Quark matter in neutron star mergers (B07)

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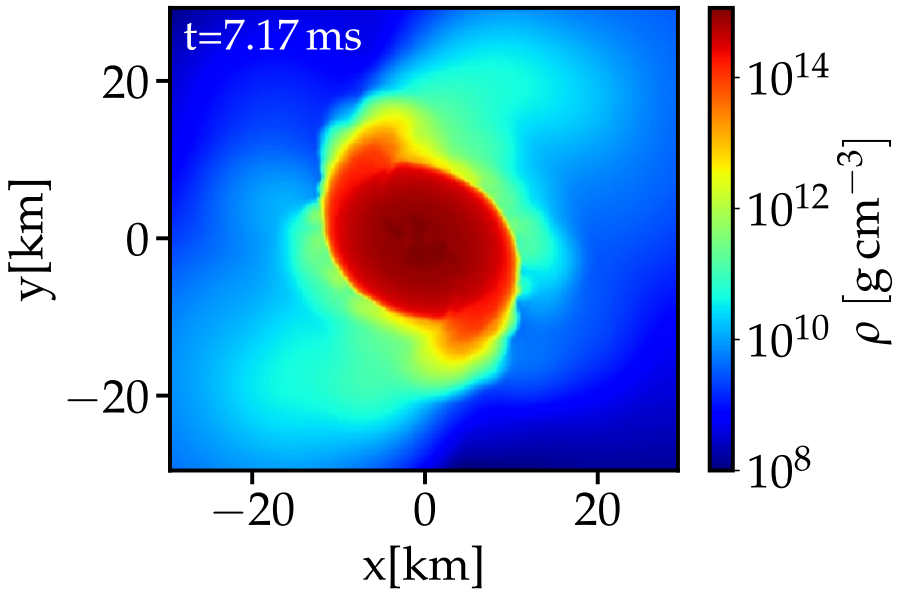
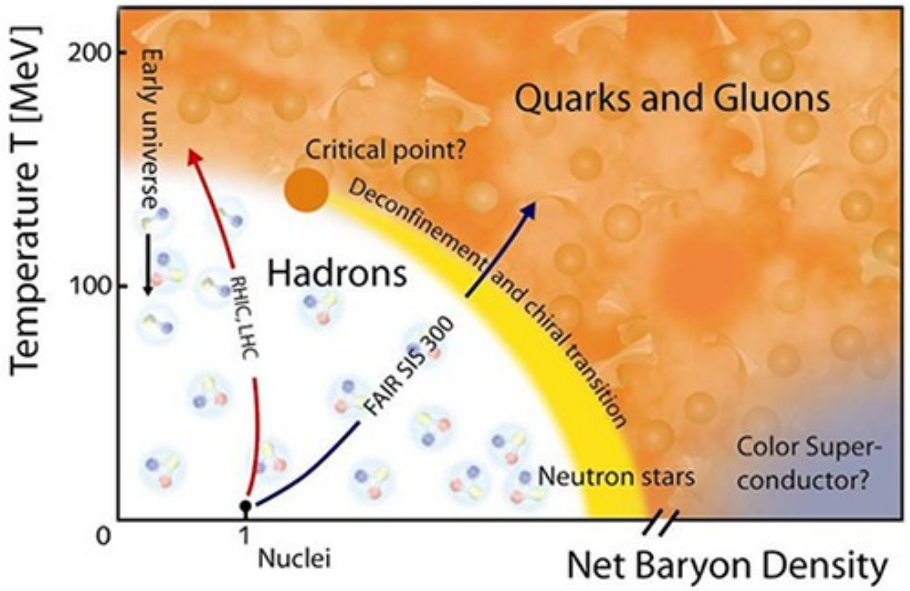
Sebastian Blacker





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Neutron star merger

- GWs carry away energy and angular momentum

  ➡ Orbits decrease and NS will eventually merge

EoS constraints via tidal effects

Inspiral

↓

Merger

Outcome depends on the mass and the EoS!!

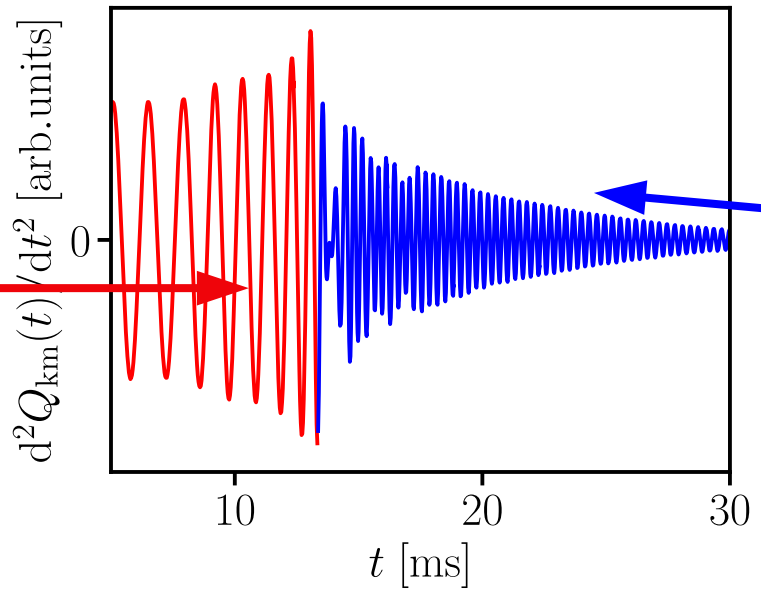
$M_{tot} \geq M_{thres}$ → Prompt collapse to black hole

$M_{tot} < M_{thres}$ → Formation of a (temporary) stable differentially rotating massive NS

GWs from neutron star mergers

- **2 main phases:**
  - **Inspiral:** EoS constraints via tidal effects
  - **Postmerger:** EoS constraints via remnant oscillations

➡ **Different EoS regions are probed!**



inspiral phase (M_{NS}, $\tilde{\Lambda}$)

postmerger Phase (oscillation frequencies)

Phase diagram of matter

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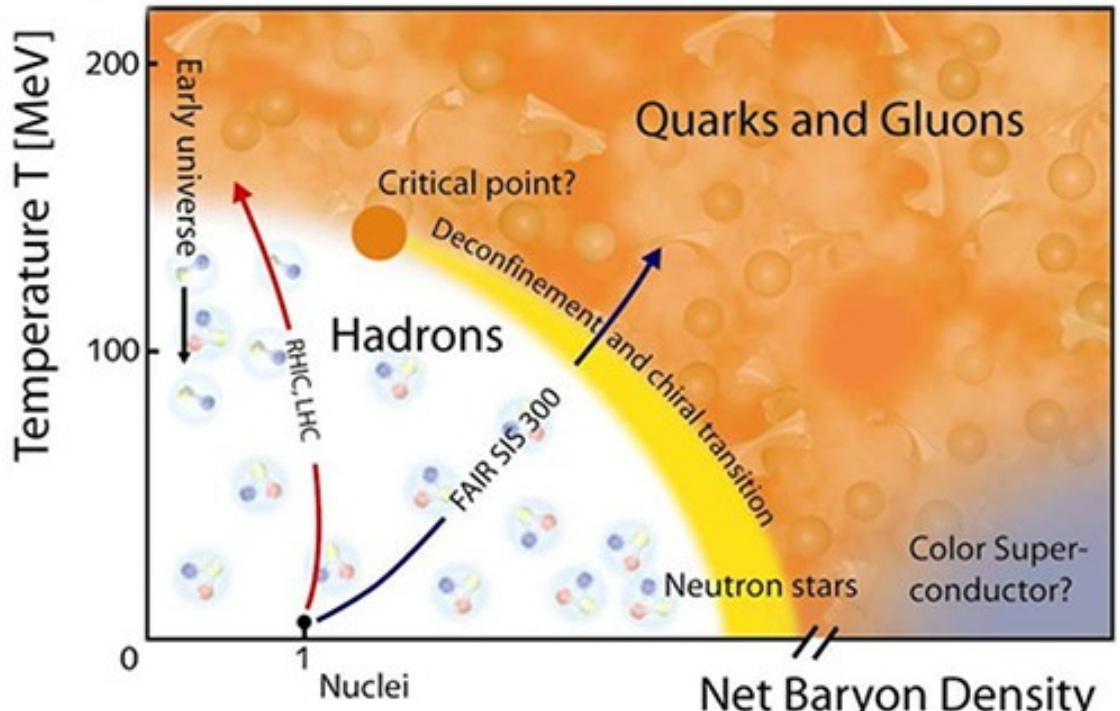
- QCD predicts a phase transition from hadronic to deconfined quark matter, but at which density?



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NS-mergers

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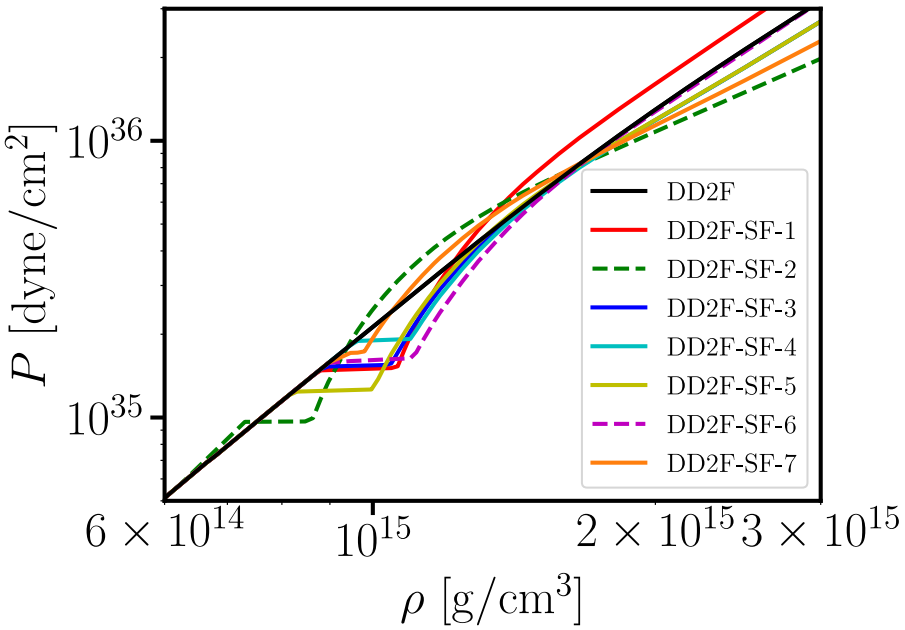
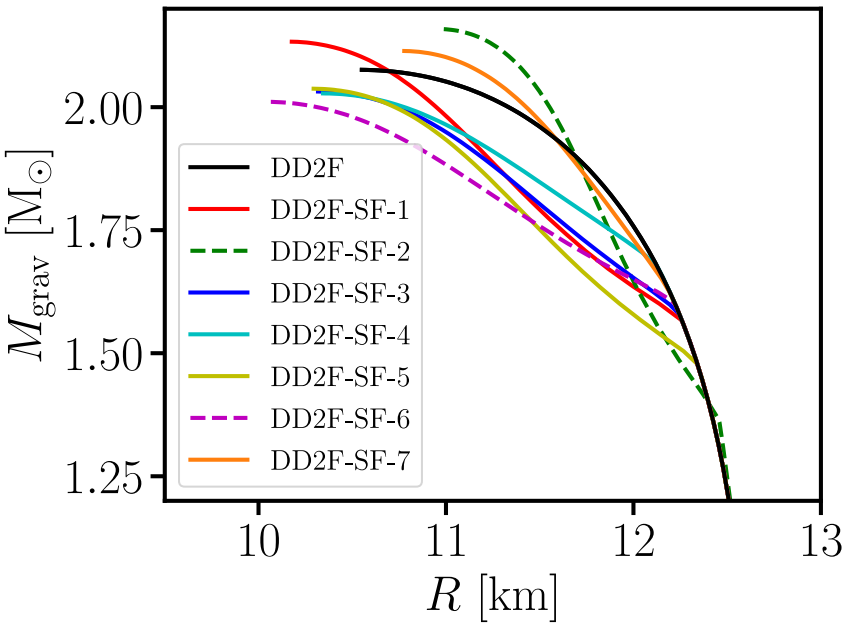
Used hybrid EoS sample





See Fischer et al. Nature Astronomy **2**, 980-986 (2018),
Bastian, PRD **103**, 023001 (2021) and references therein for underlying EoS model

The tables can be found on compose **www.compose.obspm.fr**

Merger snapshots (DD2F-SF-6)

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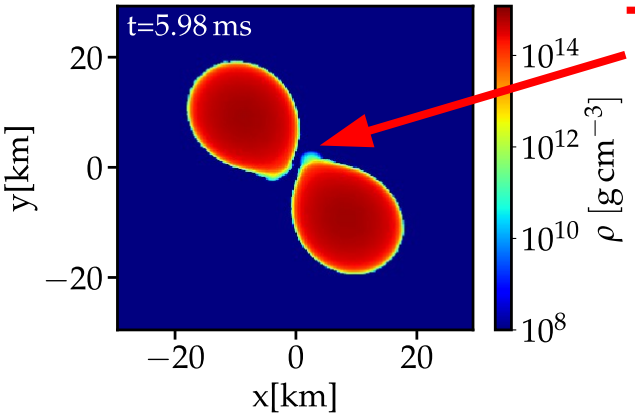
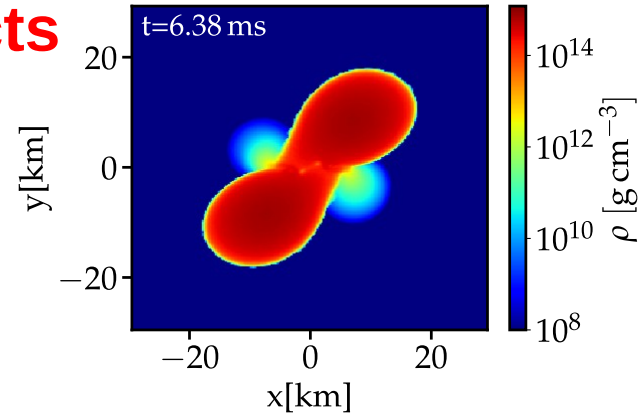
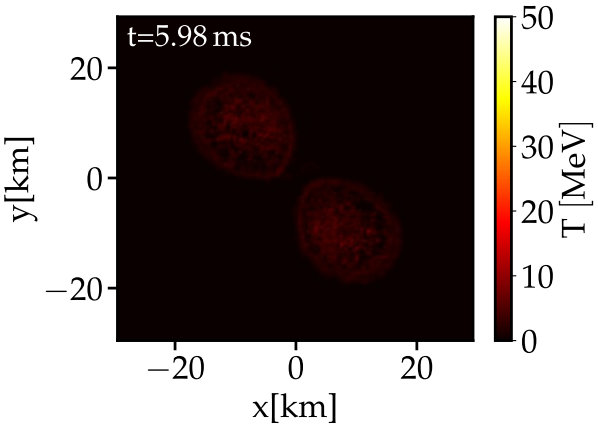
Late inspiral

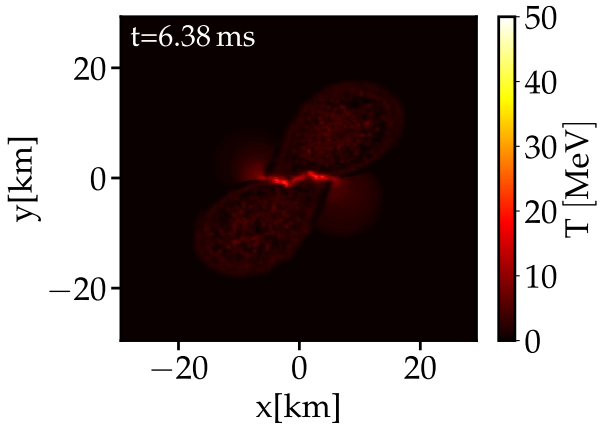
Merger

Tidal effects









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Merger snapshots (DD2F-SF-6)

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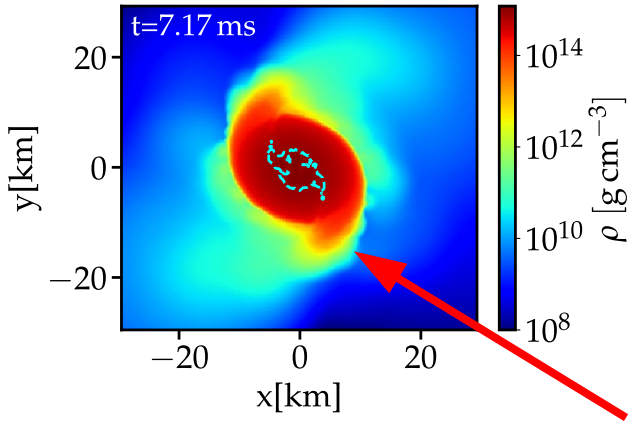
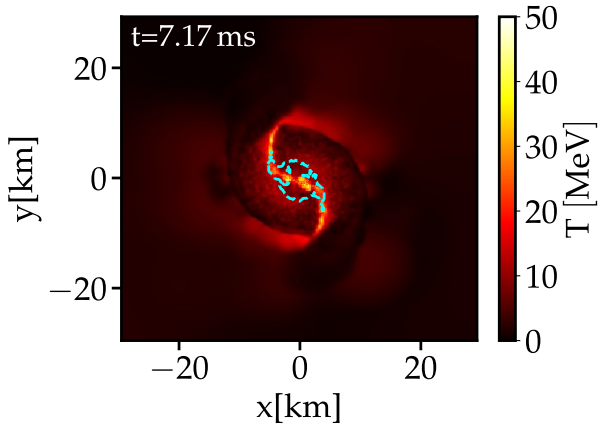
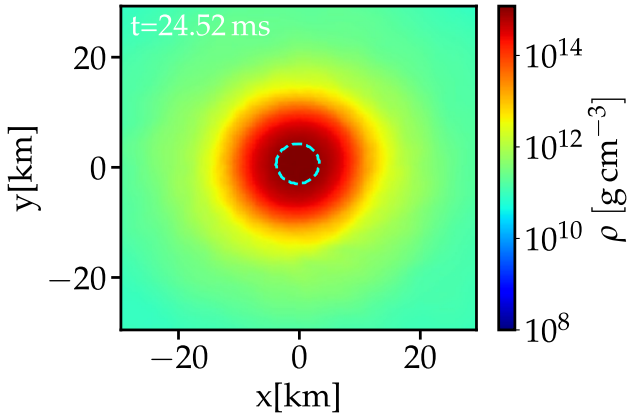
Early postmerger

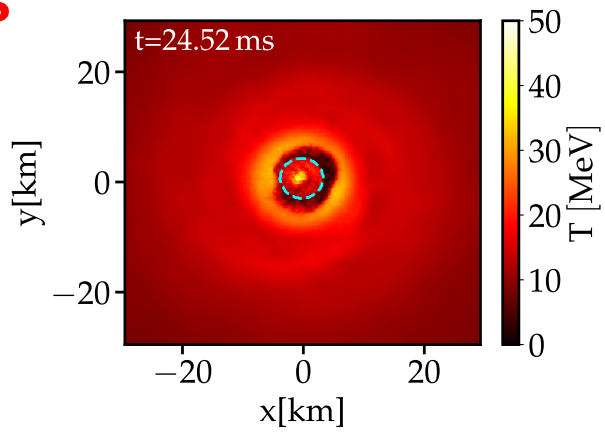




Remnant distortions

Late postmerger





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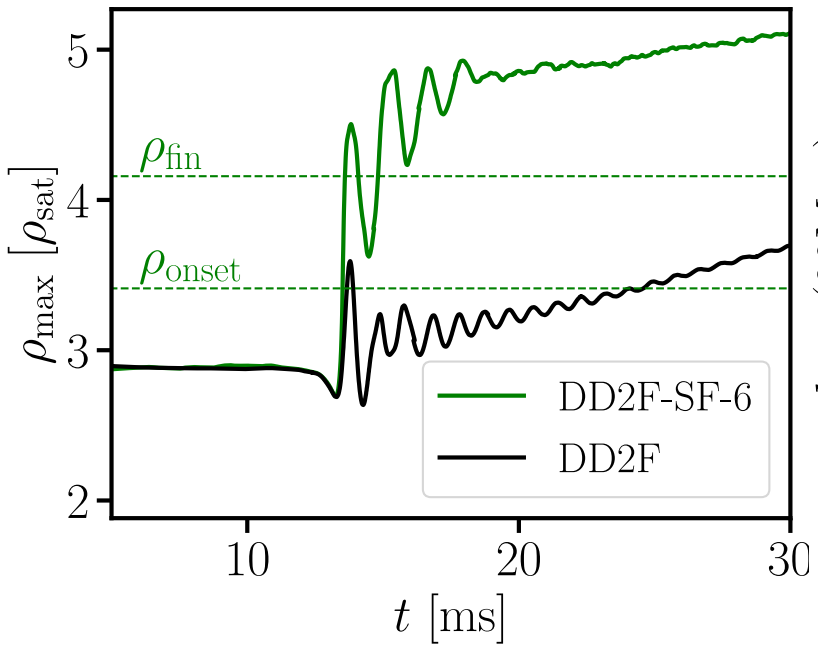
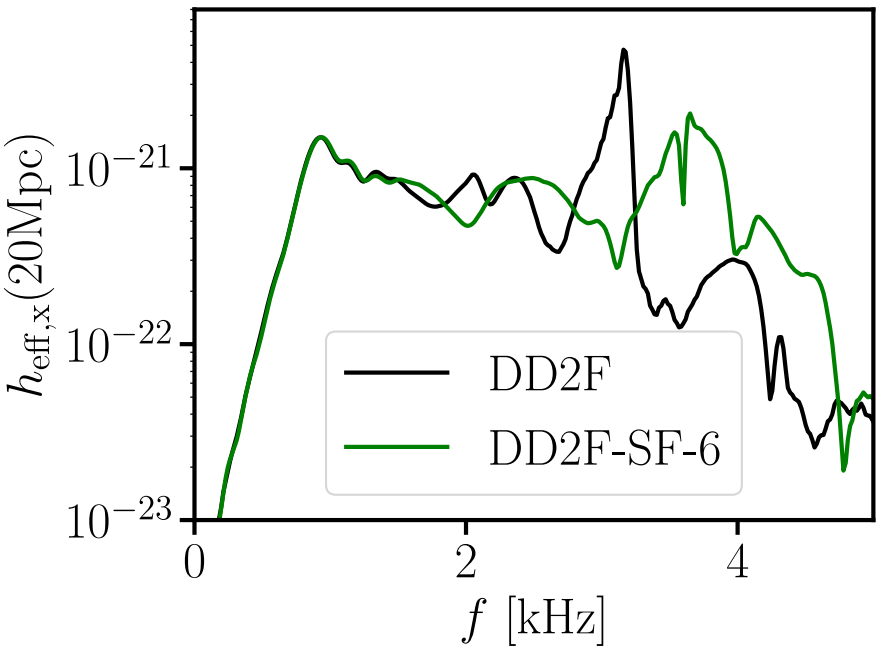
Impact of 1st order phase transition





High densities (frequencies) alone not unambiguous signature of a phase transition!

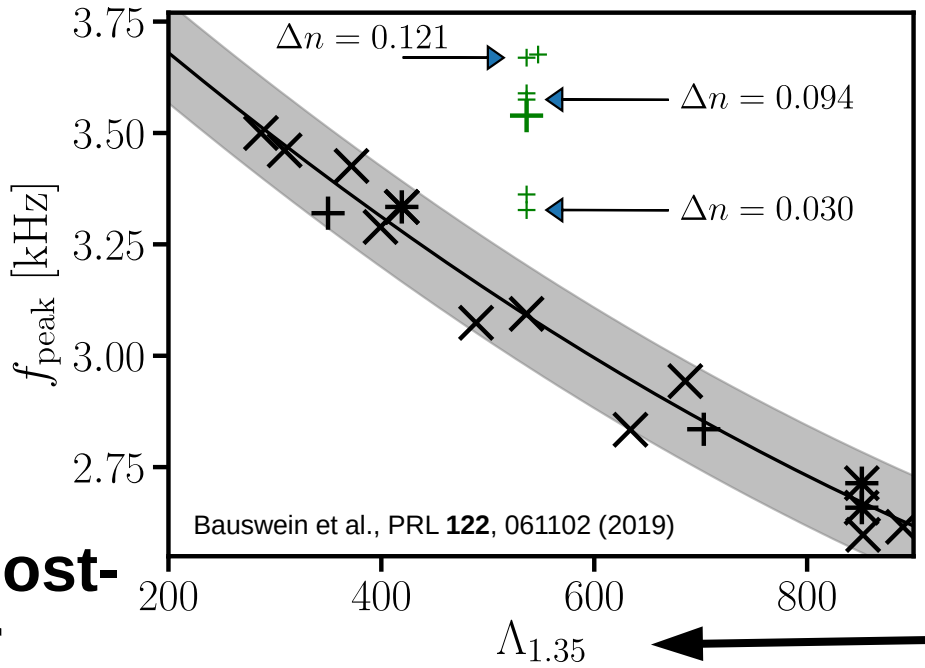
➡ **Need behaviour different from all hadronic EoS**

Identifying a 1st order phase transition

Bauswein et al., PRL **122**, 061102 (2019)

- If the transitions happens during the merger:

➡ **Inspiral signal will behave ‘hadronicly’, while postmerger signal carries imprint of quark matter!!**



From post-merger

From inspiral

- Feature of EoS with 1st order phase transition
- Size of deviation depends on density jump!

Can we constrain the onset density?

Blacker et al., PRD **102**, 123023 (2020)

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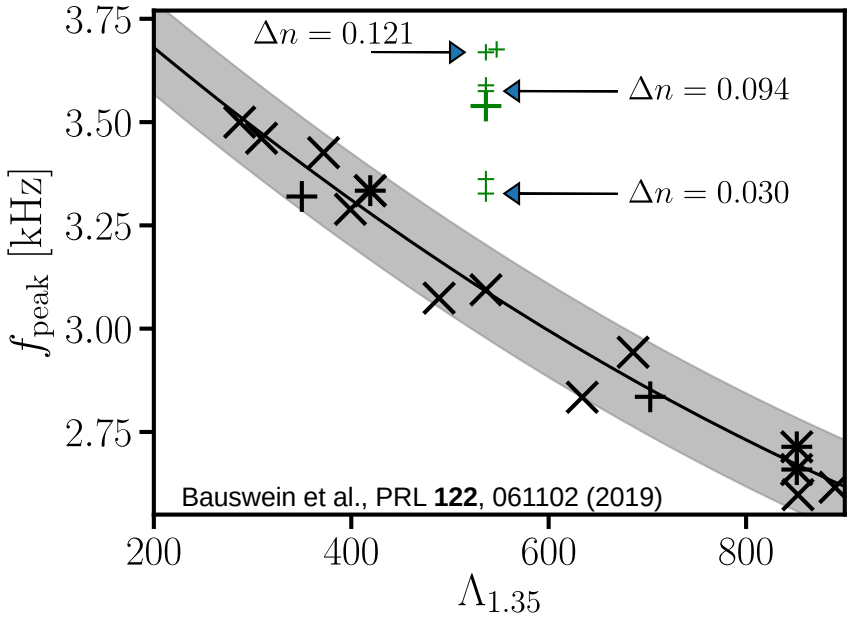
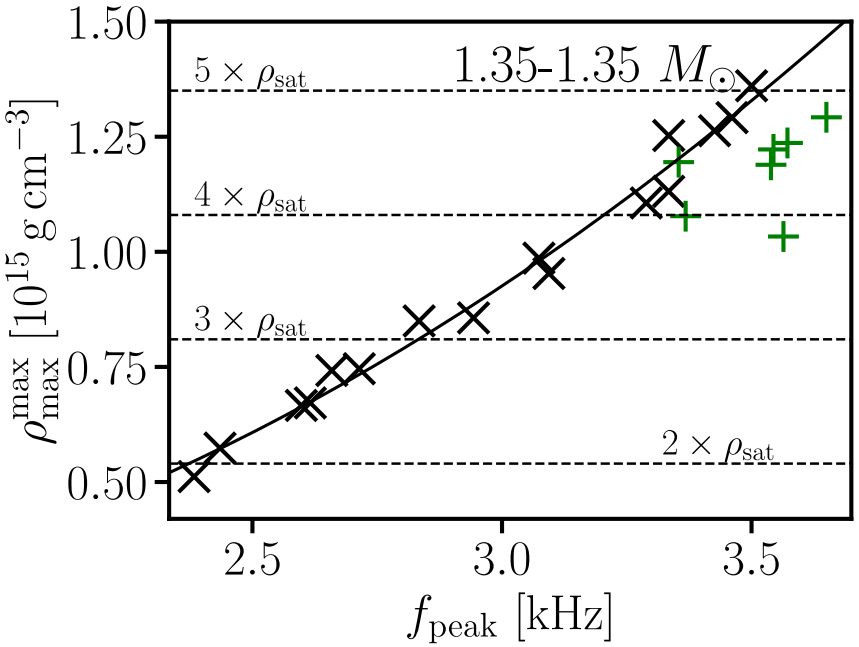
- Use empirical relations to constrain the onset density of a possible phase transition



Blacker et al., PRD **102**, 123023 (2020)



Is there a deviation? ➡ **Which densities are present?**

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Can we constrain the onset density?

Blacker et al., PRD **102**, 123023 (2020)

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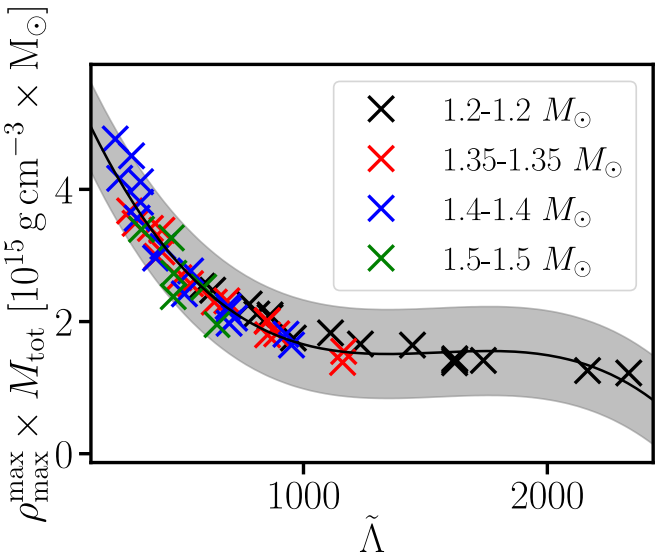
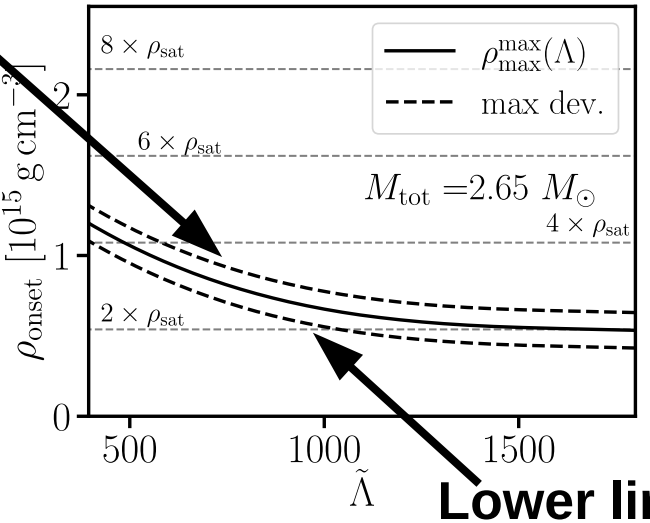


Upper limit if clear sign of PT



Lower limit if no sign of PT

Example GW170817:

- No PT: Onset density > 0.746 x 10^{15} g/cm^3 (~2.76 x nuc. sat.)
- Clear PT: Onset density < 1.230 x 10^{15} g/cm^3 (~4.56 x nuc. sat.)

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Direct black hole formation

Bauswein et al., PRD **103**, 123004 (2020)

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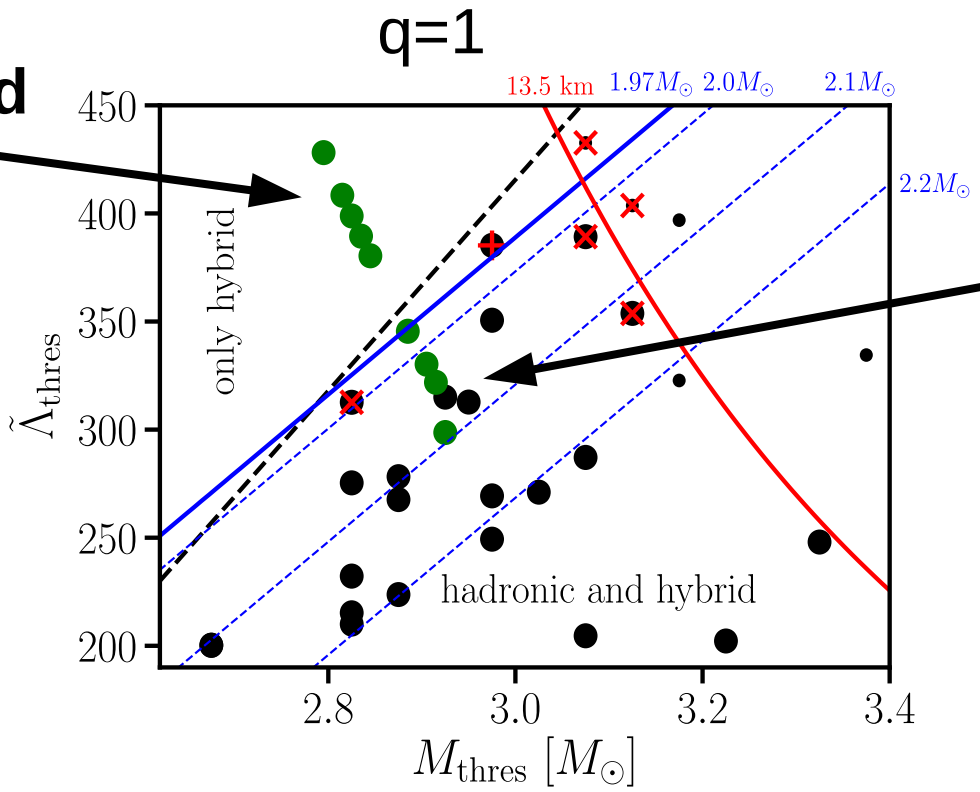
M_{thres} reduced by phase transition



Quarks not ruled out!!

PT can lower M_{thres} compared to the corresponding tidal deformability. But exclusion of quarks not possible!

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Thermal treatments

- Number of fully temperature- and composition dependent models limited!
- A workaround are simple barotropic models, e.g. piecewise-polytropic models
- Common approach for thermal effects: ‘Ideal-gas’ approach Janka et al., AAP **268**, 360 (1993)

$$P = P_{\rm cold} + P_{\rm th}$$

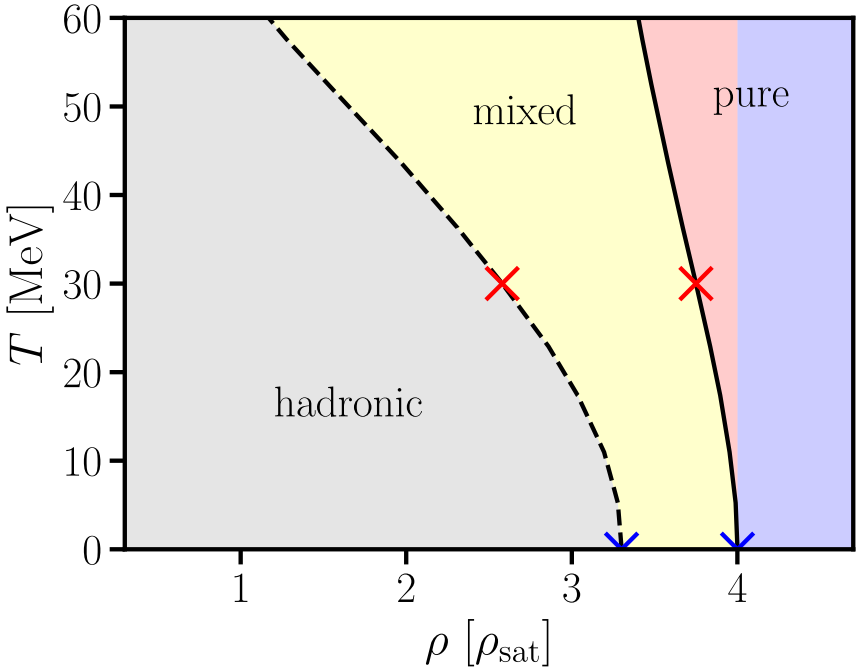
$$\epsilon = \epsilon_{\rm cold} + \epsilon_{\rm th}$$

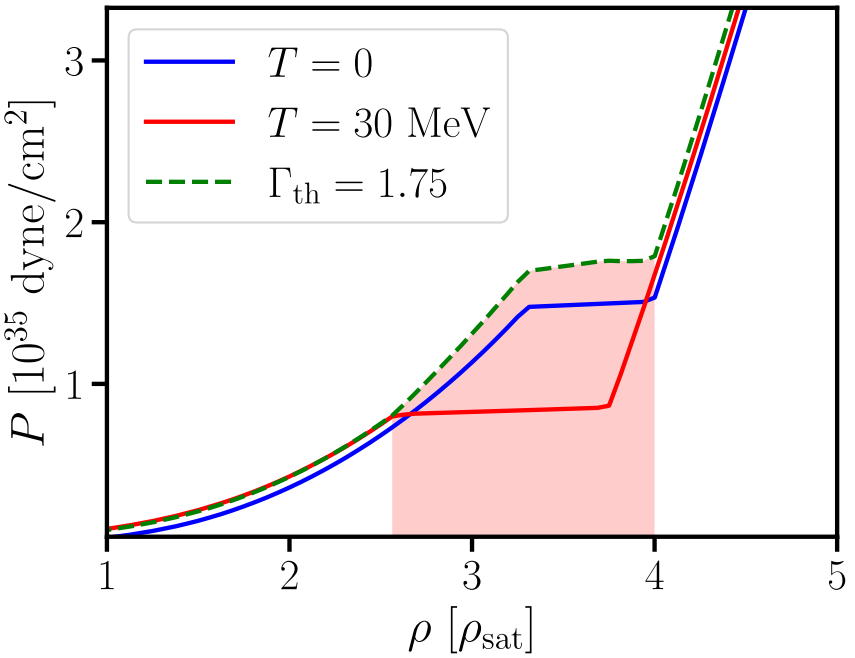
$$\epsilon = \frac{e - \rho}{\rho}$$

$$P_{\rm th} = (\Gamma_{\rm th} - 1)\rho\epsilon_{\rm th}$$

Problems with hybrid EoSs

- Effects of temperature-dependent phase boundaries not captured!
- Example: DD2F-SF-1 EoS





Summary

- **A strong phase transition can be identified by**
  - Deviations from empirical relation between tidal deformability and f_{peak}
  - Potentially reduced M_{thres} (with increased threshold tidal deformability)
- **For hybrid EoS the finite temperature part can have a big impact on NS merger observables**
  - The onset density of quark deconfinement changes with temperature