



FAST/Future Pulsar Symposium 15

致密星中的多夸克态

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Outline



➤ **Introduction**

➤ **Models**

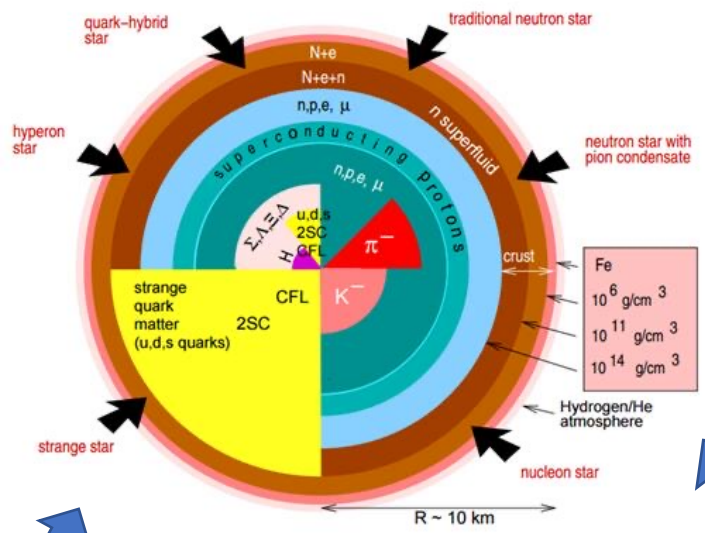
➤ **Results**

➤ **Summary**

Introduction (NS)

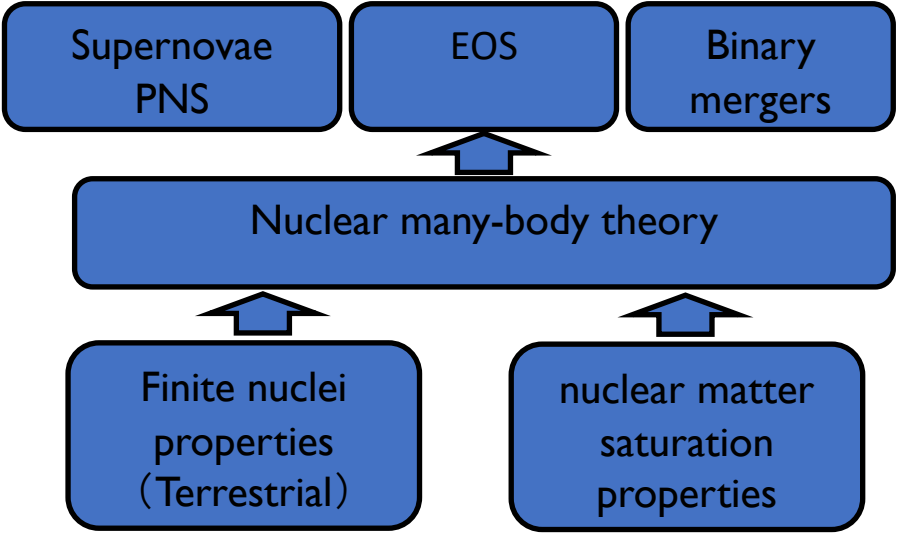
- temperature (T):
0 ~ 100 MeV
- proton fraction (Yp or YL):
0 ~ 0.5
- Rapid spin (Period)
10⁻³-10^{1.5}s

Pulsar structures

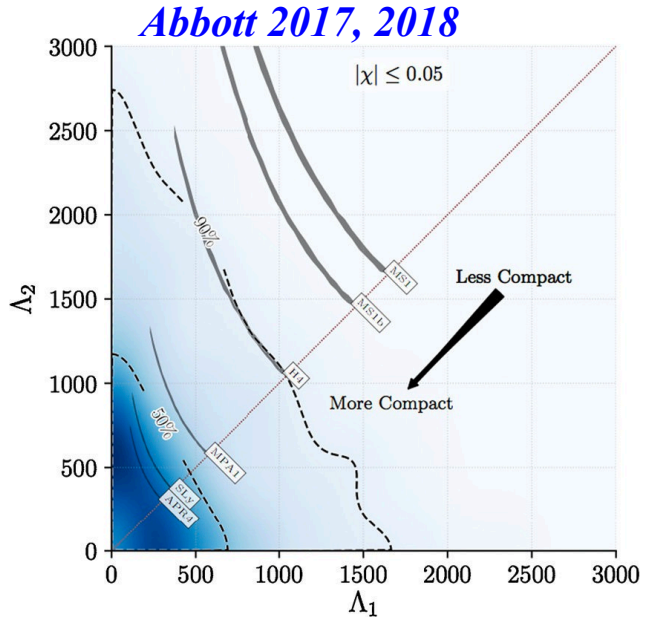
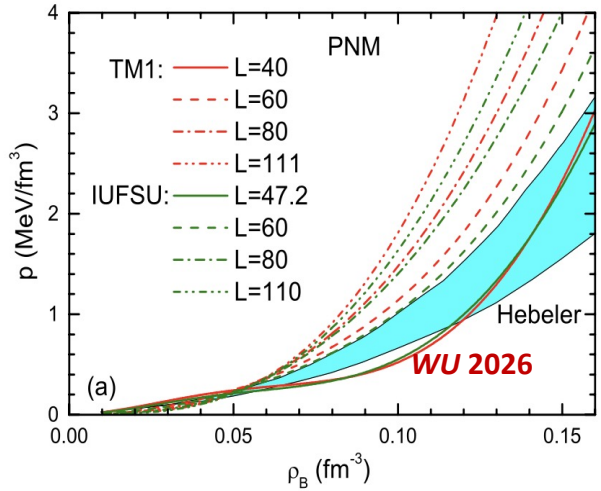


Constraints (NICER and GW):

PSR J0030+0451	2026	$12.68^{+1.31}_{-1.04}$	$1.43^{+0.20}_{-0.17}$
PSR J0740+6620	2024	$12.49^{+1.28}_{-0.88}$	2.073 ± 0.069
PSR J0437-4715	2024	$11.36^{+0.95}_{-0.63}$	1.418 ± 0.037
PSR J1231-1411	2025	$9.91^{+0.88}_{-0.86}$	1.12 ± 0.07
PSR J0614-3329	2025	$10.29^{+1.01}_{-0.86}$	$1.44^{+0.06}_{-0.07}$

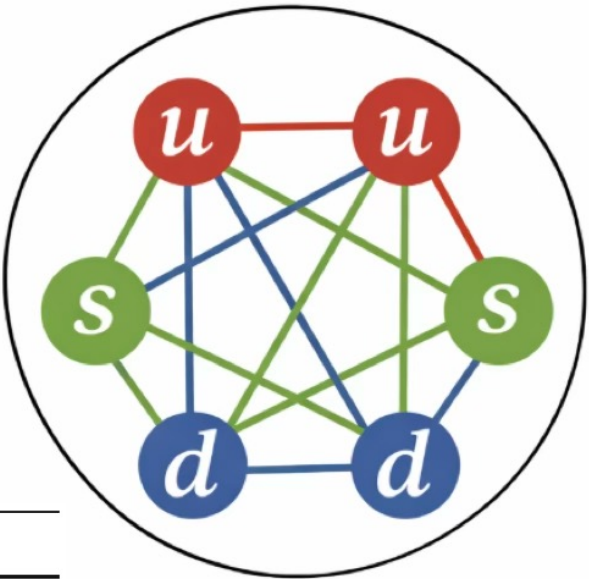


Weber 2005



Chromomagnetic Interaction (CMI) framework

$$\begin{aligned}
 H &= \sum_i m_i^0 + H_{\text{CEI}} + H_{\text{CMI}} \\
 &= \sum_i m_i^0 - \sum_{i < j} A_{ij} \vec{\lambda}_i \cdot \vec{\lambda}_j - \sum_{i < j} v_{ij} \vec{\lambda}_i \cdot \vec{\lambda}_j \vec{\sigma}_i \cdot \vec{\sigma}_j
 \end{aligned}$$



Hadron	<i>N</i>	Δ	Λ	Σ	Σ*	Ξ	Ξ*	Ω
<i>I</i> (<i>J^P</i>)	1/2(1/2 ⁺)	3/2(3/2 ⁺)	0(1/2 ⁺)	1(1/2 ⁺)	1(3/2 ⁺)	1/2(1/2 ⁺)	1/2(3/2 ⁺)	0(3/2 ⁺)
Mass	938.3	1232.0	1115.7	1189.4	1382.8	1314.9	1531.8	1672.5
Parameter	<i>m_{nn}</i>	<i>m_{ns}</i>	<i>m_{ss}</i>	<i>v_{nn}</i>	<i>v_{ns}</i>	<i>v_{ss}</i>		
Value	181.2	226.7	262.3	19.1	13.3	12.2		

<i>J^P</i>	0 ⁺		1 ⁺	2 ⁺	
Mass	2569.4	2212.7	2360.1	2752.3	2458.8

H particle mass: 2212.7 MeV
 < 2231 MeV——ΛΛ

RMF model with H particle

$$\mathcal{L}_{\text{RMFL}} = \mathcal{L}_{\text{N}} + \mathcal{L}_{\text{l}} + \mathcal{L}_{\text{m}} + \mathcal{L}_{\text{H}}$$

$$\mathcal{L}_{\text{N}} = \sum_{i=p,n} \bar{\psi}_i \left\{ i\gamma_\mu \partial^\mu - M^* \right. \\ \left. - \gamma_\mu \left[g_\omega \omega^\mu + \frac{g_\rho}{2} \tau_a \rho^{a\mu} \right] \right\} \psi_i$$

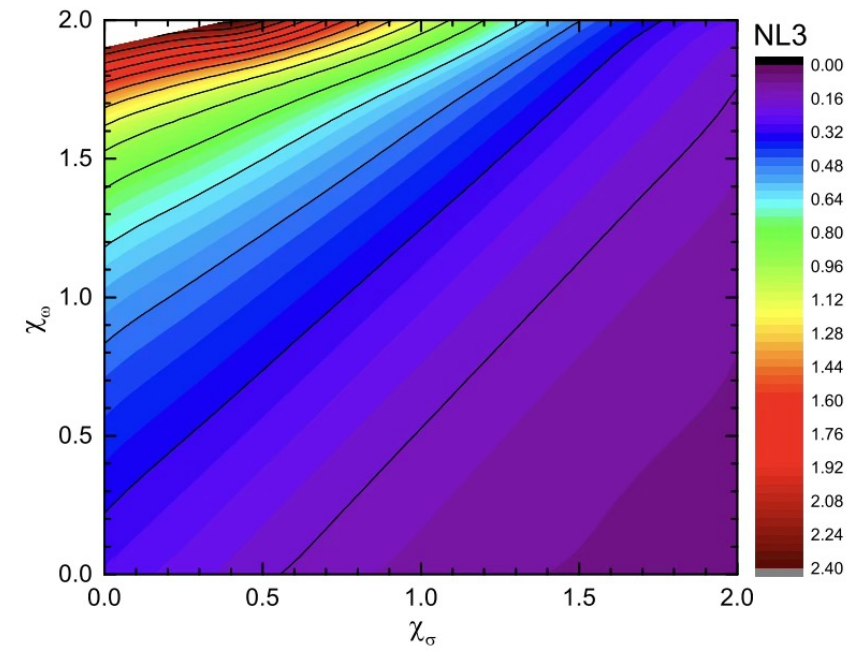
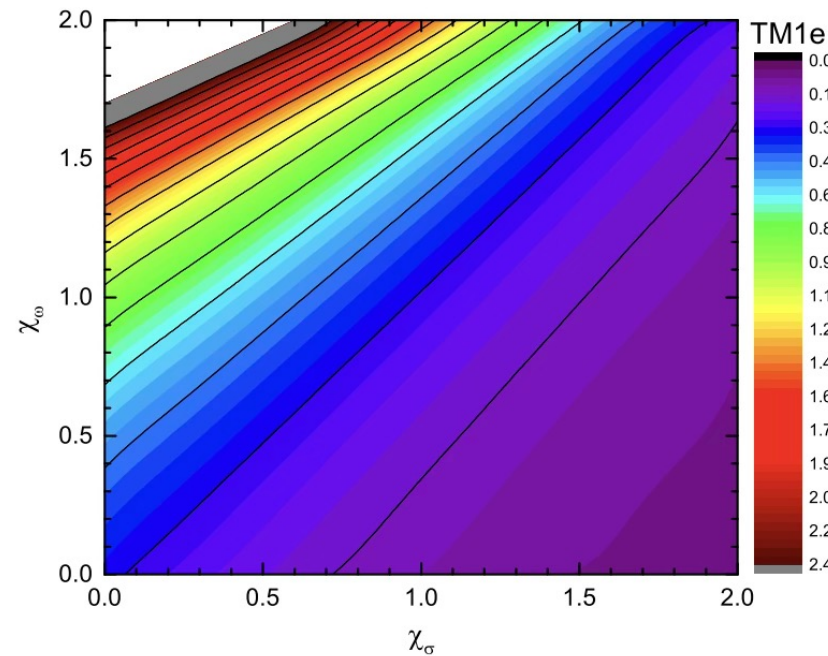
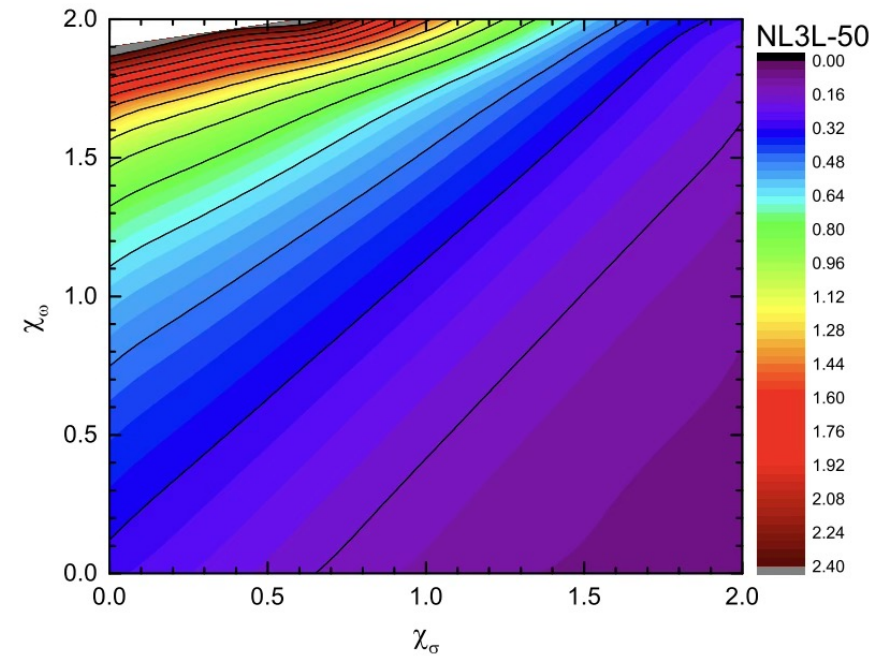
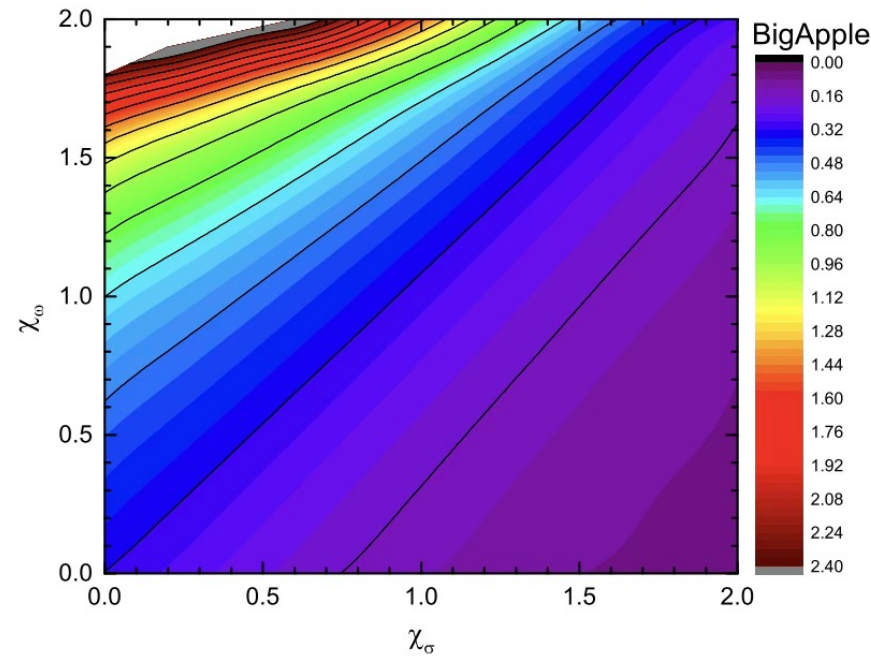
$$\mathcal{L}_{\text{l}} = \sum_{l=e,\mu} \bar{\psi}_l (i\gamma_\mu \partial^\mu - m_l) \psi_l$$

$$\mathcal{L}_{\text{H}} = (\partial_\mu - ig_{\omega H} \omega_\mu) \phi_H^* (\partial^\mu + ig_{\omega H} \omega^\mu) \phi_H \\ - (m_H + g_{\sigma H} \sigma)^2 \phi_H^* \phi_H$$

$$\mathcal{L}_{\text{m}} = \frac{1}{2} \partial_\mu \sigma \partial^\mu \sigma - \frac{1}{2} m_\sigma^2 \sigma^2 - \frac{1}{3} g_2 \sigma^3 - \frac{1}{4} g_3 \sigma^4 \\ - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu + \frac{1}{4} c_3 (\omega_\mu \omega^\mu)^2 \\ - \frac{1}{4} R_{\mu\nu}^a R^{a\mu\nu} + \frac{1}{2} m_\rho^2 \rho_\mu^a \rho^{a\mu} \\ + \Lambda_{\text{v}} g_\omega^2 g_\rho^2 \omega_\mu \omega^\mu \rho_\mu^a \rho^{a\mu}$$

$$\chi_{\sigma H} = \frac{g_{\sigma H}}{g_{\sigma N}}, \quad \chi_{\omega H} = \frac{g_{\omega H}}{g_{\omega N}}$$

Onset densities of H particle

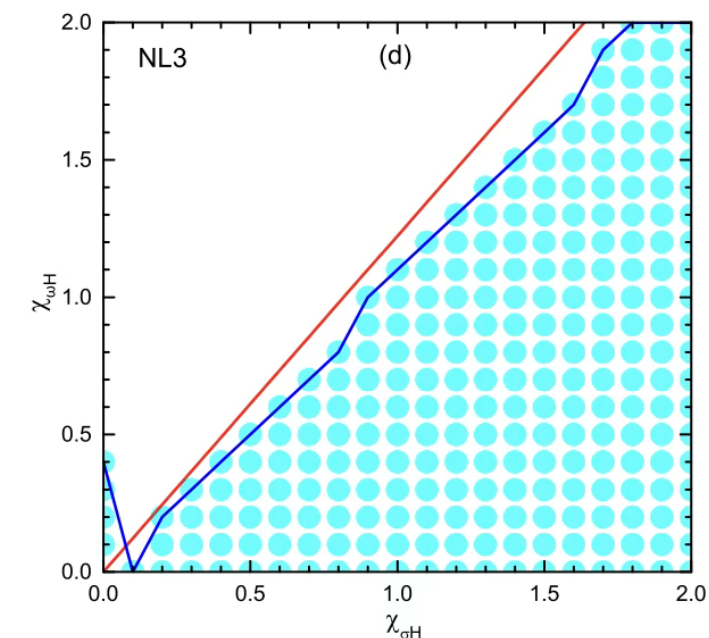
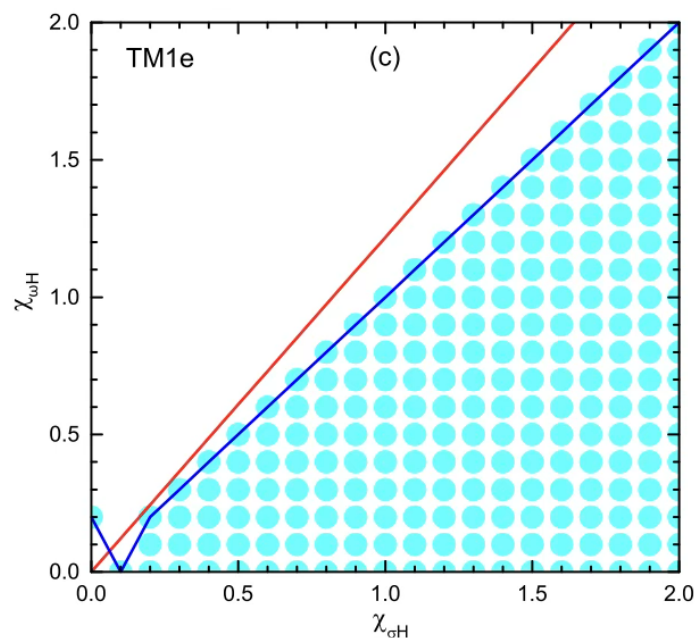
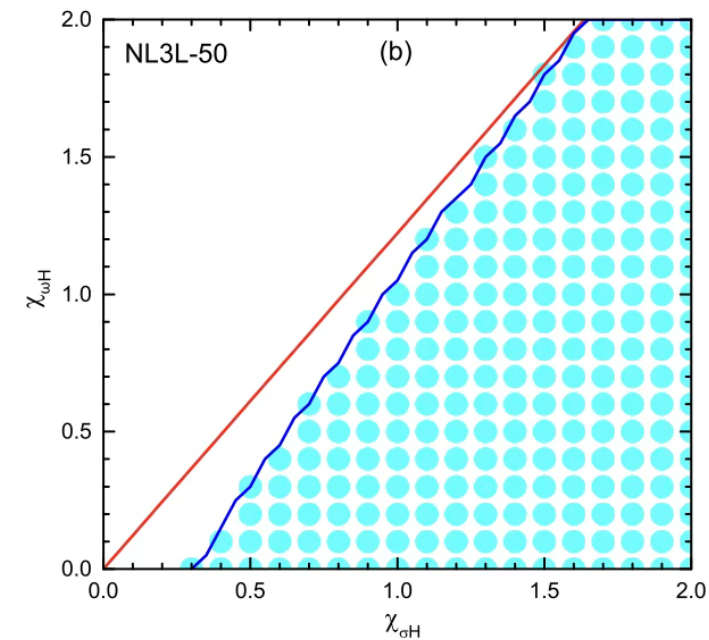
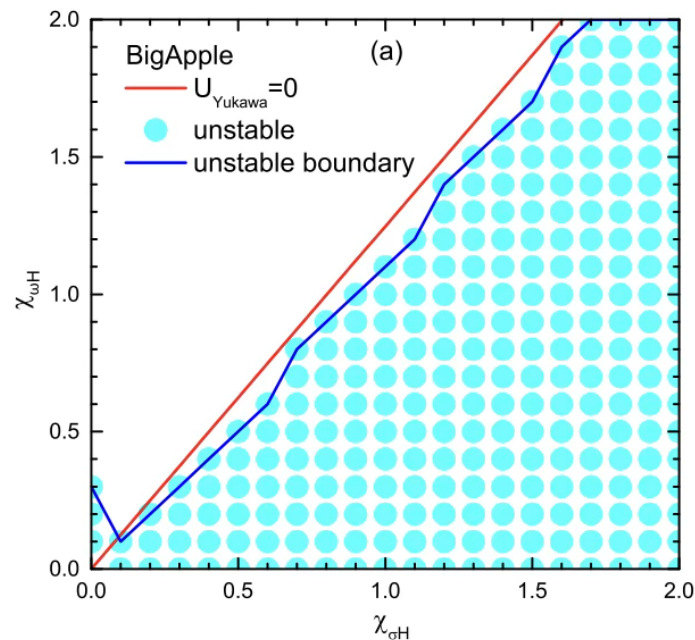


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H particle's
appearance
leads to
decreasing
pressure

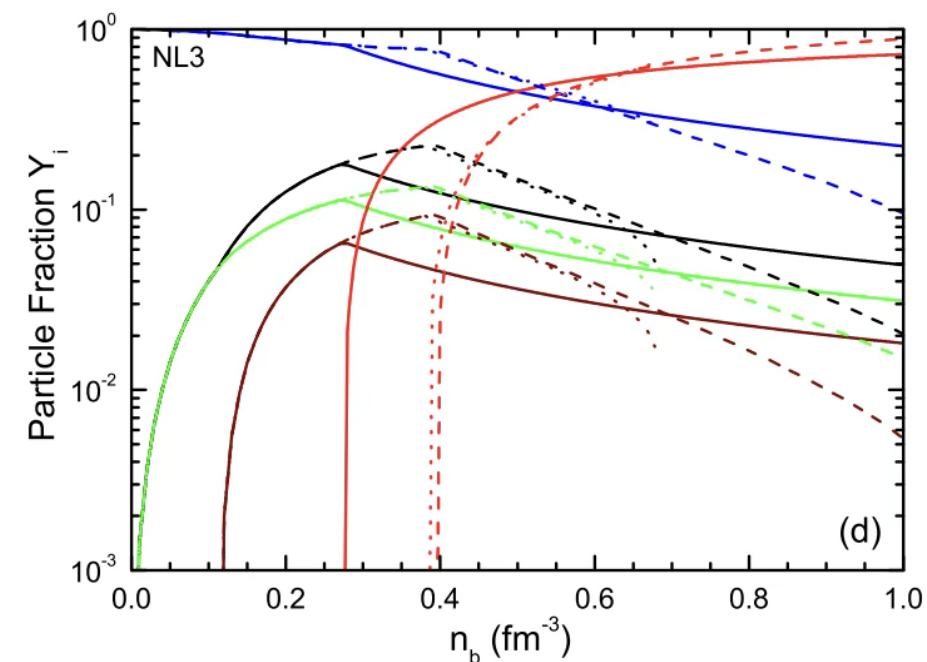
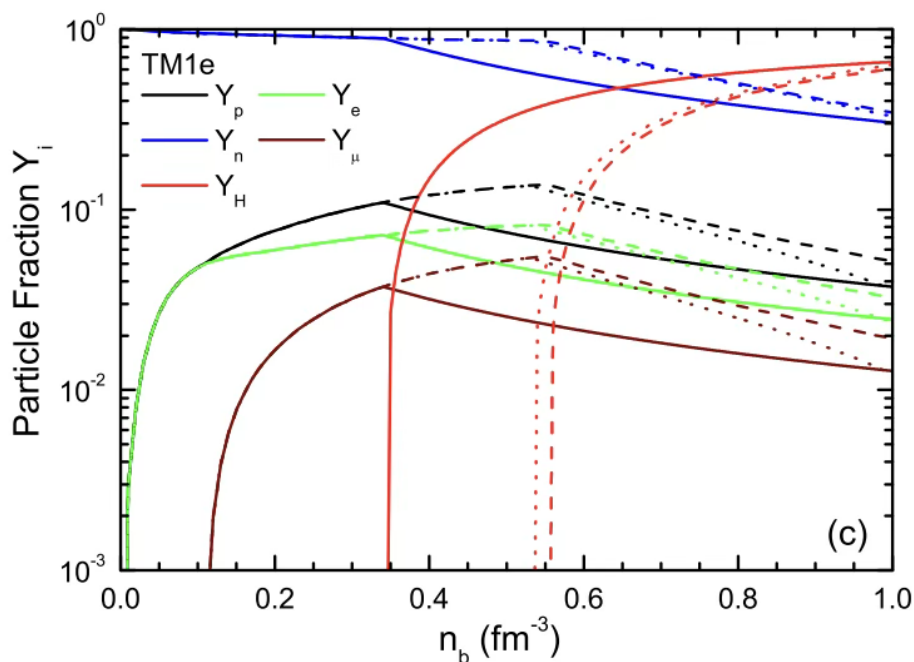
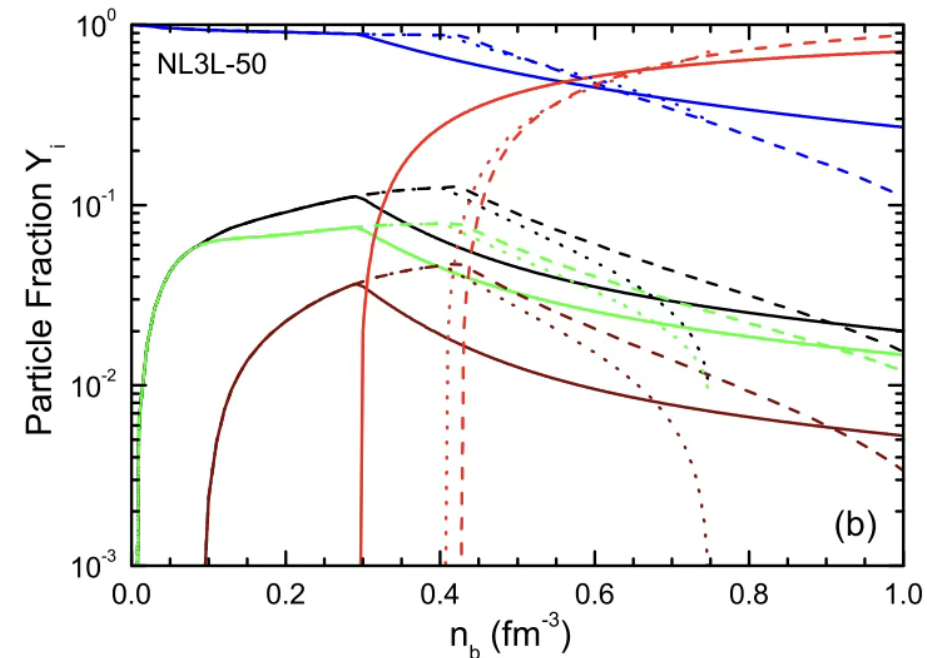
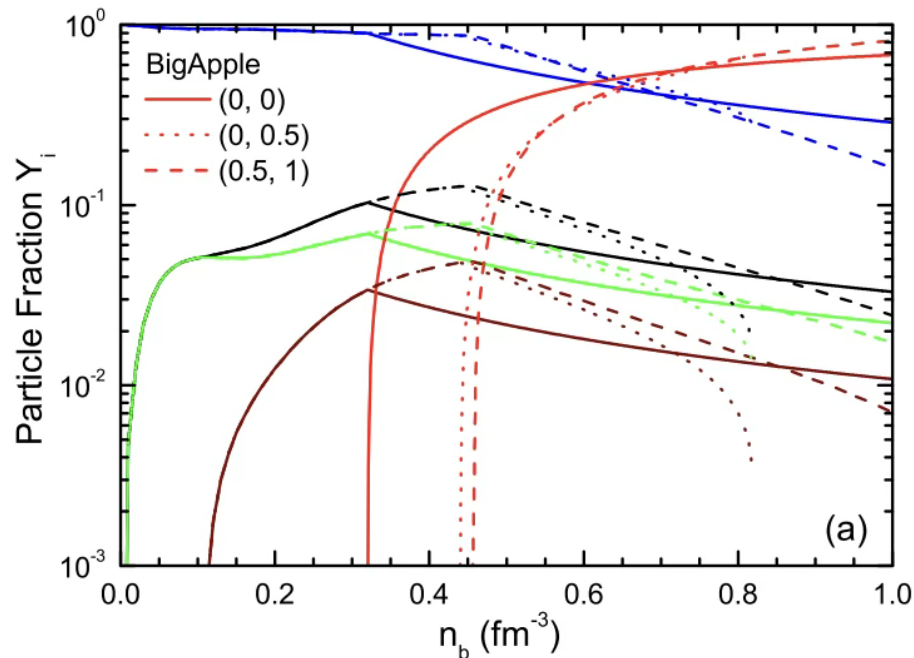
$$U_{\text{Yukawa}} = \frac{g_{\sigma H}^2}{m_{\sigma}^2} - \frac{g_{\omega H}^2}{m_{\omega}^2}$$

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Particle fractions

$$\chi_{\sigma H} = \frac{g_{\sigma H}}{g_{\sigma N}}, \quad \chi_{\omega H} = \frac{g_{\omega H}}{g_{\omega N}}$$

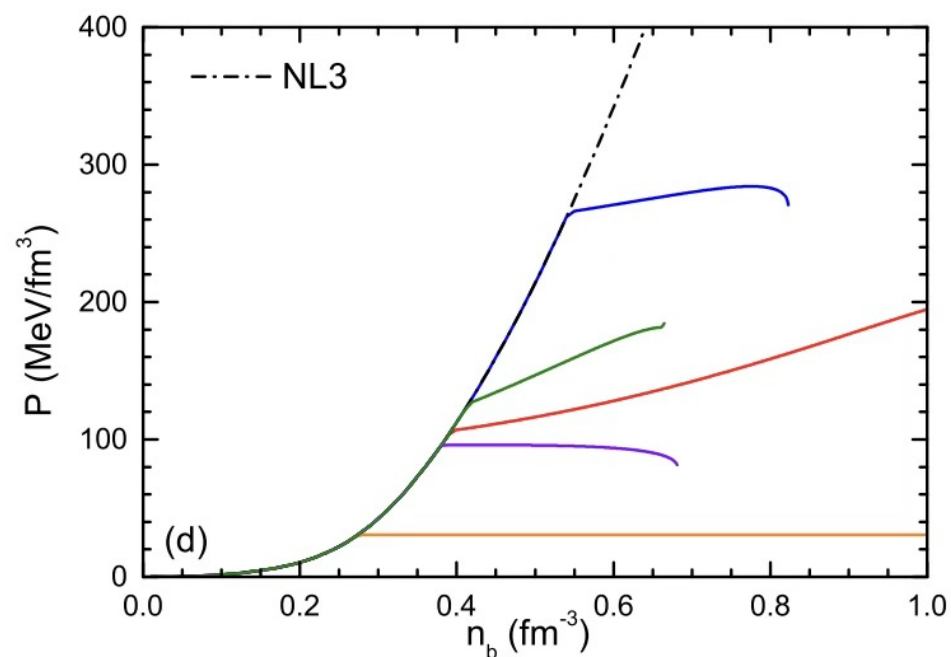
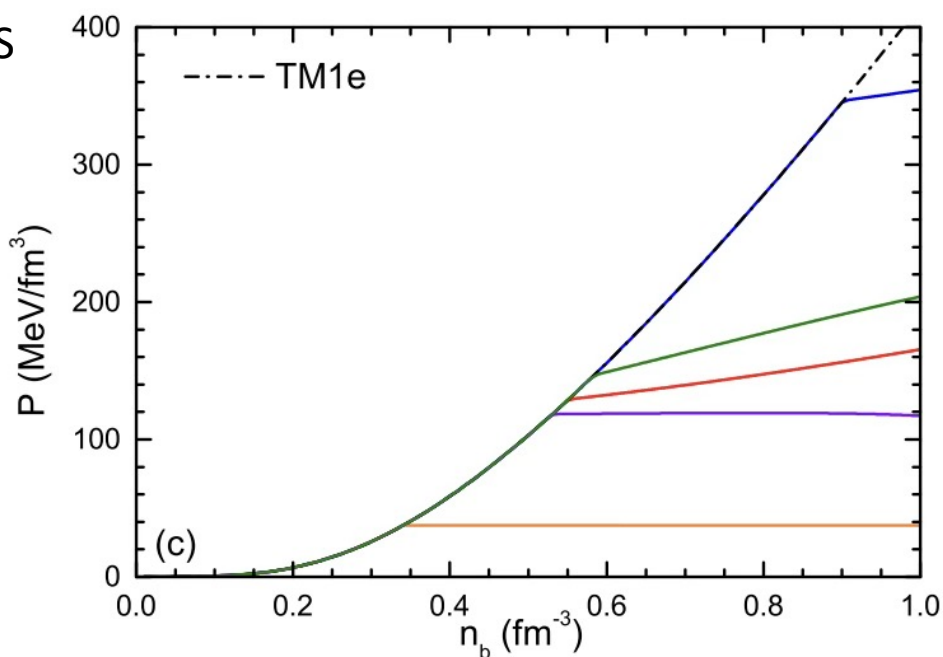
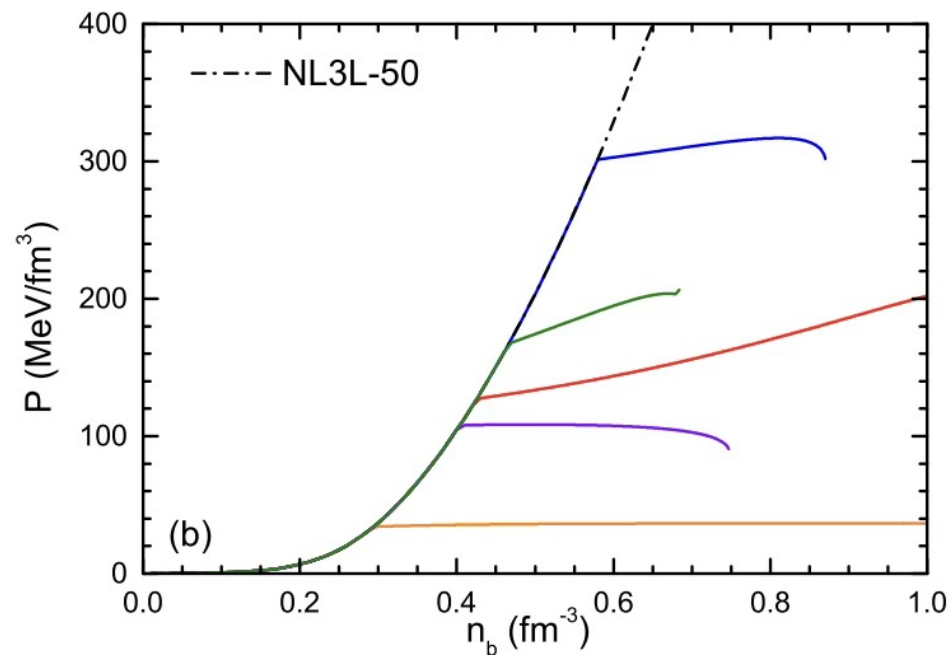
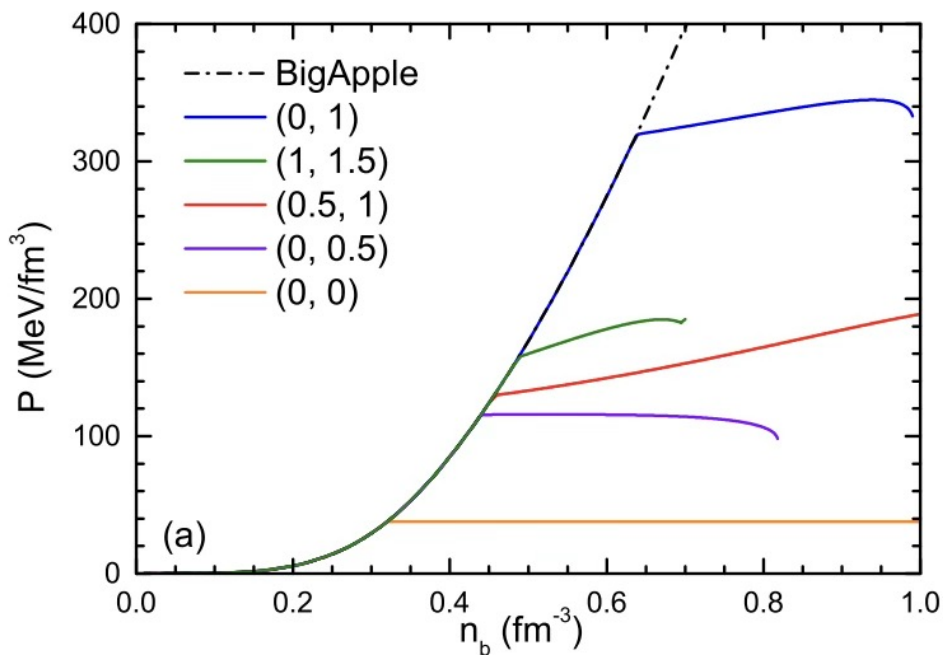


H particles replace part of the baryonic component.

β -equilibrium

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The EOSs



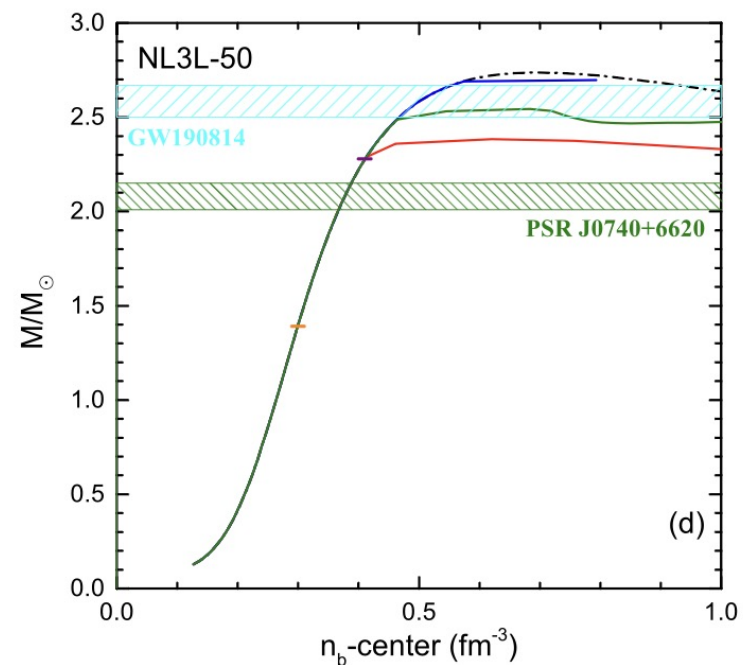
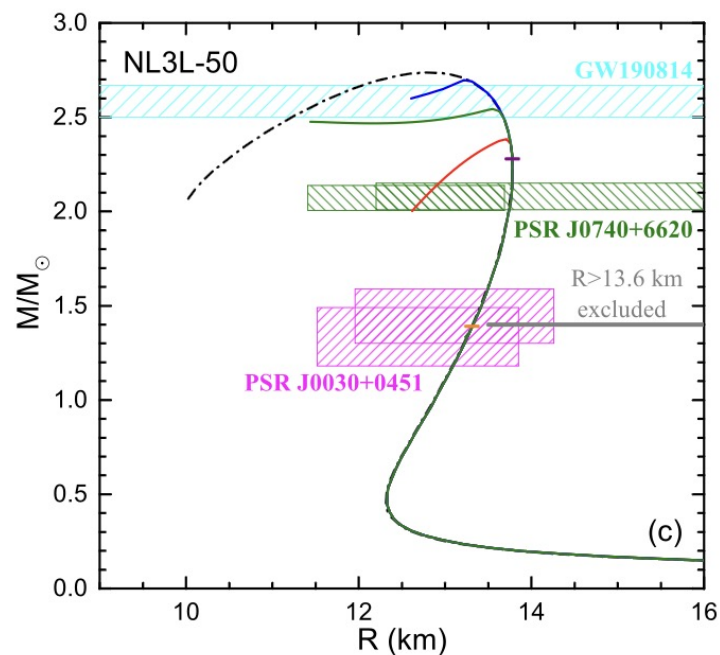
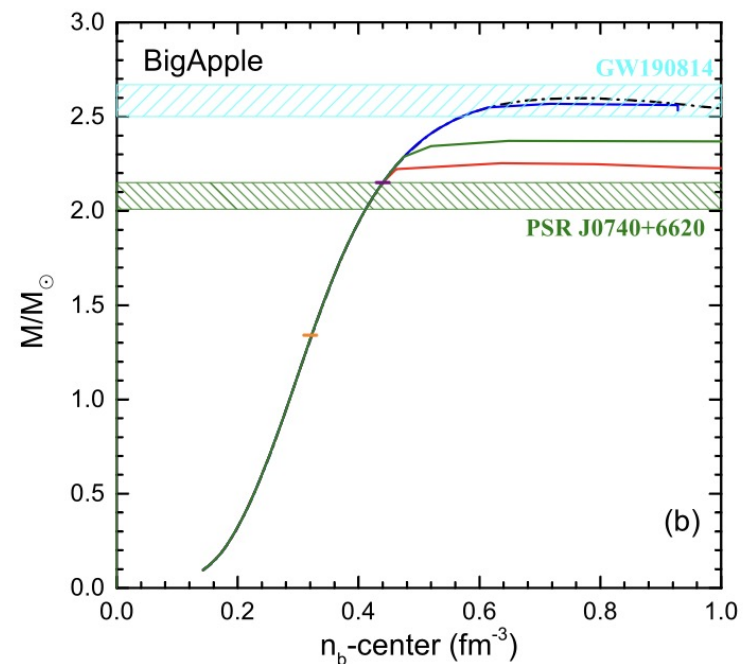
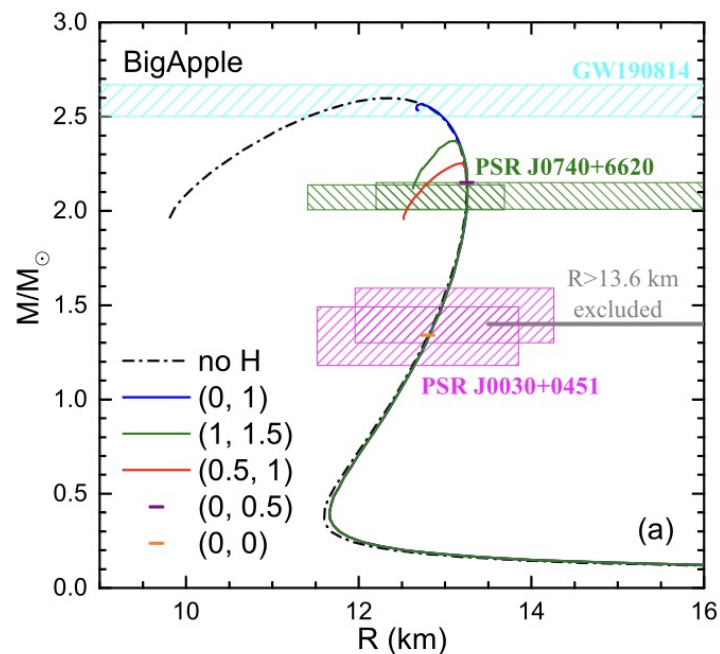
H particles soften the EOS significantly.

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Mass-radius relations and mass-central density relations

Repulsive interactions remain compatible

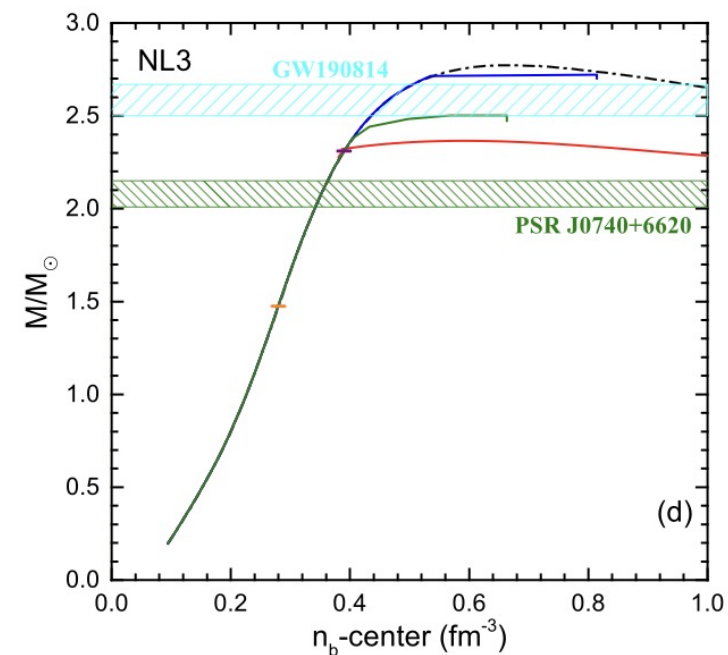
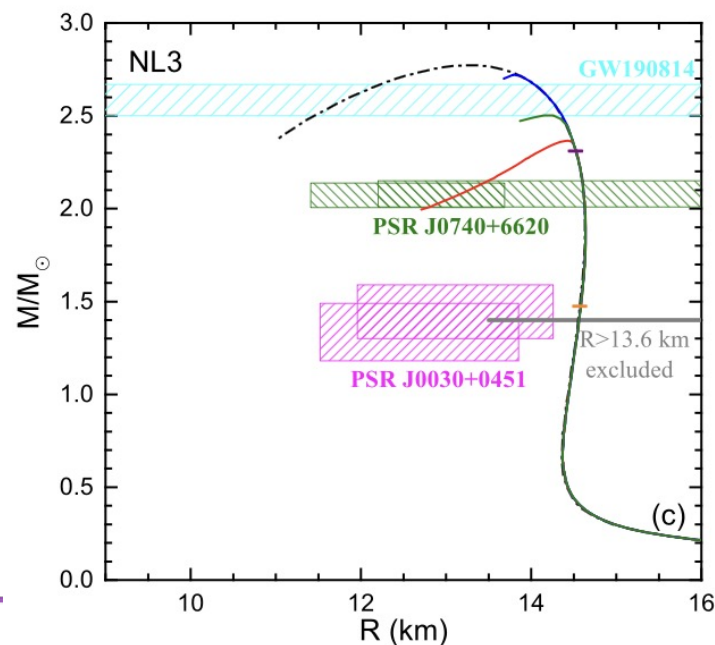
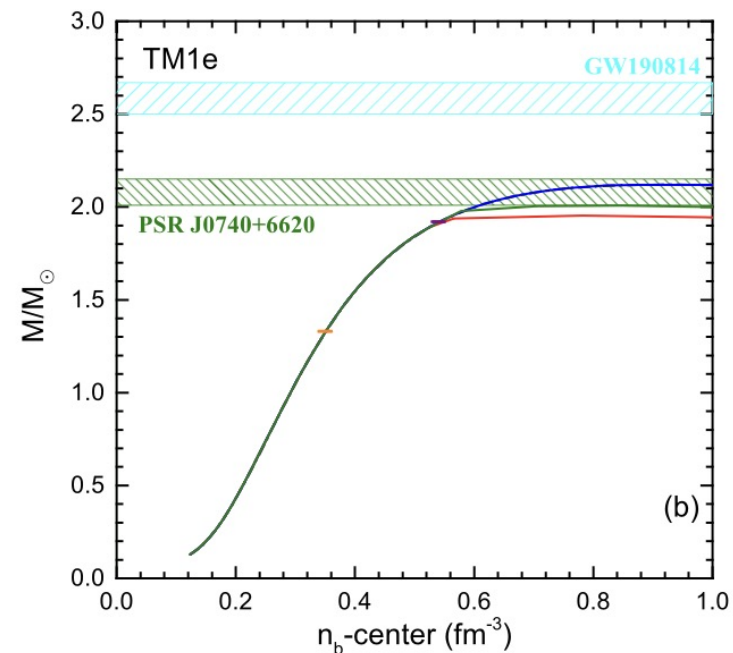
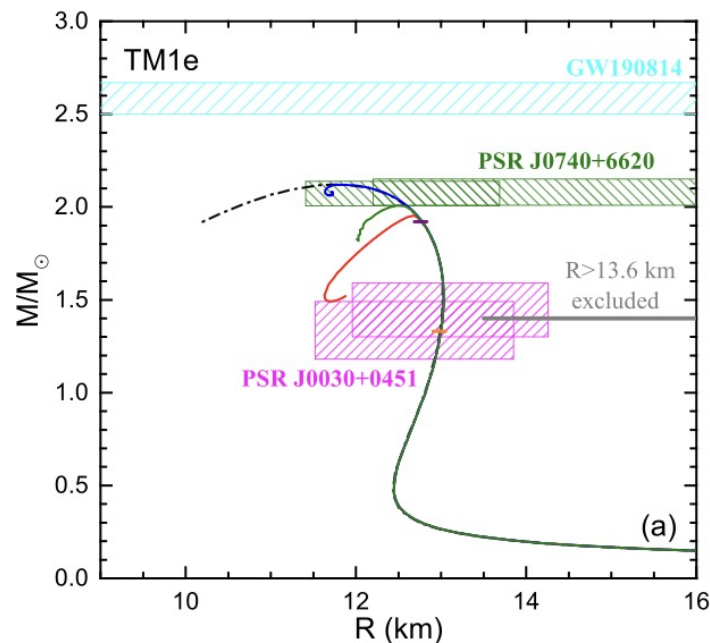
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Mass-radius relations and mass-central density relations

Attractive interactions trigger instability.

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Summary and Perspective

- We predicted an H-particle mass of 2212.7 MeV using the CMI model.
- H particles soften the EOS and reduce the maximum neutron-star mass.
- Stable H-particle neutron stars require sufficiently repulsive interactions.
- Attractive or weak interactions generally destabilize NSs and trigger collapse.

To Do: other Multi-quark states?

Thanks!

The total wave function of $nnnnss$ ($I=0$) state

$$\psi_{\text{tot}} = \psi_{\text{space}} \otimes \psi_{\text{flavor}} \otimes \psi_{\text{color}} \otimes \psi_{\text{spin}}$$

$$\begin{aligned} & \left(\begin{array}{|c|} \hline 1 \\ \hline 2 \\ \hline 3 \\ \hline 4 \\ \hline \end{array} ; \begin{array}{|c|} \hline 5 \\ \hline 6 \\ \hline \end{array} \right)_{FCS} = \sqrt{\frac{1}{2}} \left(\begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & 4 \\ \hline \end{array}_I ; \begin{array}{|c|c|} \hline 5 & 6 \\ \hline \end{array}_F \right) \\ & \quad \otimes \left(\begin{array}{|c|c|} \hline 1 & 3 \\ \hline 2 & 4 \\ \hline \end{array} ; \begin{array}{|c|} \hline 5 \\ \hline 6 \\ \hline \end{array} \right)_{CS} \\ & \quad - \sqrt{\frac{1}{2}} \left(\begin{array}{|c|c|} \hline 1 & 3 \\ \hline 2 & 4 \\ \hline \end{array}_I ; \begin{array}{|c|c|} \hline 5 & 6 \\ \hline \end{array}_F \right) \\ & \quad \otimes \left(\begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & 4 \\ \hline \end{array} ; \begin{array}{|c|} \hline 5 \\ \hline 6 \\ \hline \end{array} \right)_{CS}. \end{aligned}$$

NICER Mass-Radius Constraints: Reliability Comparison



Source	Mass Prior Knowledge	Distance Prior	Signal Strength (SNR)	Hotspot Complexity	Model Dependence	Systematic Risk	Reliability Grade
J0030-0451	None (fully inferred)	Moderate	High	Moderate	Moderate	Low	★★★★☆ (benchmark source)
J0740+6620	Strong (Shapiro delay constrained)	Moderate	Medium–High	Moderate	Moderate	Moderate (background modeling)	★★★★★ (EOS anchor point)
J0437-4715	Very strong (precise timing)	Very precise	Very High	Low–Moderate	Low	Low	★★★★★ (best $R_{1.4}$ constraint)
J0614-3329	Partial constraints	Moderate	Medium	Moderate	Low–Moderate	Moderate	★★★★☆ (soft-EOS indicator)
J1231-1411	None	Moderate	Low–Medium	Very High	Very High	High	★★☆☆☆ (degenerate geometry source)