論文の内容の要旨

Towards QCD-based equation of state of dense matter

(高密度物質状態方程式の QCD に基づく構築に向けて)

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The equation of state (EoS) of the strongly-interacting cold and dense matter is a crucial ingredient for studying extreme astrophysical objects and phenomena such as neutron stars, core-collapse supernovae, neutron star binary mergers, etc. It also serves as an essential input for theoretical studies of the finite-density region of quantum chromodynamics (QCD); in this region very little is known up to now. The EoS of dense matter should be derived from QCD, but there are a plethora of technical difficulties which prevent us from QCD-based *ab initio* calculations. Nevertheless, the QCD-based calculation is still possible at high densities where the perturbative expansion in the strong coupling constant makes sense. In the conventional perturbative QCD (pQCD) calculations, however, the results are known to be plagued by a large uncertainty originating from the ambiguity in the choice of the renormalization scale. This scale variation uncertainty becomes larger as the density decreases, so that we cannot utilize the pQCD calculation at the realistic density realized inside neutron stars. The major driving force of this thesis is to lessen this scale variation uncertainty in the pQCD calculation.

To this end, we discuss the Hard Dense Loop (HDL) resummation at finite quark mass. In the preceding works, Hard Thermal Loop (which is the high-temperature counterpart of the HDL) resummation is recognized to improve the convergence of the perturbative expansion. We employ the HDL perturbation theory, which is one of the perturbative schemes to resum HDLs, and evaluate the EoS of dense QCD matter using this theory with a hope to alleviate the scale variation uncertainty. The finite bare quark mass is important for the quantitative construction of the EoS in realistic stellar environments, where the β equilibrium and electric charge neutrality conditions are maintained.

The resummation in the quark sector has the effect of lowering the baryon number density, and the EoS turns out to have much smaller uncertainty than the existing pQCD estimate. As a result, we can plot our numerical results on top of the existing constraints on the EoS from neutron star observations; our results favor smooth matching between the EoS from the resummed QCD calculation at high density and the extrapolated EoS from the nuclear matter density region. We discuss in some detail why the scale variation uncertainty is reduced, and write down the explicit condition for the reduction of the uncertainty. We also point out that the speed of sound in our EoS slightly exceeds the conformal limit; as the speed of sound is a measure for the stiffness of the EoS, surpassing the conformal limit brings about the qualitative difference in the behavior of the EoS.