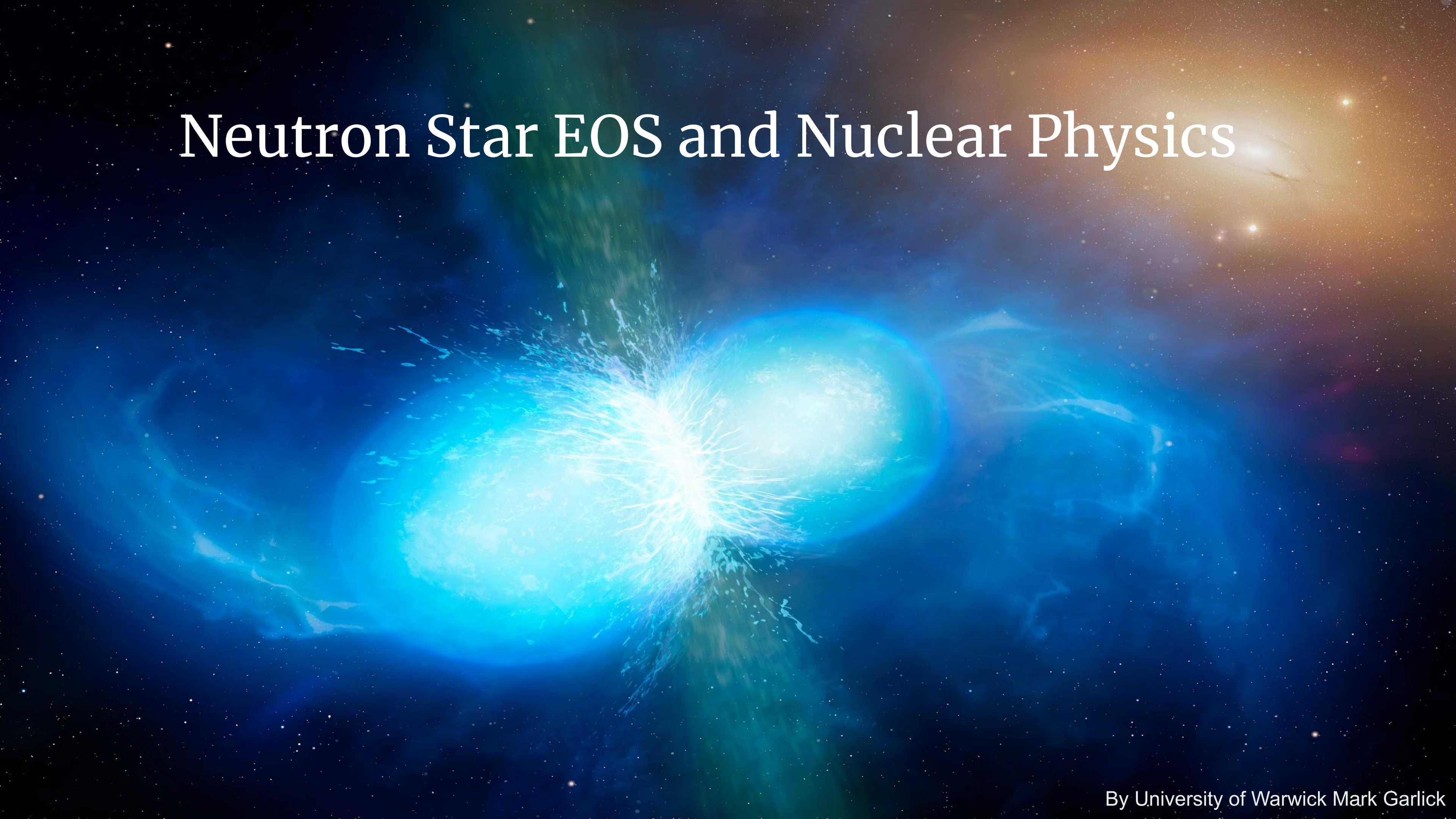
Neutron Star EOS and Nuclear Physics



By University of Warwick Mark Garlick

The panel

Tanja Hinderer (Chair)

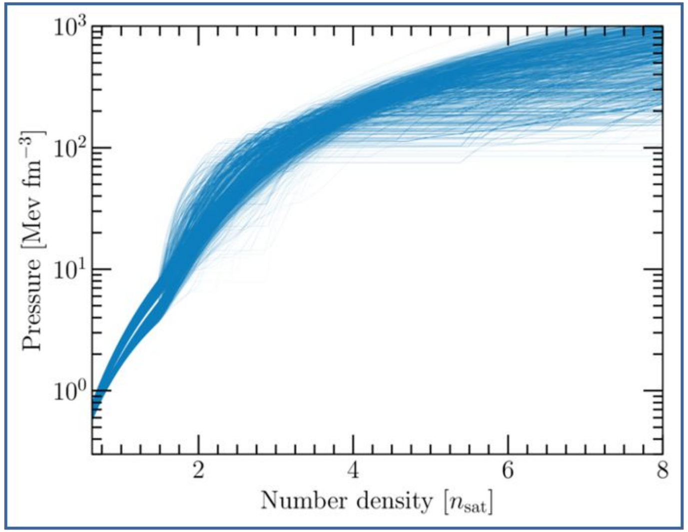
Nils Andersson

Philippe Landry

Peter T. H. Pang

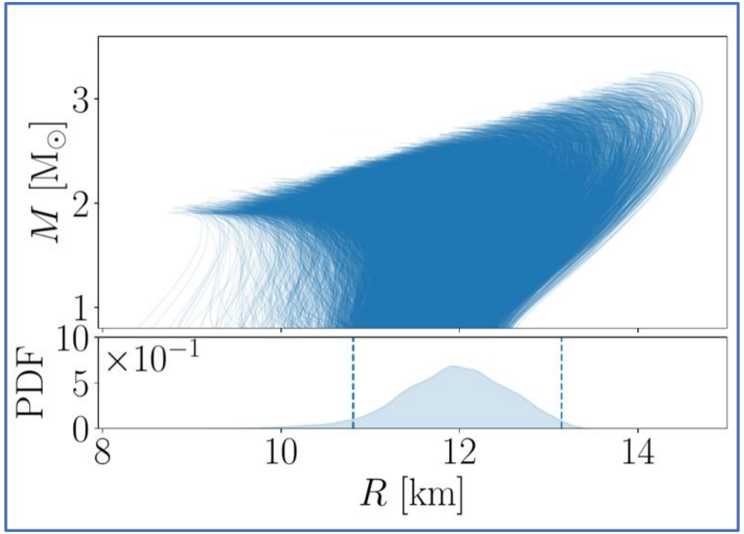
State of the field

Introduction to the NS EOS

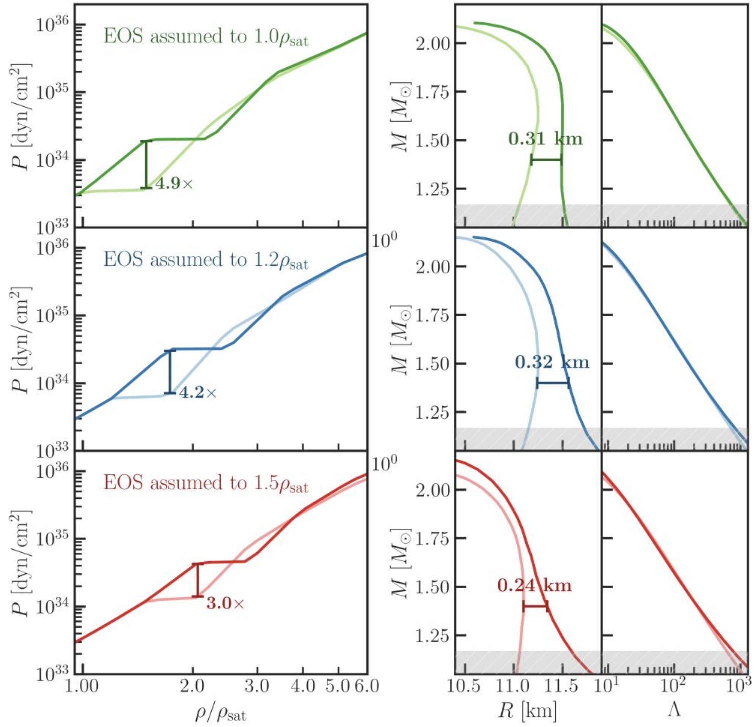


TOV equation

Observations



Masquerade problem



Raithel and Most, *Phys.Rev.Lett.* 130 (2023) 20, 201403

Introduction to the NS EOS

EOS as proxy for microscopic observables that nuclear physicists care about

Challenge of determining EOS when all nuclear theory EOS models involve phenomenology at some level

What we learned from GW170817

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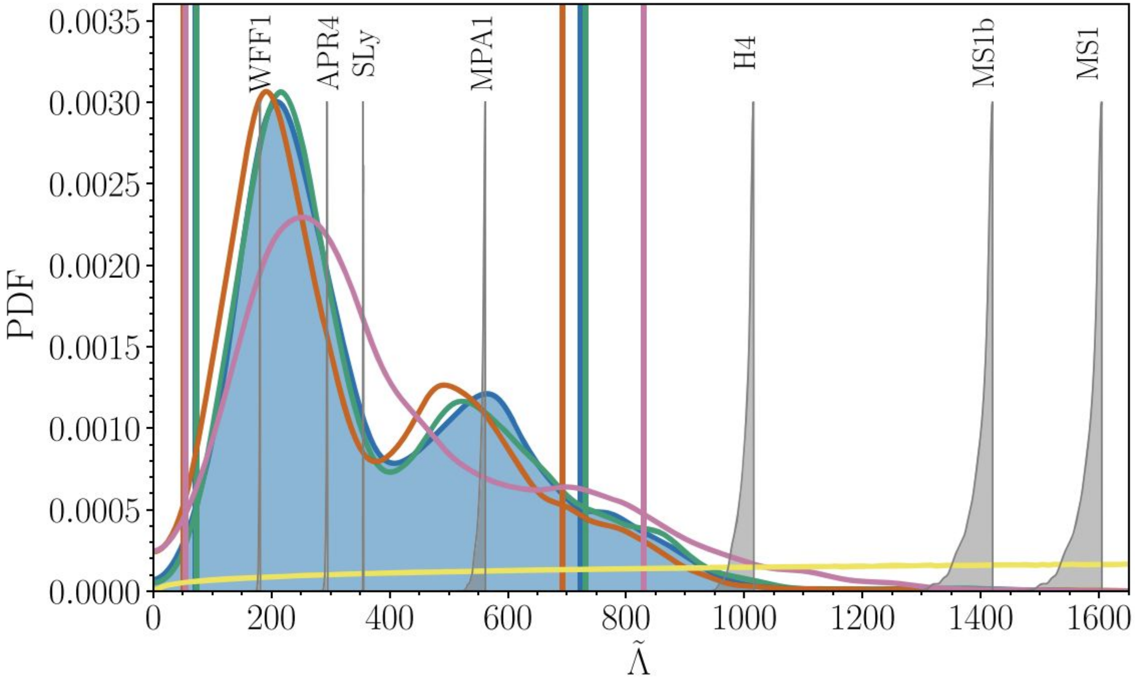
GW:

- Softness of the EOS



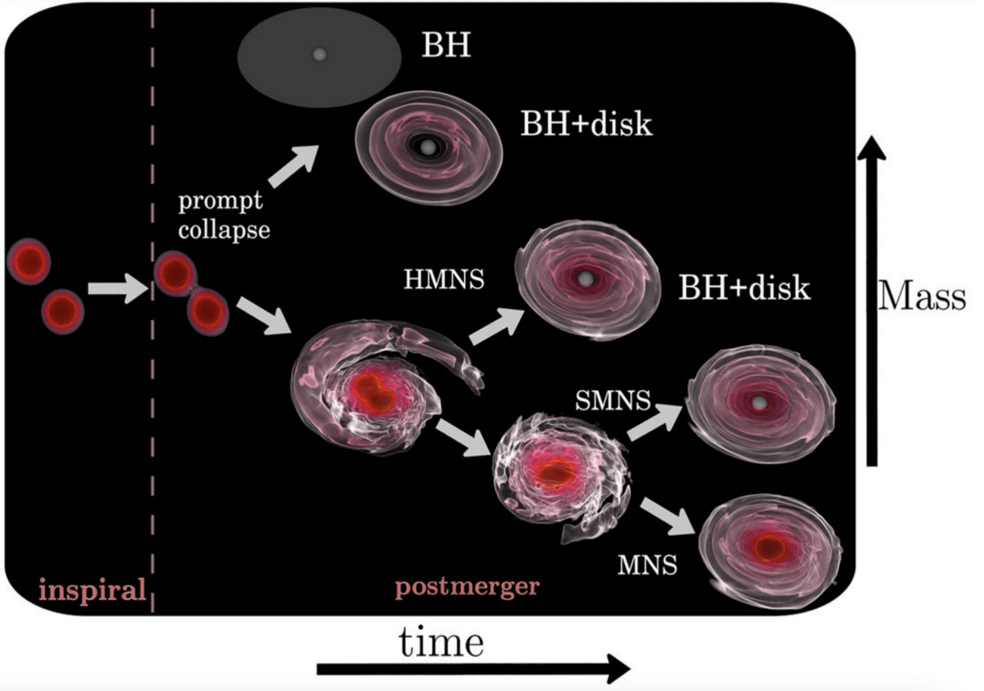
What we learned from GW170817

GW:

- Softness of the EOS

Remnant:

- Upper bound on TOV mass



Dietrich, Hinderer, & Samajdar, *Gen Relativ Gravit* **53**, 27 (2021)

What we learned from GW170817

GW:

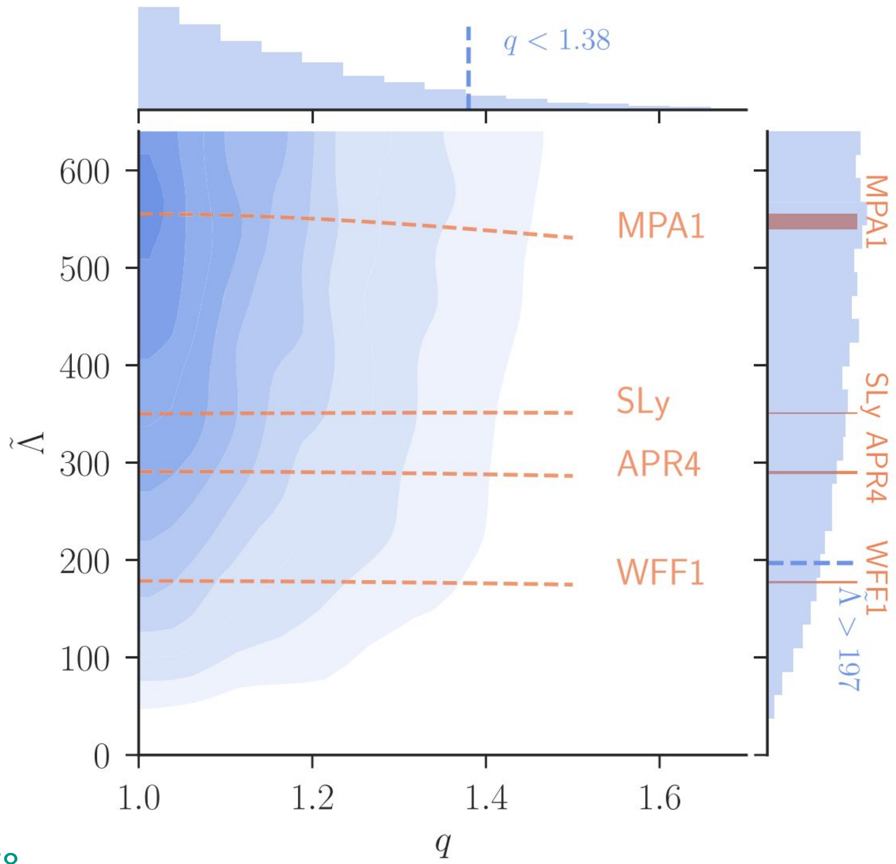
- Softness of the EOS

Remnant:

- Upper bound on TOV mass

Kilonova:

- Stiffness of the EOS

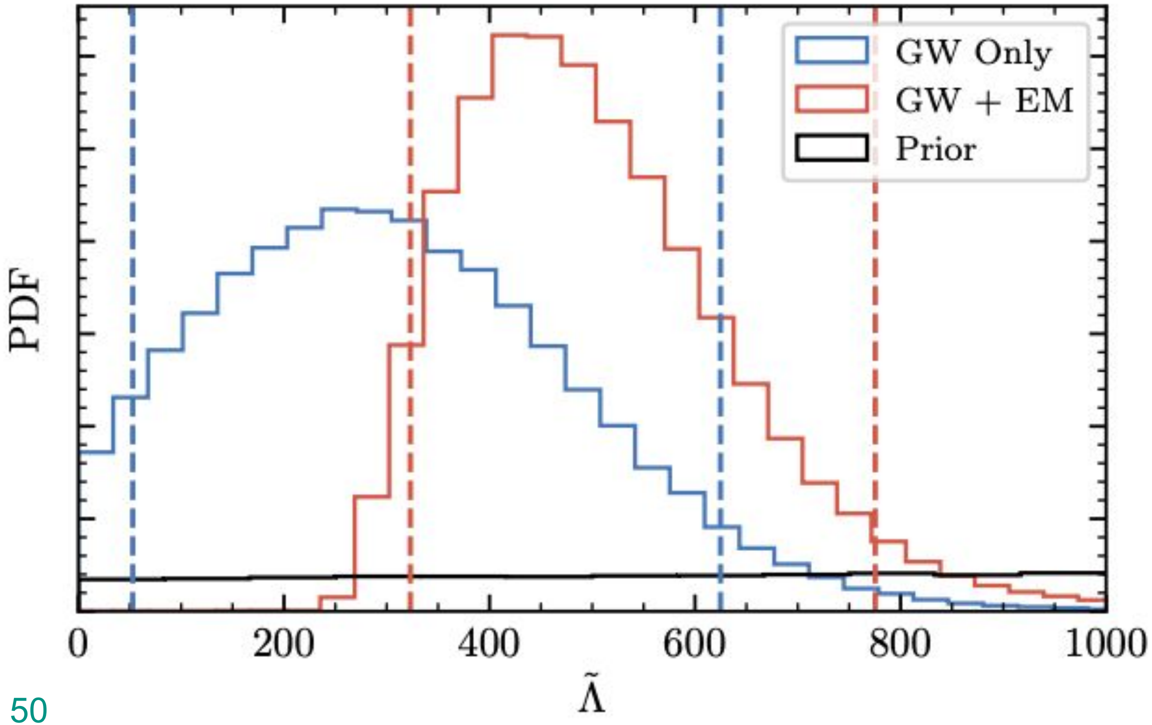


Coughlin et al., *Mon.Not.Roy.Astron.Soc.* 480 (2018) 3, 3871-3878

What we learned from GW170817

Multi-messenger astronomy on nuclear physics

- GW + EM

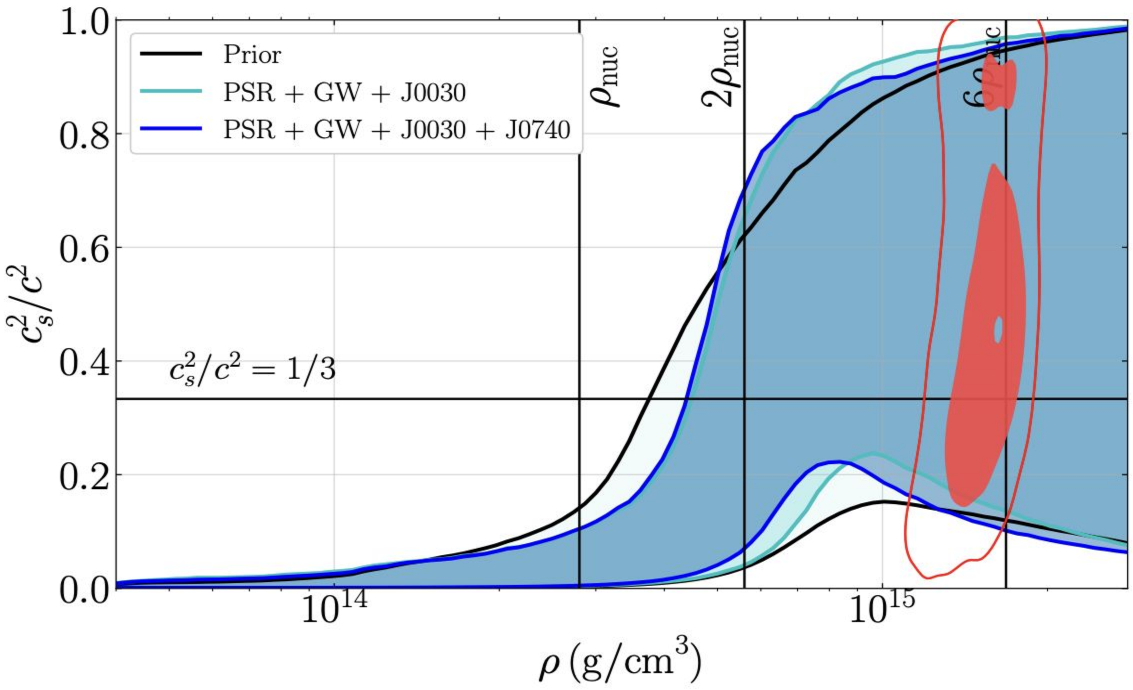


Radice et al., *Eur.Phys.J.A* 55 (2019) 4, 50

What we learned from GW170817

Multi-messenger astronomy on nuclear physics

- GW + EM
- GW + PSR

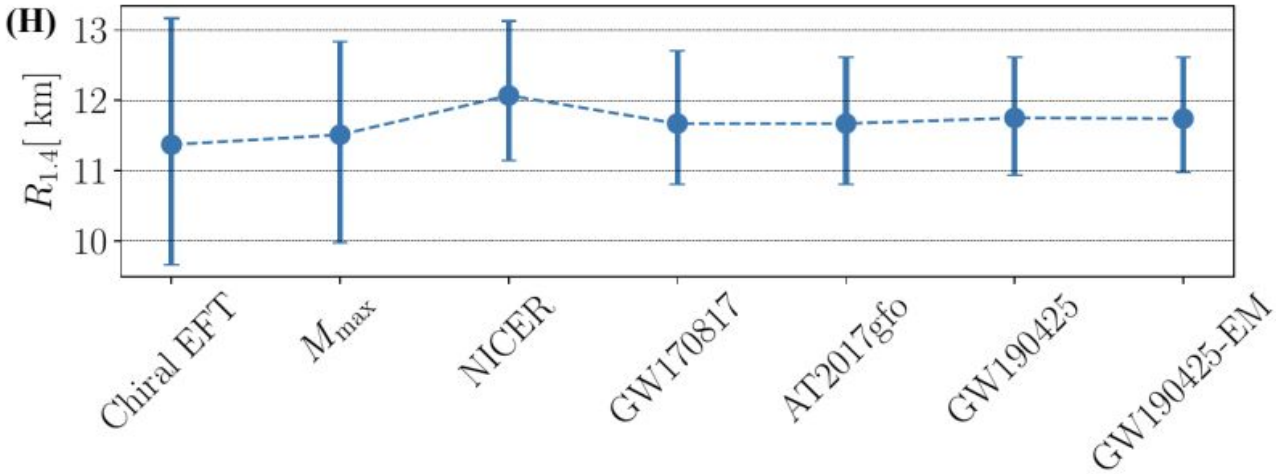


Legend et al. *Phys.Rev.D* 104 (2021) 6, 063003

What we learned from GW170817

Multi-messenger astronomy on nuclear physics

- GW + EM
- GW + PSR
- Astro + nuclear theory

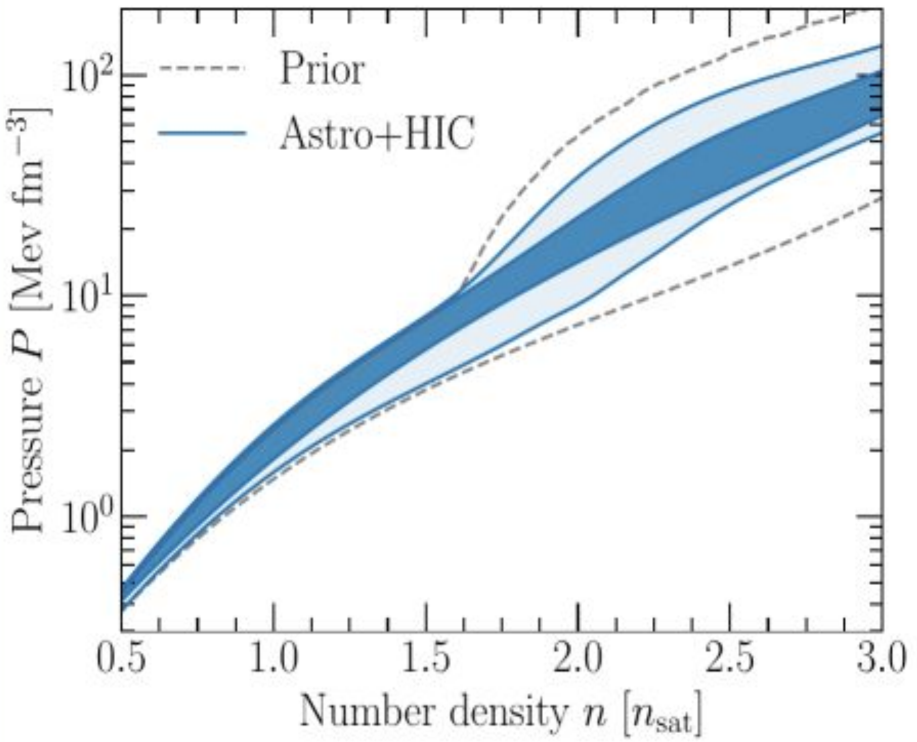


Dietrich et al., *Science* 370 (2020) 6523, 1450-1453

What we learned from GW170817

Multi-messenger astronomy on nuclear physics

- GW + EM
- GW + PSR
- Astro + nuclear theory
- Astro + nuclear theory + experiment

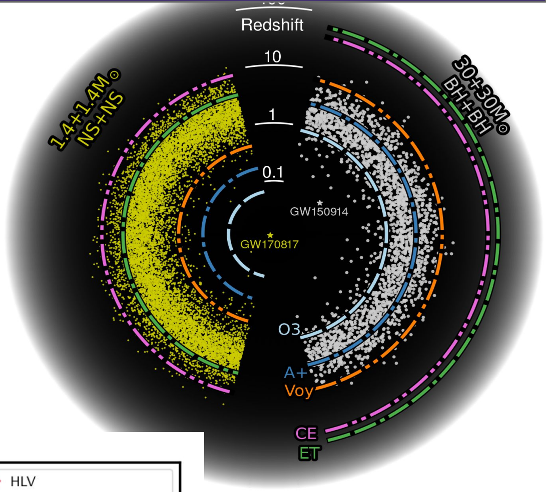


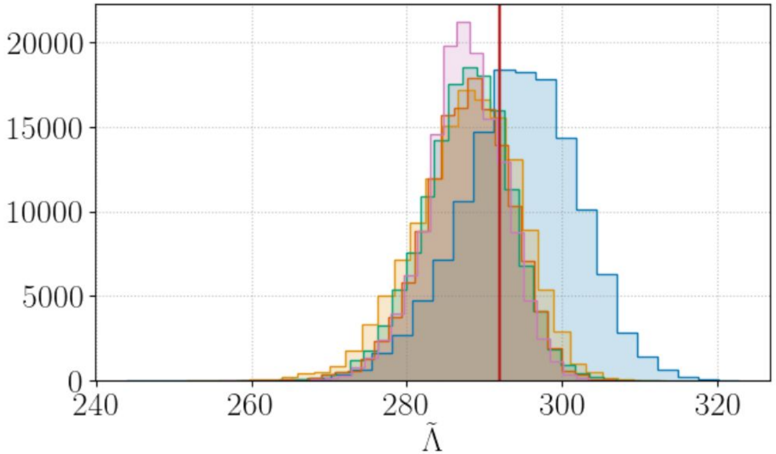
Huth & Pang et al., *Nature* 606 (2022) 276-280

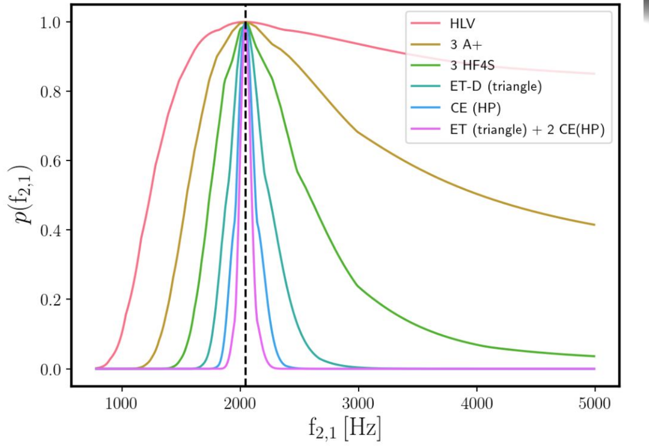
Prospects in the next-generation detector era

Binary neutron star inspirals

- XG BNS survey complete out to z ~ 0.5
- O(100) SNR > 100 BNSs per year [Gupta+ 23]
- Leading-order $\tilde{\Lambda}$ measurable to O(10) [Puecher+ 23]
- Measurable effects from dynamical tides [Pratten+ 19]





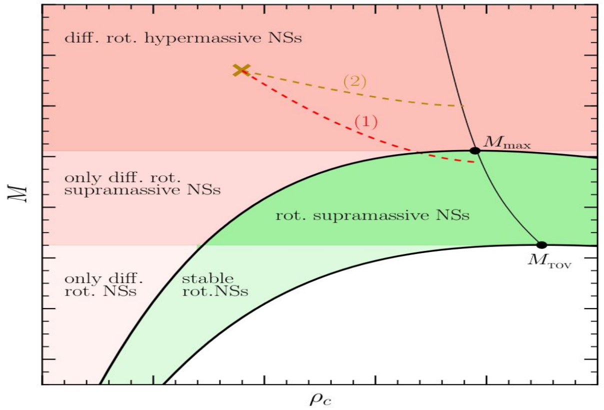


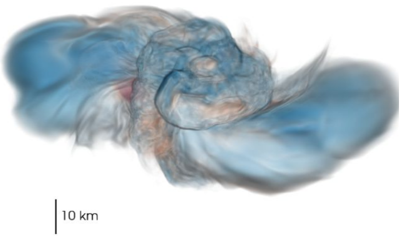
Postmerger GWs from binary neutron stars

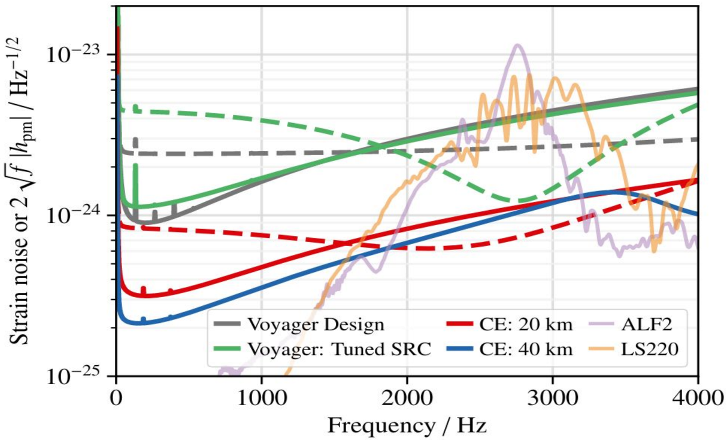
~ 1 SNR > 5 BNS postmerger GW detection per year [Gupta+ 23]

Lifetime of remnant constrains maximum NS mass [Rezzolla+ 17]

Peak frequency constrains fundamental NS oscillation mode, modulo thermal, rotational & compositional corrections [Radice+ 18]

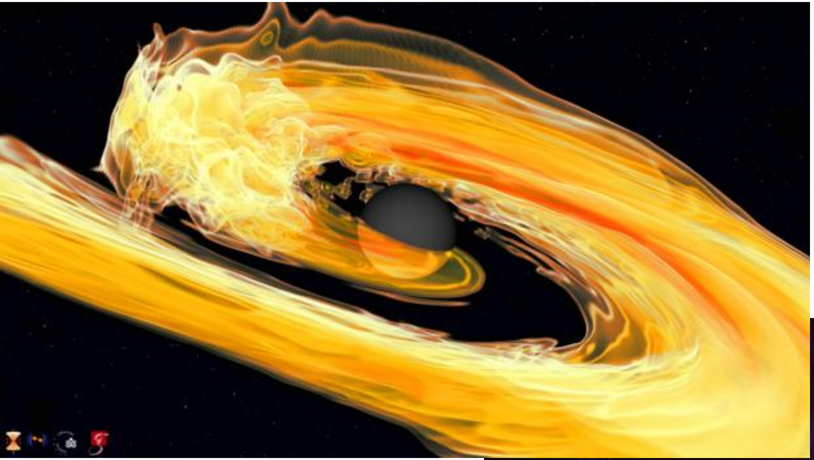




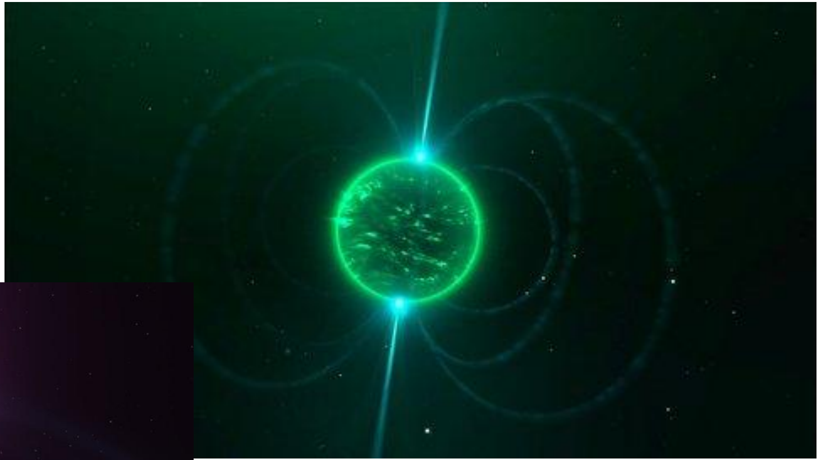


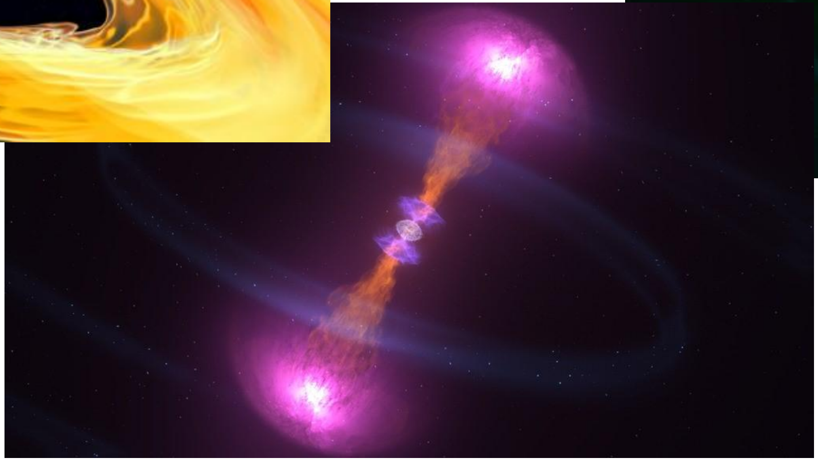
Everything else

NSBH mergers: tidal disruption?



Continuous GWs: NS ellipticity?





Kilonova counterparts: ejecta & chemical evolution

Challenges for next-generation science

Simulations vs waveforms

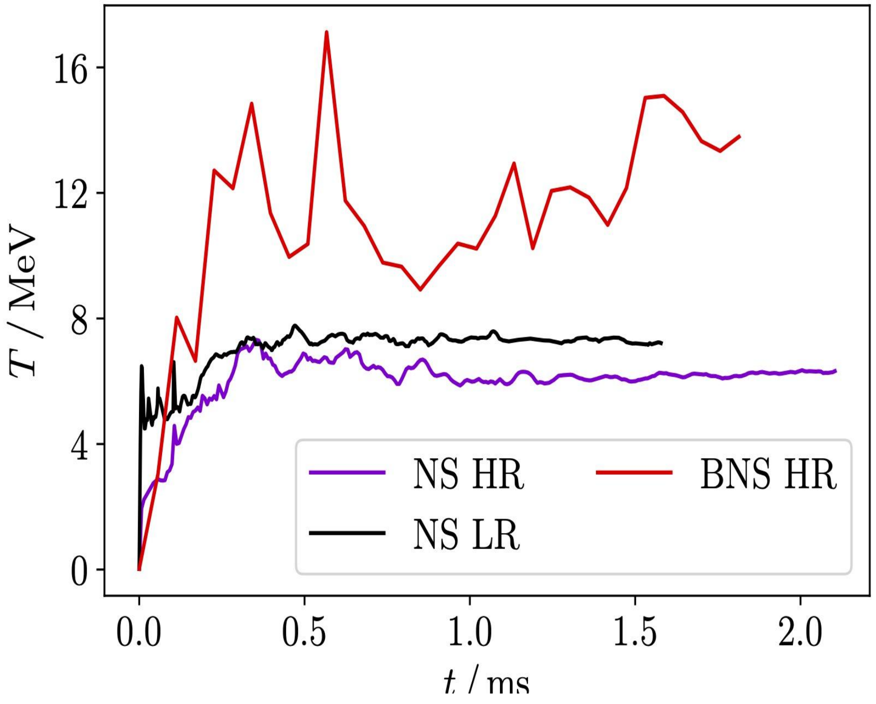
Progress may be limited by theoretical waveform models.

Statistical vs systematic/modelling errors, leading to calibration uncertainties.

Example: Temperature problem.

Are we missing important physics? Crustal effects, exotic phases/phase transitions, etc

How much of this can we "ignore"?



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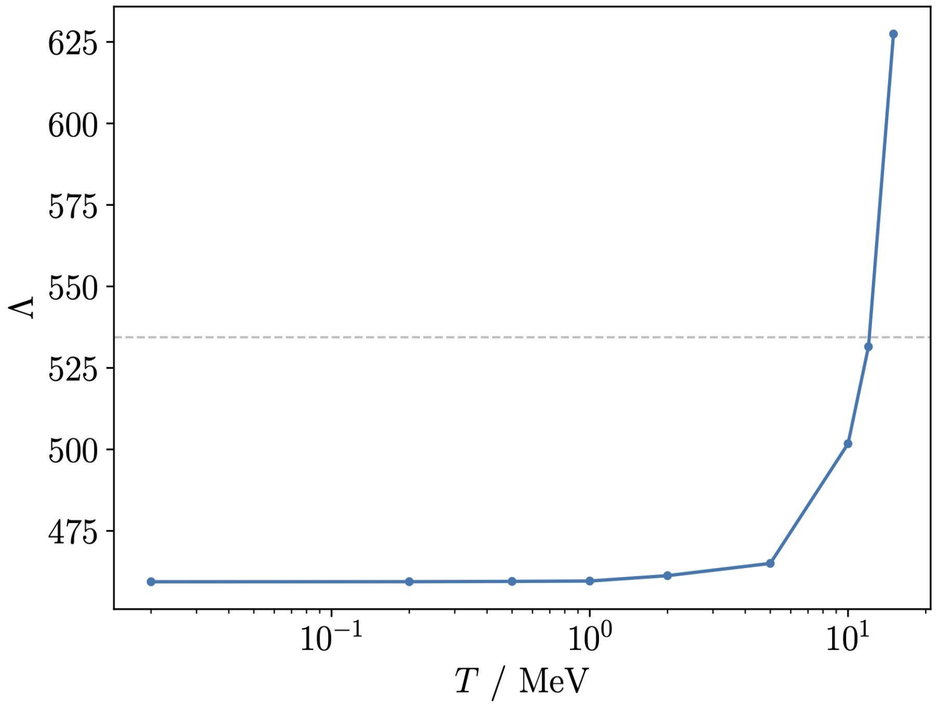


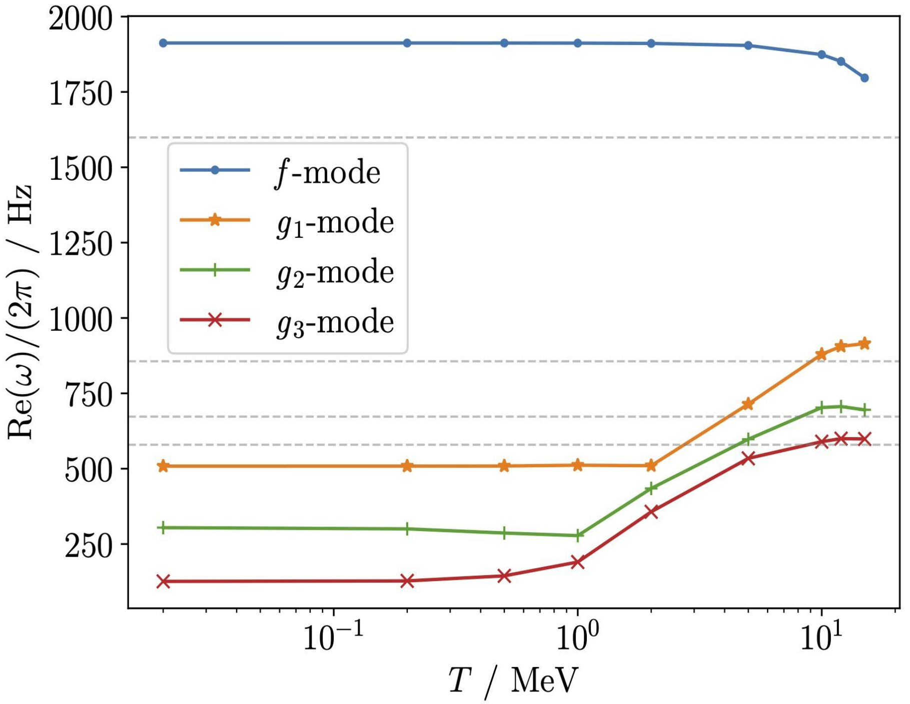
Tidal effects

Do we understand dynamical/nonlinear tides?

Resonance of fundamental f-mode dominates...

...but p/g instability, individual g-modes (composition), inertial modes (rotation), viscosity (temperature) etc.

Also, tidal response not (yet) calculated in GR, so cannot model for real EoS.



Post-merger signals

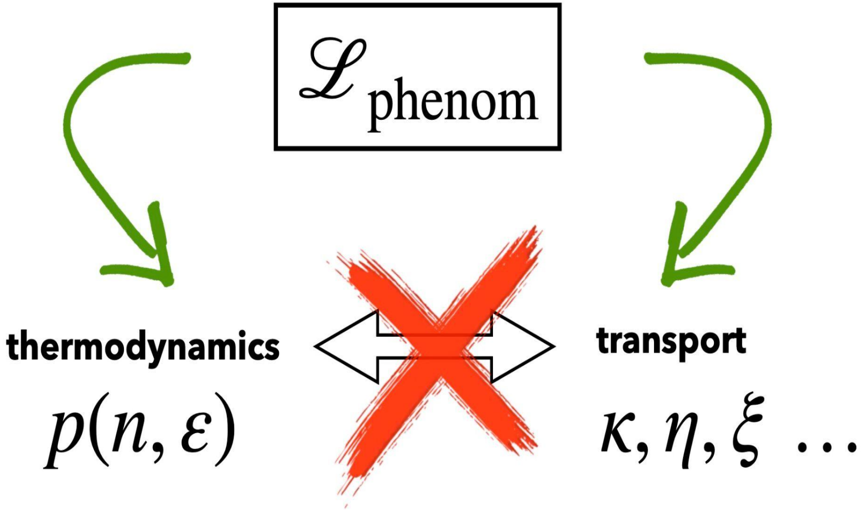
How reliable/robust are simulations?

Importance of temperature and neutrino effects + other physics (MHD+resistivity)

Impact of turbulence (large-eddy schemes).

“EoS not EoS” + statistical convergence…

What EoS should we use?



Can we converge towards common/ comparable, perhaps phenomenological) models?

Talking points

Do we need to resort to “phenomenological” models?

What quantities do nuclear physicists care about?

What kind of “data product” would be the most useful?

Should we think of this as an “experimental” problem?

Talking points

Do we have the analysis tools needed for XG EOS inference?

Will (dark?) NSBH mergers be an important source for learning about nuclear physics in the XG era?

How do EM observations of neutron stars complement GWs?

What will we learn about chemical evolution in the XG era?