NTNU – Trondheim
Norwegian University of
Science and Technology

Master projects 2016/2017

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Introduction

My research is focused on strongly interacting matter in extreme conditions, i.e. QCD at high temperature and density. High-temperature QCD is relevant for the early universe as well as heavy-ion collisions carried out at CERN (LHC) and Brookhaven (RHIC). Fig. 1 shows the QCD phase diagram as a function of baryon chemical potential and temperature. The projects sketched below are part of the efforts to understand the high-density part of the phase diagram, i.e. at high baryon chemical potential.

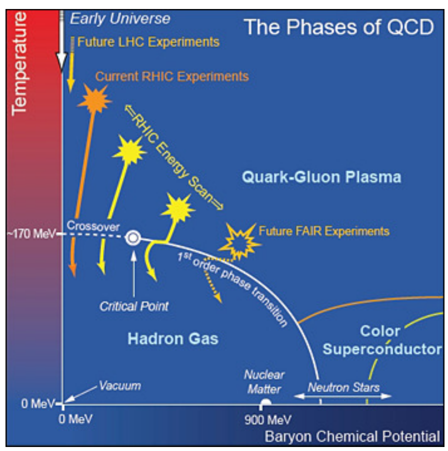

Figure 1: QCD phase diagram.

In 2015, the astroparticle group at NTNU started a formal collaboration with the astroparticle/cosmology group at the University of Stavanger (UiS). As such we are very strong group that now offers joint projects. This gives the students the possibility to work within a larger group. The idea is that the students have a local supervisor taking care of the daily supervision and a co-supervisor in Stavanger. The student will make a couple of trips to UiS during the project to be supervised and to interact with the group.

1 Joint projects

Chiral symmetry breaking in effective models of QCD:
Quantum chromodynamics (QCD) has a global symmetry which ensures among others that pions are the lightest hadrons. However, this symmetry is broken by the existence of tiny quark masses. The goal of this project will be to study in detail the effects of explicit chiral symmetry breaking in low-energy effective models of QCD - the Nambu-Jona-Lasinio model and the linear sigma model - and to work out a detailed mapping between the two models using bosonization techniques. This is a follow-up project on a recent work done jointly at NTNU and UiS (Andersen, Brauner and Naylor, Phys. Rev. D92, 114504, 2015). Required background: Classical and (basic) quantum field theory. Preliminary knowledge of basics of QCD would be an advantage, but can also be acquired at the initial stages of the project.

Massive Nambu-Goldstone bosons:
Massive Nambu-Goldstone bosons are particles with a gap that is protected by symmetry and can be computed exactly with the help thereof. The goal of this project will be to investigate their further properties using effective field theory, and compare them to those of ordinary, gapless Nambu-Goldstone bosons: low-energy theorems, interactions with other modes etc. This is a follow-up project on the work done in Watanabe, Brauner and Murayama, Phys. Rev. Lett. 111, 021601, 2013. Required background: Classical and (basic) quantum field theory, basics of the theory of Lie groups and Lie algebras.

Effective potential and beta-function of 2HDM at one loop
The two-Higgs-doublet model (2HDM) is an extension of the Standard Model of electroweak interactions that includes an additional set of scalars. The goal of this project will be to calculate the running of the parameters of 2HDM at one loop using the MS-bar scheme. This is a part of a larger collaboration project between UiS, Helsinki University and NTNU, concerned with electroweak physics in the early universe. Required background: Quantum field theory including renormalization at one loop. Preliminary knowledge of the Standard Model would be an advantage, but can also be acquired at the initial stages of the project.

Axion electrodynamics near a domain wall:
Axion electrodynamics is a classical theory of electromagnetic fields interacting anomalously with an electrically neutral scalar. It finds applications in different physics branches. The goal of this project will be to study the properties of electromagnetic fields near a topological interface (for instance a pion domain wall in dense quark matter or the surface of a topological insulator), in particular the interplay of surface and electromagnetic waves. Required background: Classical electromagnetism and field theory. Familiarity with basics of quantum field theory would be an advantage, but is not mandatory.

If you are interested, please send an email to **jensoa@ntnu.no** including a CV and a few words about yourself.

2 Other projects

Project 1

As we squeeze nuclear matter so the density is a few times nuclear matter density, it is expected that the quarks inside the hadrons are liberated and we obtain a new phase of QCD, namely quark matter. The phase transition is associated with the restoration of chiral symmetry. In this project, we are going to examine the phase transition from a low-density phase with neutrons, protons and other hadrons, to a phase of quark matter. Adding a magnetic field is relevant as there are very strong magnetic field inside neutron stars.

Prerequisites: Quantum field theory I (FY3464). Gravitation and Cosmology (FY3452). Particle Physics (FY3403). Numerical physics (TFY4235).

Project 2

Neutron stars are compact objects with a mass of 1-2 solar masses and a radius of approximately 10 kilometers. In this project, we are going to investigate the properties of so-called quark stars. These are neutron stars whose cores are so dense that the quarks inside the hadrons have been liberated. This phase of QCD is called quark matter. At lower densities, one expects that the quarks are still confined inside the neutrons. One needs to find an equation of state that describes quark matter and that can be matched onto a nuclear equation, in order to describe the star at all densities from the core to the surface. Possible phases inside a neutron star are shown in Fig. 2.

Prerequisites: Quantum field theory I (FY3464). Gravitation and Cosmology (FY3452). Particle Physics (FY3403). Numerical physics (TFY4235).

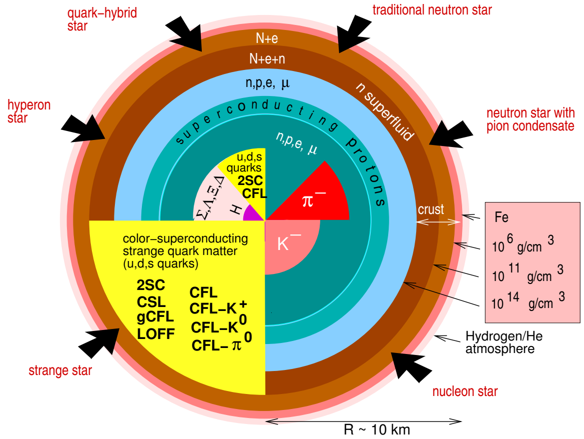

Figure 2: Possible phases inside compact stars.

Project 3

Einstein's general theory of relativity is a spectacularly successful theory. For example, it describes bending of light near heavy objects, black holes, and the perihelion precession of Mercur. However, general relativity is a classical field theory In this project, we are going to investigate general relativity as an effective quantum field theory, valid up to some scale (smaller than the Planck mass, where string theory is needed). Using the framework of effective field theory, corrections to the Newtonain $\frac{1}{r}$ potential as well as corrections to the Schwarzchild metric will be calculated.

Prerequisites: Quantum field theory I (FY3464). Gravitation and Cosmology (FY3452). It is a very challenging project and requires analytical skills.

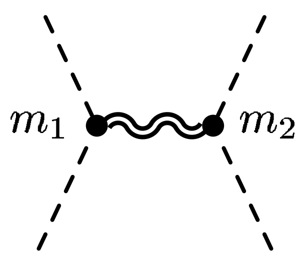

Figure 3: Exchange of a graviton.

Project 4

In this project, we are going to study quark matter in a strong magnetic field at high density. The quark-meson model is an effective low-energy theory that can be used to investigate the chiral transition as a function of the baryon density and the magnetic field. Adding a nonzero isospin chemical potential gives rise to pion condensation and superconductivity once the chemical potential exceeds the pion mass. Such calculations are relevant for compact stars as very strong magnetic fields are present.

Prerequisites: Quantum field theory I (FY3464). Particle Physics (FY3403).