Bayesian inference on quark matter from observations of neutron stars

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QM 2022, 4-10 April 2022

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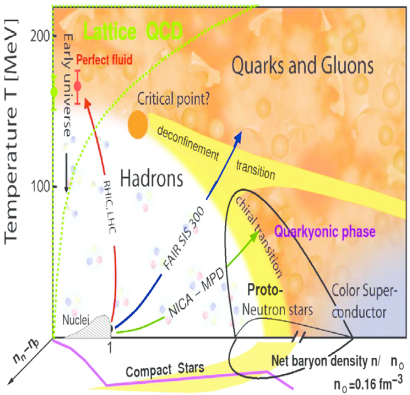
Supported by the ÚNKP-21-3 New National Excellence Program of the Ministry for Innovation and Technology.

Motivation: QCD and neutron stars

- We can not solve QCD at large densities from first principles due to the sign problem
- There are no experimental results in this region so far
- We may use effective models to try to describe strongly interacting matter
- Neutron stars may provide constraints for these models



Ingredients for hybrid stars 1

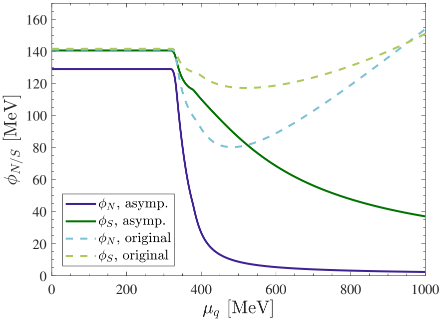
We use the (axial)vector meson extended linear sigma model
For hybrid stars we need the EoS at high density and $T = 0$:

- we need to introduce non-zero vector condensates
- β-equilibrium + charge neutrality
- 5 field equations (no Polyakov-loop contribution)

↪ a naive parametrization → chiral symmetry would be broken at high densities

↪ investigating the asymptotic behavior we get an additional constraint for the parameters

↪ we get $m_\sigma = 290$ MeV from parametrization



Ingredients for hybrid stars 2

Hybrid stars also have a hadronic crust and outer core:

- at low densities we use hadronic EoS's (SFHo and DD2)
- we apply a smooth crossover between the two phases:
  1. $\varepsilon(n)$ interpolation

$$\varepsilon(n) = \varepsilon_H(n) f_-(n) + \varepsilon_Q(n) f_+(n),$$
$$f_\pm(n) = \frac{1}{2}\left(1 \pm \tanh\left(\frac{n-\bar{n}}{\Gamma}\right)\right)$$

  2. $p(\mu)$ interpolation with polynomial

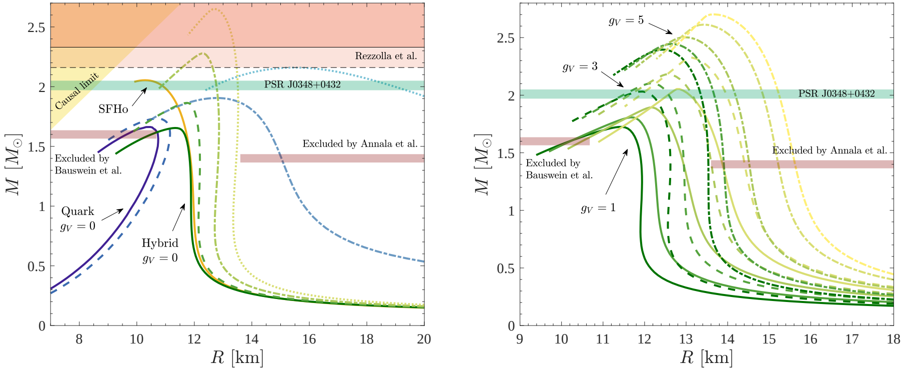
$$p(\mu_B) = \sum_{m=0}^{N} C_m \mu_B^m \, , \quad \mu_{BL} < \mu_B < \mu_{BU},$$

  the C_m coefficients are obtained by matching the pressure and its derivatives at the boundary points

↪ 4 tunable parameters altogether: m_σ, g_V, $\bar{n}$, Γ (or μ_{BL}, μ_{BU})

↪ we use the $\varepsilon(n)$ interpolation with $\bar{n} = 3.5 n_0$ and $\Gamma = 1.5 n_0$ as our standard choice

$M - R$ curves for different g_V's

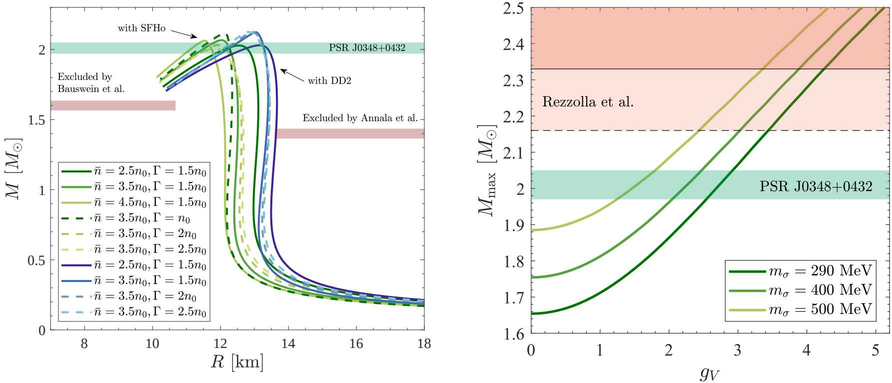


↪ larger vector couplings result in larger hybrid star masses

↪ maximum masses are increased due to the intermediate density stiffening of the hybrid EoS's

↪ large sigma masses (brighter tones) are excluded by upper radius constraints

Effect of sigma mass and phase transition

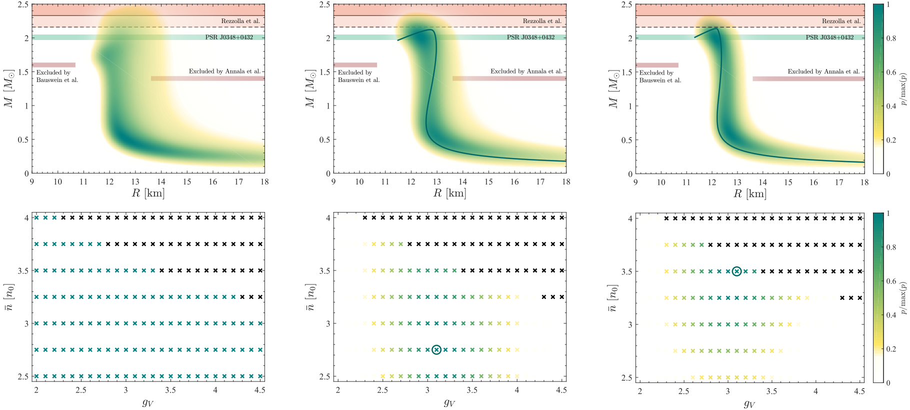


↪ maximum mass hybrid stars seem to reside in a small region, independent of the phase transition parameters[1]

↪ with $m_\sigma = 290$ MeV g_V is constrained to $2.5 < g_V < 4.3$

[1] similar results were found in *Cierniak & Blaschke, EPJ ST 229, 3663 (2020)*

Bayesian analysis results



↪ low sigma meson mass and a narrow phase transition are preferred

↪ the center of the phase transition is between $2.5n_0$ and $3.5n_0$

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Summary

Conclusions

- we developed a model that describes vacuum phenomenology and finite temperature behaviour accurately
- we found that the maximum neutron star mass can be used to constrain the parameters of the model
- from our Bayesian anlysis we found that $g_V \approx 3 - 3.5$, a low sigma meson mass and a narrow phase transition are preferred
- we still want to do a deeper analysis of all the astrophysical constraints