

The main goal of the project is to investigate the dynamical properties of hot strongly interacting matter known as the quark-gluon plasma (QGP). The matter in this unusual state consists of quarks and gluons deconfined from particles such as protons, which build up the standard nuclear matter we deal with on a daily basis. The QGP was one of the phases the Universe went through just after the Big Bang, while currently, it arises only under experimental conditions, as a result of heavy ion collisions which study the basic structure of matter. However, due to the unique properties of strong interactions and the extremely short lifetime of the plasma, we are not able to directly observe the QGP in any experiment. Hence, along with the experimental research, various theoretical and phenomenological analyzes based on the theory of strong interactions – quantum chromodynamics (QCD) – are also extremely important. The results of such studies not only complement the data collected by the detectors, but often also predict later discoveries.

At the beginning of the 21st century, experimental studies confirmed theoretical suggestions that the quark-gluon plasma is the most ideal fluid that can exist in nature, due to its extremely low ratio of the shear viscosity to the entropy density. Therefore, more transport parameters such as bulk viscosity, electrical and thermal conductivities, and other quantities indicating specific properties of the QGP, began to be investigated. However, the exact temperature dependence of such coefficients has not yet been determined due to the extreme complexity of the processes occurring in the QGP. Additionally, it is known that its characteristics depend on the number of types (flavors) of quarks present in the system. In the most common description, the QGP includes gluons, light quarks (up and down), and strange quarks, while the incorporation of heavy flavors, such as charm quarks, is a promising direction in studies of strongly interacting matter. The heavy quarks and their bound states – quarkonia - are produced in the early stages of heavy ion collisions, before the formation of the quark-gluon plasma. Hence, they are involved in all stages of its evolution. Given also that the charm quark masses are much larger than the temperature scale at which the QGP is usually studied, they are considered as powerful probes of its dynamical properties.

It is not practically possible to include all phenomena occurring in hot strongly interacting matter into theoretical models. Nevertheless, the combination of several important aspects provides new information about the properties and evolution of the QGP. Therefore, this project aims to study the bulk properties of the quark-gluon plasma, whose equation of state also includes the charm quark contribution. The calculations will be based on the quasiparticle model, in which quarks and gluons are considered massive, almost non-interacting quasiparticles, whose effective masses depend on temperature and the interaction strength within the system. The interactions between the quasiparticles are characterized by the effective coupling determined from the equation of state obtained by ab-initio lattice QCD simulations. This will allow for obtaining currently unknown values of the shear and bulk viscosities, the electrical conductivity, the spatial diffusion coefficient, and the charm quark energy loss due to its interaction with the medium. The results will bridge the gap in the knowledge of dynamical properties of the QGP in presence of charm quarks participating in its equation of state.

Due to the extreme changes which take place during the evolution of the quark-gluon plasma, it initially appears far from the thermodynamic equilibrium. Therefore, the analysis will also consider the momentum-space anisotropy of the system. This will broaden our knowledge about how different parameters depend on the changes of the momentum components of the quasiparticles. In addition, the description will consider a finite (non-zero) quark chemical potential which determines how far the system appears from the total chemical equilibrium and brings a phenomenological description of the QGP closer to a real-world scenario. Such conditions enable to calculate the quark number susceptibilities to the variation of the chemical potential. It is particularly interesting to study the temperature-dependence of these quantities in the vicinity of the pseudocritical temperature related to the transition of the quark-gluon plasma into the hadronic matter.

The effective quasiparticle model has already successfully described the transport coefficients of the isotropic plasma constituted only of gluons or additionally of light and strange quarks. Therefore we expect that the inclusion of charm quarks, the momentum-space anisotropy, and the finite chemical potential will provide new information on dynamical properties and time evolution of the quark-gluon plasma. The results can be further applied in hydrodynamic simulations of the QGP, which is another advantageous tool to explore phenomena that take place in the heavy ion collisions.