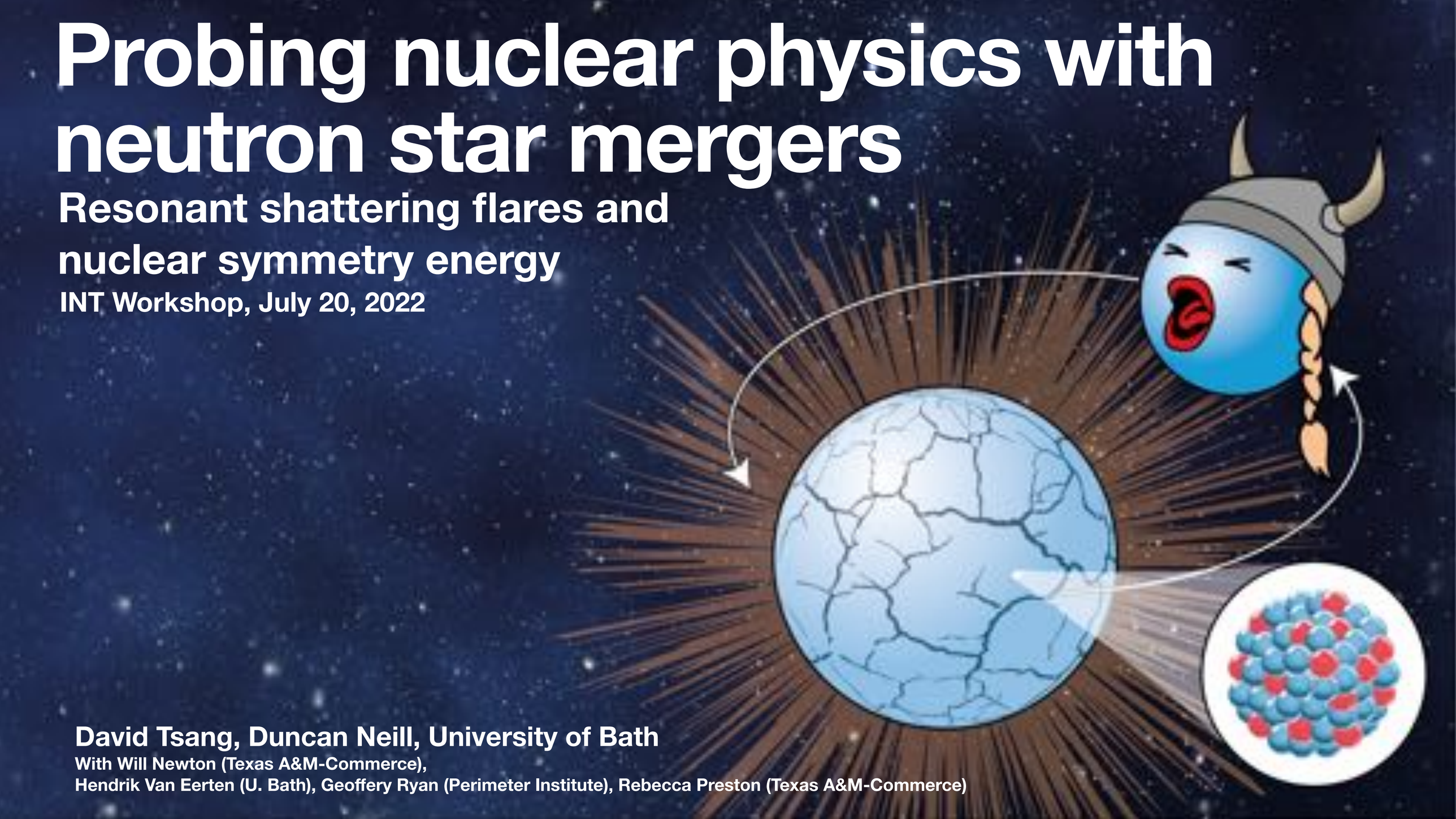
Probing nuclear physics with neutron star mergers

Resonant shattering flares and nuclear symmetry energy

INT Workshop, July 20, 2022



David Tsang, Duncan Neill, University of Bath

With Will Newton (Texas A&M-Commerce),
Hendrik Van Eerten (U. Bath), Geoffery Ryan (Perimeter Institute), Rebecca Preston (Texas A&M-Commerce)

Why are neutron stars important to nuclear physicists?

Which regions of a neutron star tell us about which physics?

What multi-messenger observables can we use?

What are Resonant Shattering Flares (RSFs)?

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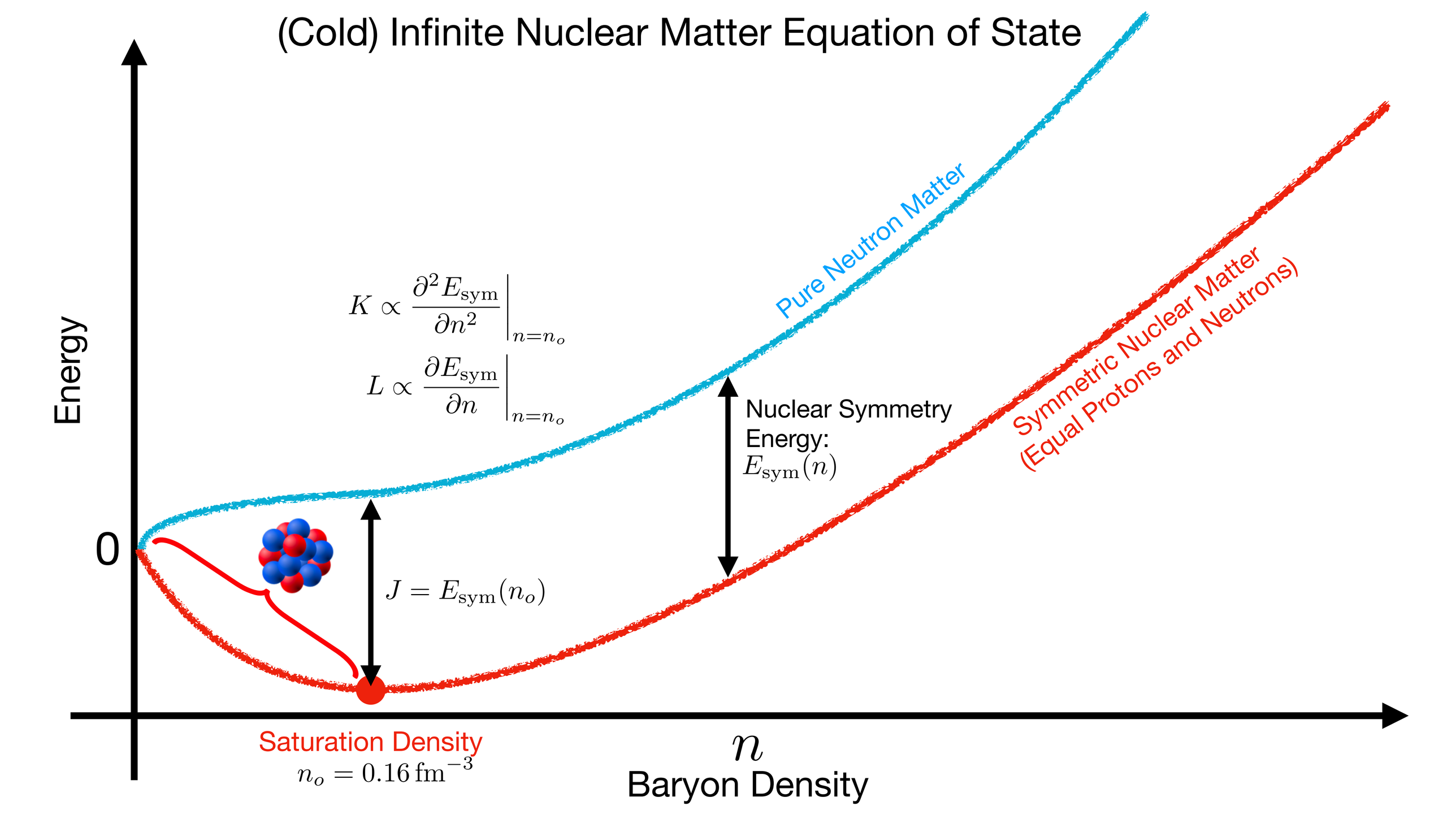
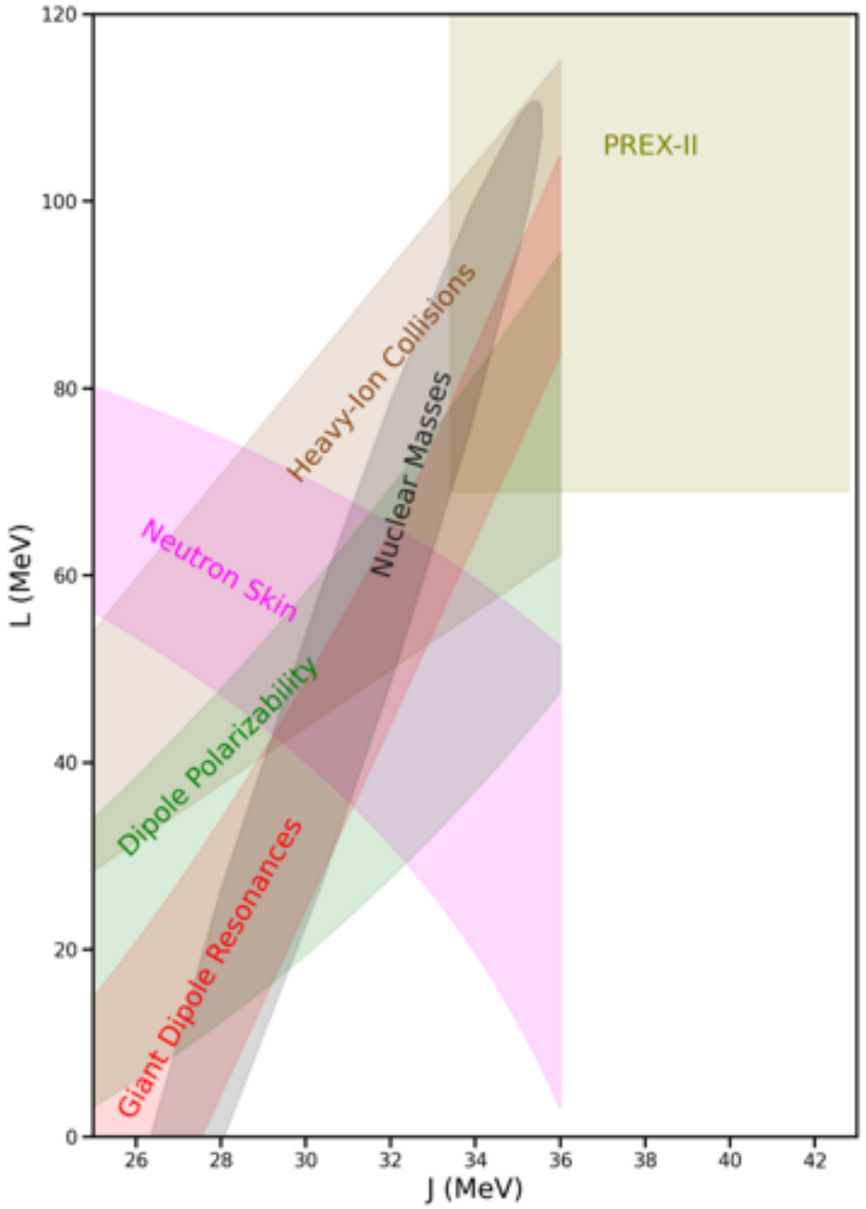
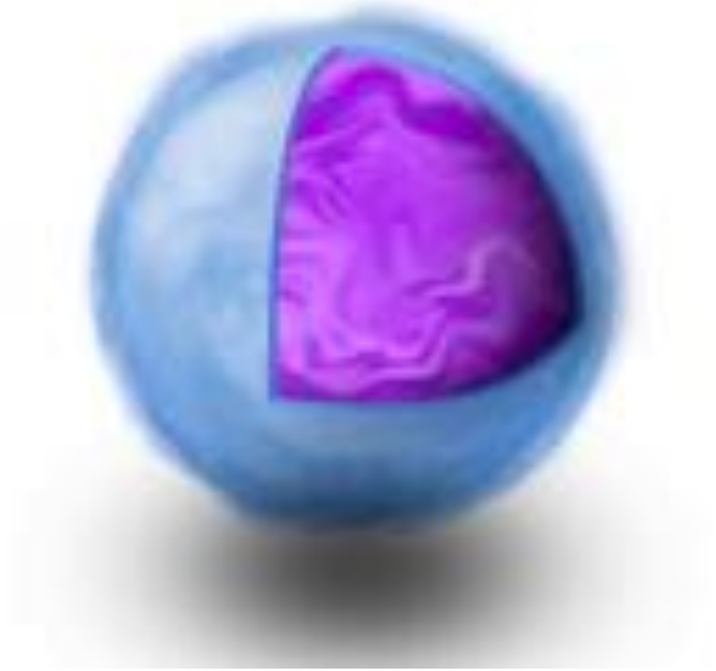

(Cold) Infinite Nuclear Matter Equation of State
Energy
0
$K \propto \left.\frac{\partial^2 E_{\rm sym}}{\partial n^2}\right|_{n=n_o}$
$L \propto \left.\frac{\partial E_{\rm sym}}{\partial n}\right|_{n=n_o}$
Pure Neutron Matter
Symmetric Nuclear Matter
(Equal Protons and Neutrons)
Nuclear Symmetry
Energy:
$E_{\rm sym}(n)$
$J = E_{\rm sym}(n_o)$
Saturation Density
$n_o = 0.16\,{\rm fm}^{-3}$
n
Baryon Density

Symmetry energy constraints from terrestrial experiments



Pb^{208} Neutron "Skin" thickness



How can we measure Symmetry Energy with astrophysics?

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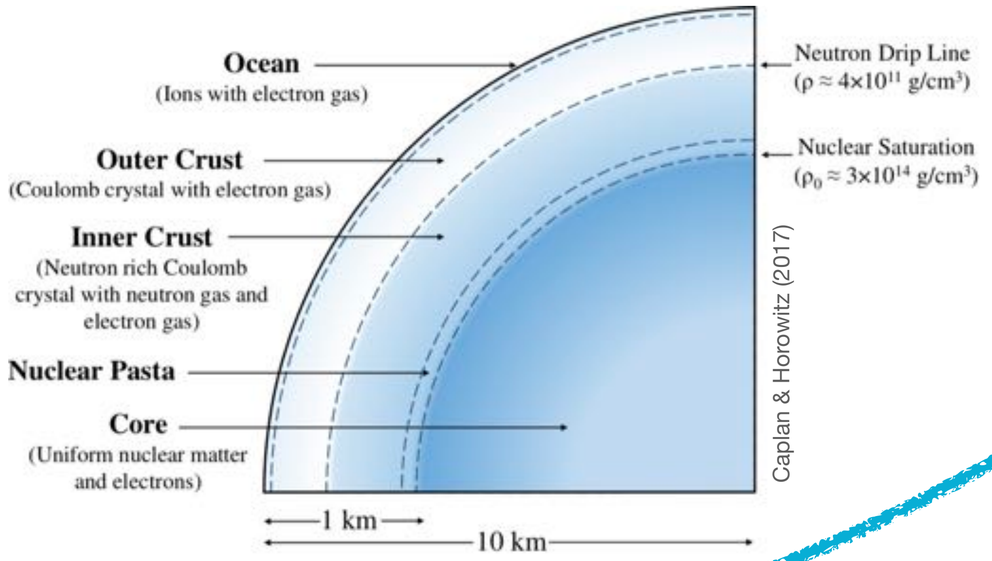

Energy

0

Pure Neutron Matter

Symmetric Nuclear Matter
(Equal Protons and Neutrons)

Nuclear Symmetry Energy:
$E_{\rm sym}(n)$

$J = E_{\rm sym}(n_o)$

Saturation Density
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n
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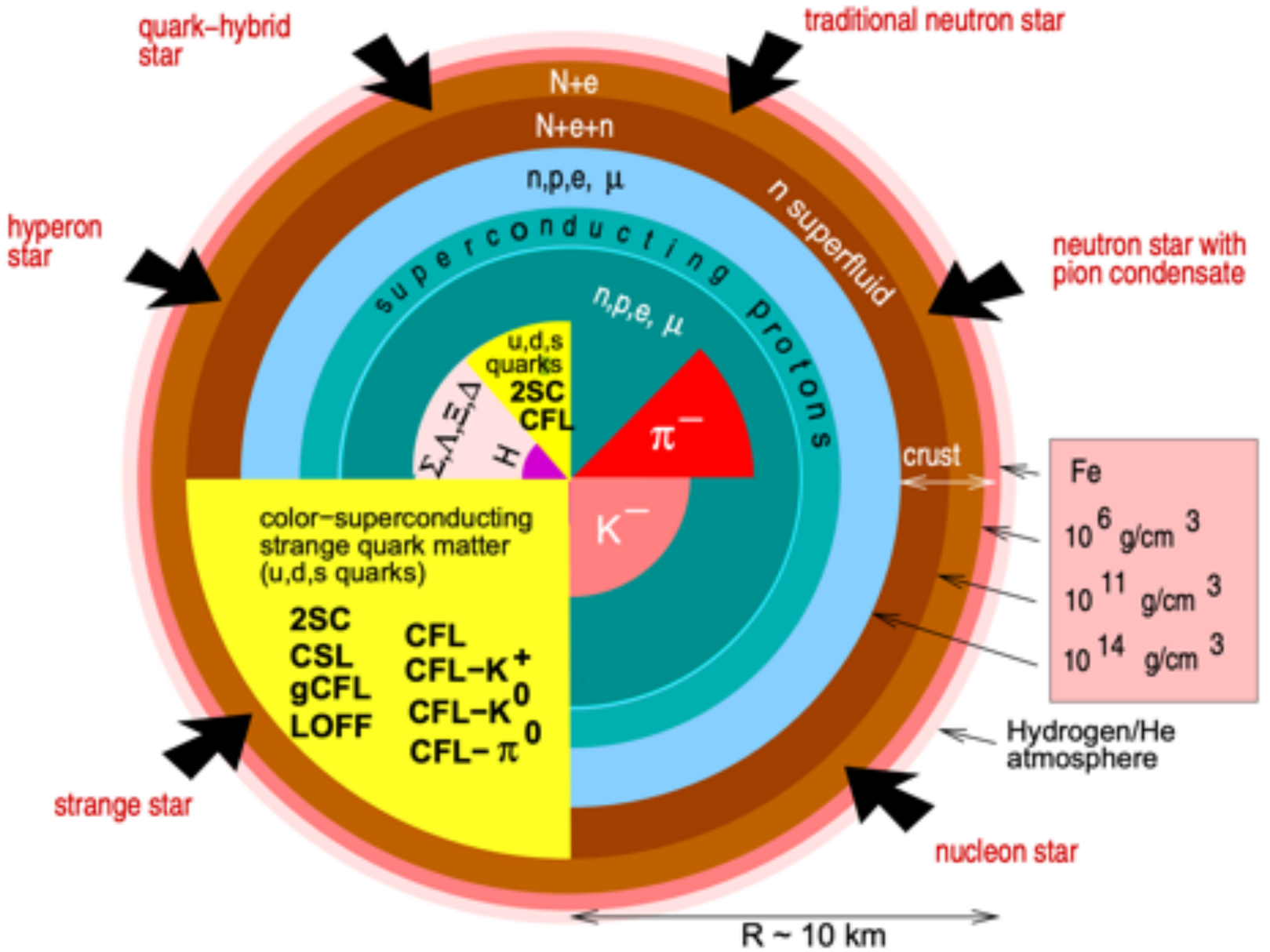
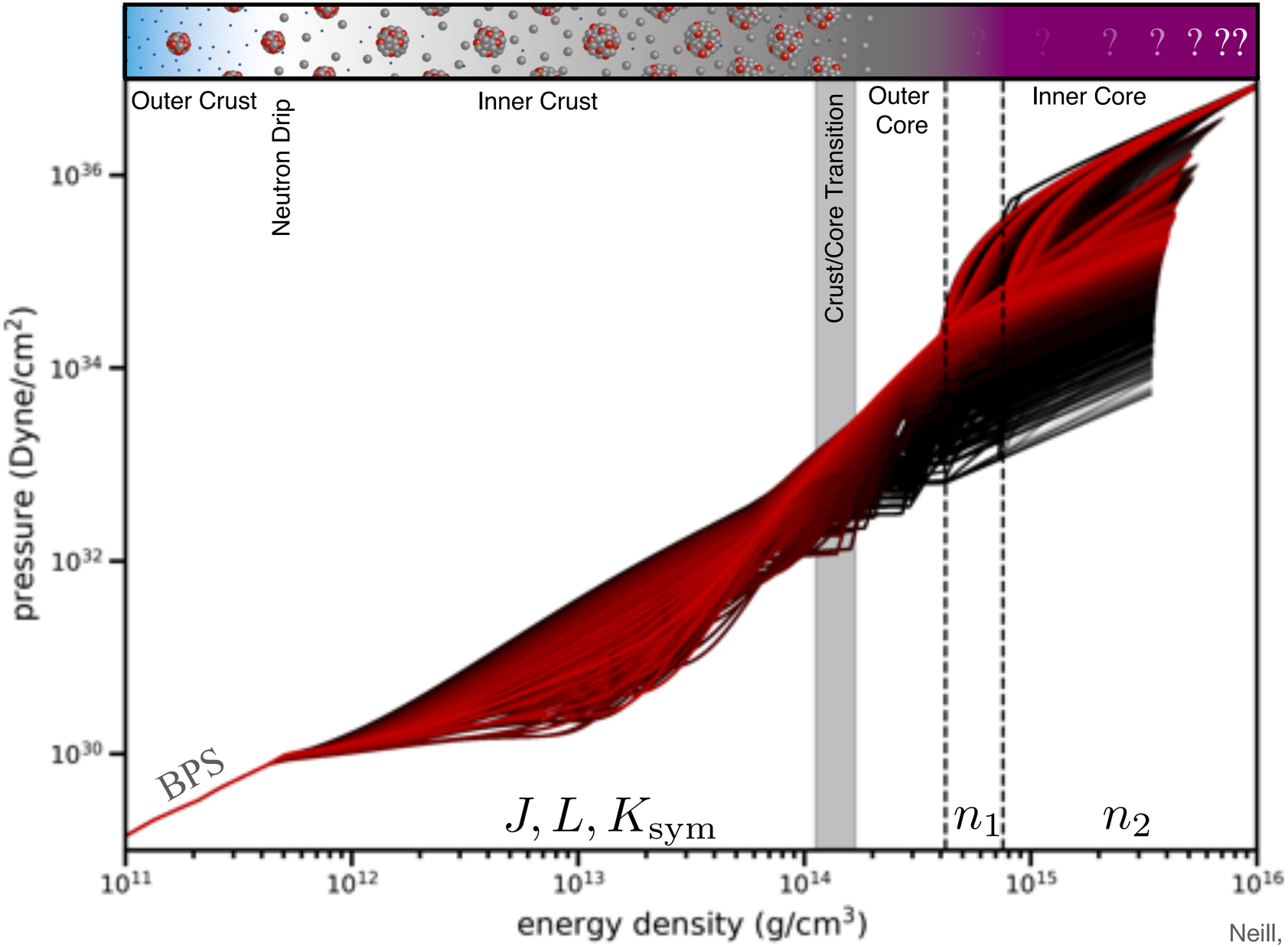


Weber 2004, arXiv:astro.ph/0407155

Parameterised Crust and Core EOS



Neill, Preston, Newton & DT in prep
Based on EOSs from Balliet et al, 2021, ApJ 918:79

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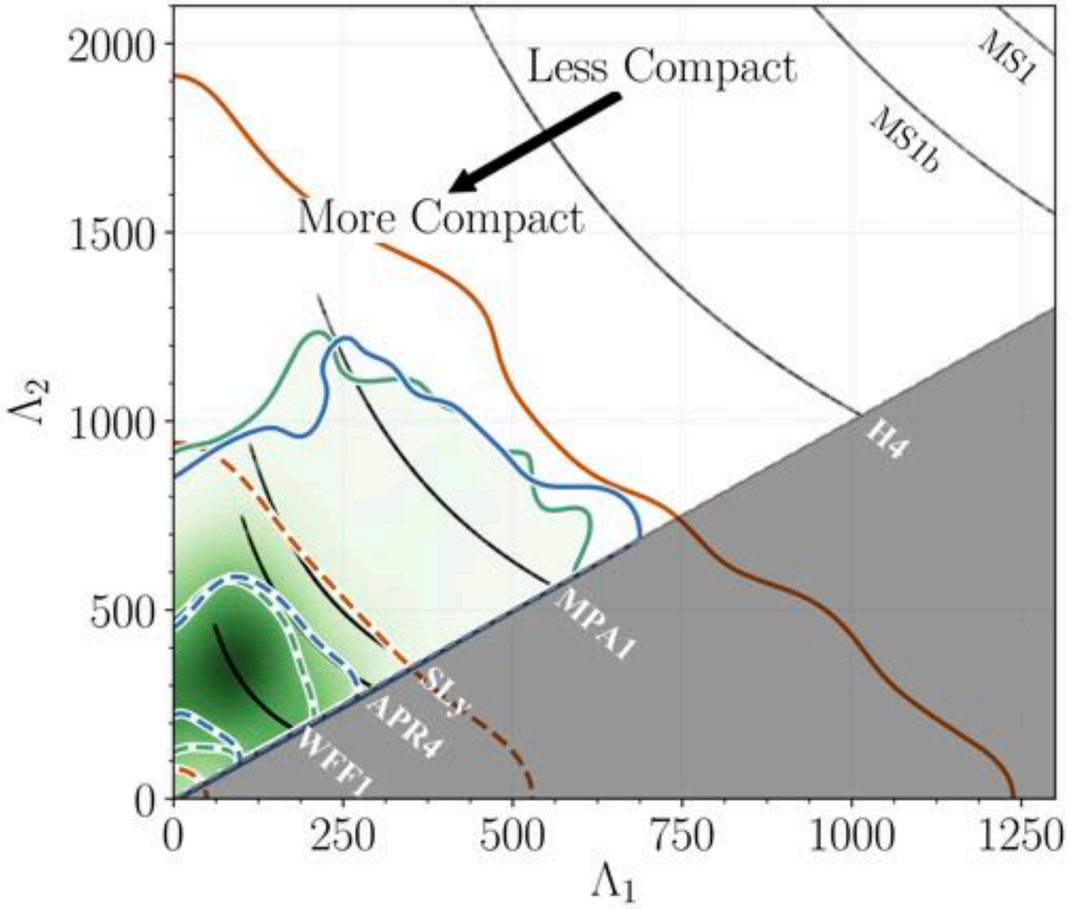
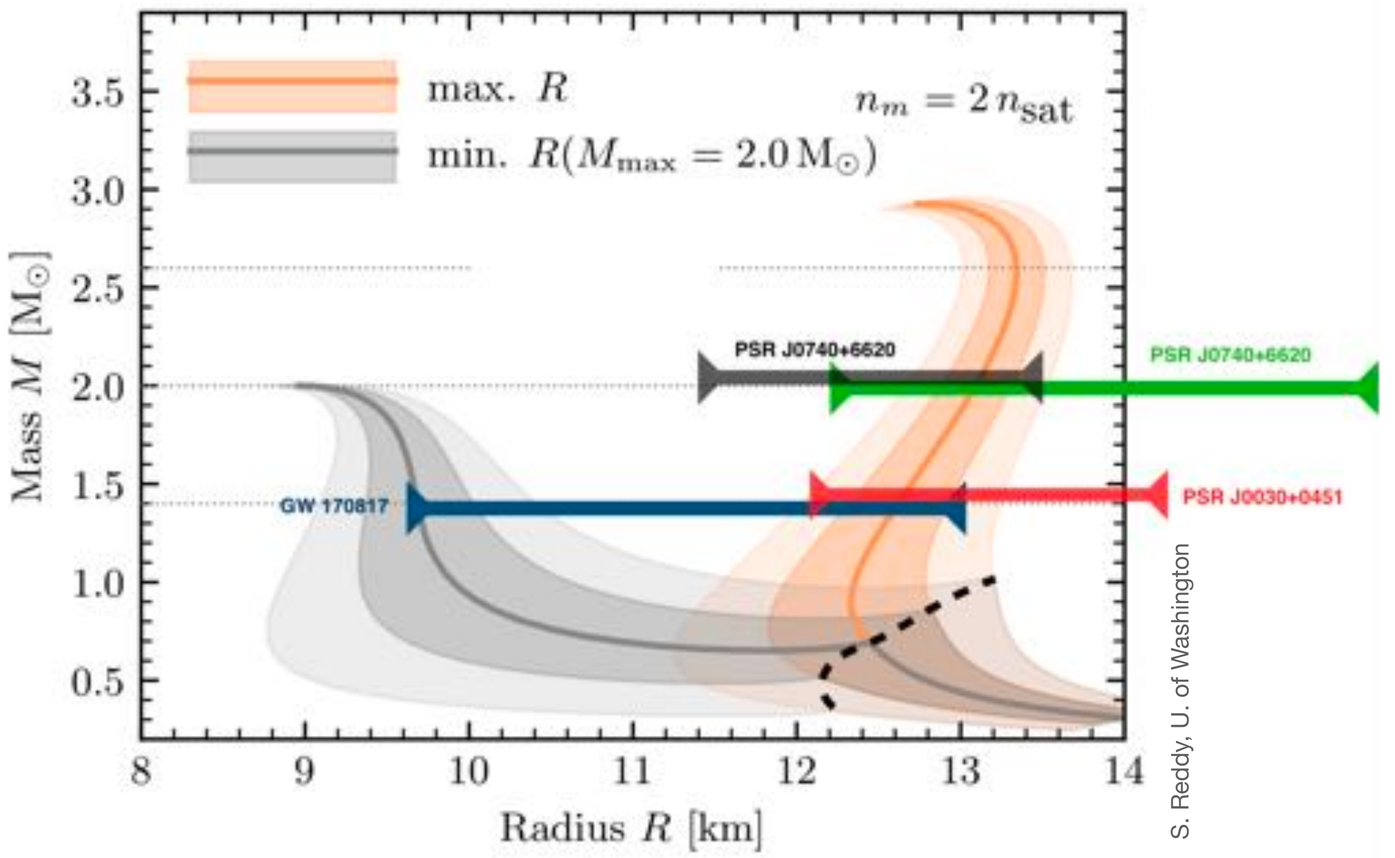
Kilonovae and Short Gamma Ray Bursts tell us a lot about the messy post-merger physics!
But it’s difficult to extract info about the neutron star progenitors themselves…

Tidal deformability, M-R, M_{max}, f-mode mostly functions of core properties

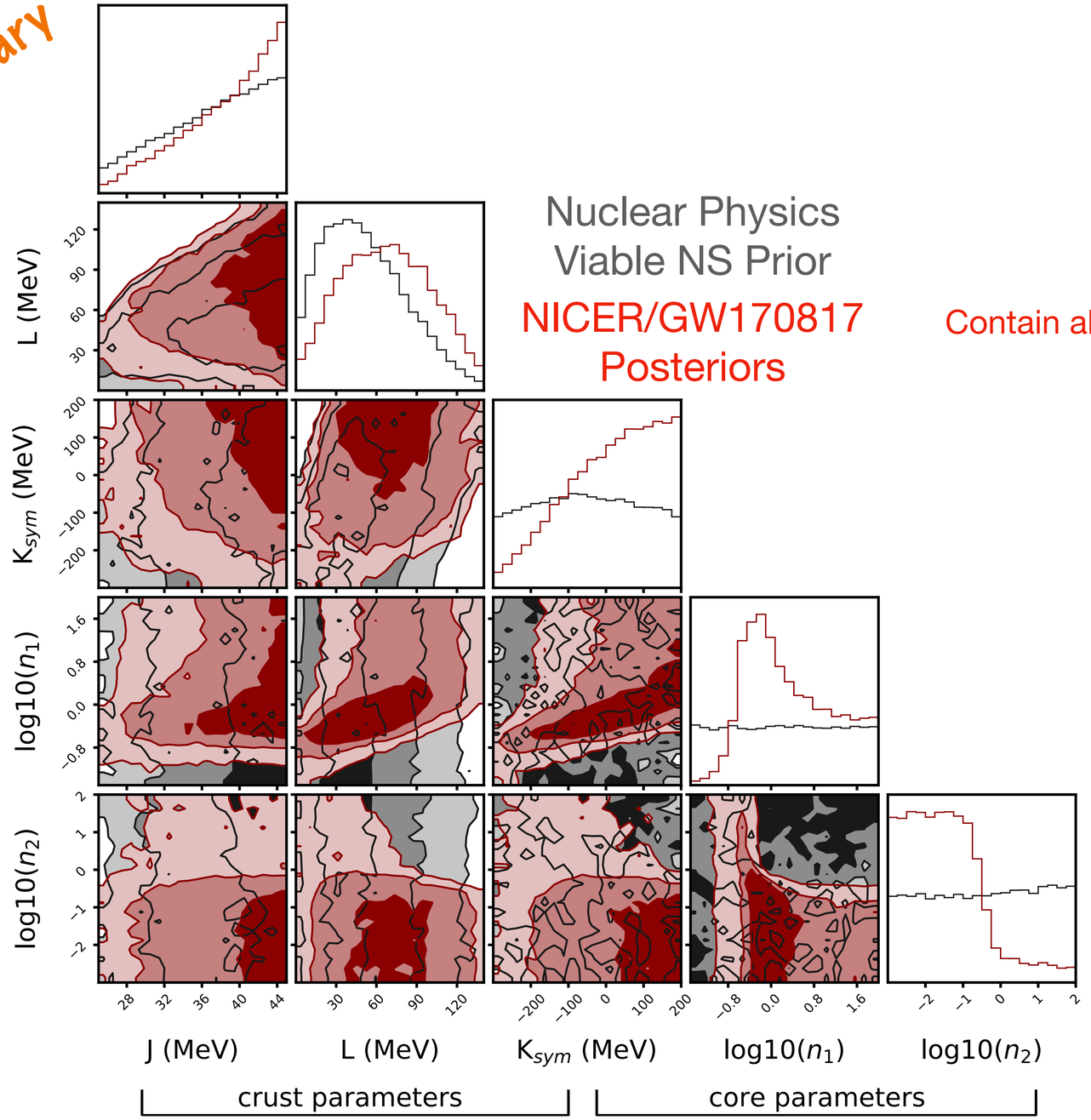


LIGO/Virgo (2018) PRL 121, 161101



S. Reddy, U. of Washington

Preliminary



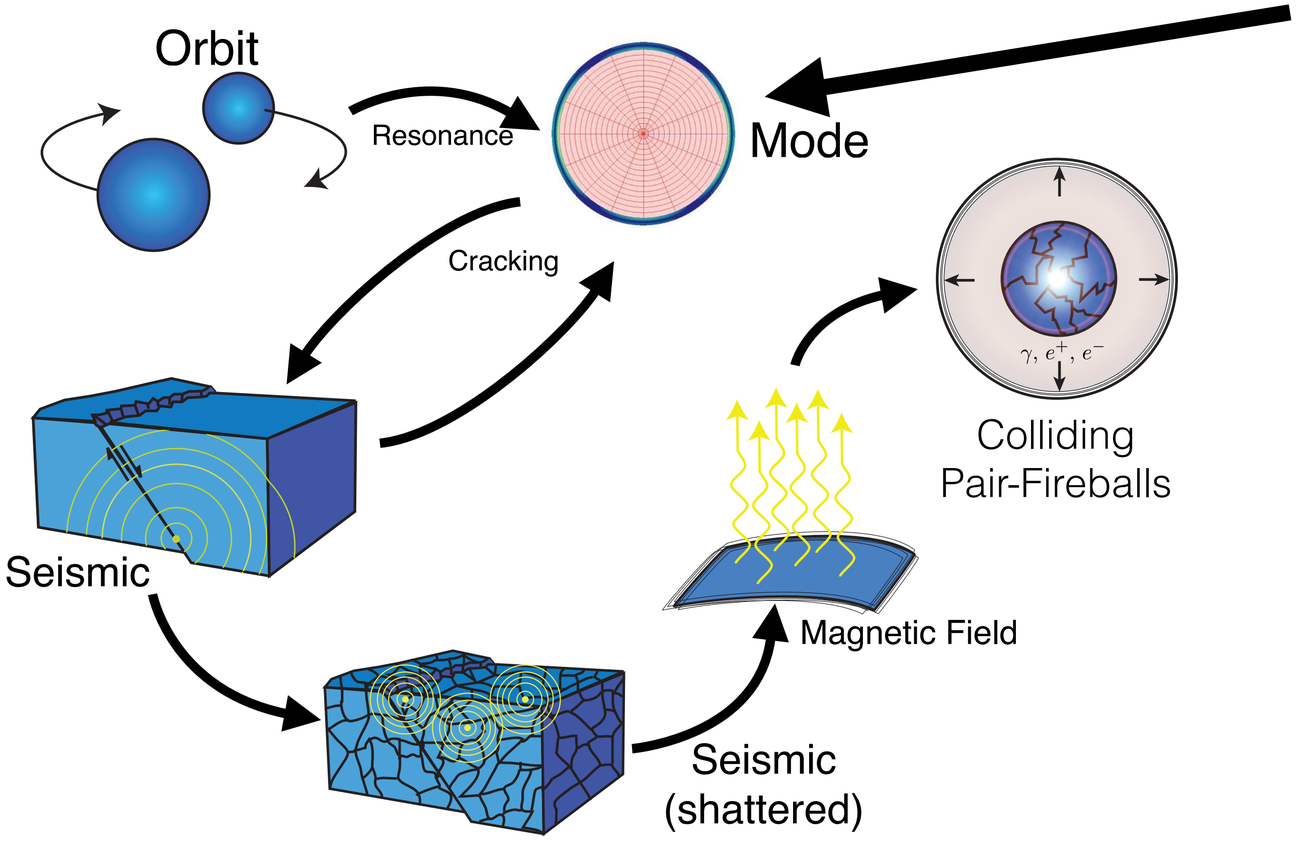
Nuclear Physics
Viable NS Prior

NICER/GW170817
Posteriors

Contain almost no information about inner/outer crust

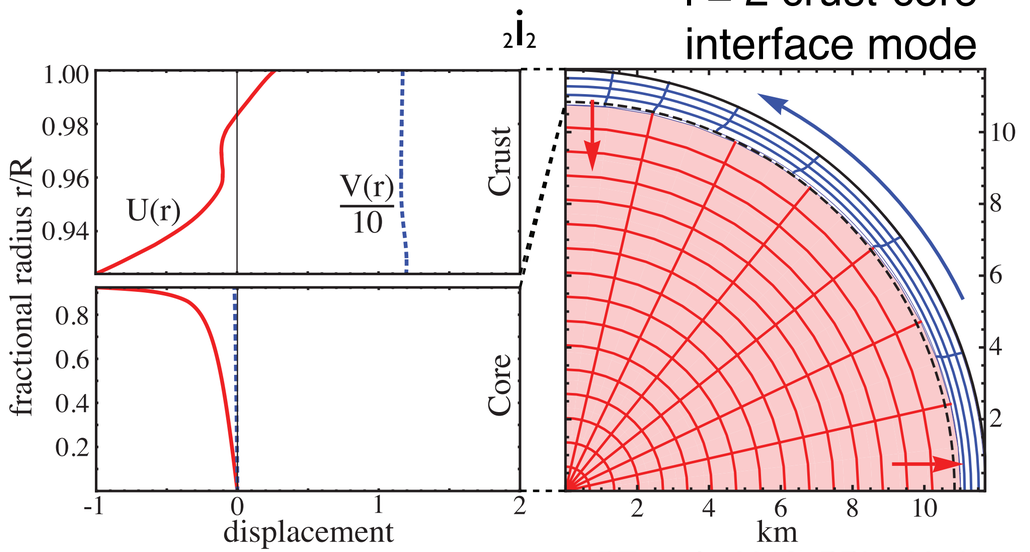
AN OBSERVABLE THAT CAN BE USED TO PROBE STRUCTURE OF THE INNER CRUST AND THEREFORE NUCLEAR SYMMETRY ENERGY

Resonant Shattering Flares



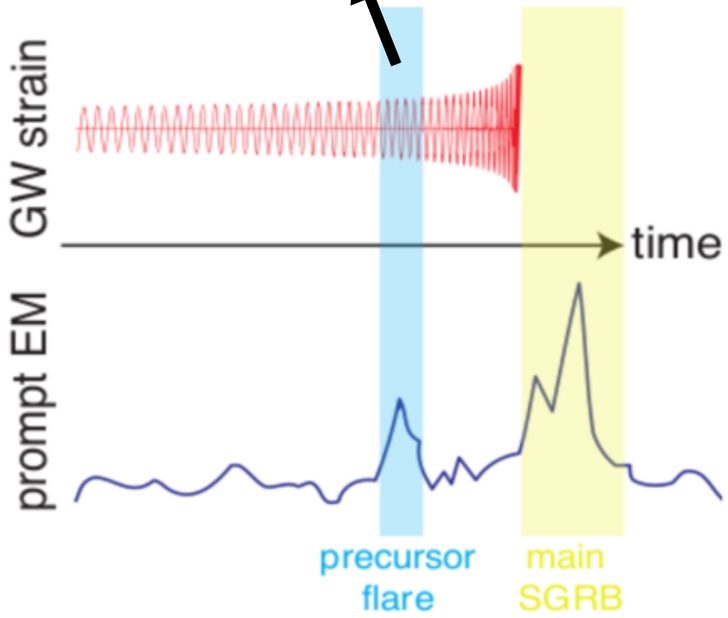
DT, et al. (2012) PRL 108, 011102
DT (2013) ApJ 777, 103
Neill, DT, Van Eerten, Ryan, & Newton (2022) MNRAS in press

l = 2 crust-core interface mode



DT et al. (2012) PRL 108, 011102

f_{mode} ~ 100Hz



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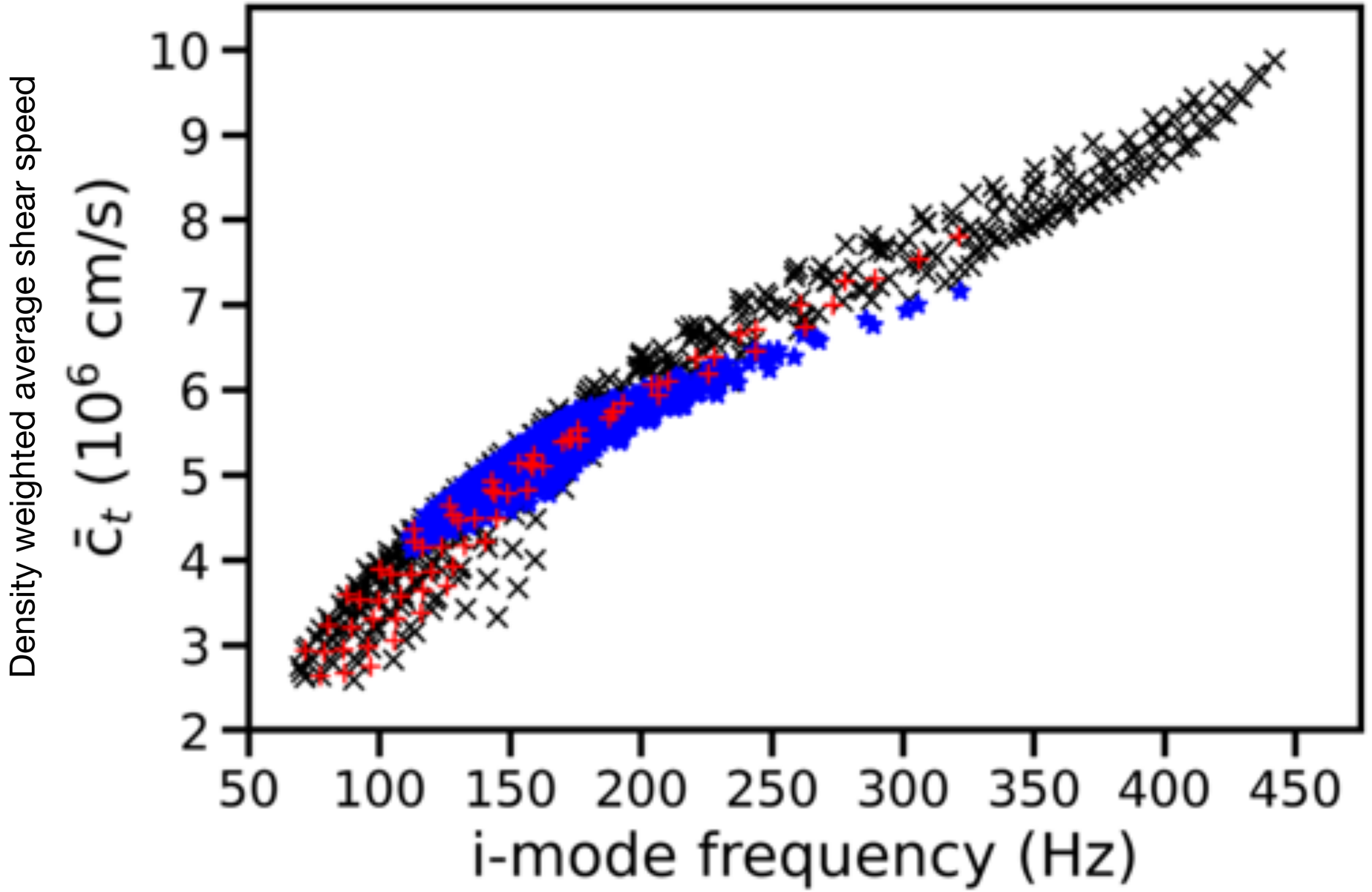
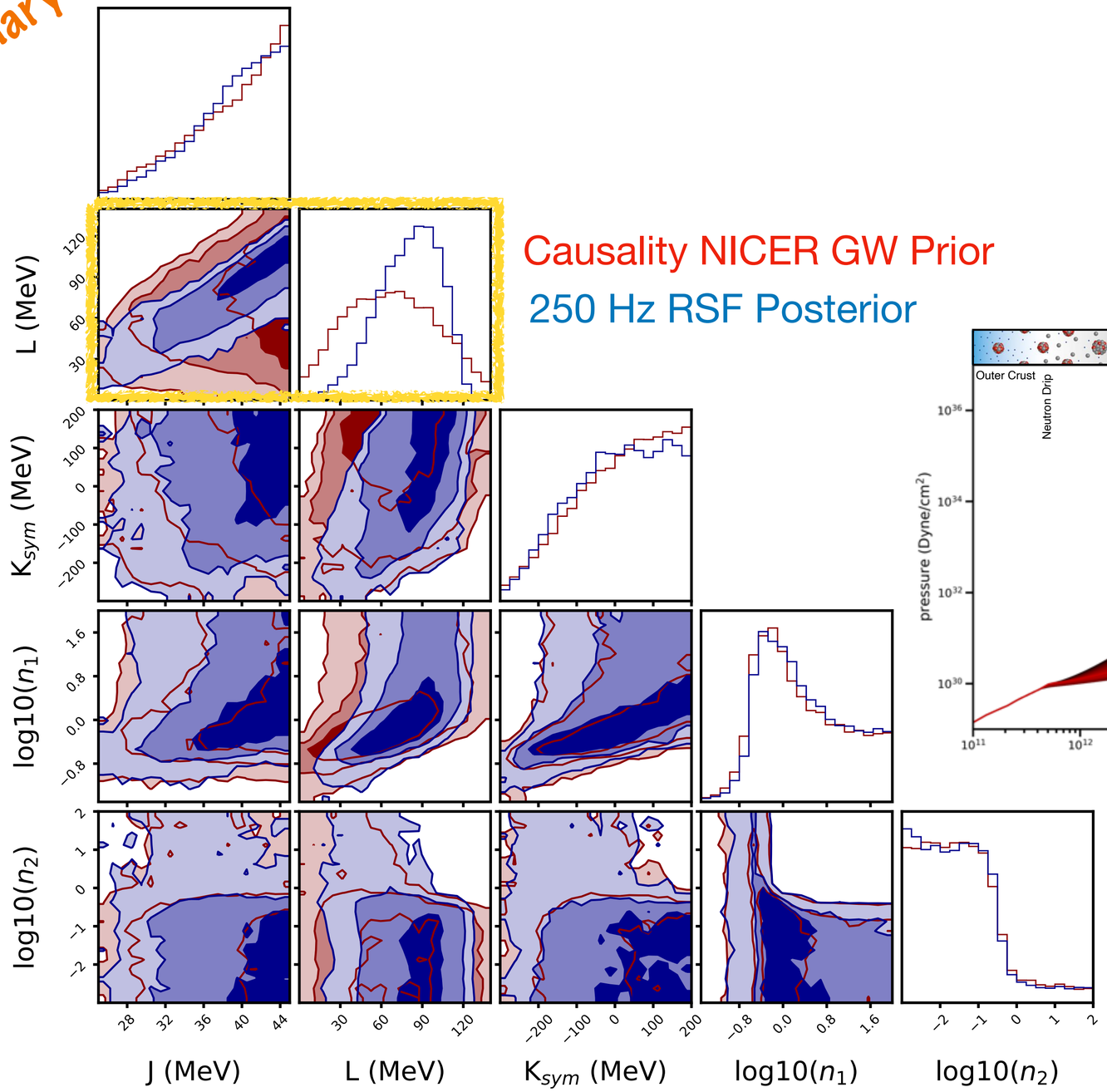


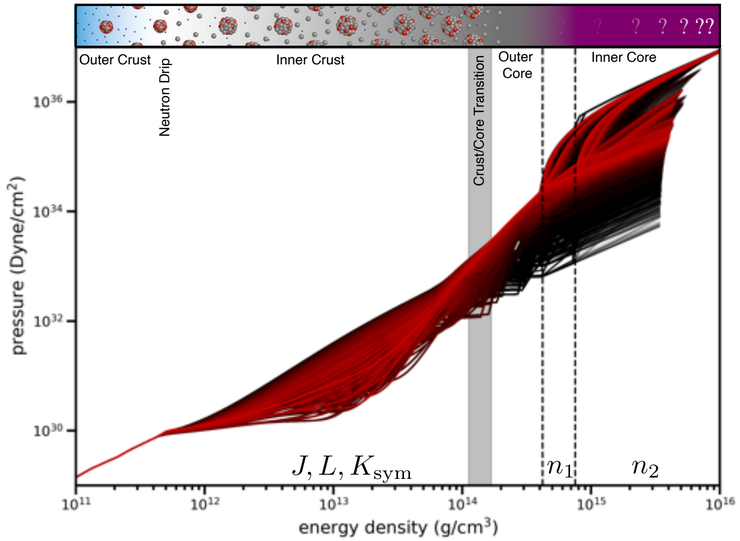
Neill, Newton, & DT 2021, MNRAS 504, 1, 1129

Preliminary



Causality NICER GW Prior

250 Hz RSF Posterior



Neill, Preston, DT, & Newton in prep

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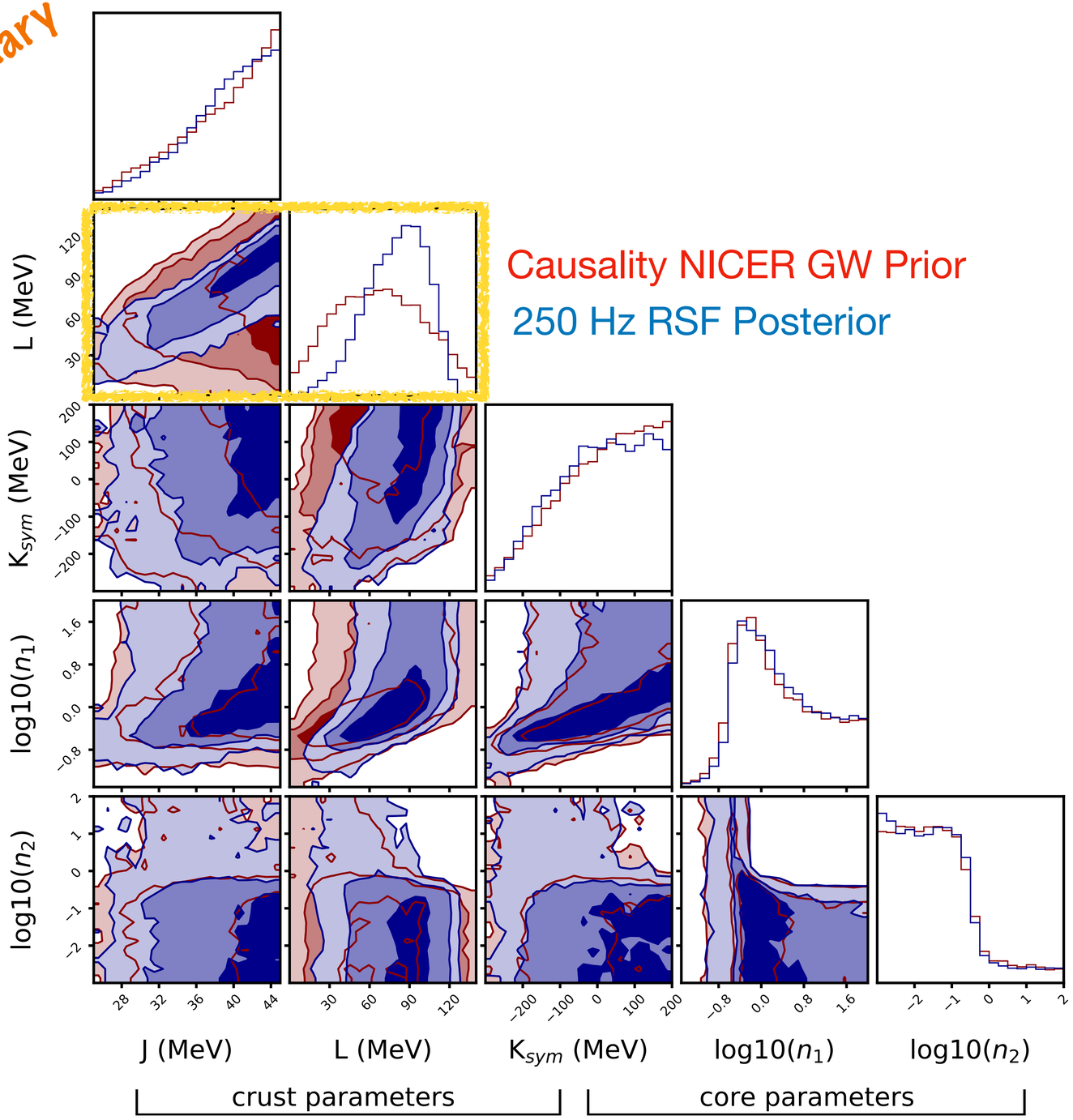

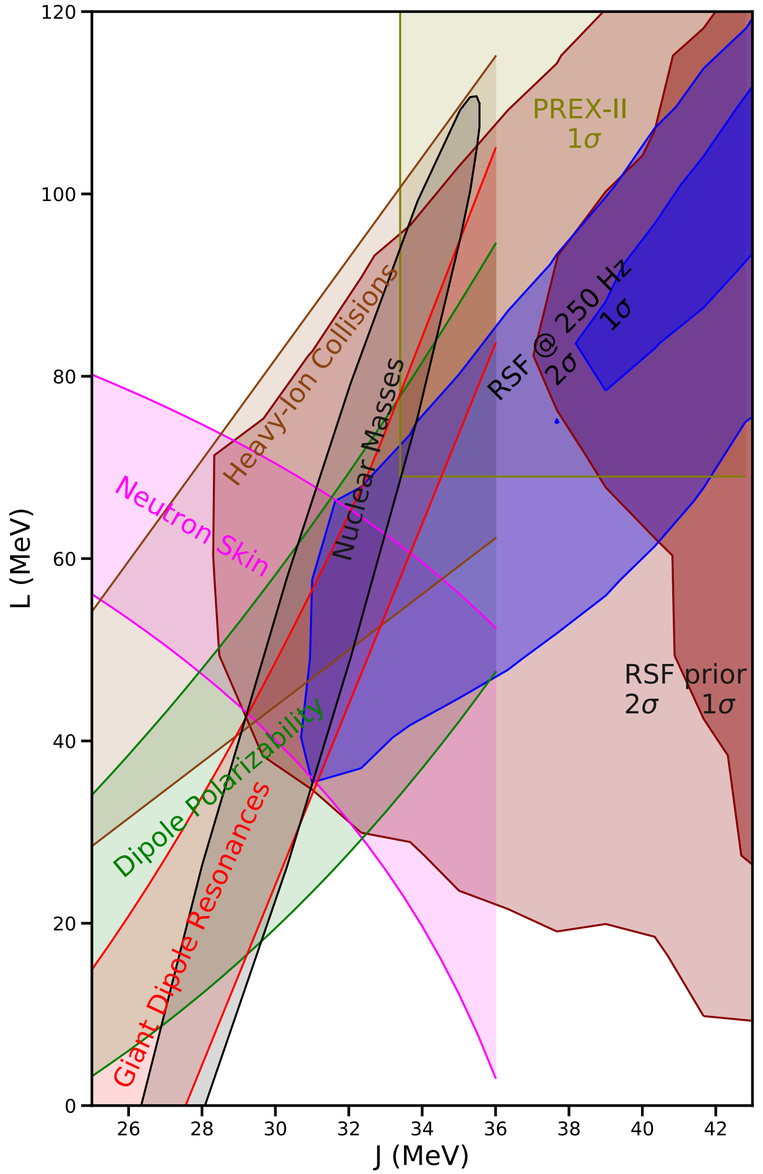

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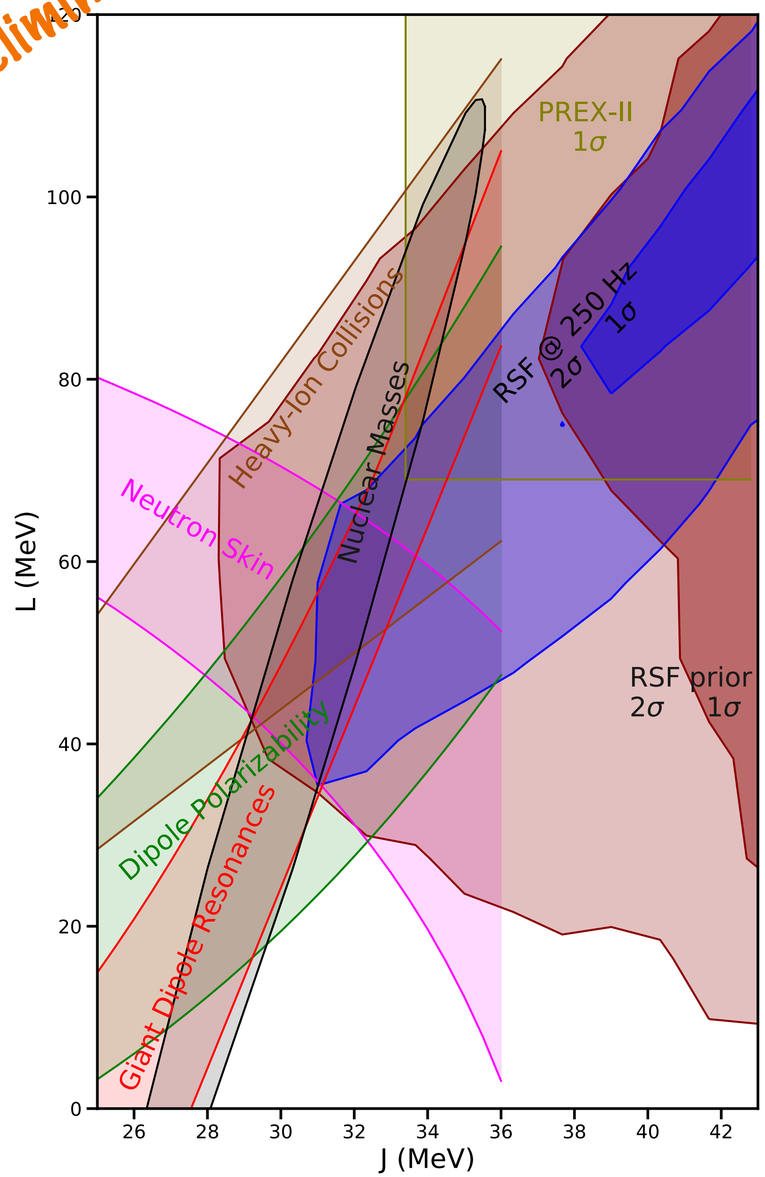

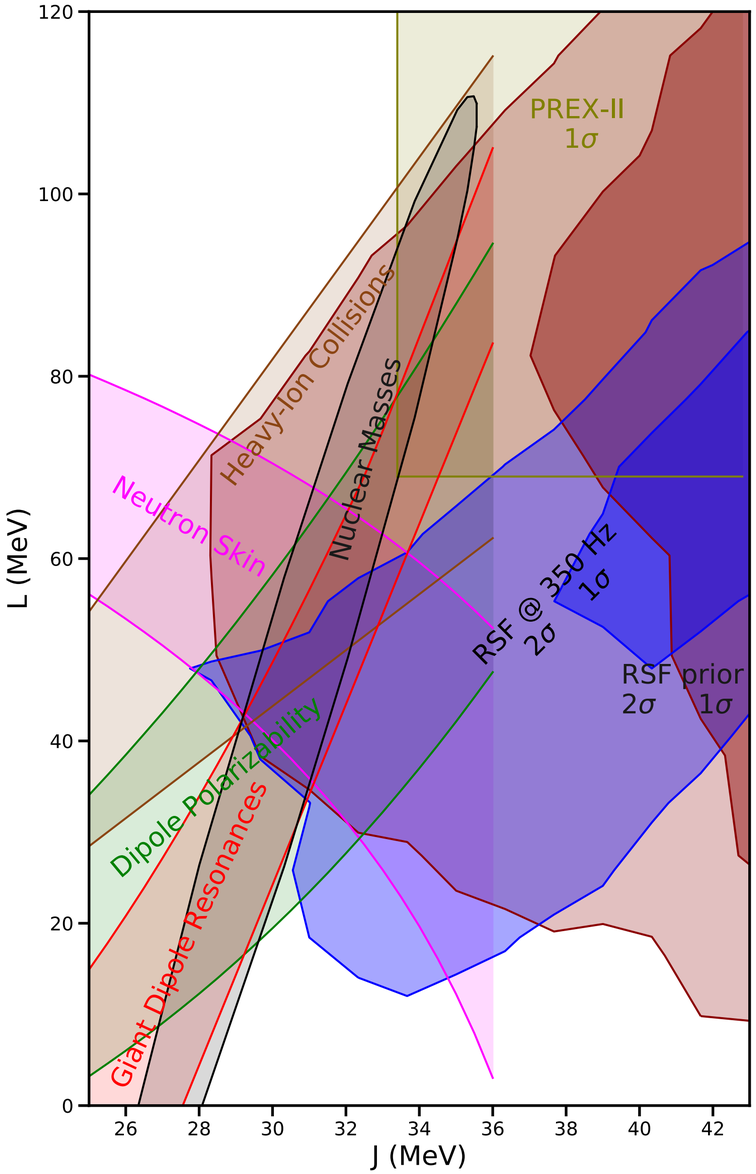

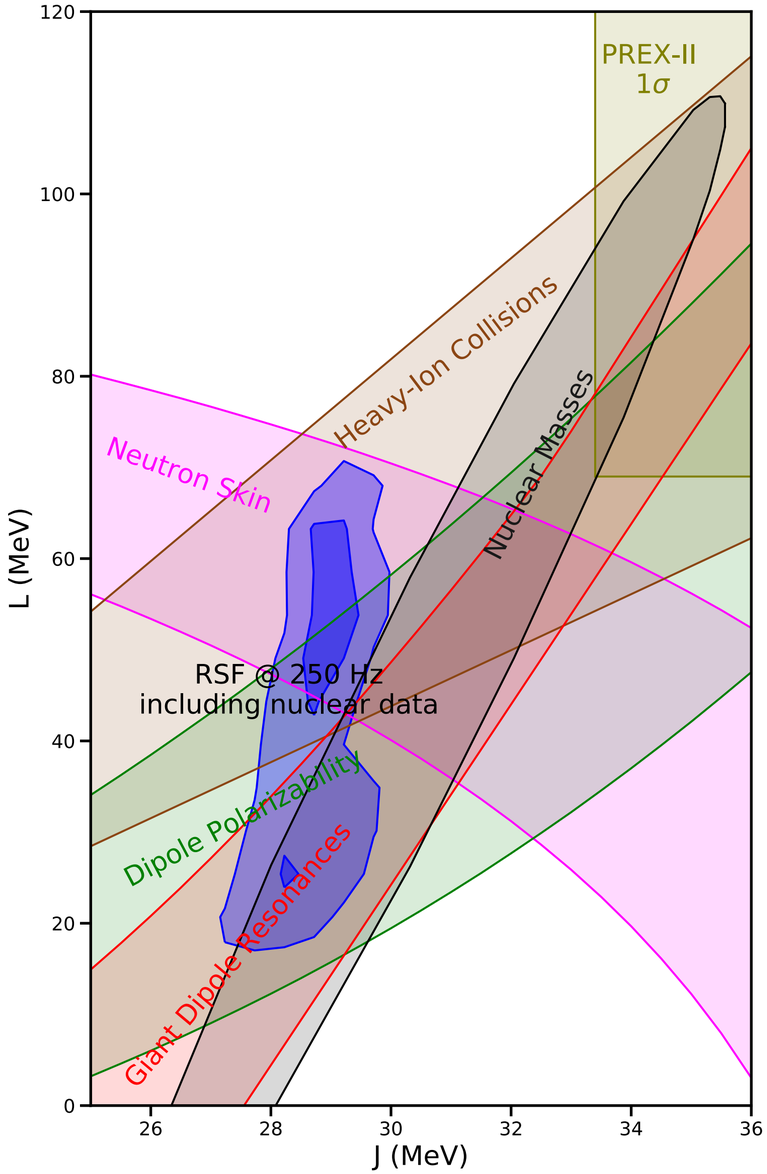

Neill, Preston, DT, & Newton in prep

Conclusions

- Nuclear Symmetry Energy is important!
- It is best probed near the core/crust boundary.
- RSFs are tidally induced resonances that cause Gamma-Ray flares
- They are induced by the i-mode, at the core-crust boundary.
- RSFs can be used to probe nuclear symmetry
- J-L constraints from a single detection are comparable to current collider experiments