Multi-physics constraints at different densities to probe nuclear symmetry energy

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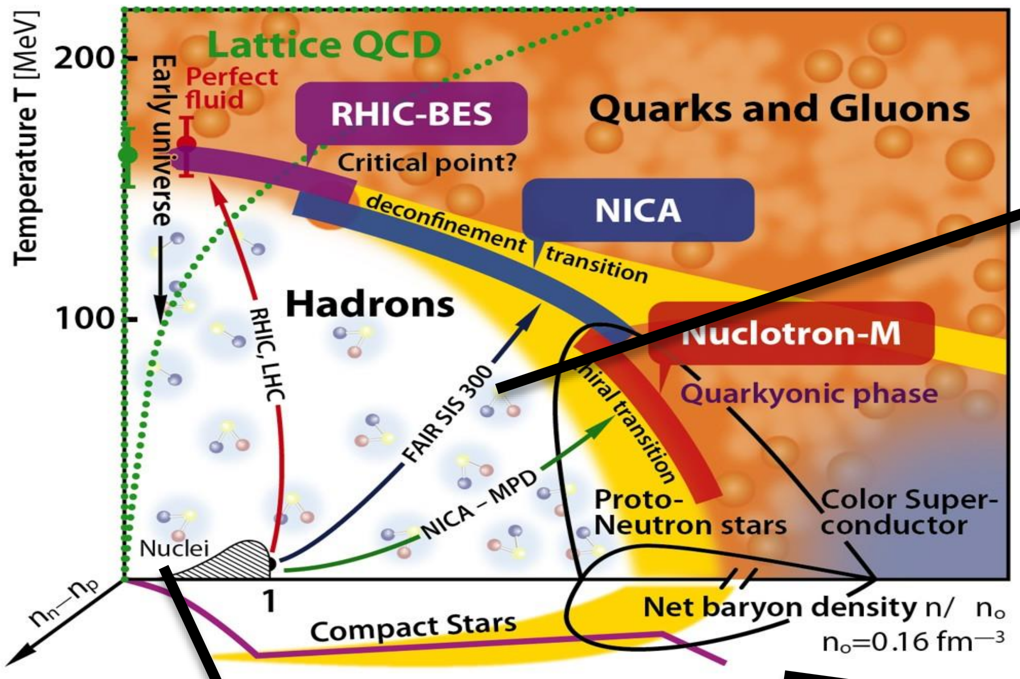
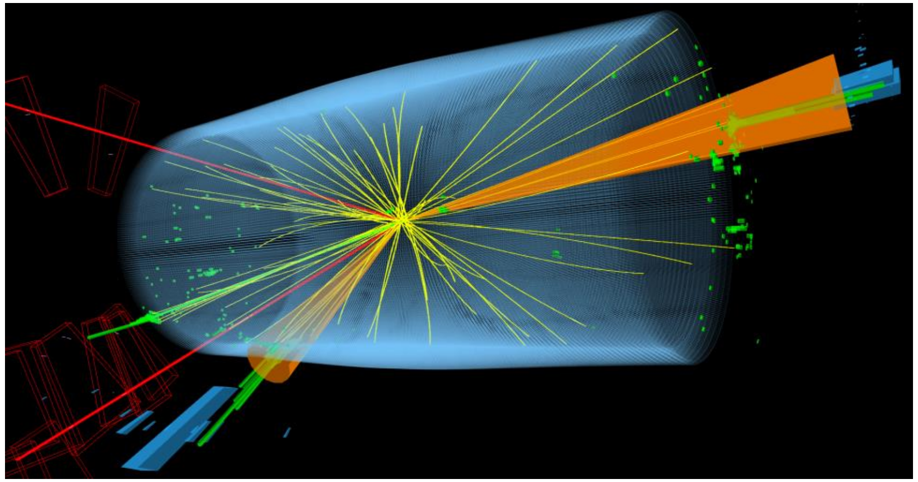
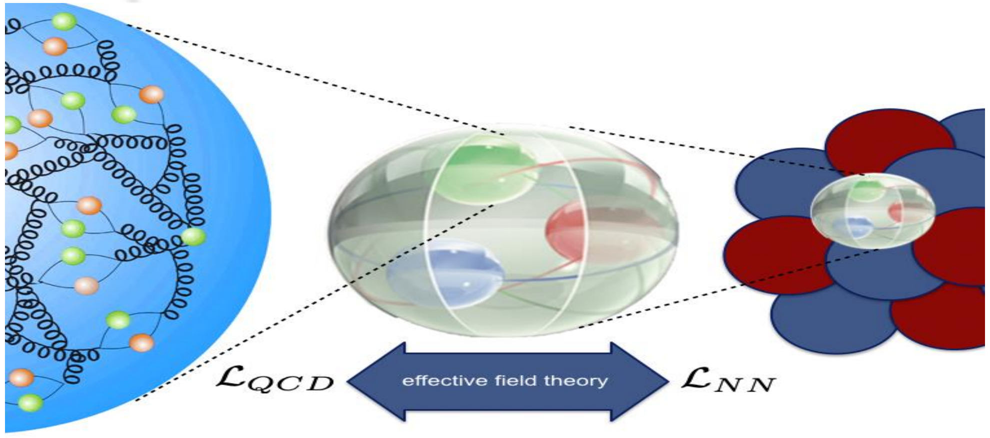
Constraints at different density regions

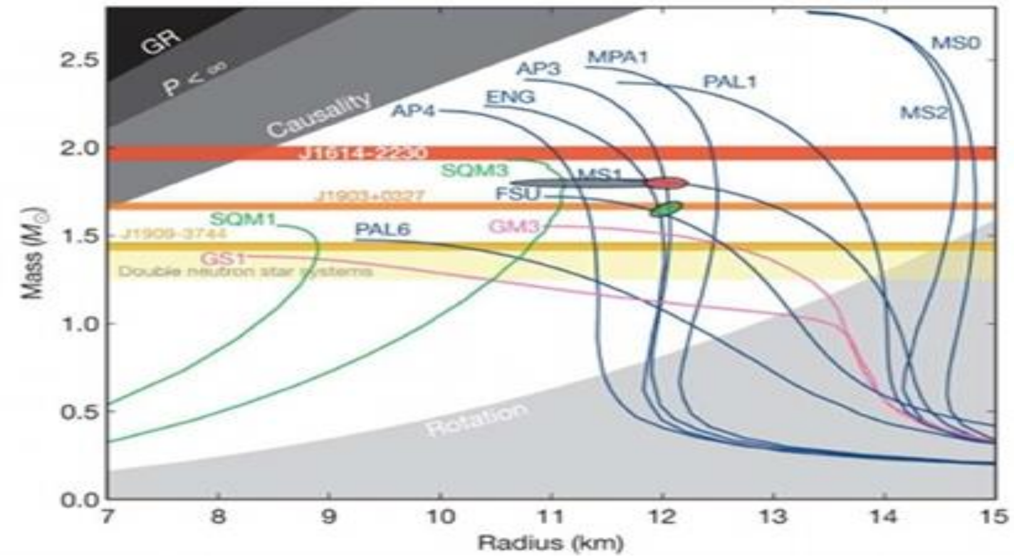


HIC experiments : KaoS, FOPI, ASY-EOS(n_b/n_0 ~ 1 - 3)



Chiral EFT (n_b/n_0 ~ 0.5 - 1)





(Demorest et al. 2010)

Formalism

➢ Microscopic description

- EoS : Relativistic mean field theory

$$\mathcal{L}_{int} = \sum_N \bar{\Psi}_N \left[g_\sigma \sigma - g_\omega \gamma^\mu \omega_\mu - \frac{g_\rho}{2} \gamma^\mu \vec{\tau} \vec{\rho_\mu} \right] \Psi_N$$
$$- \frac{1}{3} b m (g_\sigma \sigma)^3 - \frac{1}{4} c (g_\sigma \sigma)^4$$
$$+ \Lambda_\omega (g_\rho^2 \vec{\rho_\mu} \vec{\rho^\mu})(g_\omega^2 \omega_\mu \omega^\mu) + \frac{\zeta}{4!} (g_\omega^2 \omega_\mu \omega^\mu)^2$$

- Range of empirical parameters considered

n_0 (fm^{-3})	E_{sat} (MeV)	K_{sat} (MeV)	E_{sym} (MeV)	L_{sym} (MeV)	m^*/m
0.14 - 0.17	-16±0.2	200 - 300	28 - 34	40 - 70	0.55 - 0.75

➢ Macroscopic description

$$\frac{dm(r)}{dr} = 4\pi\varepsilon(r) r^2 \ ,$$
$$\frac{dp(r)}{dr} = -\frac{[p(r) + \varepsilon(r)][m(r) + 4\pi r^3 p(r)]}{r(r - 2m(r))}$$
$$\Lambda = \frac{2}{3} k_2 \left(\frac{R}{M} \right)^5$$

➢ Baysian Scheme

- Cut-off filters

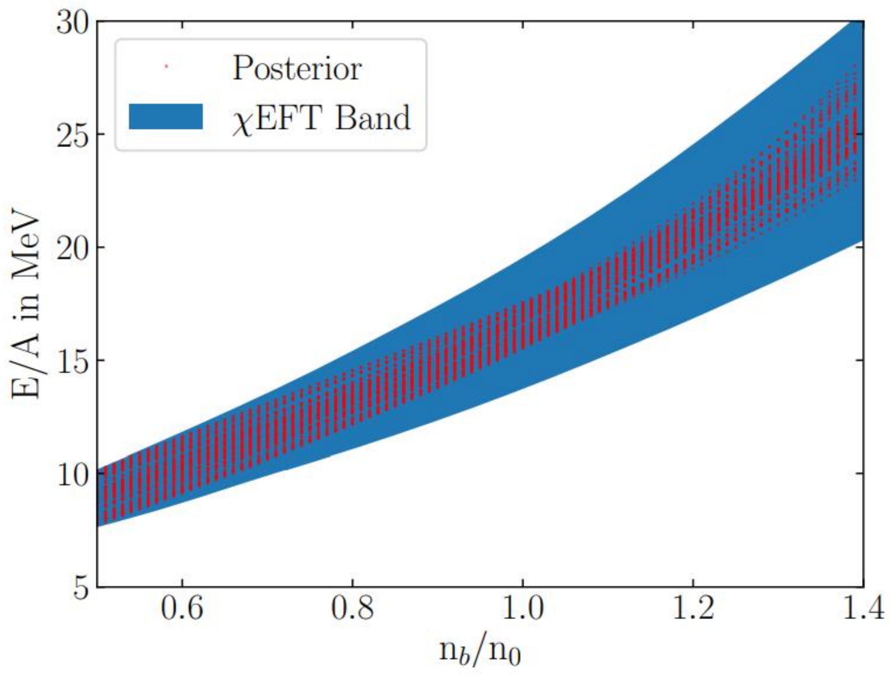
$$p(\{P_\alpha\}) = \frac{1}{N} w_{filter}(\{P_\alpha\}) \prod_\alpha g_\alpha(P_\alpha)$$

- Uniform prior of the nuclear parameters.

Filter functions

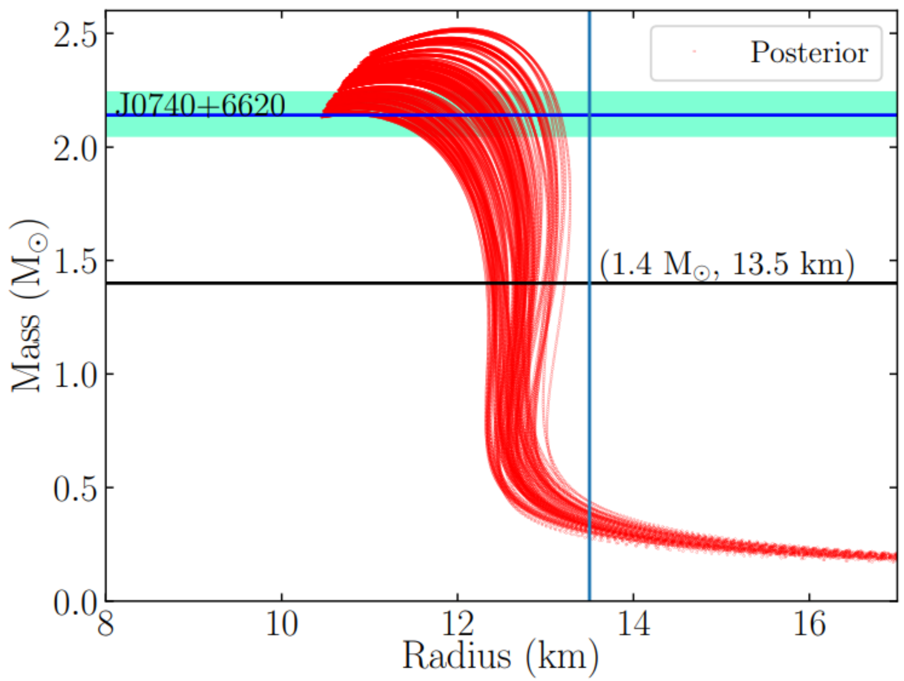
➢ Low density : CEFT

- many-body interactions among nucleons
- $n_b/n_0 \sim 0.5 - 1.4$
- Pure Neutron matter(PNM) EoS



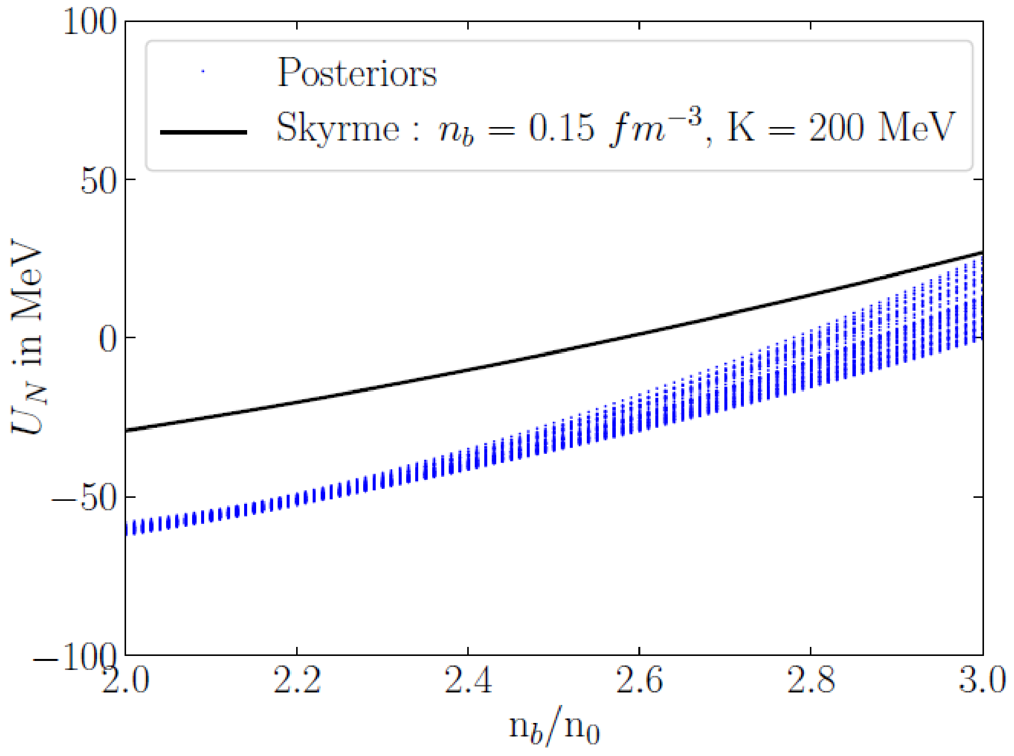
➢ High density : NS observations

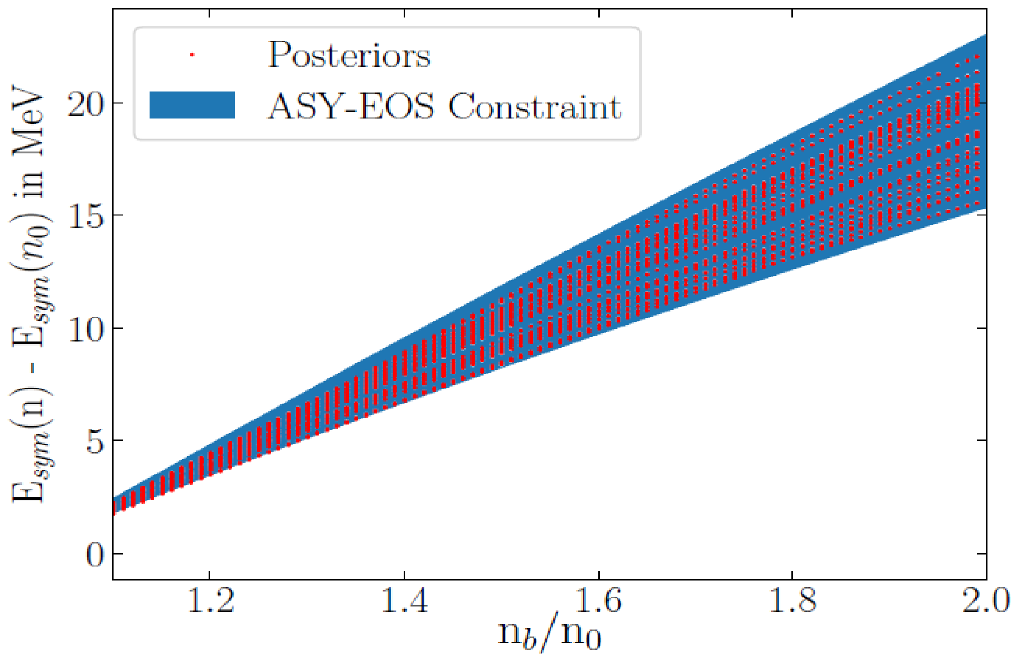
- Maximum mass : $2.14^{+0.10}_{-0.09}\ M_\odot$
- Tidal deformability estimate from the recent analyses of the GW170817 event : $\Lambda < 720$

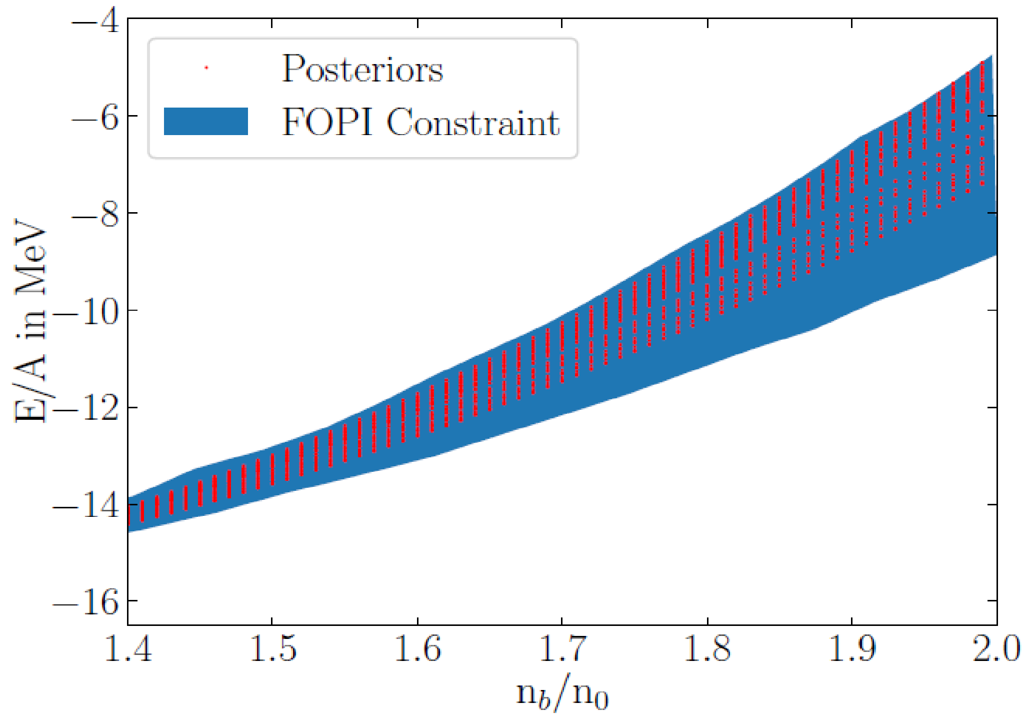


HIC Constraints

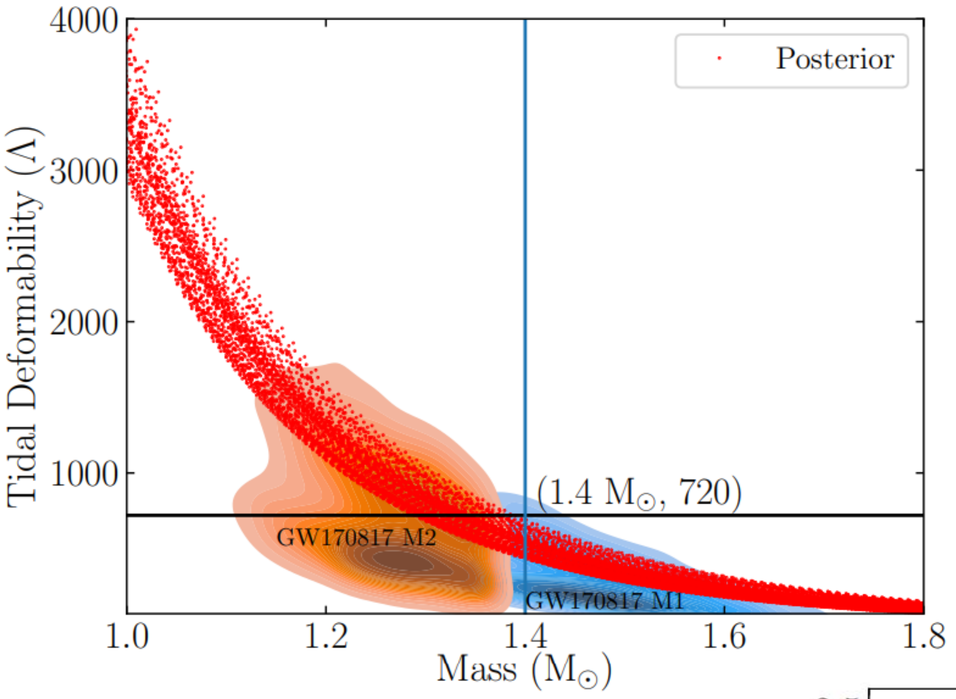
- KaoS : - Nucleon Potential in $n_b/n_0 \sim 2 - 3$
- FOPI :- Binding energy of SNM in $n_b/n_0 \sim 1.4 - 2$
- ASY-EOS :- Symmetry Energy of ANM in $n_b/n_0 \sim 1 - 2$

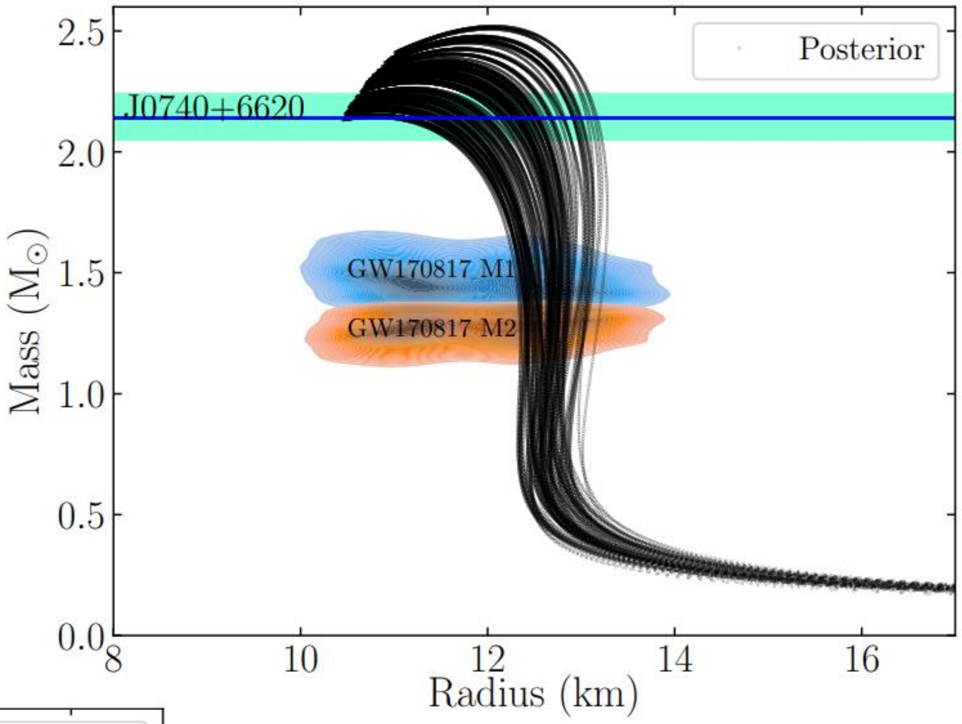


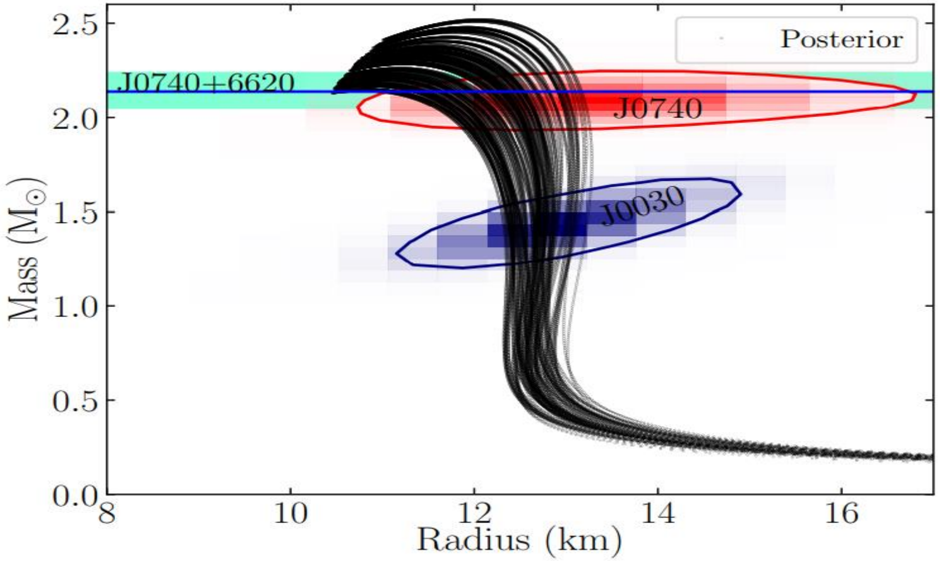




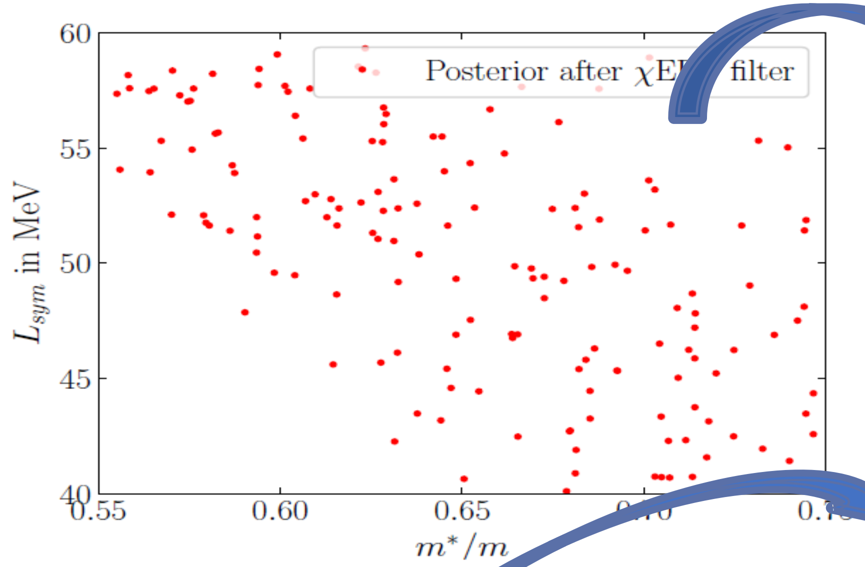
Comparing with GW170817 and NICER results







Correlation with Symmetry energy and its slope



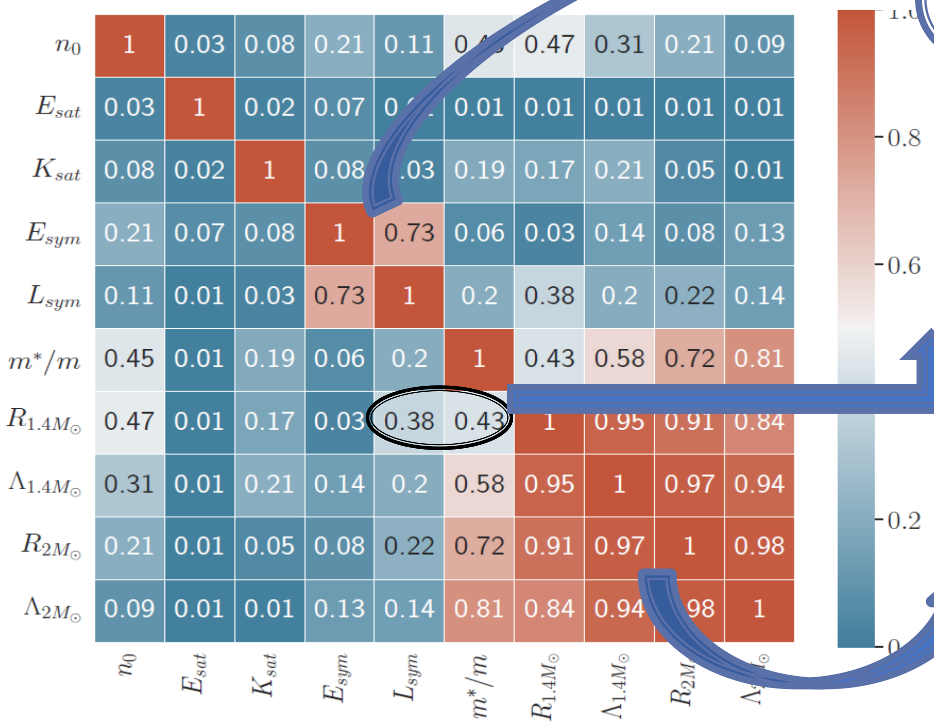
No physical solutions for the neutron matter EoS with simultaneously small slope of symmetry energy and small effective mass compatible with the Chiral EFT results due to the Hugenholtz-van Hove theorem.

Strong correlation between symmetry energy and its slope at saturation density but they are weakened after applying the HIC filters

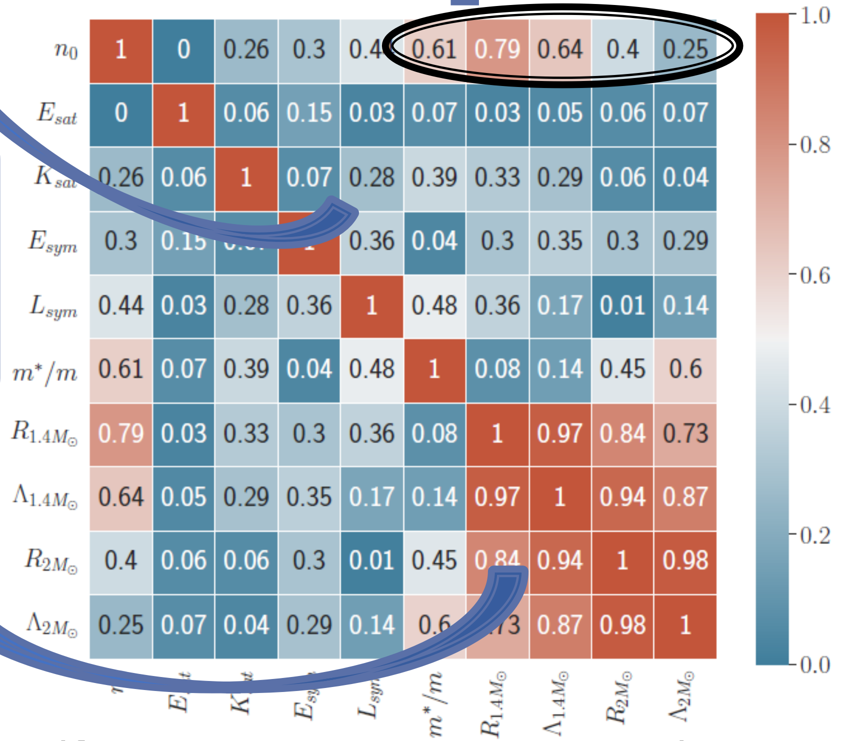
The nuclear saturation density has good correlation with the effective mass and the astrophysical observables.

Radius of 1.4 solar mass neutron star has low correlation with slope of symmetry energy but high correlation with effective mass.

High correlation between the astrophysical observables.



Filters : CEFT + Astro



Filters: CEFT + Astro + HIC experiments

Summary and outlook

- To constraint the parameter space of our RMF model, We applied low-density constraints from neutron matter from CEFT ab-initio approach, heavy-ion collision experimental results at intermediate densities and multi-messenger astrophysical observational data at high densities.
- We applied the constrained EoS parameter space to study correlations among nuclear empirical parameters and NS observables by applying a Bayesian scheme.
- We observed the usual strong correlation of L_{sym} with E_{sym} which are weakened by HIC filters.
- We found a weaker correlation of L_{sym} with $R_{1.4M\odot}$ in accordance with recent results.
- The most important nuclear parameters to consider for astrophysical data are the efffective nucleon mass m*/m and the nuclear saturation density n_0.