Postmerger GW emission and collapse behavior of NS mergers

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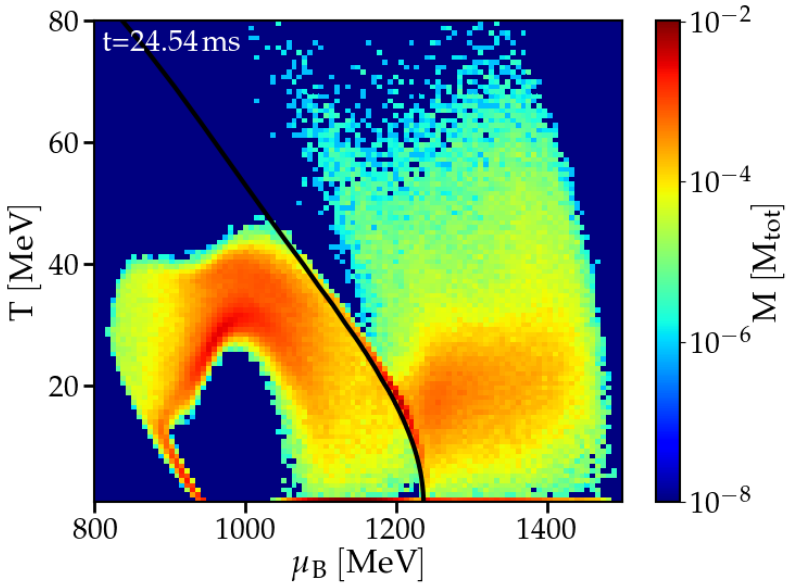
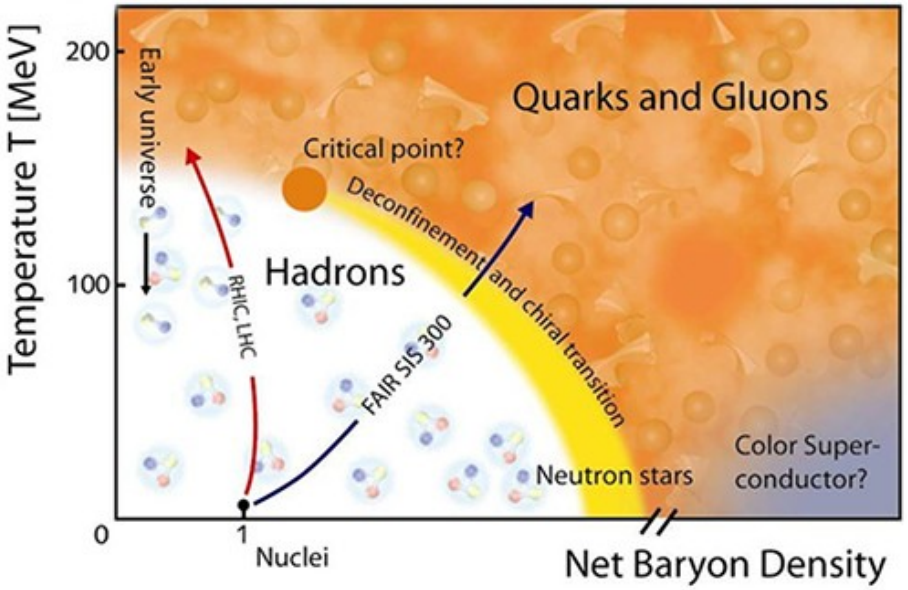
Sebastian Blacker
Project B07



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



GSI/FAIR

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

Merger snapshots

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

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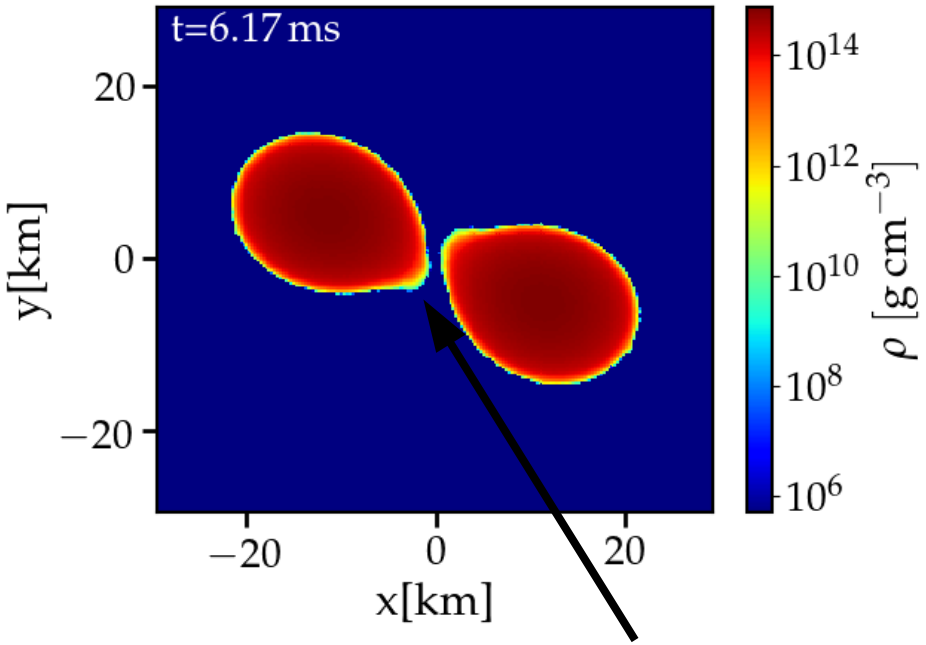
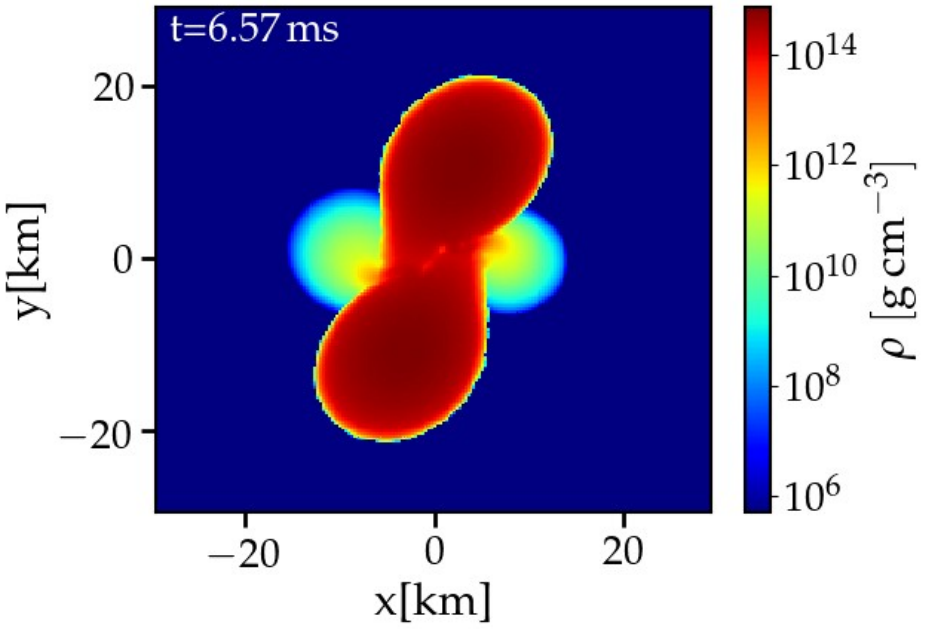
Late inspiral



Merger



Tidal effects Λ

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Merger snapshots

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

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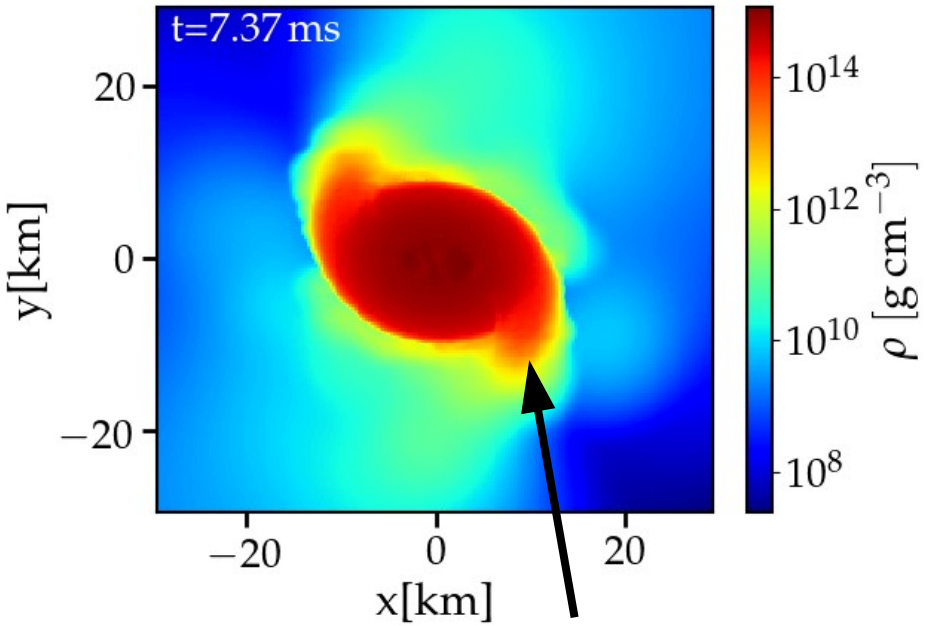
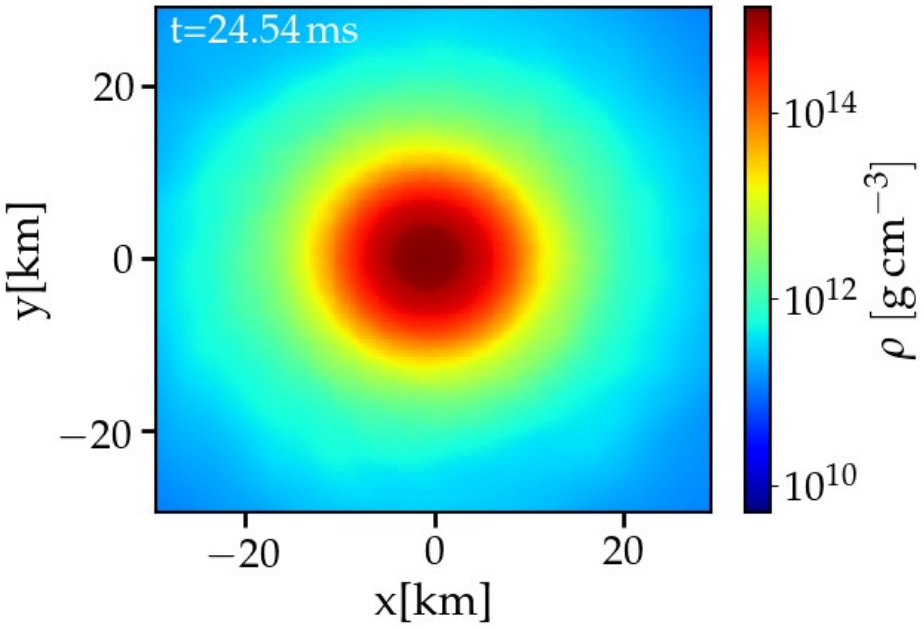
Early postmerger



Late postmerger



Remnant distortions and oscillations

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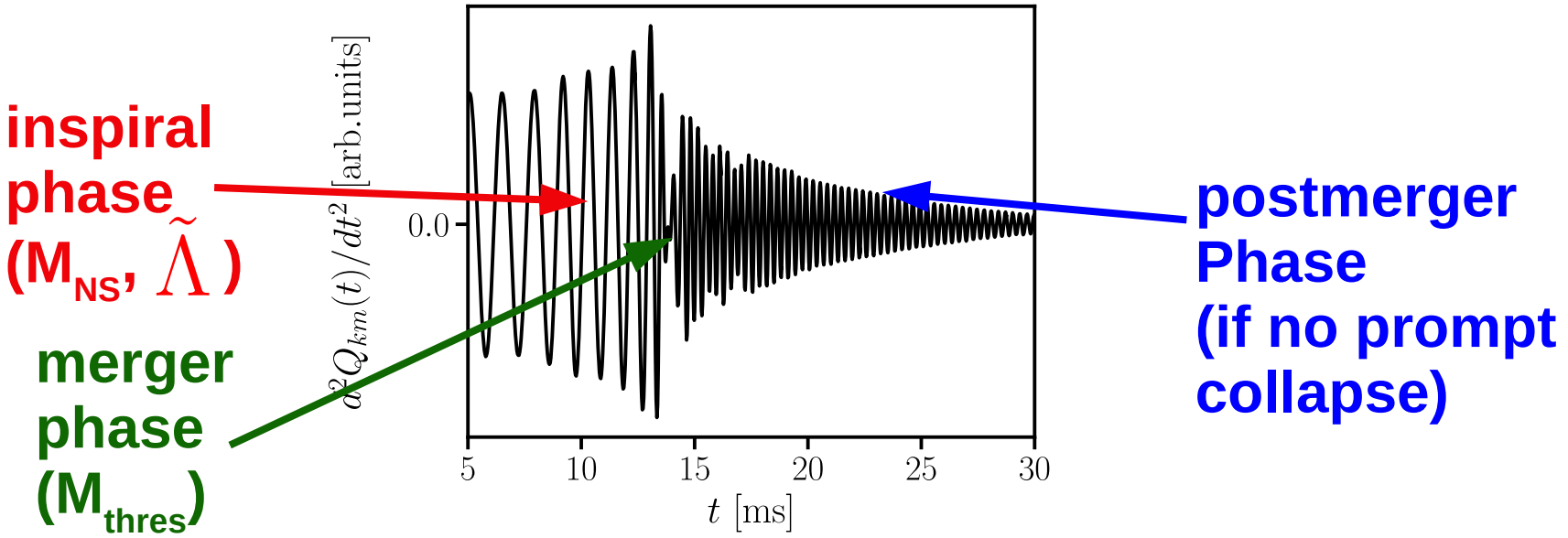
GW from neutron star mergers

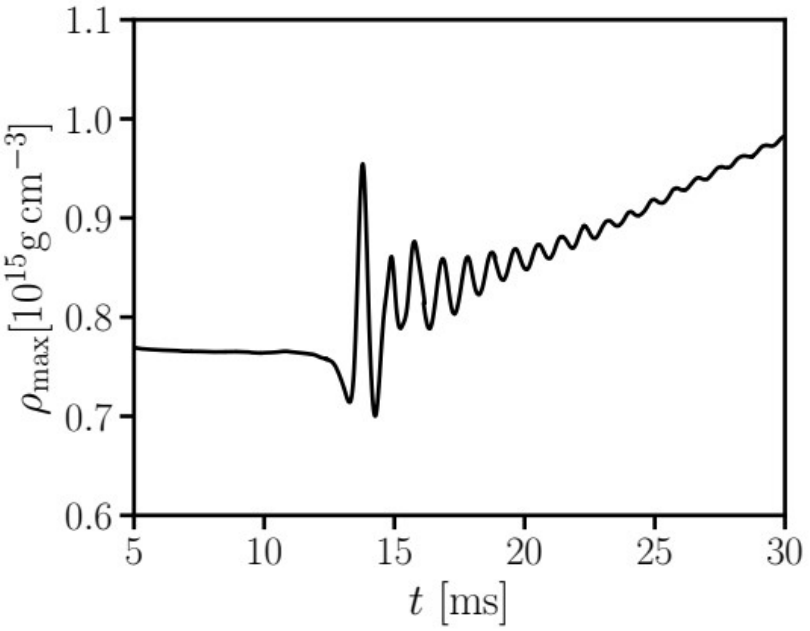
- **3 phases:**
  - **Inspiral:** EoS constraints via tidal effects
  - **Merger:** EoS constraints via collapse behaviour
  - **Postmerger:** EoS constraints via remnant oscillations

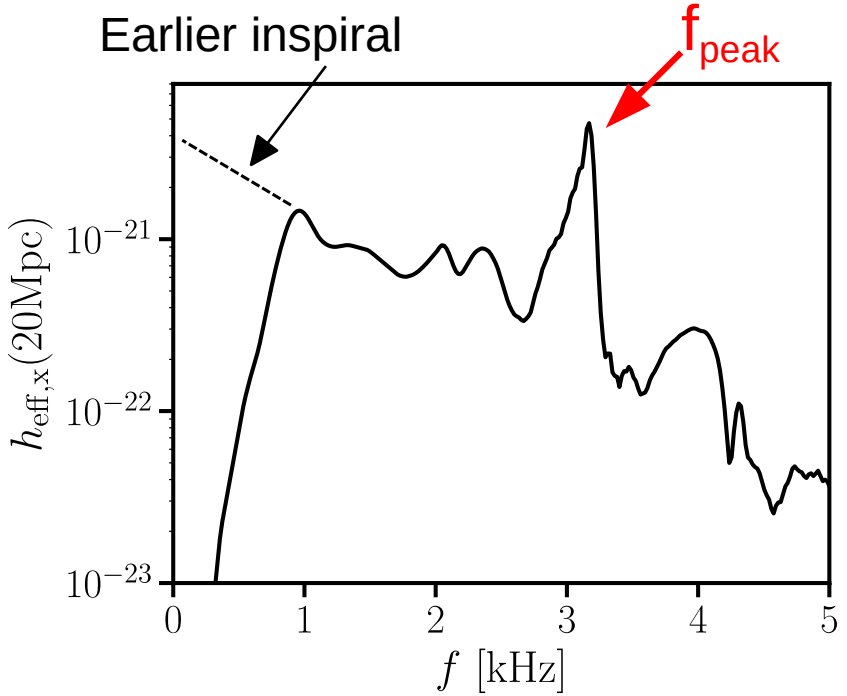


GW spectra

- The remnant is (temporarily) stable and oscillates

➡ Produces a postmerger gravitational wave signal

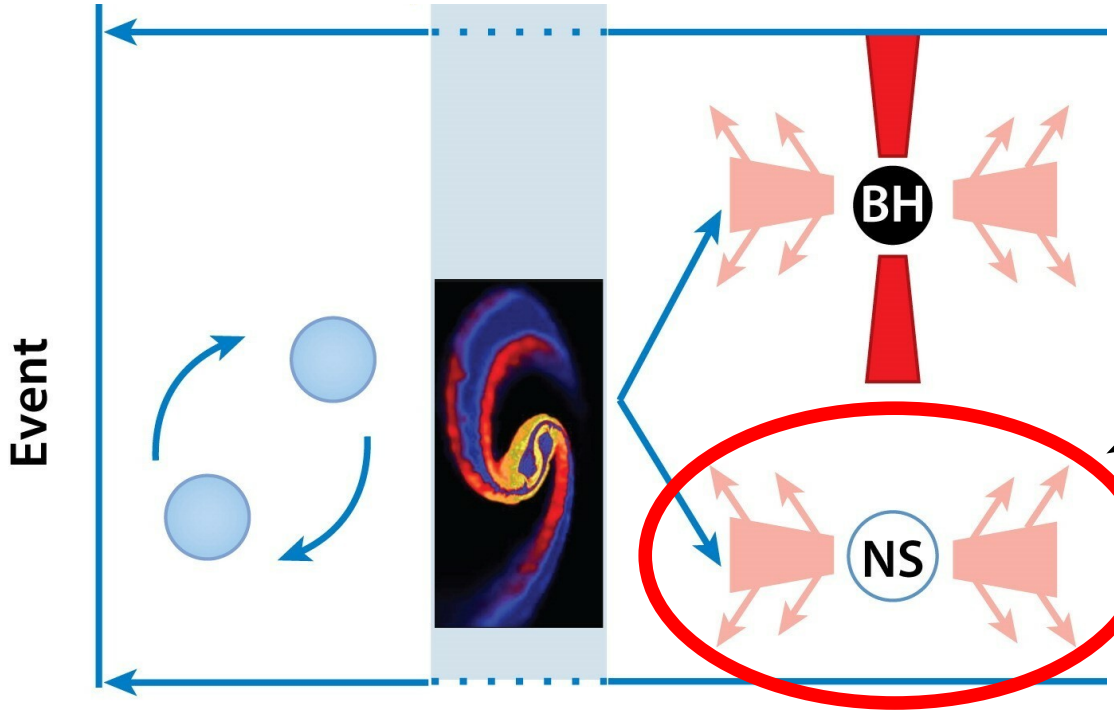




Oscillation frequency depends on EoS!

Constraining a strong phase transition

Bauswein et al., PRL **122**, 061102 (2019)
Blacker et al., PRD **102**, 123023 (2020)

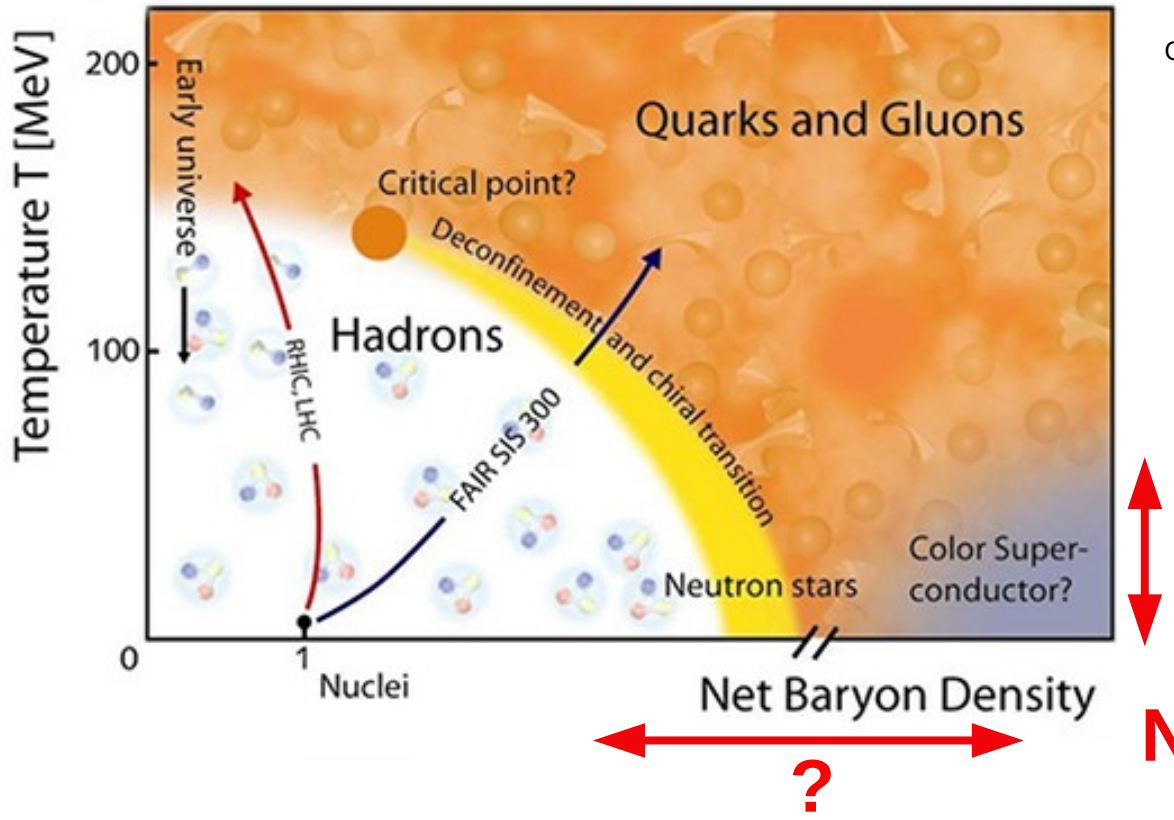


Assuming no direct BH formation

Burns 2020, arXiv:1909.06085

Phase diagram of matter

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



More Snapshots

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

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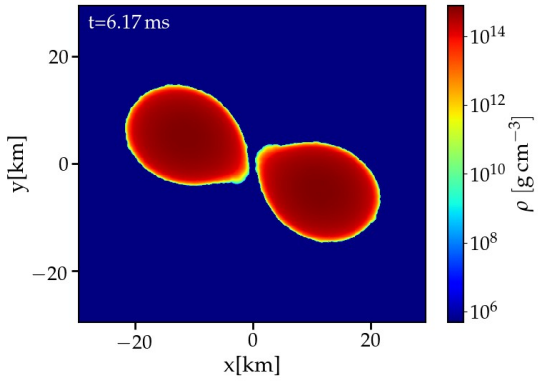
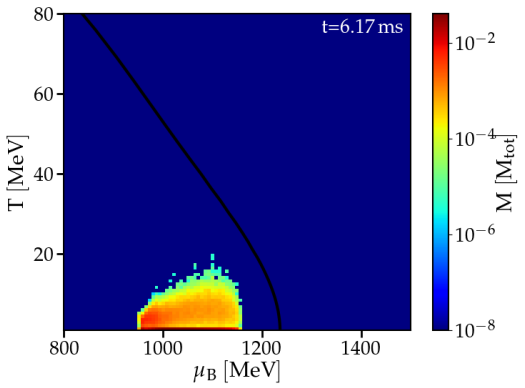
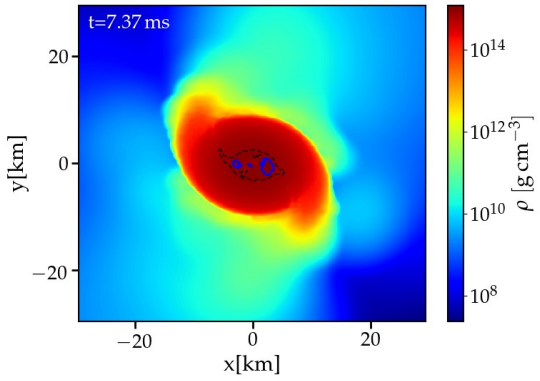
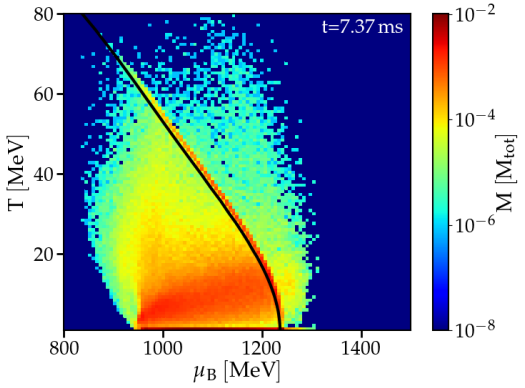
Inspiral



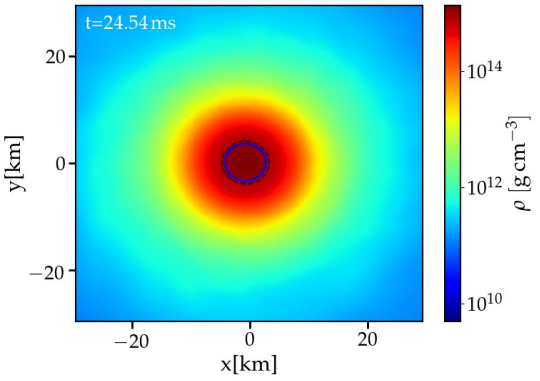


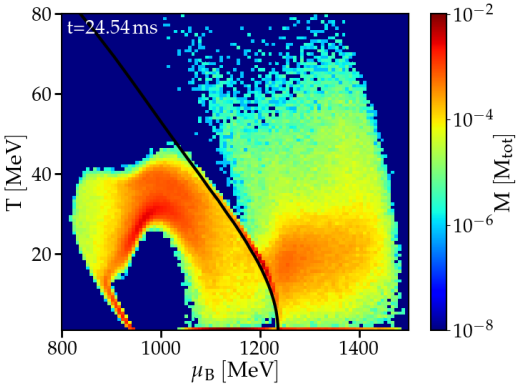
Early postmerger





Late postmerger





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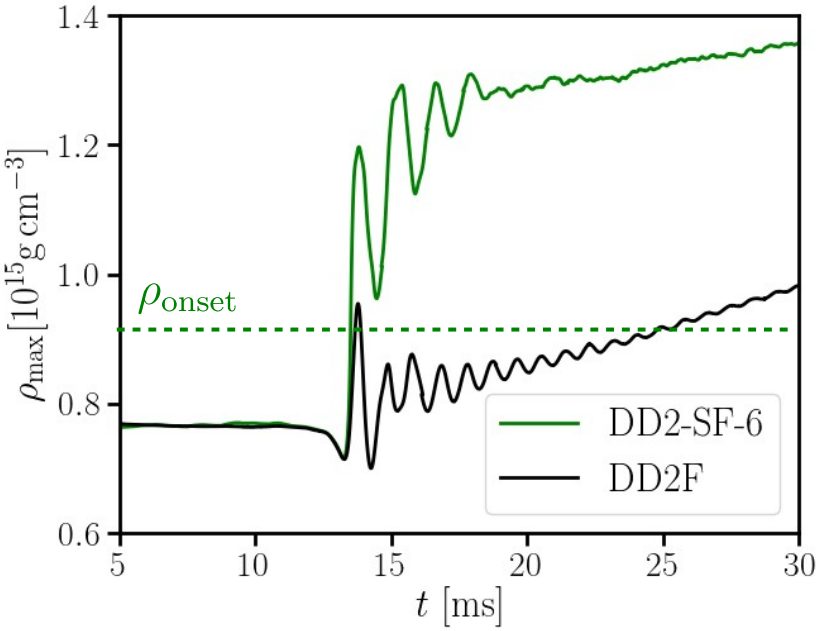
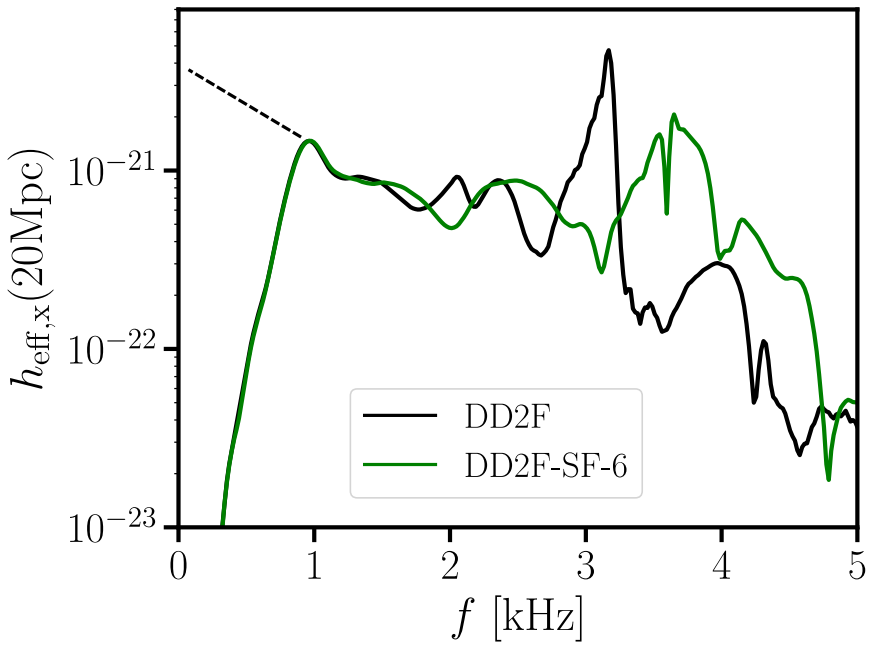
Impact of 1st order phase transition

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





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

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

Impact of 1st order phase transition

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

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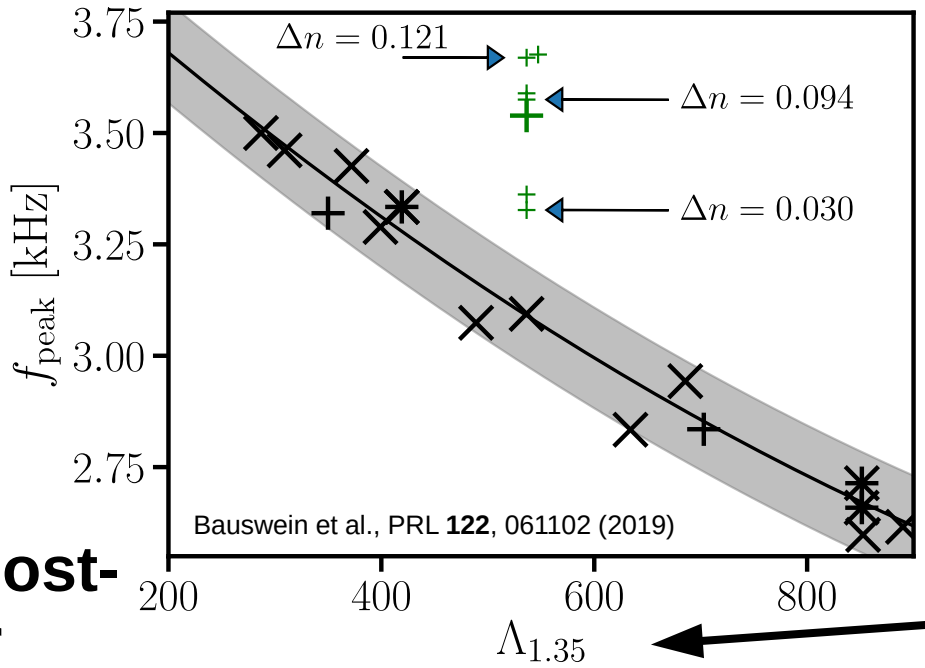
- If the transitions happens during the merger:

➡ **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!

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Can we constrain the onset density?

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

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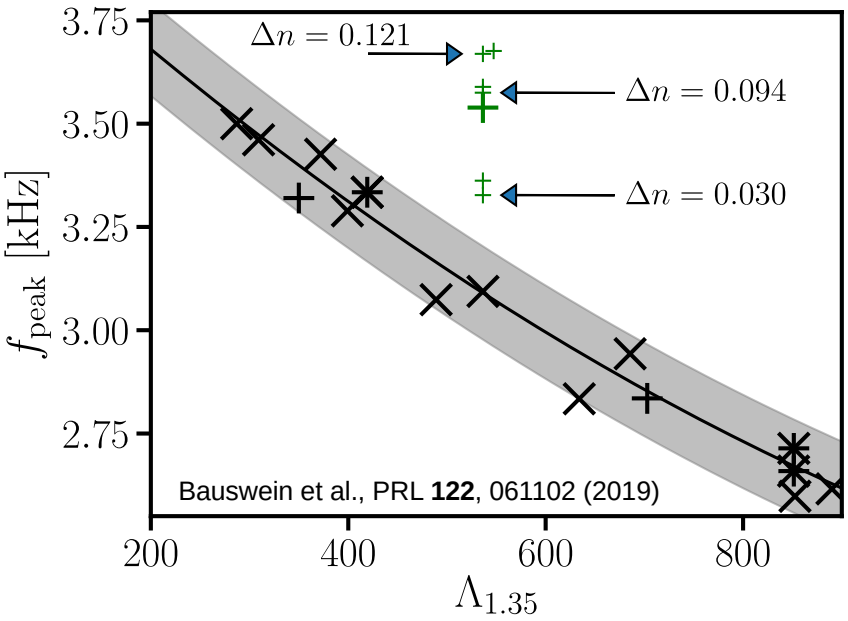
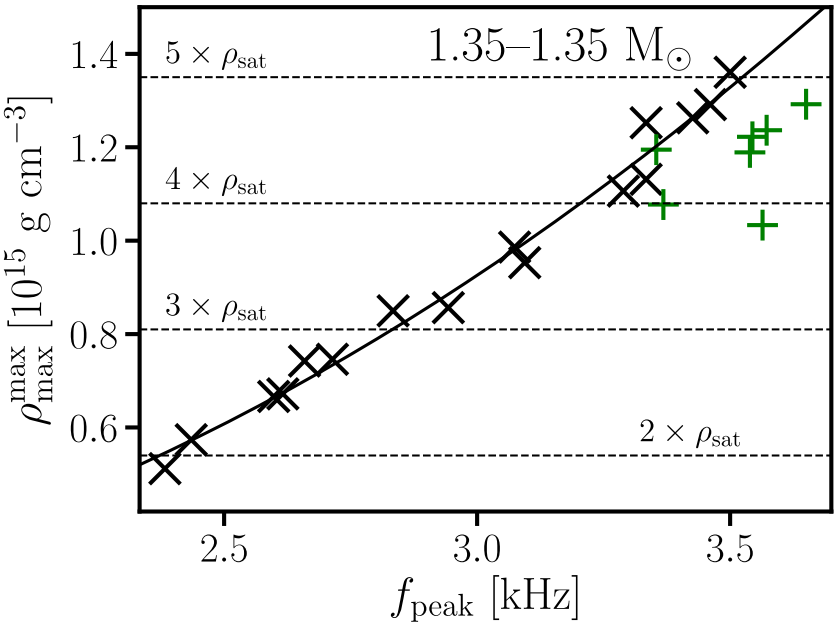
- Use empirical relations to constrain the onset density of a possible phase transition

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





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

Can we constrain the onset density?

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

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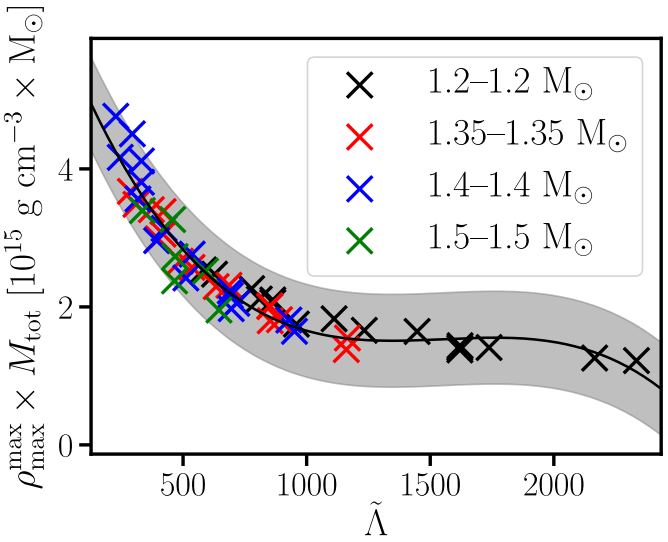
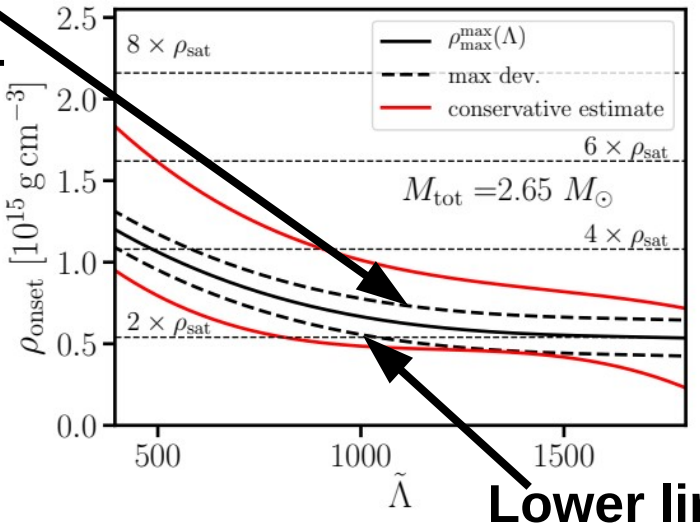


Upper limit if clear sign of PT



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.)

See also Lioutas et al. 2021 (arXiv:2102.12455) for updated relations

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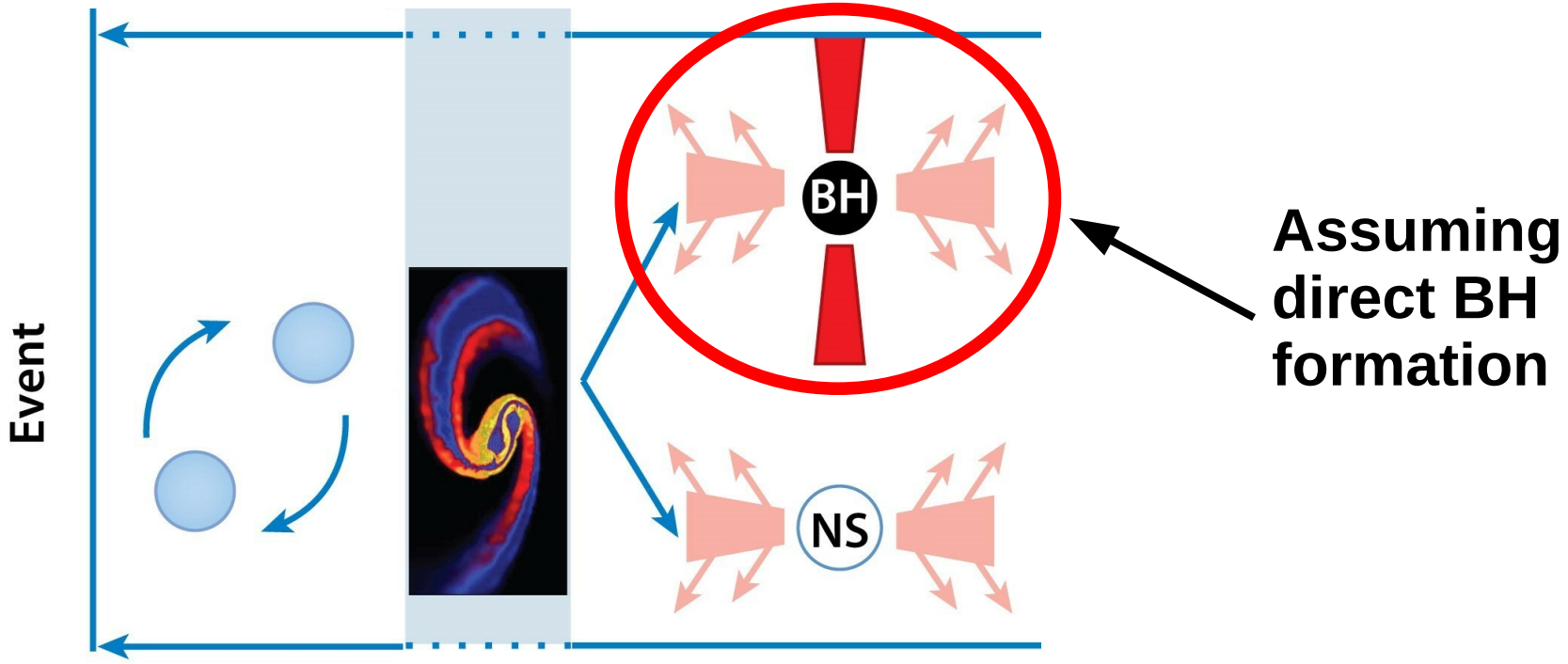
Systematics of direct BH formation in NS mergers

Bauswein et al., PRL **125**, 141103 (2020)
Bauswein et al., arXiv:2010.04461 (2020), submitted to PRD



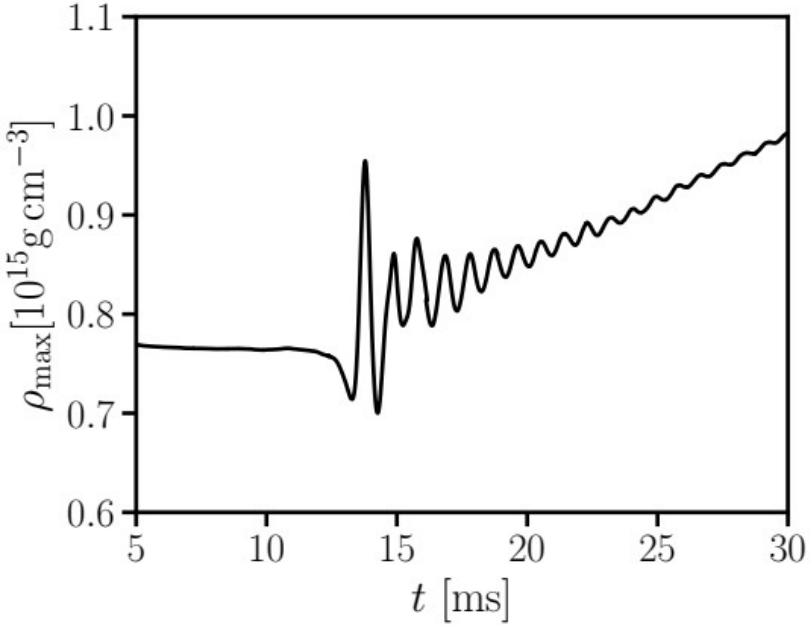
Burns 2020, arXiv:1909.06085

Threshold mass for prompt BH formation

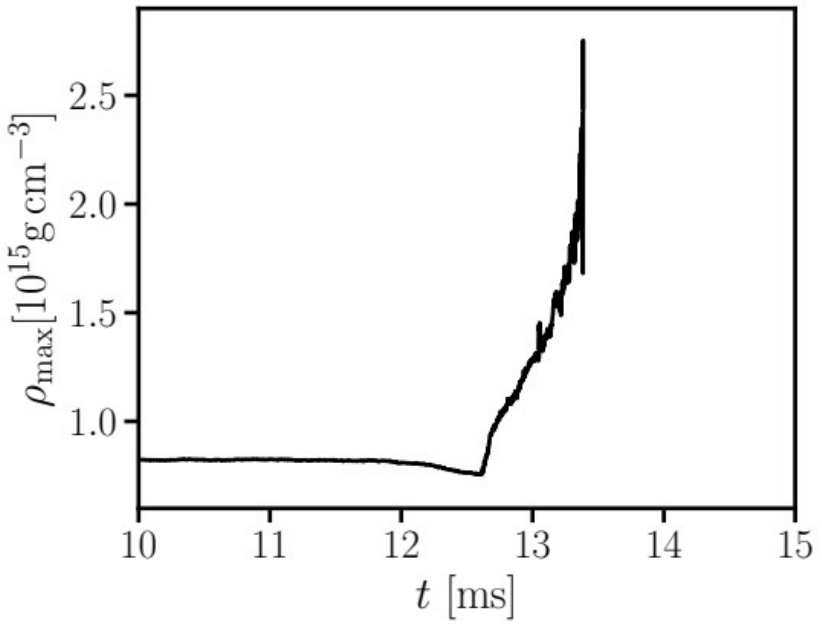
- Direct BH formation

  ➡ No postmerger density oscillations (**measurable!**)

- $M_{thres}=0.5*(M_{min,collapse}+M_{max,\ no\ collapse})$



vs



Determined for 40 EoS models and 3 different mass ratios

Relations for M_{thres}

Bauswein et al., arXiv:2010.04461 (2020)

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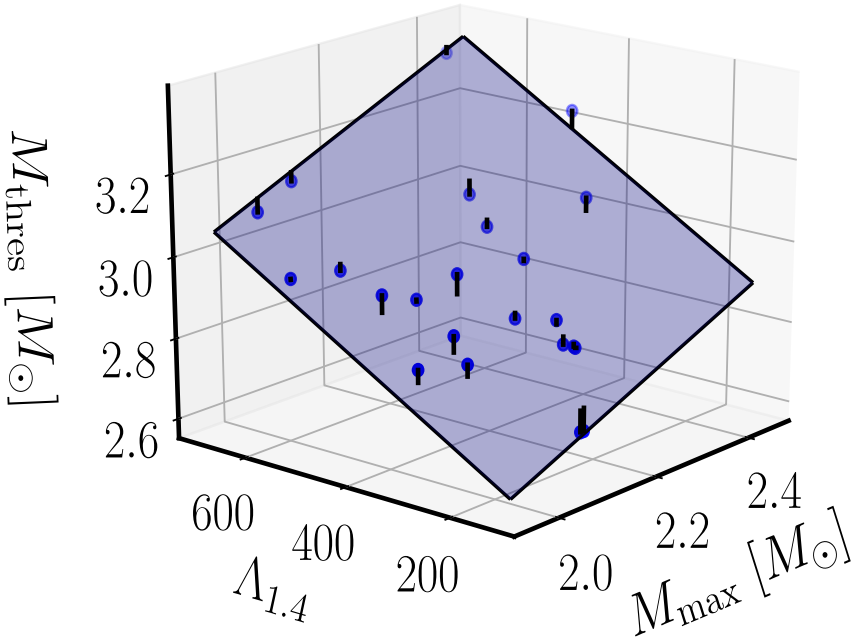
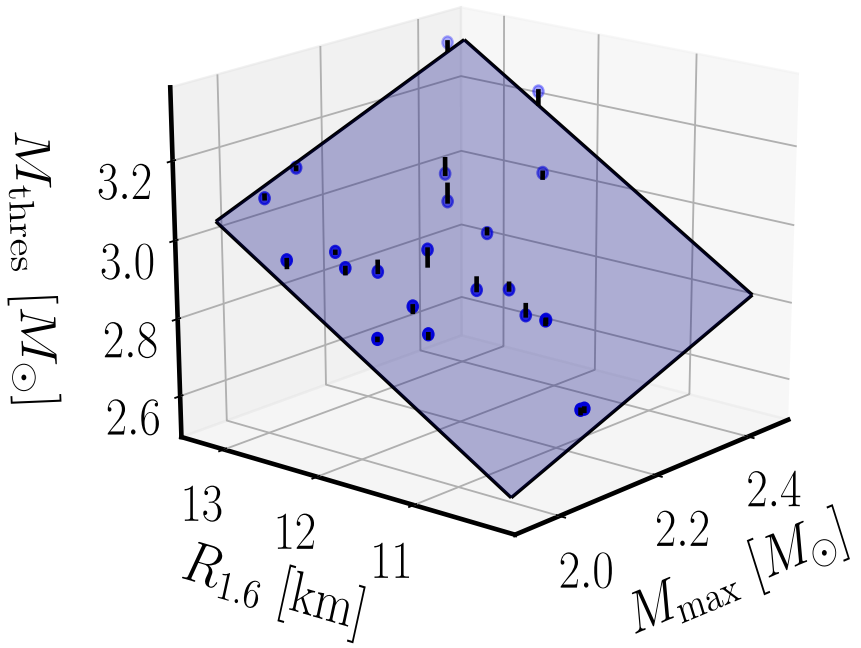
- Tight expressions (fixed mass ratio q)





Measurement of M_{thres} provides additional constraints on neutron star properties

Example GW170817 : $R_{1.6} > 10.56$ km

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A new signature of a phase transition

Bauswein et al., arXiv:2010.04461 (2020)

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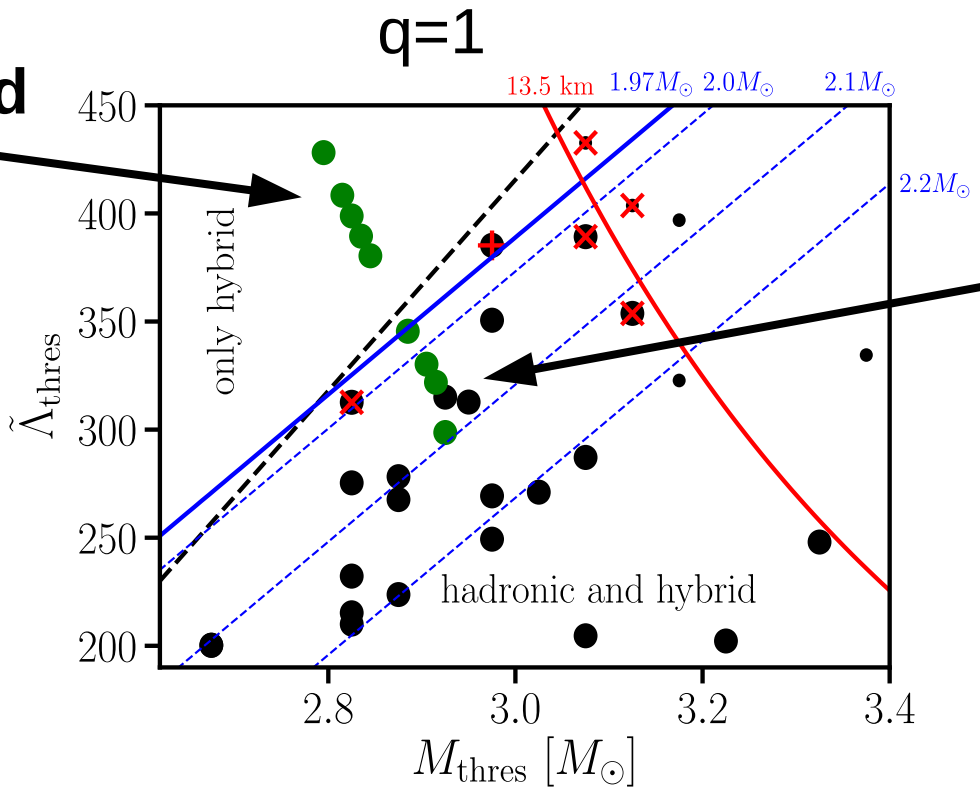
M_{thres} reduced by phase transition



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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Summary

- **GW from NS mergers give constraints on the EoS via**
  - Inspiral phase (tidal effects)
  - Merger phase (collapse behavior, M_{thres})
  - Postmerger phase (remnant oscillations, $f_{peak,}$)
- **Signals of a phase transition are**
  - Deviations from empirical relation between tidal deformability and f_{peak}
  - Constraints on the onset density possible from GWs
  - Potentially reduced M_{thres} (with increased threshold tidal deformability)
- **M_{thres} informs about neutron star properties**

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Thank you for your attention!!

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