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Simulations of massive star explosions driven by a first-order QCD phase transition. Neutrino signal and gravitational wave mode analysis

Astrophysical simulations are crucial for investigating high baryon density environments and exploring the occurrence of a first-order QCD hadron-quark matter phase transition under extreme conditions. Specifically, multi-messenger neutrino and gravitational wave emissions from corecollapse supernovae not only provide a measurable signal for the presence of deconfined quark matter, but also offers insights into the state of matter at extreme conditions within the supernova core [1,2]. This phenomenon manifests as a non-standard second neutrino burst dominated by electron-antineutrinos as well as heavy lepton flavour (anti)neutrinos. Extensive simulations of core-collapse supernovae have been conducted, integrating various stellar progenitor models and equations of state that incorporate the quark-hadron phase transition based on the String-Flip model for deconfined quark matter featuring the relativistic density functional approach [3]. The supernova simulations employ general relativistic neutrino-radiation hydrodynamics with threeflavour Boltzmann neutrino transport, establishing a direct connection between intrinsic signatures of the neutrino signal and selected bulk properties of the hadron-quark hybrid equation of state. Notably, a set of novel empirical relations has been discovered, potentially providing constraints on the onset density of a phase transition [4]. This determination is presently one of the major
uncertainties in contemporary investigations of the QCD phase diagram, and it can be informed by future neutrino observations of the next galactic core-collapse supernova.

References

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