Recently, there has been an impressive progress in the investigation of the extreme states of matter in lattice quantum chromodynamics (QCD) as well as in experiments with ultrarelativistic heavy-ion collisions and by multi-messenger observations of neutron stars and their mergers. The main goal of these studies is to uncover the nature and the location of the transition from the hadronic phase of matter (described for instance by a statistical system of hadronic resonances) to the quark-gluon plasma in the phase diagram spanned by temperature T and chemical potential μ_B (fixing the baryon density), see Fig. 1. This phase diagram can be divided into three regions: 1) to the left of the red dashed line lattice QCD is applicable and provides the equation of state of matter which can be directly used to simulate and interpret high-energy heavy-ion collisions (HIC) at the RHIC and LHC collider facilities; 2) to the left of the green dashed line heavy-ion collisions can probe the state of matter and investigate the phase transition to the quark-gluon plasma (orange blurred line) where possibly a first-order phase transition (red line) with a critical endpoint (red dot) can be located, and 3) states of matter to the right of the green dashed line are exclusively accessible under astrophysical conditions, in the interior of neutron stars (NS), their mergers, or in supernova explosions. Here, the color superconducting quark matter phase can be found, indicated by pairing of the quarks (colored dots joined with lines).

Only a joint investigation of the phenomenology from HIC and NS astrophysics has the potential to provide a complete picture of the QCD phase diagram. In order to quantify the location and character of the transition between hadronic and (color superconducting) quark matter phases, the development of an appropriate Bayesian analysis (BA) is suggested in the present project.

The BA method has been successfully applied in the case of region 1), where the equation of state has a single parameter T and large statistics high precision data from RHIC and LHC could be used to find the most probable parameter values of the EoS which then passed the test of comparison with the well-known EoS from lattice QCD.

At T=0, the EoS is also dependent on a single parameter only, the chemical potential. We have performed pioneering work in developing the BA for extracting the most probable EoS from NS observations that provide constraints on their masses and radii. We have found evidence for a strong phase transition to deconfined, color superconducting quark matter in NS interiors.

It is the goal of the present project to generalize the BA method in order to use the data from both, the HIC as well as NS astrophysics in determining the most probable EoS in the multi-parameter phase diagram and to determine in particular the location and character of the phase transformation.

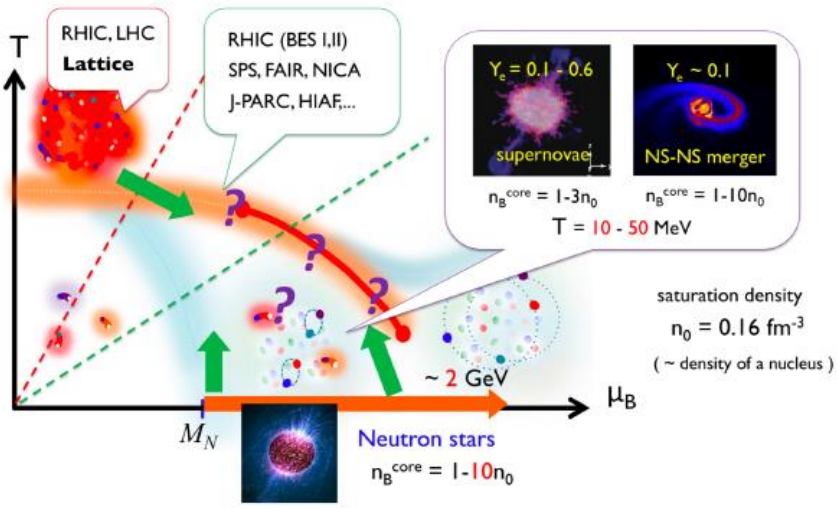

Fig. 1. Sketch of the QCD Phase diagram with three regions (delimited by the red and green dashed lines) from which data will be implemented in the Bayesian analysis of the present project in order to extract the most probable equation of state of strongly interacting matter.