Gravitational Laboratories for Nuclear Physics

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The structure of neutron stars provides a unique way to probe two fundamental physical interactions: gravity and the strong nuclear force. I will review our current understanding of the macroscopic properties of neutron stars and discuss associated constraints on microscopic phenomenology, including the presence of strong phase transitions. Time permitting, I will also discuss how well we can distinguish neutron stars from black holes within gravitational-wave signals from coalescing compact binaries.

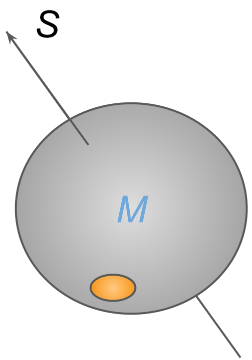
Understanding EoS Inference

NS Observables: mass

M_{max}

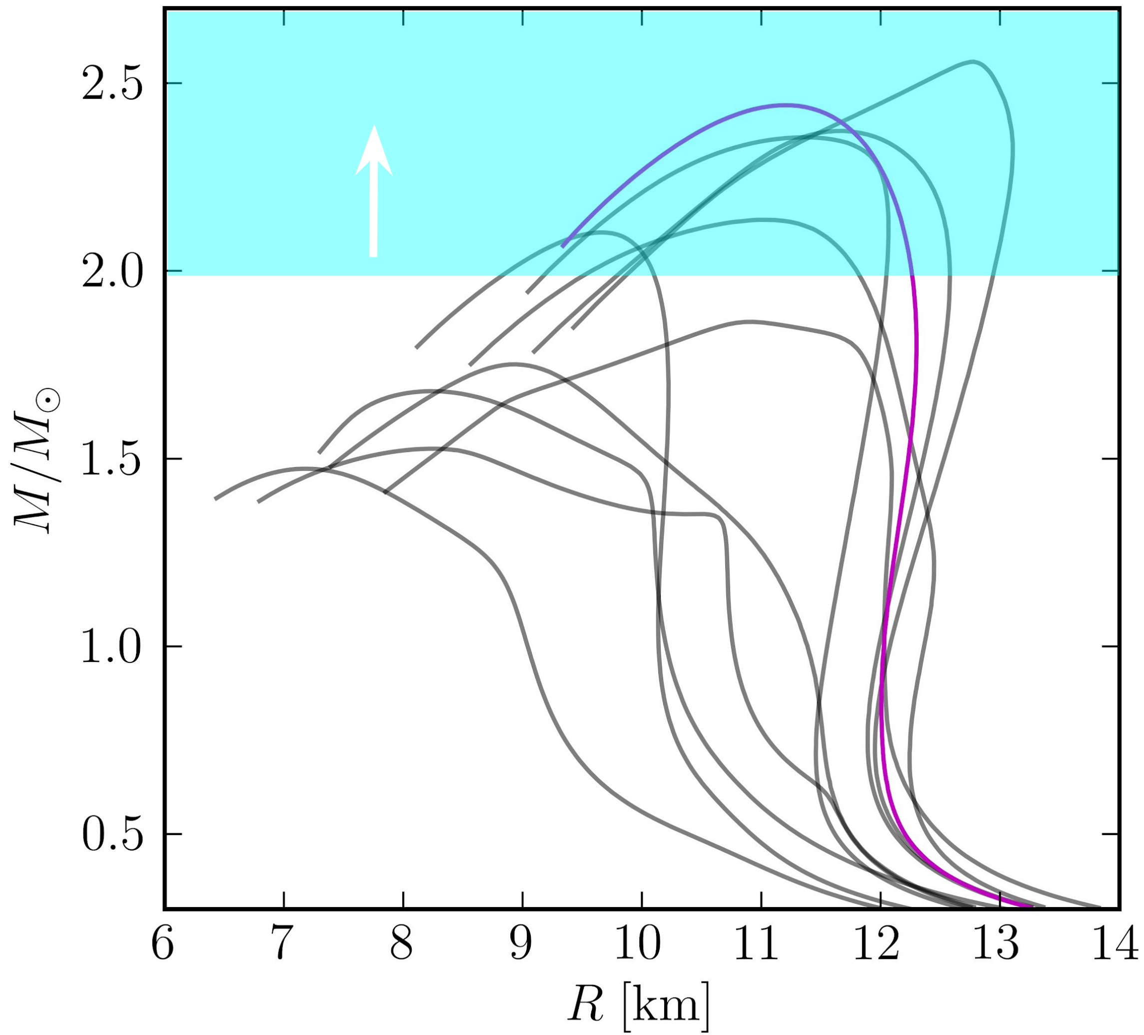
Massive pulsars (PSRs)
J0740+6620 Cromartie+(2019)
Fonseca+(2021)

EoS
nuclear
microphysics

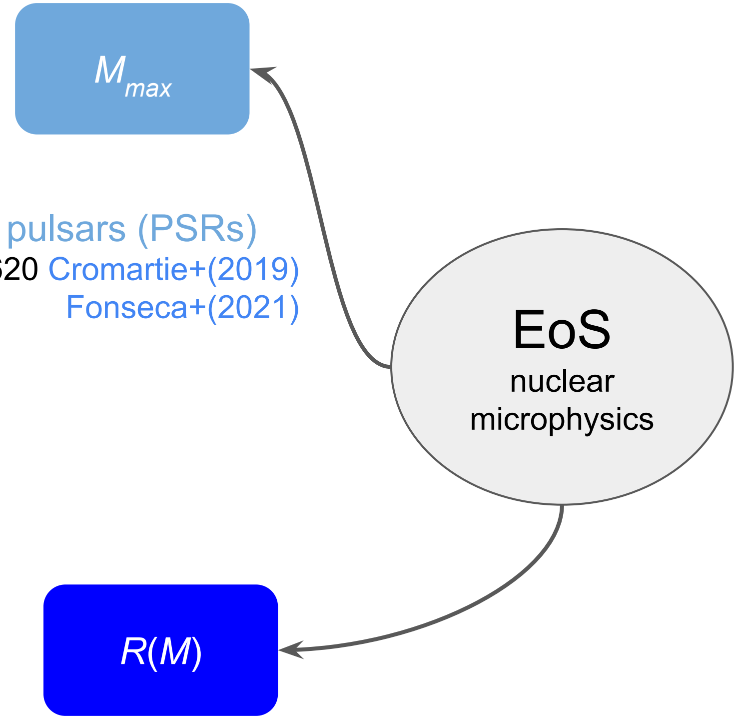


pulsar observations
radial velocity
Shapiro delay

NS Observables

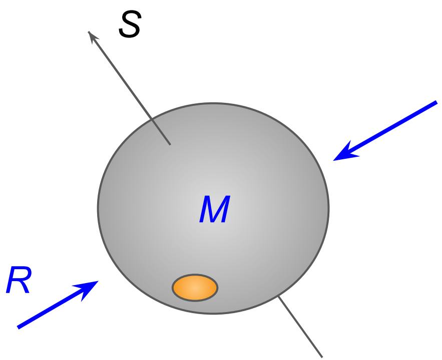


NS Observables: mass and radius



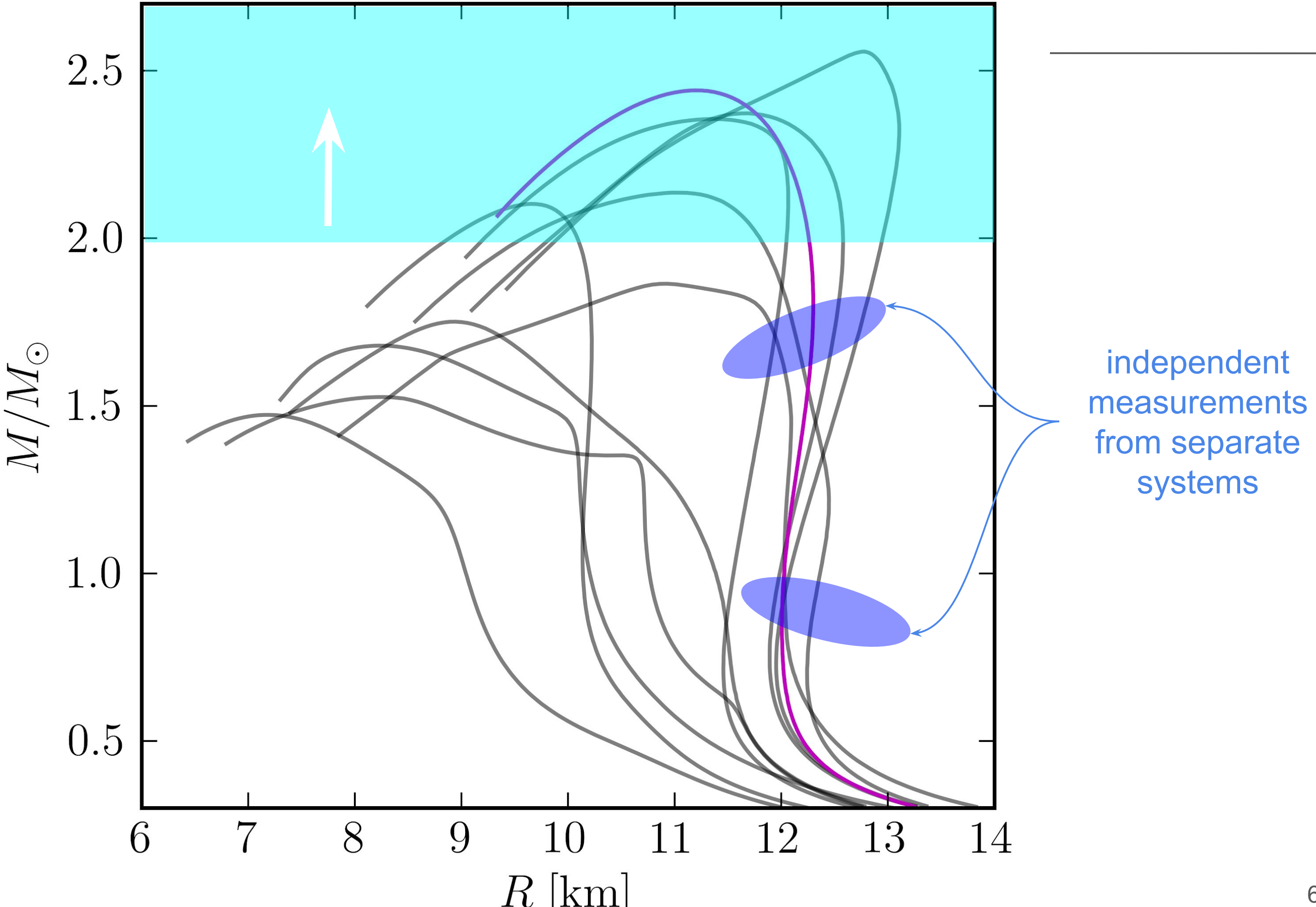
Massive pulsars (PSRs)
J0740+6620 Cromartie+(2019)
Fonseca+(2021)

X-ray pulse timing (NICER)
J0030+0451 Miller+(2019)
J0740+6620 Miller+(2021)

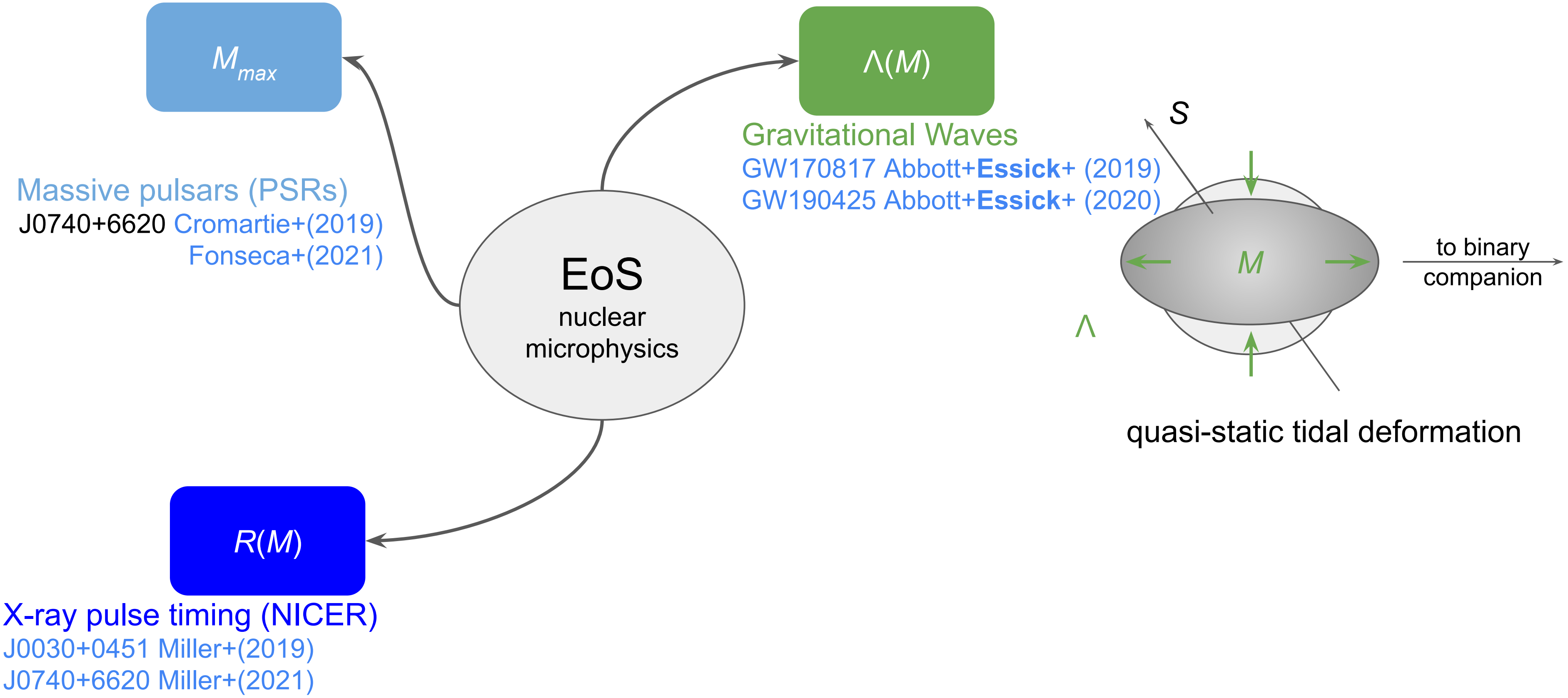


X-ray timing
Pulse profile modeling

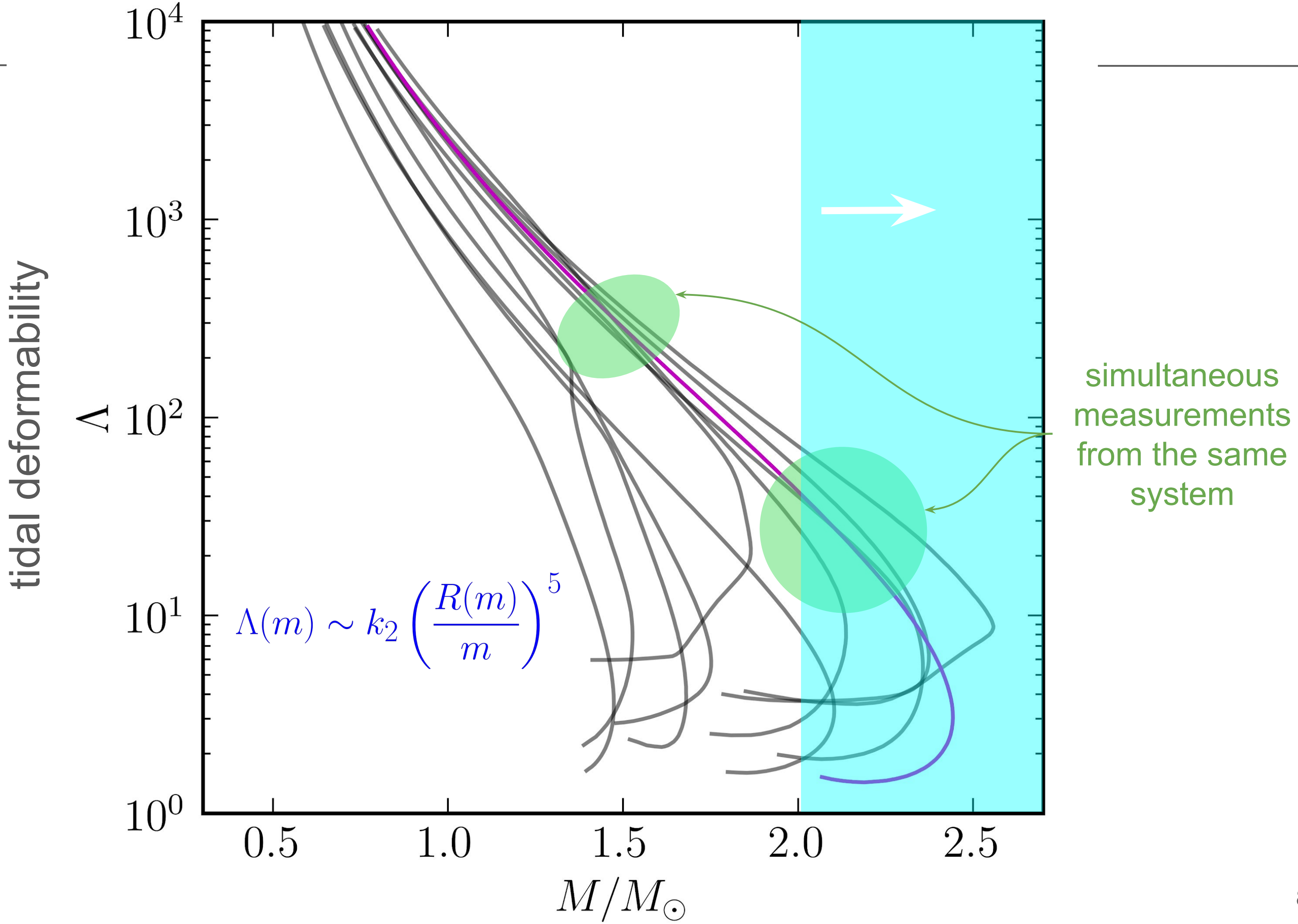
NS Observables



NS Observables: mass and tidal deformability

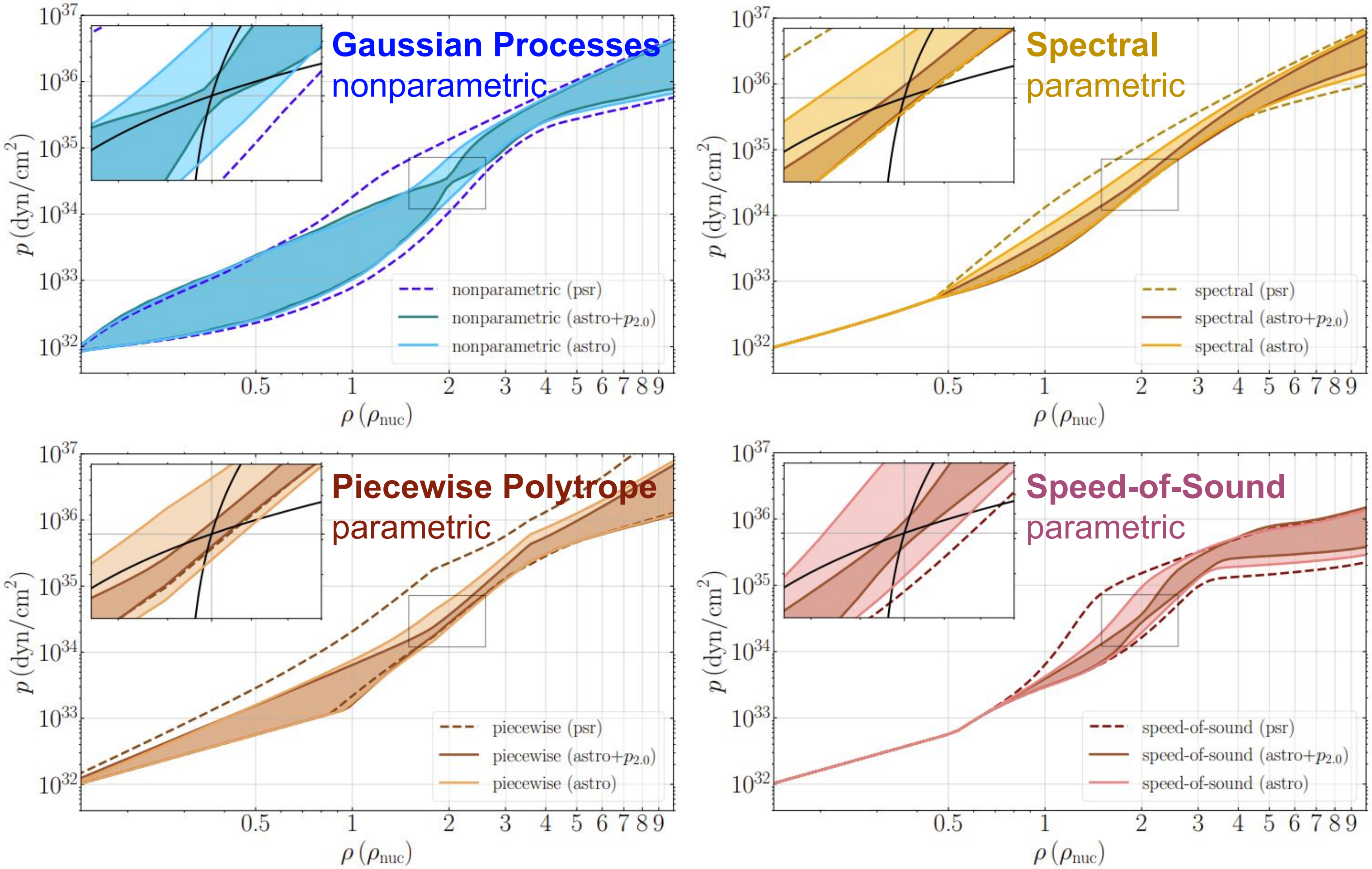


NS Observables



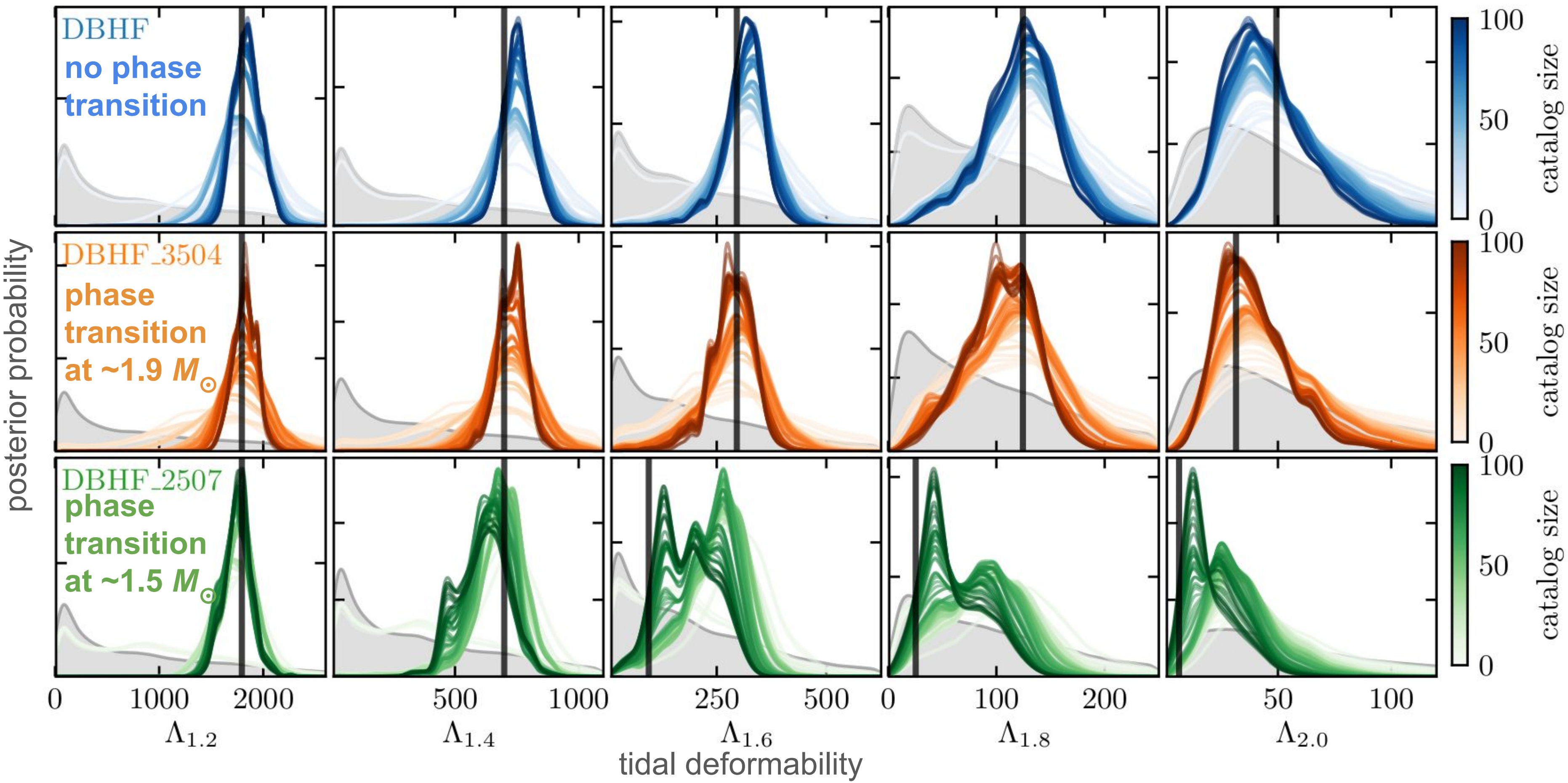
Inference of the NS EoS: systematics from parametric models

Legred+**Essick**+ (2022)



Inference of the NS EoS: no systematics with nonparametrics

Essick+ (2023)

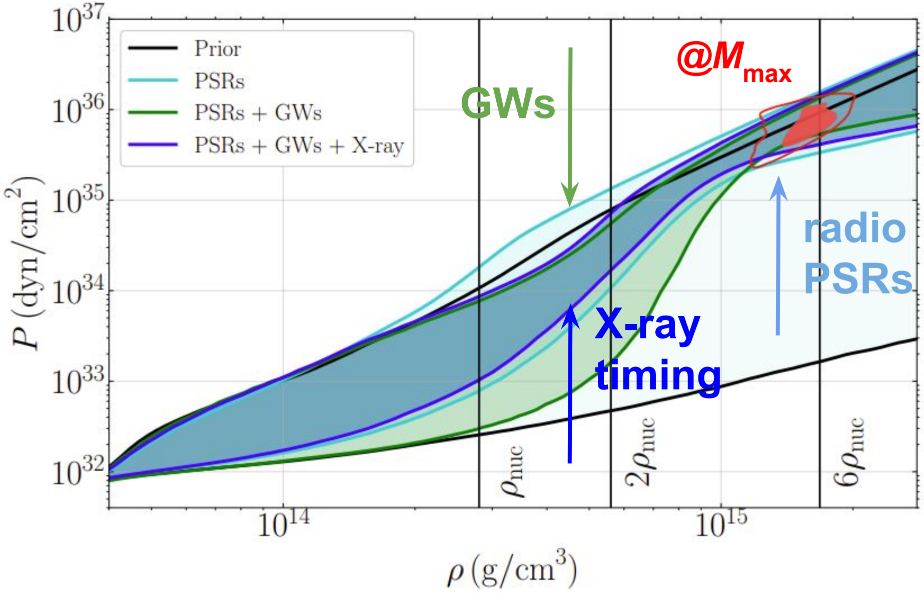


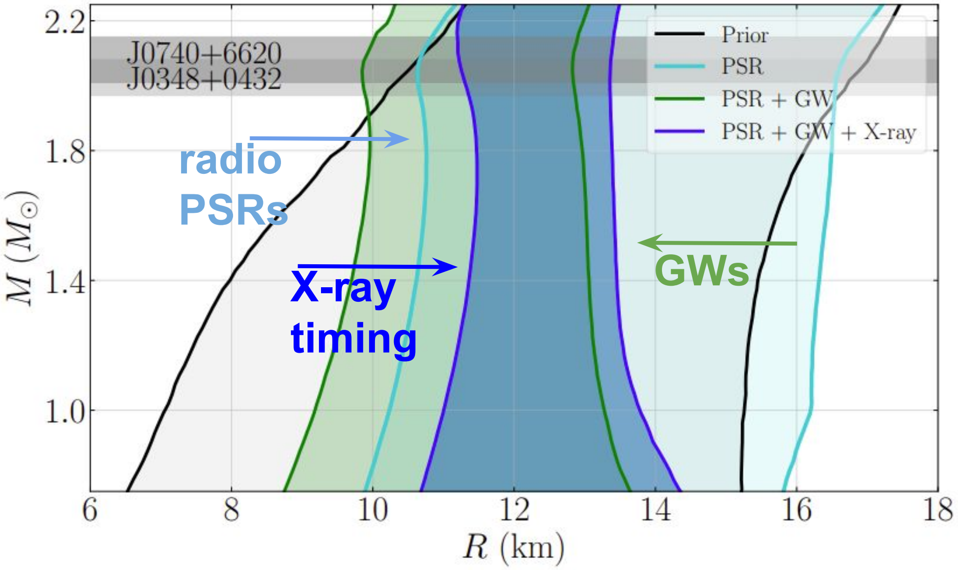
Current Constraints EoS Inference

Inference of the NS EoS: nonparametric results

Legred+**Essick**+ (2021)

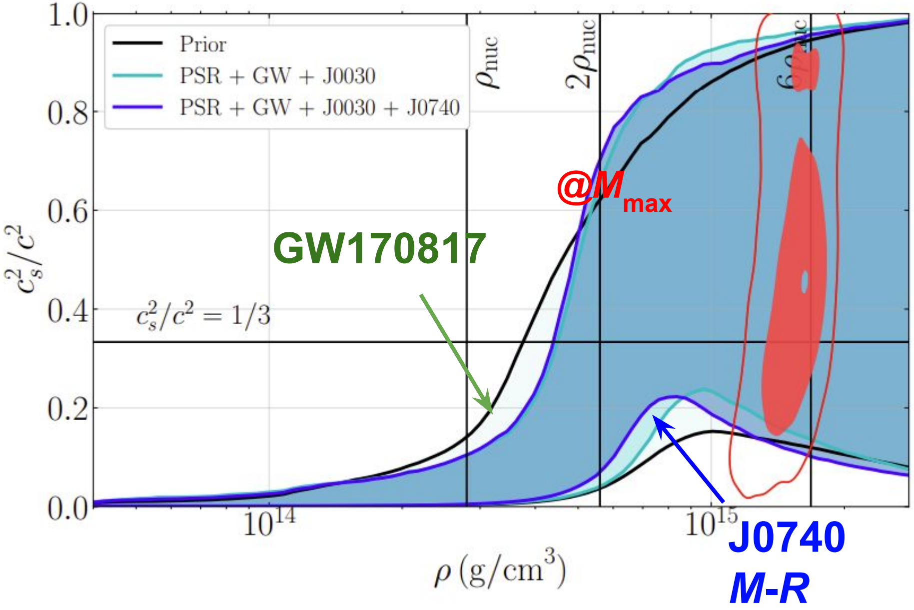
Current *Theory Agnostic* Constraints

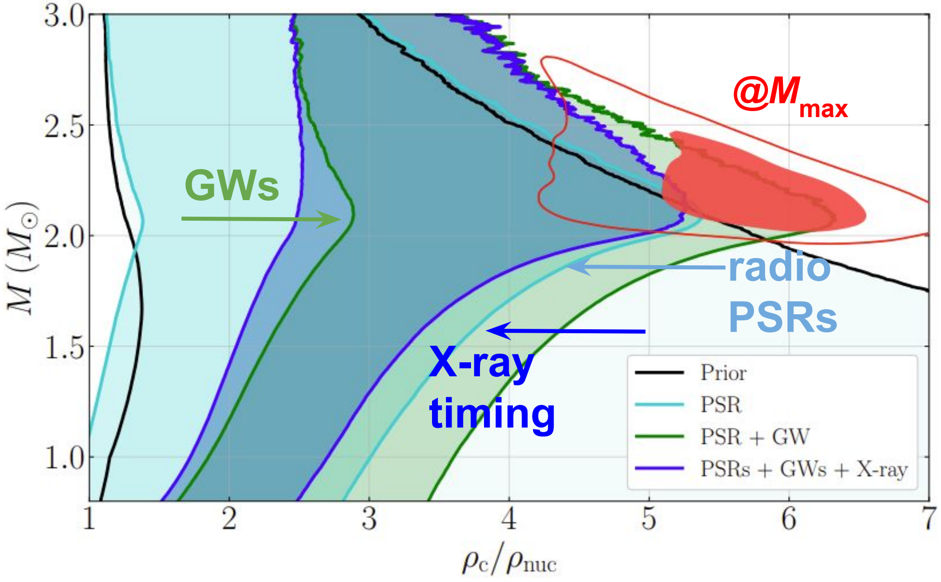




Inference of the NS EoS

Legred+**Essick**+ (2021)





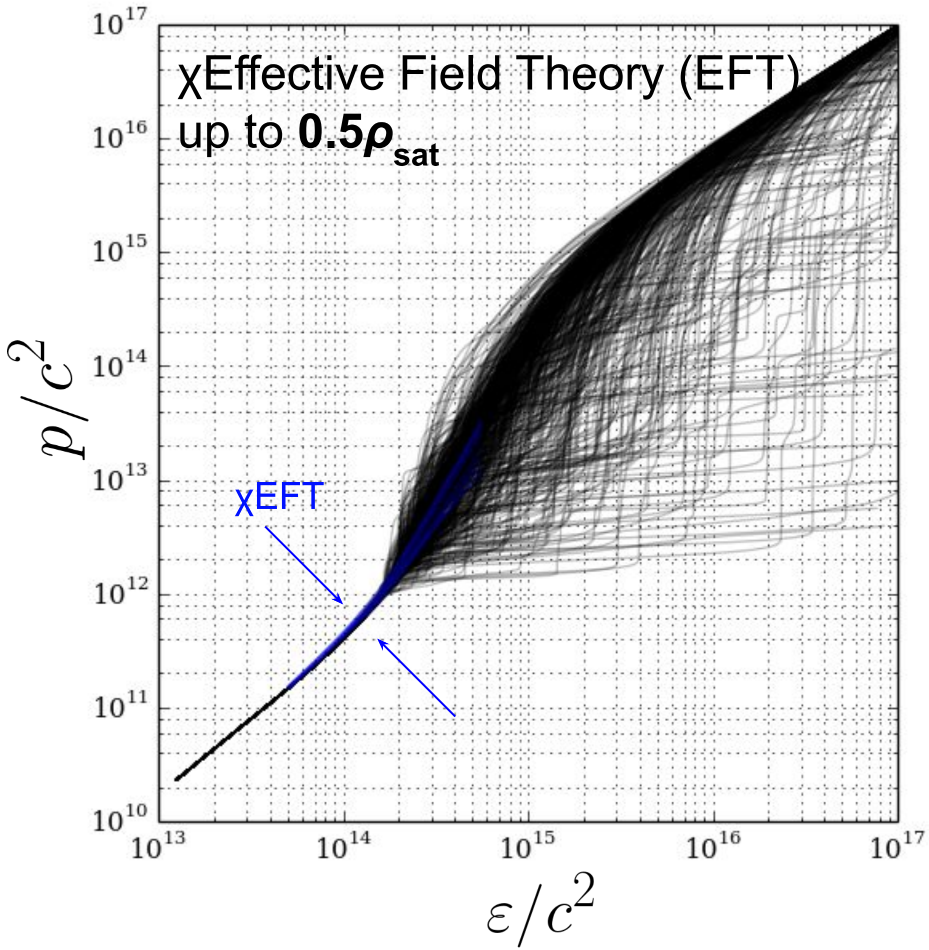
supranuclear sound speed almost certainly exceeds the conformal limit
→strongly-coupled interactions

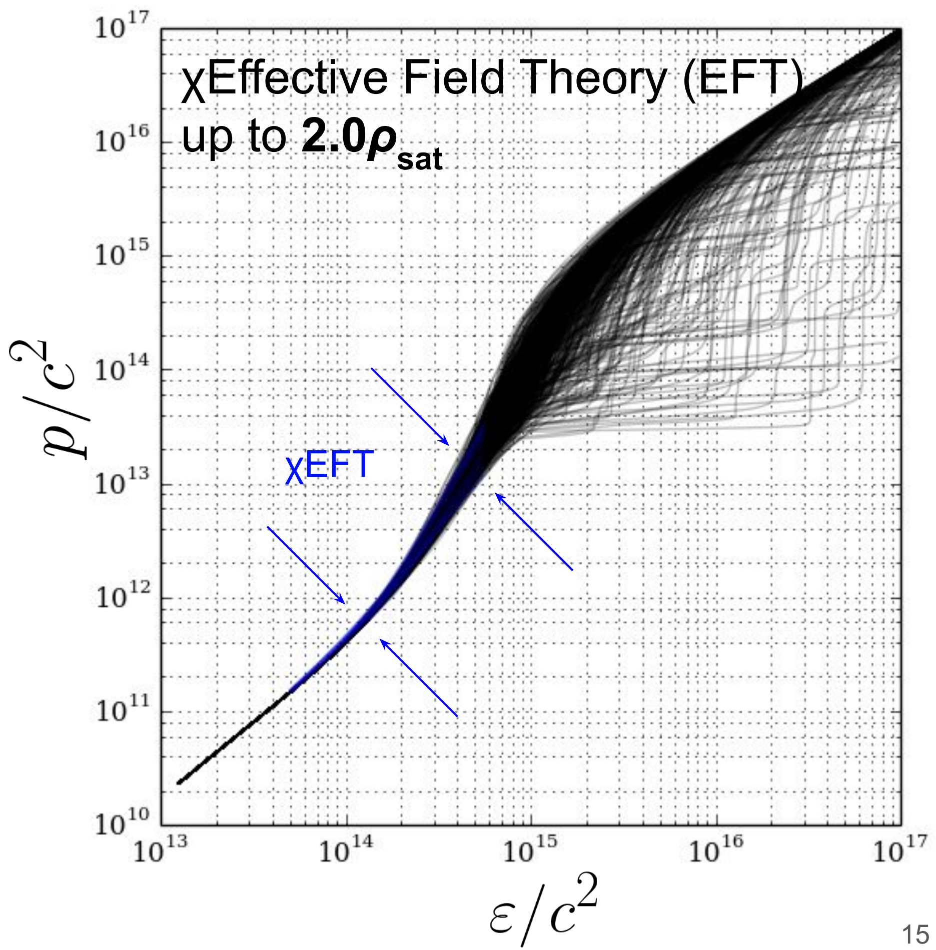
maximum central density is likely ~6ρ_{nuc}

Connections with Low-Density Theory

Inference of the NS EoS: incorporating low-density nuclear theory

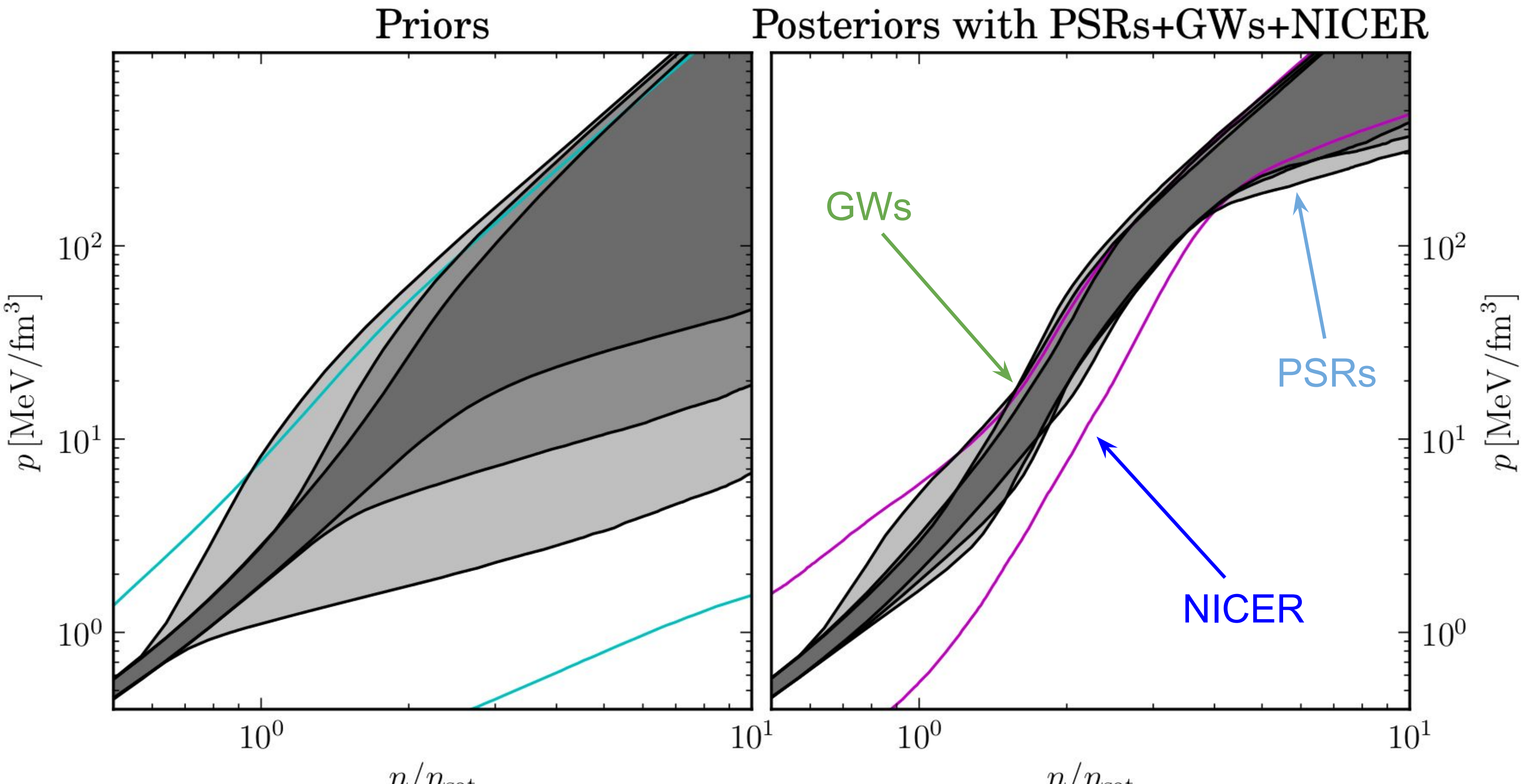
Essick+ (2020)





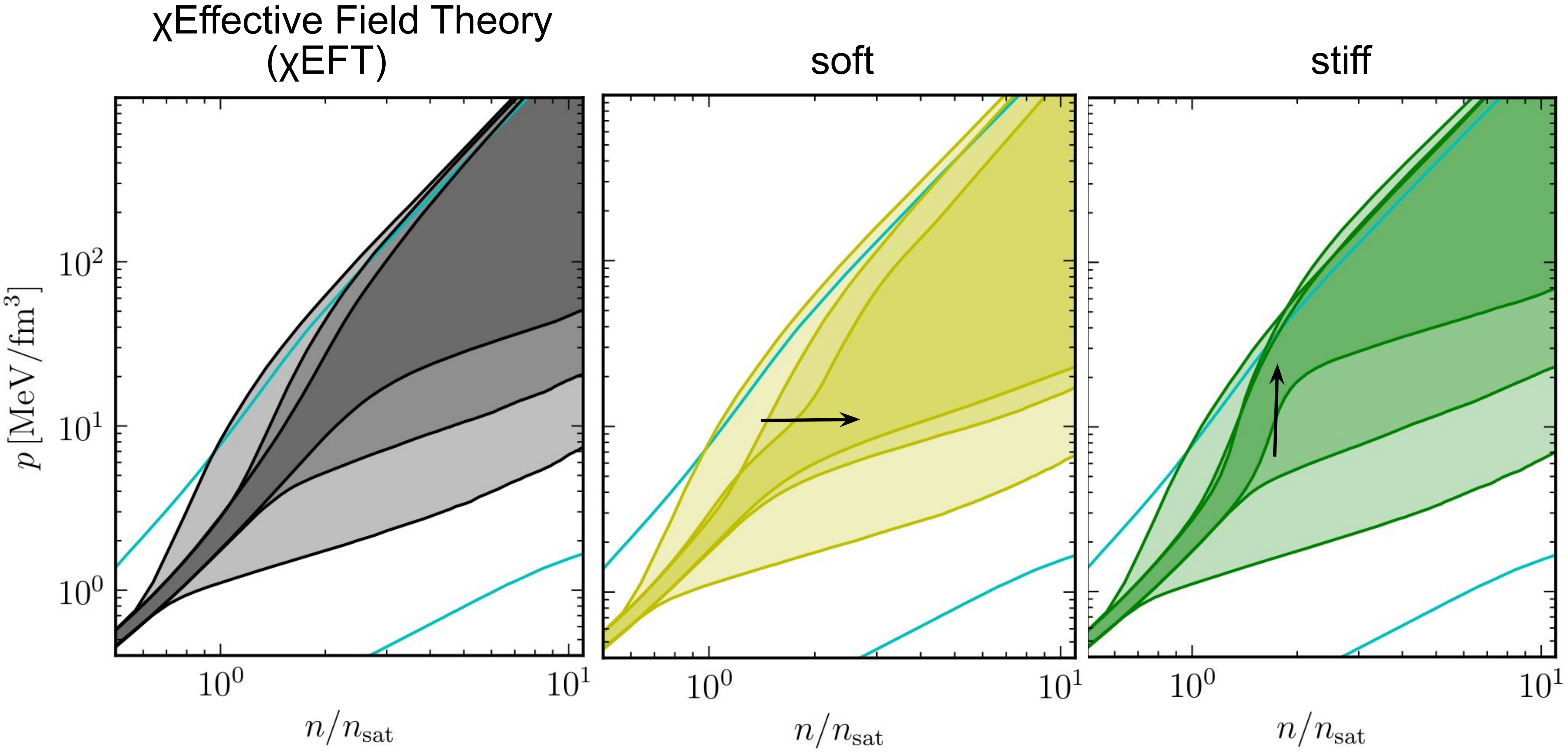
Inference of the NS EoS: incorporating low-density nuclear theory

Essick+ (2020)



Inference of the NS EoS: comparing low-density theories

Essick+ (2020)



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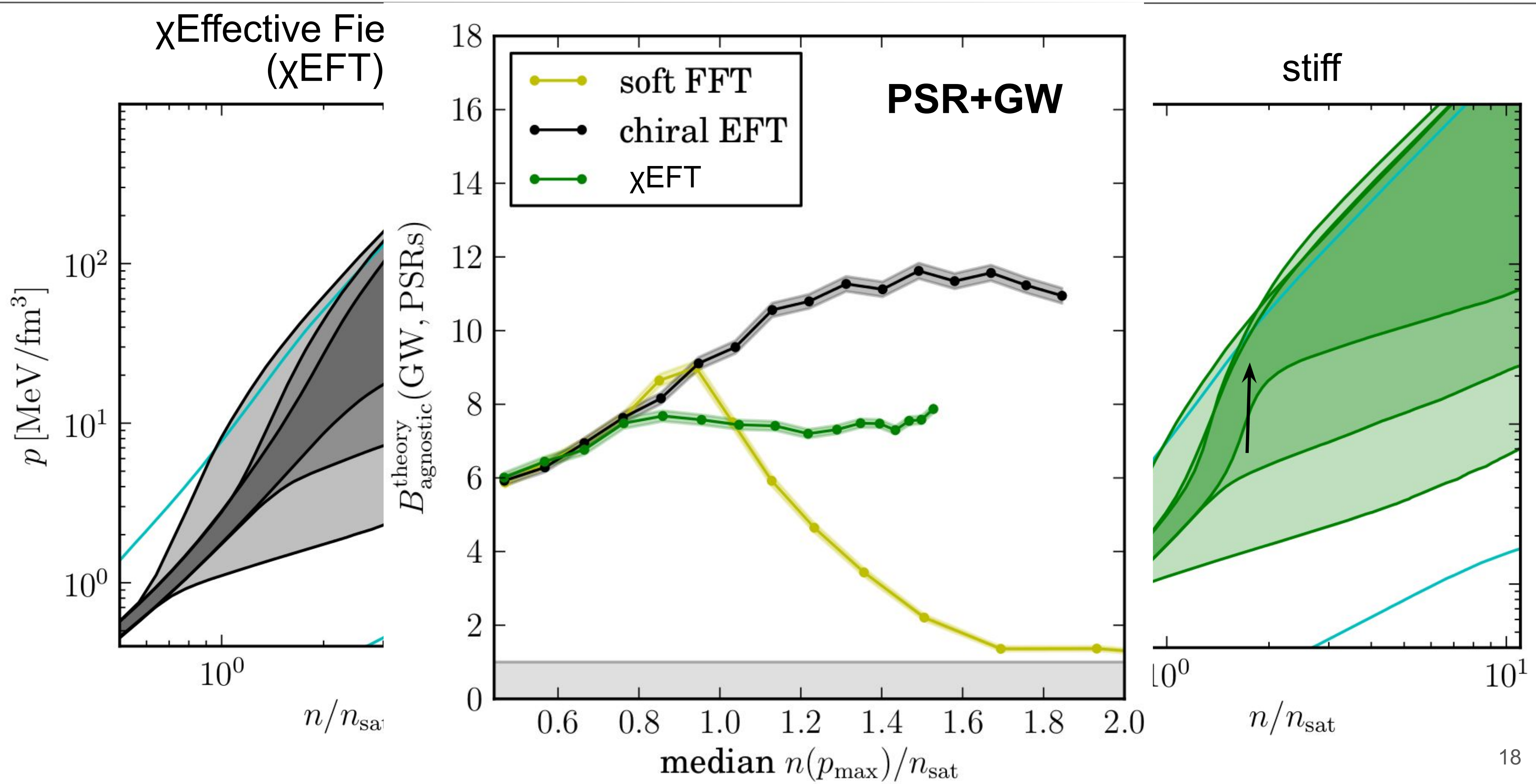
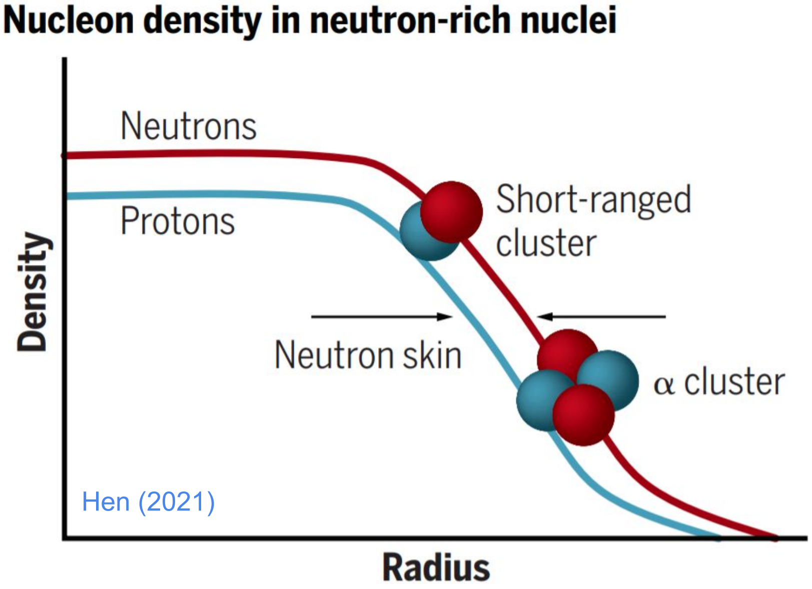


Connections with Low-Density Experiment

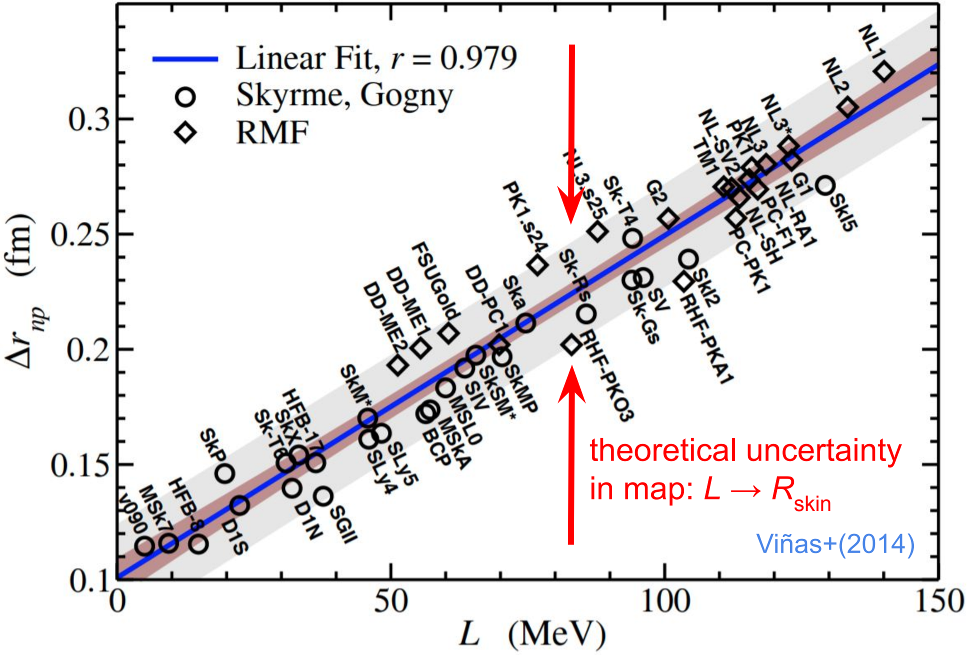
Inference of the NS EoS: low-density nuclear experiment

Connection to “new” experimental probes: Neutron Skin Thickness ($R_{\rm skin}$)

Reed+(2021) infer $L \gtrsim 100$ MeV based on $R_{\rm skin} = 0.29 \pm 0.07$ fm. Suggest this implies $R_{1.4} \gtrsim 14$ km.



Scattering experiments (PREX) measure this

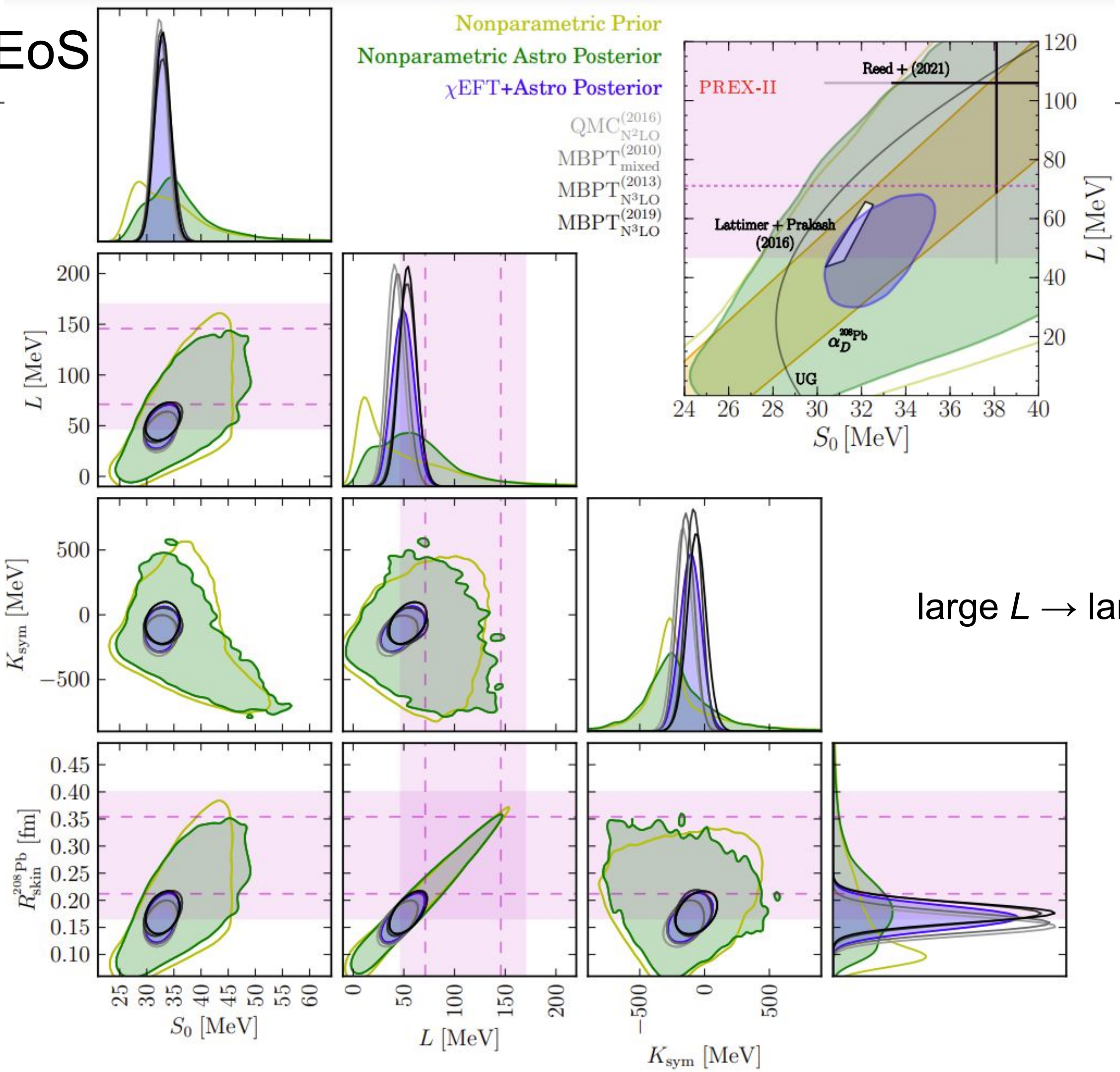


we constrain this with astrophysical observations

Inference of the NS EoS

Essick+ (2021)
Essick+ (2021)

We can also extract "nuclear parameters" directly from nonparametric EoS without the need for parametrized EoS models



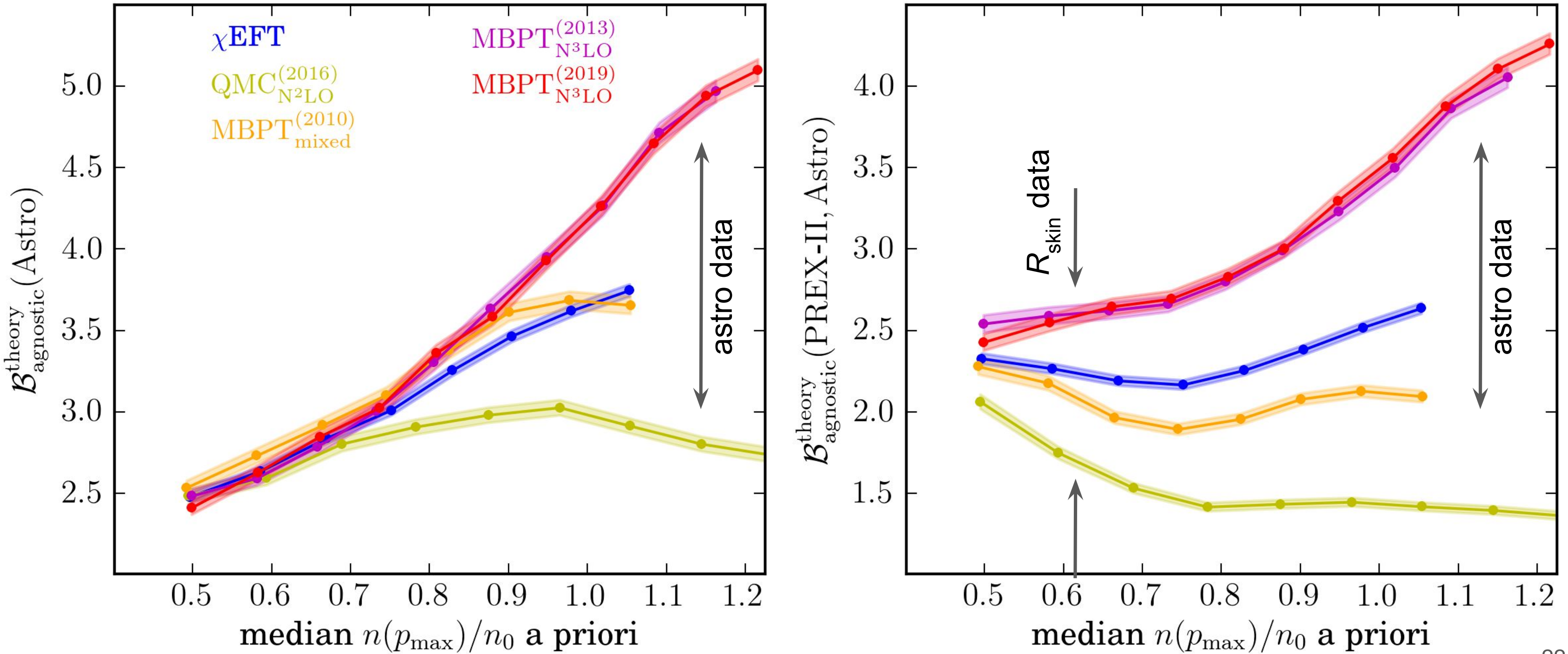
large $L \rightarrow$ large $p(n_{sat})$

Inference of the NS EoS: low-density nuclear experiment

Essick+ (2021)
Essick+ (2021)

astro data can distinguish between nuclear theories at high densities

nuclear experiments probe lower densities



Inference of the NS EoS: low-density nuclear experiment

Essick+ (2021)
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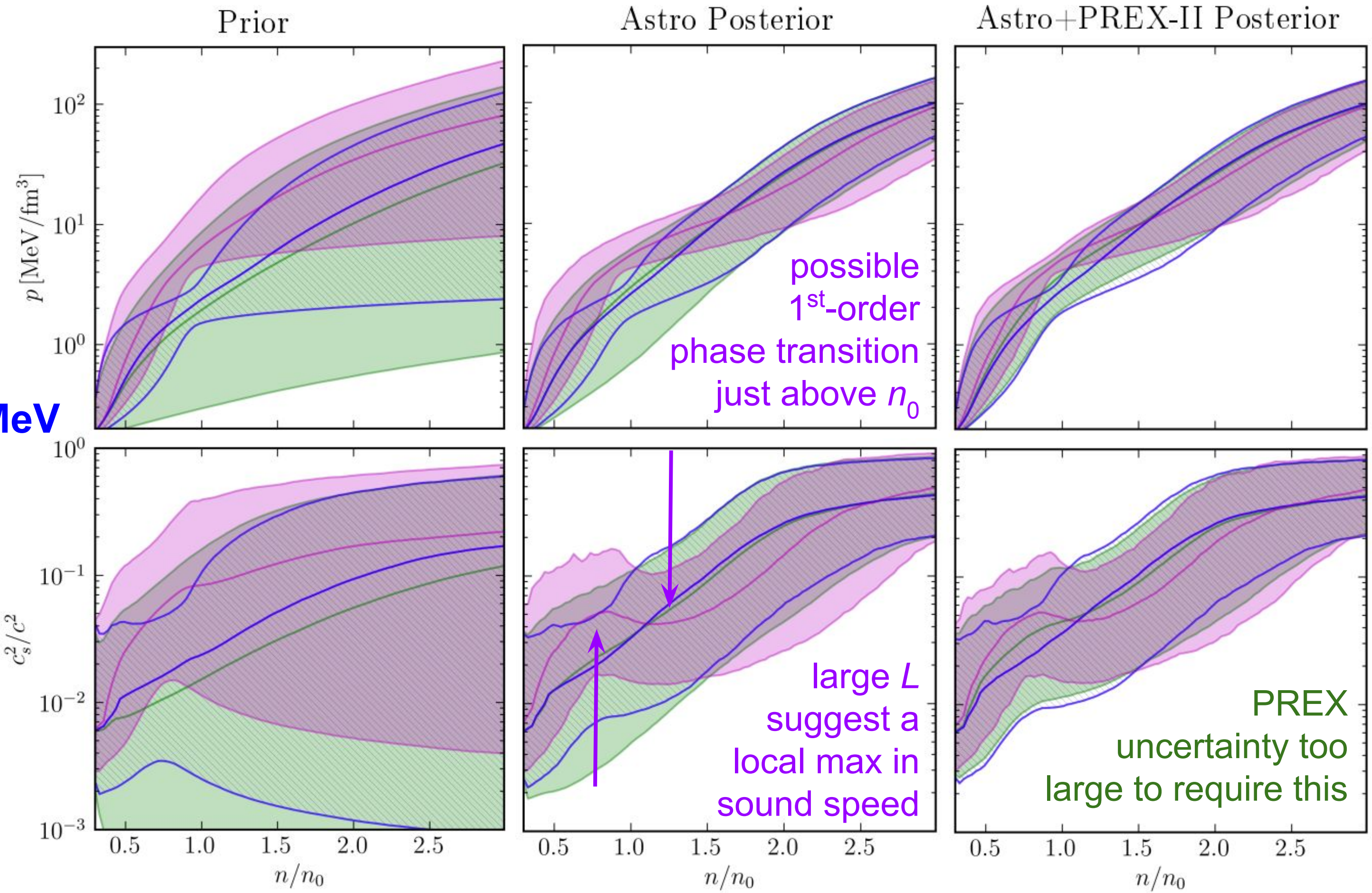
100 MeV < *L*
30 MeV < *L* < 70 MeV
All *L*

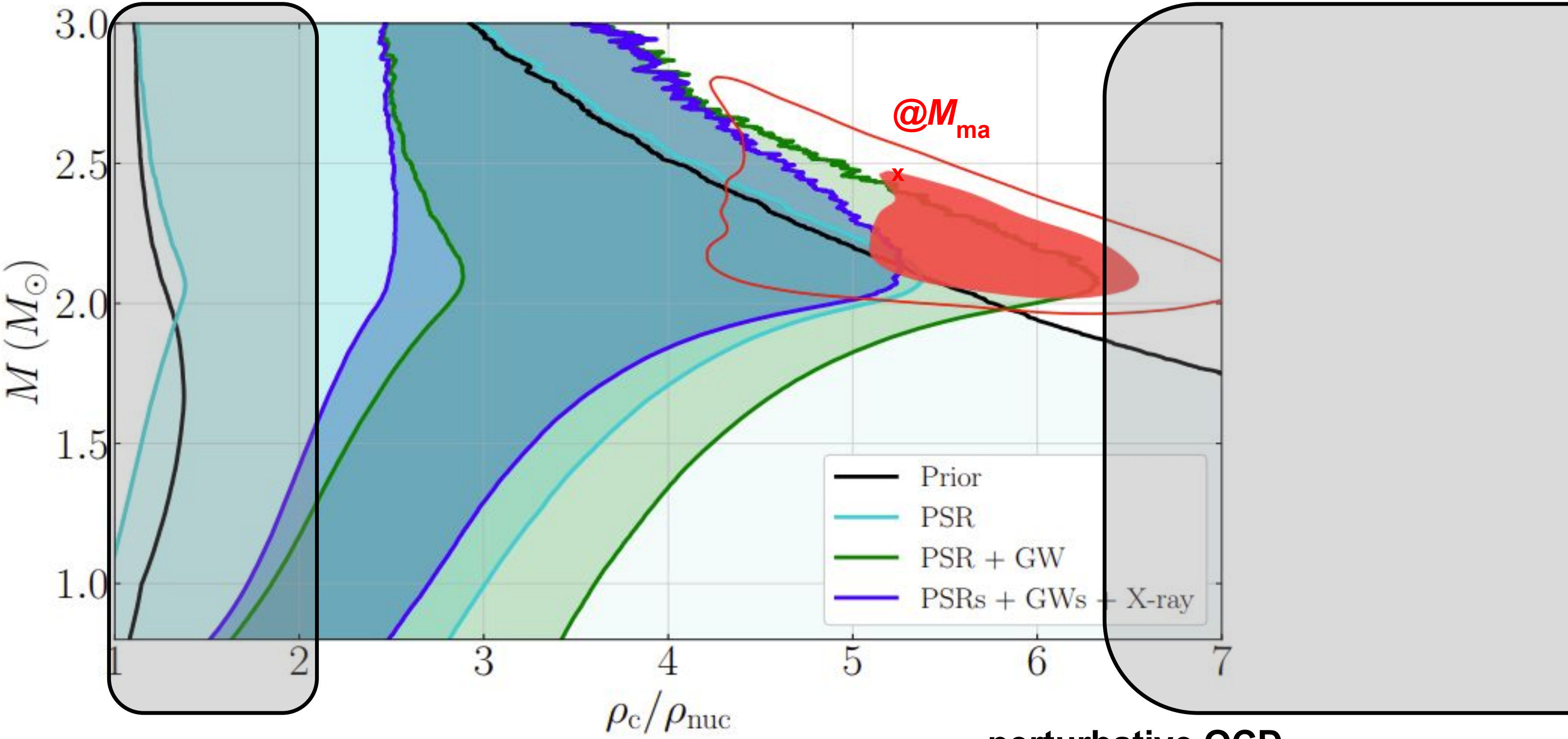


Future Prospects

Future Prospects: EoS constraints

Legred+**Essick**+ (2021)

nuclear experiment



χEffective Field Theory

Lynn+ (2016)
Drischler+ (2020), Drischler+ (2020)

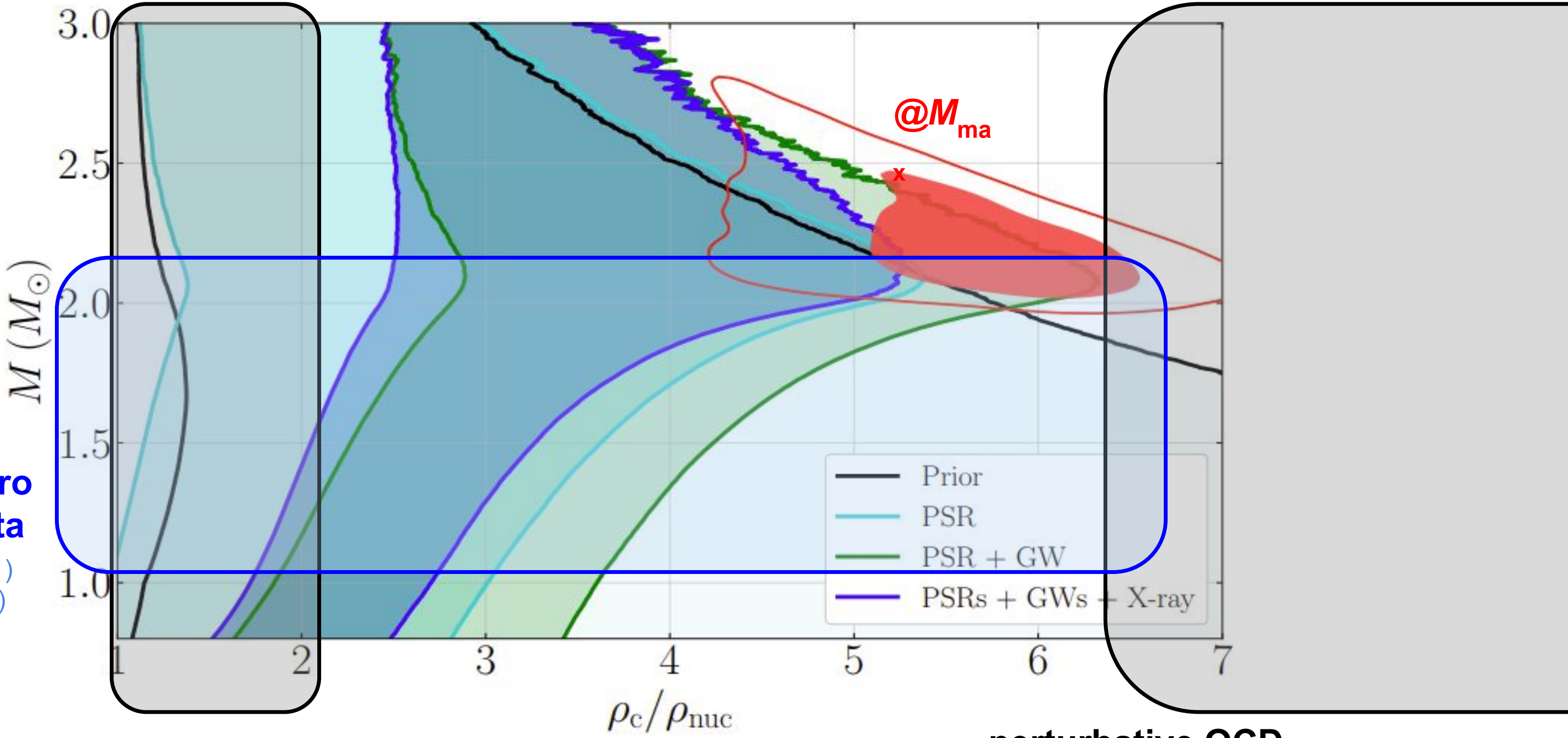
perturbative QCD

Komoltsev+Kurkela (2022)
Gorda+ (2022)
Komoltsev+ (2023)

Future Prospects: EoS constraints

Legred+**Essick**+ (2021)

nuclear experiment



Astro Data

Abbott+**Essick**+ (2021)
Farah+**Essick**+ (2022)
Landry+Read (2021)

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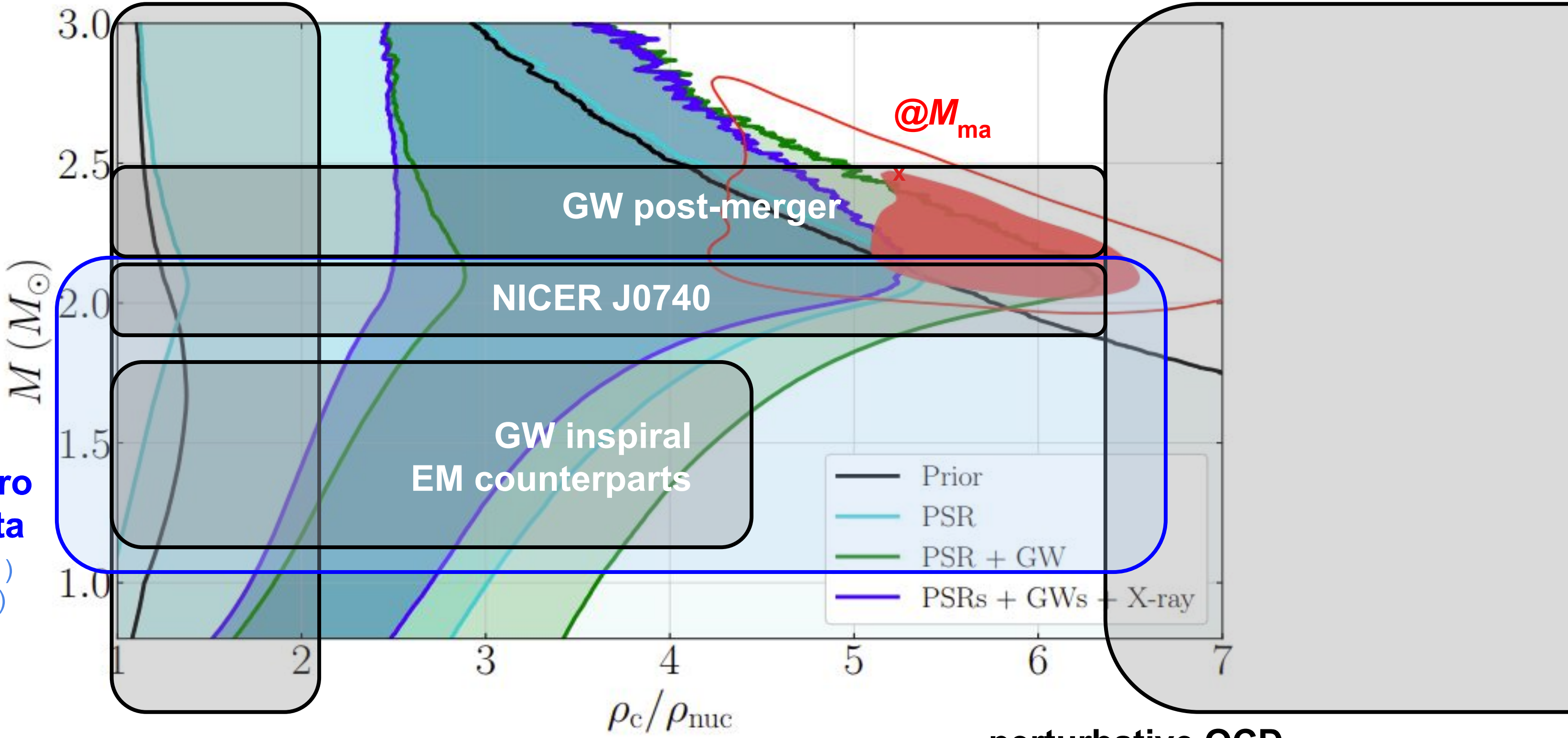

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