Revealing a strong phase transition in neutron star mergers with gravitational waves

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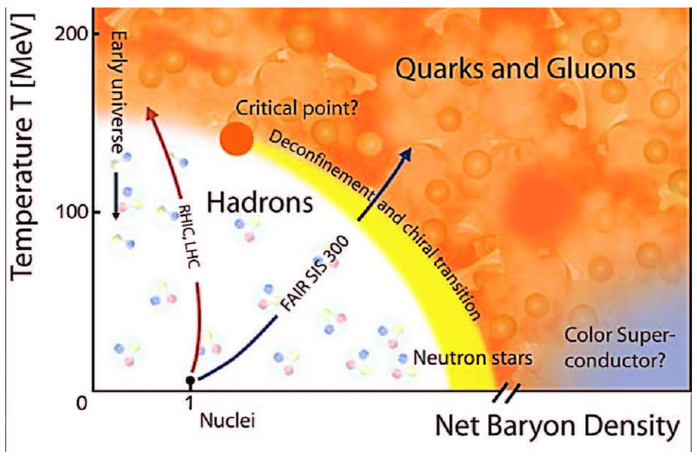
Phase diagram of matter



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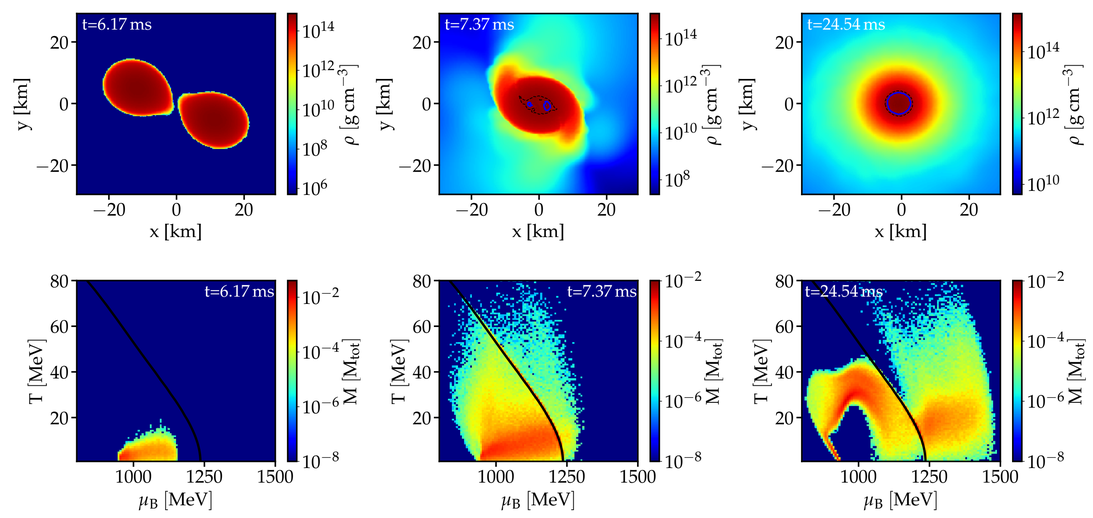
QCD predicts a phase transition from hadronic to deconfined quark matter, but at which density?

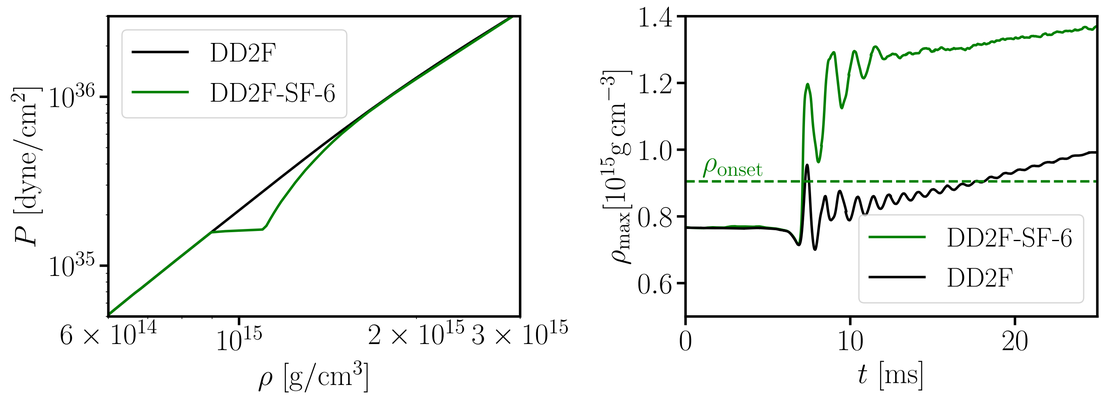
Neutron star mergers probe the high density and low temperature region inaccessible to experiments.

Merger Snapshots



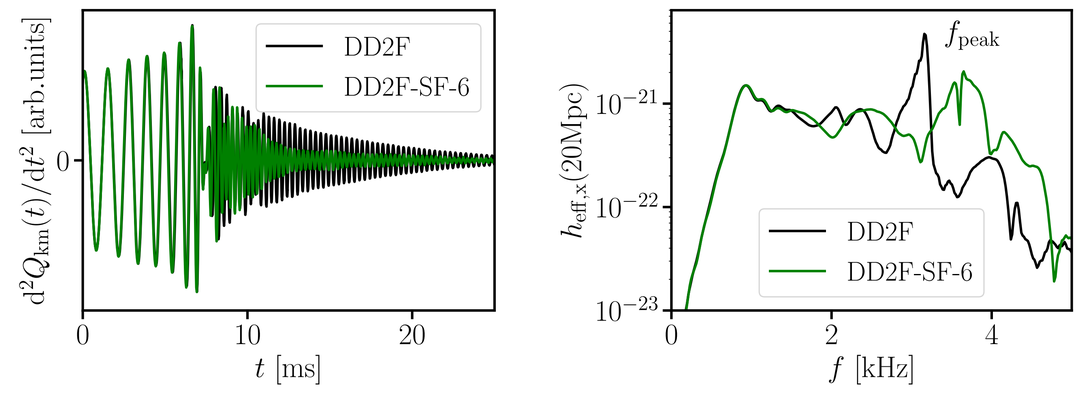
Plots taken from [1], contours highlight regions with mixed and pure quark phases.

Impact of a phase transition



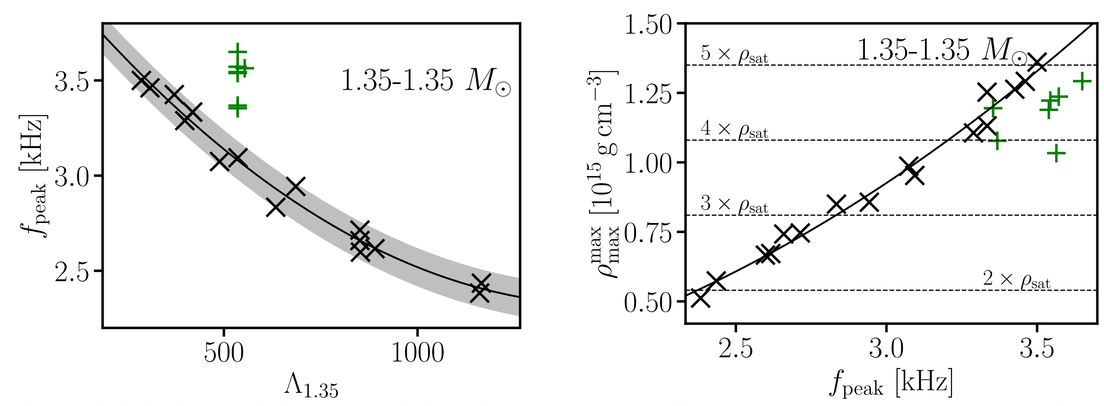
The quark-hadron phase transition strongly softens the equation of state. This softening leads to higher densities densities in merger remnants compared to a model with no phase transition. See [2] for details on the used model.

Gravitational wave signal



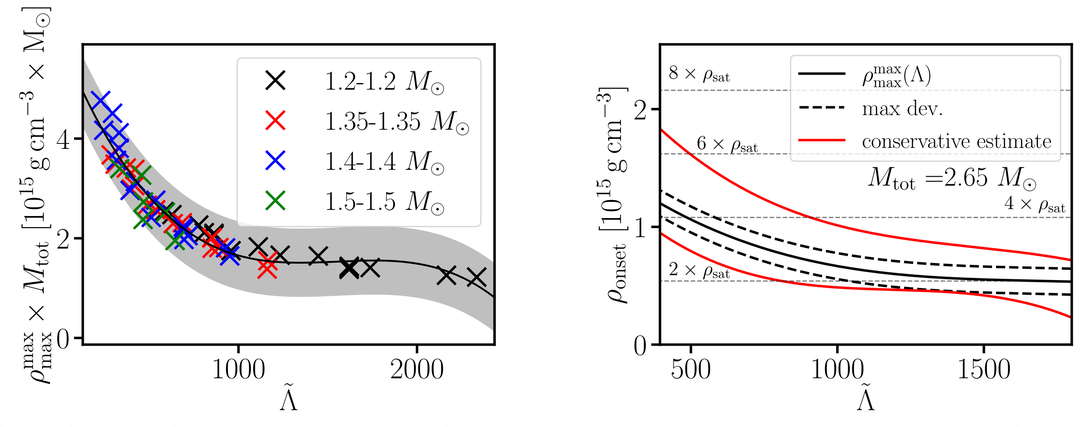
The phase transition impacts the postmerger GW signal and leads to larger frequencies. Since deconfined quarks appear after the merger the inspiral signal is unaffected.

Identifying a phase transition



The tidal deformability Λ and the dominant GW frequency $f_{\rm peak}$ are encoded in the pre- and the postmerger, respectively. Outliers from empirical relations can be used to detect a strong phase transition and constrain the onset density.
See [3] for details. Figures taken from [1].

Constraining the onset density



The relations between Λ, $f_{\rm peak}$ and maximum postmerger density $\rho_{\rm max}^{\rm max}$ can be combined to estimate the onset density of a strong phase transition $\rho_{\rm onset}$. If no sign of a transition is present a lower limit on $\rho_{\rm onset}$ can be inferred. A clear indication of a transition provides an upper limit on $\rho_{\rm onset}$. Figures taken from [1].

Acknowledgment

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References

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

[2] Bastian, PRD **103**, 023001 (2021)

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