The Complexity of Neutron Star Matter: from Liquid-Gas Phase Transition to Chiral Symmetry Breaking and Restoration - II

Constança Providência

Universidade de Coimbra, Portugal

60th Karpacz Winter School on Theoretical Physics, May 16-24, 2024

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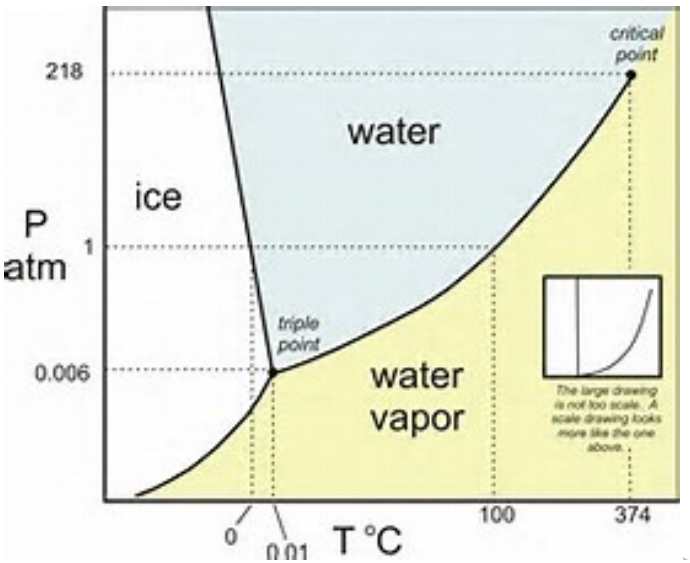
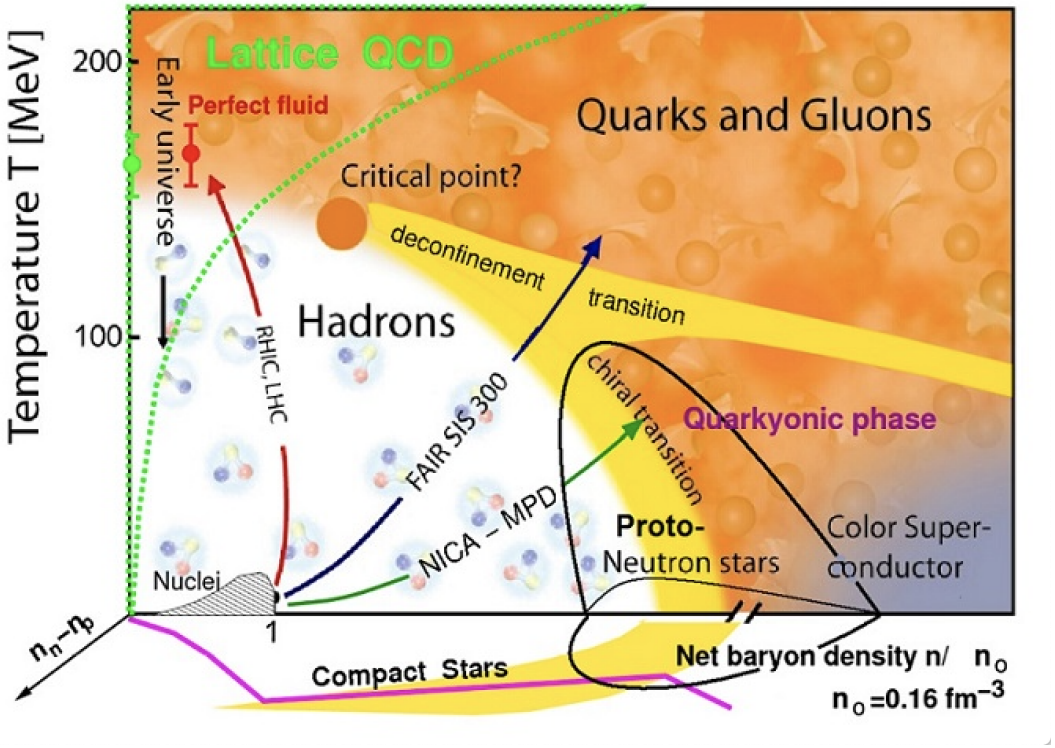
MAGSTARMATTER

QCD phase diagram





Chiral symmetry in QCD

Nambu-Jona-Lasinio Model

The NJL model:

- low-energy approach to the QCD problem
- has built in chiral symmetry
- has a nontrivial vacuum structure
  - The vacuum is populated by scalar quark-anti quark pairs $\rightarrow$ finite quark condensate $\langle \bar{q}q \rangle$
- quark mass is generated by spontaneous symmetry breaking
- has been very successful in the description of the meson sector

NJL Model for Quark matter

- quark phase: NJL model for quarks with scalar meson exchange
- Lagrangian for quark matter

$$\mathcal{L} = \bar{\psi}(i\gamma^\mu\partial_\mu)\psi + G_s\left[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2\right] - G_v(\bar{\psi}\gamma^\mu\psi)^2$$

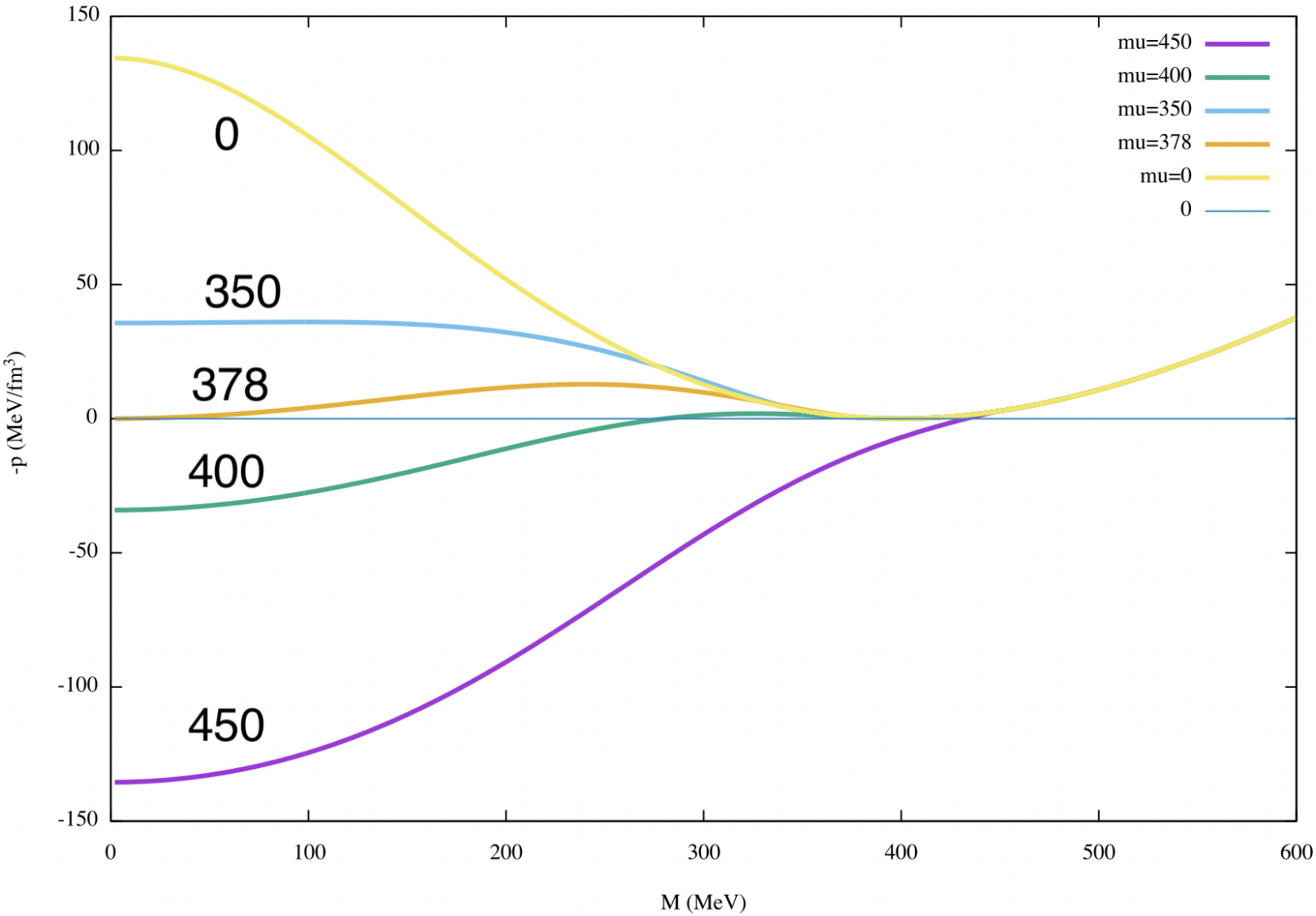
- Mean field Lagrangian for quark matter for finite density

$$\begin{aligned}
\mathcal{L}_{q,MF} &= \bar{\psi}(i\gamma^\mu\partial_\mu - M + \gamma^0\tilde{\mu})\psi + U(\phi, n), \\
\phi &= \langle\bar{\psi}\psi\rangle, \quad n = \langle\psi^\dagger\psi\rangle \\
M &= m_0 - G_s\phi, \qquad \tilde{\mu} = \mu - G_v n
\end{aligned}$$

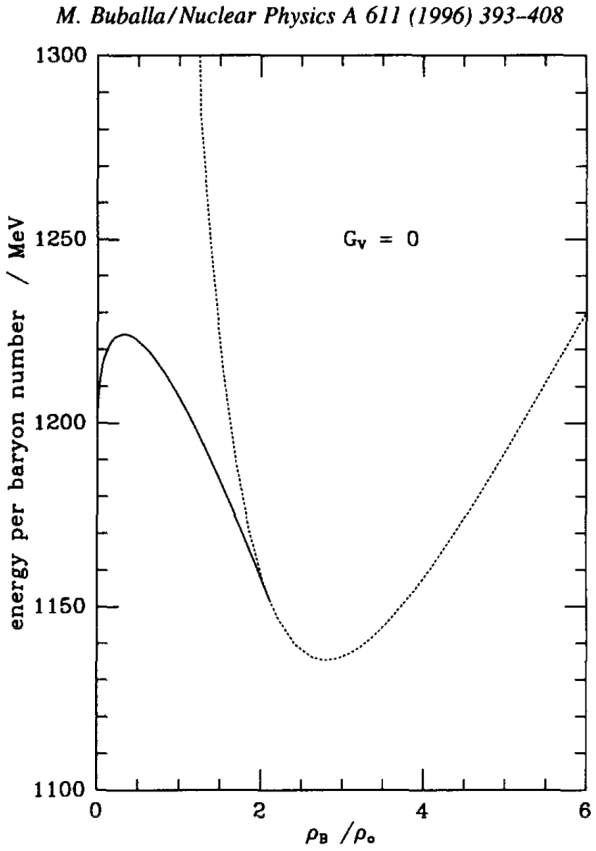
Choice of Parameters

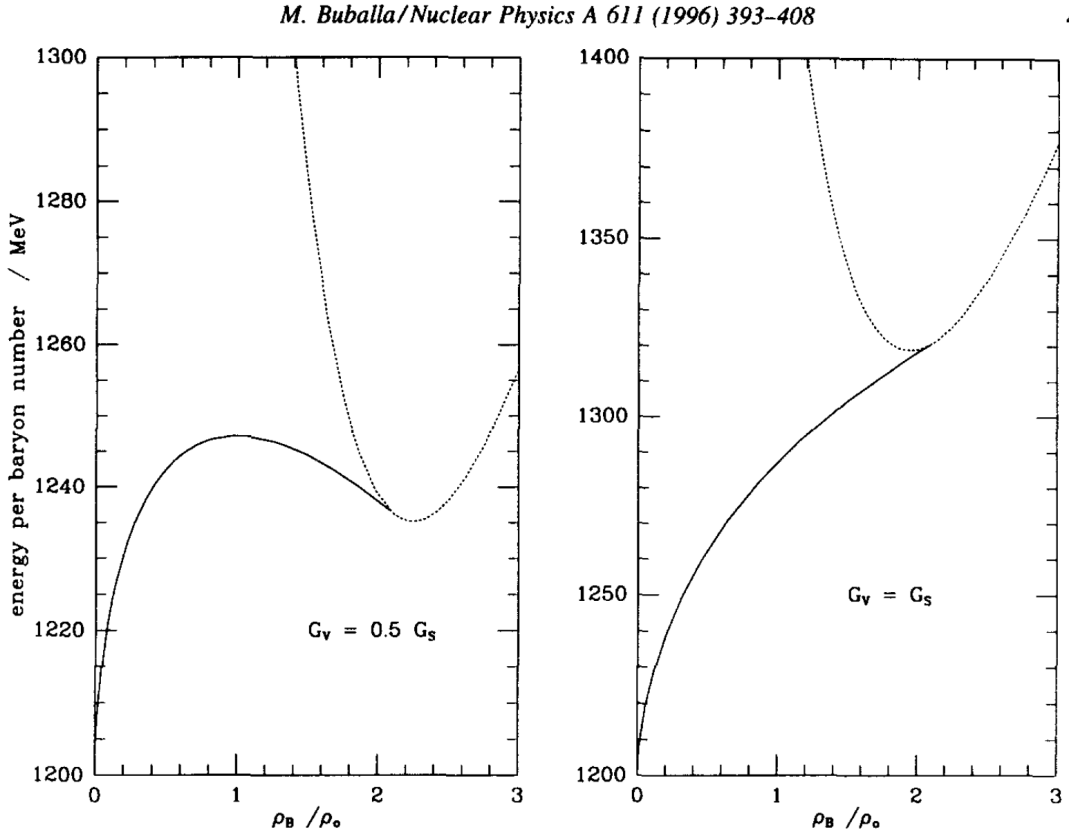
- Parameters of the model: cutoff Λ, coupling constants G_i and current masses
- Parameters of the model fitted to:
  - pion decay constant f_π
  - quark condensates $\langle \bar{\phi}\psi \rangle$
  - nucleon mass in the vacuum

NJL: Mass versus Ω

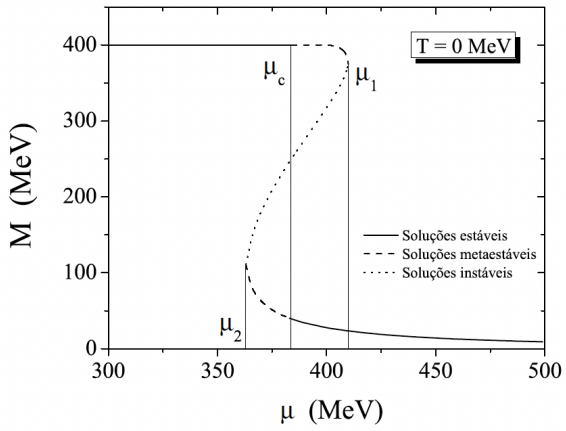


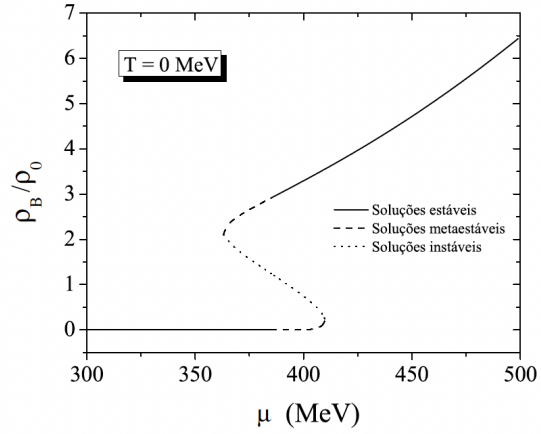
NJL: effect of vector interaction

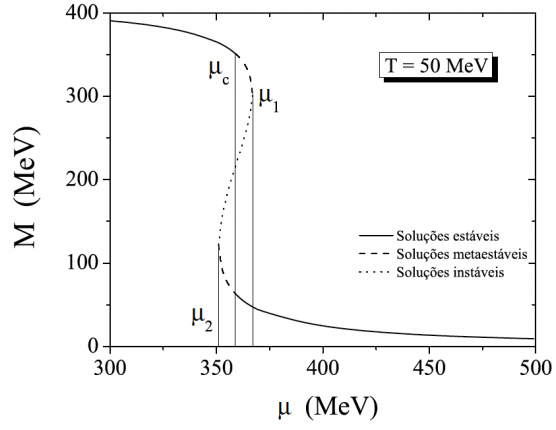


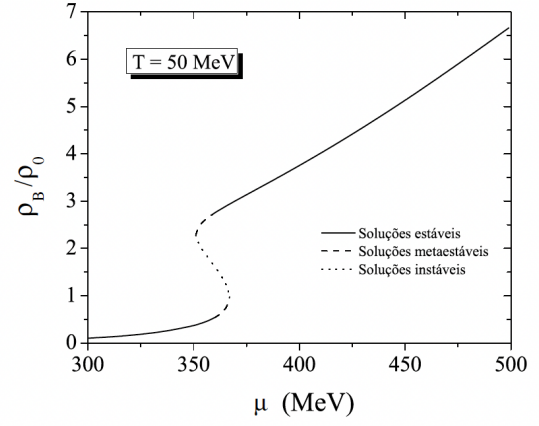


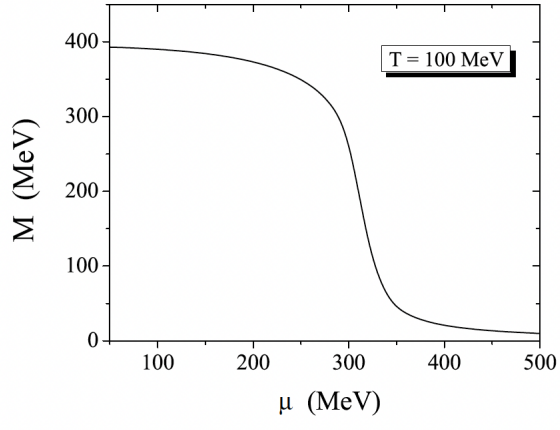
NJL:
effect of temperature

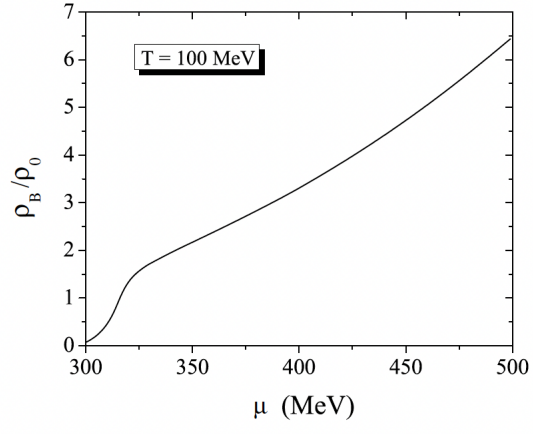












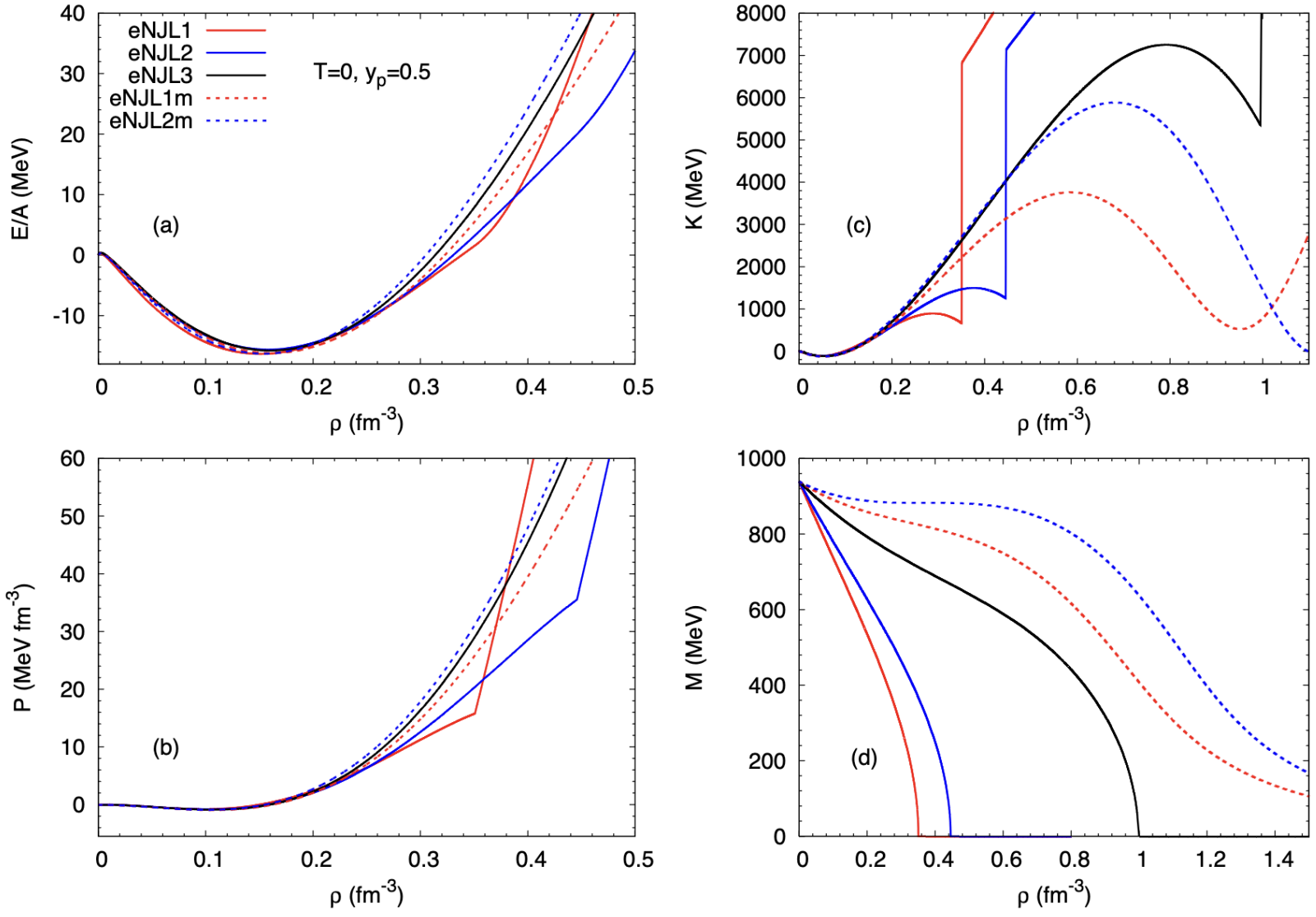
extended NJL for nuclear matter

- Koch, Biro, Kunz, Mosel, PLB 185 (1987) 1: introduced G_{sv} term to reproduce saturation properties
- J Providencia, Moszkowski, CP, Int.J.Mod.Phys.B 17 (2003) 5209
- Mishustin, Satarov, Greiner, Phys.Rept. 391 (2004) 363-380
- Si-Na Wei, Wei-Zhou Jiang, Rong-Yao Yang, Dong-Rui Zhang, Phys.Lett.B 763 (2016) 145-150
- Pais, Menezes, Providência, PRC 93, 065805 (2016)

$$
\begin{aligned}
\mathcal{L} &= \bar{\psi}(i\gamma^\mu\partial_\mu - m)\psi + G_s[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2] \\
&- G_v(\bar{\psi}\gamma^\mu\psi)^2 - G_{sv}[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2](\bar{\psi}\gamma^\mu\psi)^2 \\
&- G_\rho\left[(\bar{\psi}\gamma^\mu\vec{\tau}\psi)^2 + (\bar{\psi}\gamma_5\gamma^\mu\vec{\tau}\psi)^2\right] \\
&- G_{v\rho}(\bar{\psi}\gamma^\mu\psi)^2\left[(\bar{\psi}\gamma^\mu\vec{\tau}\psi)^2 + (\bar{\psi}\gamma_5\gamma^\mu\vec{\tau}\psi)^2\right] \\
&- G_{s\rho}\left[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2\right]\left[(\bar{\psi}\gamma^\mu\vec{\tau}\psi)^2 + (\bar{\psi}\gamma_5\gamma^\mu\vec{\tau}\psi)^2\right].
\end{aligned}
$$

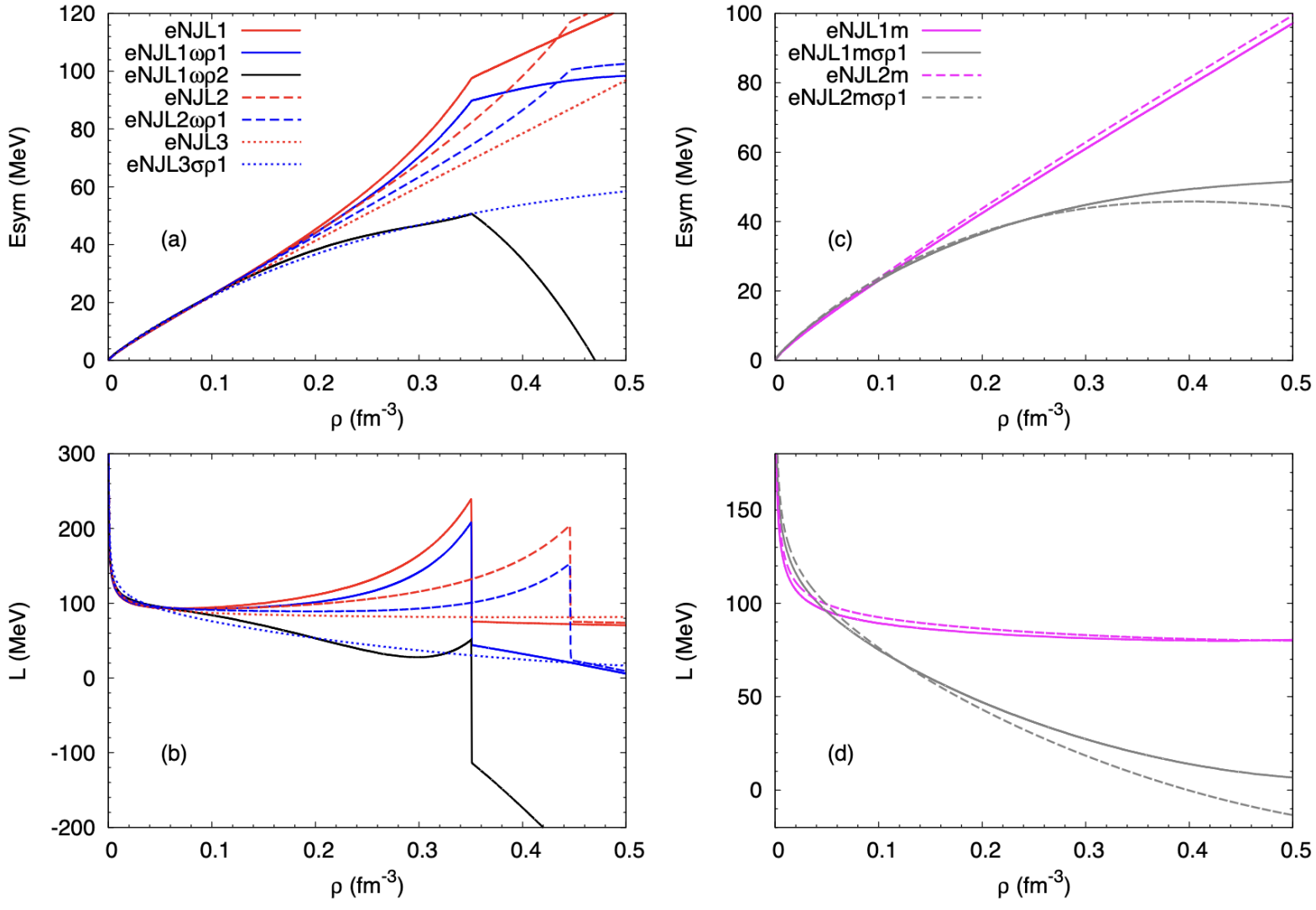
extended NJL for nuclear matter

isoscalar properties



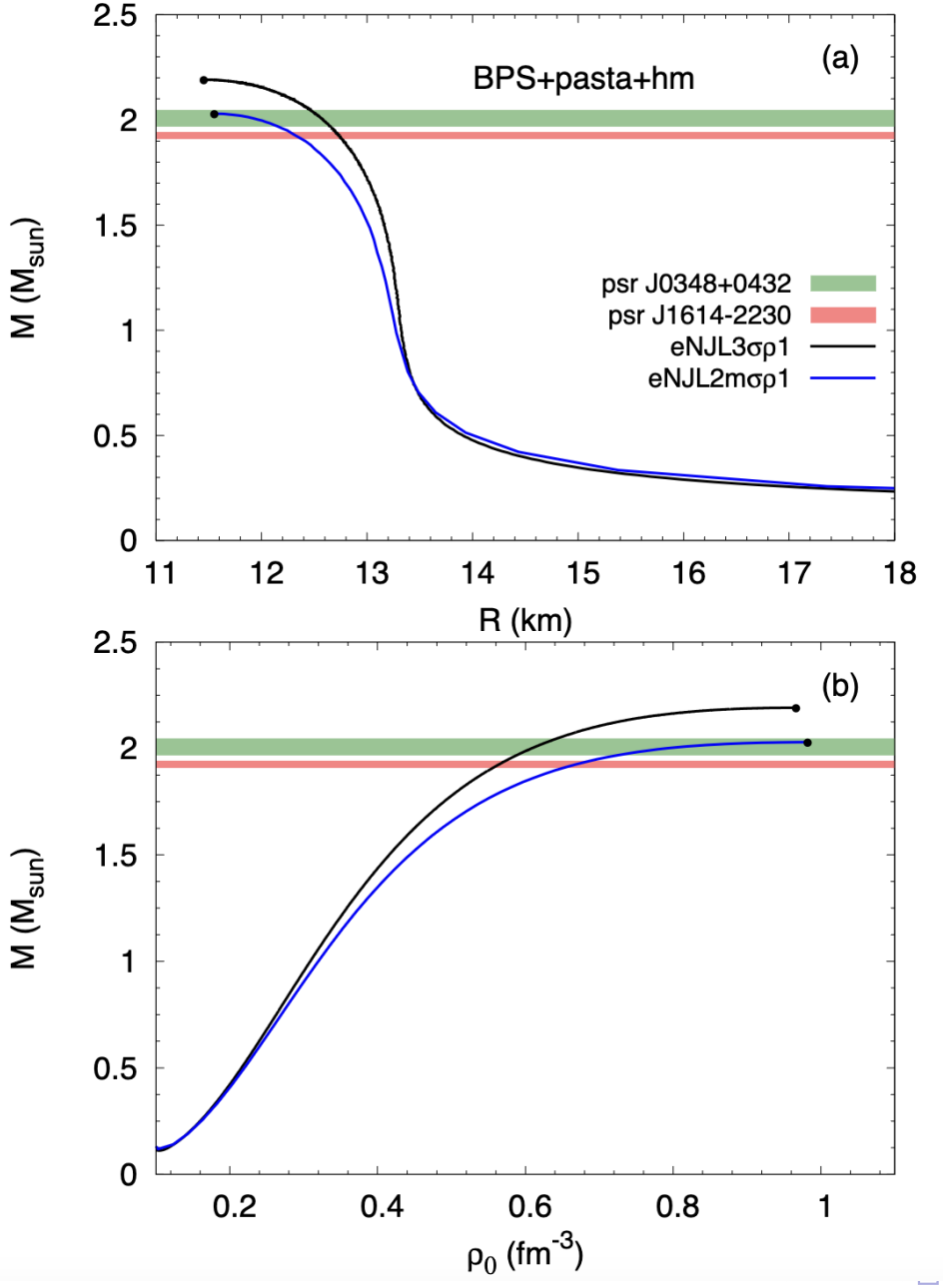
extended NJL for nuclear matter

isovector properties



extended NJL for nuclear matter

Neutron star MR



extended NJL for nuclear matter

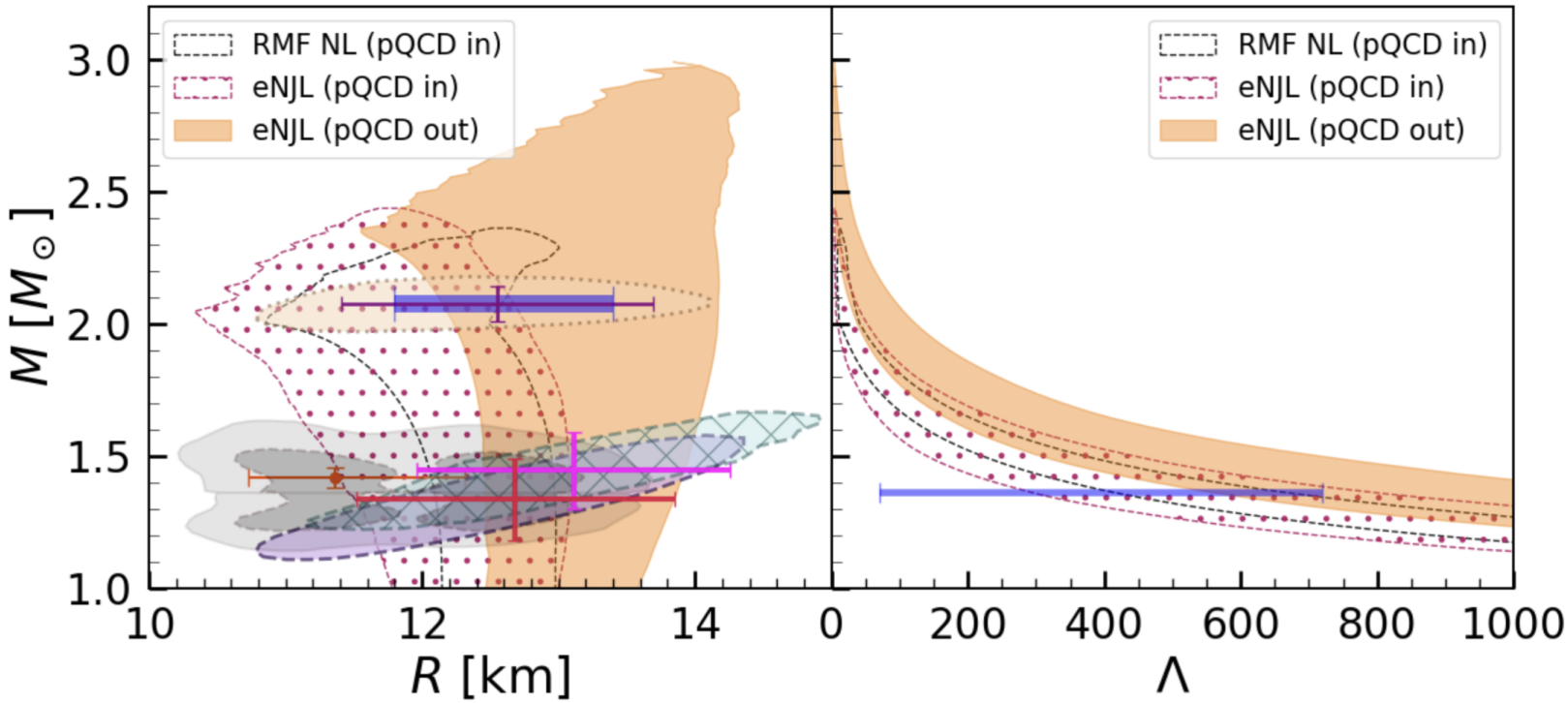
parameters

TABLE I. The coupling constants of the models discussed in the present work.

Model	G_s (fm^2)	G_v (fm^2)	G_{sv} (fm^8)	G_ρ (fm^2)	$G_{v\rho}$ (fm^8)	$G_{s\rho}$ (fm^8)	Λ (MeV)	m (MeV)
eNJL1	4.855	4.65	-6.583	0.5876	0	0	388.189	0
eNJL1$\omega\rho$1	4.855	4.65	-6.583	0.5976	-1	0	388.189	0
eNJL1$\omega\rho$2	4.855	4.65	-6.583	0.6476	-6	0	388.189	0
eNJL2	3.8	3.8	-4.228	0.6313	0	0	422.384	0
eNJL2$\omega\rho$1	3.8	3.8	-4.228	0.6413	-1	0	422.384	0
eNJL3	1.93	3.	-1.8	0.65	0	0	534.815	0
eNJL3$\sigma\rho$1	1.93	3.	-1.8	0.0269	0	0.5	534.815	0
eNJL1m	1.3833	1.781	-2.943	0.7	0	0	478.248	450
eNJL1m$\sigma\rho$1	1.3833	1.781	-2.943	0.0739	0	1	478.248	450
eNJL2m	1.078	1.955	-2.74	0.75	0	0	502.466	500
eNJL2m$\sigma\rho$1	1.078	1.955	-2.74	-0.1114	0	1	502.466	500

extended NJL for nuclear matter: Bayesian inference

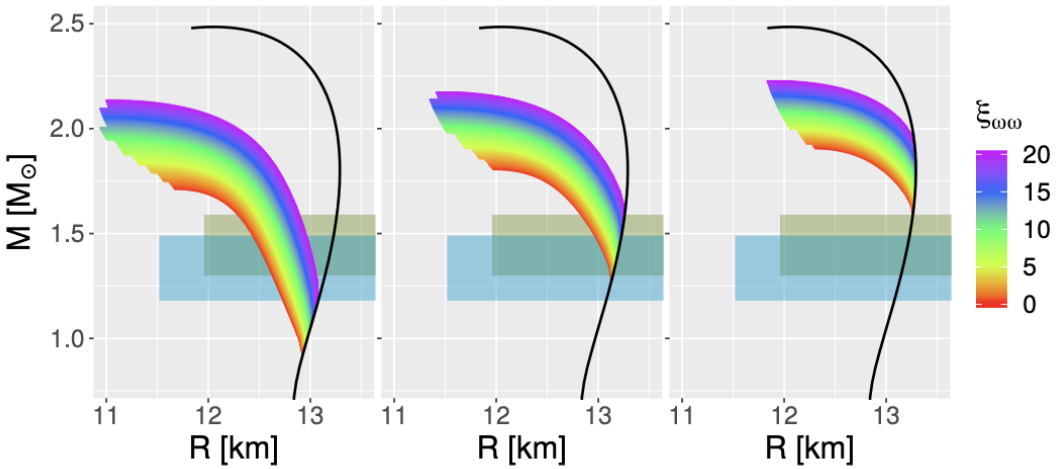
Preliminary

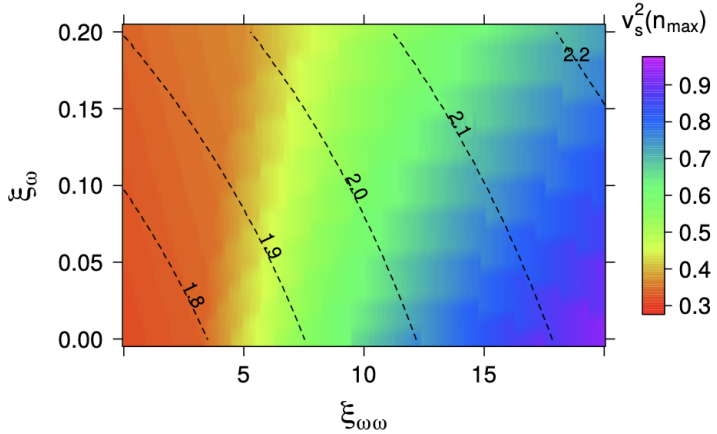


K Marquez, T. Malik, H. Pais, CP

Hybrid stars with NJL

Preliminary

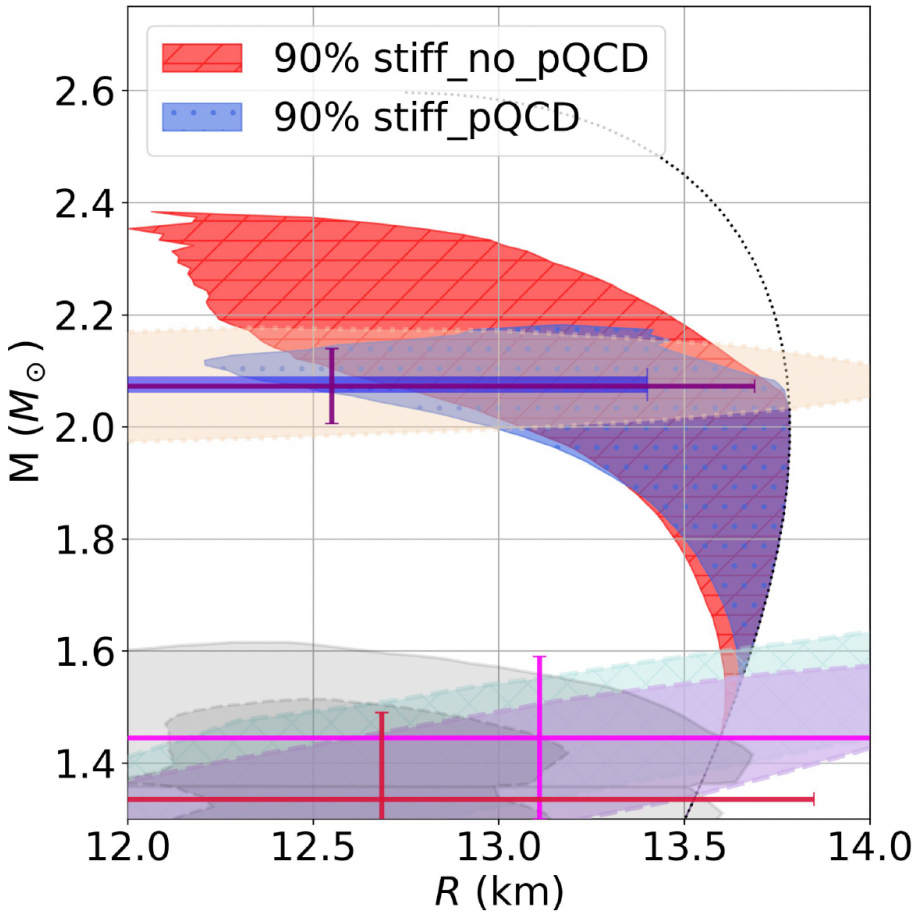




Ferreira, Pereira, CP PRD102, 083030

Hybrid stars with NJL: pQCD filter

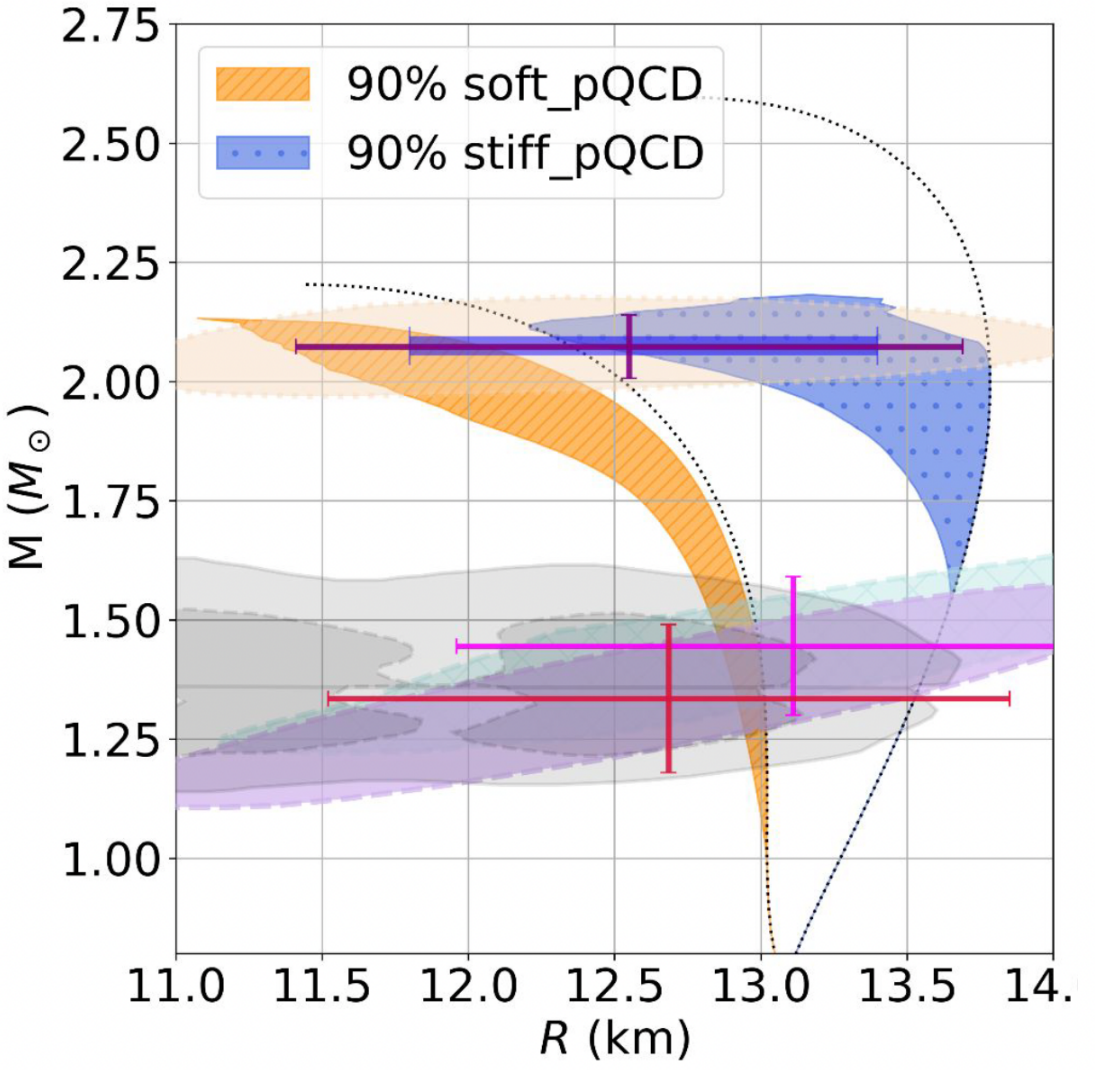
Preliminary



Milena Albino, T Malik, M Ferreira, CP

Hybrid stars with NJL

Preliminary



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Thank you !