The nuclear matter density functional under the nucleonic hypothesis

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Theory and experiment/observation

Jumping across scales

Jumping across the scales!

Density

$10^{18}$ g/cm$^3$

$10^{14}$ g/cm$^3$

Observation

Astro model

EoS, Reaction rate

Nuclear experiment

Nuclear theory

constraint

prediction

constraint

prediction

constraint

prediction

$L(m)$

$10^3$

$10^{-3}$

$10^{-9}$

$10^{-15}$
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Equation of State
One-to-one correspondence

GR imposes a one-to-one correspondence between the nuclear EoS and static properties of NS.

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- What about composition? Hyperons? Quarks?
- Reactions ⇒ nucleosynthesis ⇒ kilonova as well as cooling ⇒ X-ray spectra.
- Impact of new observations like M(R) (NICER), Λ(R) (LIGO/VIRGO).

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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!!!
Nucleonic meta-modelling
Founding aspects (Based on J. Margueron et. al., PRC 97, 025805 (2018))

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Beta-equilibrium!!!

- The energy per particle is given by ($x = \frac{n_b-n_{sat}}{3n_{sat}}$, $n_b = \rho_n + \rho_p$, $\delta = \frac{\rho_n-\rho_p}{n_b}$)

$$e(\rho_n, \rho_p) \approx e_{SNM}(n_b, 0) + e_{sym}(n_b)\delta^2$$
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$$e(\rho_n, \rho_p) \simeq e_{SNM}(n_b, 0) + e_{sym}(n_b)\delta^2$$
$$e_{SNM}(n_b) \simeq E_{sat} + \frac{1}{2}K_{sat}x^2 + \frac{1}{6}Q_{sat}x^3 + \frac{1}{24}Z_{sat}x^4$$
$$e_{sym}(n_b) \simeq J_{sym} + Lx + \frac{1}{2}K_{sym}x^2 + \frac{1}{6}Q_{sym}x^3 + \frac{1}{24}Z_{sym}x^4.$$
Impact of recent data on Meta-model

Obtaining the filters

Prior = Nuclear physics informed prior with AME2016 fit.
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**Prior** = Nuclear physics informed prior with AME2016 fit.

**Filters in Bayesian Analysis**

- **LD** = EFT energy band at low density.

**EFT**

![Graph showing the relationship between energy (e) and density (n) in the EFT model.](image)
Impact of recent data on Meta-model

Obtaining the filters

Prior = Nuclear physics informed prior with AME2016 fit.

Filters in Bayesian Analysis

- **LD** = EFT energy band at low density.
- **HD+LVC** = HD (causality, thermodynamic stability, $M_{max}$ constraint) + LVC tidal deformability $\tilde{\Lambda}$ PDF.

![EFT and LVC graphs](image_url)
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**Filters in Bayesian Analysis**

- **LD** = EFT energy band at low density.
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- **All** = EFT + HD + LVC + NICER.

**Graphs**

- **EFT**
  - $e$ [MeV] vs. $n$ [fm$^{-3}$]
  - $\rho$ [MeV/fm$^3$] vs. $n$ [fm$^{-3}$]

- **LVC**
  - $P_{\text{LVC}}$ vs. $\Lambda$
Impact of recent data on Meta-model EoS

The nuclear matter ... nucleonic hypothesis
Impact of recent data on Meta-model

Hoa Dinh Thi, CM & F. Gulminelli (In press, Universe)
Impact of recent data on Meta-model
Isovector parameters

![Graphs showing the impact of recent data on meta-model parameters.](image)
Impact of recent data on Meta-model

Isoscalar parameters

[Graphs showing PDF distributions for various parameters]
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Wish list

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Thank You