Use of Unified Equations of state in the modelisation of Neutron Stars mascroscopic properties

Elbereth Conference

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Plan of the talk

Exploring dense matter with Neutron Stars observations

Compact objects :

- Mass = 1-2 $M_\odot$
- Radius $= 10 - 14$ km
- Density $\rightarrow 10^{15}$ g/cm^3

Structure :

- Crust : lattice
  - outer crust : well constrained from laboratory measurements
  - inner crust : free neutrons in the gaz
- Core : still a mystery
  - Outer core : *npeμ* gaz
  - Inner core : quarks ? Confined or deconfined ? Hyperons ?

- Magnetic field = up to 10^{11} Tesla

Super precise clocks
$\rightarrow$ **Pulsars** > 2000 observed

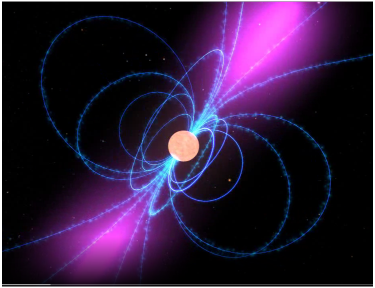

Figure: *From Nasa website*

Neutron Stars characteristics

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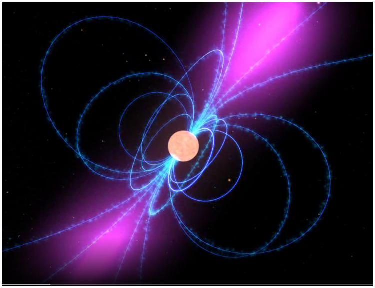

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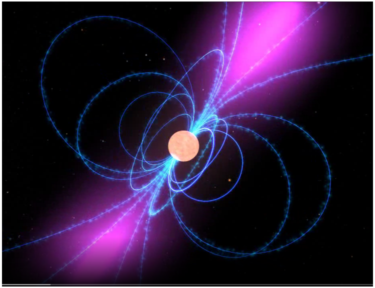

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From microscopic to macroscopic to observations

Modelisation of macroscopic parameters

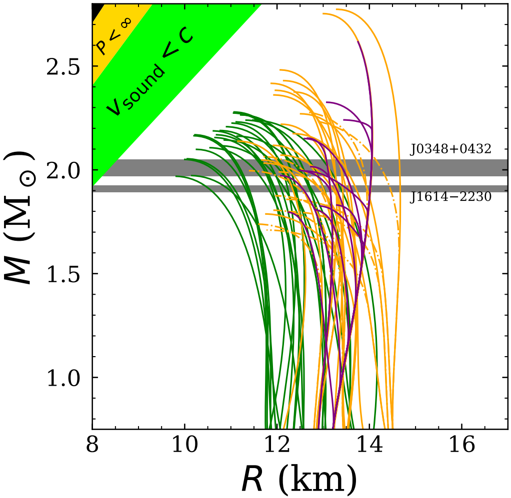
Equations of state = description of the matter inside the star

Hydrodynamics equations =
Tolmann-Oppenheimer-Volkoff

- Input P, ρ, ϵ
- Output M, R, Λ, I

Transport and **Cooling** equations

- Input : P, ρ, ϵ + neutrino processes
- Output : $L^{\infty}(t)$



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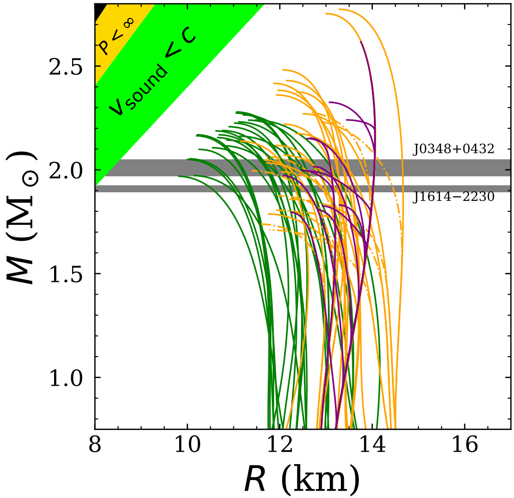

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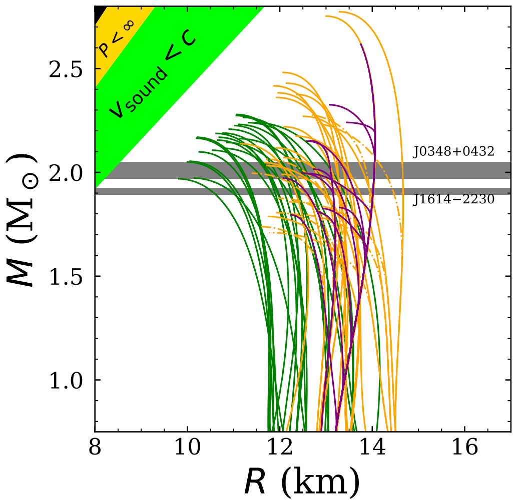


Core-Crust bound Equations of State

Core-crust binding of EoS

Non unified EoS

Dozens of EoS (CompOSE) **in tables** : calculations techniques (*ab initio*, RMF, Skyrme functionnal etc.) + core composition

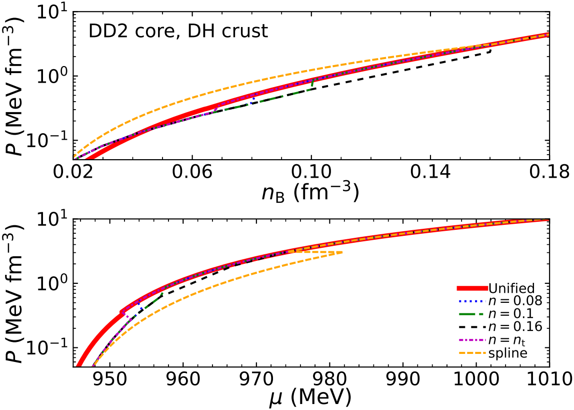
Analytical expressions = fits of EoS

Construction flaws :

- Piecewise polytropic fits [Read et al. 2009]
- Spectral fits [Lindbloom 2010]

Bound core and crust EoS

→ Thermodynamic inconsistencies



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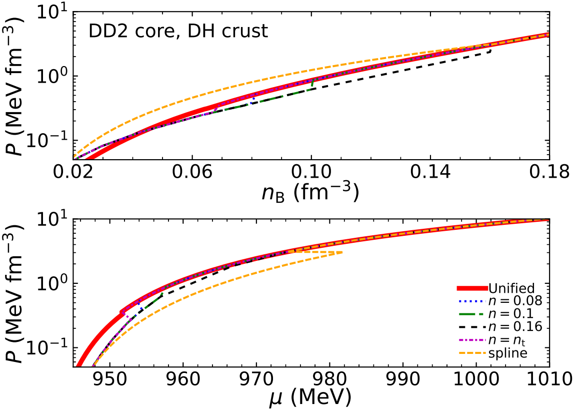

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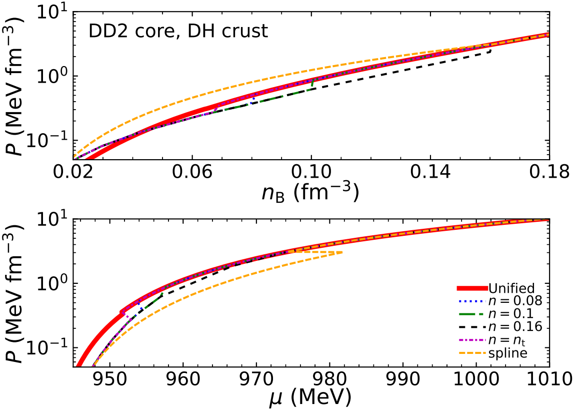
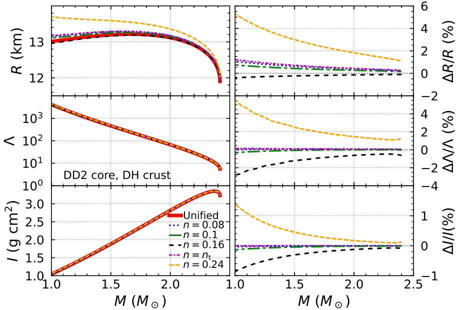


Consequences on macroscopic parameters

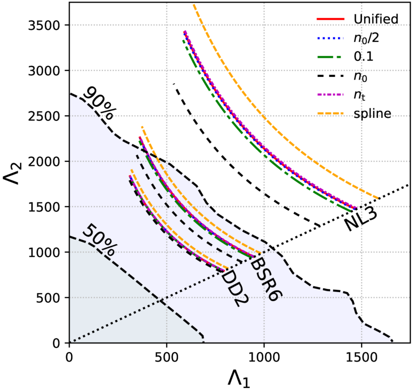
Non unified EoS



- Mass measurement → eliminate EoS under M_{max}
- NICER precision on the radius : promise a few %
- GW → eliminate too stiff EoSs

GW170817: DNS Binary merger

Λ = parameter in waveform of the post-Newtonian templates for inspiral phase



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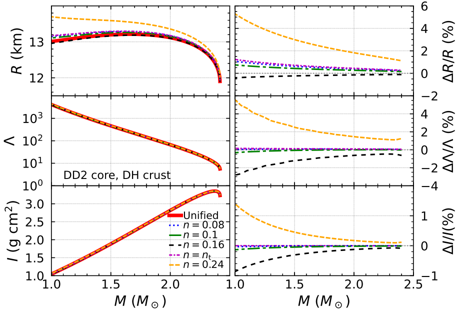

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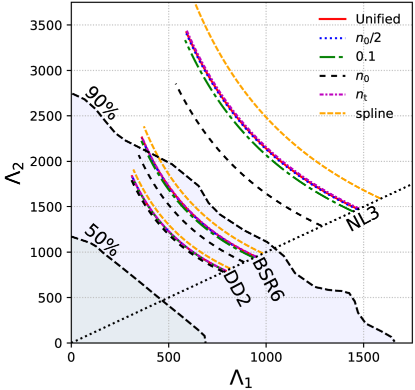

Conclusion

Importance of EoSs

We propose :

- use unified EOS
- if not, use intelligently bound EoS
- carefully consider universal relation

$$\bar{I}_{\mathrm{fit}} = \sum_{k=1}^{4} a_k C^{-k}$$

- brand new fits of EoS made from unified EoS

Suplementary material