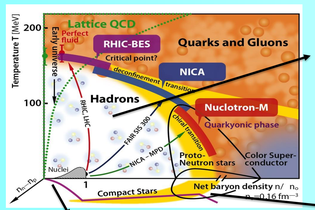
Multi-physics constraints at different densities to probe nuclear symmetry energy*

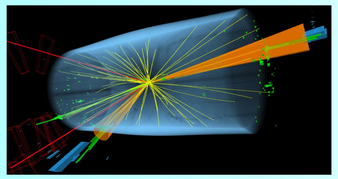
(Suprovo Ghosh[1a], Debarati Chatterjee[1] and Jürgen Schaffner-Bielich[2])

[1] Inter-University Centre for Astronomy and Astrophysics, Pune- India , [2] Institut für Theoretische Physik, Frankfurt - Germany

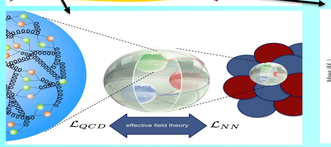
AIM AND MOTIVATION

- Imposing multi-physics constraints using a Bayesian scheme at different density regimes to constrain the nuclear parameter space.

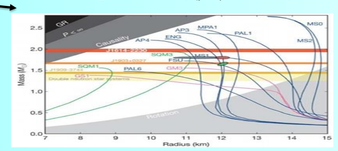




HIC experiments (n_b/n_0 ~ 1 - 3)



Chiral EFT(nb/n0 ~ 0.5 - 1)

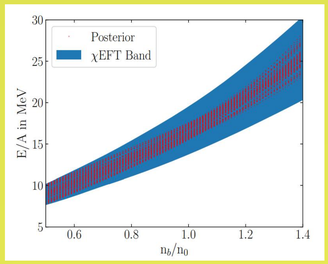


Multi-messenger observations

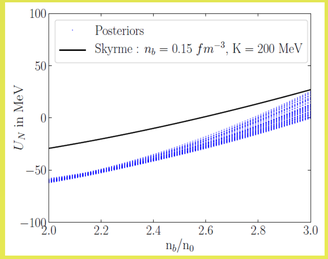
- Investigate possible correlations between empirical nuclear parameters, particularly symmetry energy and its slope, and astrophysical observables.

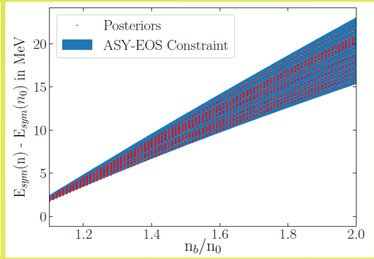
CONSTRAINTS AT DIFFERENT DENSITY REGIONS

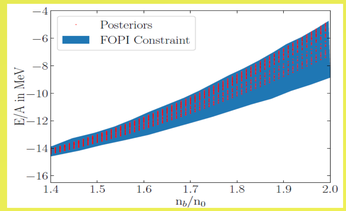
(Low density)
(CEFT)



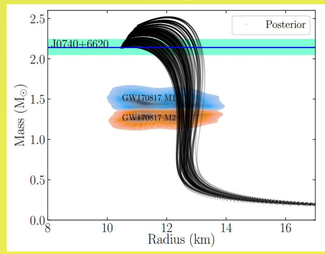
(Intermediate density)
(HIC experiments)
(KaOS, FOPI, ASY-EOS)

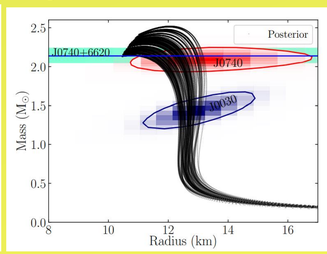


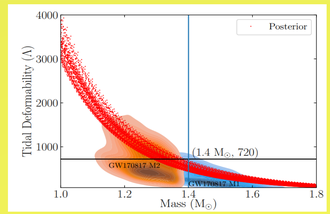




(High density)
(Astrophysical constraints)
(Highest observed pulsar mass and tidal deformability from NS merger event GW170817)







FORMALISM

- **Microscopic description :-**
  - Phenomenological RMF model.
  - Strong interaction mediated by scalar σ meson, vector ω meson and isovector ρ meson.
  - The nucleon-nucleon couplings are fitted to the nuclear saturation properties.

Range of nuclear empirical parameters :

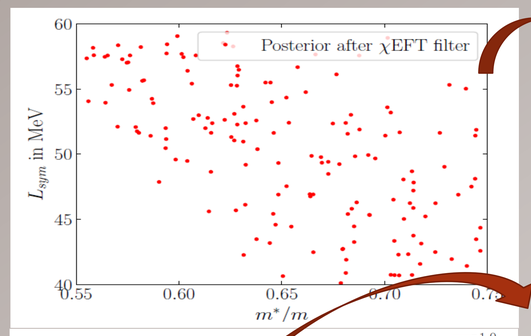
n_0 (fm^{-3})	E_{sat} (MeV)	K_{sat} (MeV)	E_{sym} (MeV)	L_{sym} (MeV)	m^*/m
0.14 - 0.17	-16±0.2	200 - 300	28 - 34	40 - 70	0.55 - 0.75

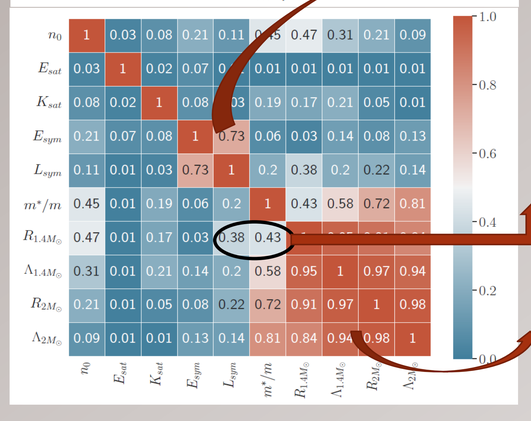
- **Macroscopic description :-**
  - The equilibrium configurations of non-rotating Neutron stars are obtained by solving the TOV equations of hydrostatic equilibrium.
  - Tidal deformability is obtained by solving differential equations coupled to the TOV equations[1].

- **Bayesian Scheme :-**
  - Uniform prior of the nuclear parameters.
  - The likelihood functions are filter functions appropriately chosen from the physical constraints at different densities.

[1] T. Hinderer, The Astrophysical Journal **677**(2008)

CORRELATION WITH SYMMETRY ENERGY AND ITS SLOPE





Filters : CEFT + Astro

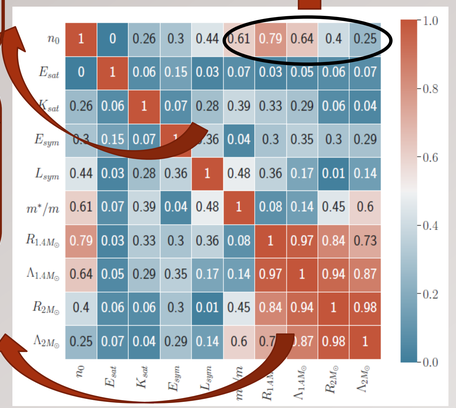
No physical solutions for the neutron matter EoS with simultaneously small slope of symmetry energy and small effective mass compatible with the Chiral EFT results due to the Hugenholtz-van Hove theorem.

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 + HIC experiments

CONCLUSION

- Parameter space of the applied RMF model is constrained using CEFT, HIC experiments and multi-messenger astrophysical observations.
- Strong correlation between symmetry energy and its slope, which is weakened by HIC filters.
- Weak correlation of slope of symmetry energy with radius of 1.4 solar mass neutron stars.
- Most important nuclear parameters to consider for astrophysical data are the effective nucleon mass and the nuclear saturation density.

* https://arxiv.org/abs/2107.09371

[a] suprovo@iucaa.in