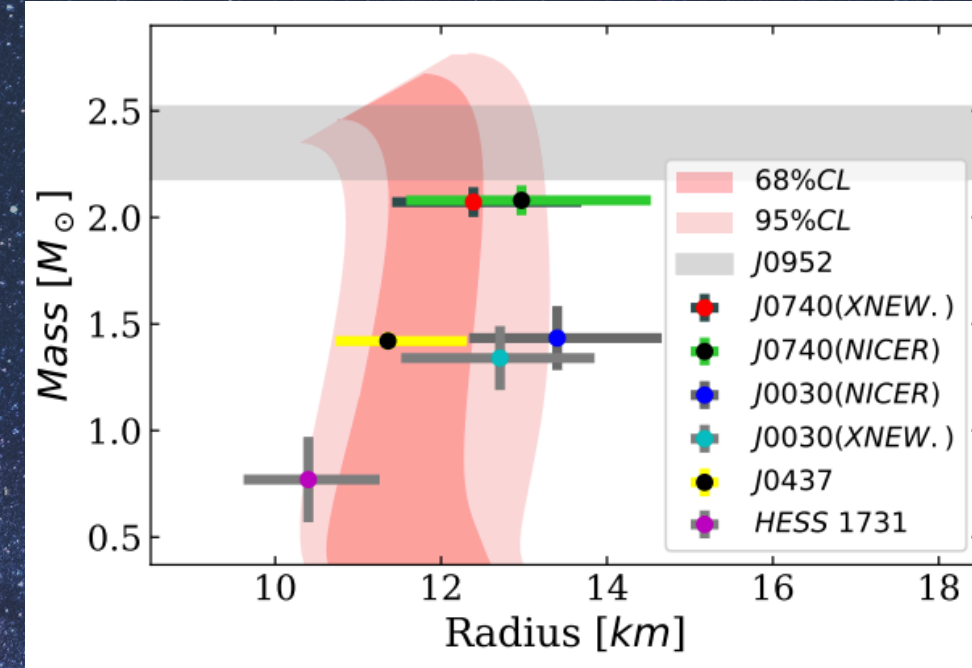
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$$F(r) = \frac{r - 4\pi r^3 (\varepsilon + P)}{r - 2M} \quad Q(r) = \frac{4\pi r}{r - 2M} \times \left[5\varepsilon + 9P + \frac{\varepsilon + P}{c_s^2} - \frac{6}{4\pi r^2} \right] - 4 \left[\frac{M + 4\pi r^3 P}{r^2 - \left(1 - \frac{2M}{r}\right)} \right]^2$$

$$k_2 = \frac{8C^5}{5} (1 - 2C)^2 [2 + 2C(y_R - 1) - y_R [2C(6 - 3y_R + 3C(5y_R - 8))]]$$

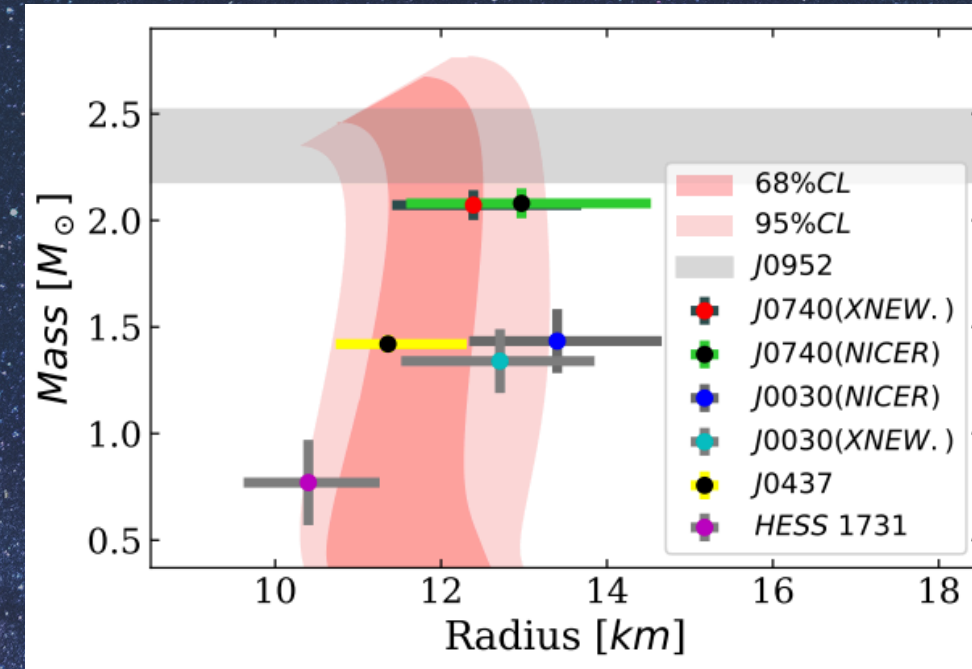
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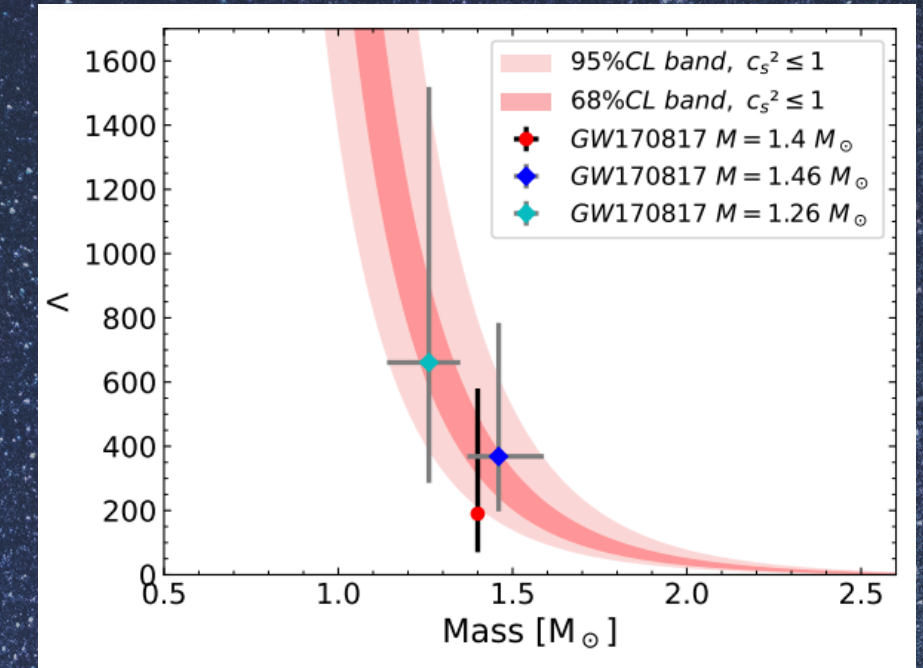
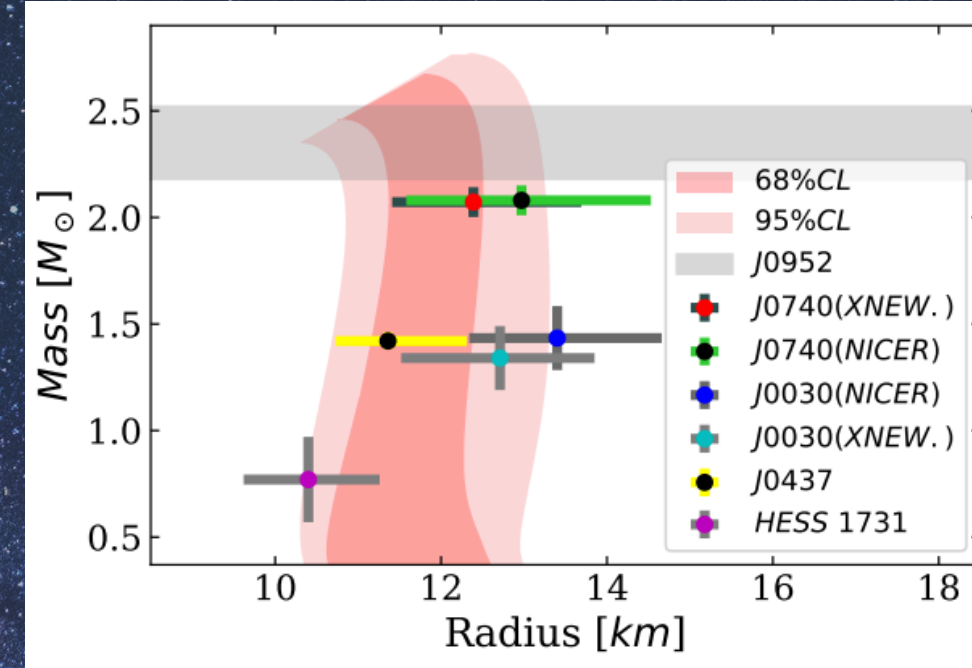
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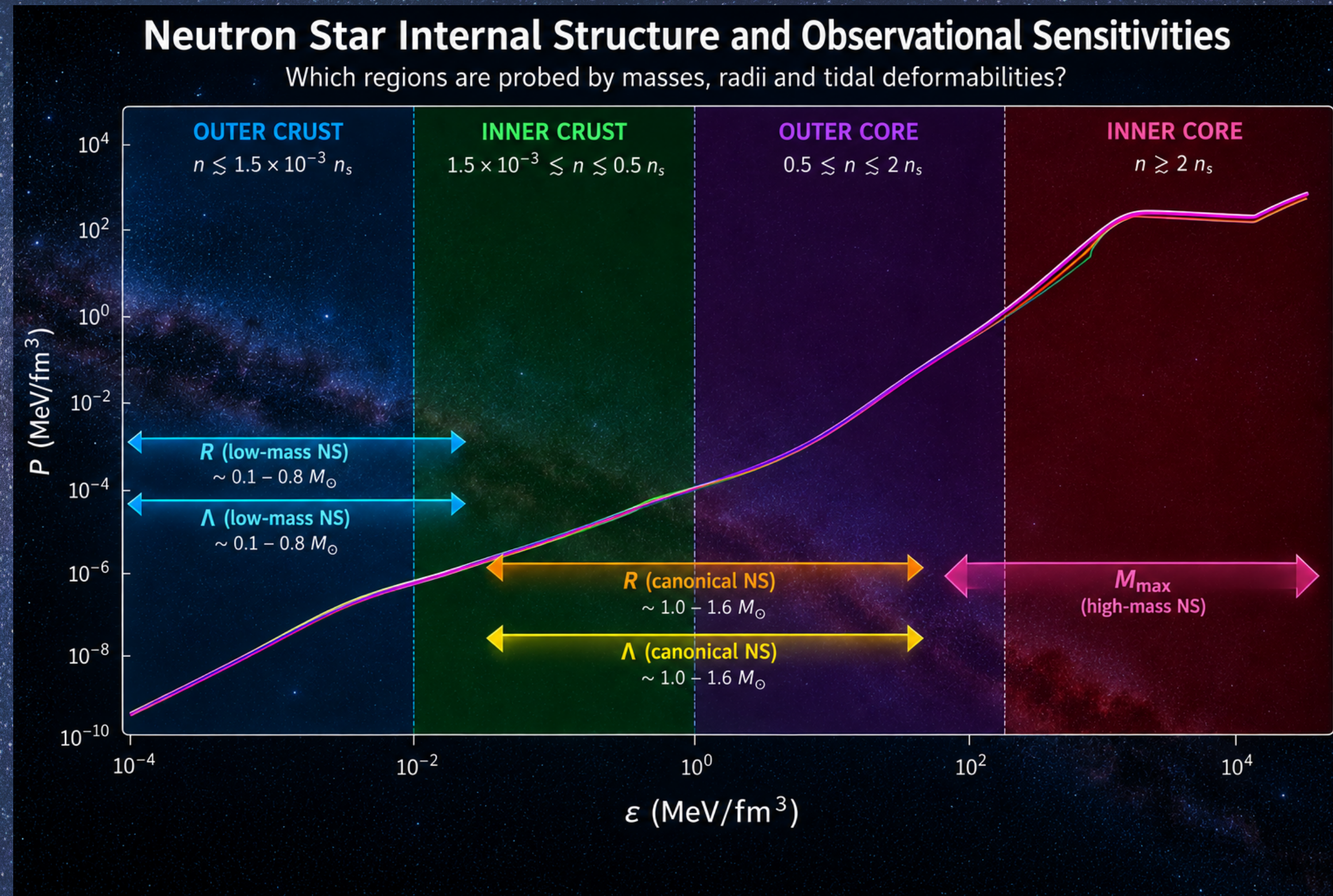
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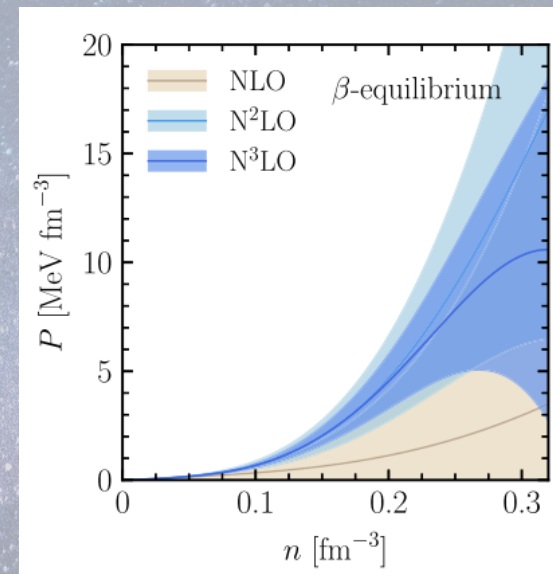
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Results from the EFT analysis

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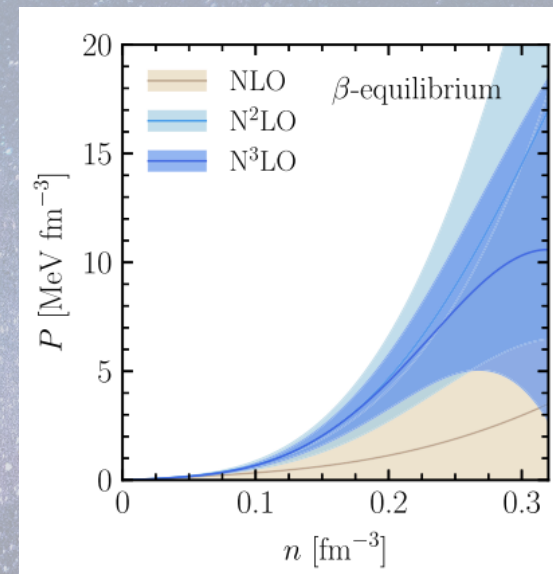
Many-Body Perturbation Theory



[Gottlieb et al., PRC 113, 055804 (2026)]

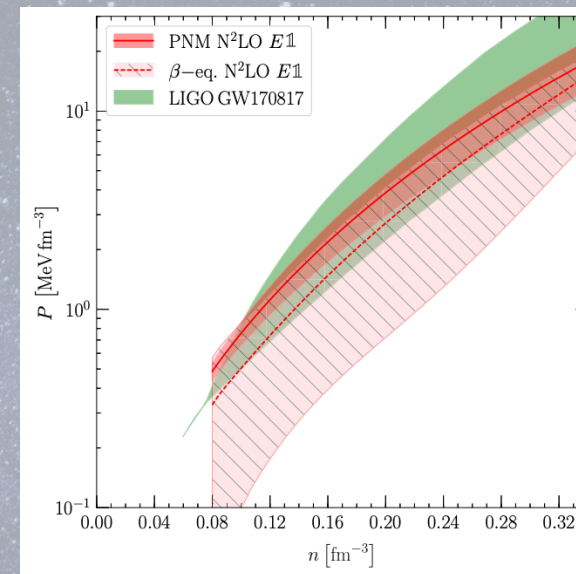
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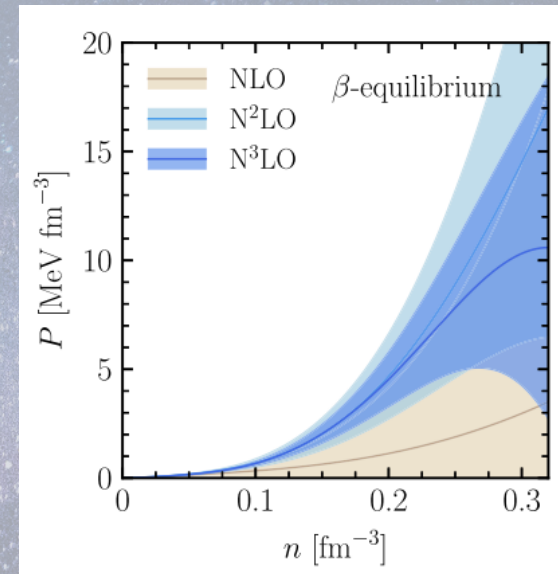
Quantum Monte Carlo



[Lonardoni et al., PRR 2, 022033(R) (2020)]

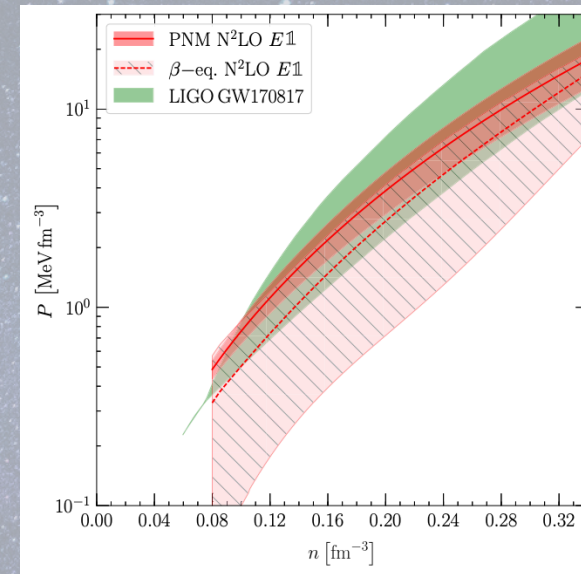
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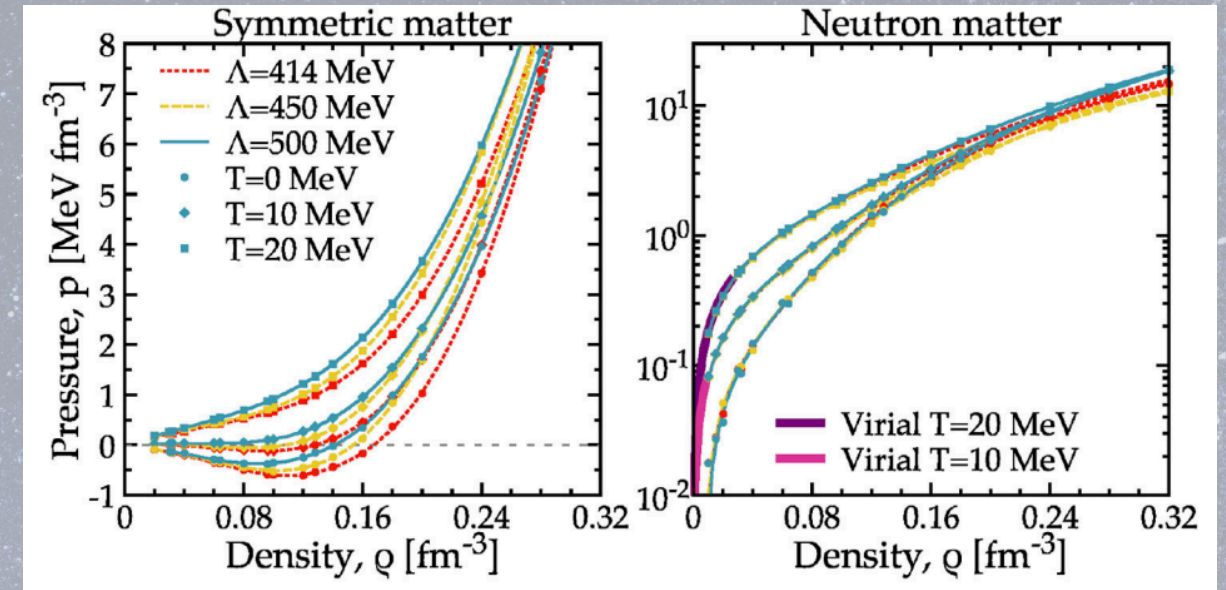
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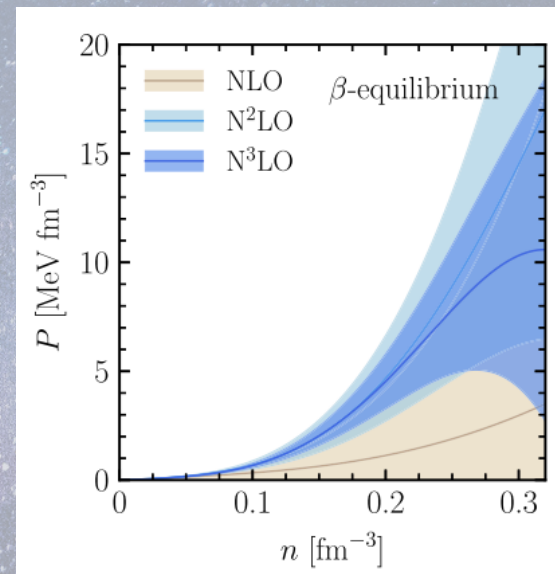
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[A. Rios, Frontiers in Physics 8, 387 (2020).]

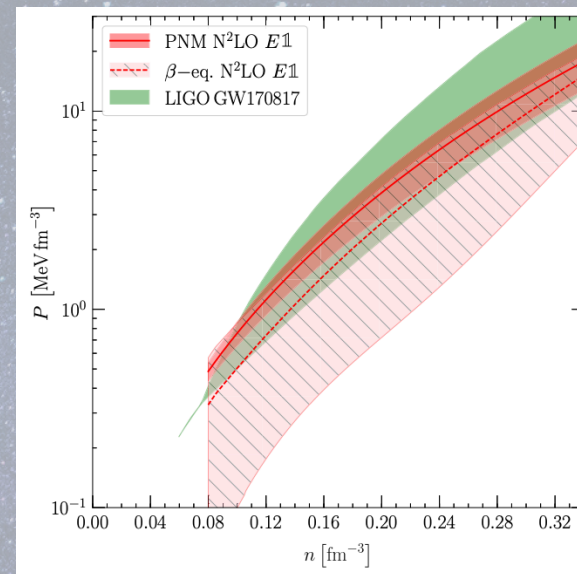
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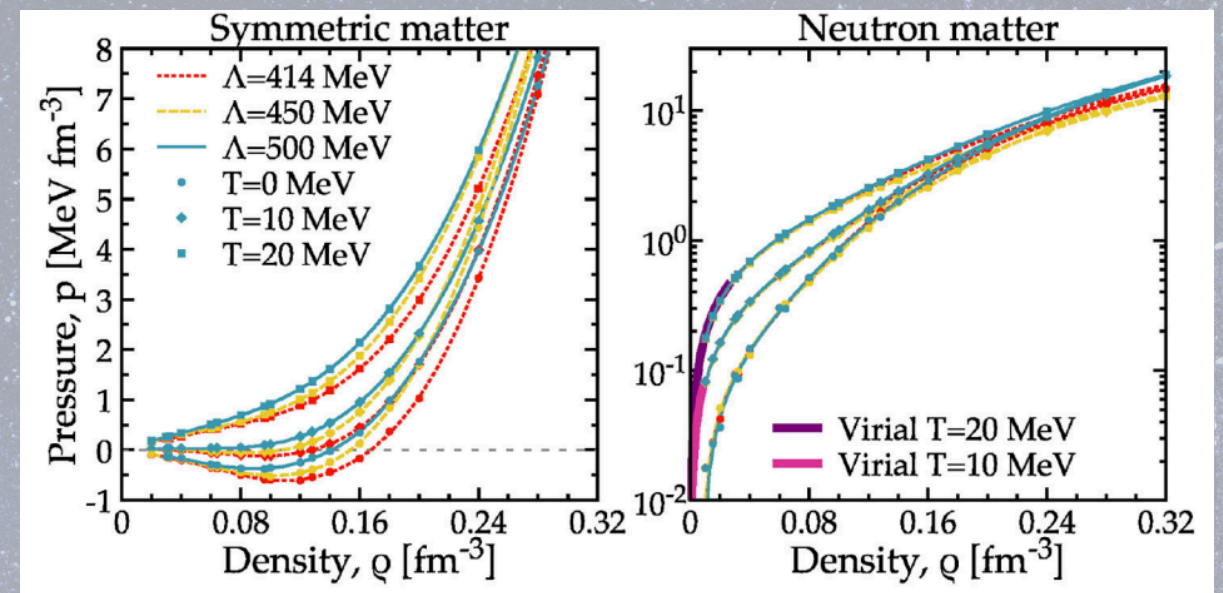
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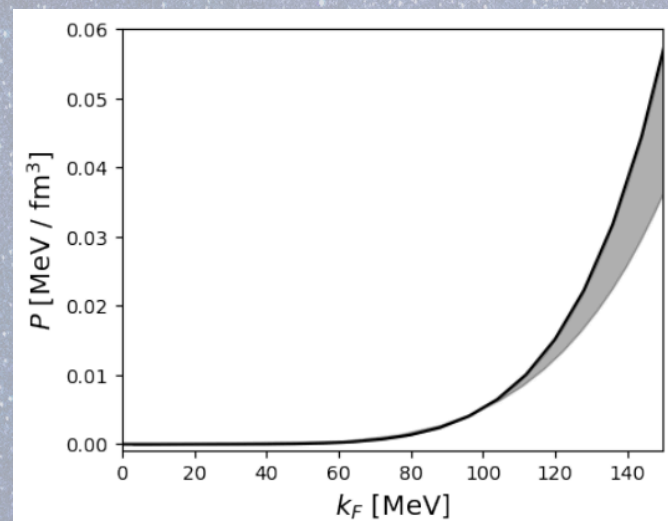
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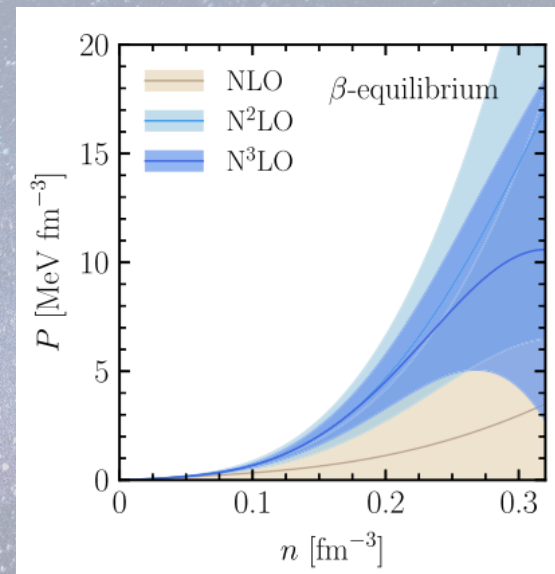
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[J. M. Alarcón and J. A. Oller PRC 107 (2023)]

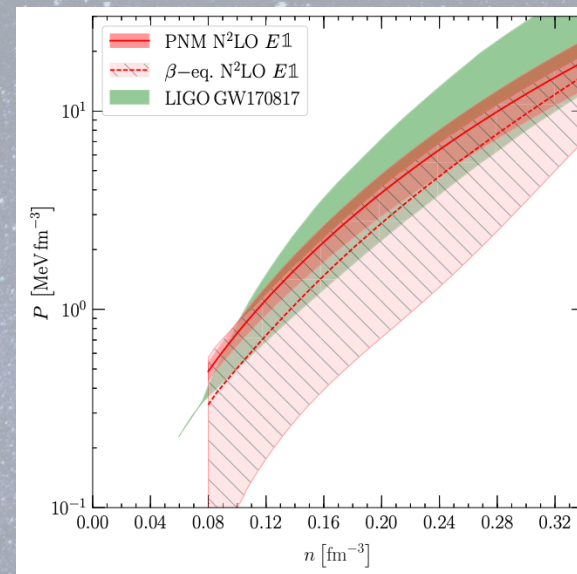
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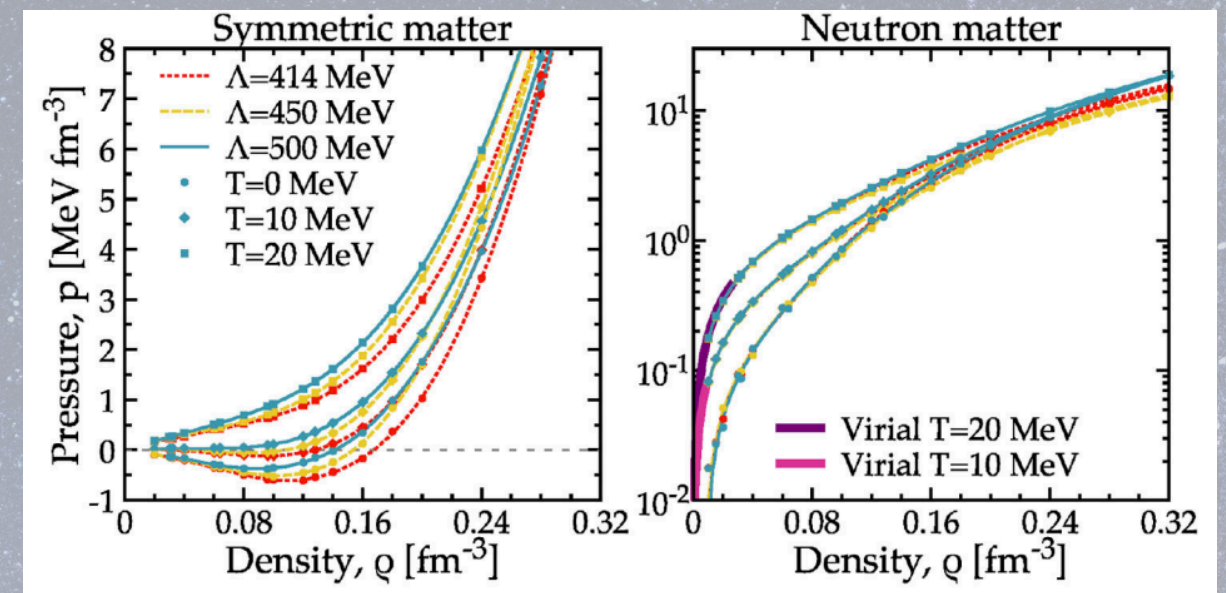
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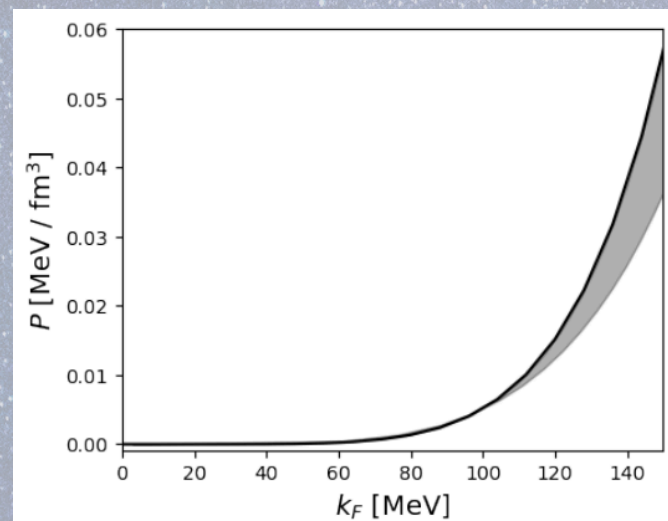
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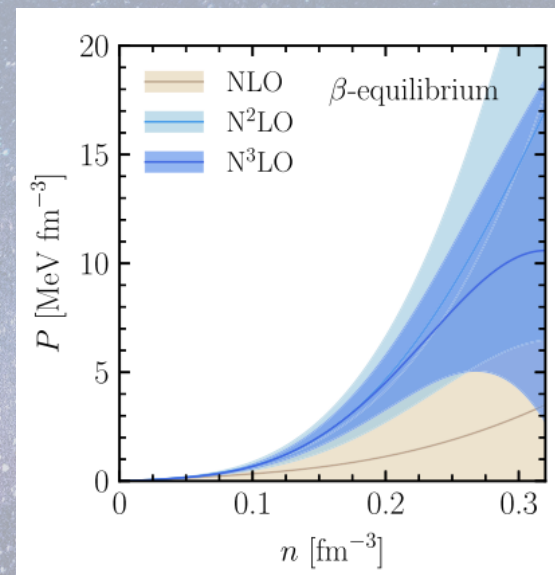


[J. M. Alarcón and J. A. Oller PRC 107 (2023)]

- Ab-initio results for the EoS of PNM or NM in β -equilibrium.

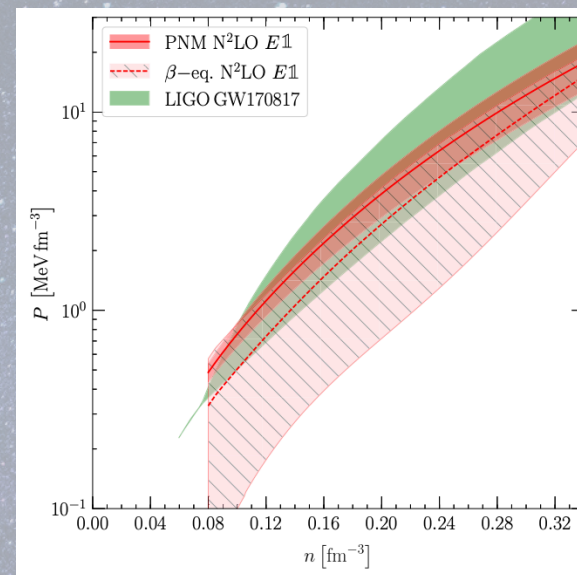
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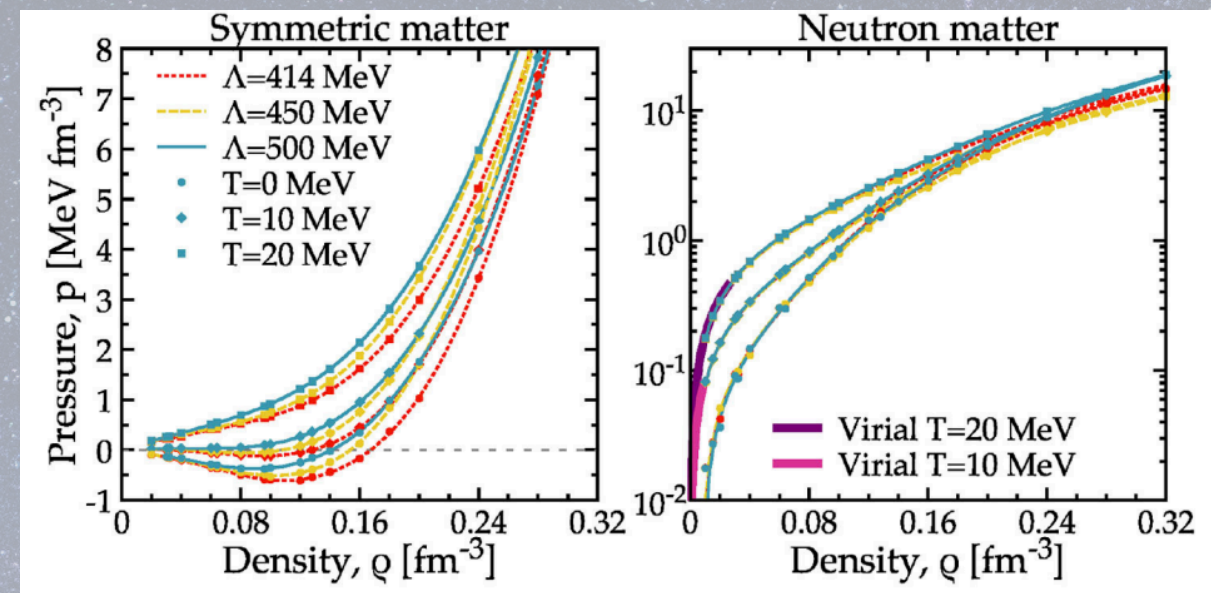
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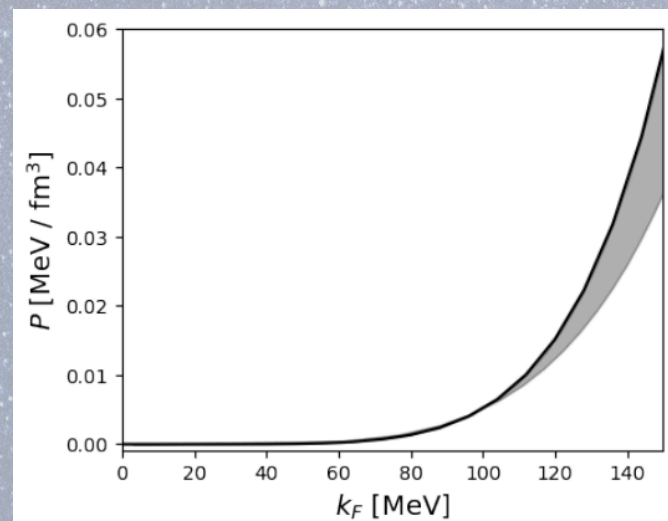
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[A. Rios, Frontiers in Physics 8, 387 (2020)]

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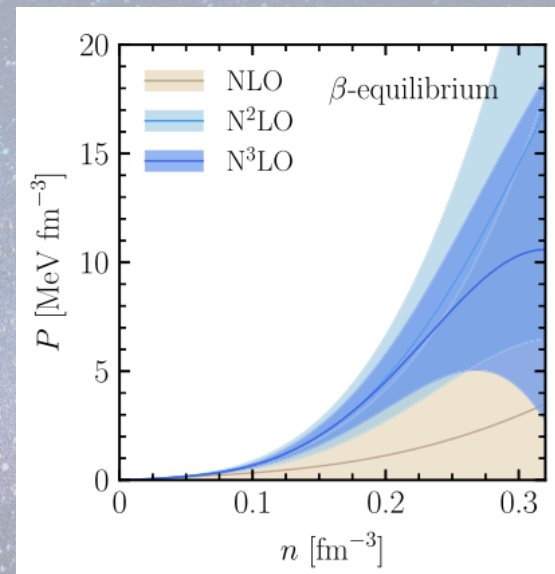


[J. M. Alarcón and J. A. Oller PRC 107 (2023)]

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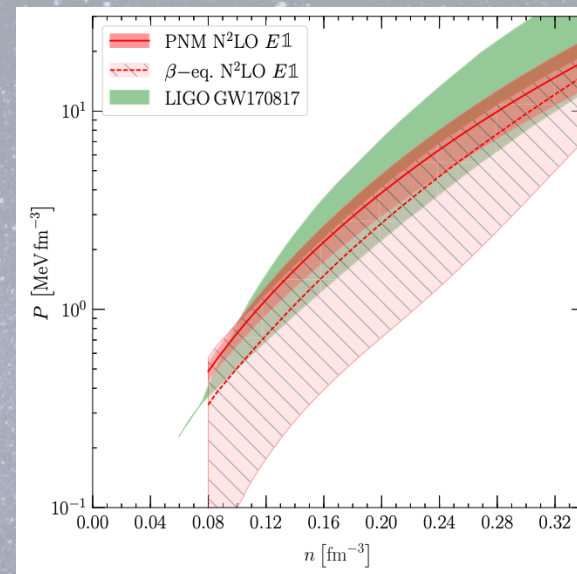
Results from the EFT analysis

Many-Body Perturbation Theory



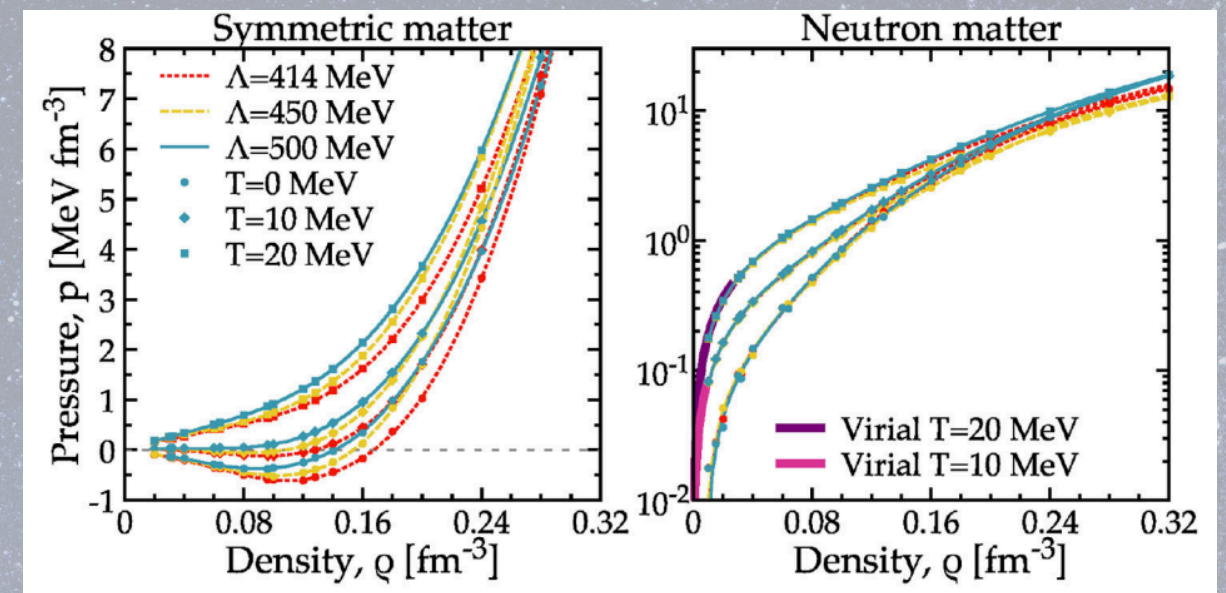
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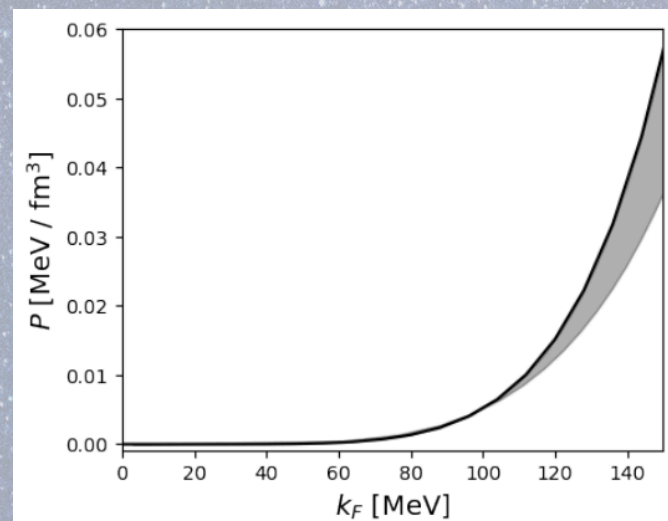
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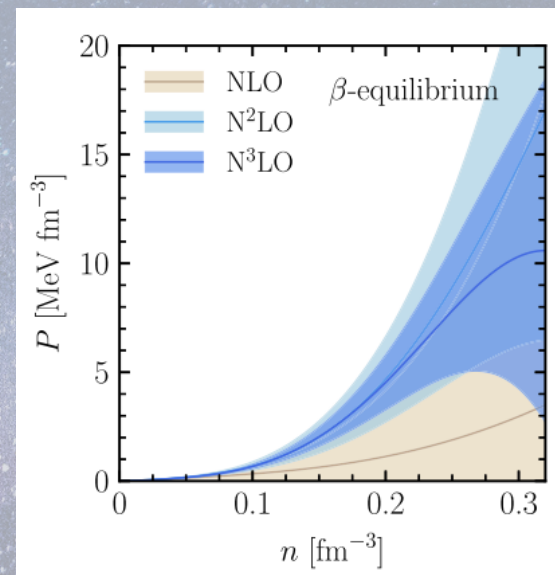


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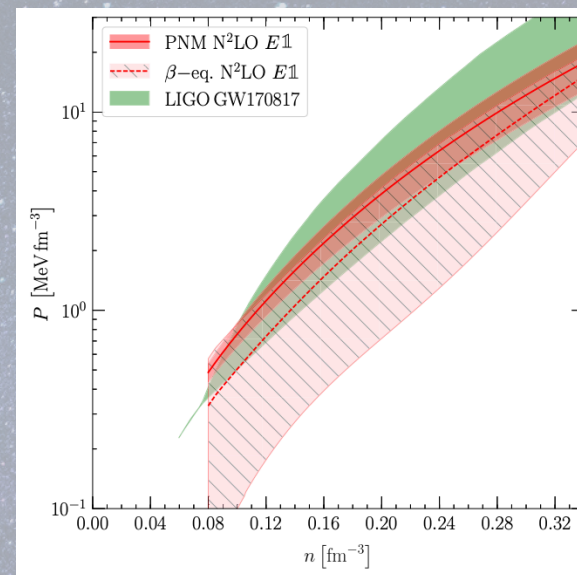
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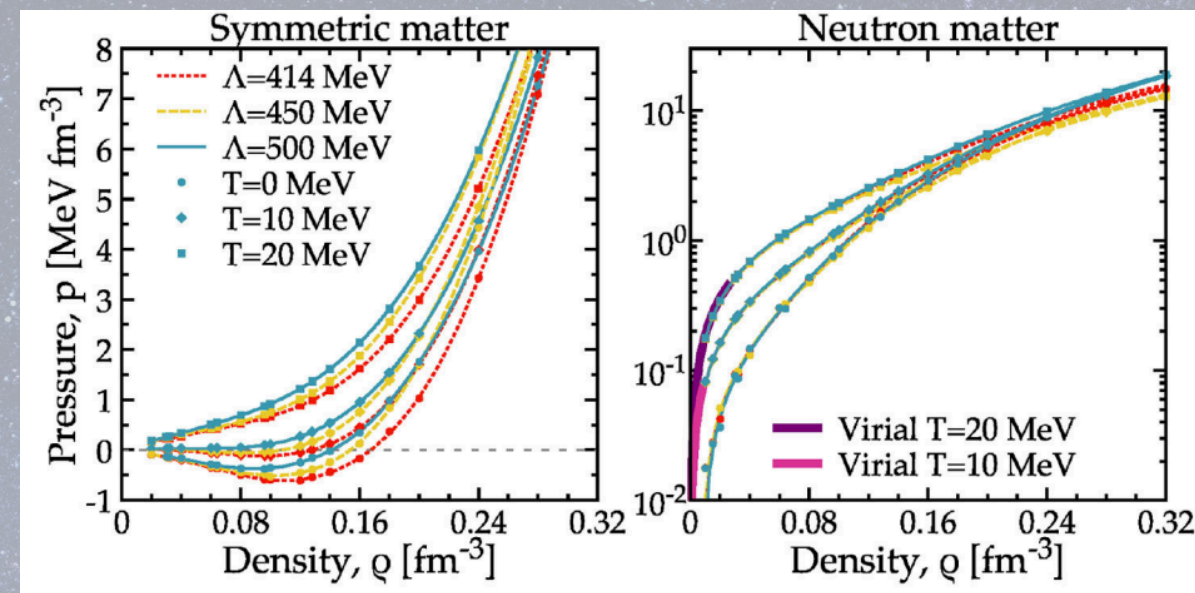
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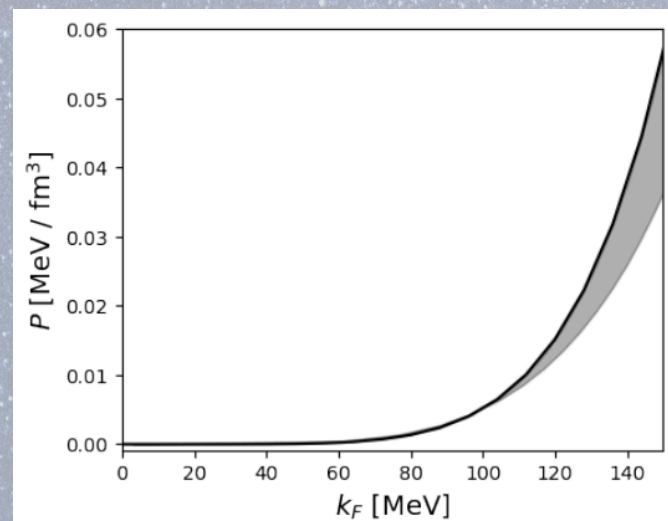
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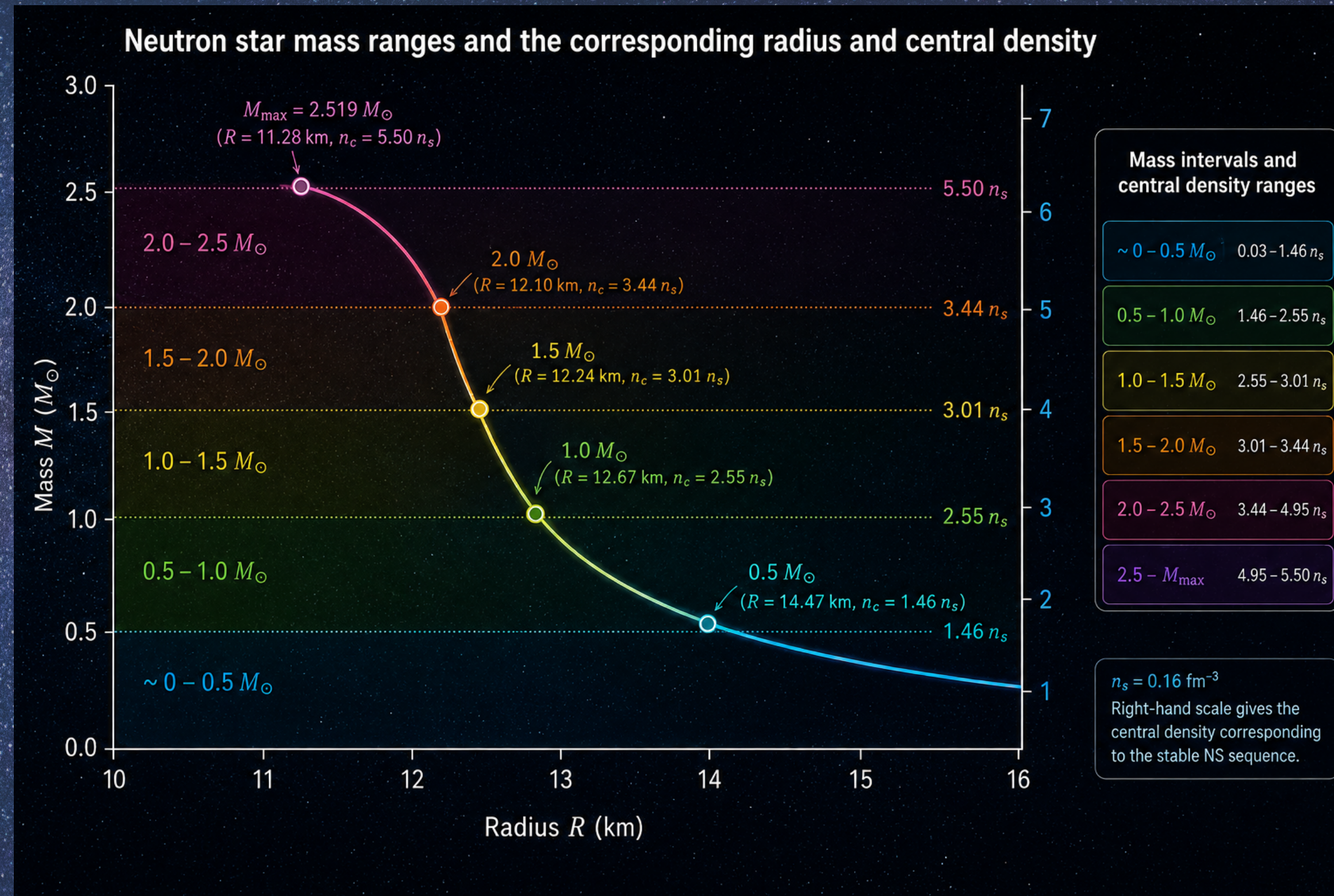
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[J. M. Alarcón and J. A. Oller PRC 107 (2023)]

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Results from the EFT analysis



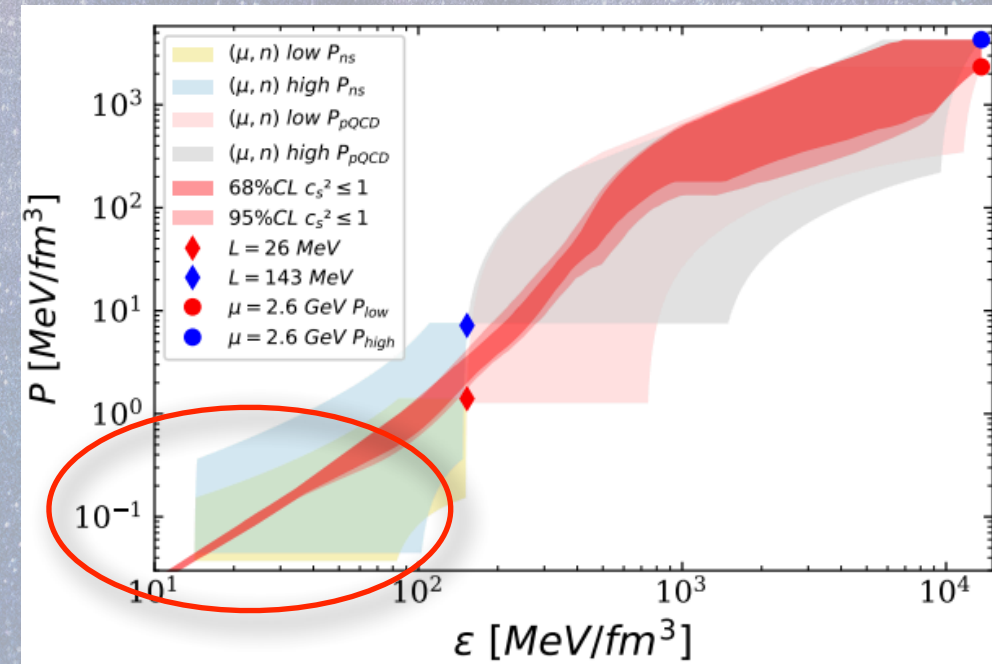
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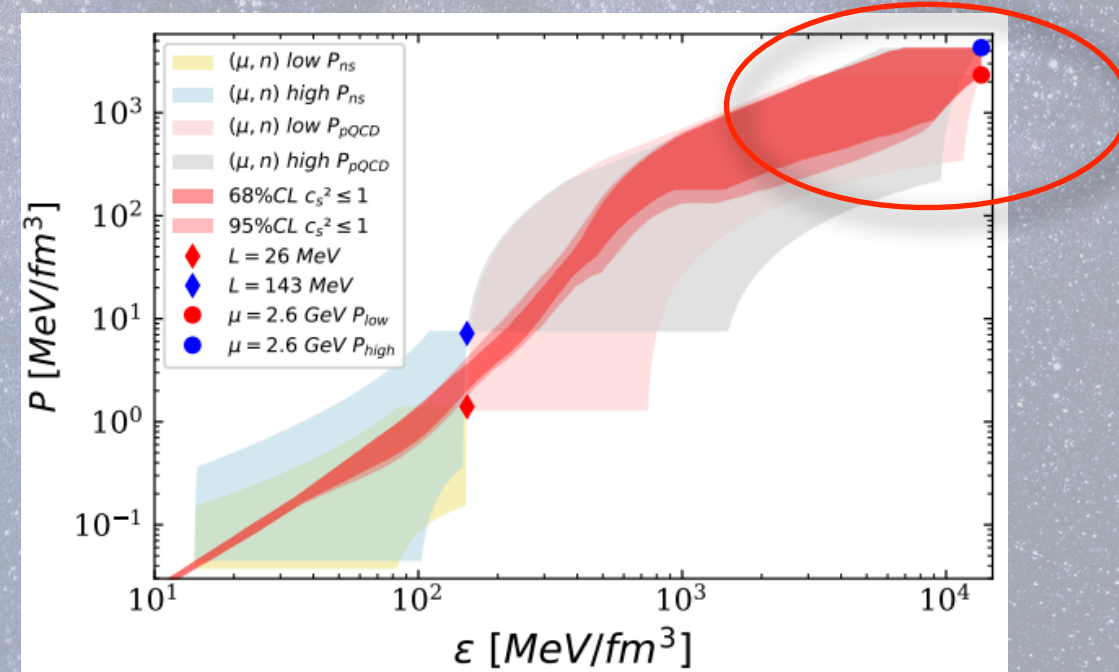


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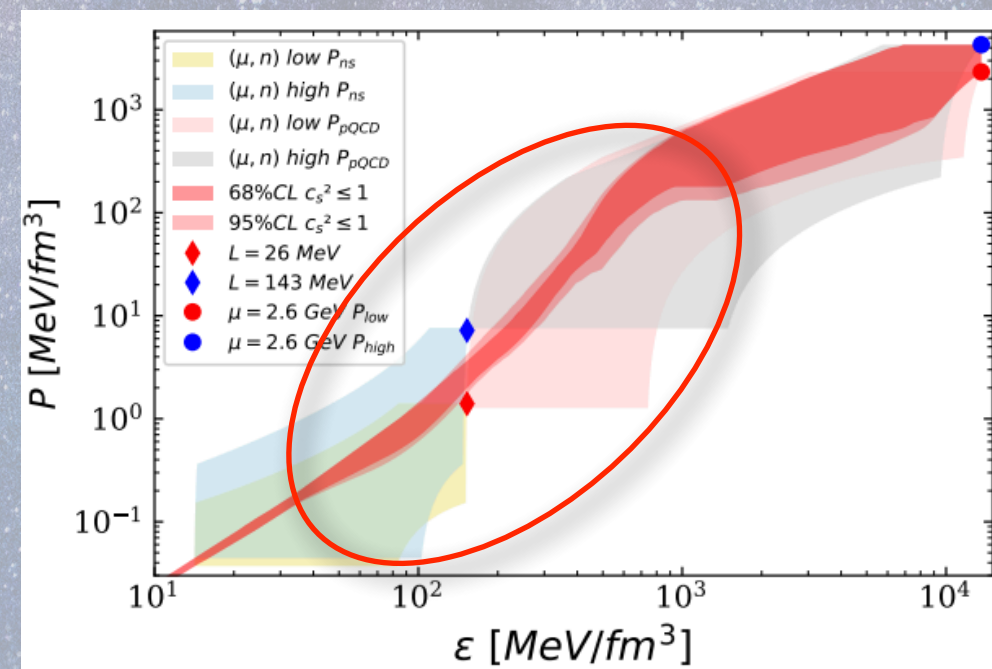


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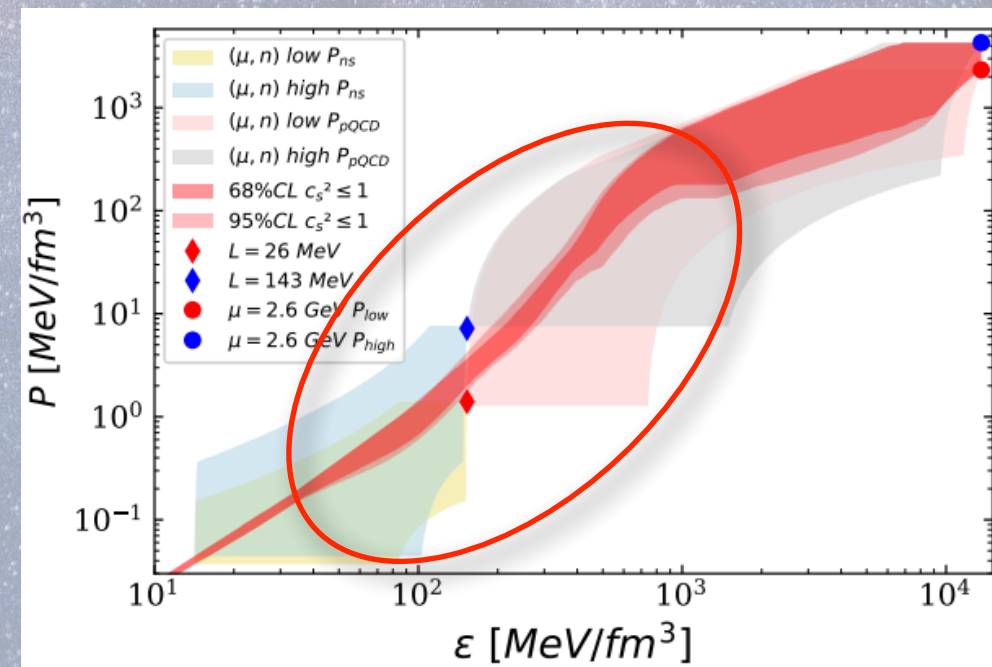


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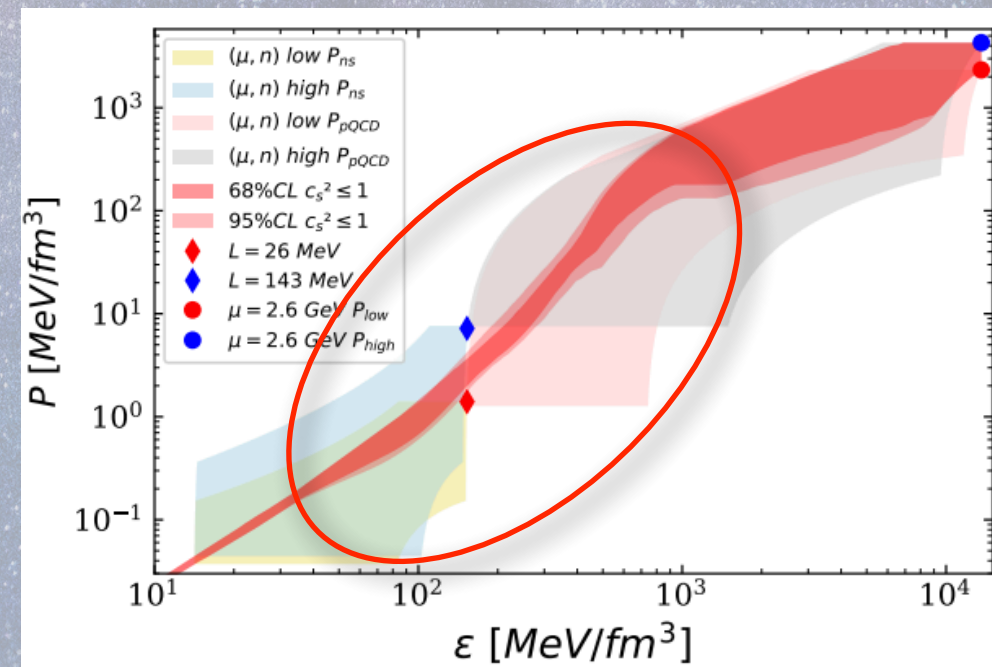


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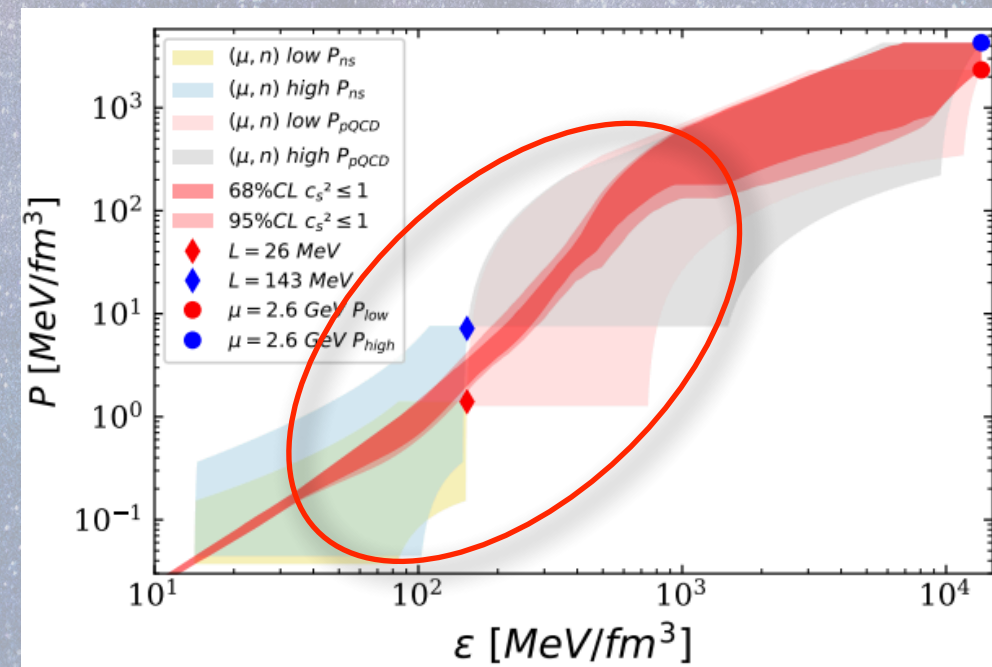


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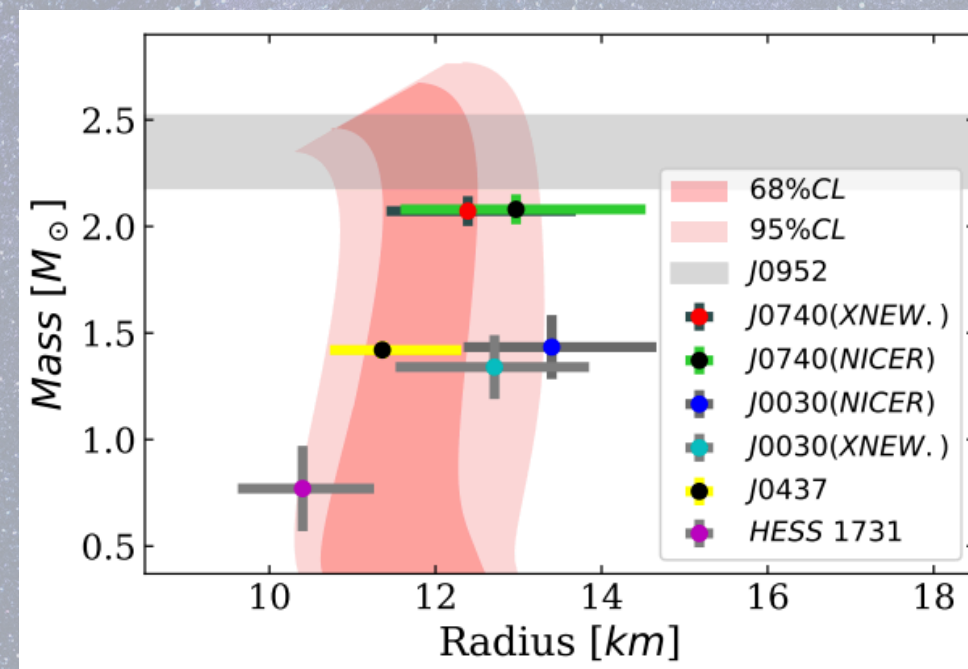
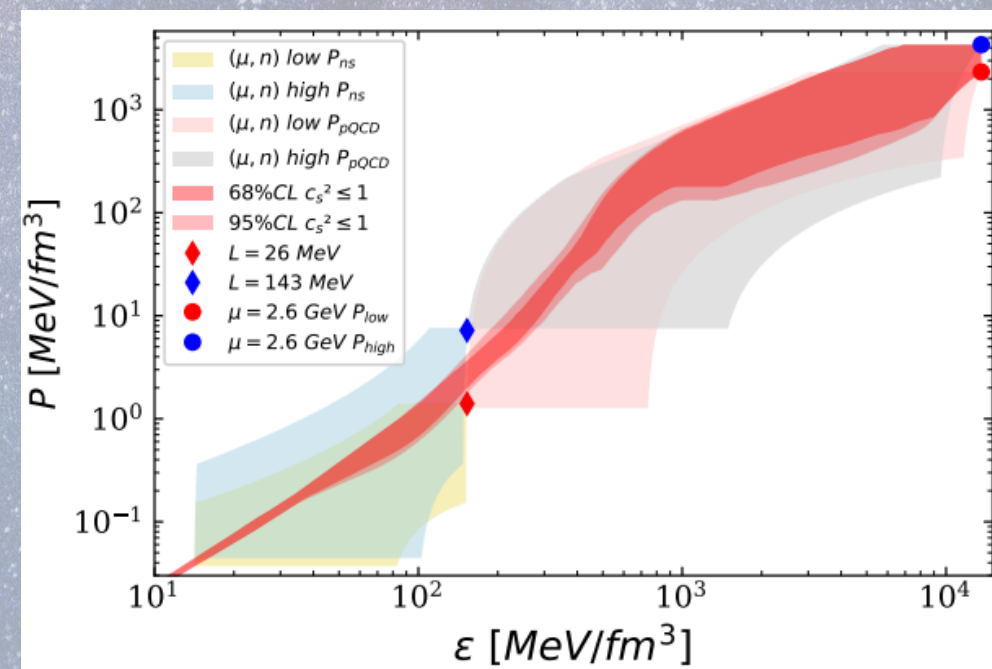


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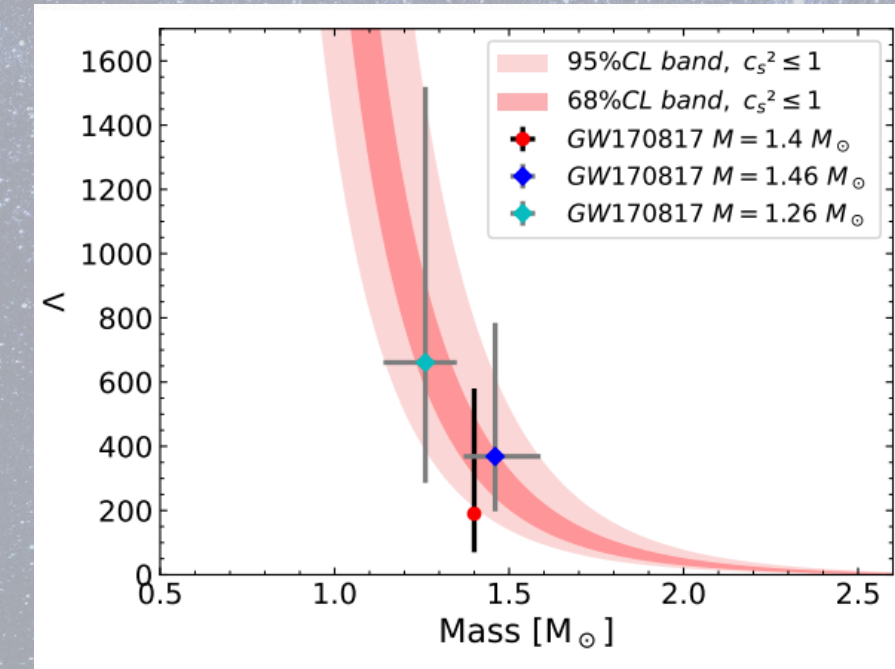
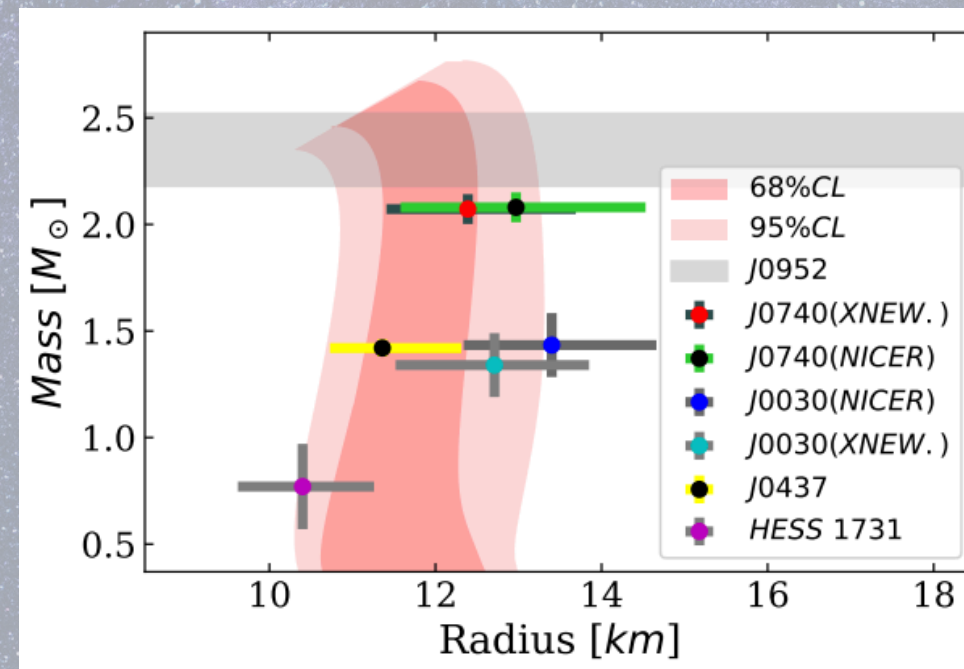
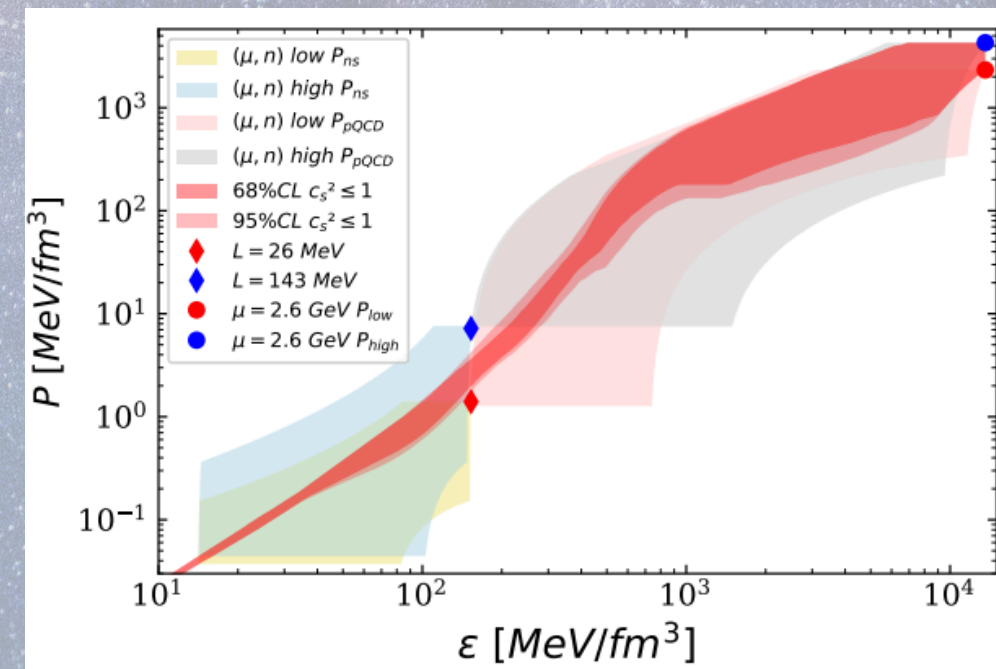


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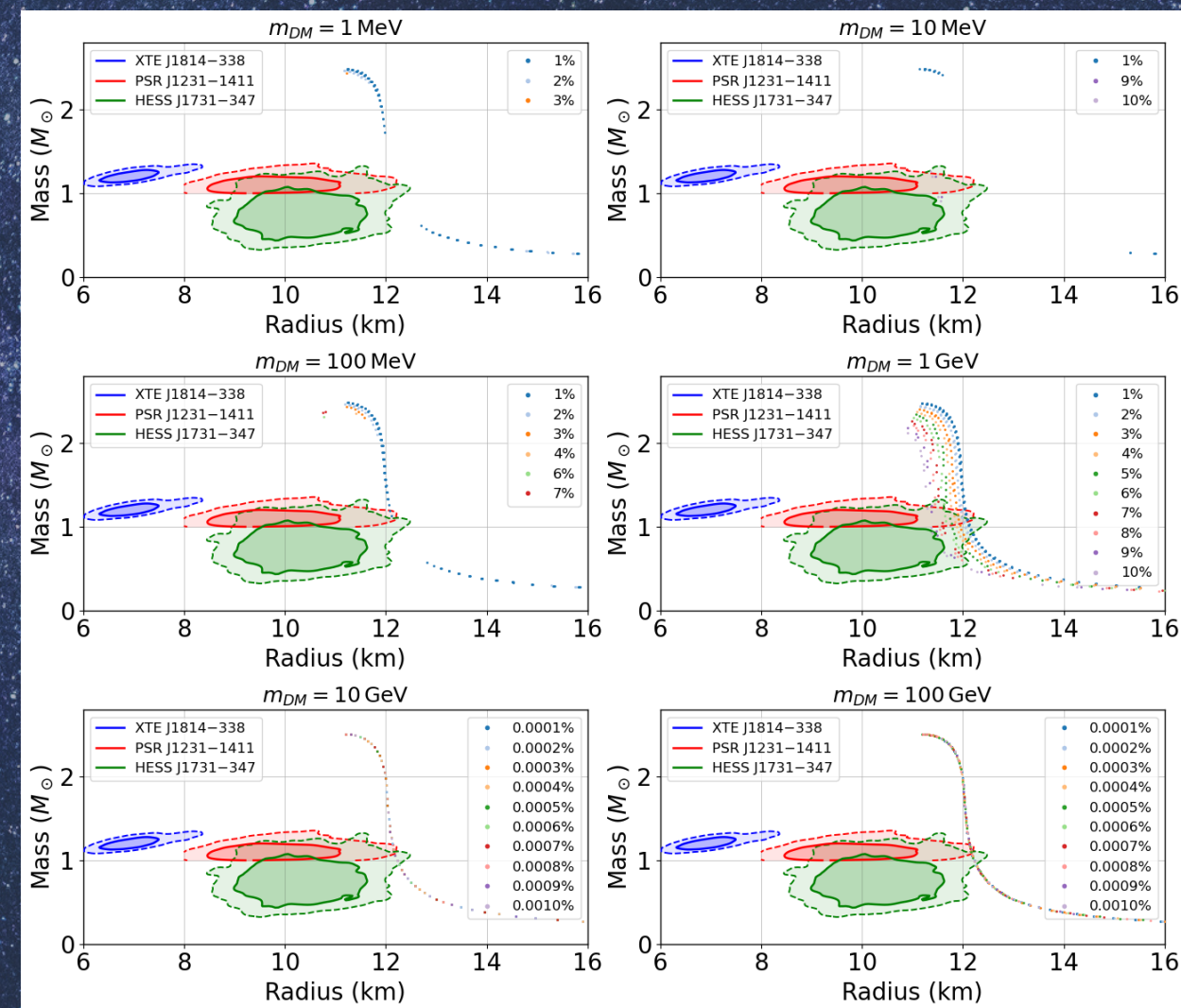
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- Determination of DM model parameters.
- Used in DM searches in compact objects.



[Y. Cano, J. M. Alarcón, 2603.22490]

New physics searches in NS

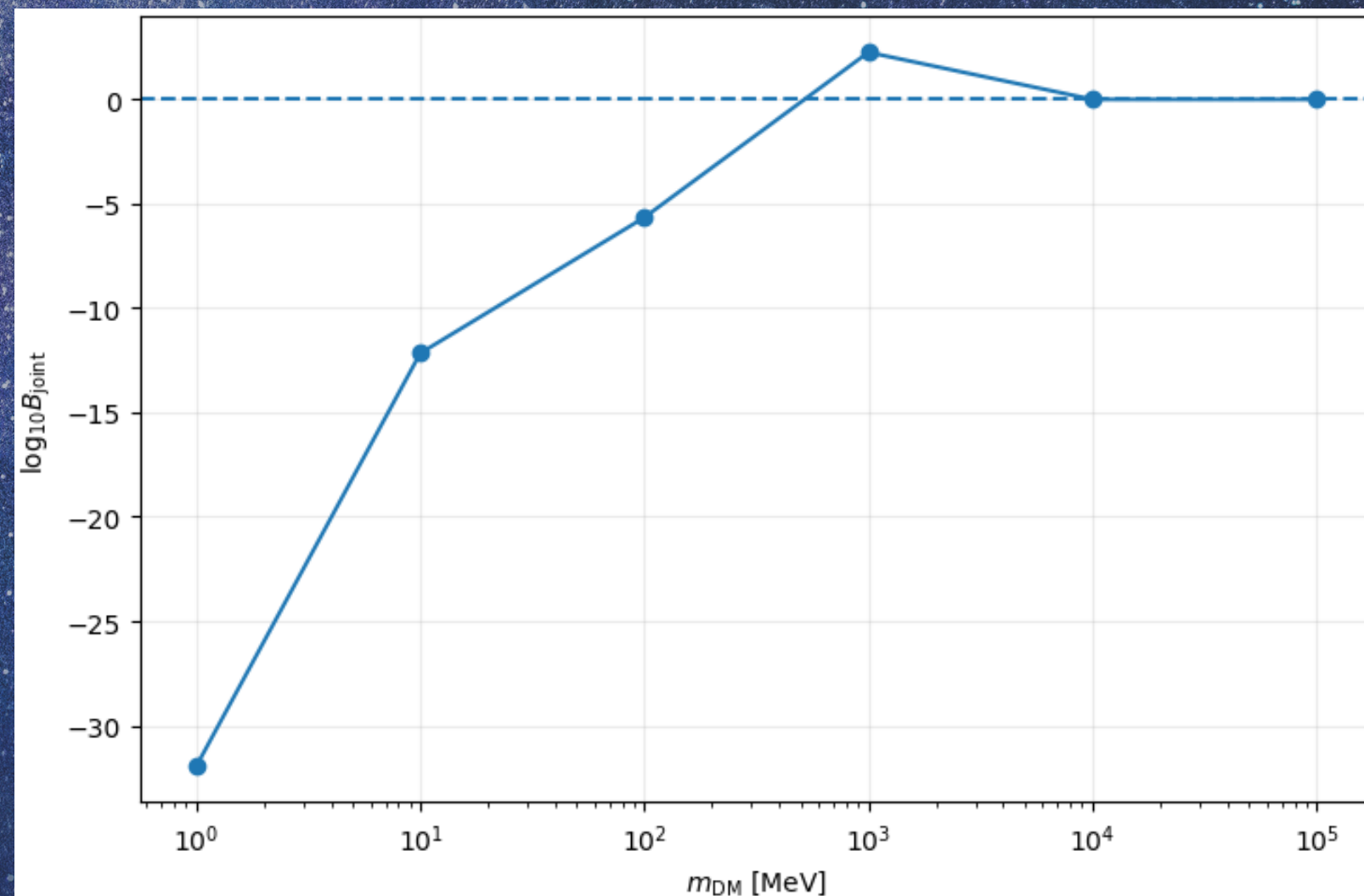
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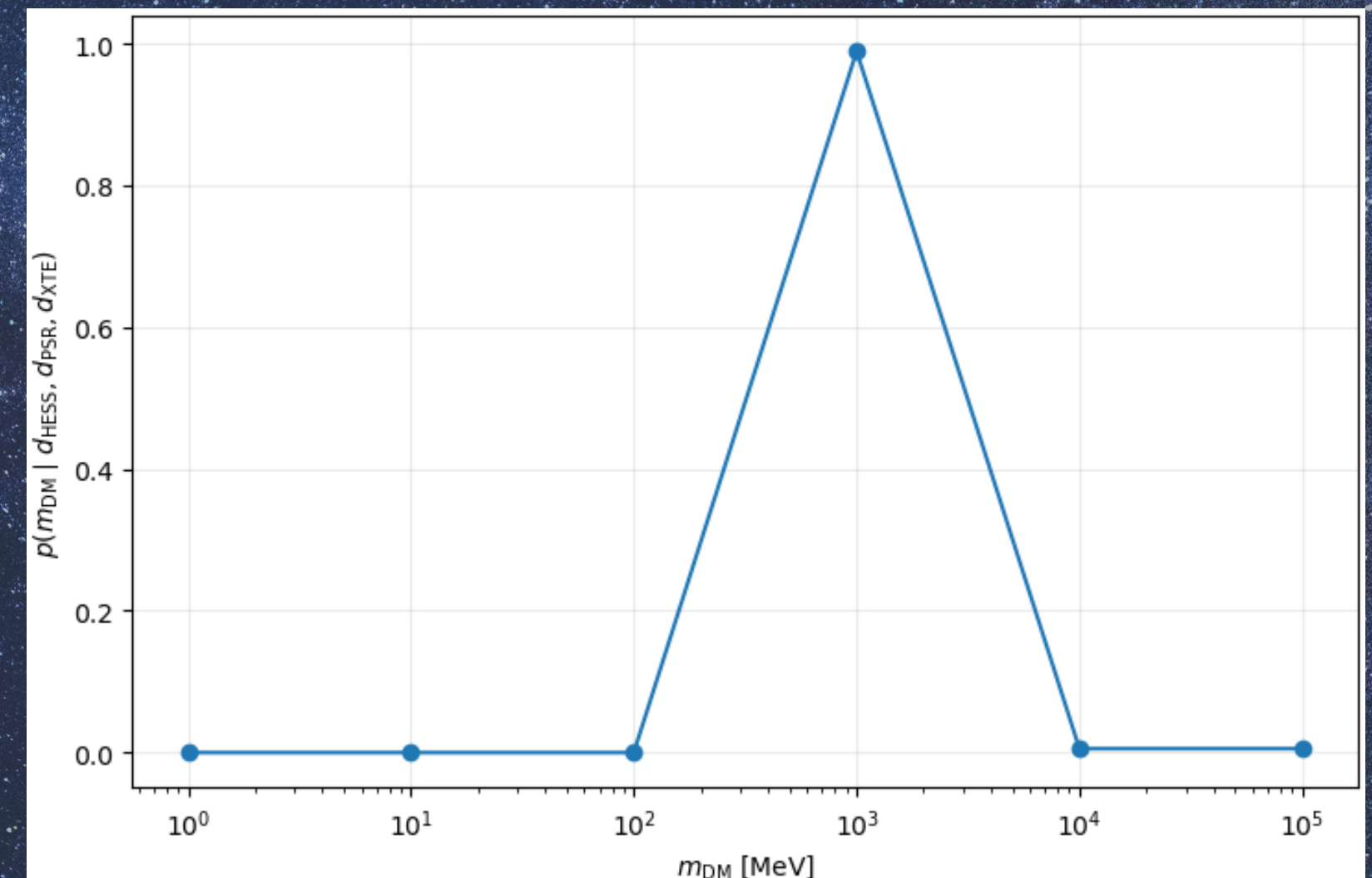
- **Inferred properties of DM**

- For $m_{\text{DM}} \sim 1 \text{ MeV}$, $m_{\text{DM}} \sim 10 \text{ MeV}$, $m_{\text{DM}} \sim 100 \text{ MeV}$ DANS hypothesis is disfavored
- DANS hypothesis clearly favored for $m_{\text{DM}} \sim 1 \text{ GeV}$
- For $m_{\text{DM}} \sim 10 \text{ GeV}$ or $m_{\text{DM}} \sim 100 \text{ GeV}$, there is no difference

Bayes factor (DANS vs PBNS hypothesis)



Posterior probability of each DM mass

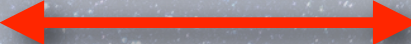


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Summary and Conclusions

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- Neutron stars give the opportunity to study nuclear matter under extreme conditions
- There is an interplay between the properties of neutron stars and nuclear physics calculations

Nuclear physics  Properties of neutron star

- The equation of state of NS can be calculated with EFT + Many-Body Methods
- Results with controlled systematics
- Applications to astrophysics and new physics searches
- DM properties can be inferred from anomalous measurements



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