Phenomenology of cold and dense strongly interacting matter

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Approximately 10 μs after the Big Bang, as the Universe was cooling, a phase transition happened, the so-called *color confinement*. As a result, almost massless elementary particles–quarks and gluons–have lost their asymptotic freedom, forming massive bound states–hadrons–from which most of the mass in the observable Universe is made of. This raises very interesting questions. Namely, why hadrons are massive, while their individual constituent quarks are practically massless, and why one cannot observe quarks and gluons separately. The underlying interaction behind these peculiar phenomena is the *strong interaction*, and the theory that describes it *quantum chromodynamics* (QCD). Understanding the nature of QCD is one of the biggest challenges in modern particle physics. Unfortunately, due to its complexity, the theory cannot be entirely solved, and thus other, indirect, means have to be harnessed. At finite temperature, the first-principle ab-initio calculations provide an answer to the nature of the quark-hadron phase transition and the QCD phase structure. Unfortunately, despite enormous effort put to extending its predictive power, the high-density regime is still far from being achievable in the first-principle calculations. The state-of-the-art knowledge about high densities comes mostly from effective phenomenological approaches. The primary objective of the project is to investigate and provide a better understanding of significant aspects of the thermodynamics of strongly interacting matter; namely, how the transition from hadrons to their constituents–quarks and gluons–relates to the underlying deconfinement and chiral dynamics. This problem is of major importance for heavy-ion collisions and the physics of compact stellar objects, such as neutron stars. The main focus of the project will be on the regime beyond the applicability of the ab-initio methods and current experimental reach. The project is devoted to an extensive study of a phenomenological hybrid hadron-quark model designed for QCD phase transitions. An array of applications and various thermodynamic quantities, such as equation of state or fluctuaions of conserve charges, will be thoroughly investigated as possible probes for expected phase transitions. The study will help to better understand the QCD phase transitions and their underlying dynamics, provide new possible scenarios and shed light onto yet incomplete description, in particular, of the low-temperature and high-density regime of the QCD phase diagram.