Chromo-magnetic Gluons in QCD Thermodynamics

Quantum Chromodynamics (QCD) is the modern theory to describe strong interactions responsible for nuclear forces binding protons and neutrons in nuclei. The mechanism to generate the proton mass has a crucial impact over the formation of matter in the Universe after the Big Bang. Because of the characteristic feature of QCD, called asymptotic freedom, *confinement* of the elementary particles (quarks and gluons) into composite systems (hadrons) emerges, and the pair of a quark and an anti-quark gets condensed leading to *spontaneous breaking* of the QCD global symmetry, which gives rise to the mass of the hadrons in the ground state as well as a tower of resonances. These two phenomena cannot be reached in any theoretical framework with naive expansion schemes around the trivial ground state. Thus, it is the standard approach to employ relevant symmetries of the system to build an effective theory as an approximation of QCD yet valid within a certain range of the characteristic scale. There exists a variety of such effective theories to explain, to some extent, the aforementioned phenomena. Yet, it remains highly challenging to reach a contemporary consensus on the mysterious interplay between the two phenomena. This is one of the central issues in understanding the physics of early Universe in which the temperature reaches 10^{12} Kelvin (n.b. 10^7 Kelvin in the core of the Sun) accessible in present and near-future accelerators, and of compact stellar objects that are much denser than the ordinary matter around us.

The main goal of this project is to disentangle the interplay between the emergence of massive hadrons and confinement of quarks and gluons in extreme environments. The ordinary matter composed of hadrons is expected to change into a plasma of quarks and gluons at high temperature and/or high density. Such a phase transition is driven by a drastic change of the strong interaction mediated by the gluons in a medium, in particular the gluons in the *chromo-magnetic* sector (as a subspace of the entire color space) exhibit a totally different property from the *chromo-electric* ones. Thus, the crucial question is how to describe the in-medium modification of the gluon properties near the QCD phase transition to disentangle the nontrivial aspect from the bulk. So far, numerical simulations of QCD and experiments with heavy-ion collisions have revealed a number of nontrivial results, but at present we do not find a mutual description of all of them. We aim at bridging the gap among them to reach a qualitative understanding of the intrinsic properties of QCD and its phase structure.

The impact of our project is of great significance in providing us a more elementary view on the mysterious aspects of QCD. Our comprehensive study will offer a primary description of the complex phenomena anchored to the underlying symmetries and topology of QCD. Selected quantities testable in heavy-ion experiments and in numerical simulations will also be provided to verify our predictions. This has a big phenomenological impact in searching for signatures of the QCD phase transition and its critical phenomena.