Astrophysical Observations And Constraints

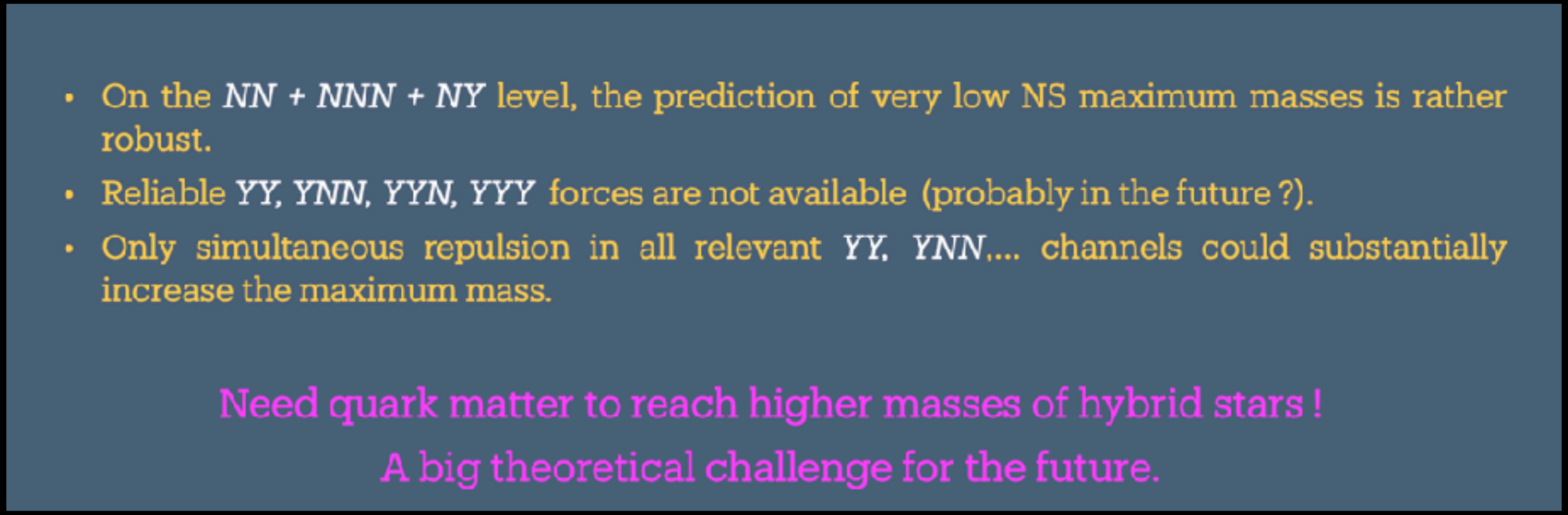
Summary for Panel Discussion

NuSym2024, 13 September 2024

David Tsang, University of Bath

Fiorella Burgio

The Hyperon Puzzle in Neutron Stars :
status and possible solutions



- On the *NN* + *NNN* + *NY* level, the prediction of very low NS maximum masses is rather robust.
- Reliable *YY, YNN, YYN, YYY* forces are not available (probably in the future ?).
- Only simultaneous repulsion in all relevant *YY, YNN*,... channels could substantially increase the maximum mass.

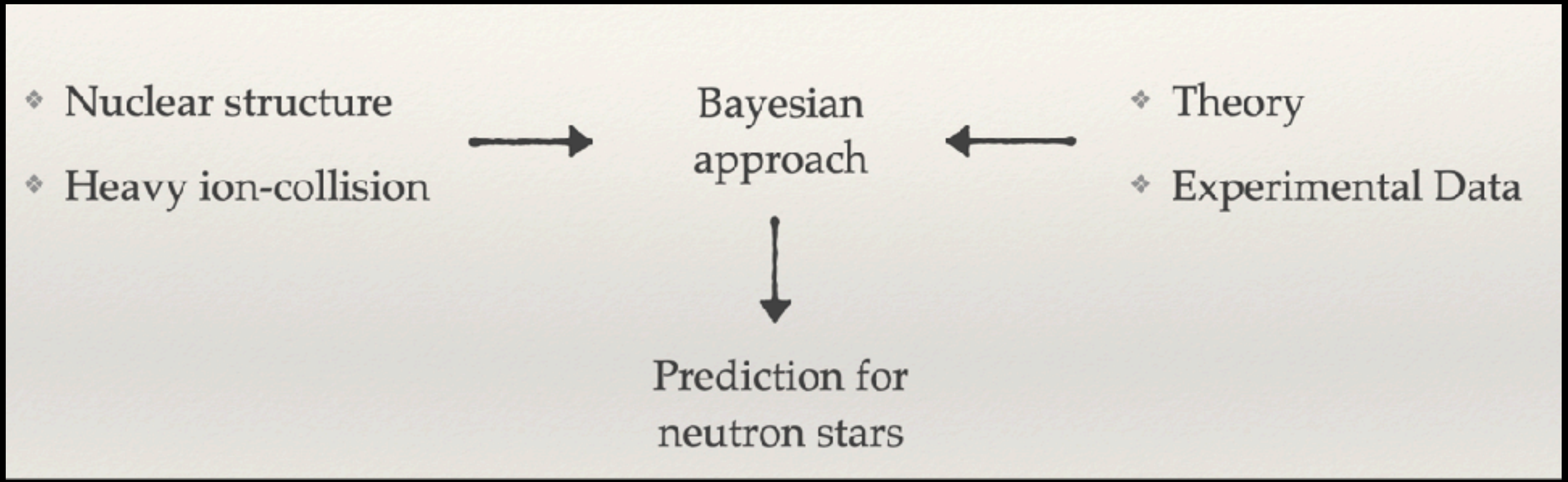
Need quark matter to reach higher masses of hybrid stars !

A big theoretical challenge for the future.

Equation of state in dense nuclear matter controlled by nuclear data

Flow data,
Giant Monopole Resonance.

Jérôme Margueron, IRL-NPA, CNRS & MSU, FRIB, East Lansing, USA.

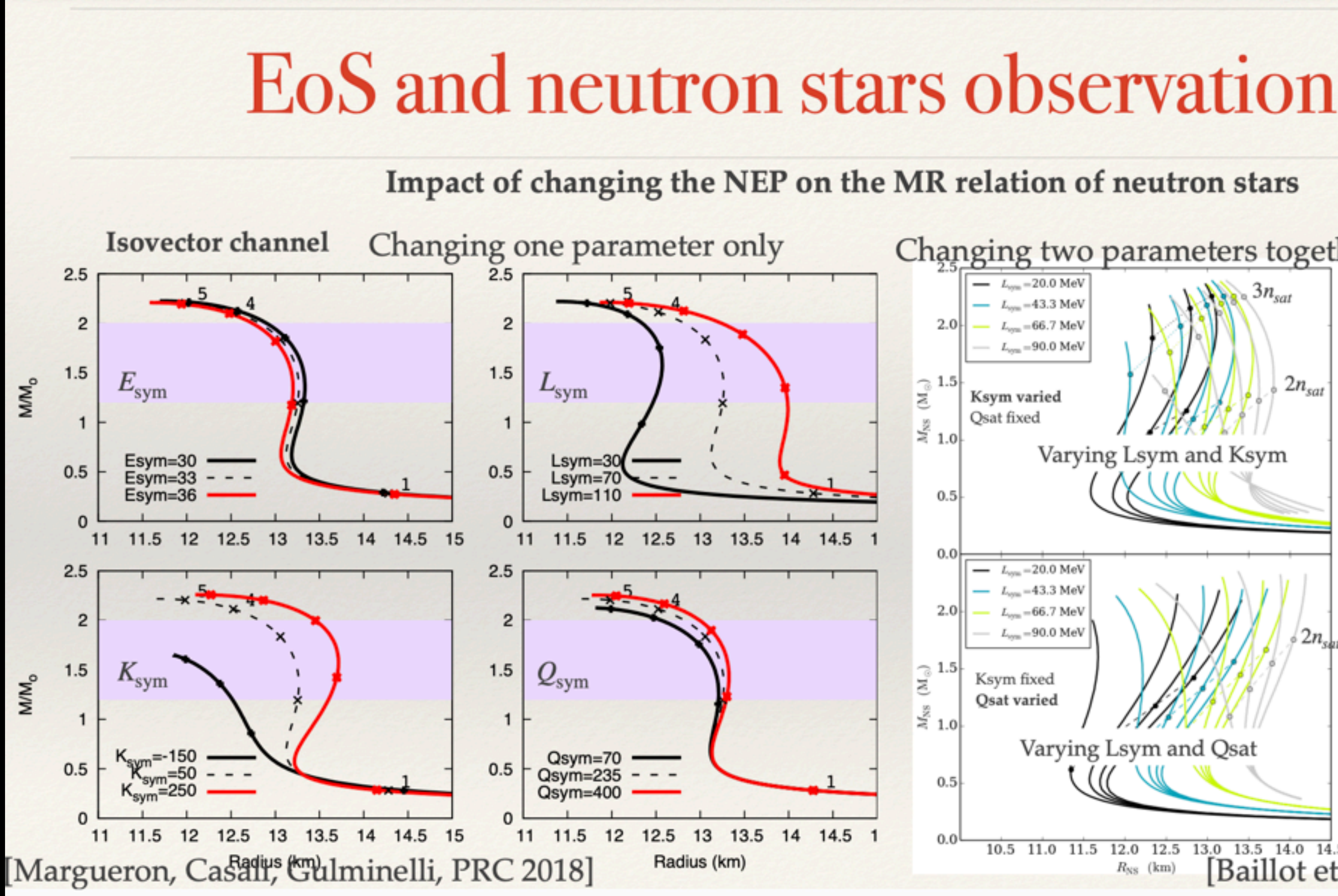


- Nuclear structure
- Heavy ion-collision

Bayesian approach

- Theory
- Experimental Data

Prediction for neutron stars



EoS and neutron stars observation

Impact of changing the NEP on the MR relation of neutron stars

Isovector channel Changing one parameter only

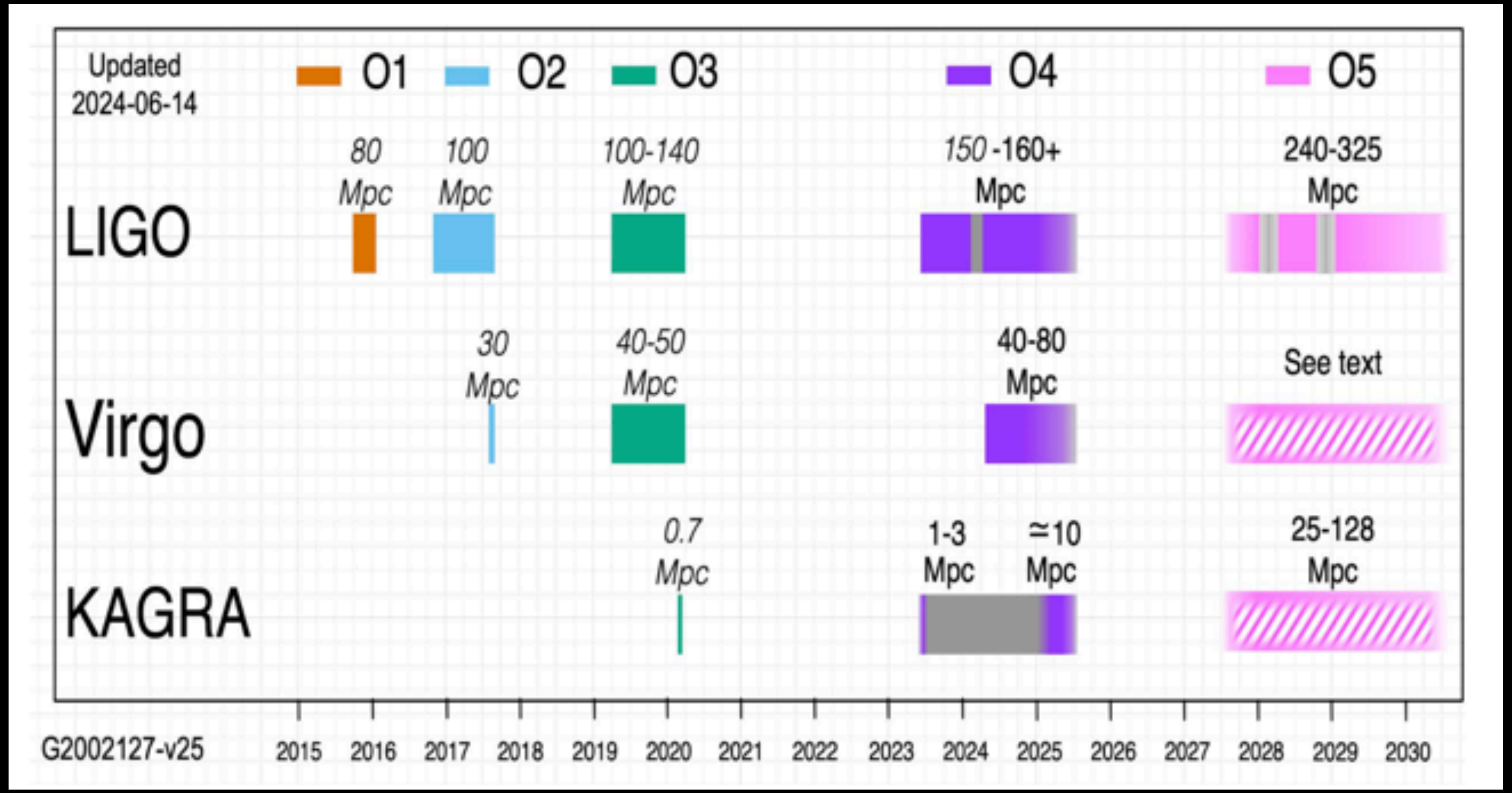
Changing two parameters toget

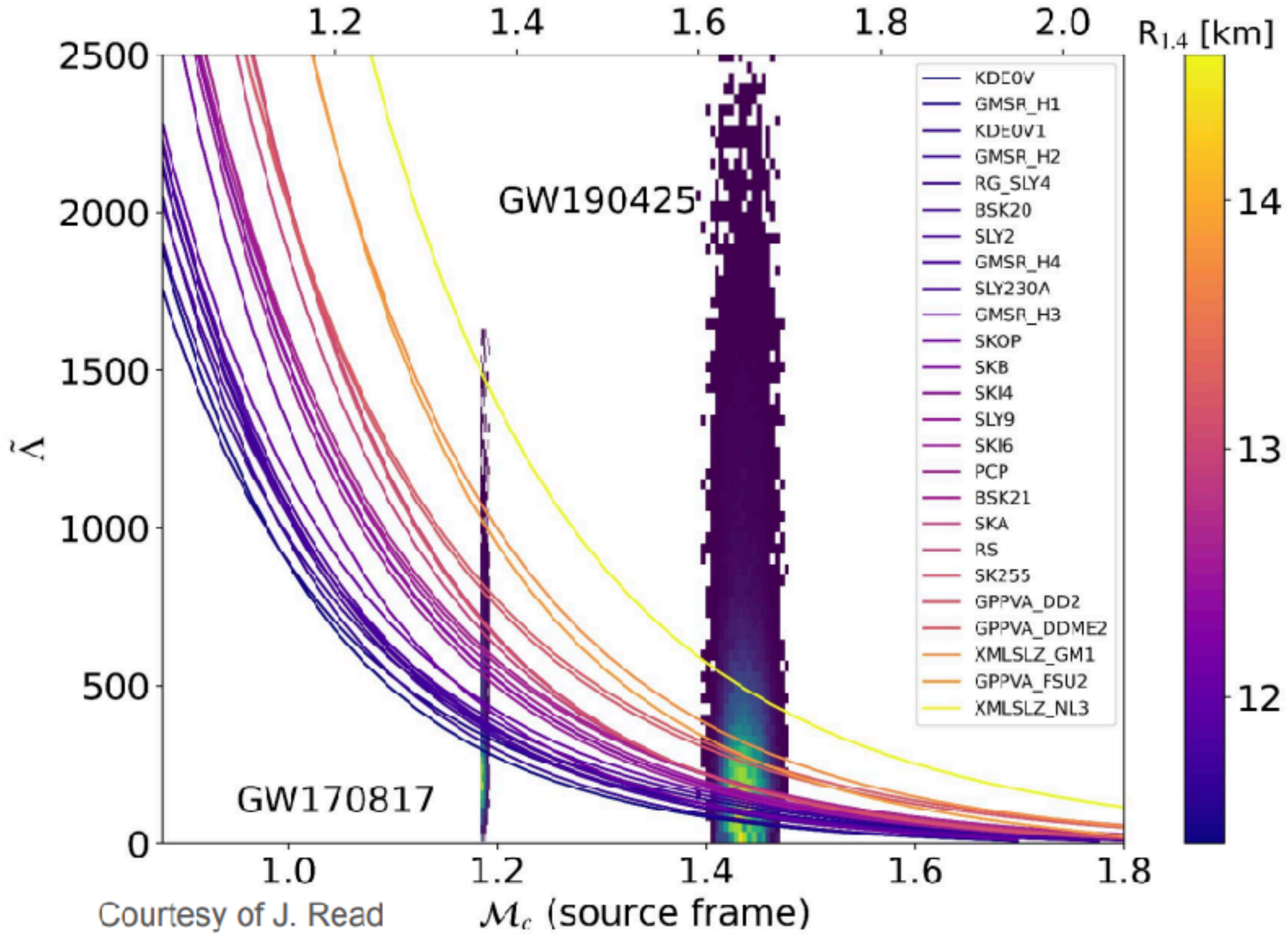
[Margueron, Casali, Gulminelli, PRC 2018]

[Baillot et

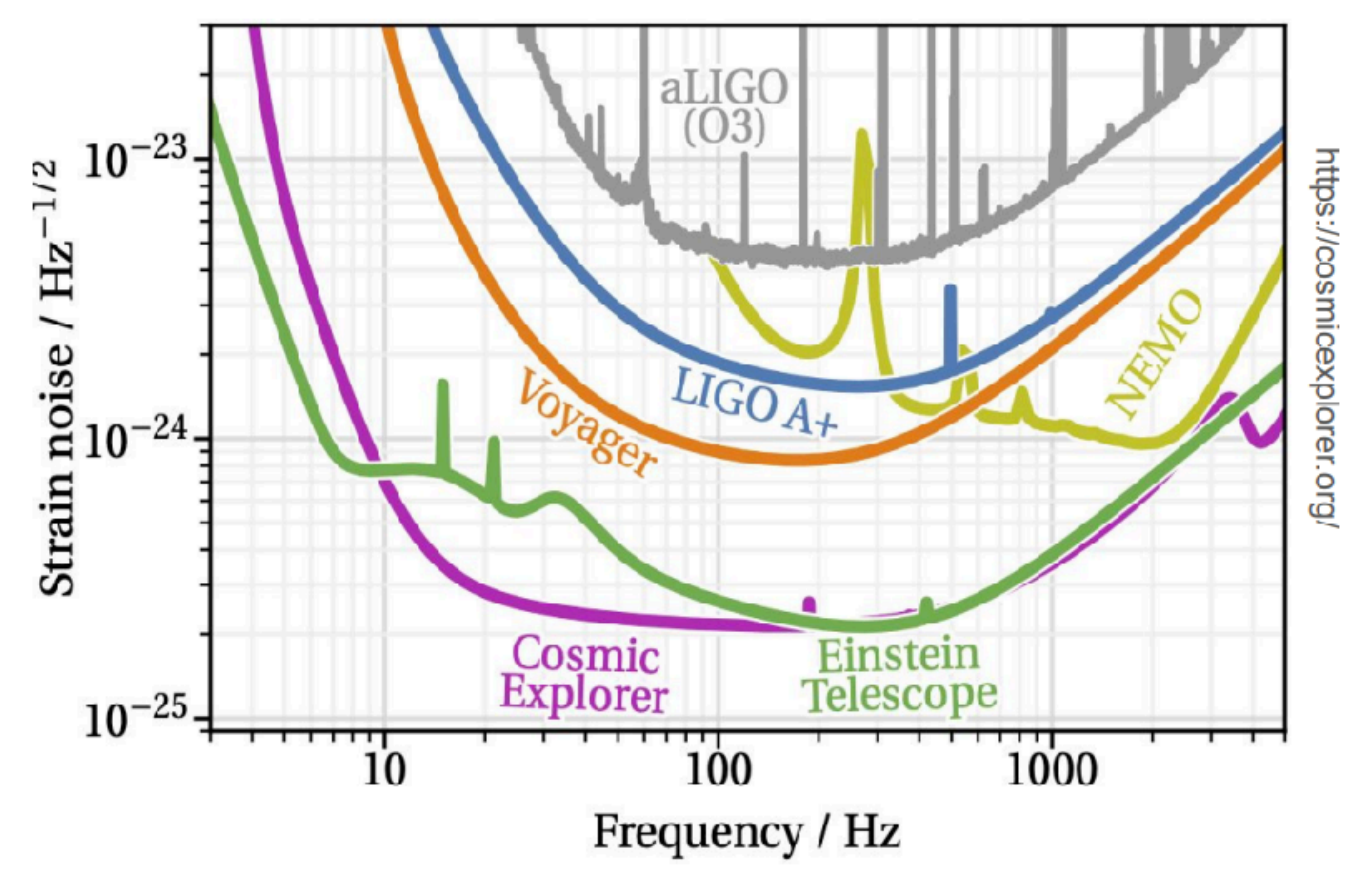
Exploring Neutron Stars with Gravitational waves: current observations and future challenges

Lami Suleiman
On behalf of the **Extreme Matter** group
of the LIGO/Virgo/KAGRA collaboration.





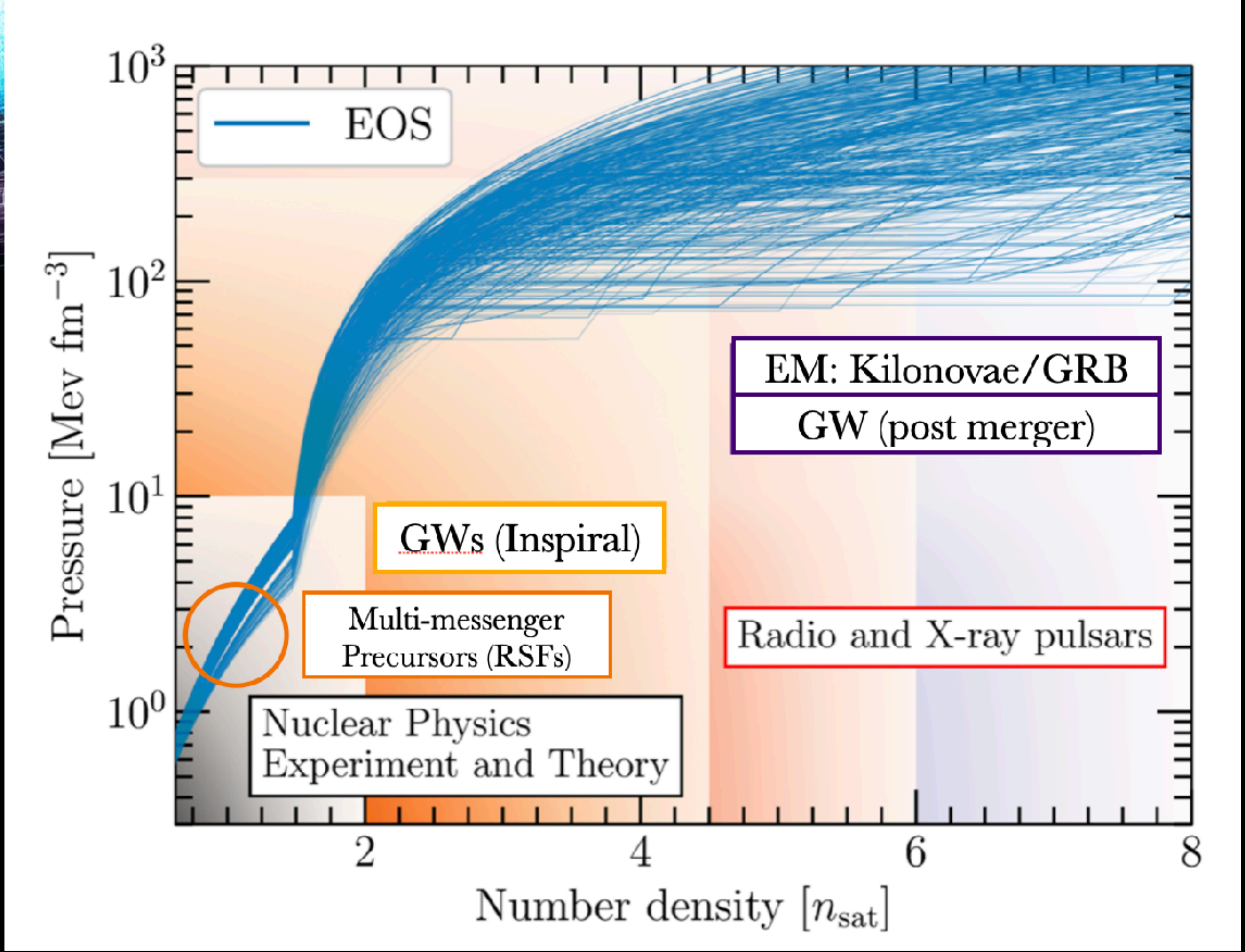
Courtesy of J. Read



Constraining the EOS and Symmetry Energy with Neutron Star Mergers

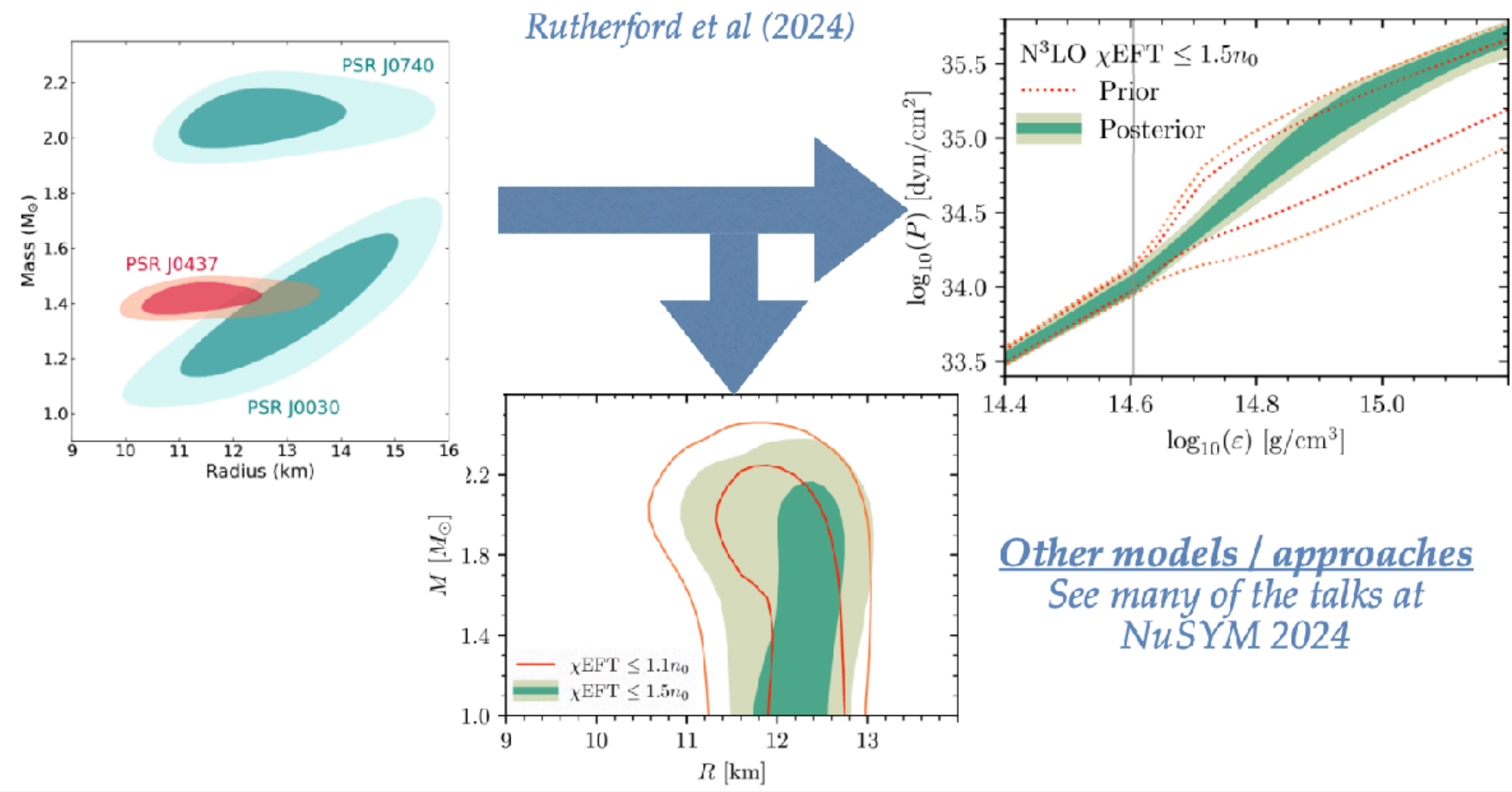
NuSym2024, Caen France
Sept 10, 2024

David Tsang, University of Bath



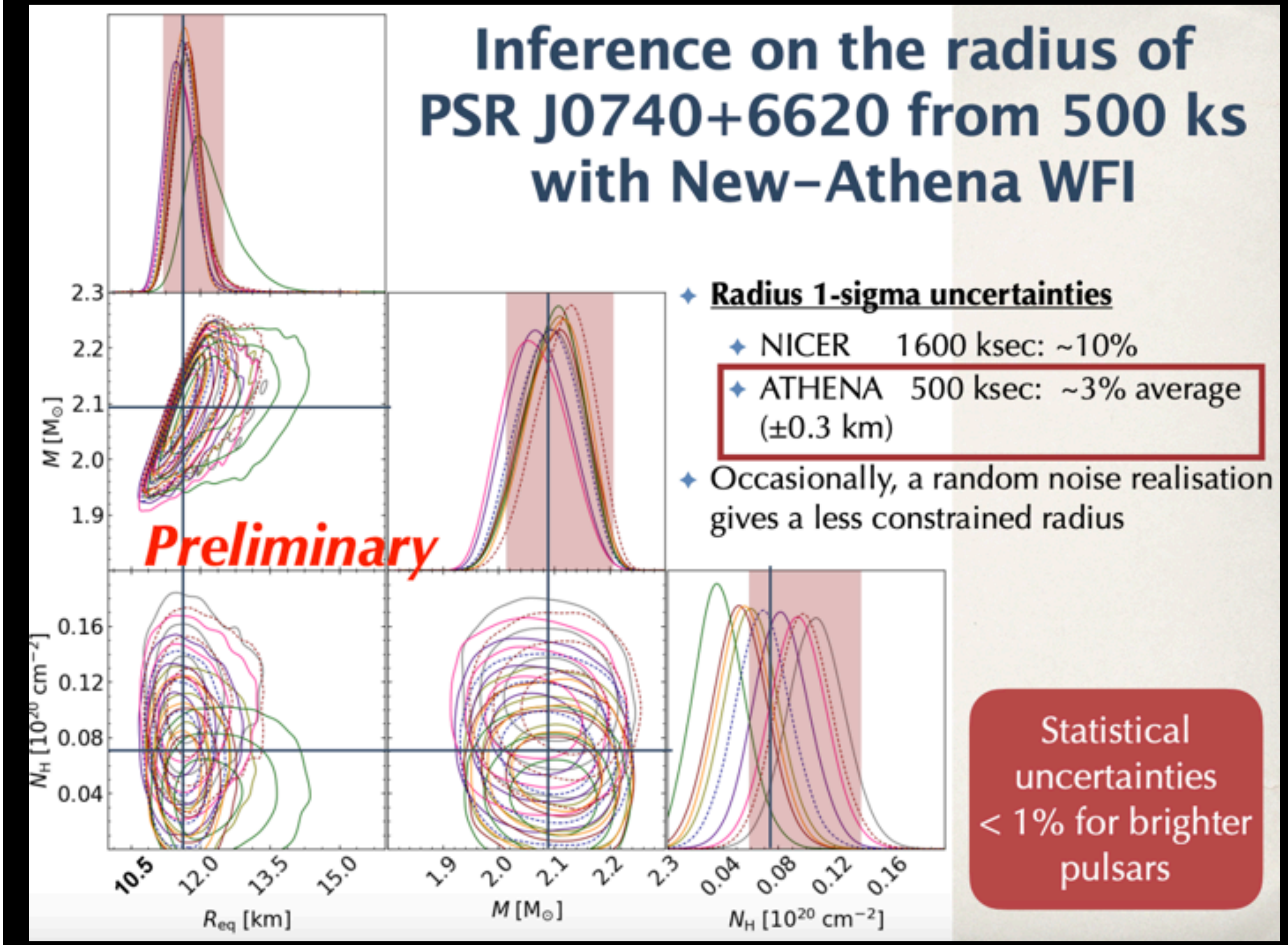
More neutron star radius measurements from NICER to understand dense nuclear matter

Sebastien Guillot



Rutherford et al (2024)

<u>Other models / approaches</u>
See many of the talks at NuSYM 2024



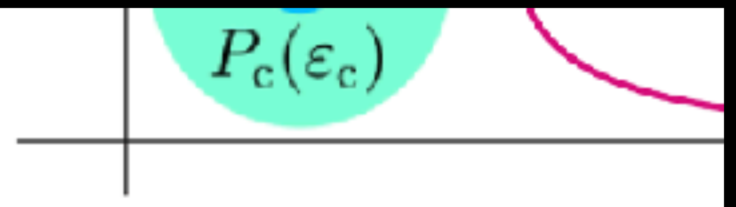
Inference on the radius of PSR J0740+6620 from 500 ks with New-Athena WFI

- **<u>Radius 1-sigma uncertainties</u>**
  - NICER 1600 ksec: ~10%
  - ATHENA 500 ksec: ~3% average (±0.3 km)
- Occasionally, a random noise realisation gives a less constrained radius

Statistical uncertainties < 1% for brighter pulsars

Equation of State of Dense Matter in Neutron Star Cores

Bao-Jun Cai



$$\frac{dP}{dr}=-\frac{M\varepsilon}{r^2}\left(1+\frac{P}{\varepsilon}\right)\left(1+\frac{4\pi r^3P}{M}\right)\left(1-\frac{2M}{r}\right)^{-1};\ \frac{dM}{dr}=4\pi r^2\varepsilon;\ (c=G=1)$$

small $r\approx 0$; $X=$

$$P=P_c+b_2r^2+b_4r^4+\cdots;\varepsilon=\varepsilon_c+a_2r^2+a_4r^4+\cdots;M=c_3r^3+c_5r^5+\cdots$$

$$\rightarrow R\sim\nu_c\equiv\frac{X^{1/2}}{\sqrt{\varepsilon_c}}\underbrace{\left(\frac{1}{1+3X^2+4X}\right)^{1/2}}_{\equiv\vartheta(X)<1};\quad\underbrace{M_{\rm NS}\sim R^3\varepsilon_c}_{\textbf{macroscopic observations}}\sim\underbrace{\Gamma_c\equiv\frac{1}{\sqrt{\varepsilon_c}}\left(\frac{X}{1+3X^2+4X}\right)^{3/2}}_{\textbf{microscopic combination (EOS)}}$$

$P(R)=0$

(strong gravity reduces the radius)

Equation of State of Dense Matter in Neutron Star Cores

Bao-Jun Cai

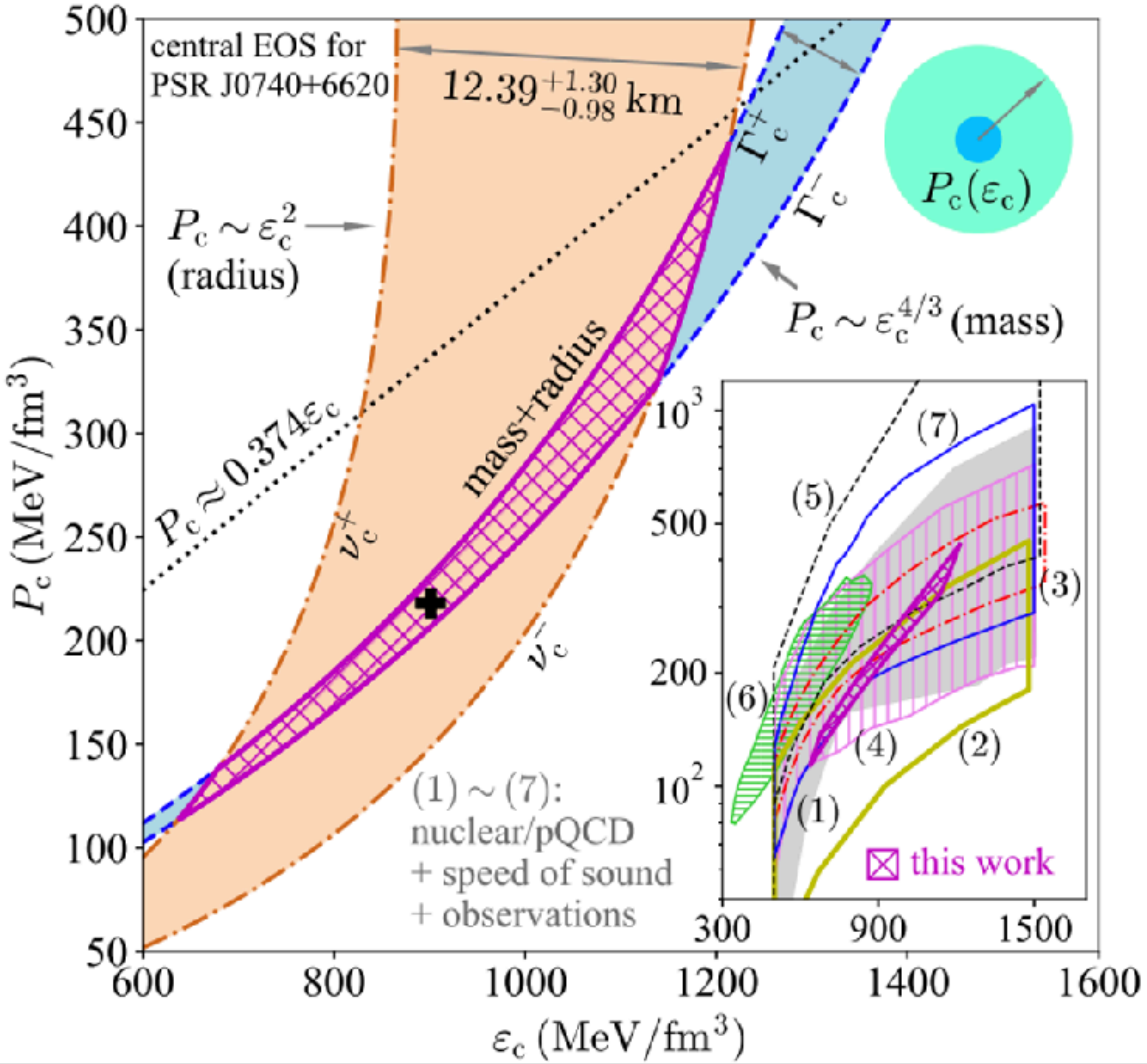
$$\frac{dP}{dr}=-\frac{M\varepsilon}{r^2}\Bigg(1+\frac{P}{\varepsilon}\Bigg)\Bigg(1$$

$$P=P_{\rm c}+b_2r^2+b_4r^4$$

$$\rightarrow R\sim\nu_{\rm c}\equiv\frac{X^{1/2}}{\sqrt{\varepsilon_{\rm c}}}\Bigg(\frac{}{1+}$$

$P(R)=0$

(strong gravity



$$s_{\rm c}^2=X\left(1+\frac{1}{3}\frac{1+3X^2+4X}{1-3X^2}\right)$$

$P_{\rm c}\approx218^{+93}_{-125}\,\rm MeV/fm^3$; $\varepsilon_{\rm c}\approx902^{+214}_{-287}\,\rm MeV/fm^3$

$X=P_{\rm c}/\varepsilon_{\rm c}\approx0.24^{+0.05}_{-0.07}\rightarrow s_{\rm c}^2\approx0.45^{+0.14}_{-0.18}>1/3$

causality requires $s_{\rm c}^2\leq1$

$\rightarrow$*upper limit for* $X=P_{\rm c}/\varepsilon_{\rm c}\lesssim0.374$

(1) $s_{\rm c}^2\neq0\leftrightarrow$ no sharp phase transitions near center

(2) $\gamma_{\rm c}=d\ln P_{\rm c}/d\ln\varepsilon_{\rm c}=s_{\rm c}^2/(P_{\rm c}/\varepsilon_{\rm c})\geq4/3$

$\leftrightarrow$ central matter could not be conformal

(3) $\Delta\equiv1/3-P/\varepsilon\gtrsim-0.04$

Clustering in the (proto)neutron star crust
and the contribution of nuclear experiments

F.Gulminelli, (LPC and Normandie Université, Caen)
NUSYM 2024 GANIL

Transport properties in compact stars

- Most signals from CS involve transport properties
- Some of them mainly concern $\rho \lesssim \rho_0$ matter ≡ clusters
  - NS cooling: B-thermal evolution
  - Relaxation after accretion & deep crust heating
  - CC, PNS cooling & mergers

} e-Z, $T \approx 10^8 K$

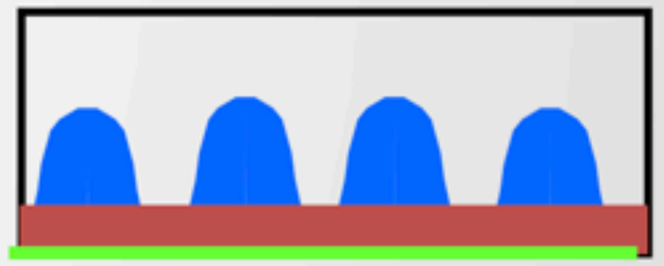
ν-Z $T > 10^{10} K$

Schmitt&Shternin Springer 2018

- Key micro feature: charge distribution => resistivity
  - T≈0 : impurities in the catalyzed crust
  - **A strong crustal resistivity due to impurities affects the NS magneto-thermal evolution**

=> Optimal particle (and pairing) densities

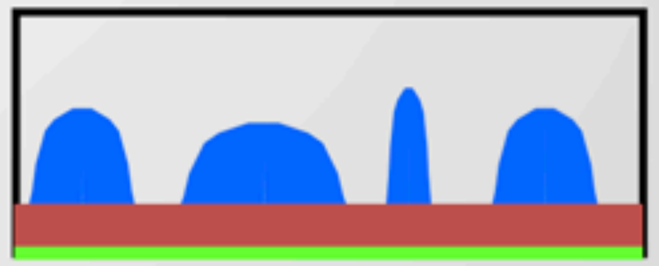
$= min(A, Z, \rho_{gq})$



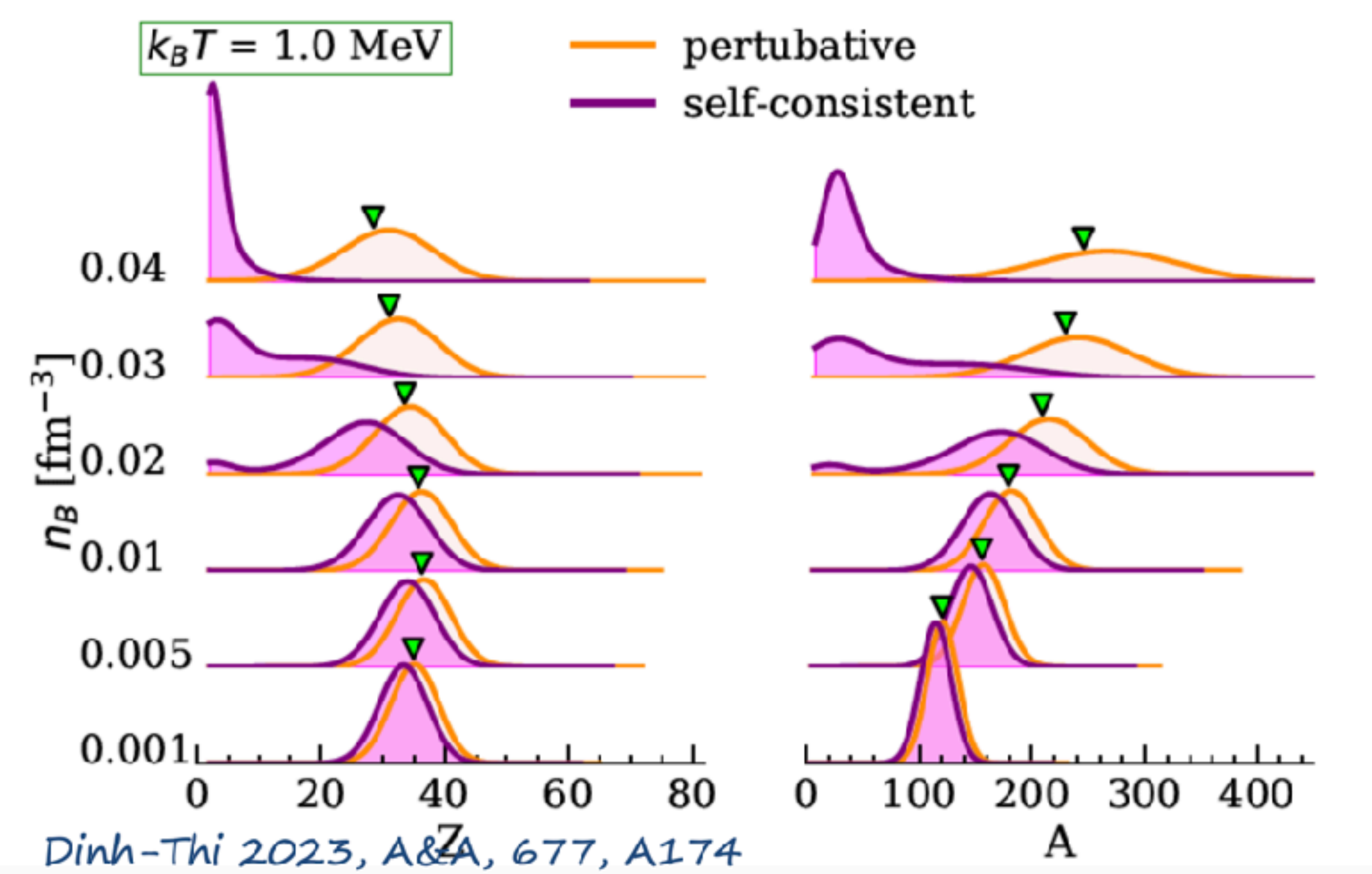
=> Optimal cluster

$= min(\{n_{AZ}\}, \rho_{gq})$

=> Optimal distribution



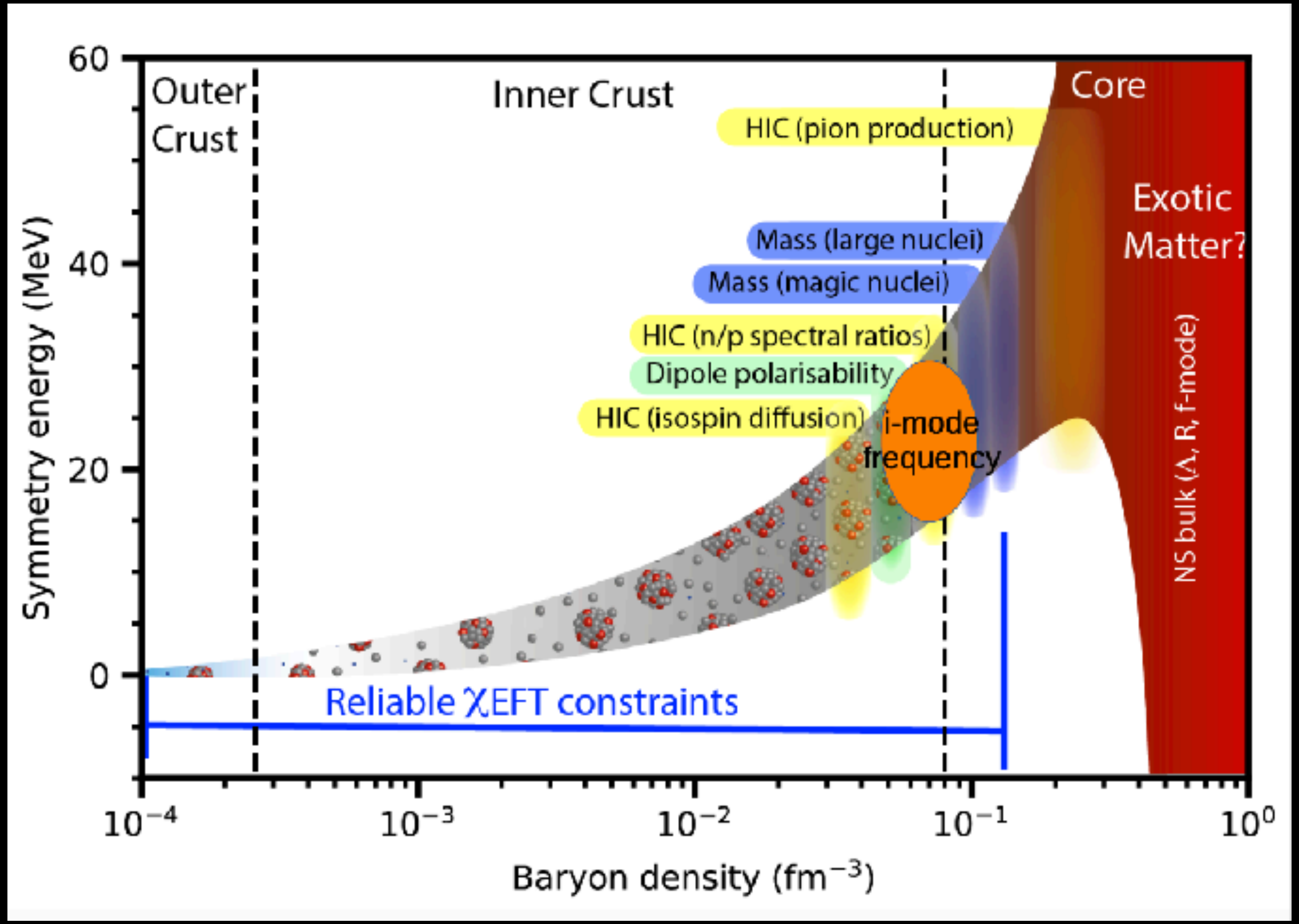
Nuclear distribution in the inner crust

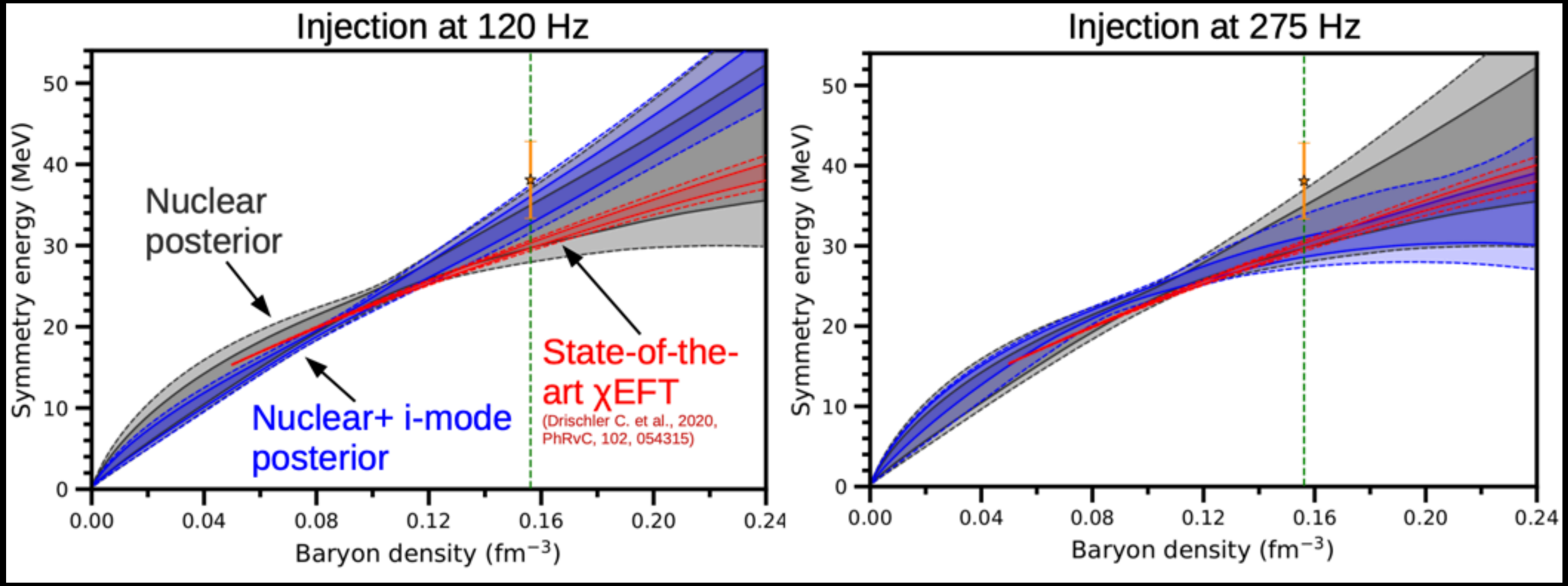


Dinh-Thi 2023, A&A, 677, A174

Resonant shattering flares as astrophysical tests of chiral effective field theory

Duncan Neill*, David Tsang, Christian Drischler,
Jeremy Holt, William G. Newton





Exploring robust correlations between fermionic dark matter model parameters and neutron star properties

Phys.Rev.D 110 (2024) 4, 4 & e-Print: 2408.03780

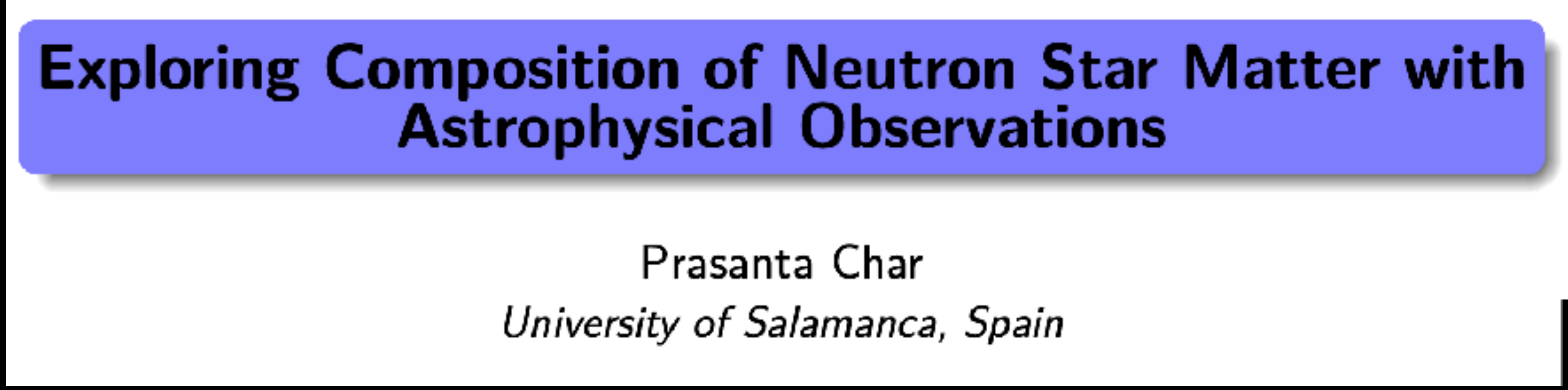
Prashant Thakur, Tuhin Malik, Arpan Das, T. K. Jha and Constança Providência

Tuhin Malik

- Strong correlations between dark matter parameters and neutron star properties are evident, but these correlations weaken once uncertainties in the nuclear matter EOS are considered.
- Universal relations, like compactness versus Lambda, remain intact even with the presence of dark matter in neutron stars.
- Dark matter can facilitate processes such as hyperon onset, nucleonic URCA, and quark-hadron phase transitions.
- The NL-σ cut model, exhibiting behavior contrary to that of dark matter, is highly favored according to recent constraints, suggesting a preference for a stiffer equation of state at high densities.
- Models that include dark matter are the least supported; accurate and high-precision observations from multiple measurements will be required to provide more insights.

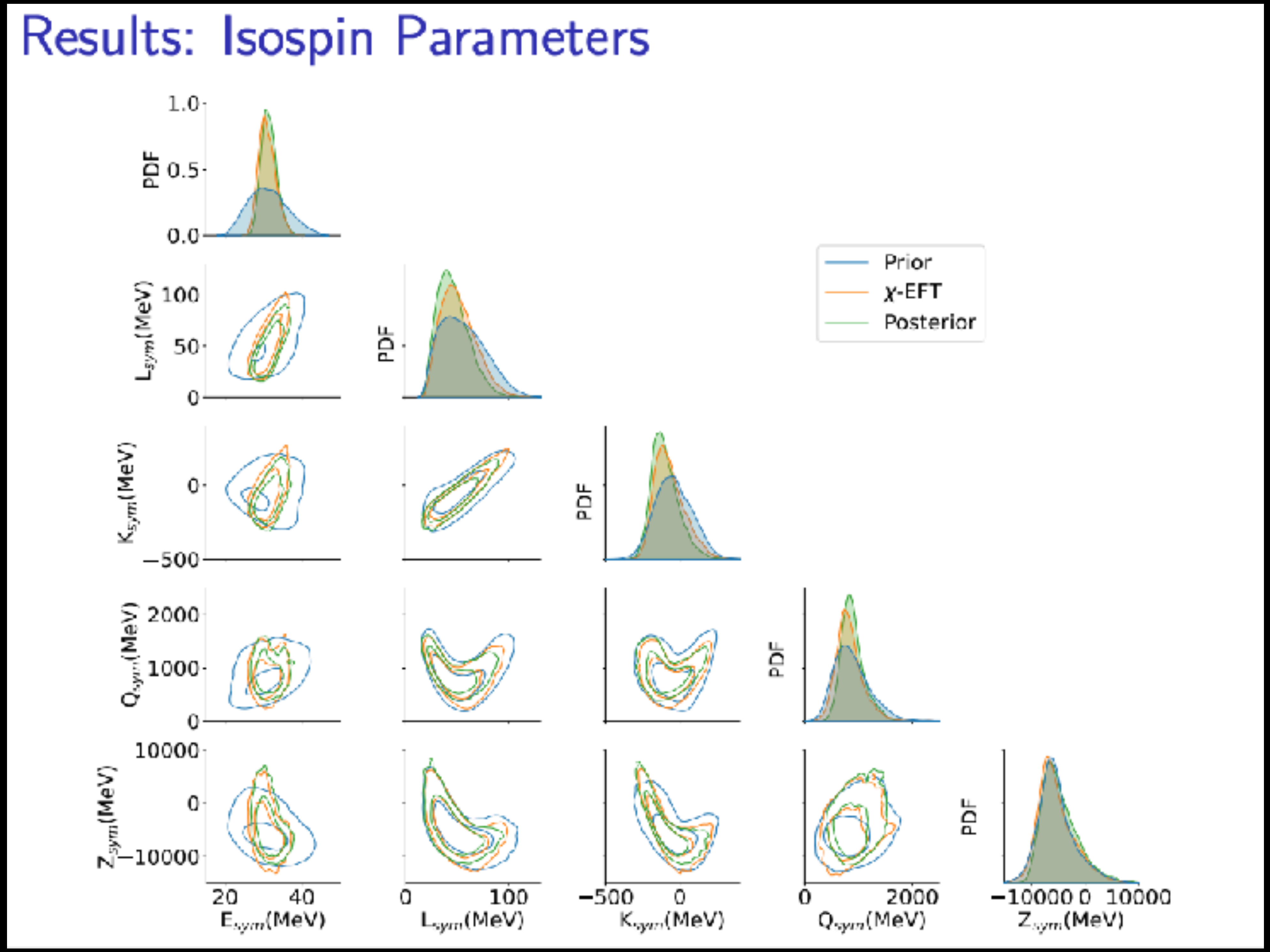
Nuclear equation of state from nuclear experiments and neutron stars observations

NuSYM 2024, Caen
Pietro Klausner
12/9/2024

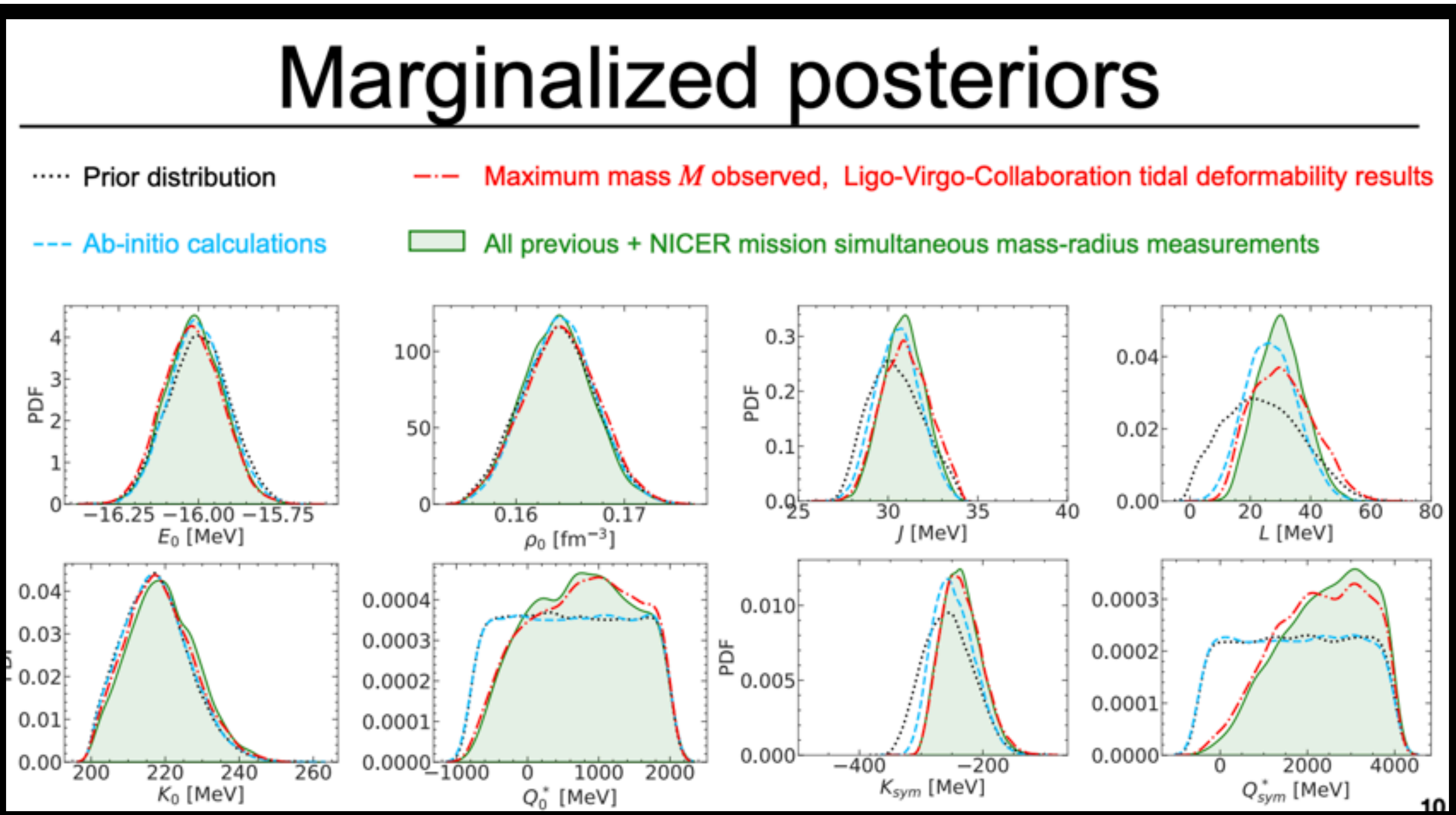


Exploring Composition of Neutron Star Matter with Astrophysical Observations

Prasanta Char
University of Salamanca, Spain



Results: Isospin Parameters



Marginalized posteriors

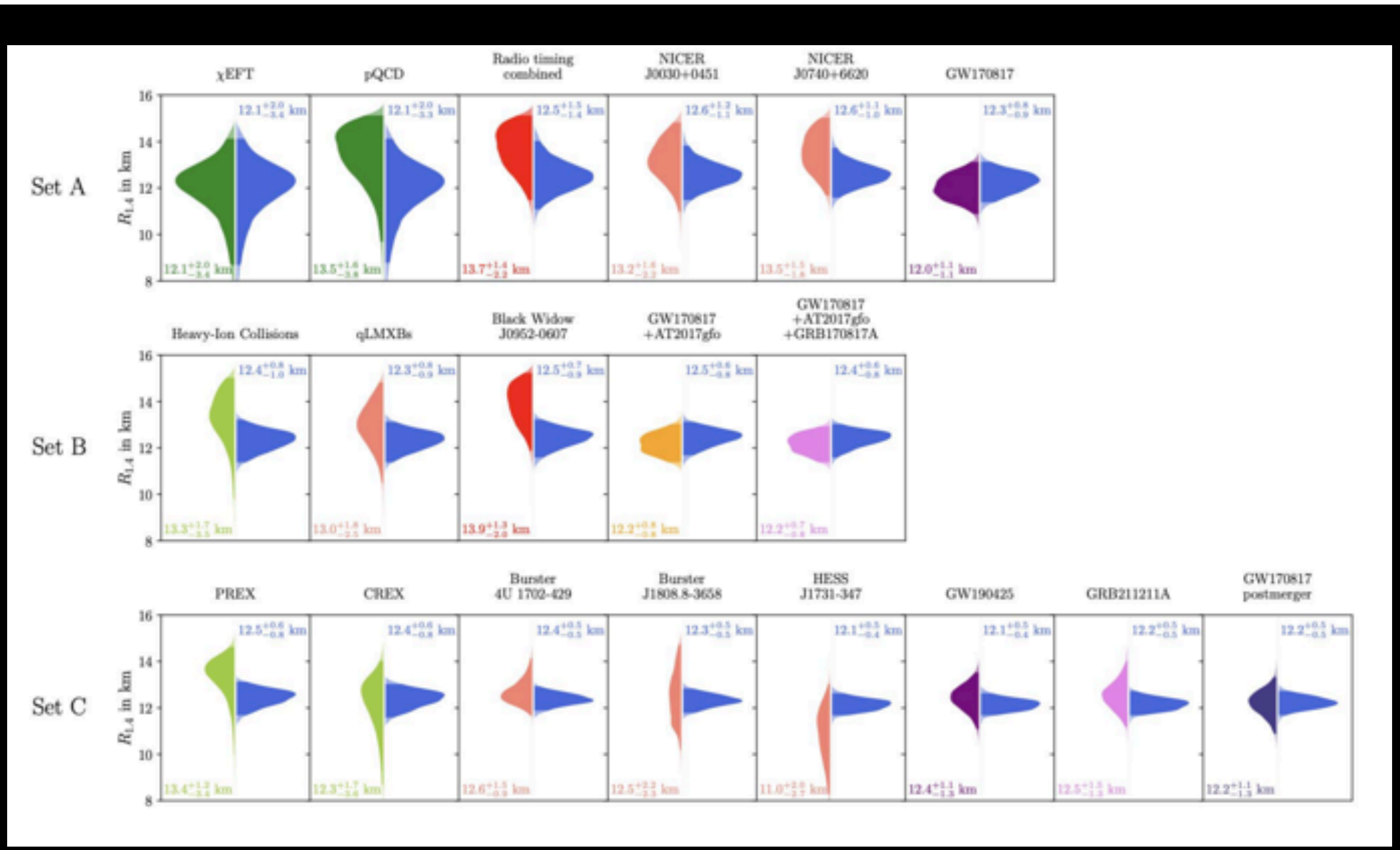
An overview on EOS constraints

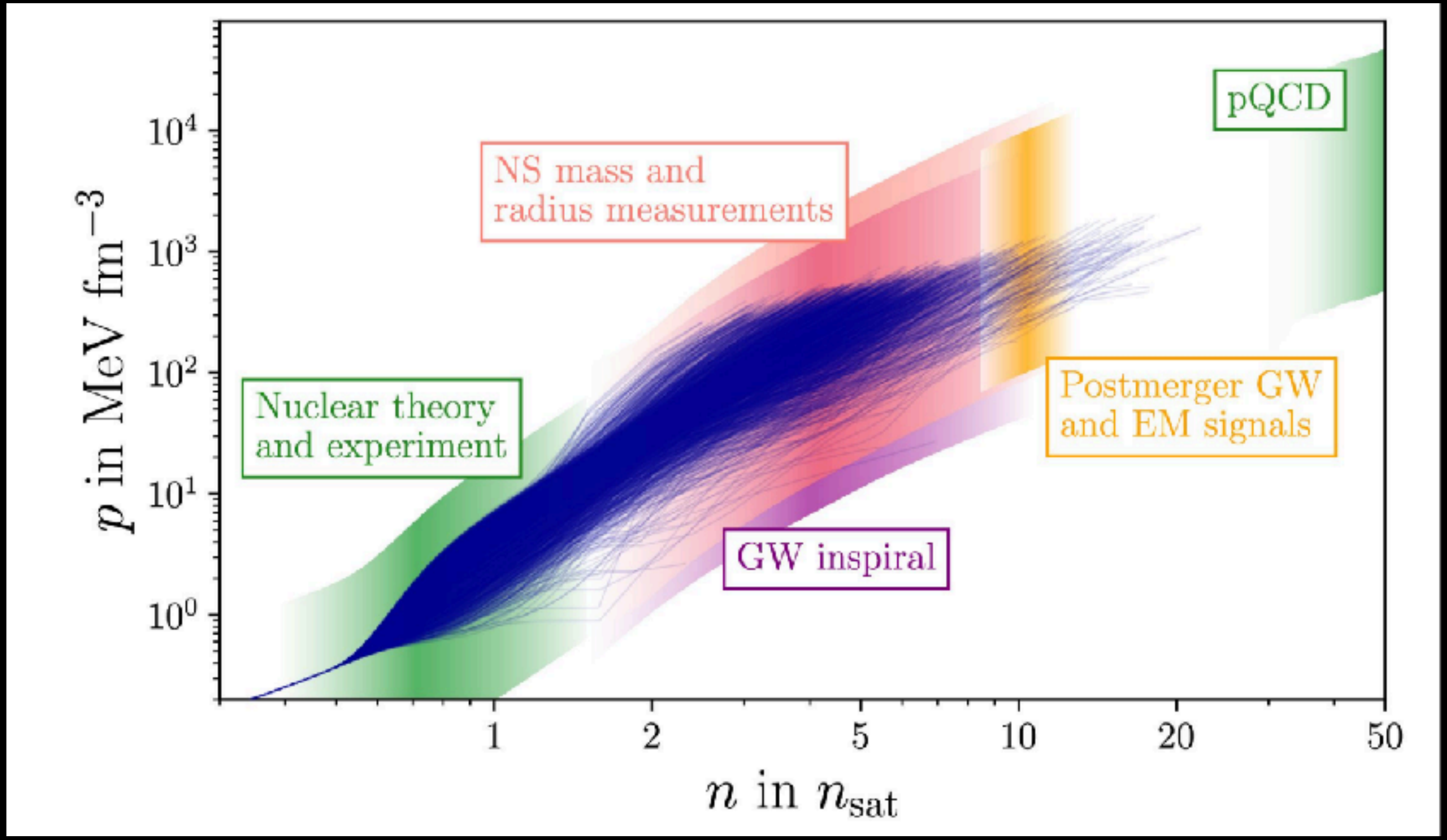
Nuclear theoretical, experimental and astrophysical constraints

Koehn et al., arxiv: 2402.04172

Peter T. H. Pang

Set A (Conservative)	Set B (Middle ground)	Set C (Aggressive)
Chiral EFT	Set A	Set B
pQCD	Heavy ion collision	PREX-II + CREX
Radio timing	Black widow	GW190425
NICER J0030+0451 J0740+6620	qLMXBs	Brusters, HESS, GRB211211A
GW170817	GW170817 + KN + GRB	Post-merger of GW170817





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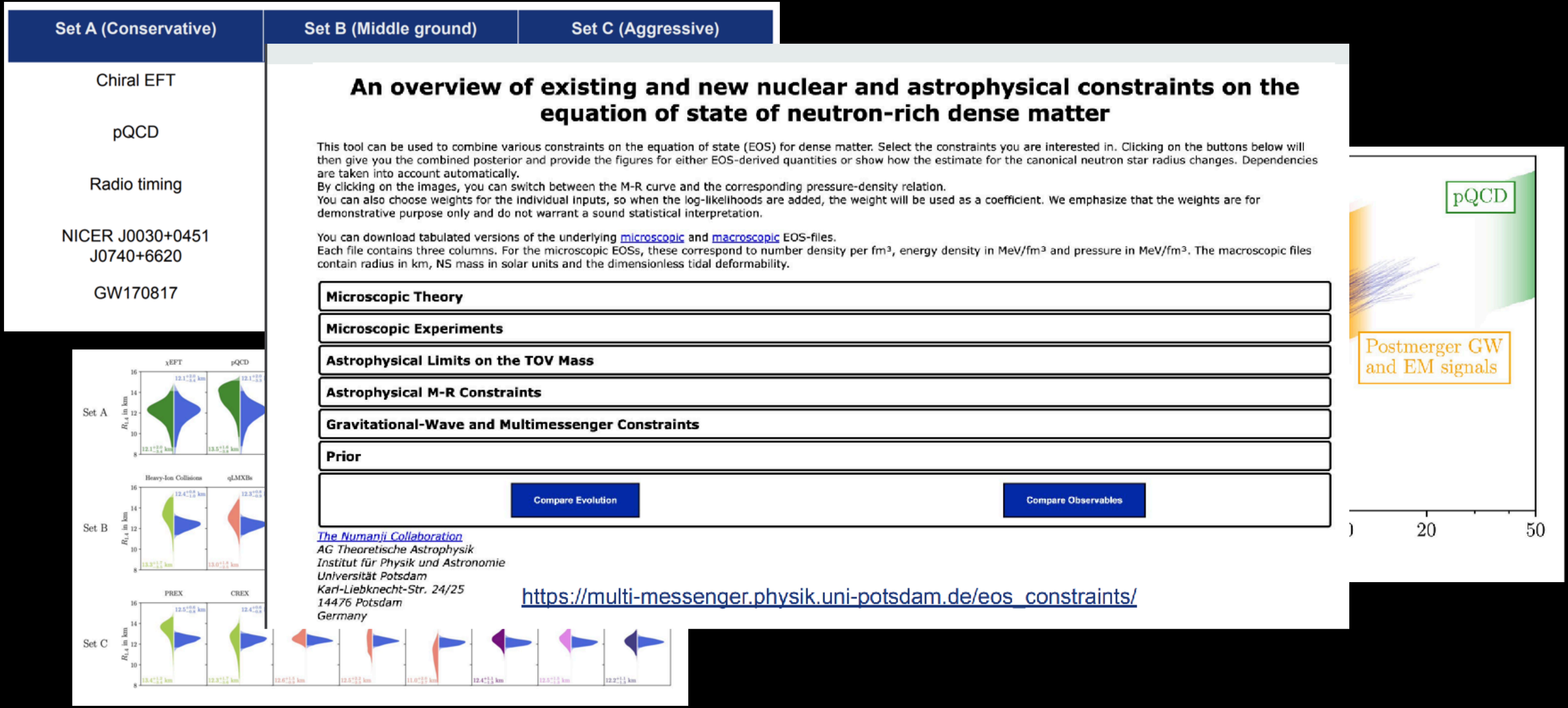

Set A (Conservative)	Set B (Middle ground)	Set C (Aggressive)
Chiral EFT		
pQCD		
Radio timing		
NICER J0030+0451 J0740+6620		
GW170817		

An overview of existing and new nuclear and astrophysical constraints on the equation of state of neutron-rich dense matter

This tool can be used to combine various constraints on the equation of state (EOS) for dense matter. Select the constraints you are interested in. Clicking on the buttons below will then give you the combined posterior and provide the figures for either EOS-derived quantities or show how the estimate for the canonical neutron star radius changes. Dependencies are taken into account automatically.
By clicking on the images, you can switch between the M-R curve and the corresponding pressure-density relation.
You can also choose weights for the individual inputs, so when the log-likelihoods are added, the weight will be used as a coefficient. We emphasize that the weights are for demonstrative purpose only and do not warrant a sound statistical interpretation.

You can download tabulated versions of the underlying microscopic and macroscopic EOS-files.
Each file contains three columns. For the microscopic EOSs, these correspond to number density per fm³, energy density in MeV/fm³ and pressure in MeV/fm³. The macroscopic files contain radius in km, NS mass in solar units and the dimensionless tidal deformability.

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Karl-Liebknecht-Str. 24/25
14476 Potsdam
Germany

https://multi-messenger.physik.uni-potsdam.de/eos_constraints/

Determination of the Equation of State from Nuclear Experiments and Neutron Star Observations

Chun Yuen Tsang, Rohit Kumar, Bill Lynch, Betty Tsang, Chuck Horowitz

Based on Nature Astronomy volume 8, 328–336 (2024)