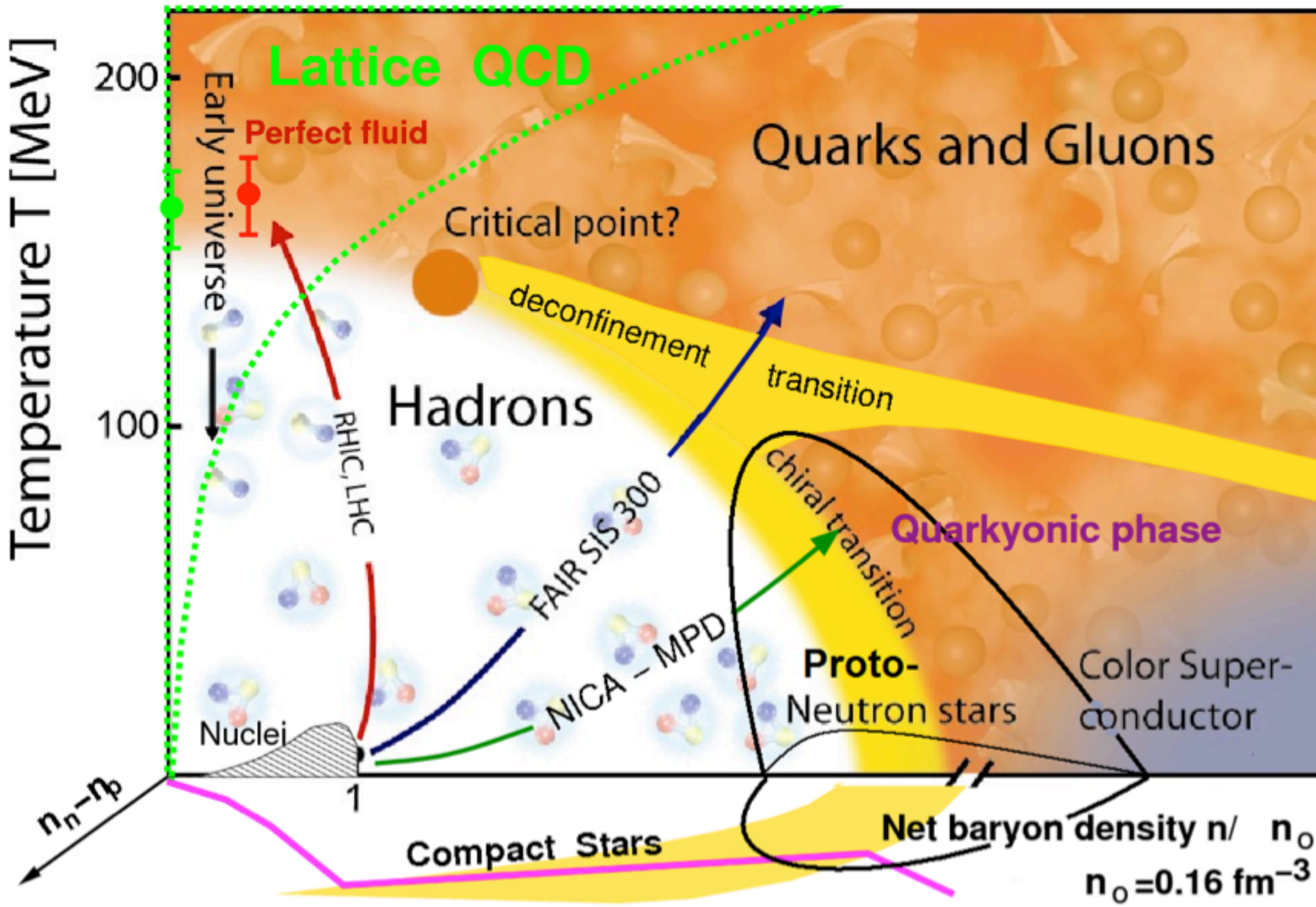




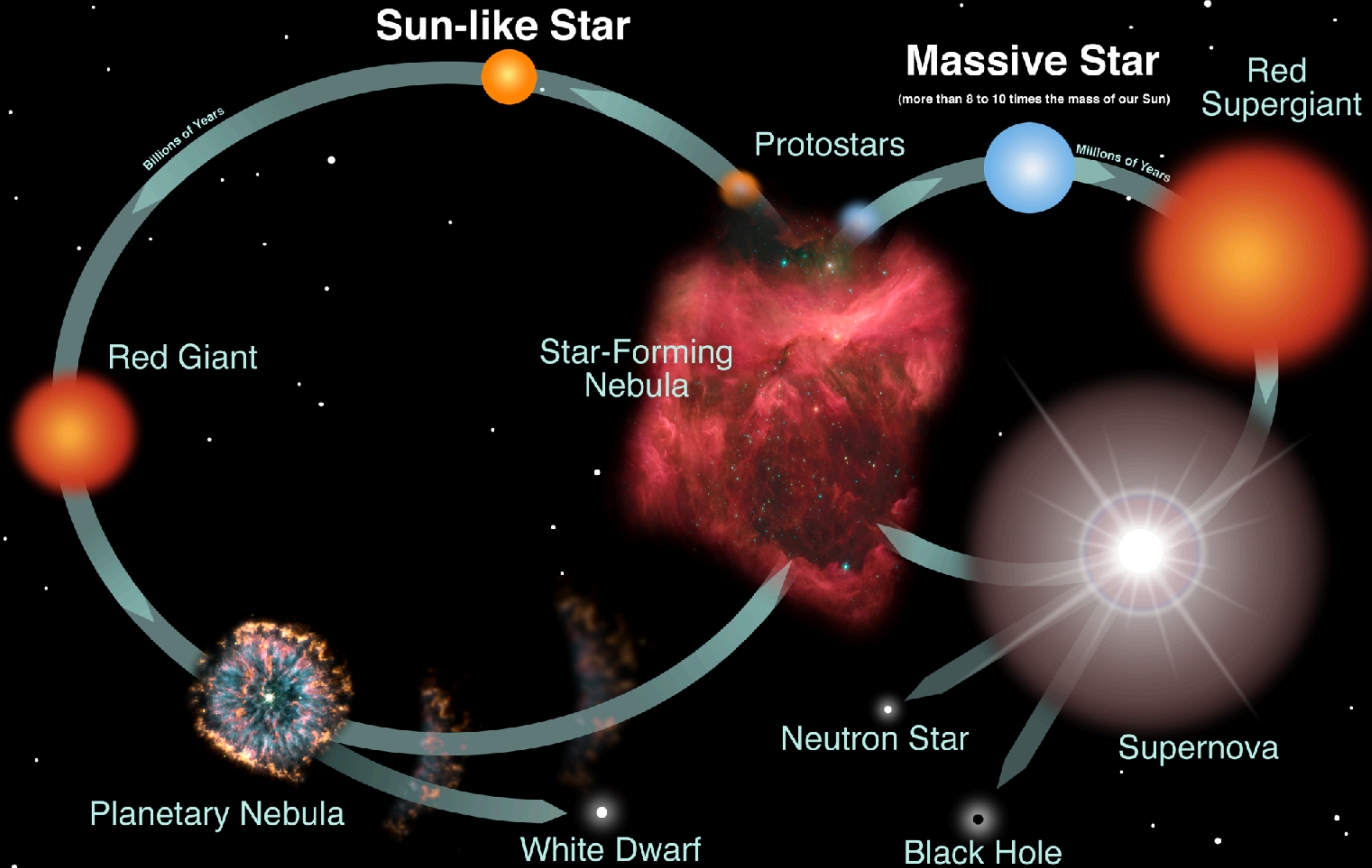
Constraining the EOS with Neutron Star Mergers

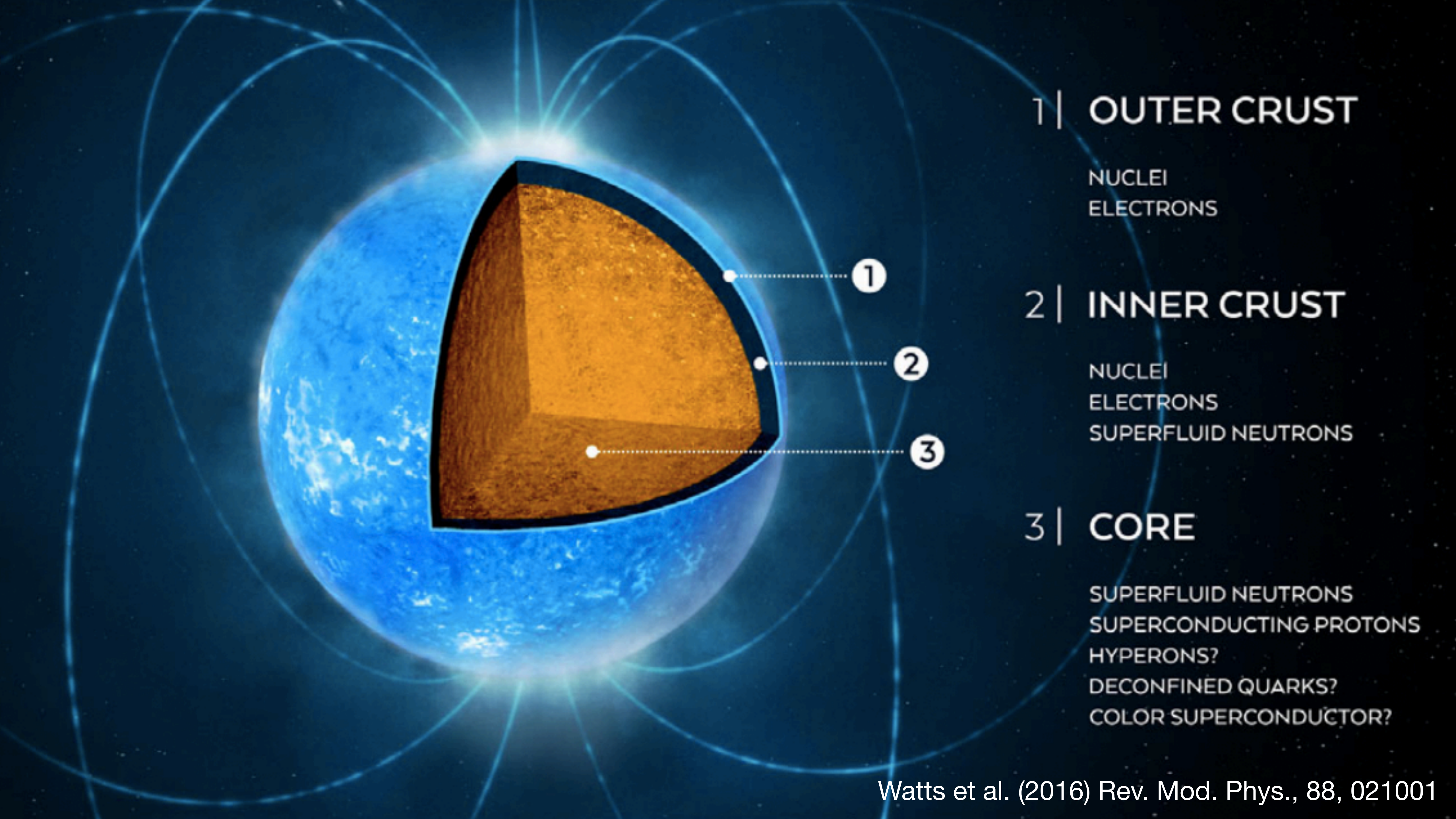
Probing dense baryonic matter with hadrons II
GSI Darmstadt Feb 21, 2024

David Tsang, Token Astrophysicist, University of Bath



<https://web.infn.it/CSN4/IS/Linea3/STRENGTH/>





1 | **OUTER CRUST**

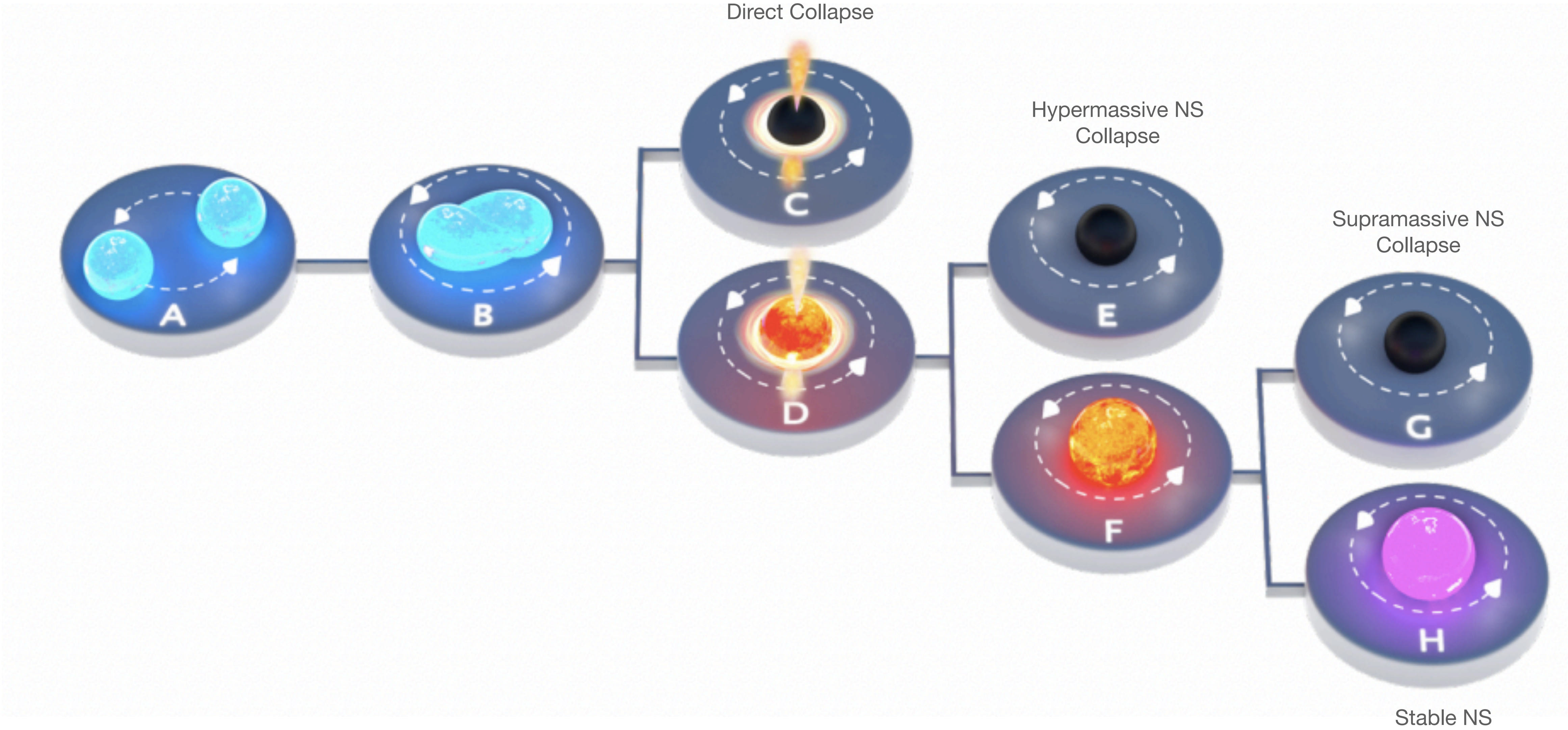
NUCLEI
ELECTRONS

2 | **INNER CRUST**

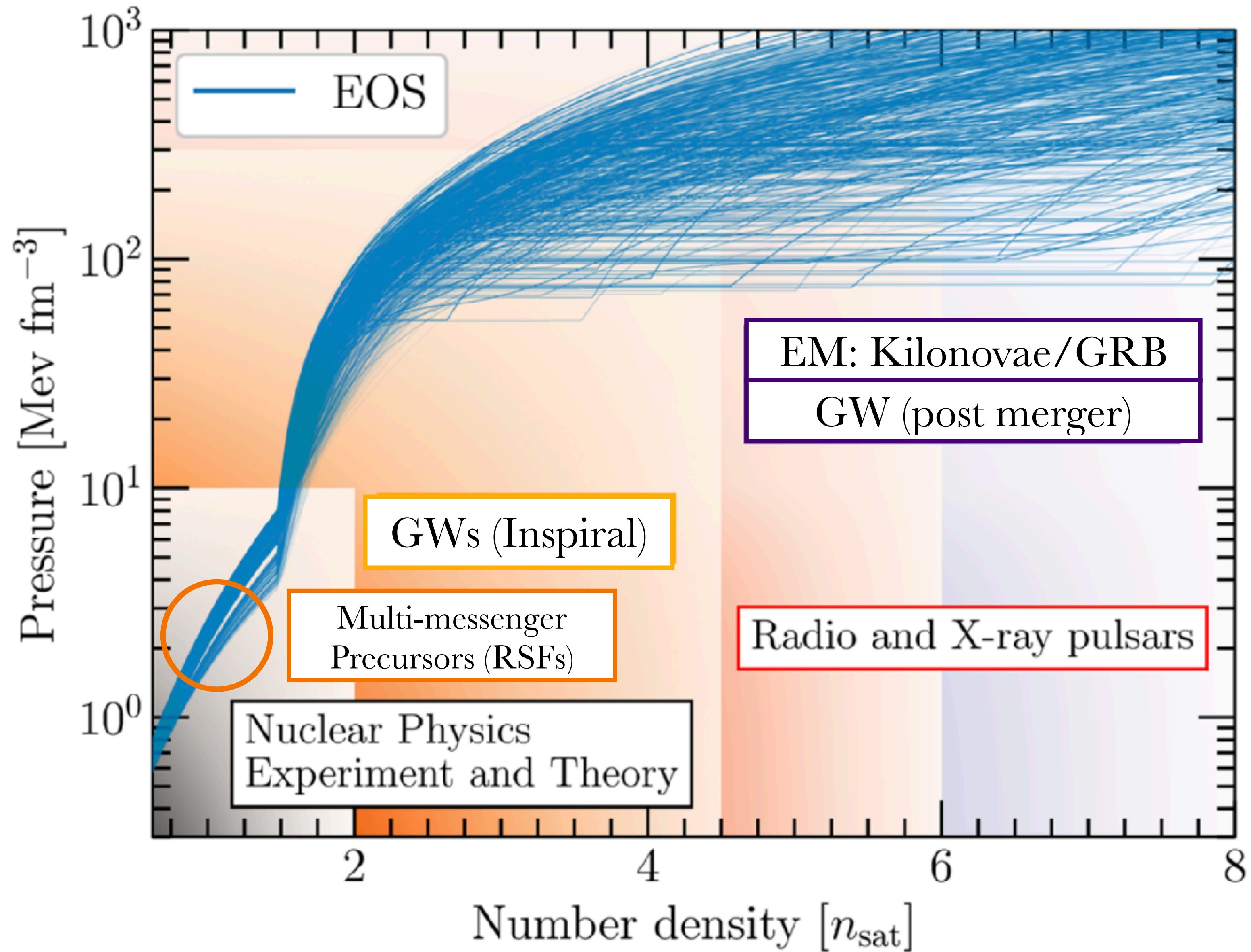
NUCLEI
ELECTRONS
SUPERFLUID NEUTRONS

3 | **CORE**

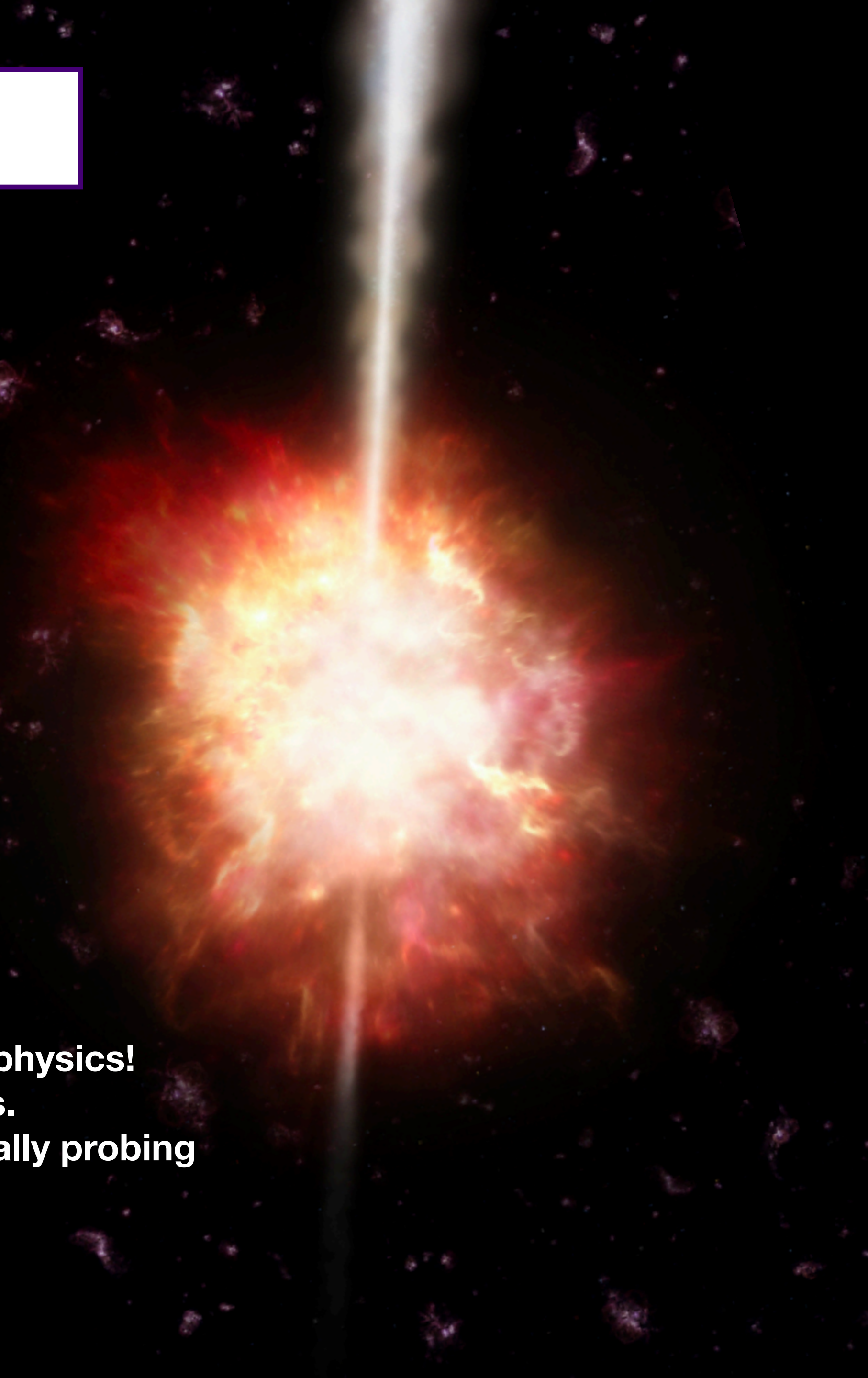
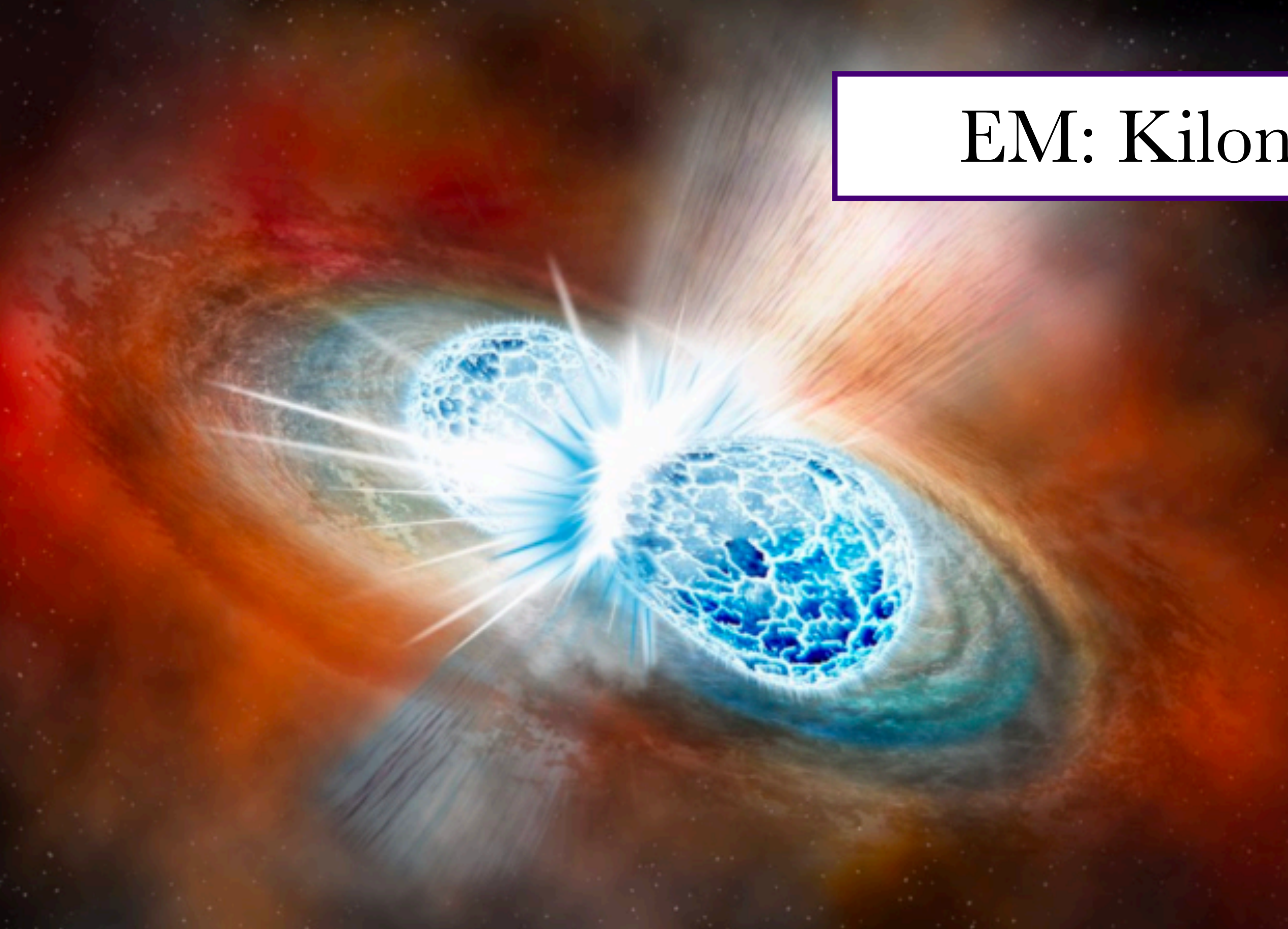
SUPERFLUID NEUTRONS
SUPERCONDUCTING PROTONS
HYPERONS?
DECONFINED QUARKS?
COLOR SUPERCONDUCTOR?



Adapted from Sarin & Lasky (2021) GR&G, 53, 6, 59

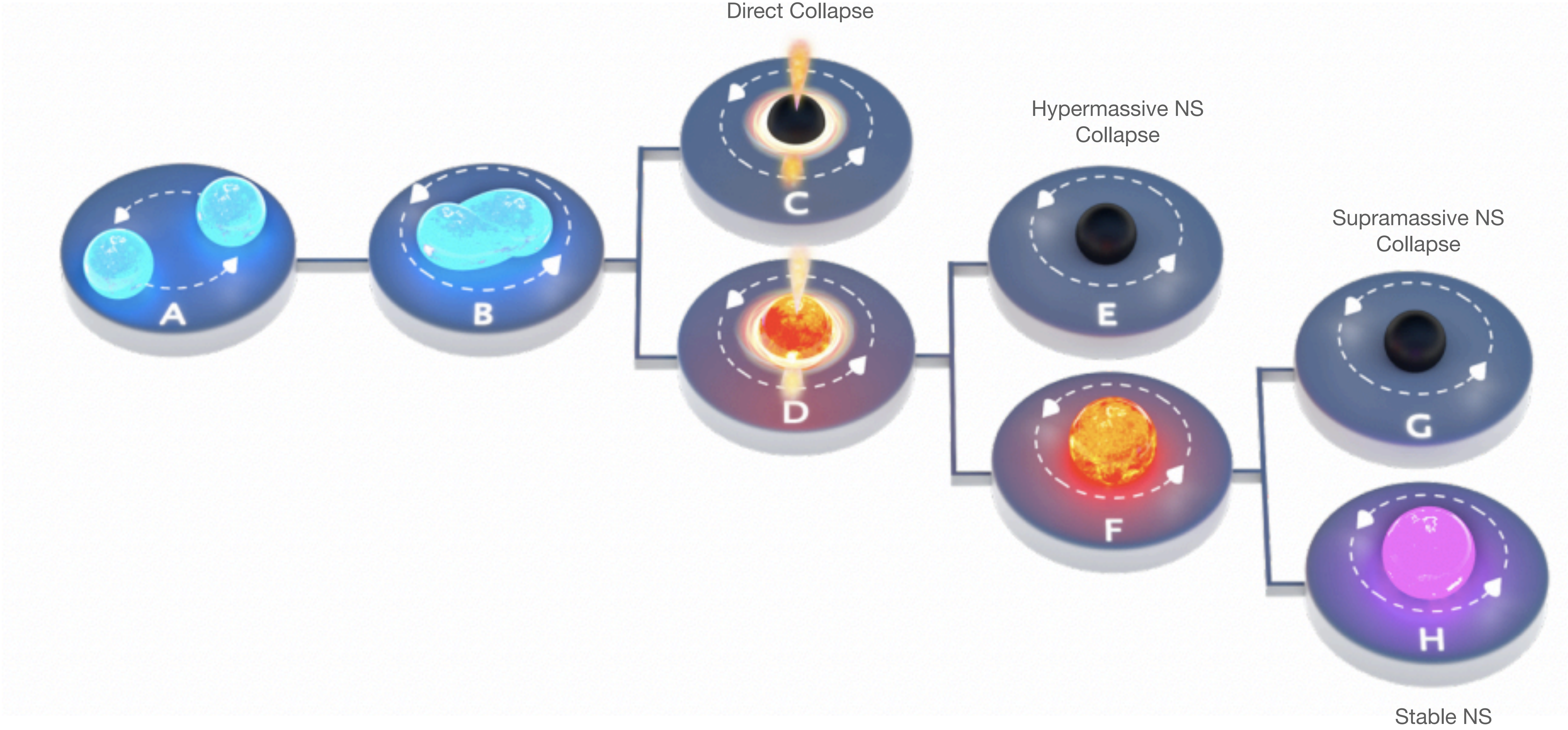


EM: Kilonovae/GRB



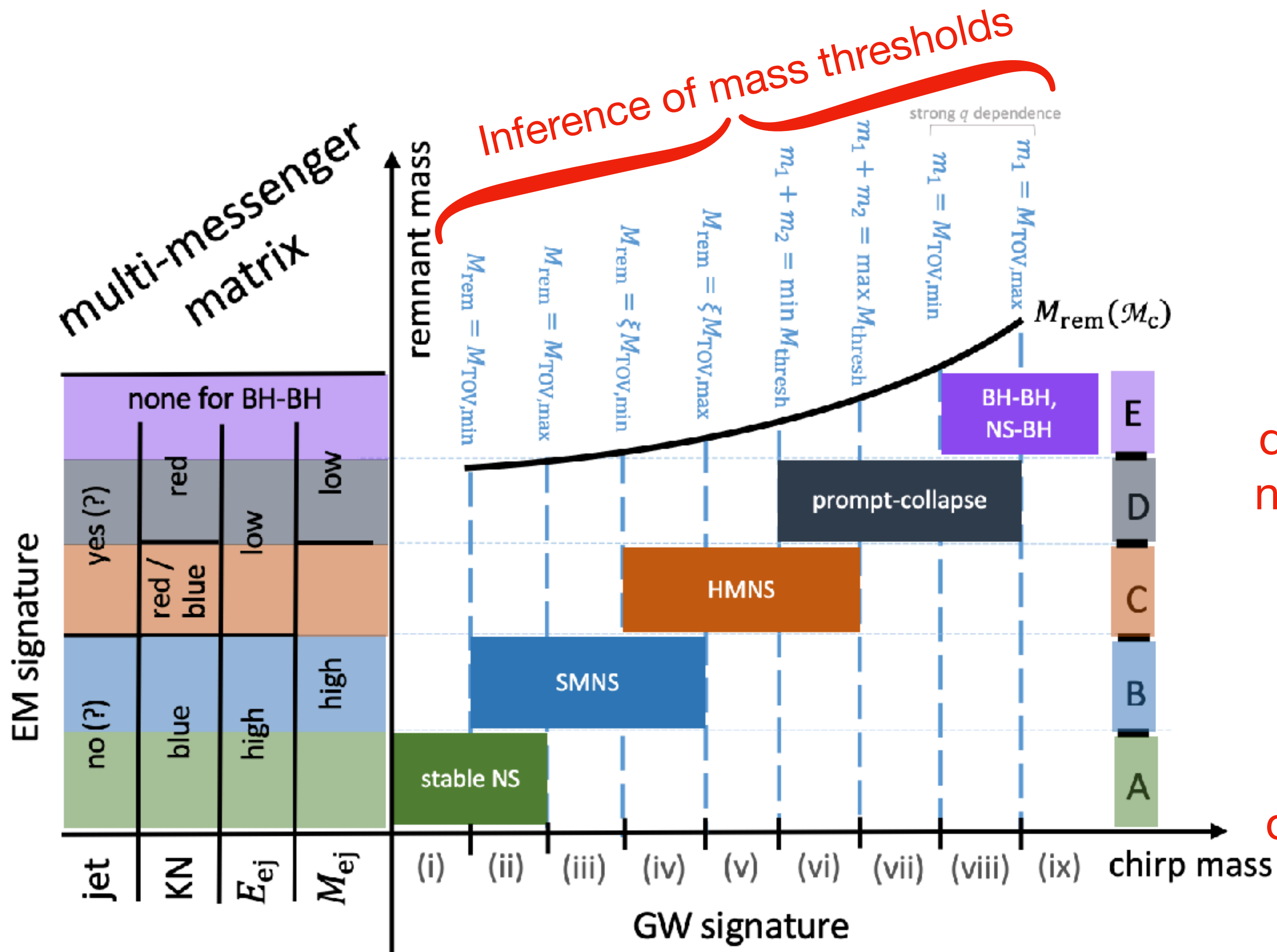
**Kilonovae and Short Gamma Ray Bursts tell us a lot about the messy post-merger physics!
But it's difficult to extract info about the neutron star progenitors themselves.
However, they can provide some (qualitative) information on merger remnants, potentially probing
the even higher density cores of HMNSs/SMNSs.**

EM: Kilonovae/GRB



EM: Kilonovae/GRB

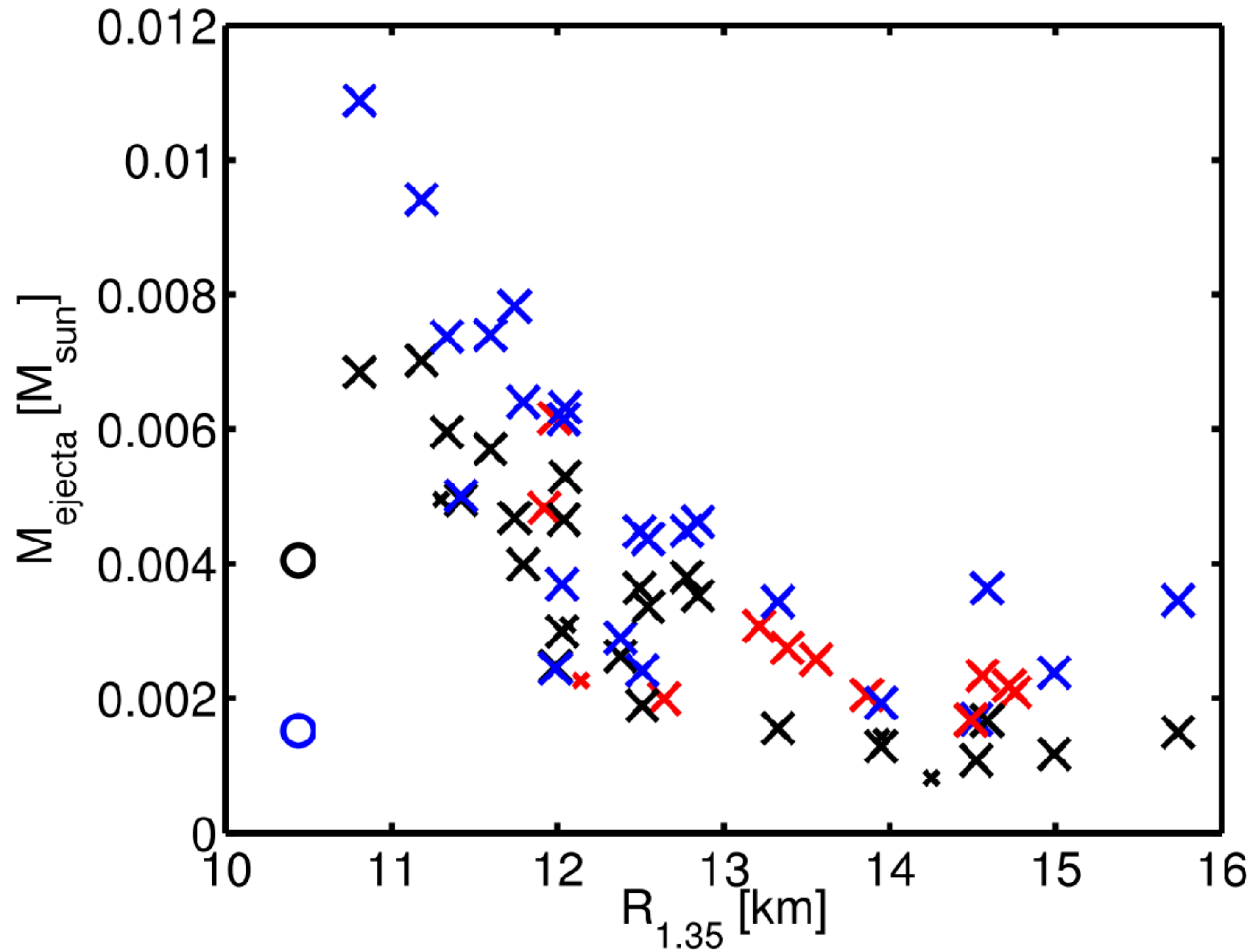
Qualitative Interpretation To Determine Type



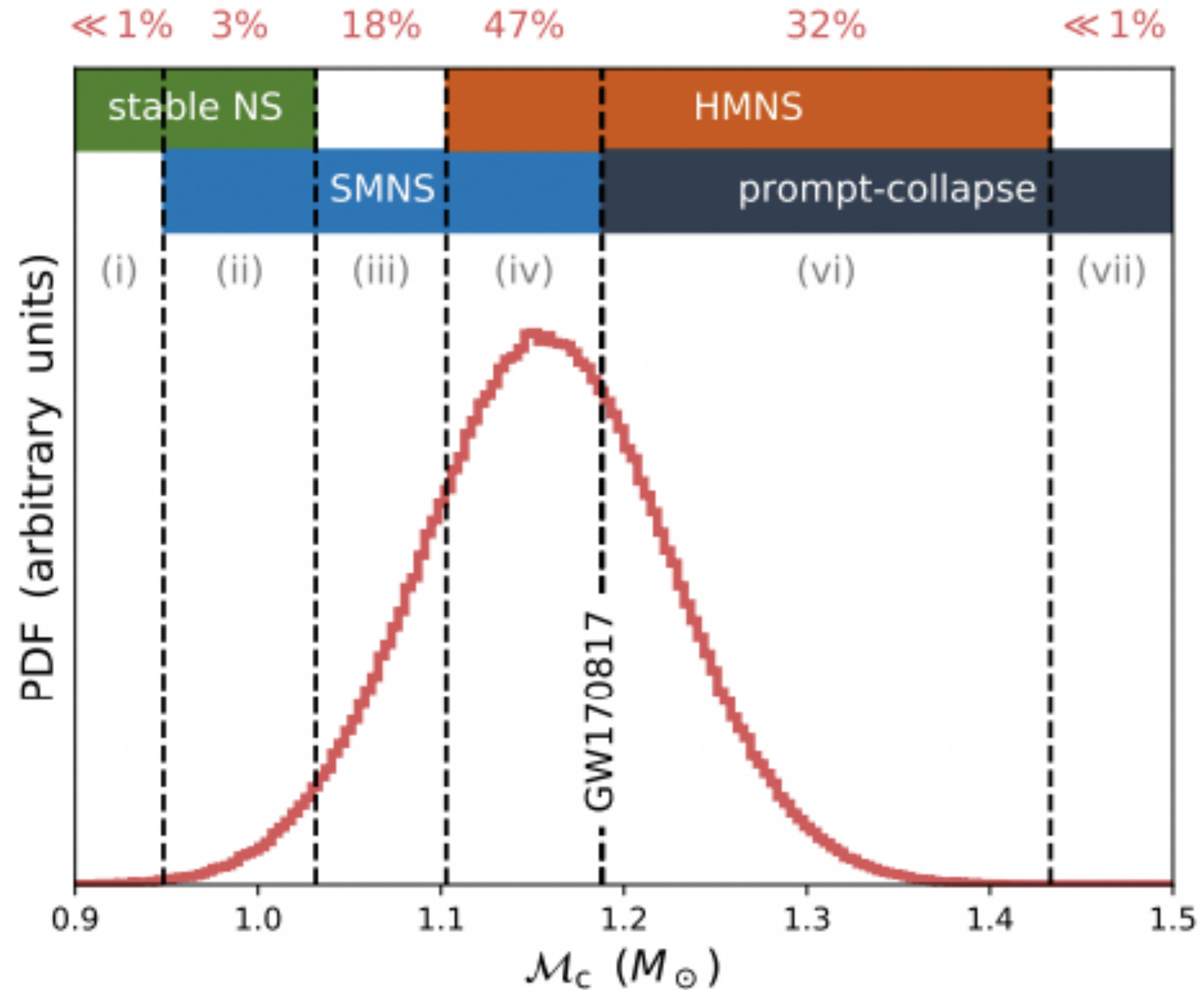
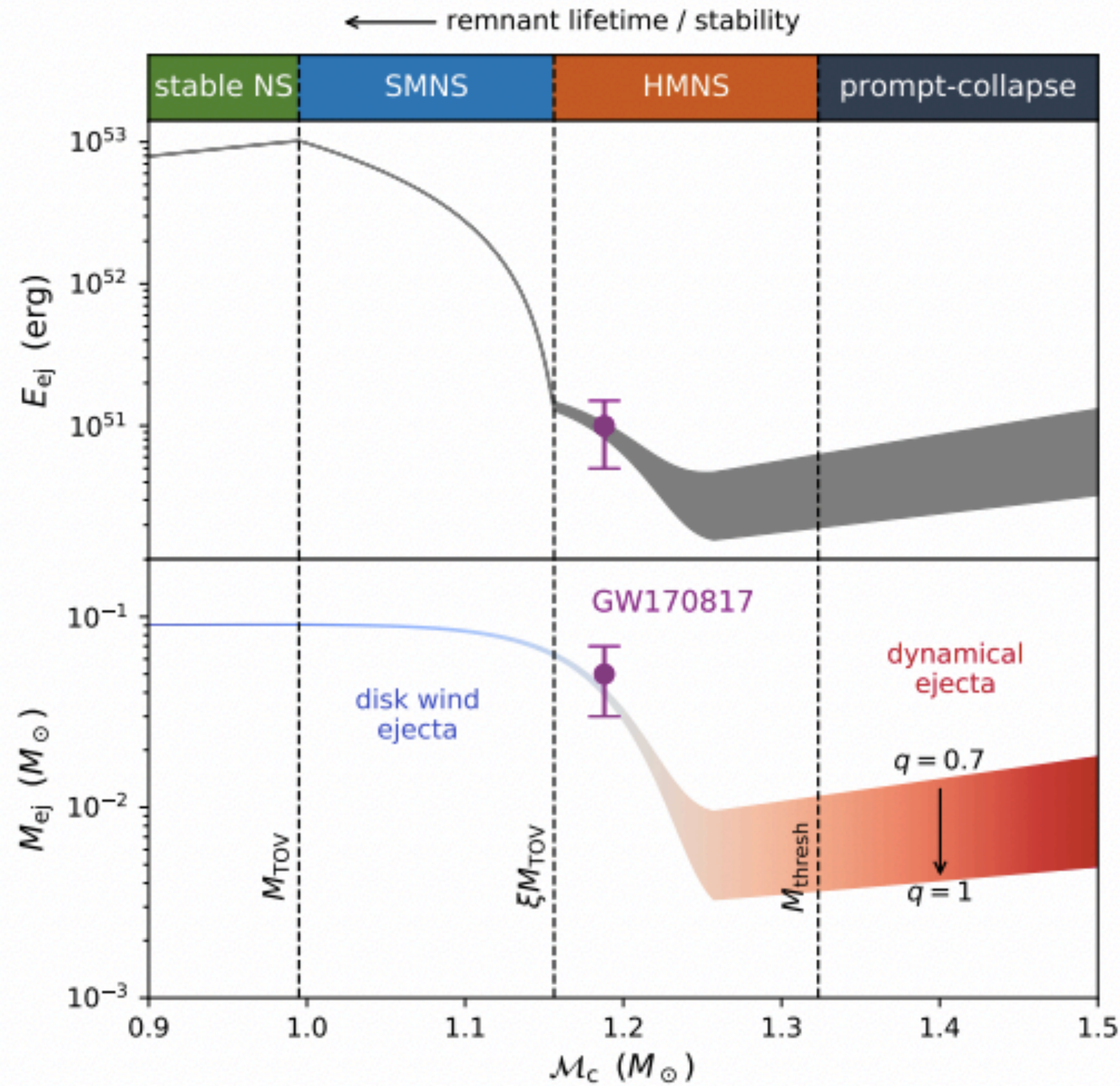
Huge uncertainties due to systematics in numerical simulations and choice of EOS

Perhaps more solid once you have many events of qualitatively different types

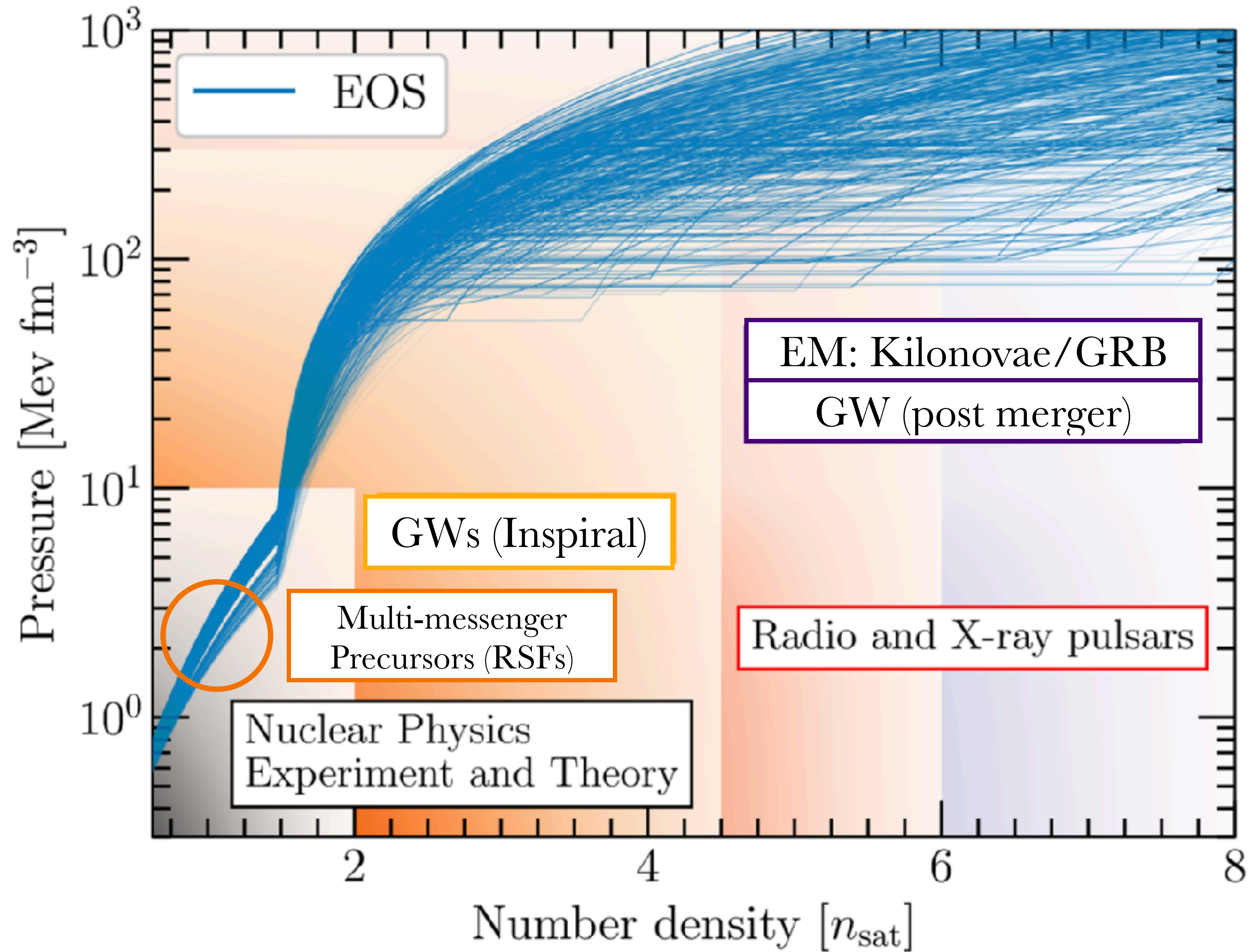
EM: Kilonovae/GRB



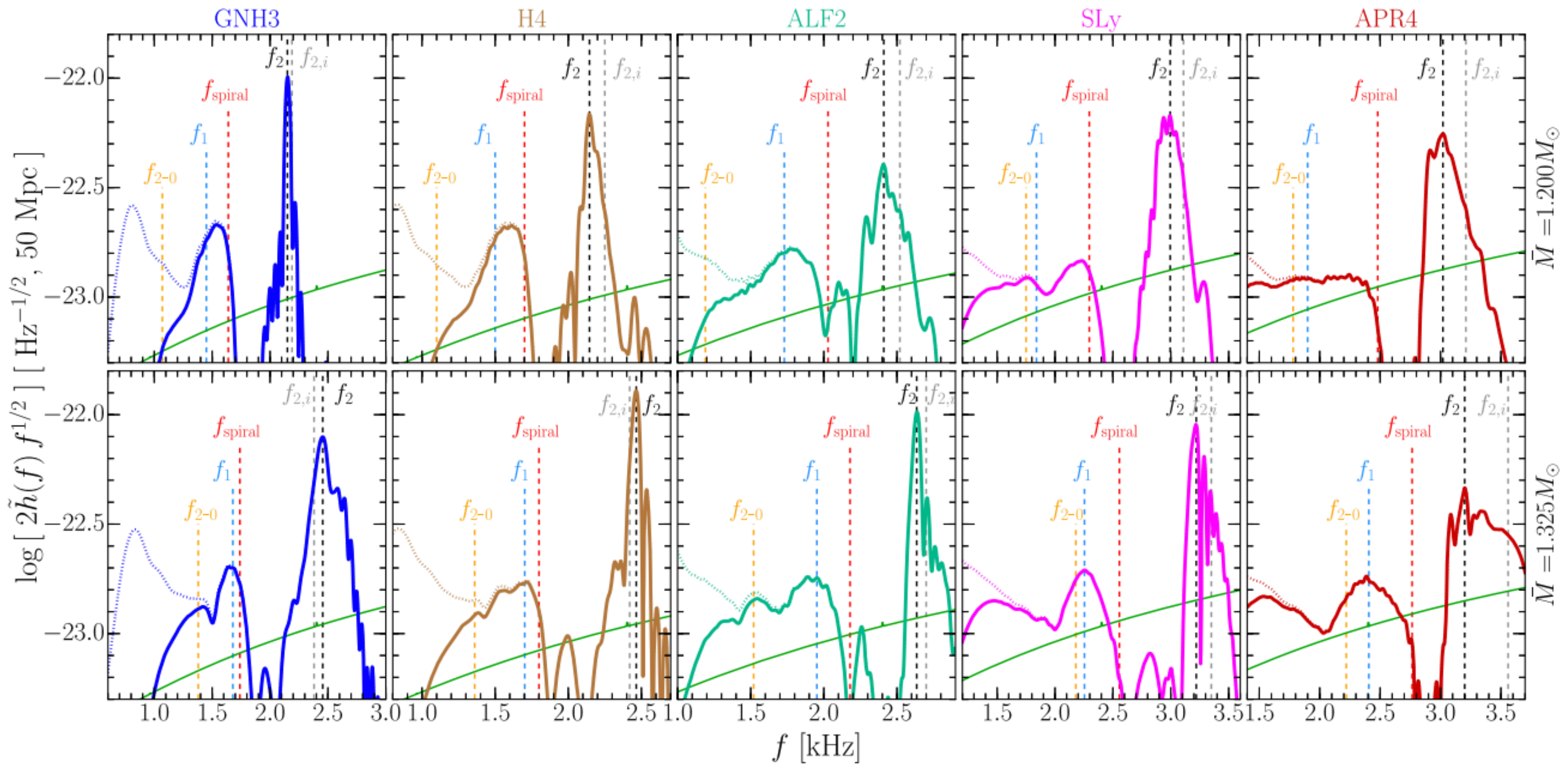
EM: Kilonovae/GRB



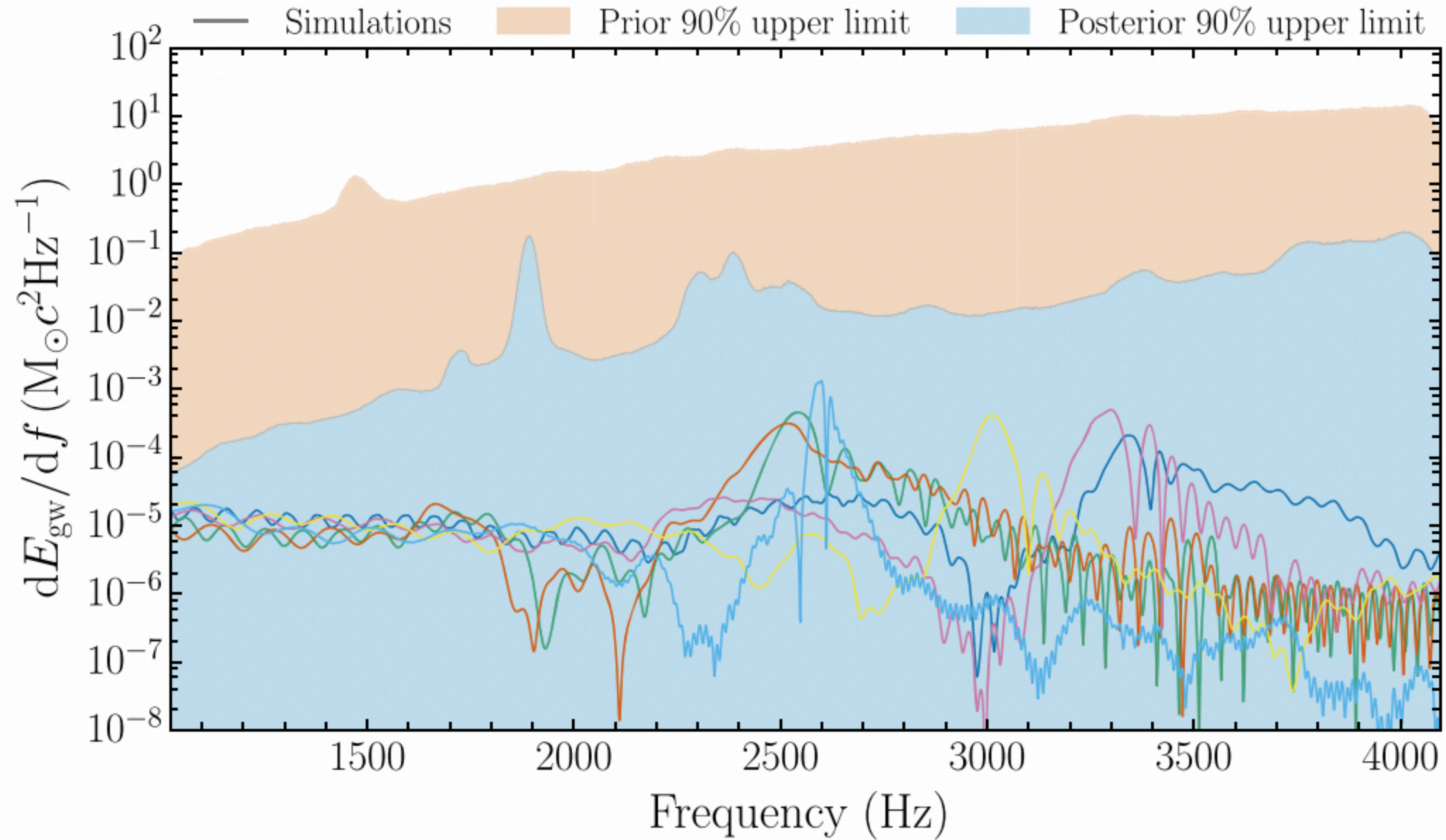
Huge systematics for individual events/interpretations!



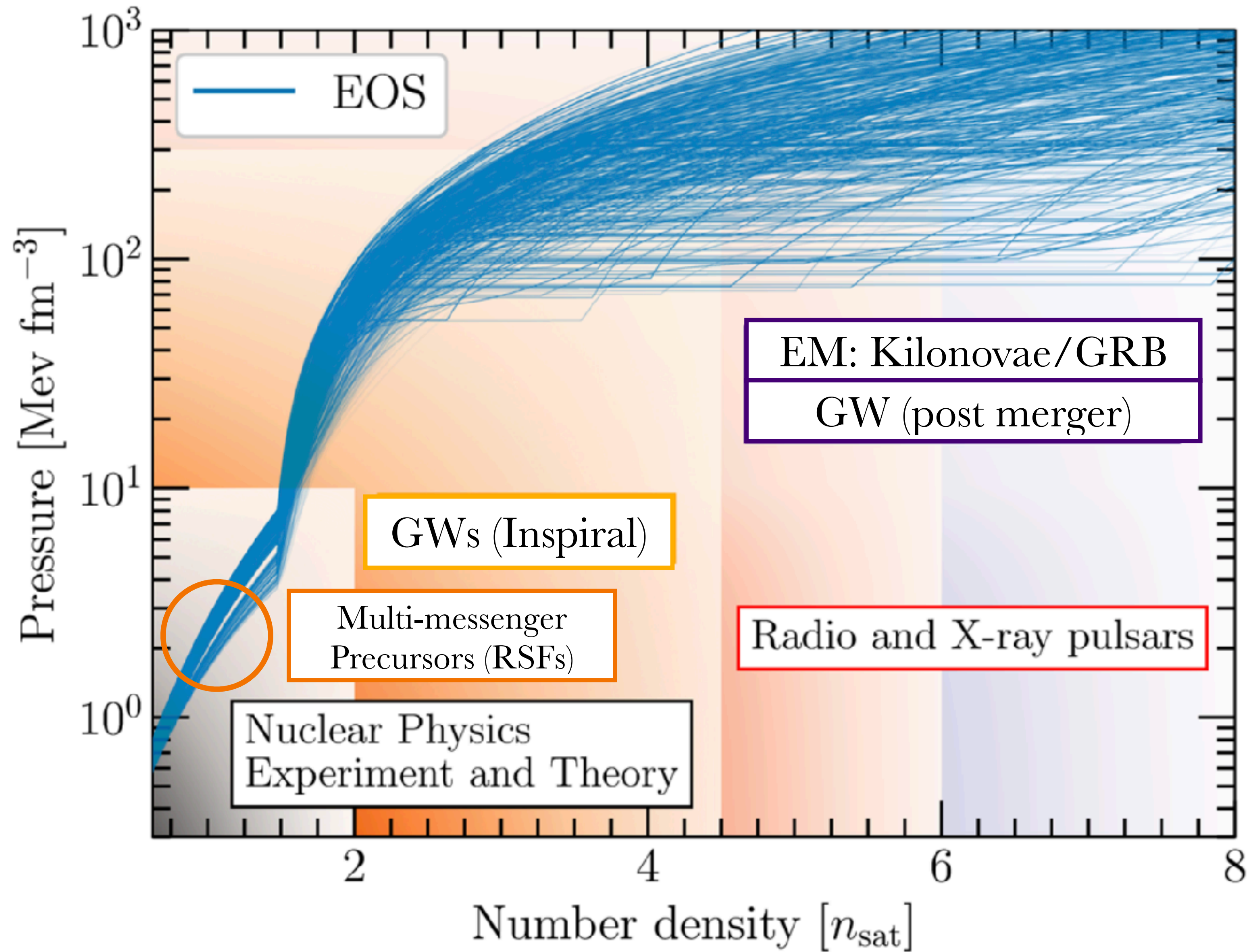
GW (post merger)



GW (post merger)



Post Merger Ringing of SMNS/HMNS. Not detectable with this generation - but likely with 3G



GWs (Inspiral)

The lowest order at which the EOS contributes to the the GW waveform is through the “tidal deformability” Λ
(Quadrupolar polarizability?)

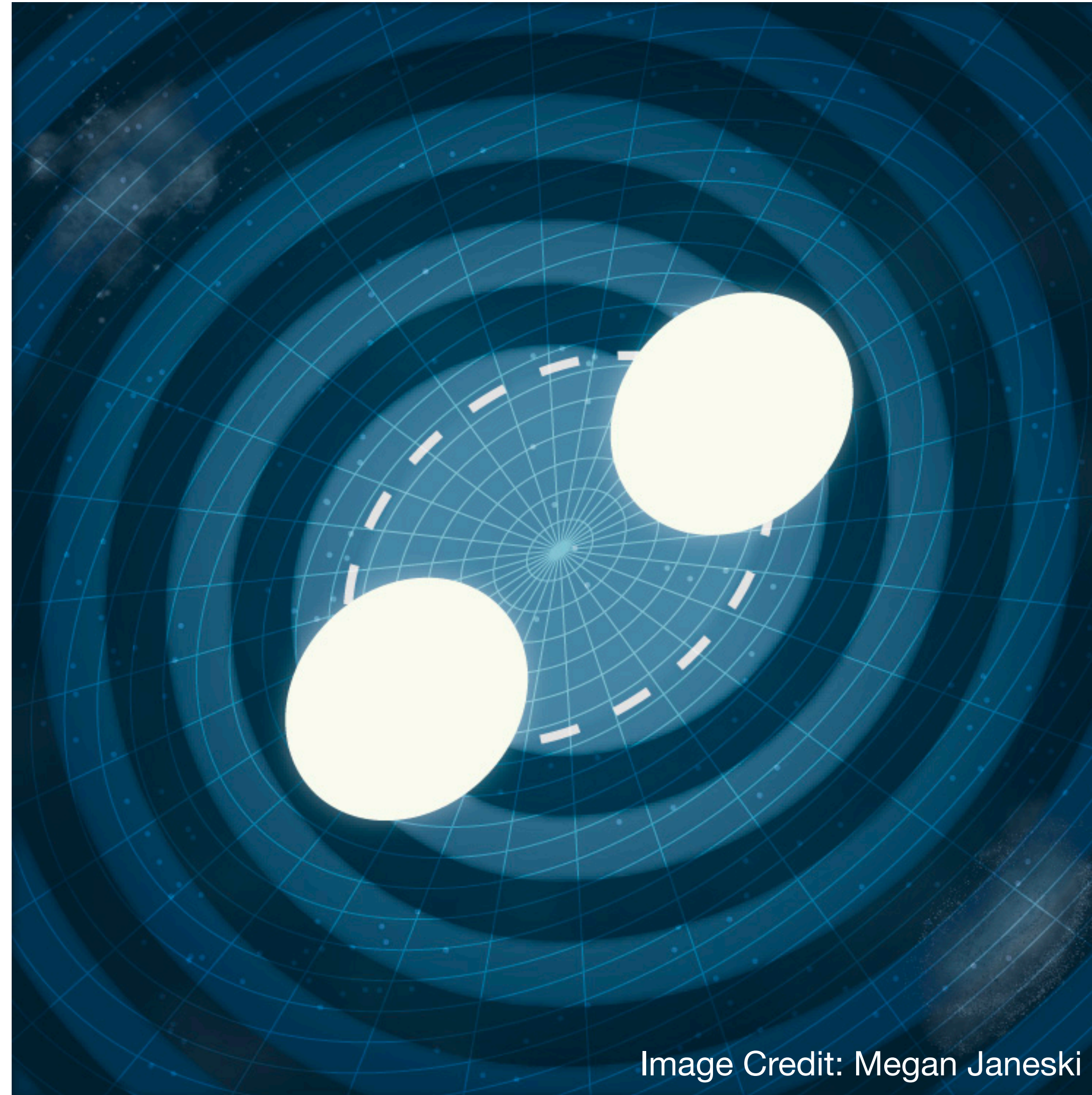
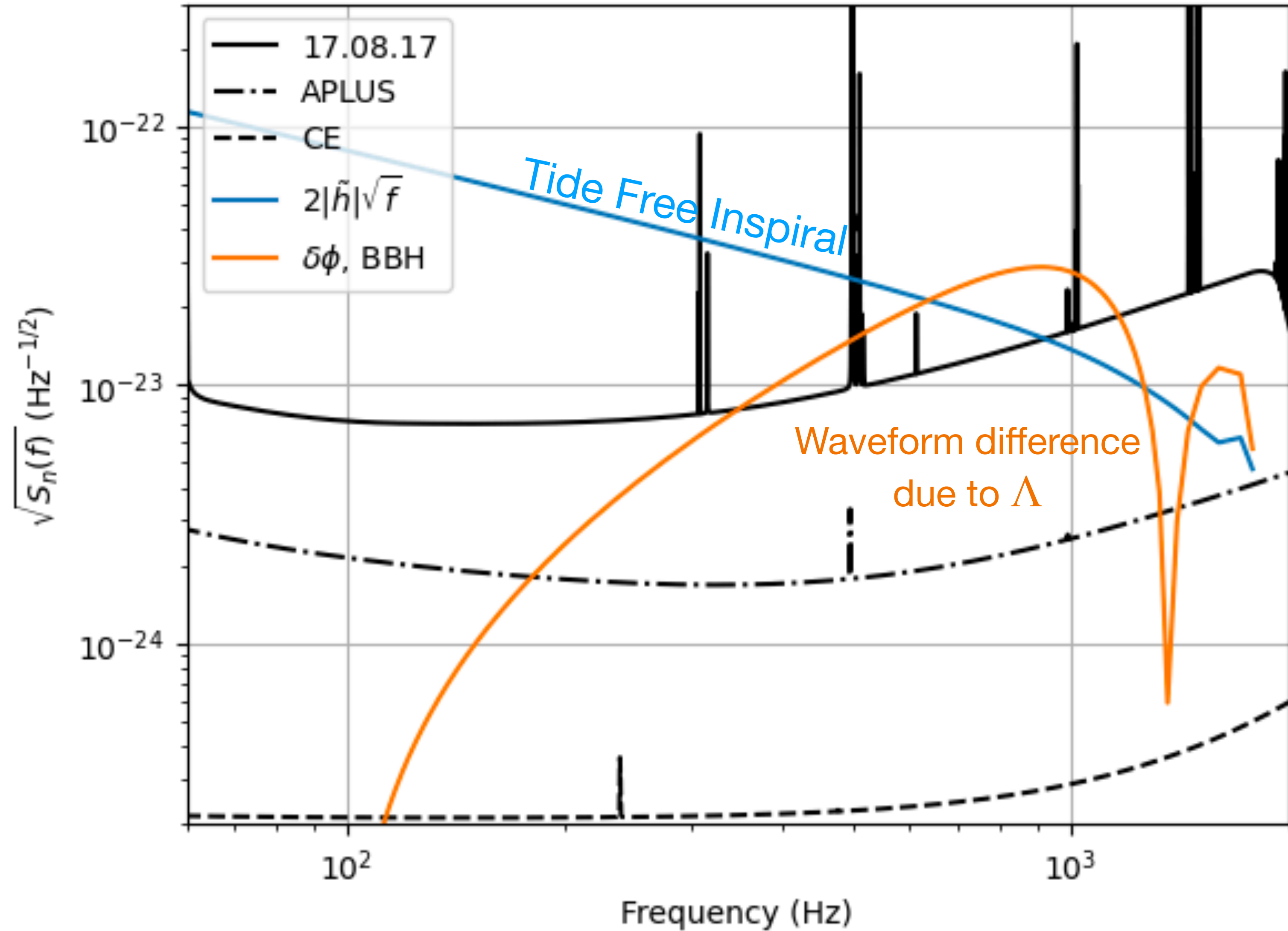


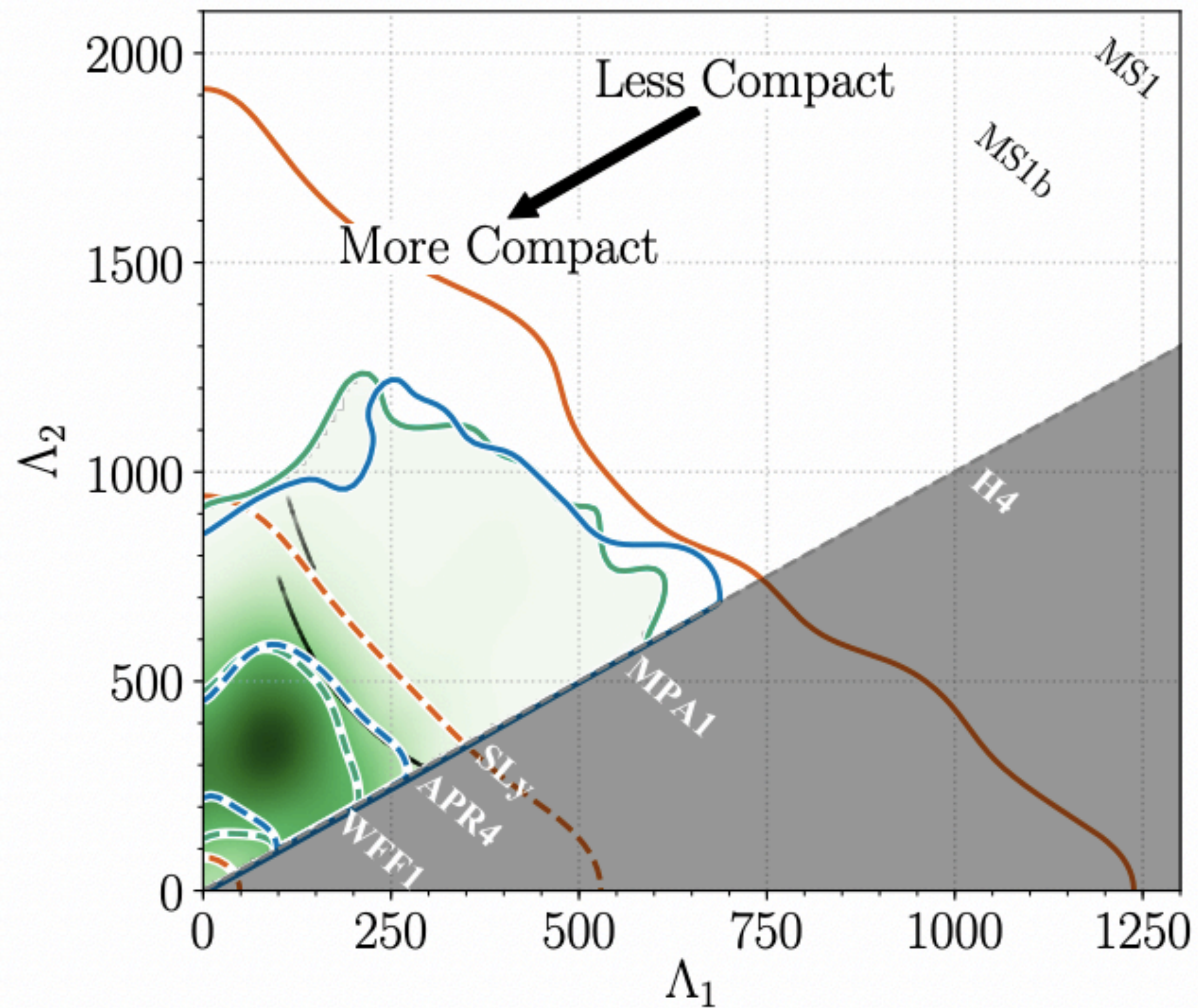
Image Credit: Megan Janeski

$$Q_{ij} = -\Lambda \frac{\partial \Phi_{\text{ext}}}{\partial x^i \partial x^j}$$

GWs (Inspiral)



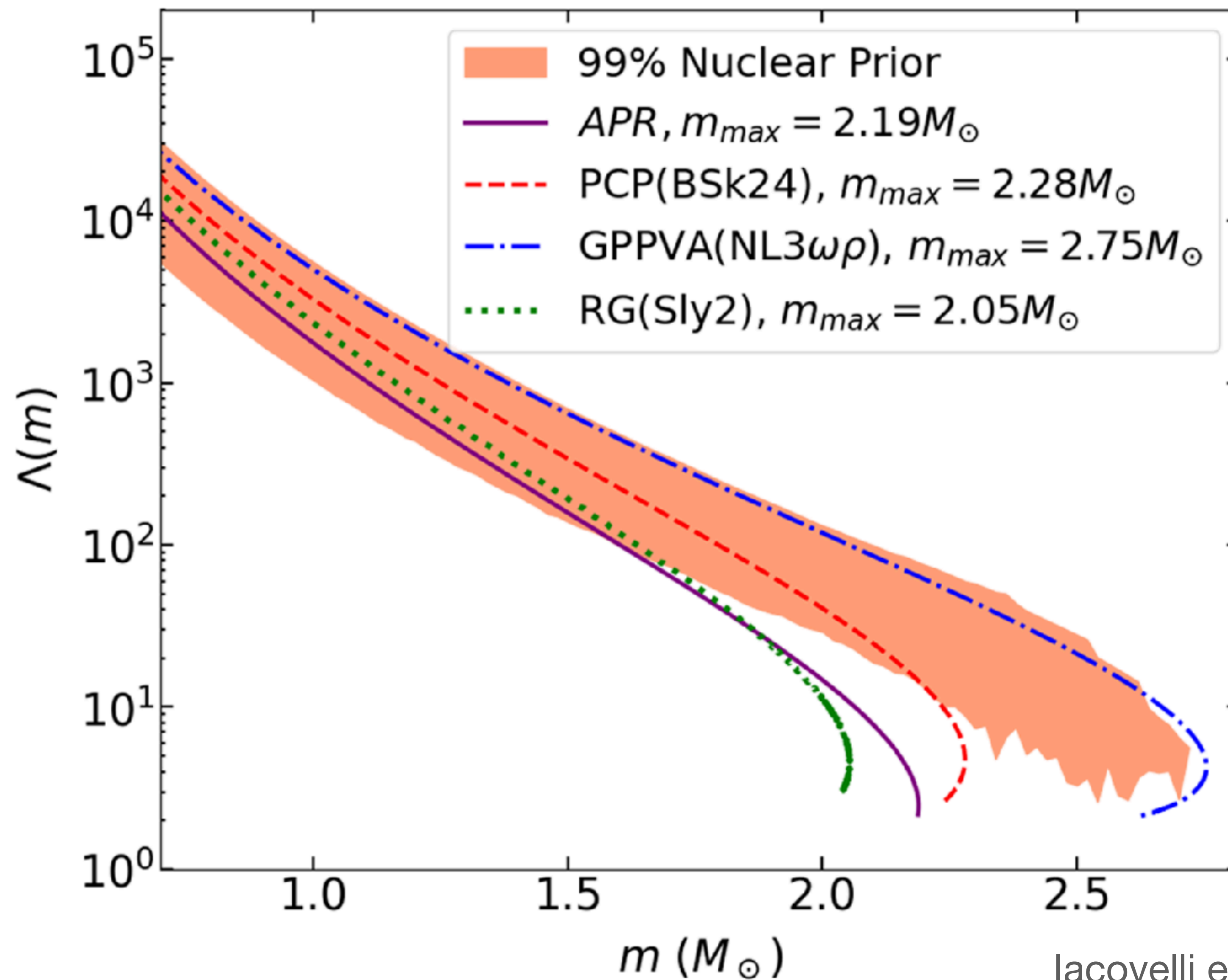
GWs (Inspiral)

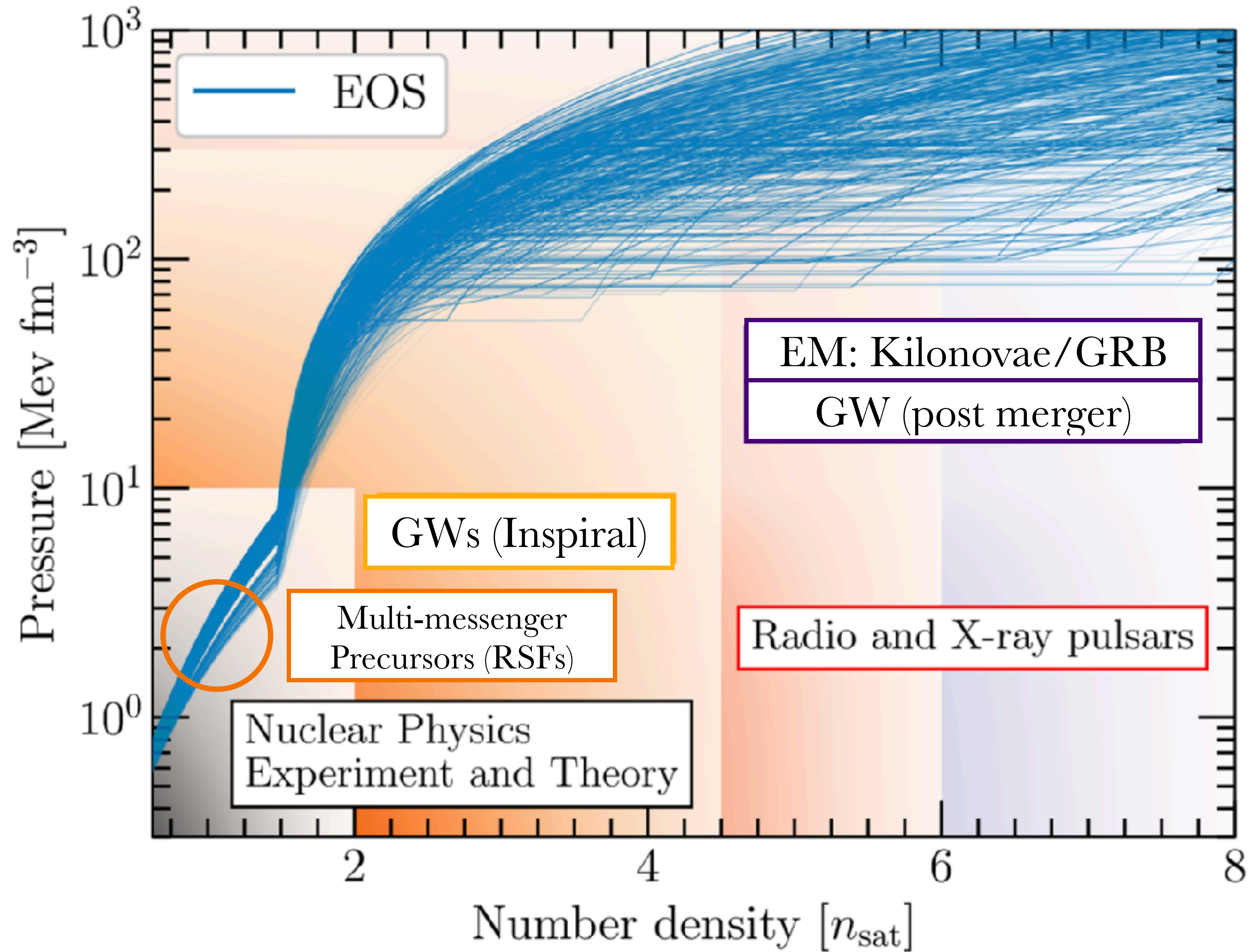


GW170817

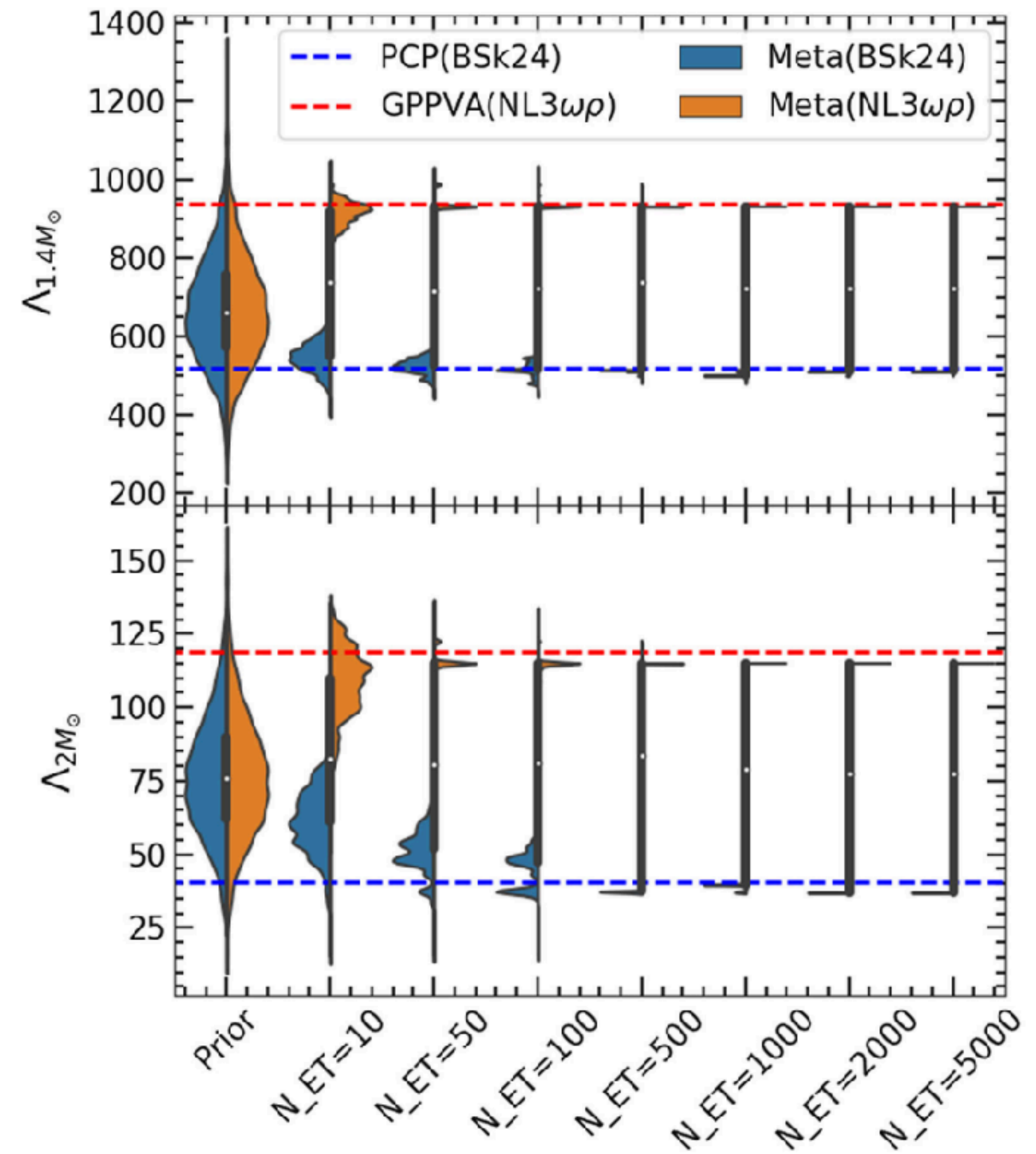
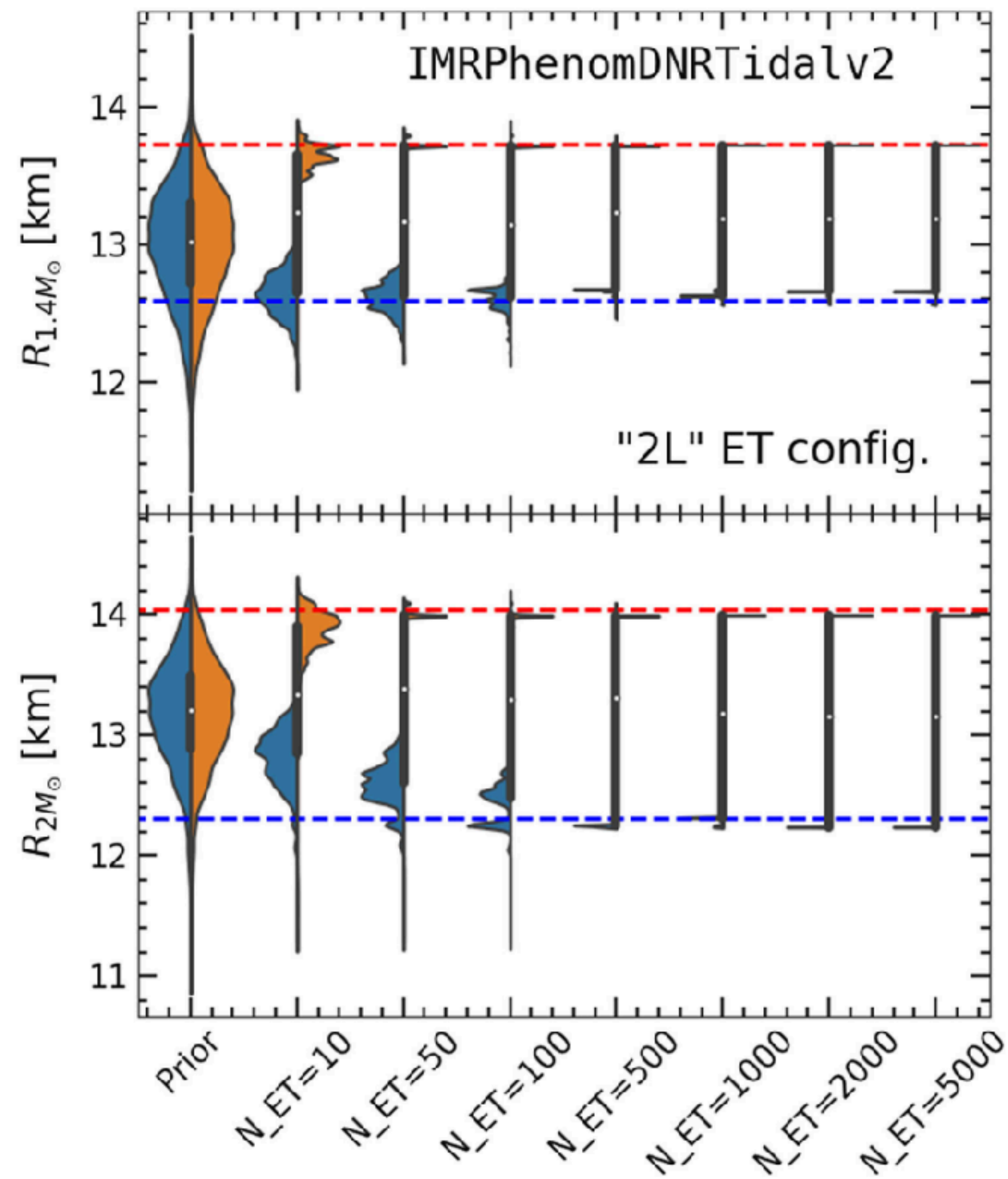
LVC (2018), PRL, 121, 161101

GWs (Inspiral)



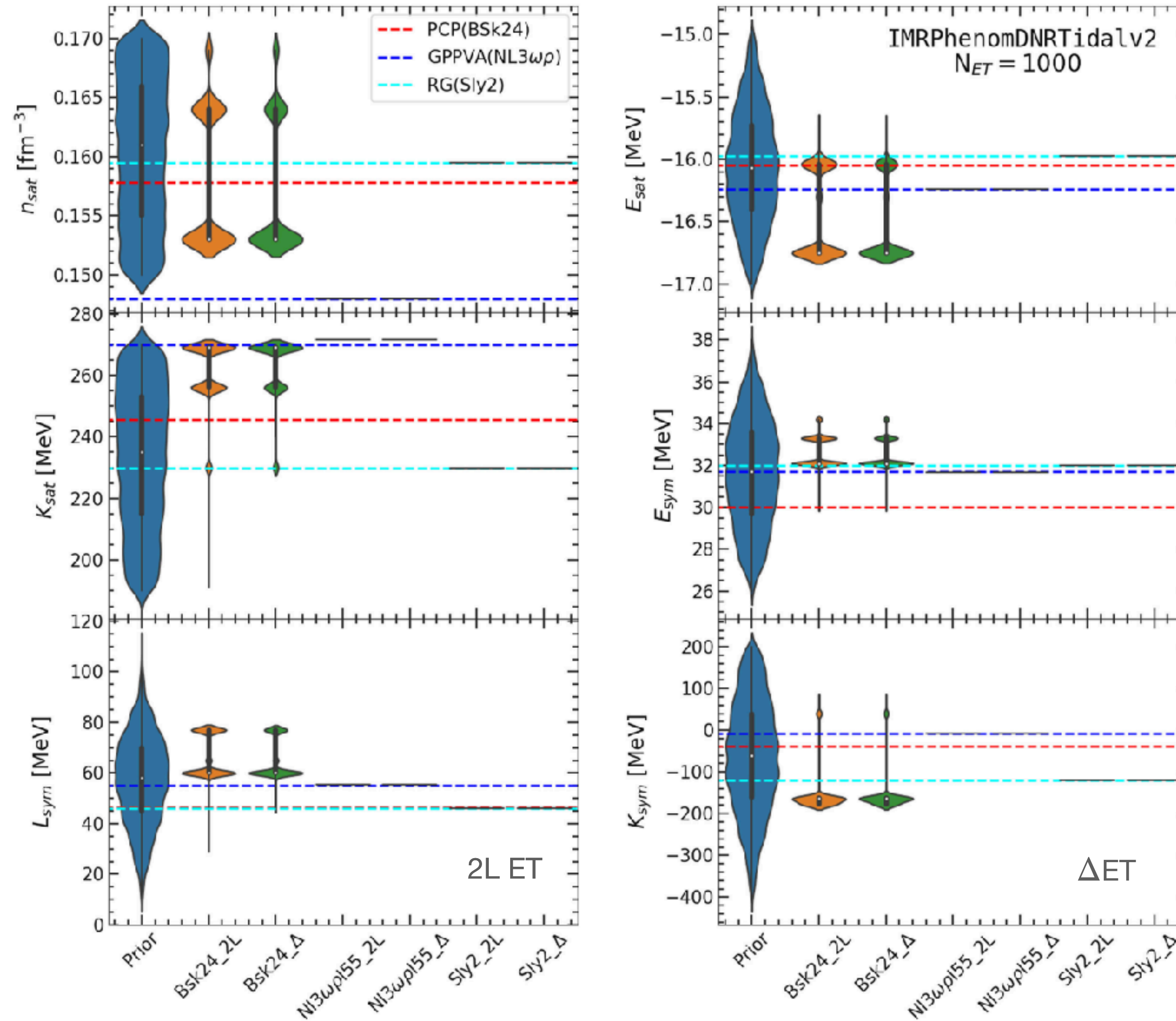


GWs (Inspiral)



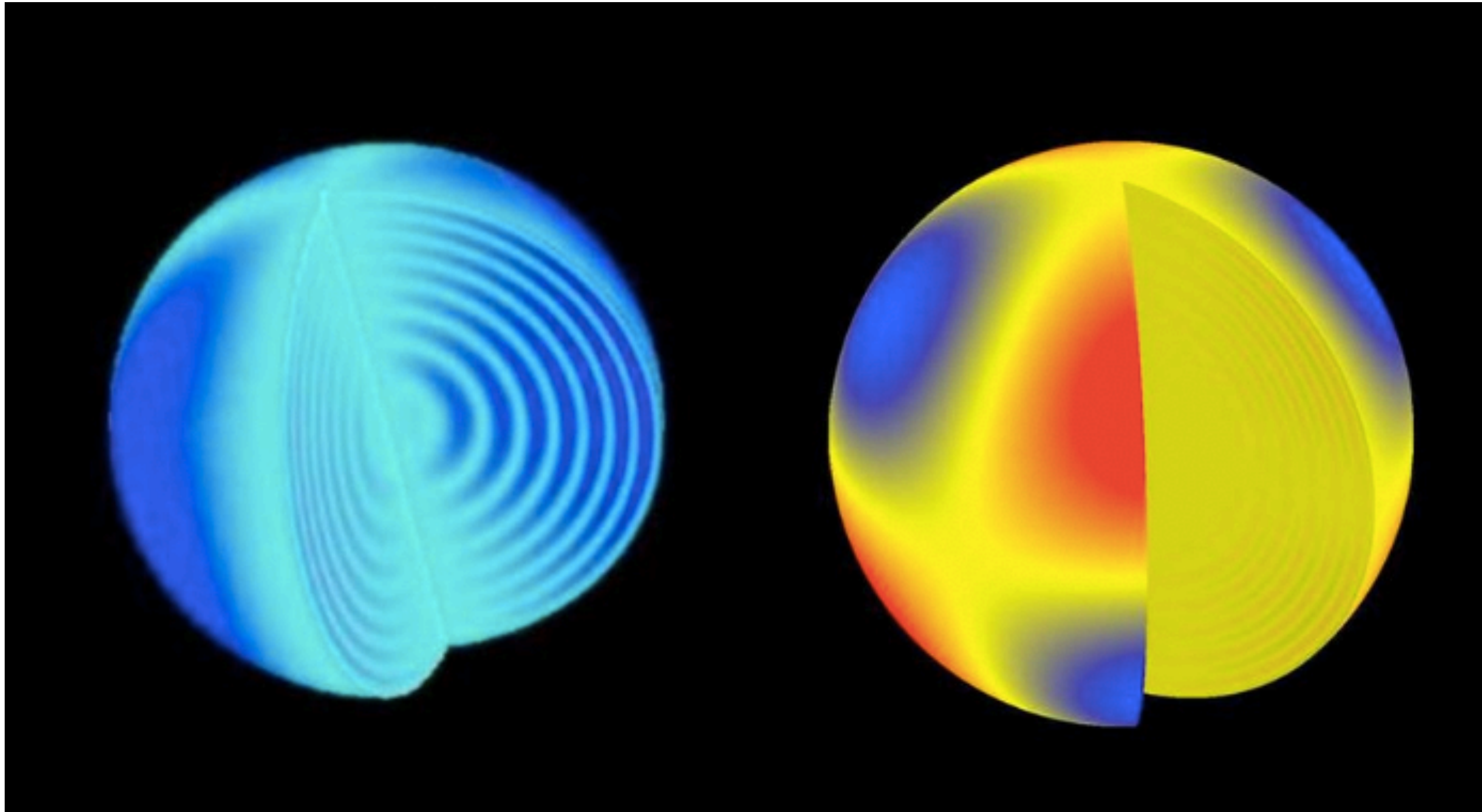
GWs (Inspiral)

Assuming the star is nucleonic constraints can be placed on the isovector/isoscalar parameters



GWs (Inspiral)

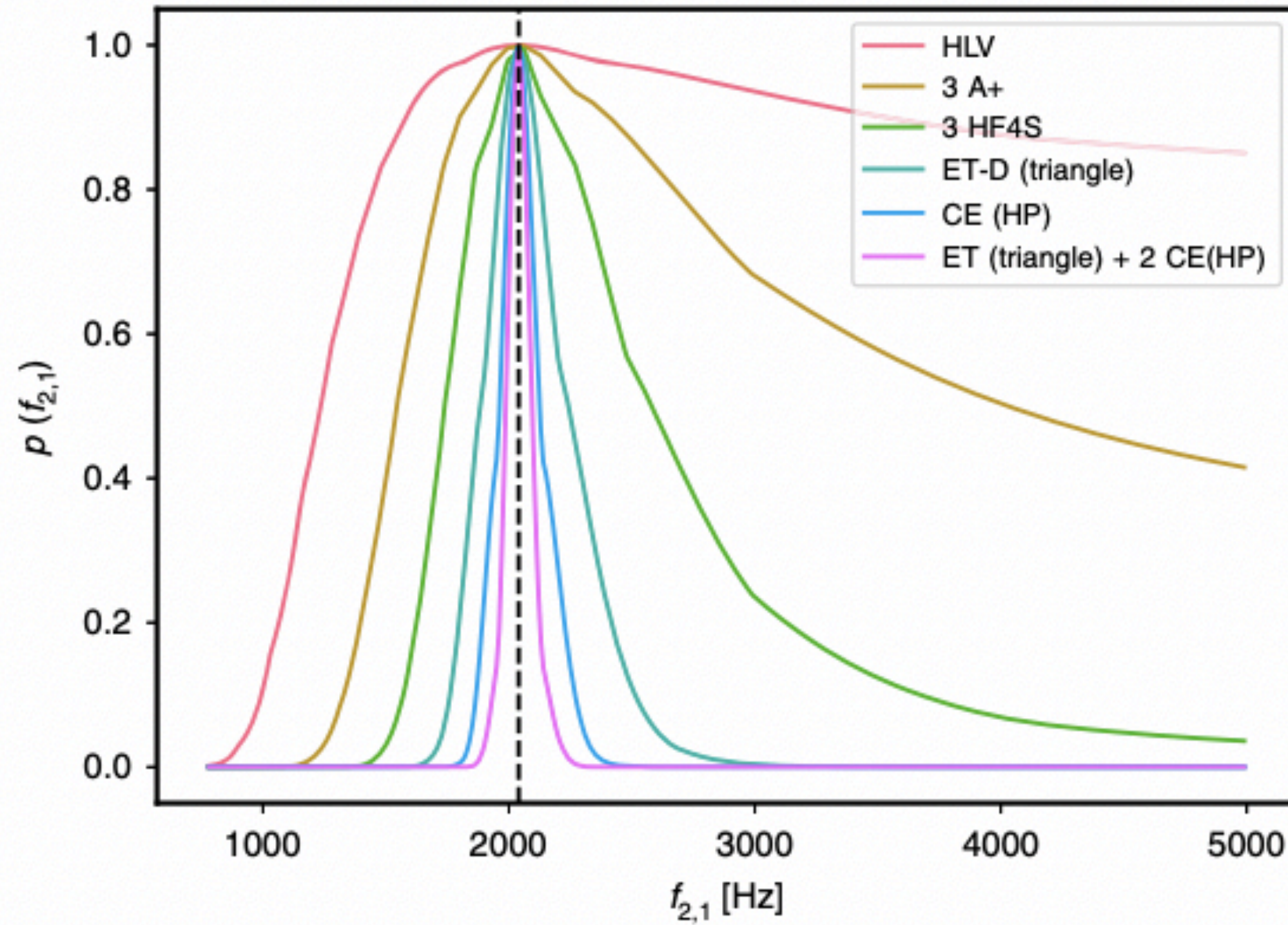
Asteroseismology!



Modes probe the structure where their eigenfunctions are concentrated

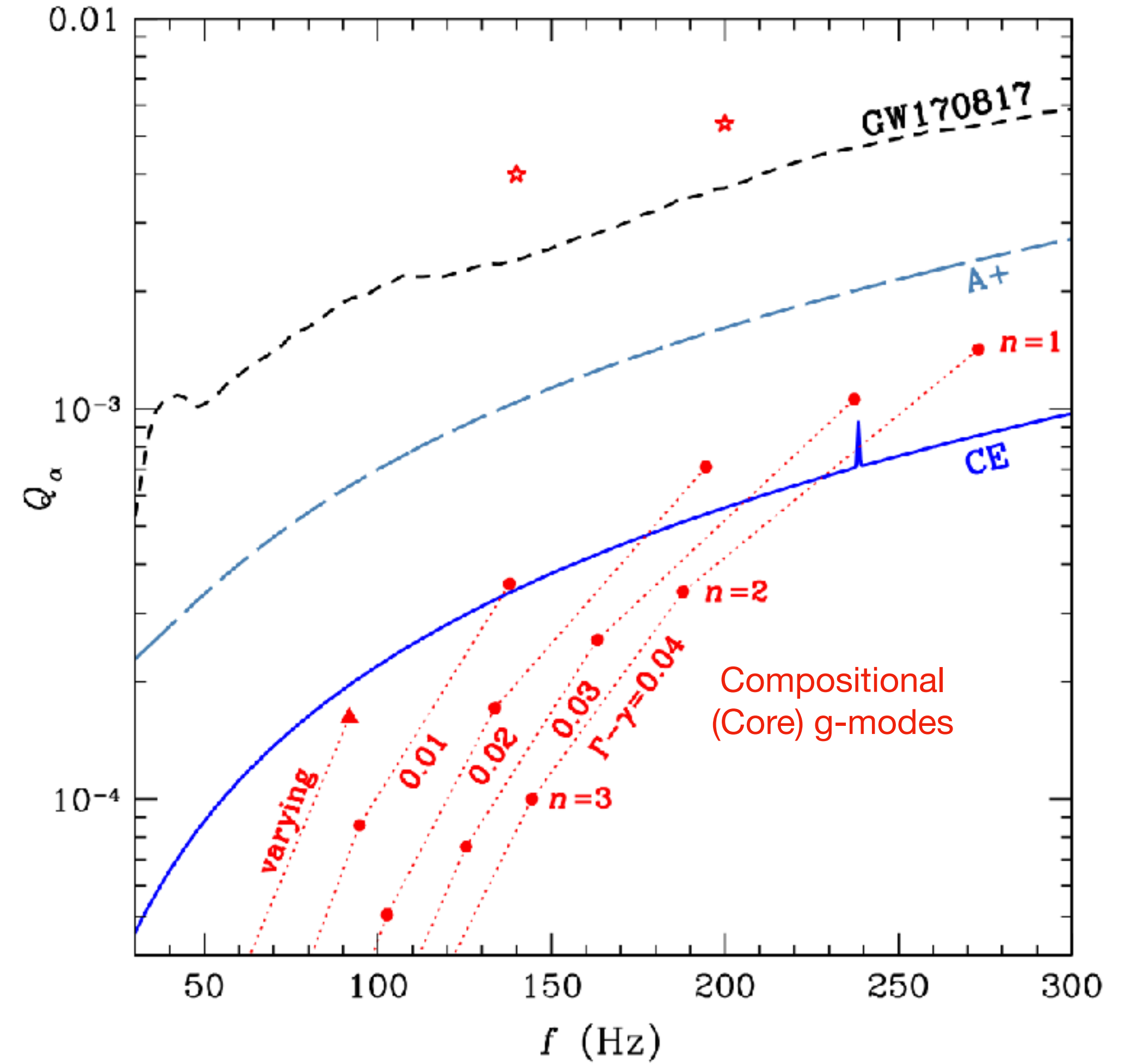
GWs (Inspiral)

Asteroseismology!



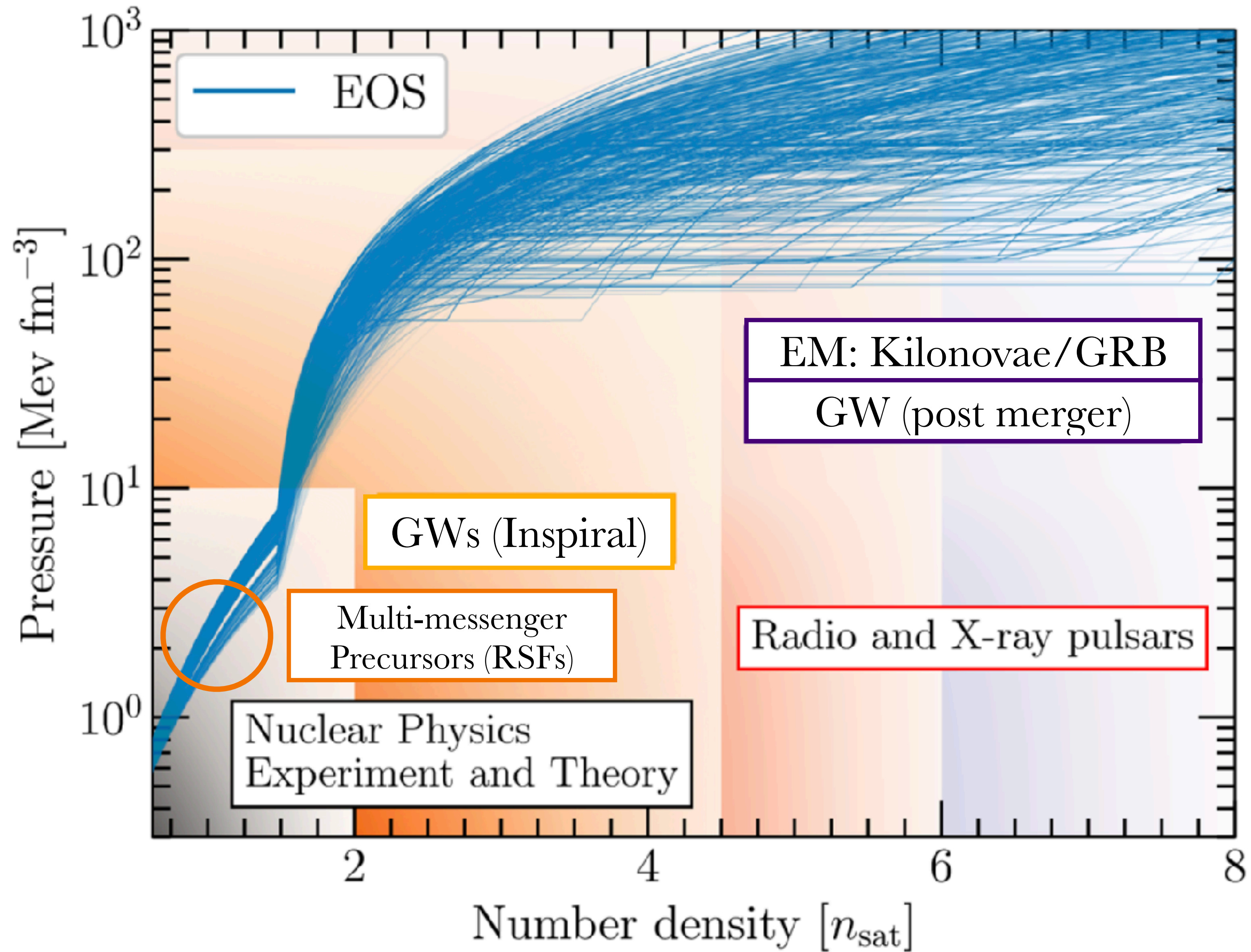
Fundamental modes (same EOS info as Λ)
(non-resonant during inspiral)

Pratten, Schmidt, & Hinderer (2020) Nature Comm., 11, 2553

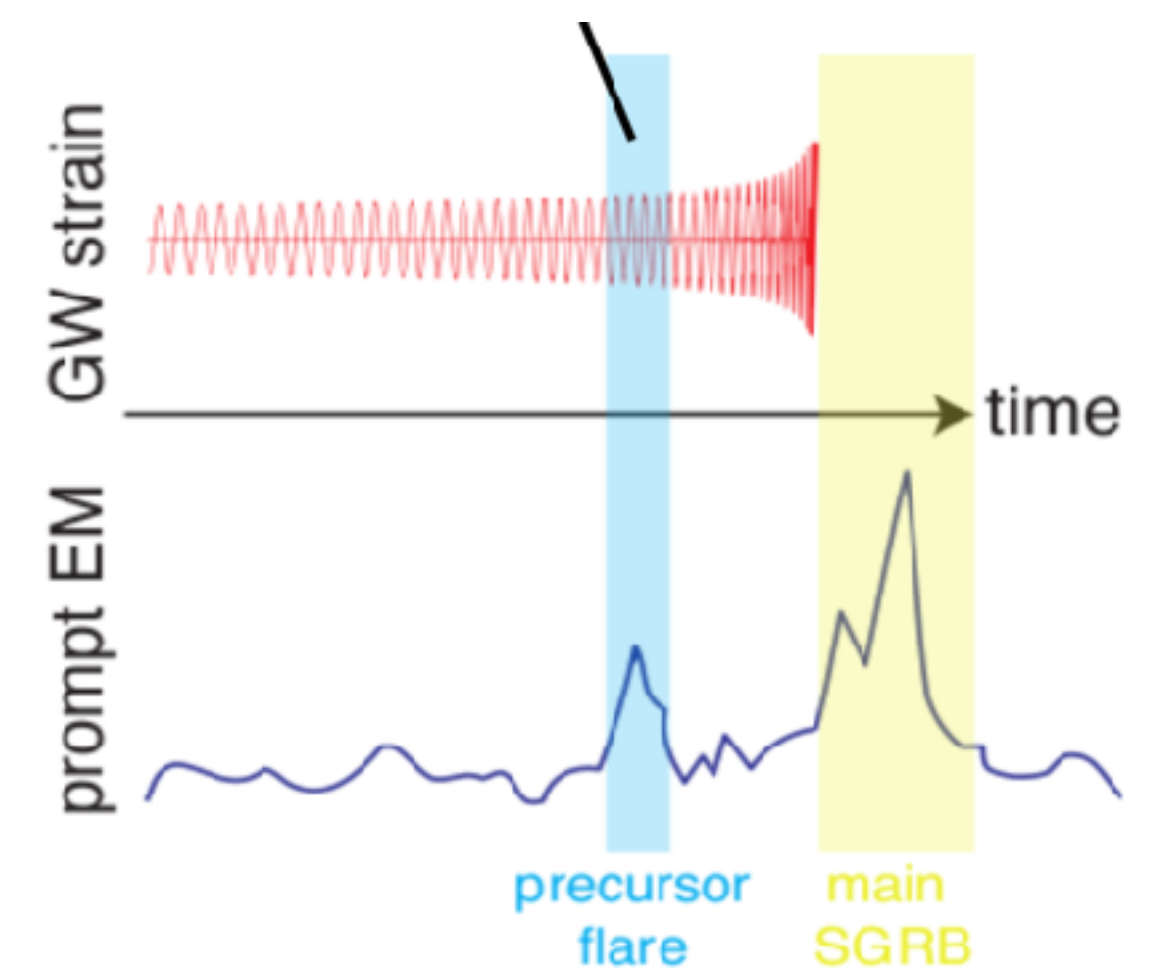
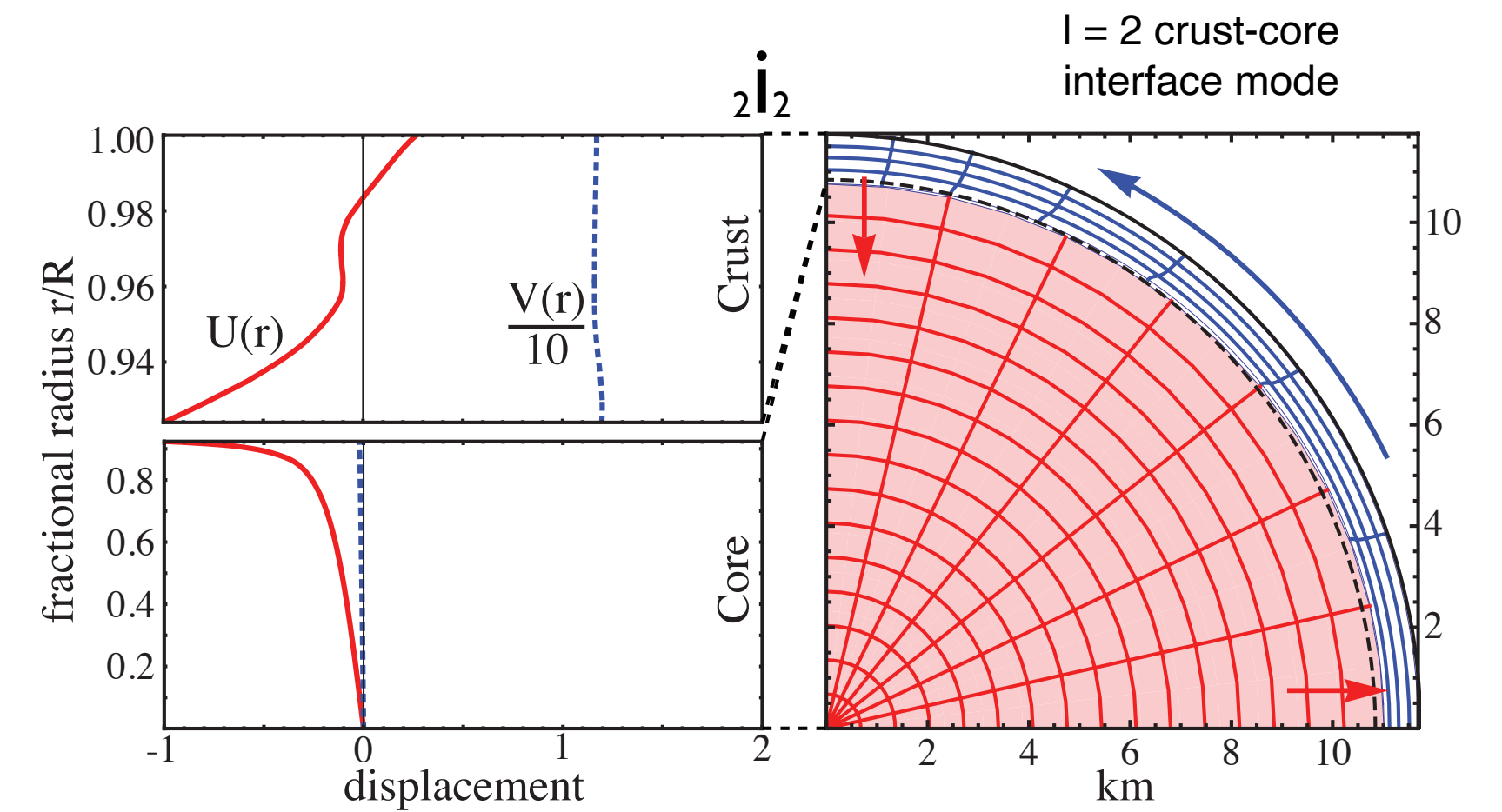
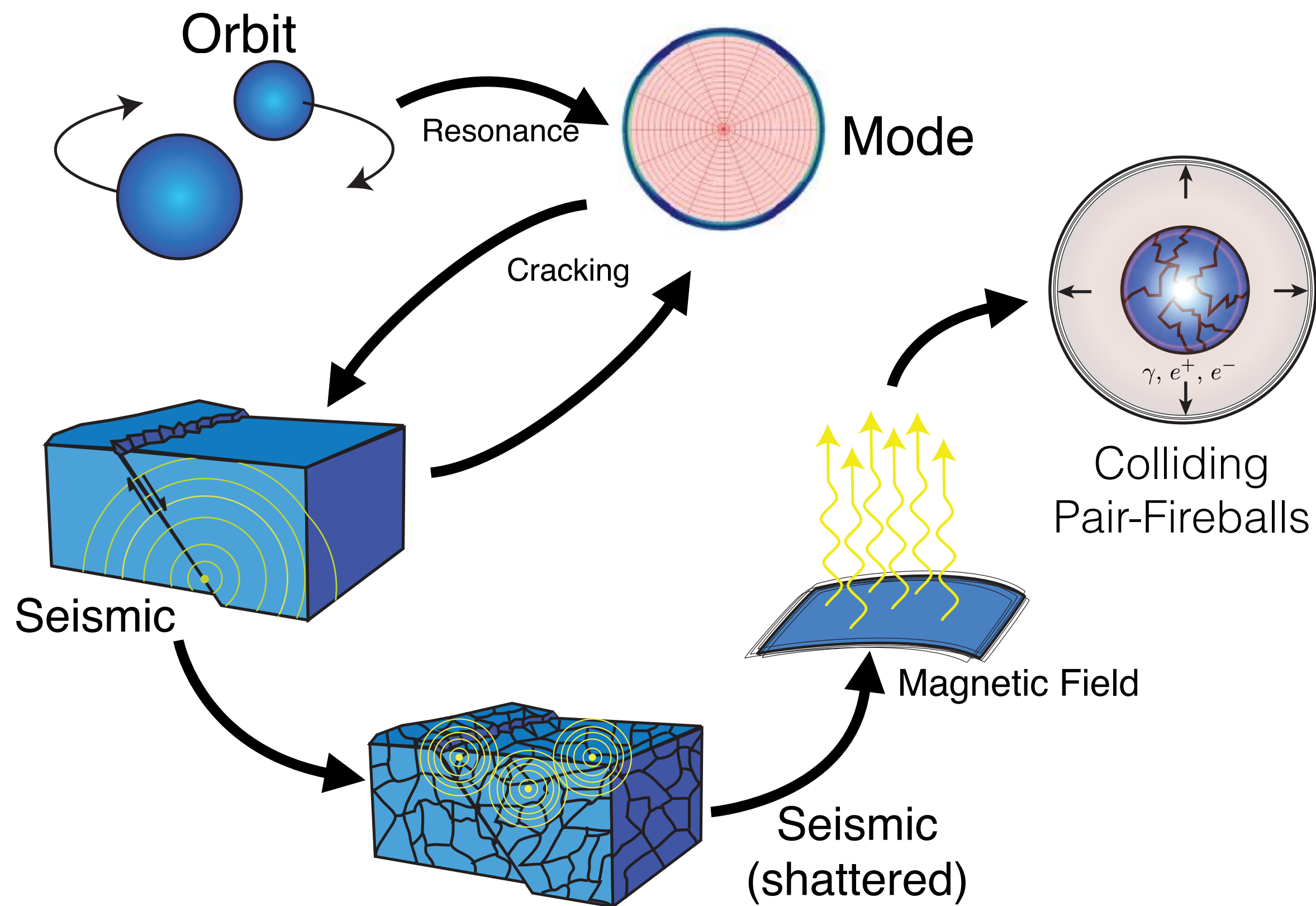


Other asteroseismic modes
(resonant during inspiral)

Ho & Andersson (2023), PRD 108, 043003



Multi-messenger Precursors (RSFs)

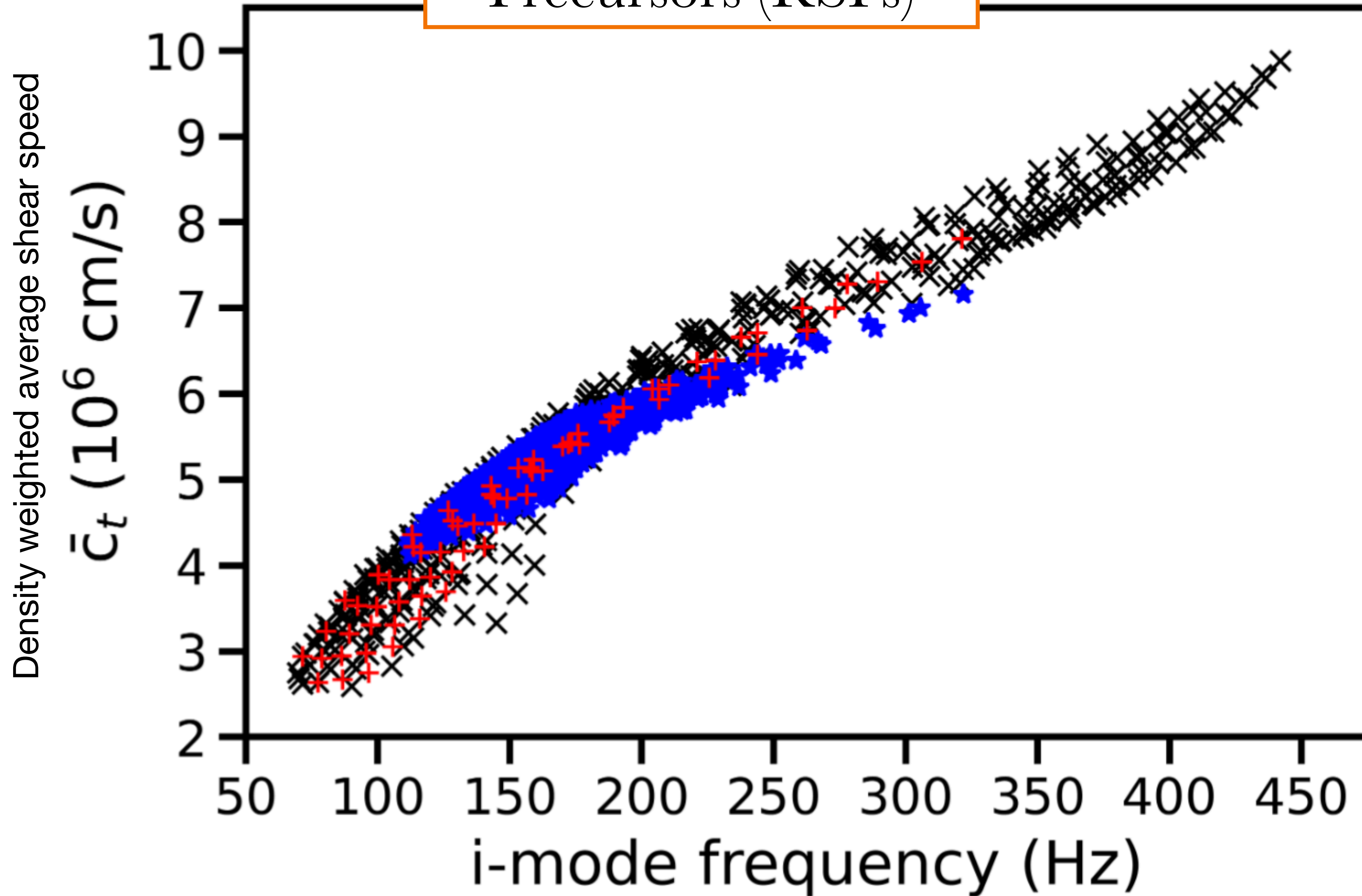


DT, et al. (2012) PRL 108, 011102

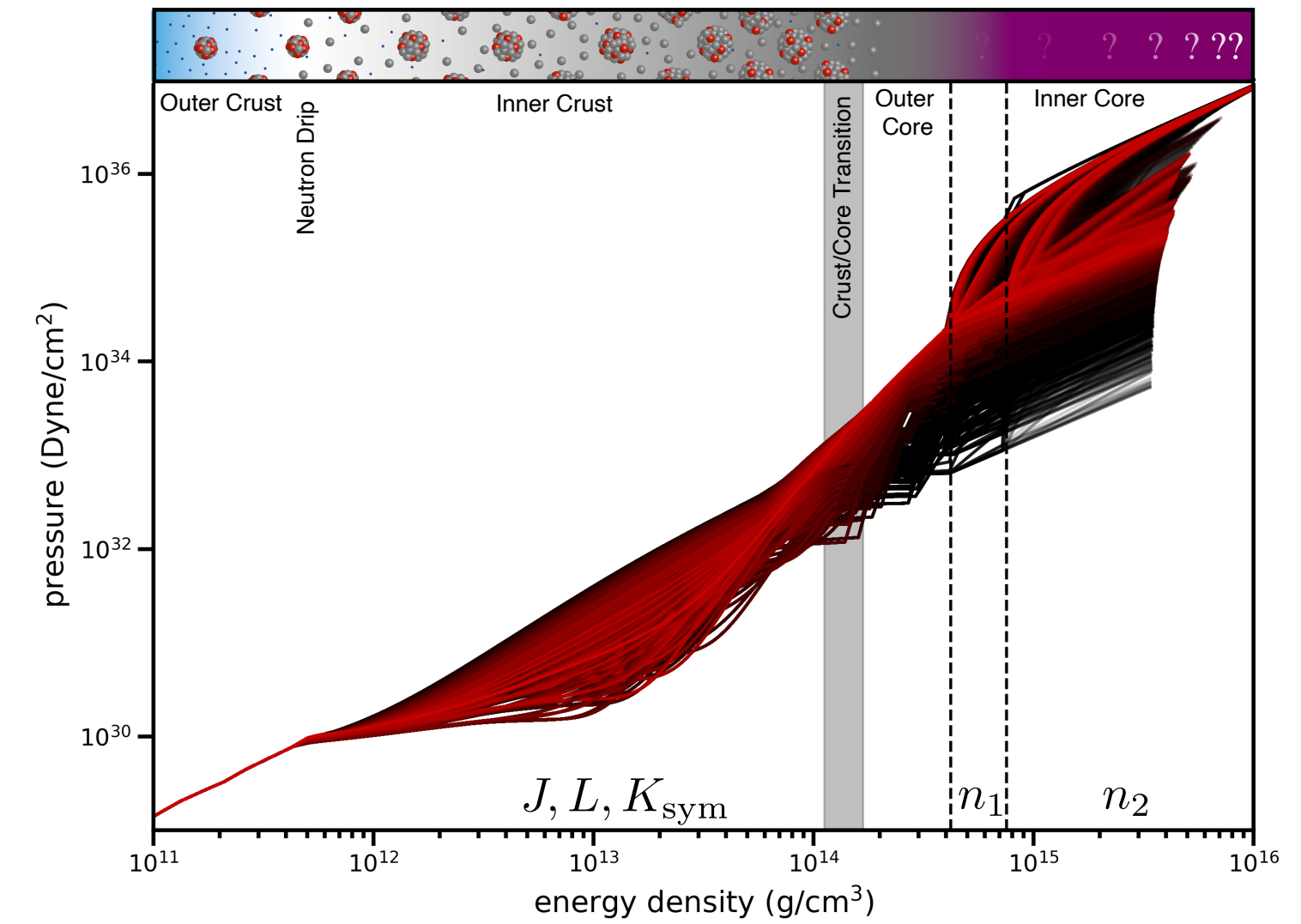
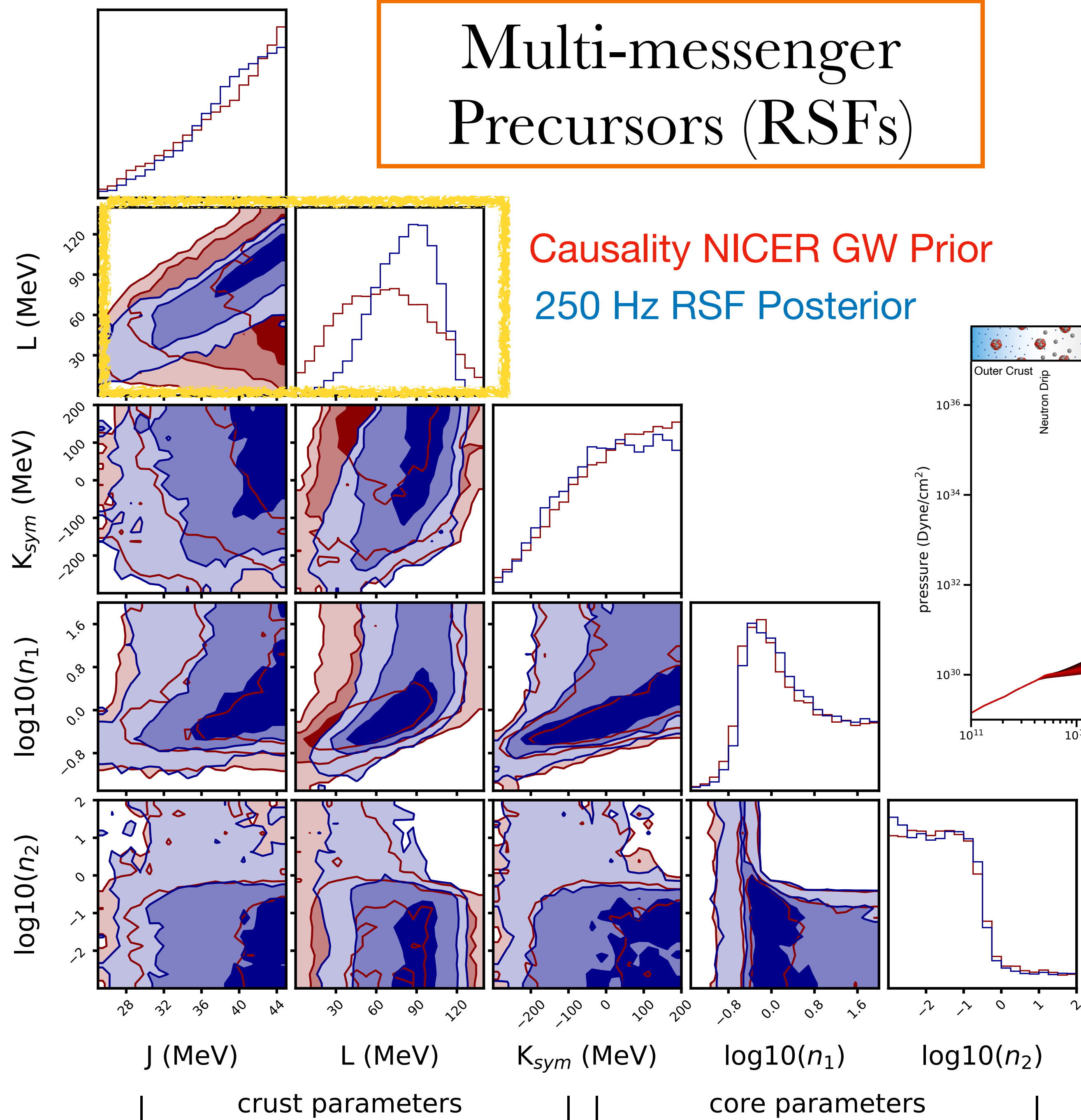
DT (2013) ApJ 777, 103

Neill, DT, Van Eerten, Ryan, & Newton (2022) MNRAS, 514, 4

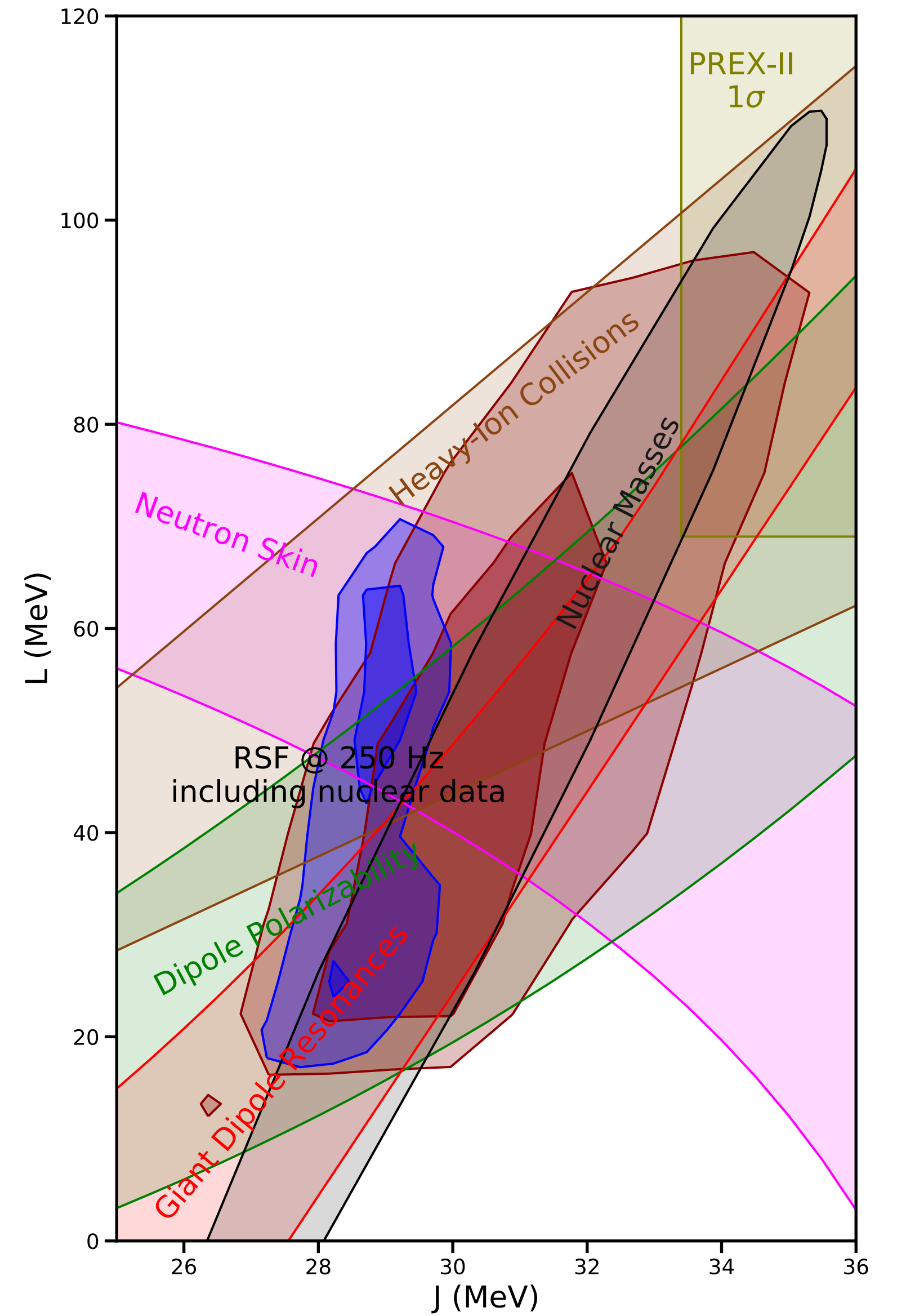
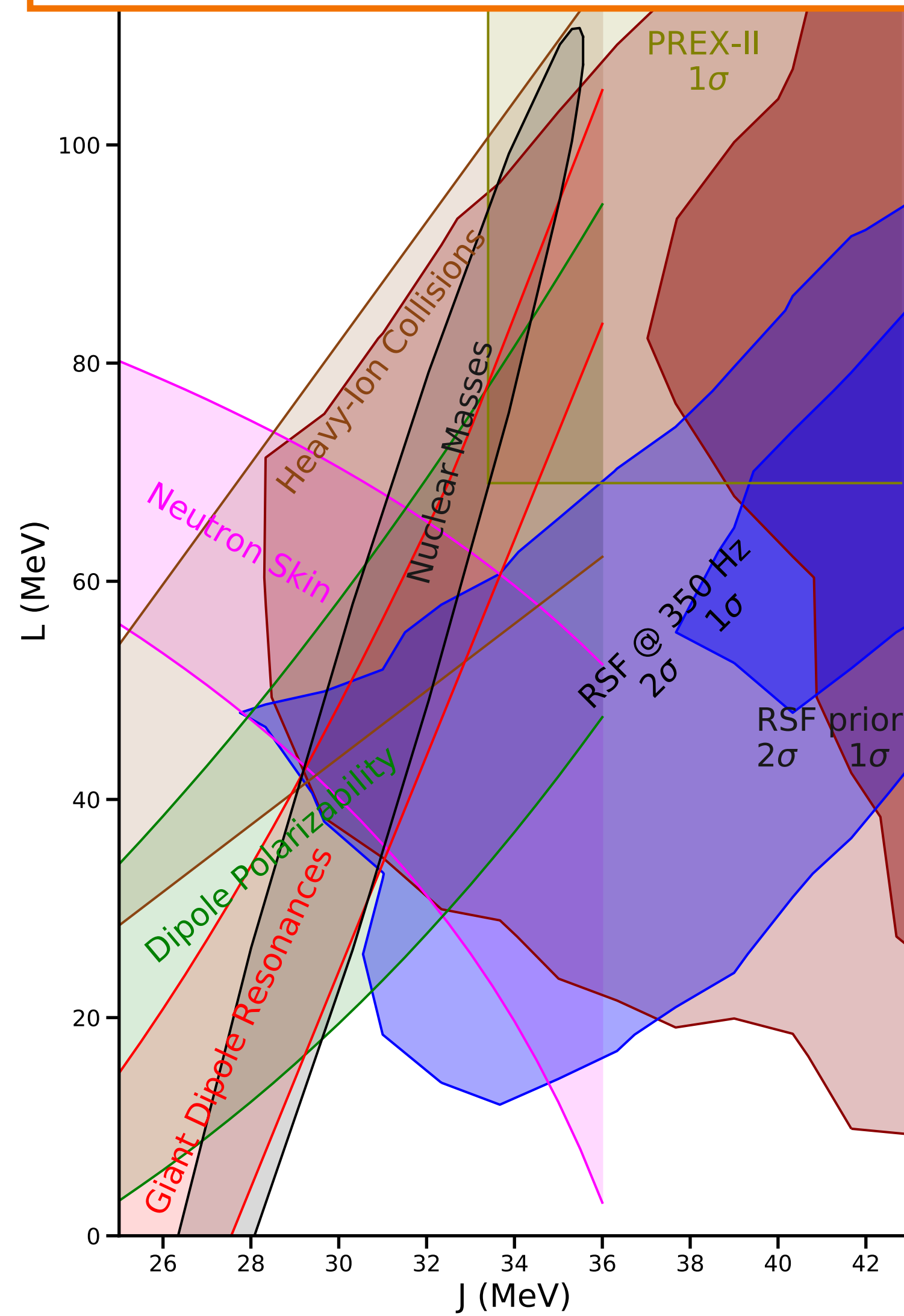
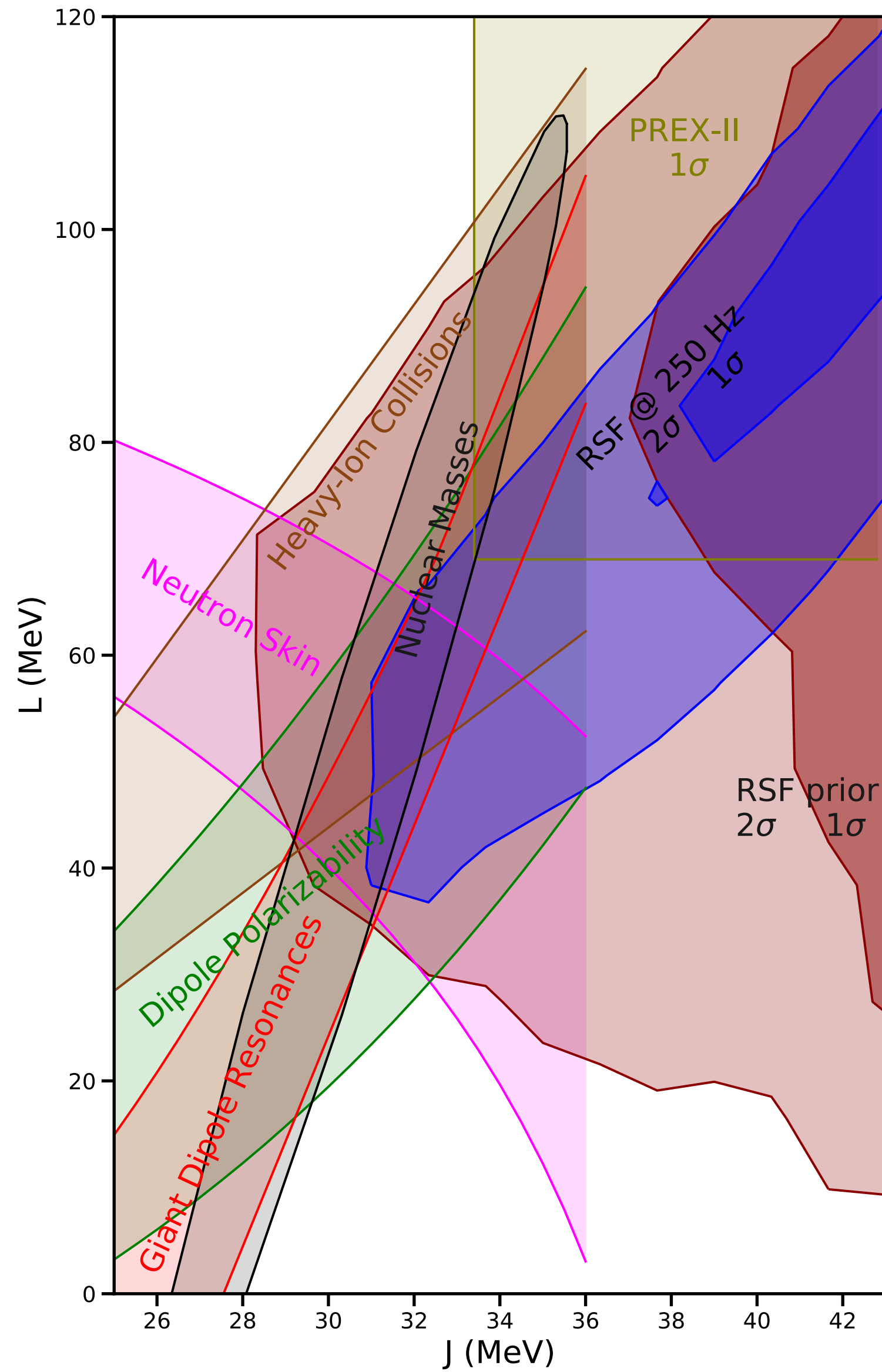
Multi-messenger
Precursors (RSFs)



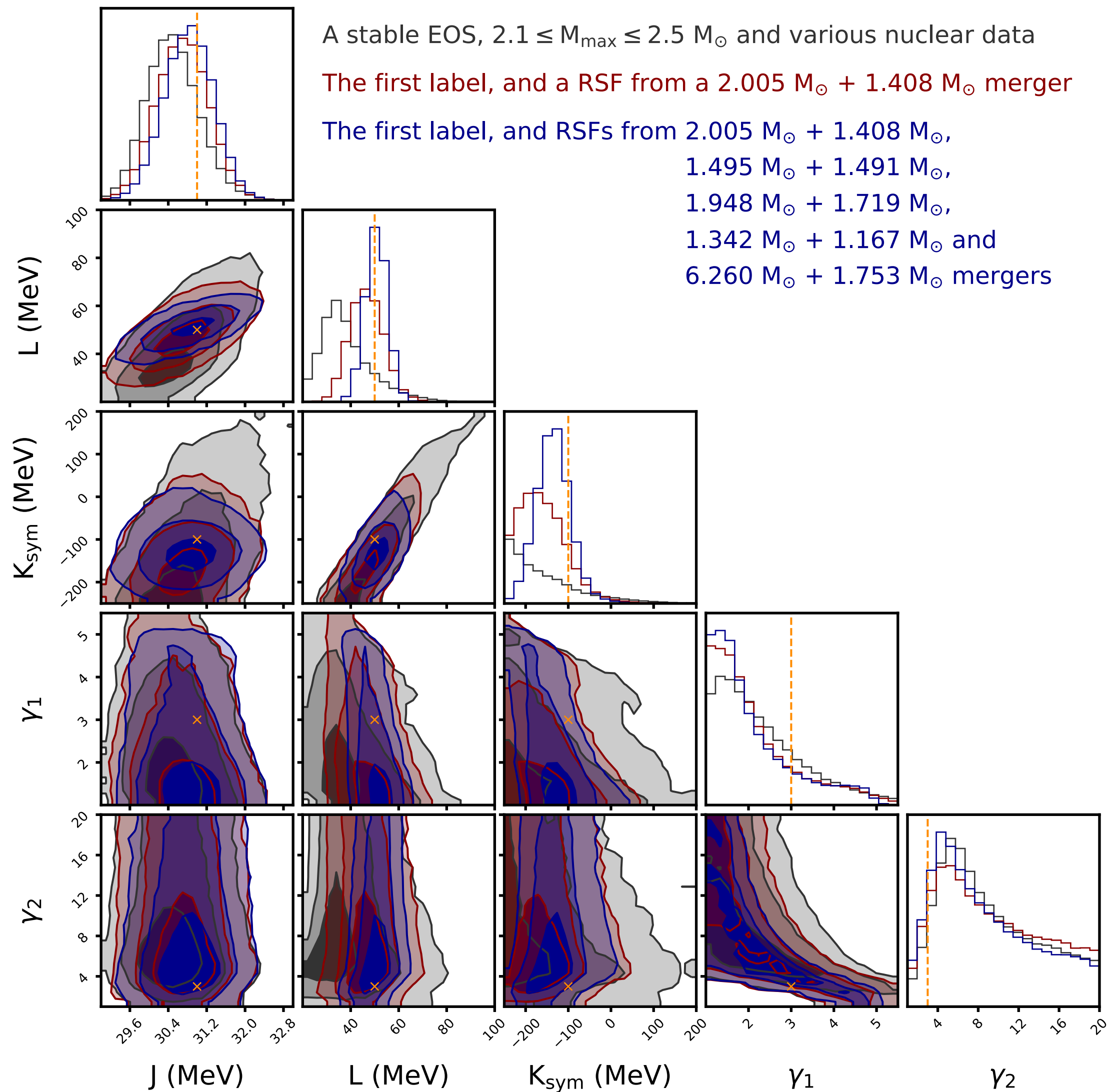
Multi-messenger Precursors (RSFs)



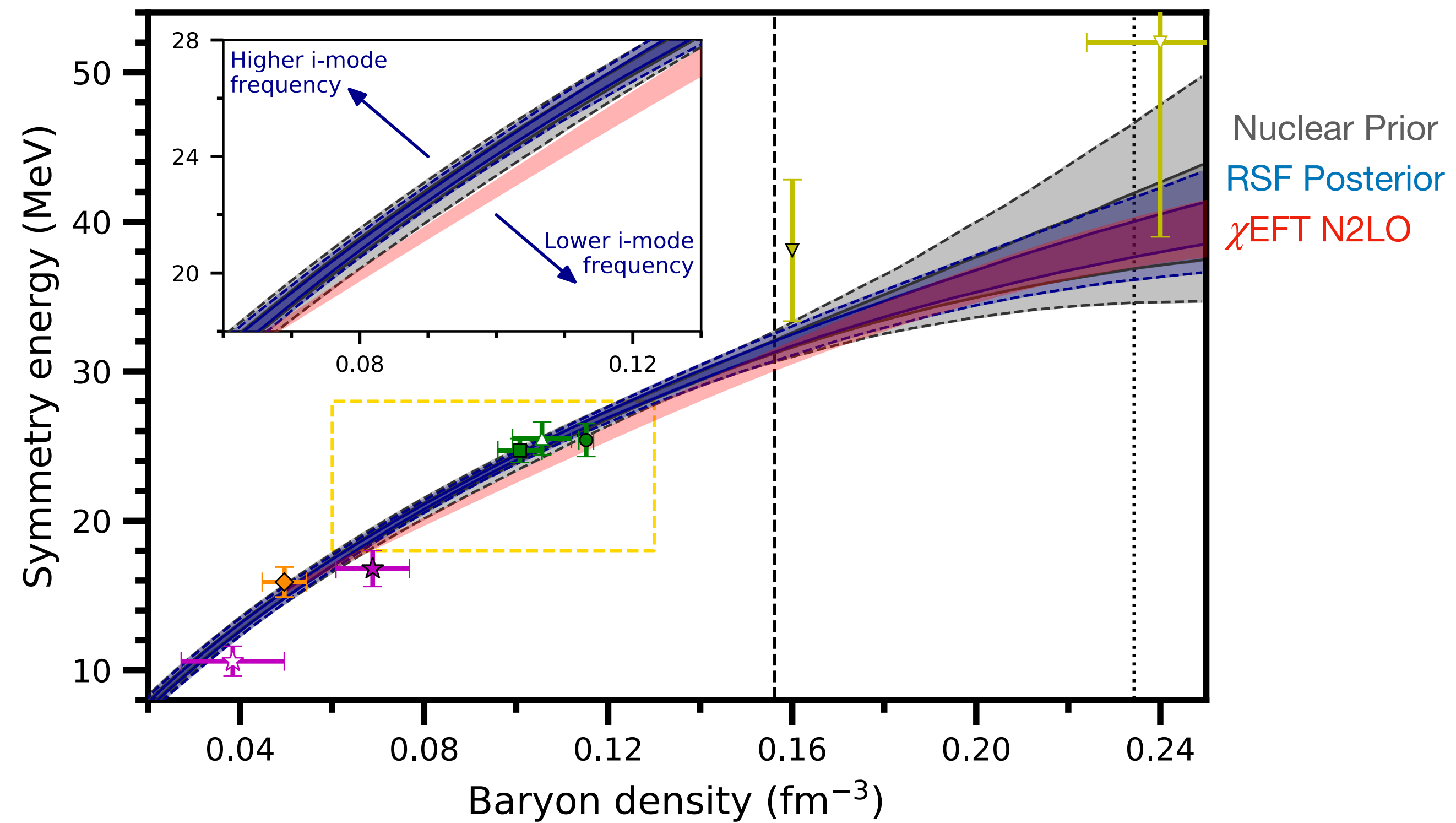
Multi-messenger Precursors (RSFs)



Multi-messenger Precursors (RSFs)

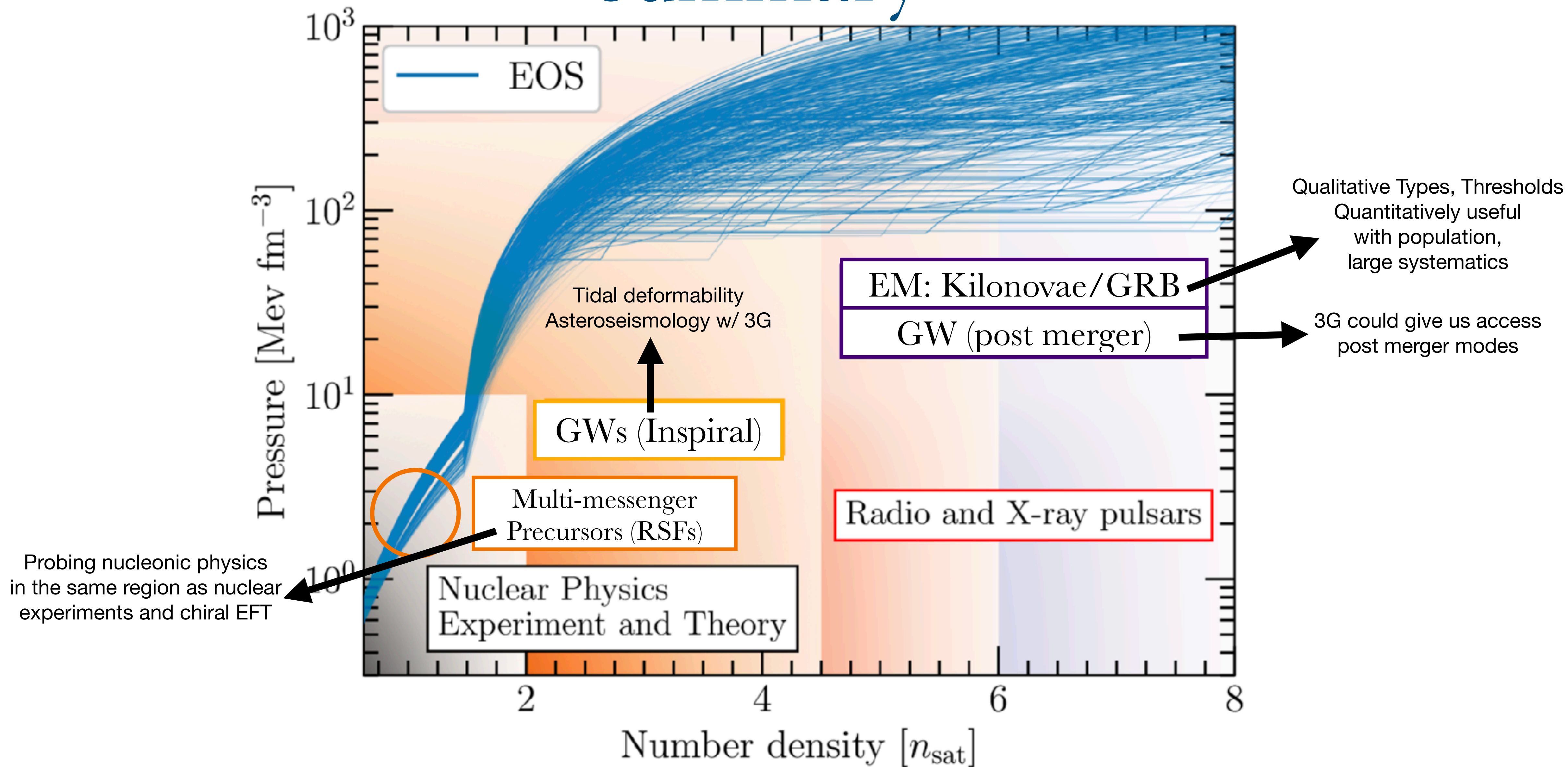


Neill, Preston, Newton & DT (2024) in prep



Neill, Drischler, Newton, Salafia & DT (2024) in prep

Summary



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Observables & Metadata Database

COMING SOON!

JUST APPROVED!



eXtreme Matter in eXtreme Stars

Lorentz Center, Netherlands

Sept 23-27, 2024