PAP301 Seminar in Particle Physics and Astrophysical Sciences
Sofia Blomqvist
Abstract (12.3.2024)

# Constraining twin stars with *ab initio* calculations

The matter in neutron stars exists under extreme conditions, offering a promising way to investigate high-density matter, described by the theory of quantum chromodynamics (QCD). The properties of QCD matter are encoded in the equation of state (EoS), which describes the relationship between pressure and energy density. However, due to the limited availability of the first-principle calculations, the exact form of the EoS can be determined only at high- and low-density limits, excluding the intermediate densities reached inside neutron stars. Given that the deconfining phase transition (PT), separating hadronic matter and quark matter, may occur in this density range, its presence could affect the observable properties of corresponding stars and provide insights into the structure of the largely uncharted QCD phase diagram.

This work centers around twin stars, hypothetical compact objects that extend beyond the neutron star sequence in the mass-radius relation. They originate from a strong first-order PT in the relevant density range, and we make an assumption that this PT corresponds to the deconfining PT in the QCD phase diagram. We study the constraints on these PTs using a model independent approach by employing a continuous piecewise interpolation in the intermediate densities and construct a large ensemble of twin star EoSs with an explicit first-order PT. We approximate the sides of the PT with a simple polytropic form and connect the ends to the chiral effective field theory result at nuclear densities and extrapolated perturbative QCD result at high densities. No *a priori* limitations for the strength and onset of the PT are set to probe all possible twin star EoSs within the scope of our approach. The resulting EoSs are then subjected to astrophysical constraints obtained from high-mass neutron stars and gravitational wave detections to verify their compatibility with observations.

Upon imposing the astrophysical constraints, we observe that only a small subset of twin star solutions survive. We then identify two distinct types of twin stars, originating from separate small regions in the parameter space, with a notable difference in the strength of the PT. Examination of the macroscopic properties of twin stars, such as mass and radius, reveals that these solutions only marginally pass the astrophysical constraints. Given these observations, we conclude that twin stars do not seem to be a very probable scenario. However, a hypothetical observation of twin stars would serve as a signal of a first-order PT between hadronic matter and quark matter. Such an outcome would not only be significant for the understanding of neutron stars but serve as a powerful way to shed light into the structure of the QCD phase diagram.