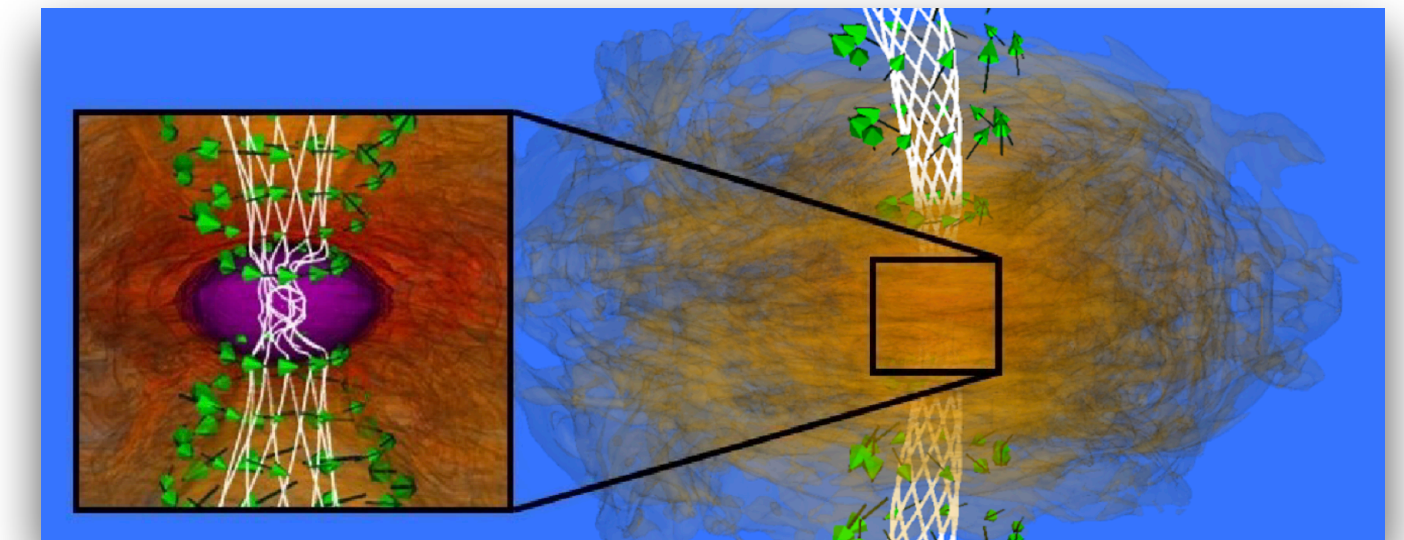


# Post-merger gravitational wave signals from binary neutron stars: Effect of the magnetic field

Milton Ruiz  
University of Valencia  
[milton.ruiz@uv.es](mailto:milton.ruiz@uv.es)

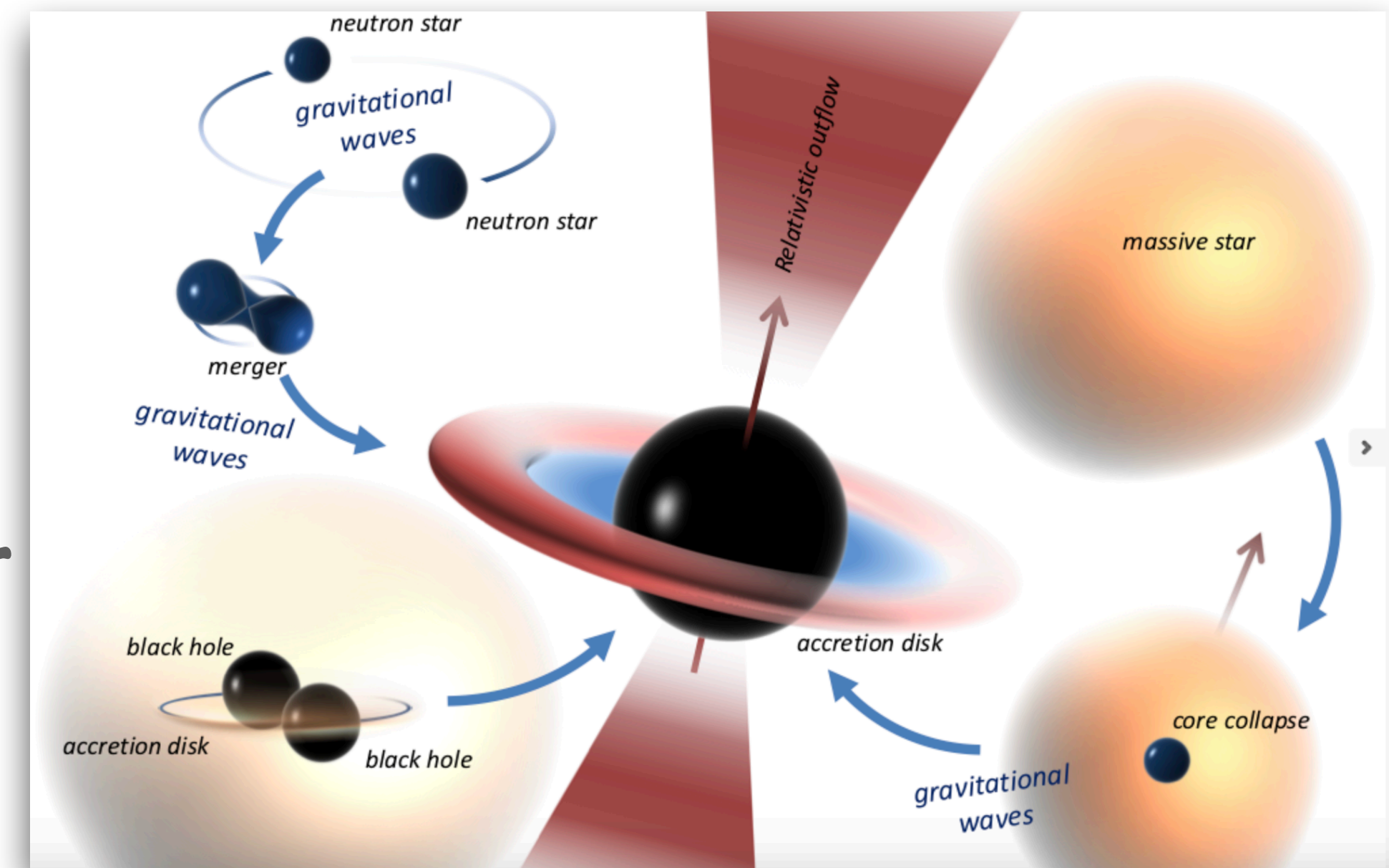


arXiv:2411.00943/2411.00939

In collaboration with J. Bamber, A. Tsokaros, & S. Shapiro

# Physics to infer from binary neutron star mergers

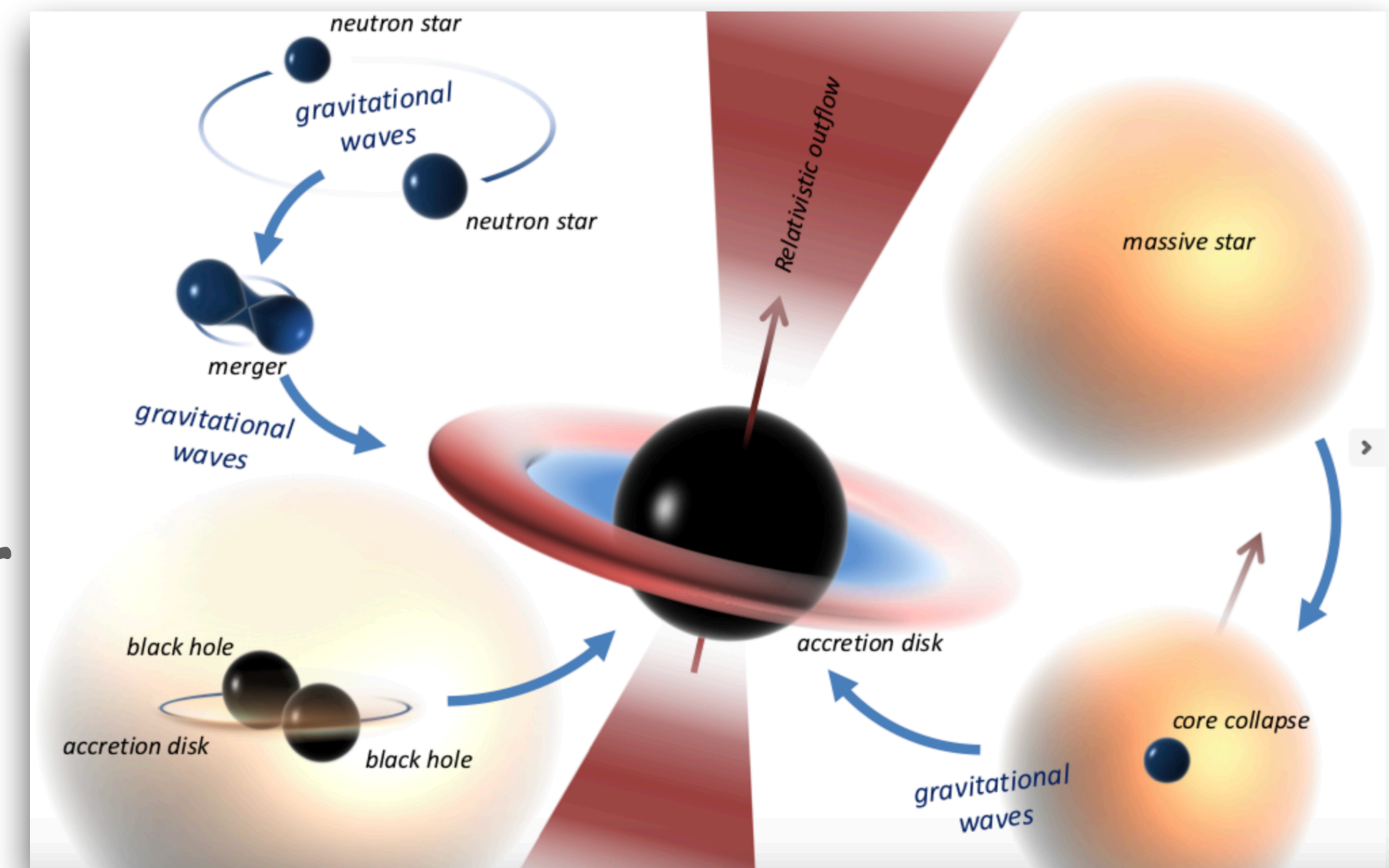
- \* **Gravitational wave physics:** Binary neutron stars (BNSs) among strongest sources.
- \* **GRB physics:** Central engine of short Gamma-Ray Bursts → BNS merger + GRB association.
- \* **Cosmology:** Measure of Hubble parameter with GW information (BNSs as standard sirens).
- \* **Nuclear physics:**
  - Laboratory to study high-density physics:
  - key to decipher EoS
  - nucleosynthesis of heavy elements



Bartos '17

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  - **nucleosynthesis of heavy elements**



Bartos '17

# Equation of State for neutron stars

\* **Constraining the EoS (spherical NS):**

A. Margalit and Metzger '17: **Kilonova observations + GWs**

$$M_{\max} \lesssim 2.17 M_{\odot}$$

B. Shibata et al. '17: **Neutrino arguments**

$$M_{\max} = 2.15 - 2.25 M_{\odot}$$

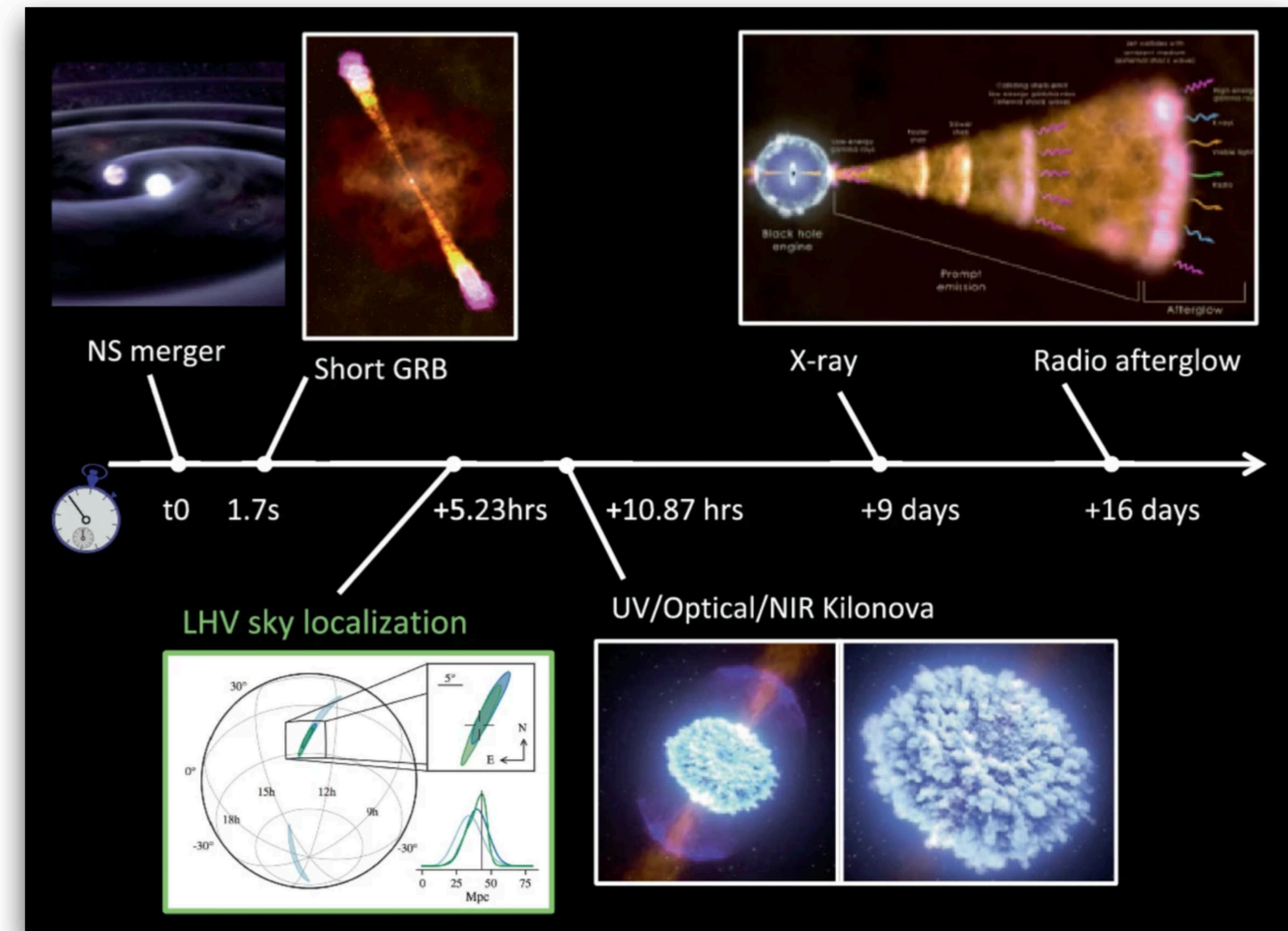
C. M.R. et al. '17: **sGRBs arguments**

$$M_{\max}^{\text{sph}} \lesssim 2.16$$

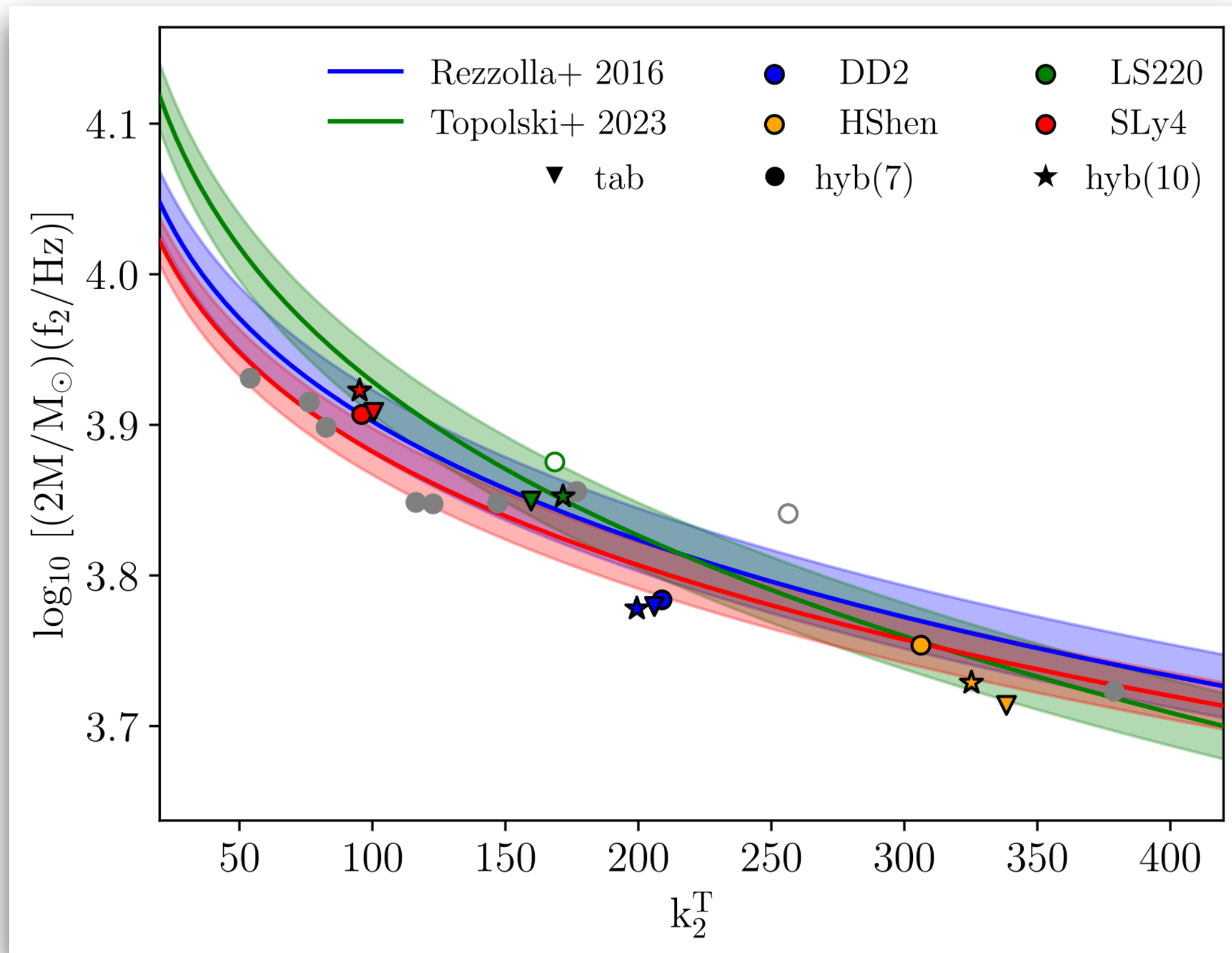
D. Rezzolla et al. '17: **Combining GWs + quasi-universal relations**

$$M_{\text{TOV}} / M_{\odot} \lesssim 2.16^{+0.17}_{-0.15}$$

## GW170817 + EM counterparts

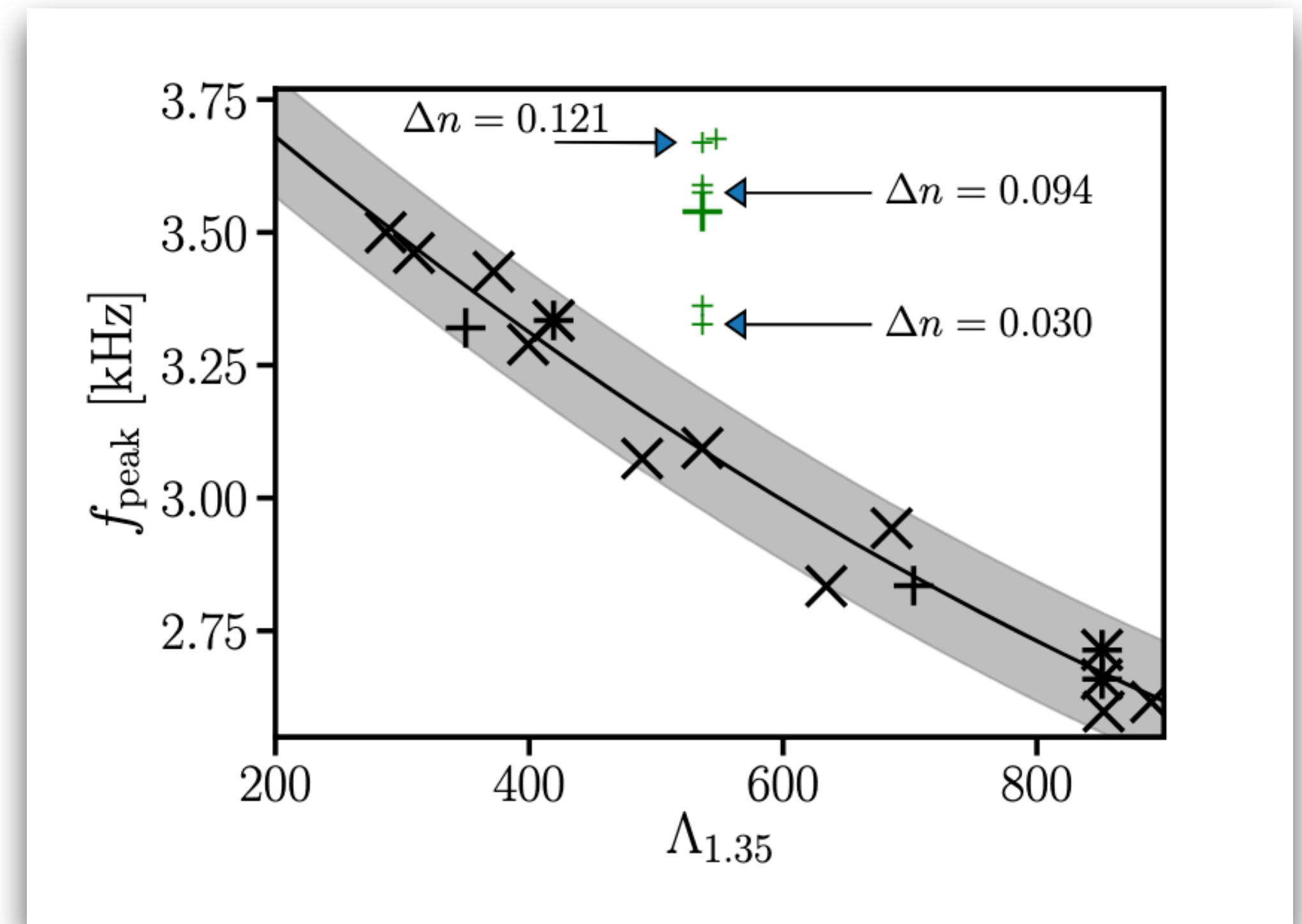


# Equation of State for neutron stars



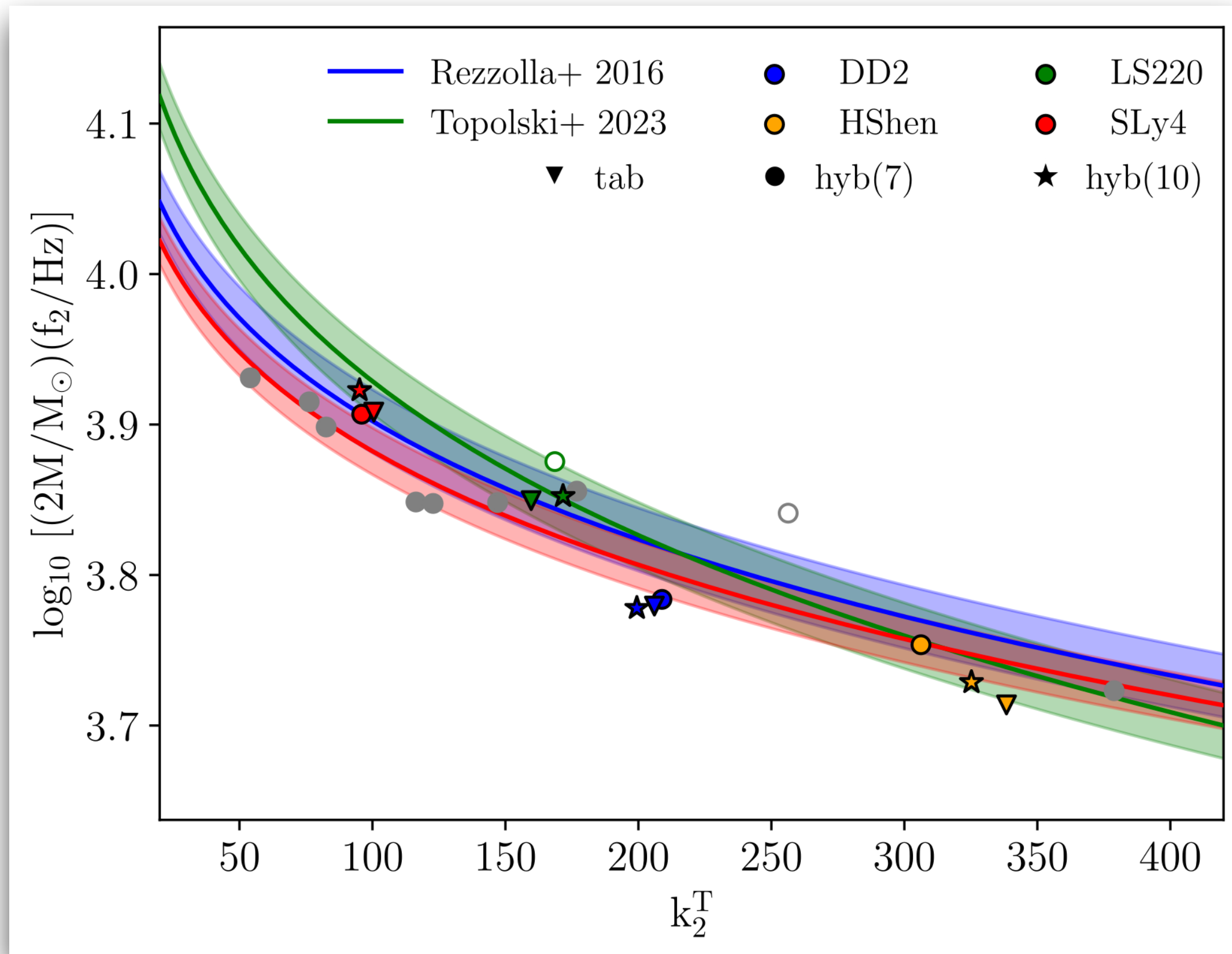
Guerra, M.R. et al. in prep.

Using GW observations + quasi-universal relations:  
**obtain the stellar radius and the compactness**



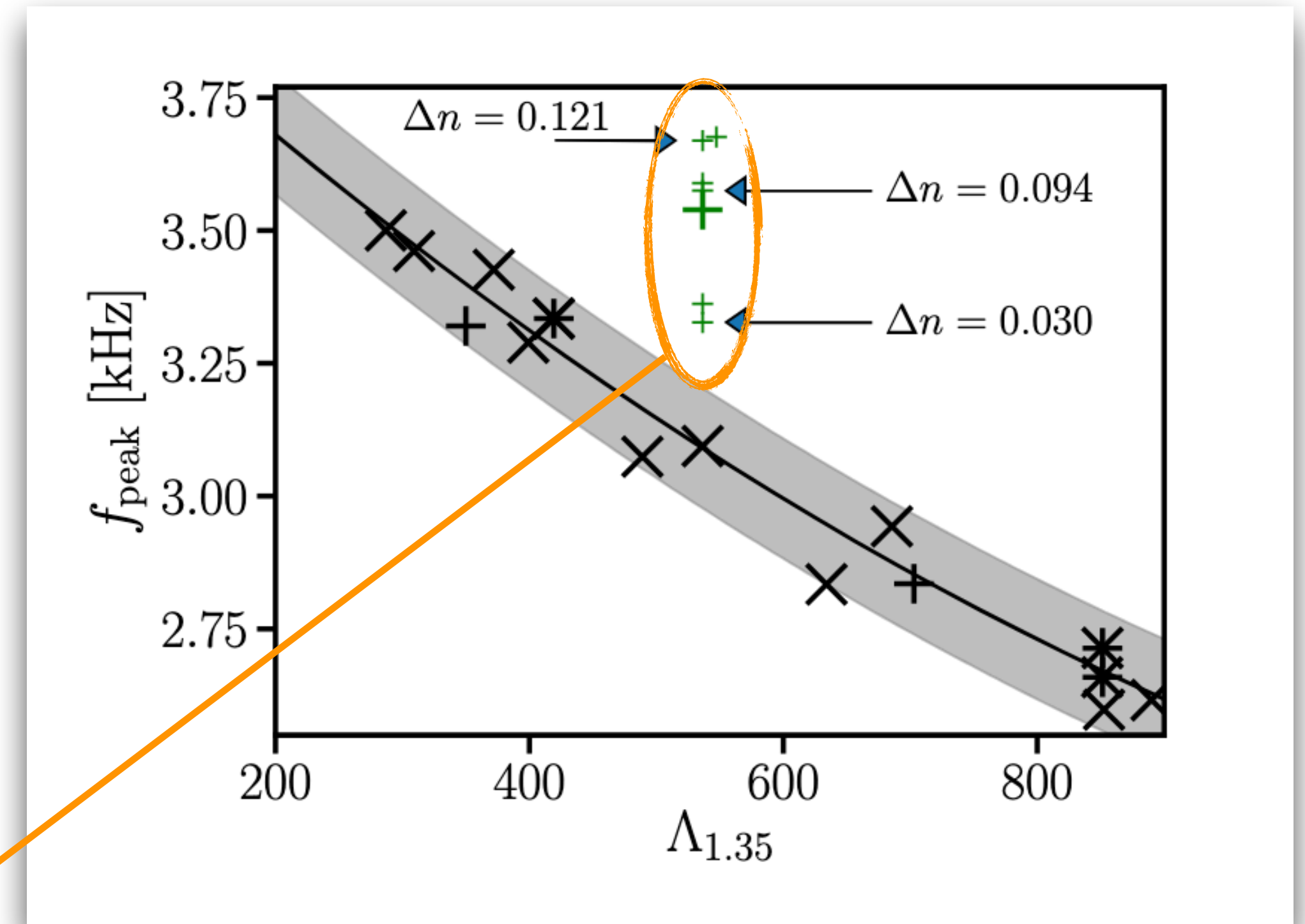
Bauswein et al. '19

# Equation of State for neutron stars



Guerra, M.R. et al. in prep.

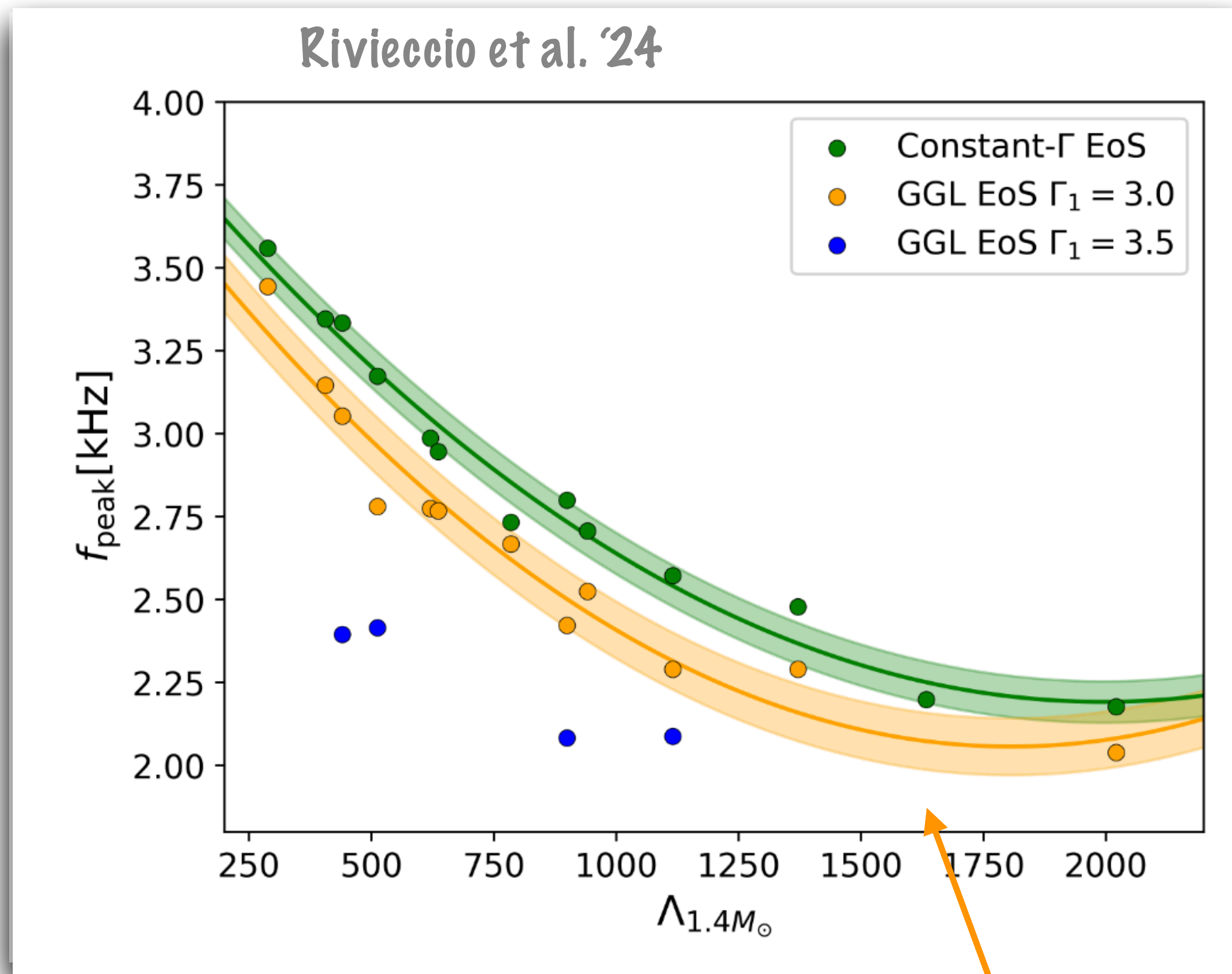
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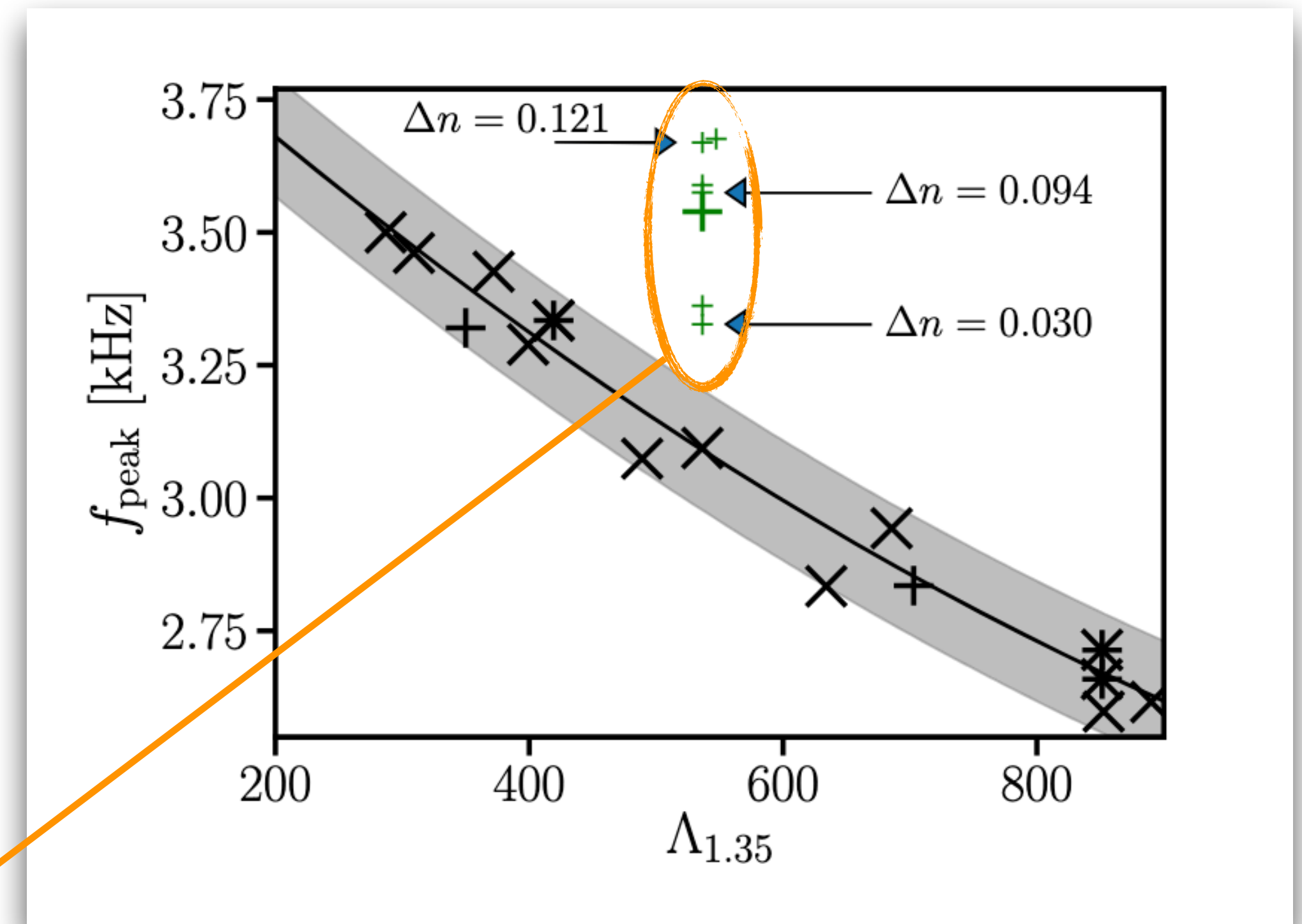
Bauswein et al. '19

First order  
phase transition

# Equation of State for neutron stars



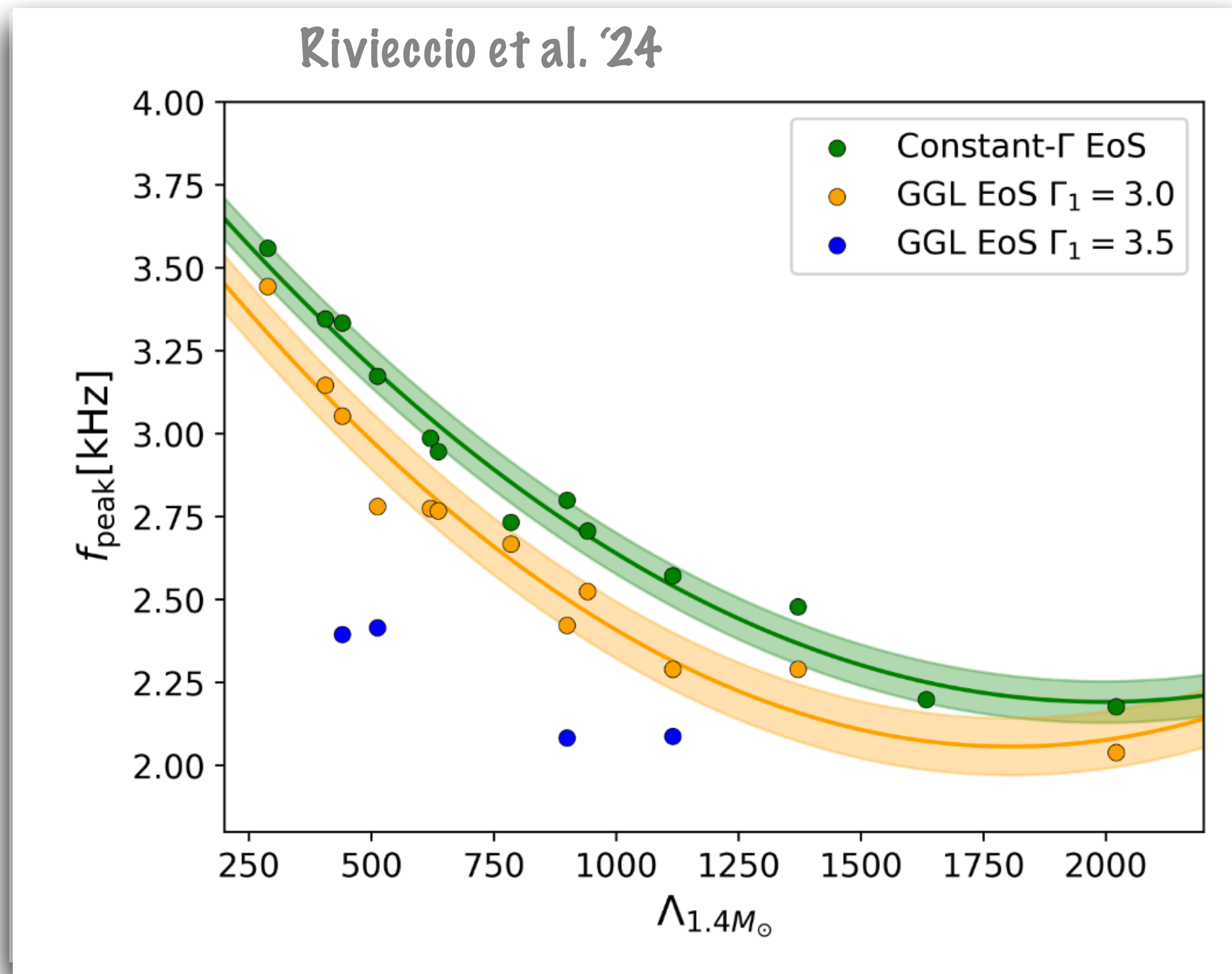
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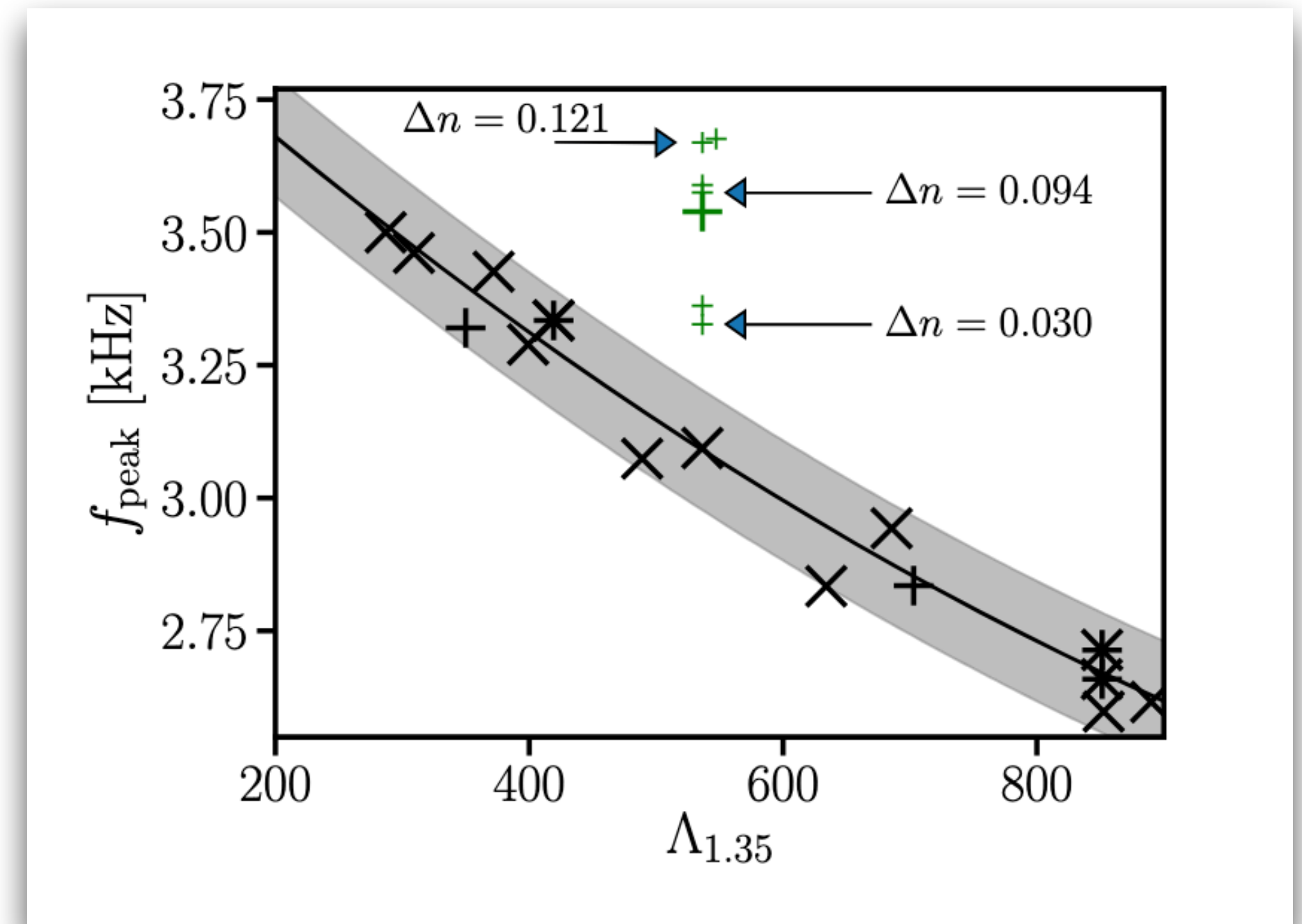
Bauswein et al. '19

**Non-convex dynamics:** appearance of expansive shock and compressive rarefactions waves

# Equation of State for neutron stars



Using GW observations + quasi-universal relations:  
**obtain the stellar radius and the compactness**

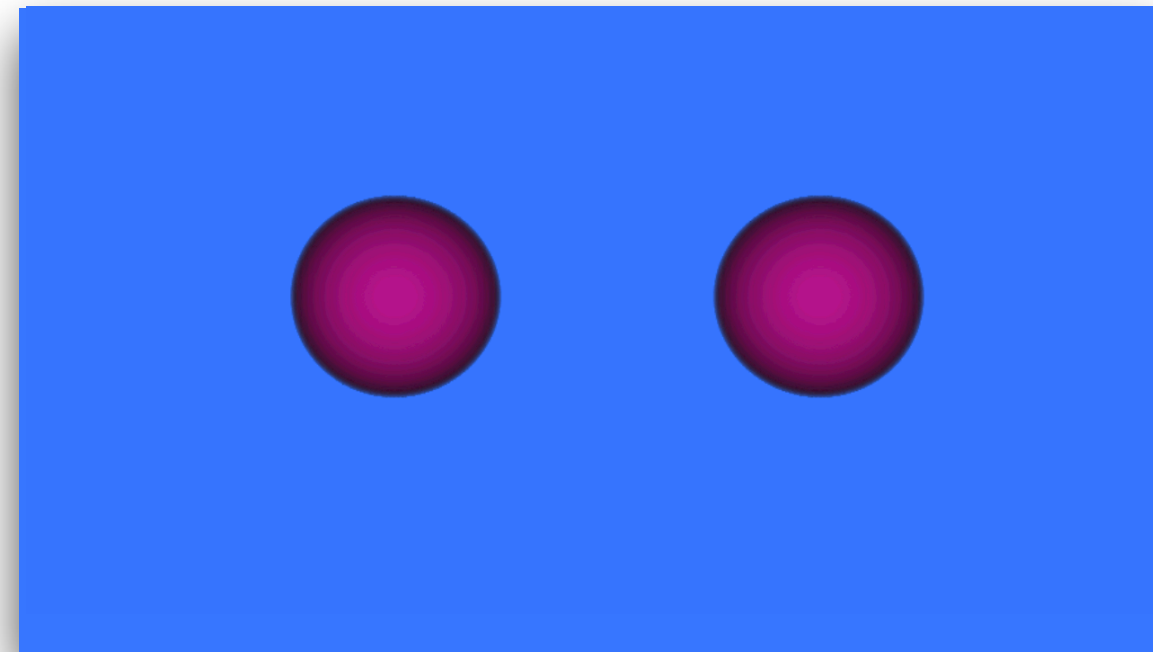


Bauswein et al. '19

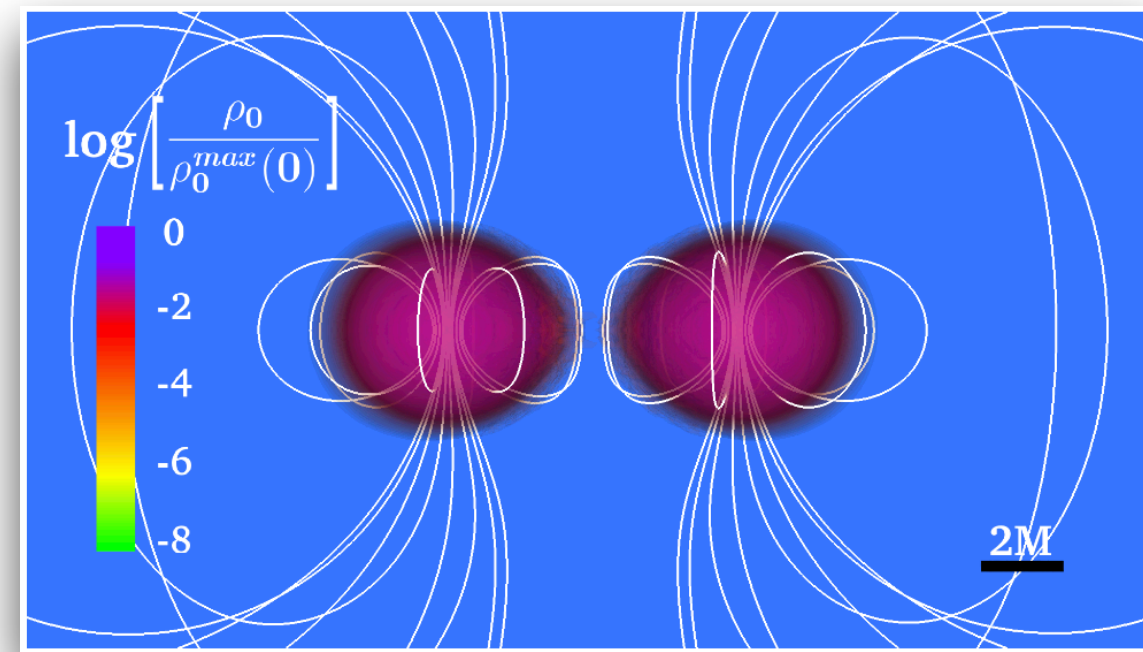
What's the effect when  $\mathcal{B}$ -fields or microphysics are incorporated?

# Neutron star binary mergers

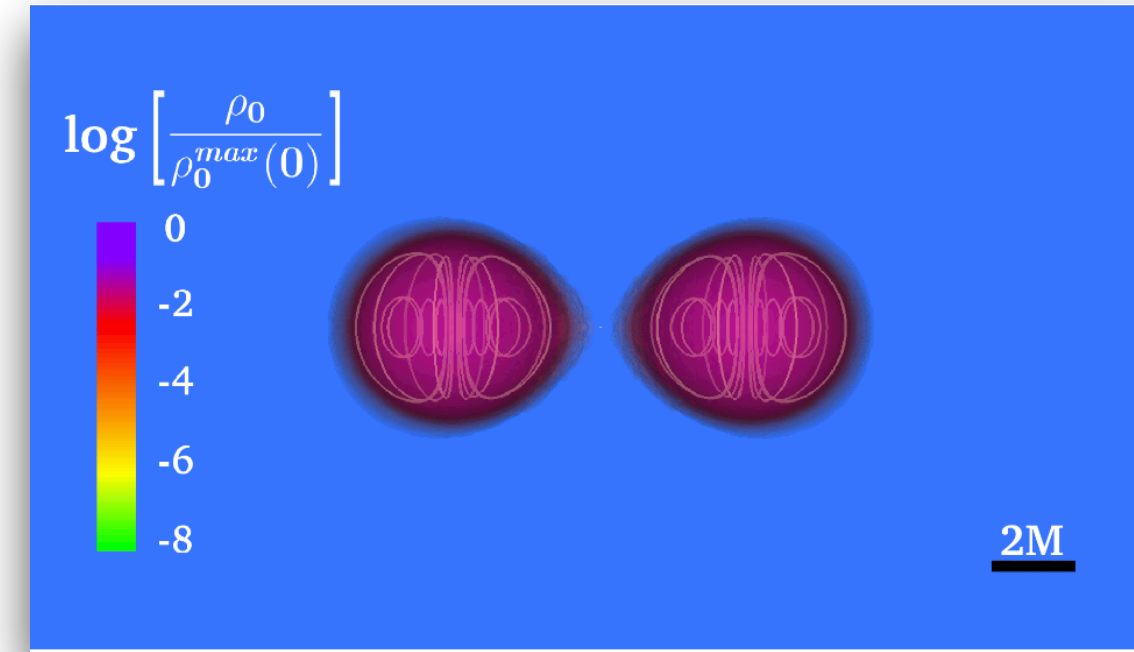
non-magnetized



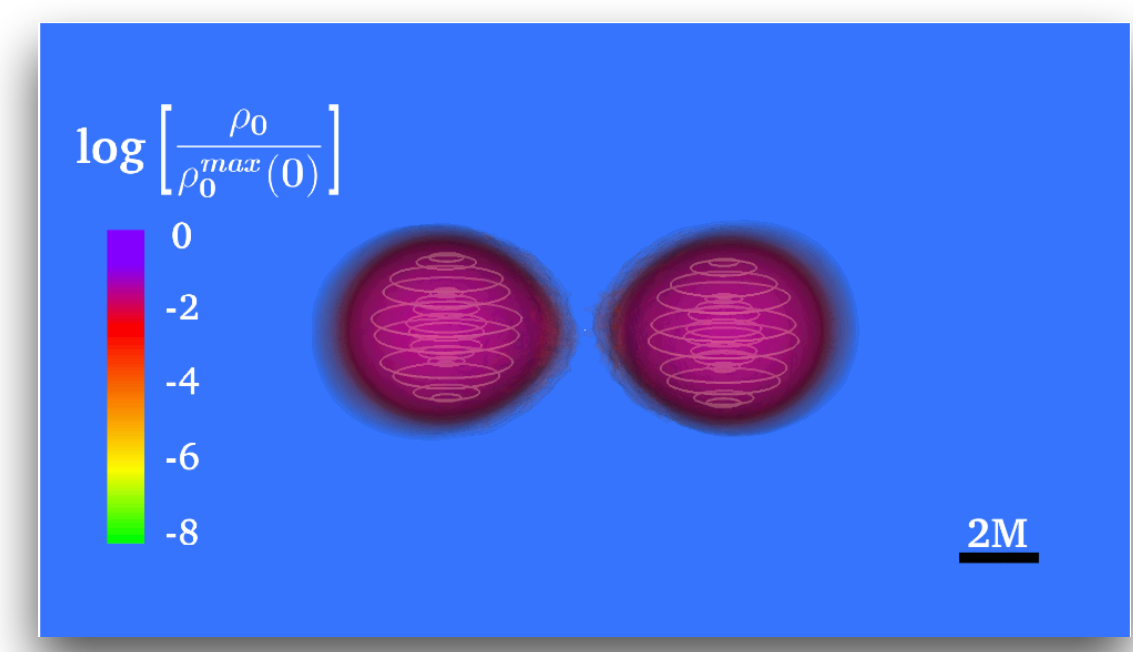
Pulsar-like



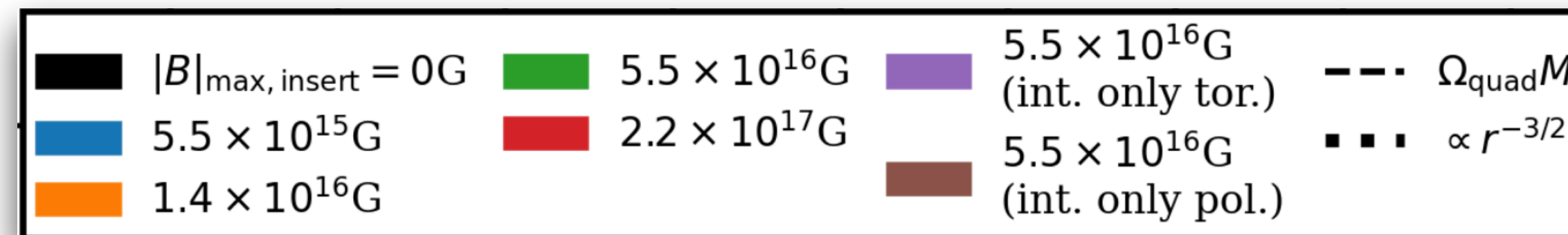
Poloidal



Toroidal



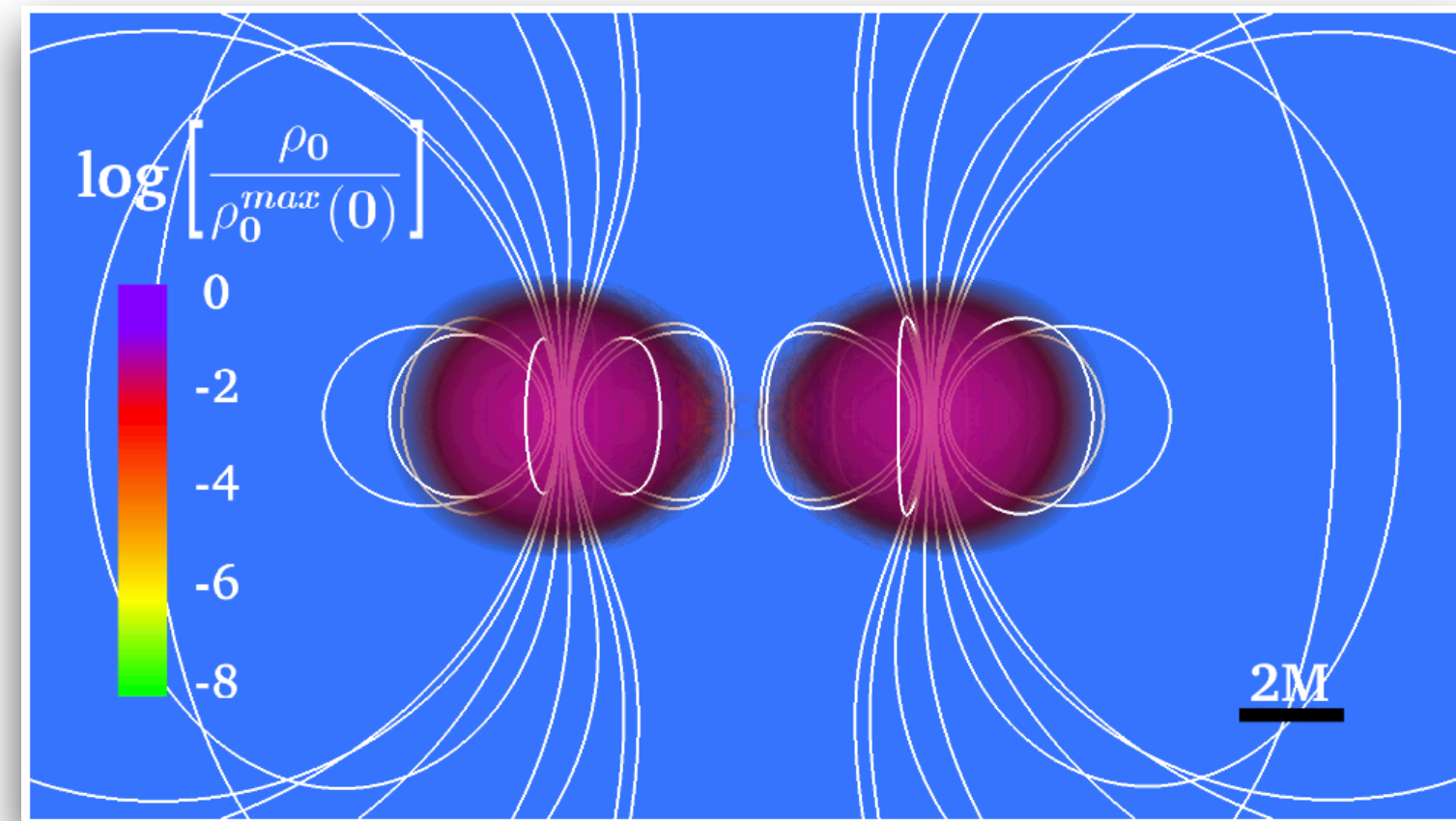
Bamber et al. '24



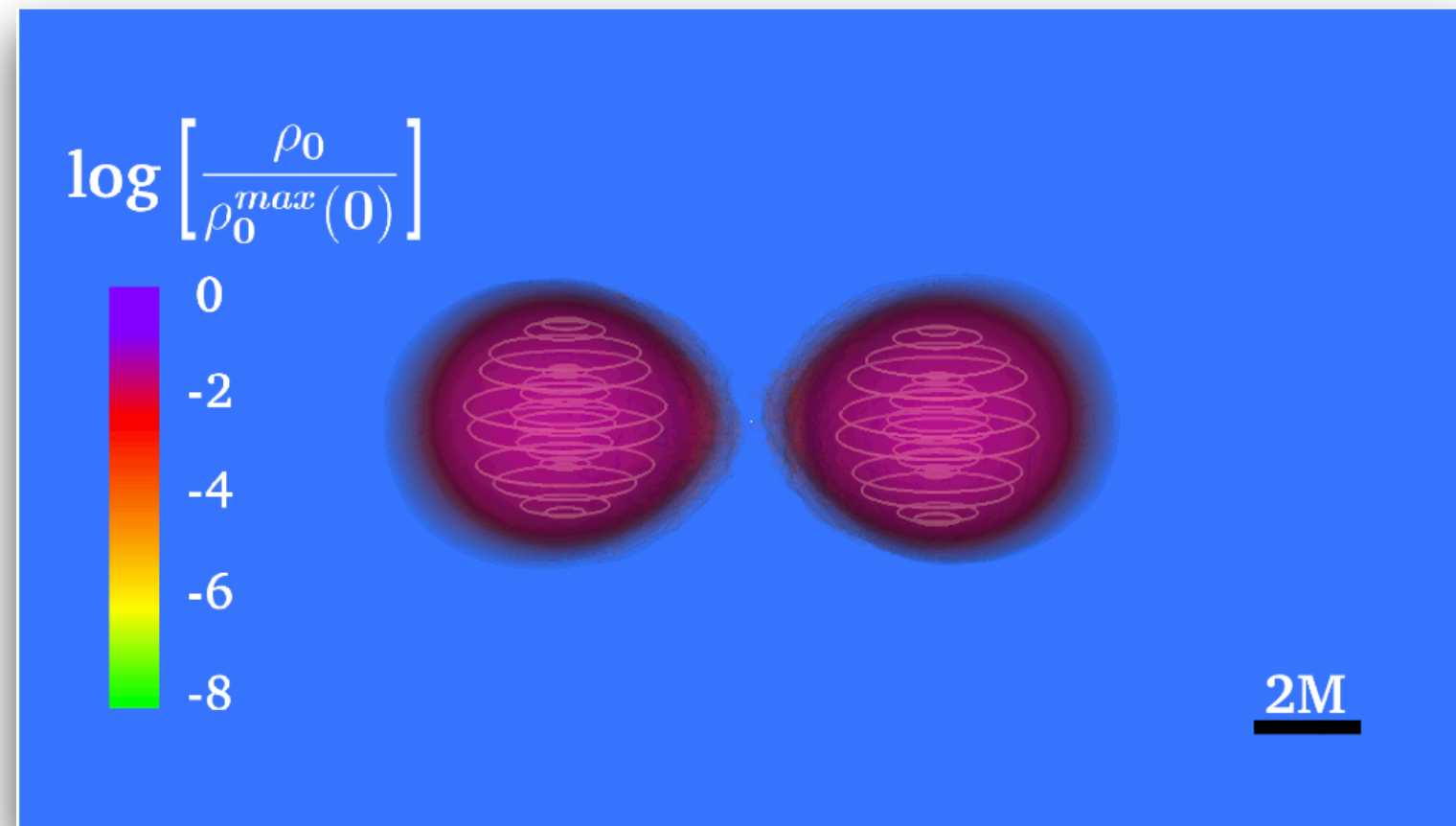
Effect of the B-field on the main GW peak

# Neutron star binary mergers

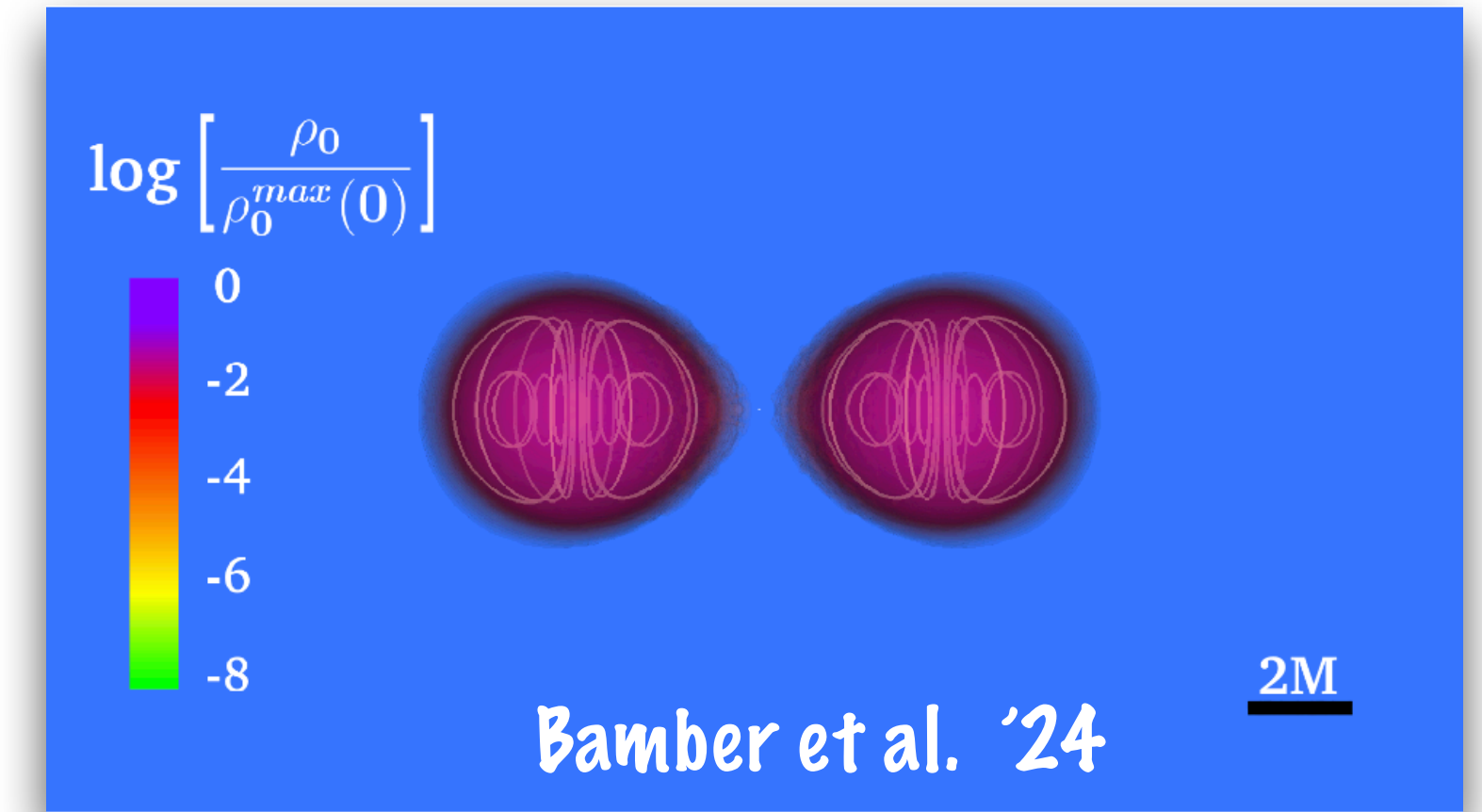
Pulsar-like



Toroidal



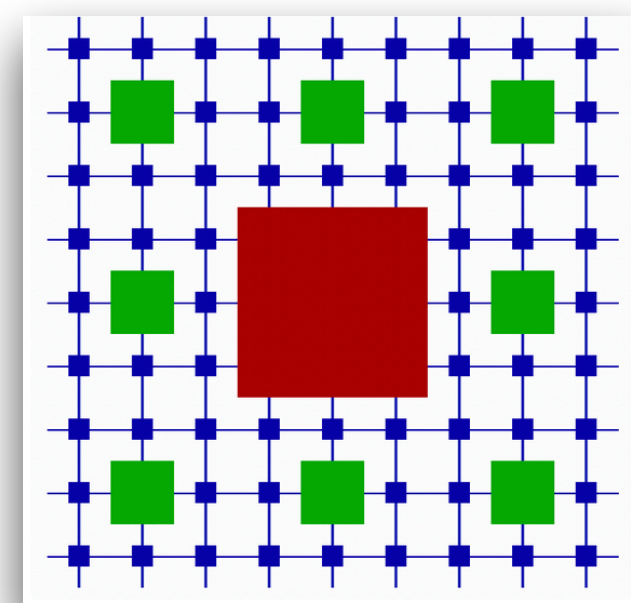
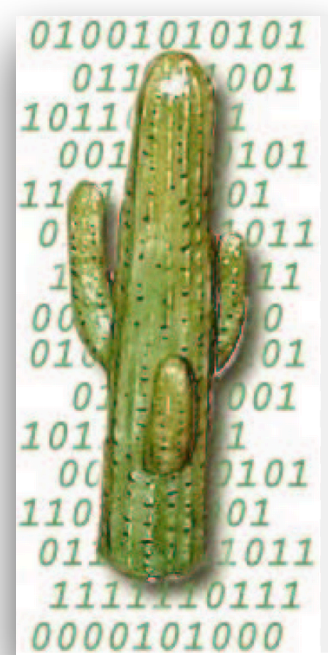
Poloidal



## Tools:

- Illinois GRMHD:

Cactus code + Carpet



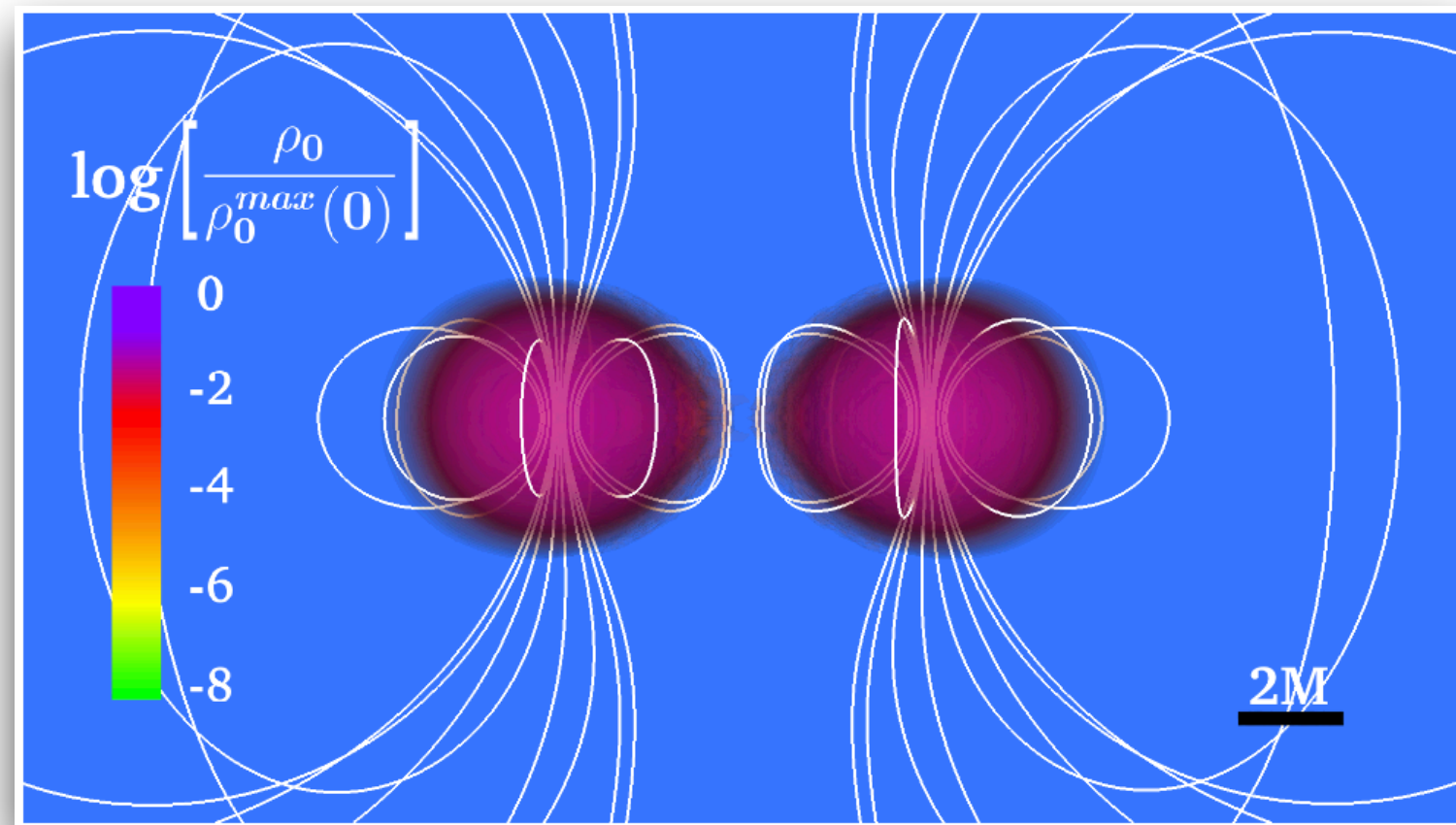
\* NSs are modeled using a piecewise representation of the EoS

\* BSSN formulation + puncture gauge

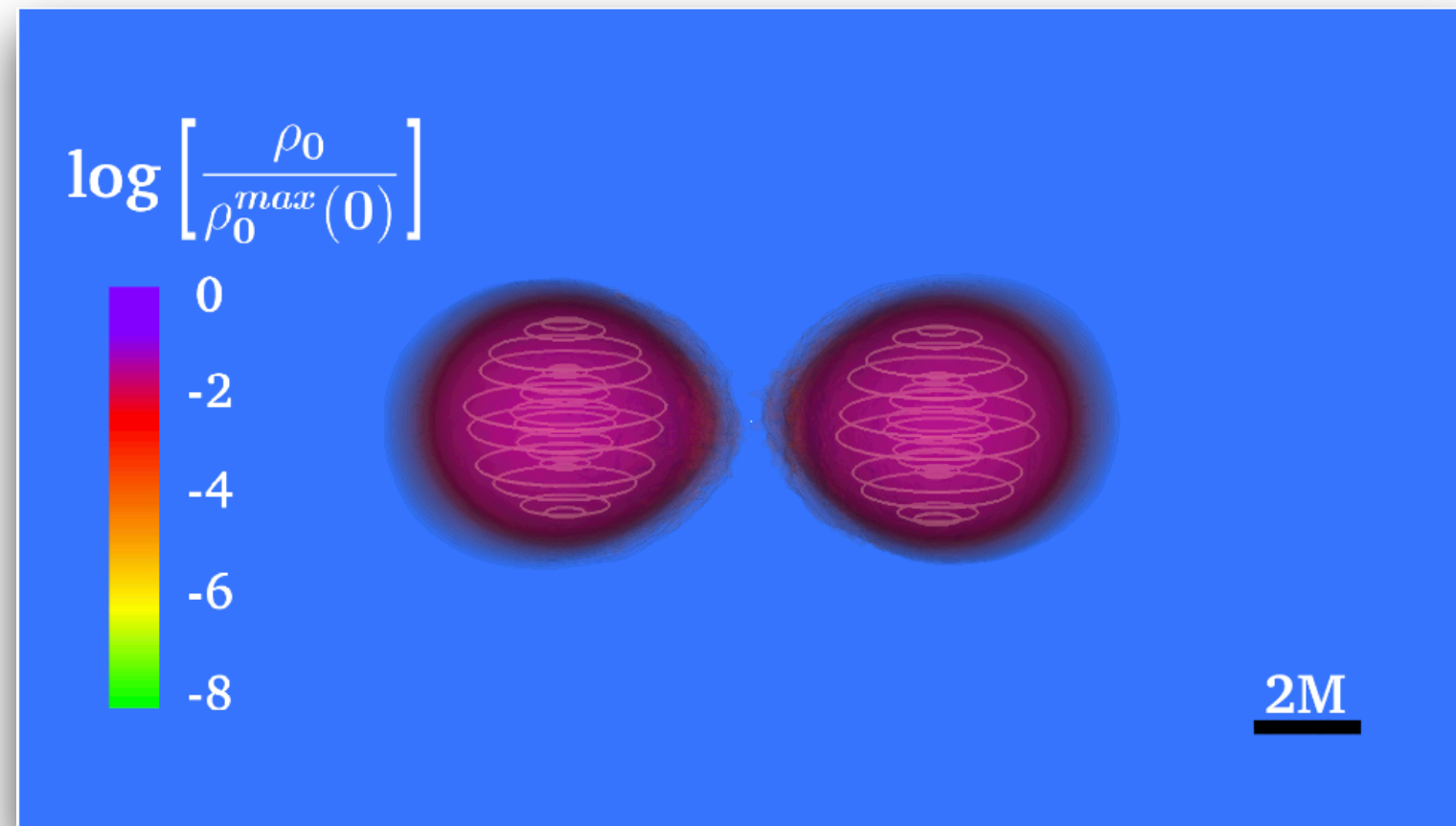
\* Ideal magnetohydrodynamics

# Neutron star binary mergers

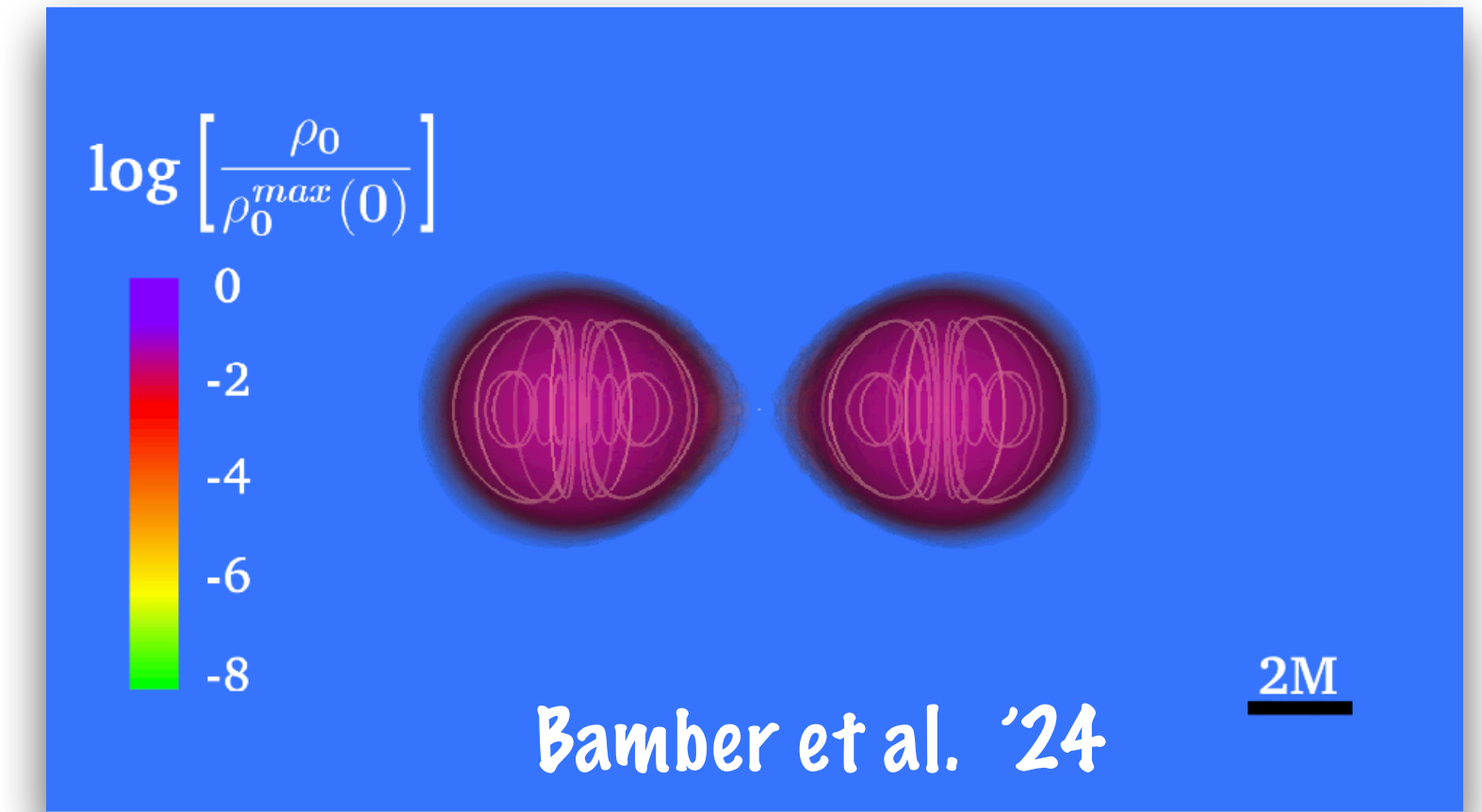
Pulsar-like



Toroidal

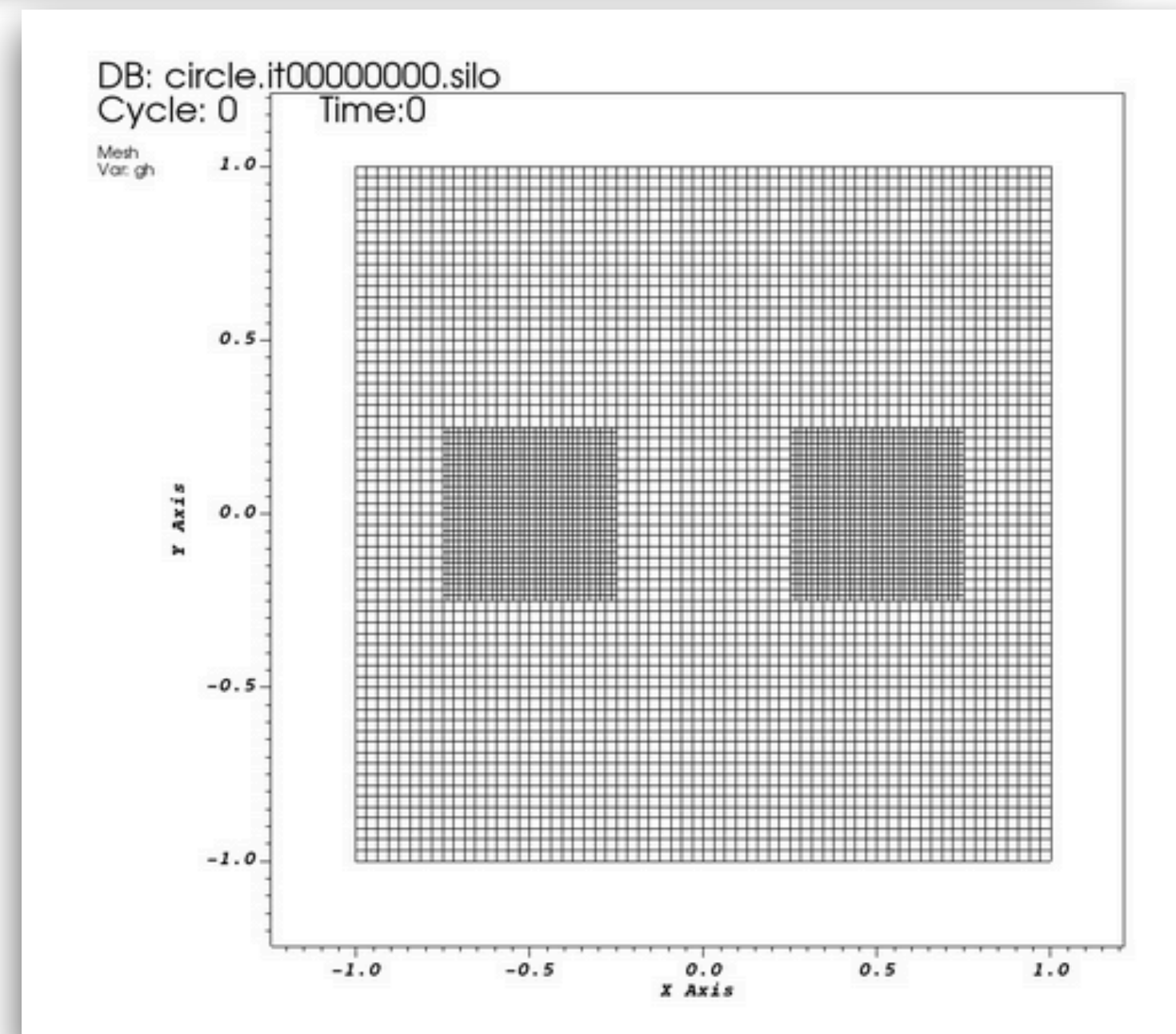
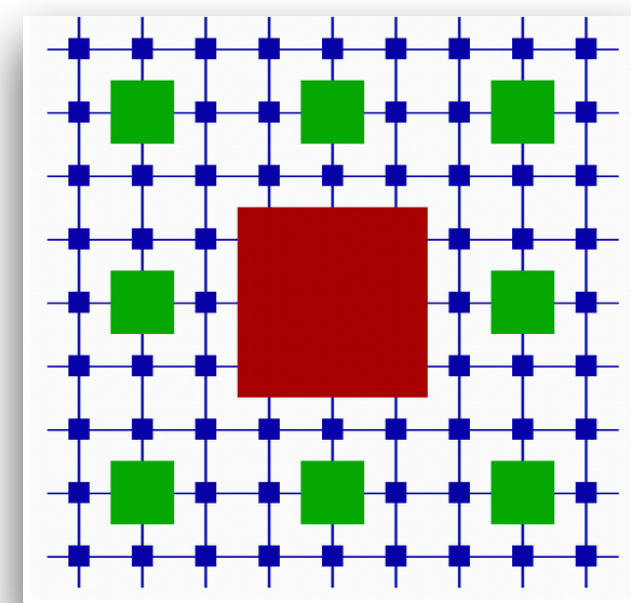
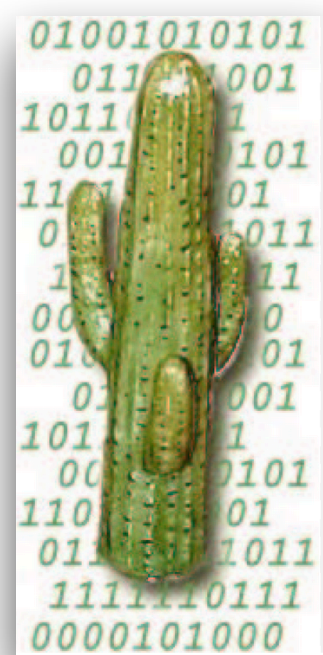


Poloidal

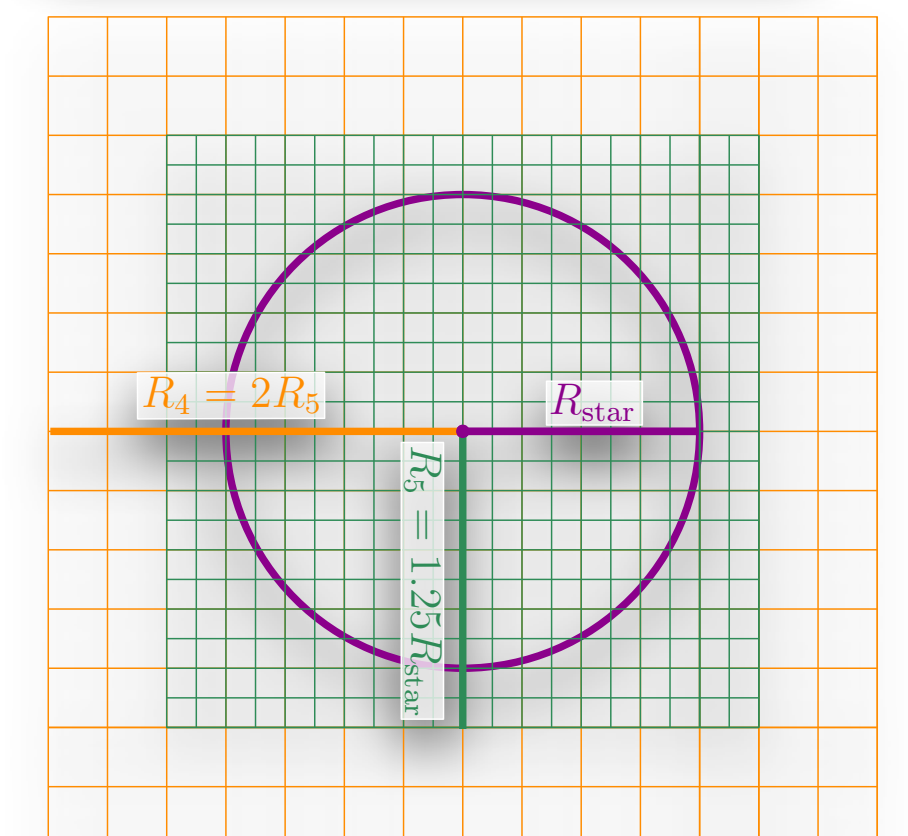


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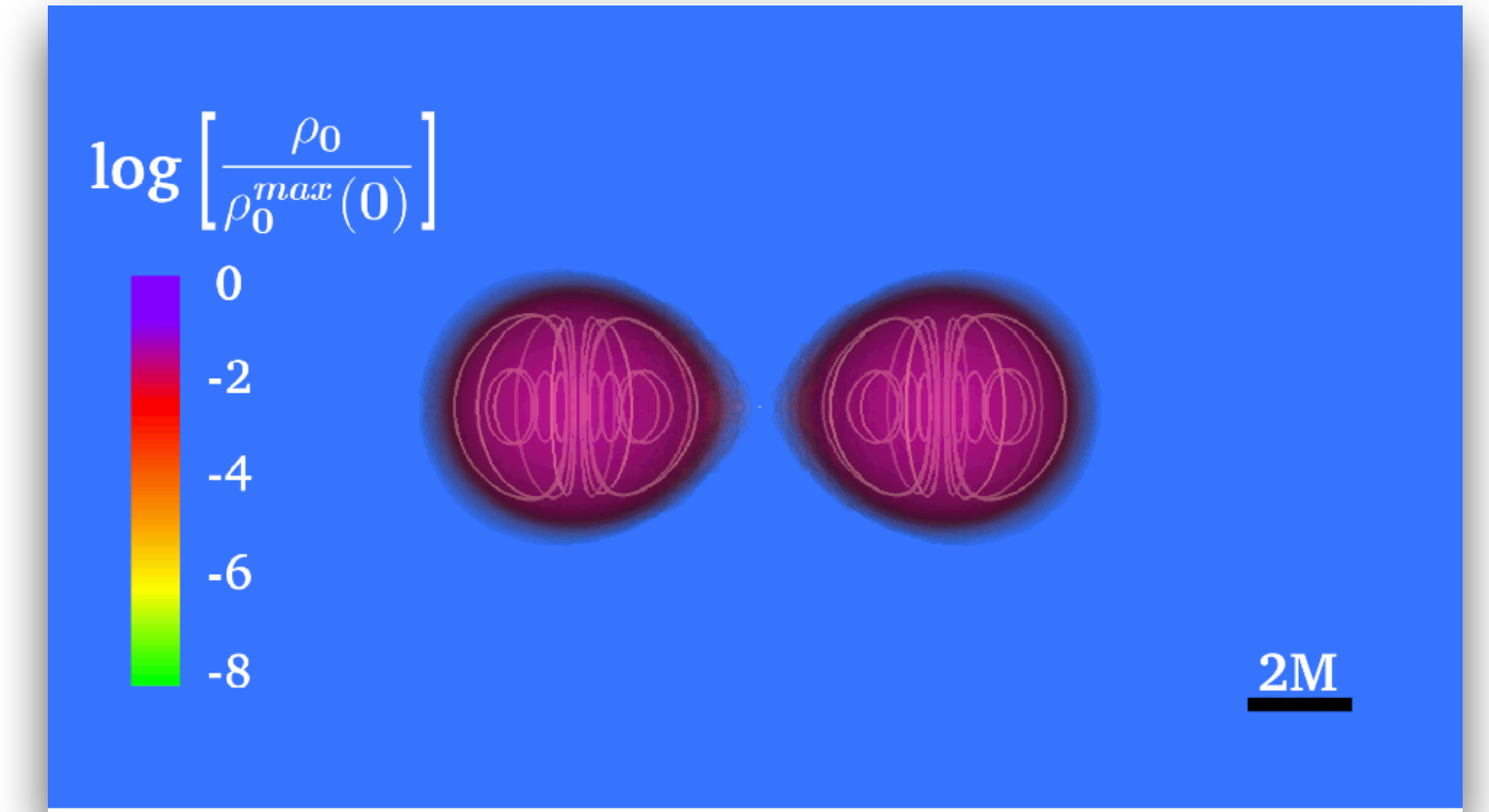
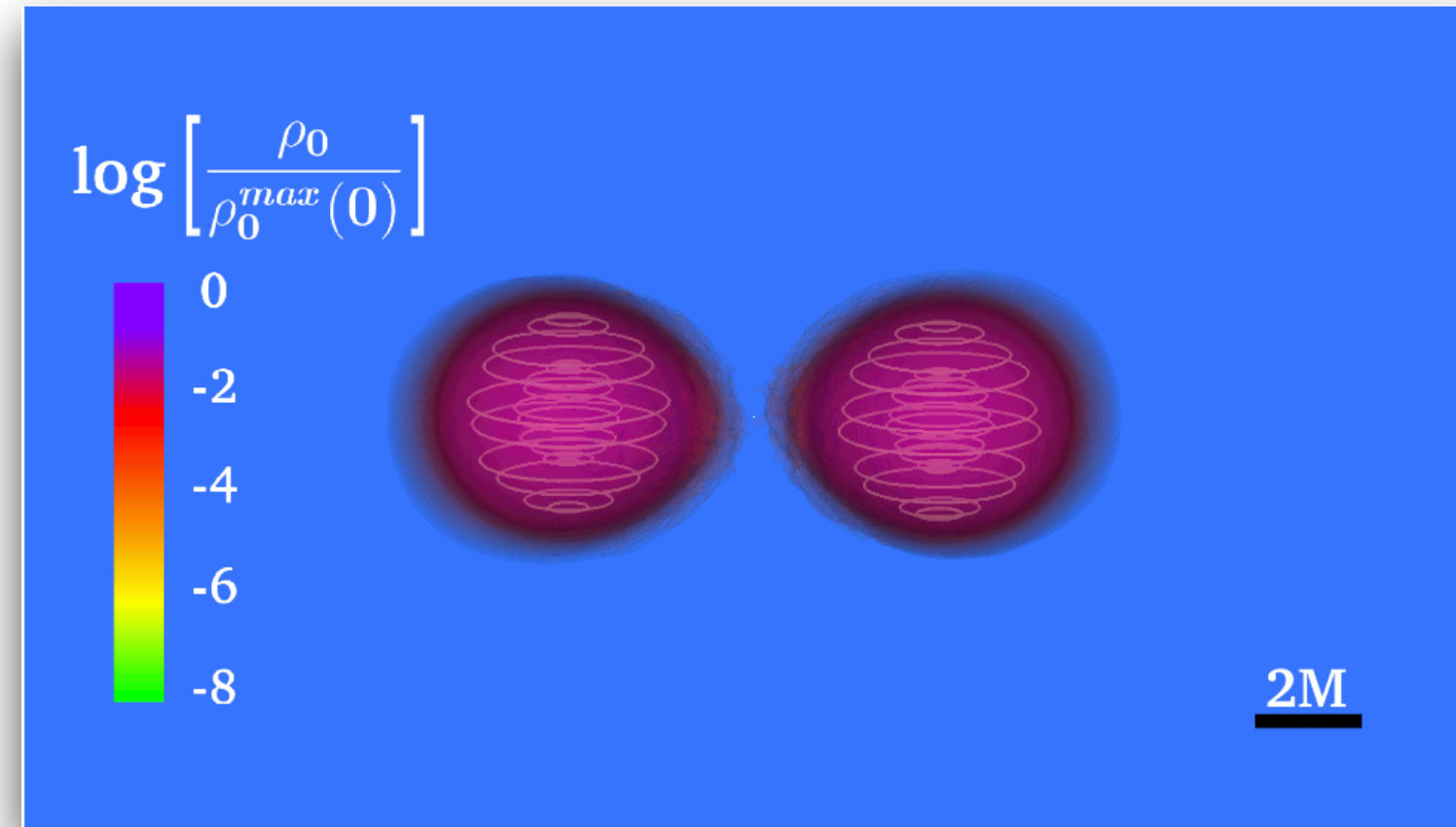
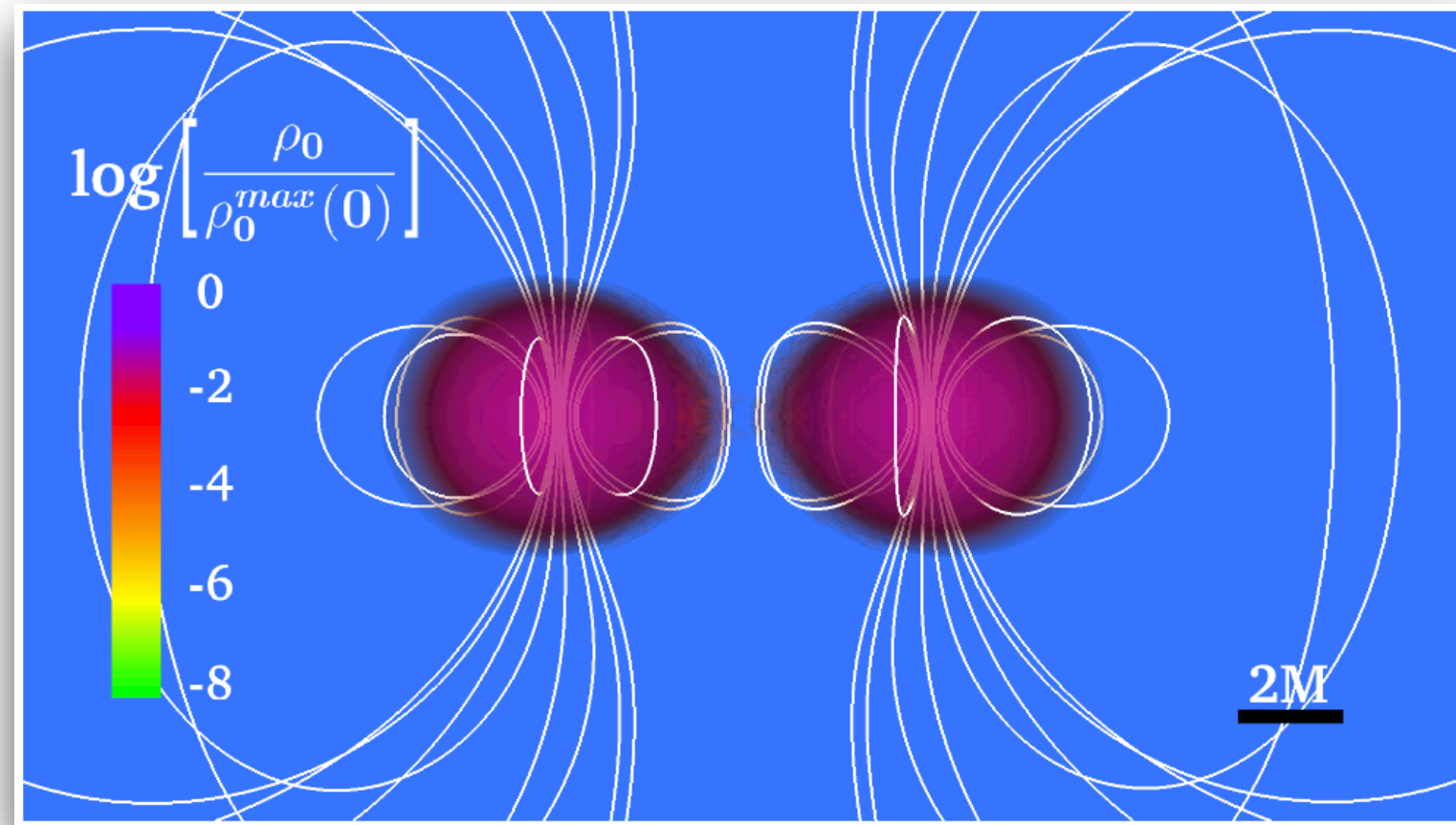


$$\Delta x_{\min} = 90\text{m}$$

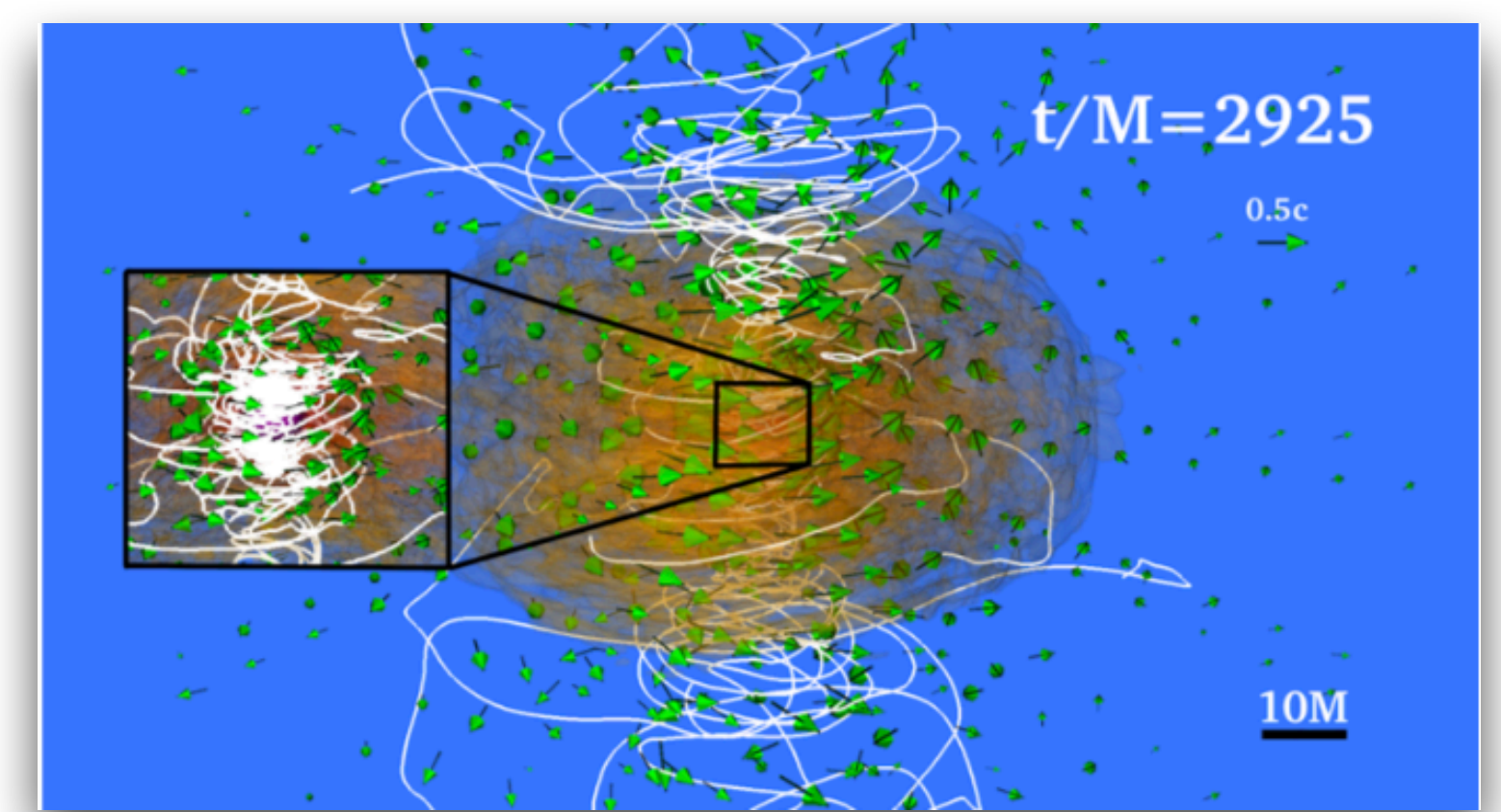
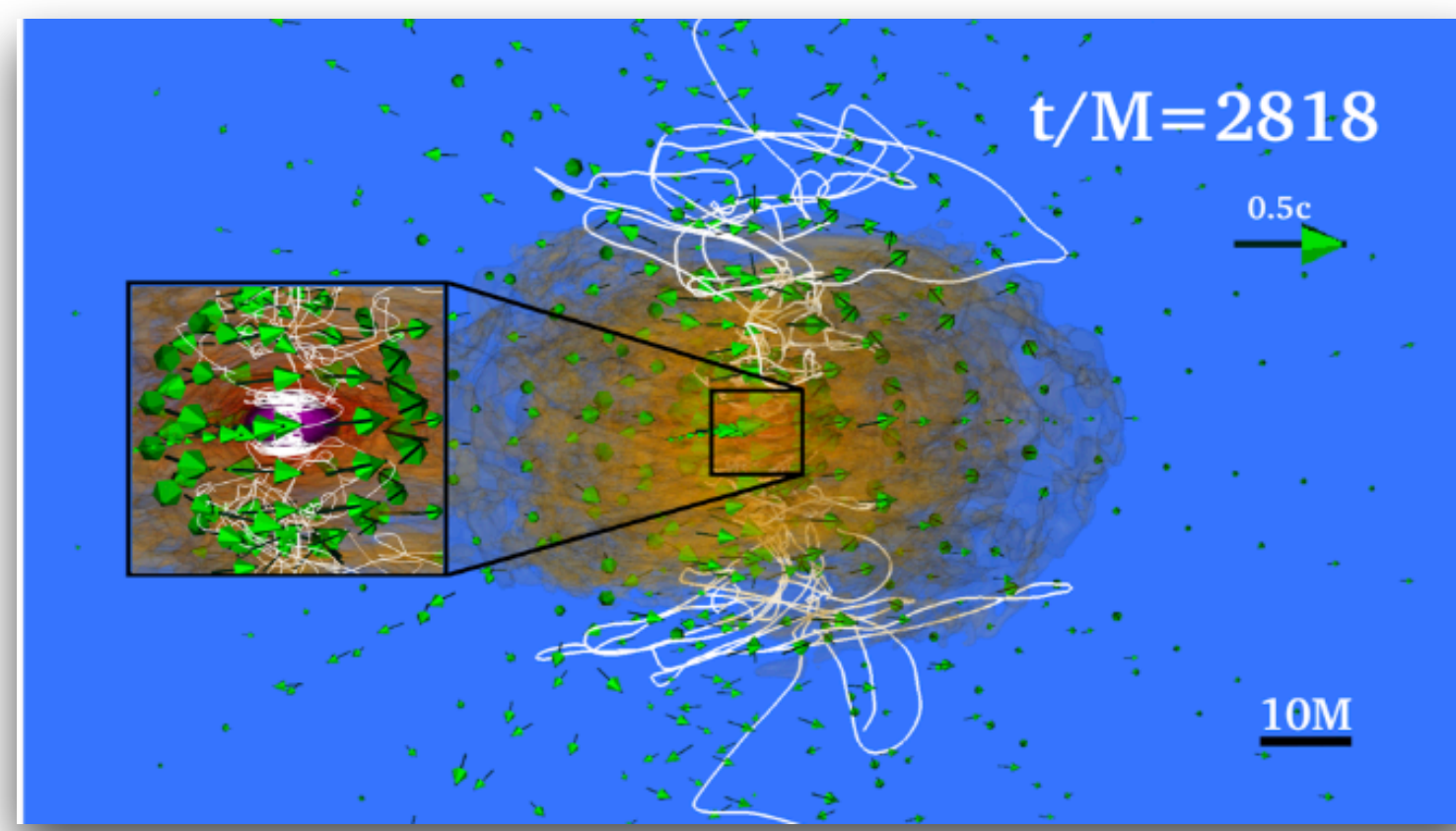
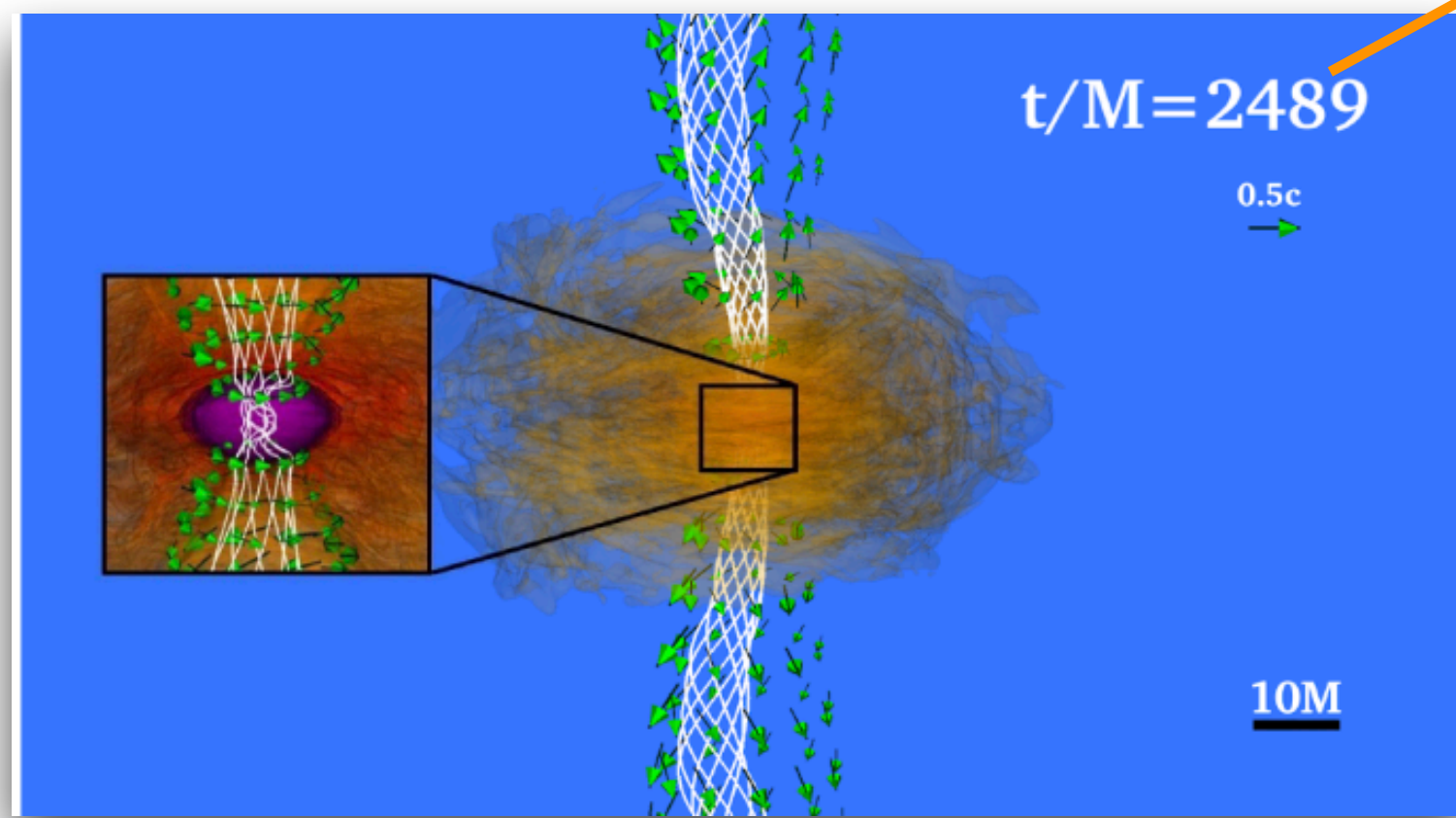


Guerra, M.R. et al. in prep.

# Neutron star binary mergers: EM counterparts



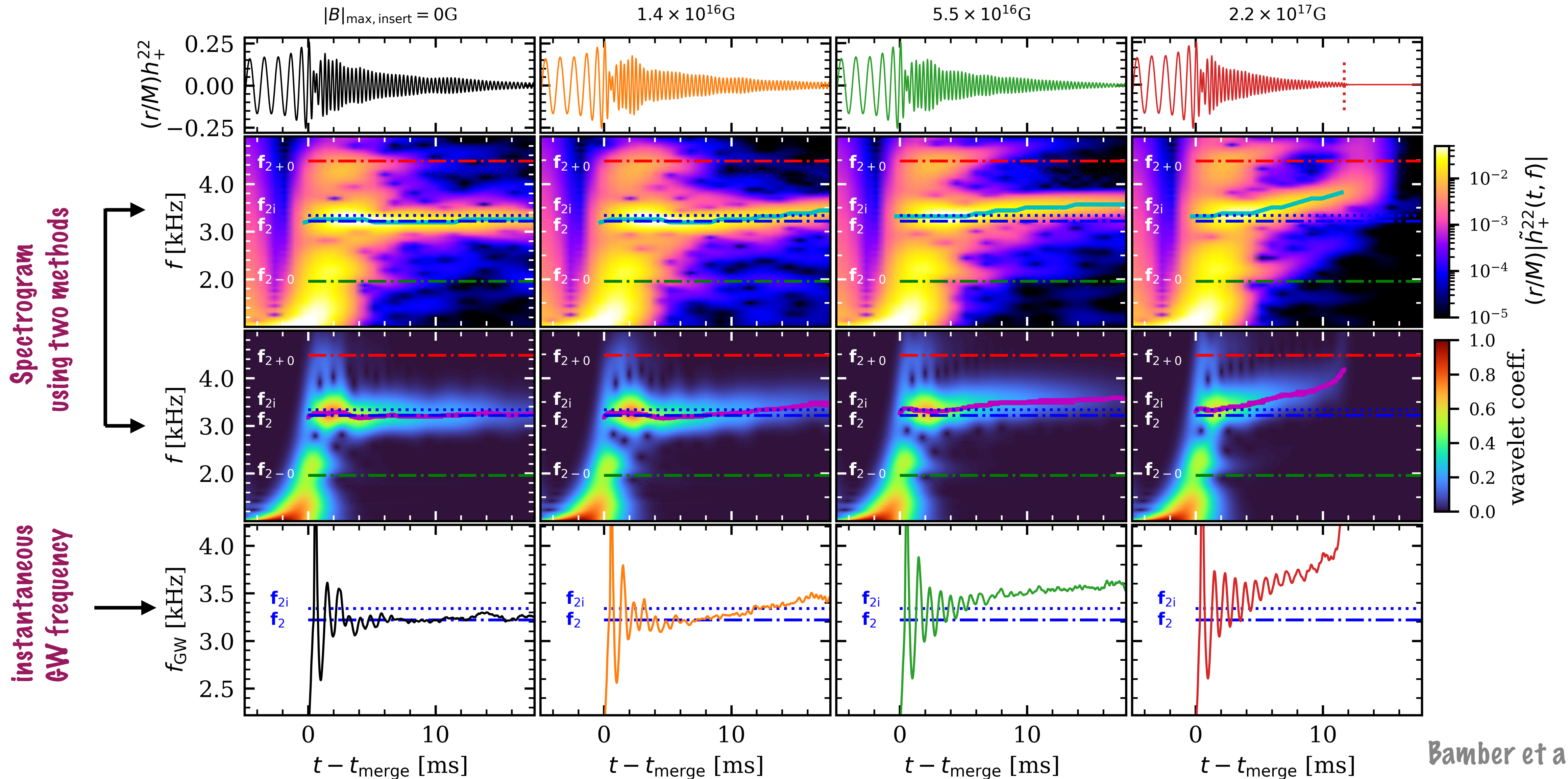
around 20ms



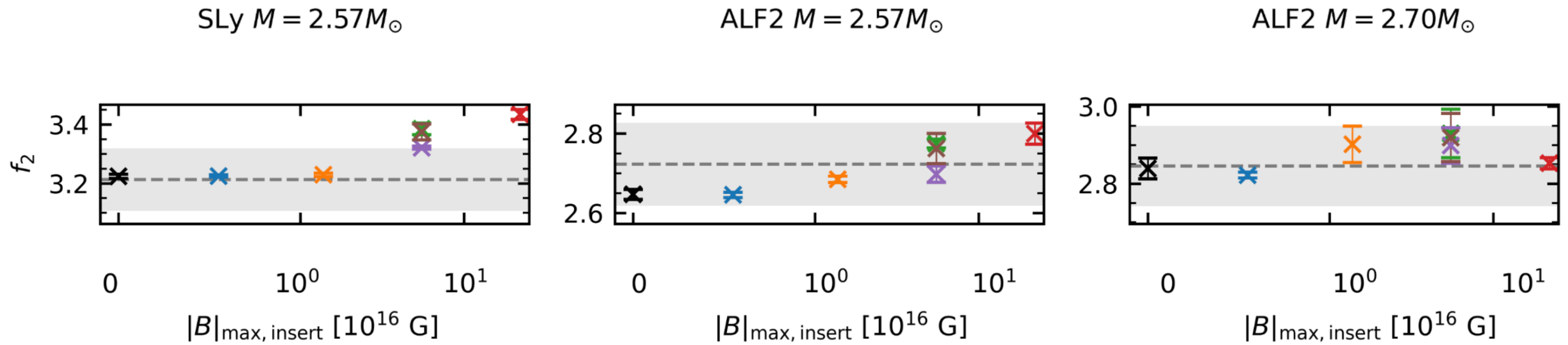
# Neutron star binary mergers: GWs

Pulsar-like B-field

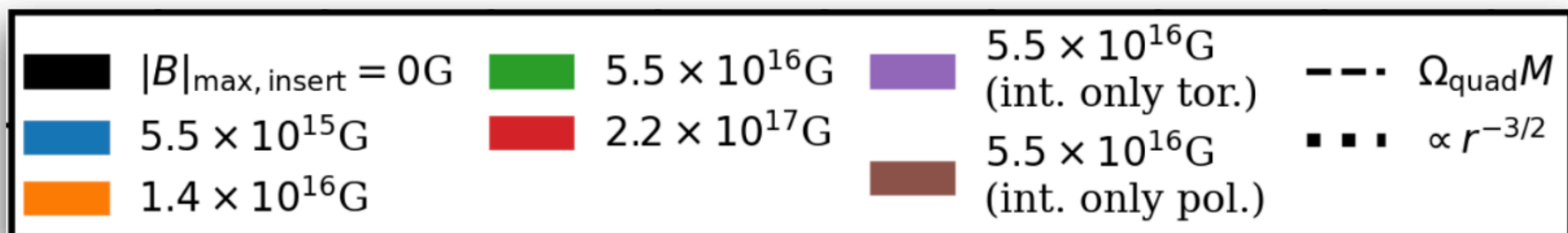
SLy  $M = 2.57M_{\odot}$



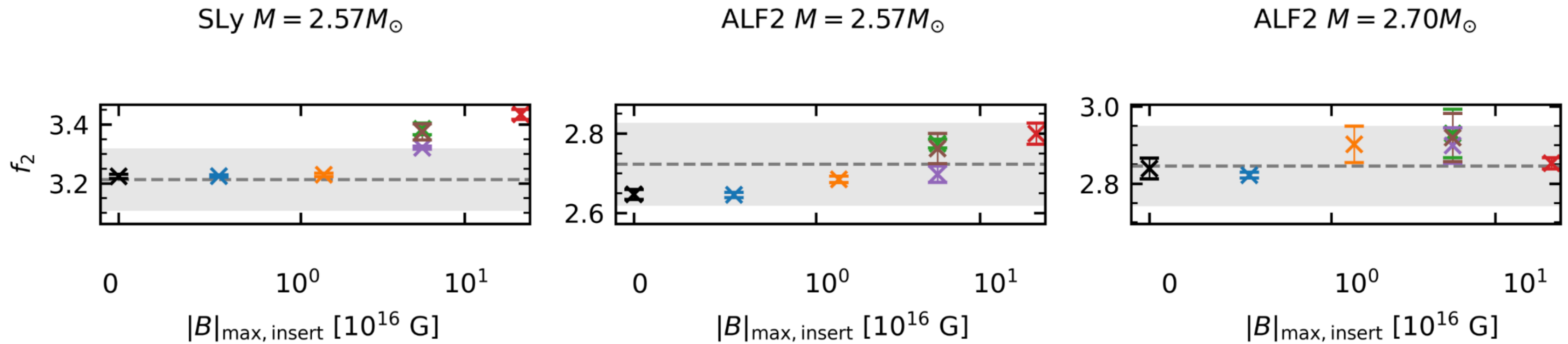
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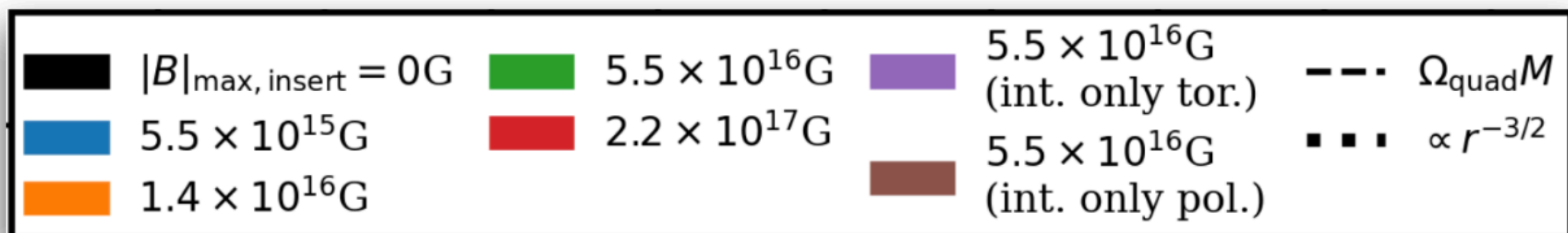
Bamber et al. '24



# Neutron star binary mergers: GWs



Bamber et al. '24



the overall shift is up to  $\sim 200$  Hz consistent with values reported from e.g. Huang et al. '22 attributed to first order phase transitions

# Takeaway messages

- \* Numerical relativity plays a **crucial role in linking** the various signals observed in multi-messenger astronomy.
- \* Long-term simulations of BNS mergers require the inclusion of both **magnetic fields and microphysics to constrain the EoS as they can mimic other EoSs or non-existent physical phenomena.**
- \* High resolution and **convergence studies** are **essential** for accurately interpreting multi-messenger observations.

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Thank you!