First Year PhD Report

Cycle: XXXIX

Student: Jonas Rongen

Supervisor: Prof. Andrea Amoretti

Research Activity

My research focuses on the intersection of hydrodynamics and holography. Hydrodynamics is an effective field theory that describes interacting systems near thermal equilibrium in the long-wavelength, long-time regime. The dynamics of such systems are governed by the conservation of energy and momentum, as well as potential U(1) charge conservation laws. This approach provides a robust framework for studying strongly interacting systems where particle-like degrees of freedom are not well-defined, and the only long-lived excitations are conserved currents dictated by the system's symmetries.
Another powerful tool for analysing strongly interacting systems is gauge/gravity duality, using its property being a weak/strong coupling duality. By combining these two approaches, my work seeks to better understand the behaviour of strongly coupled systems where conventional methods fall short.

Dissipative electrically driven fluids
My first project built upon a previous one by my supervisor, which aimed to develop a hydrodynamic formulation to describe the stationary states of electrically driven systems in a manner similar to the Drude model. Drude's model of electron transport offers a simple, phenomenological framework to describe charge transport in a conductor under the influence of an external electric field. In this model, a mechanism that dissipates both energy and momentum is necessary to prevent the indefinite acceleration of charge carriers, which would otherwise continue due to the energy and momentum supplied by the electric field. The balance between energy and momentum sinks and the applied electric field allows the system to reach a steady state.
In the standard hydrodynamic description of a charged fluid subjected to an external electric field, a stationary state is achieved when the external electric field is balanced by the gradient of the chemical potential. Consequently, unlike in Drude's model, the fluid's velocity and the external electric field are treated as independent degrees of freedom.
To address this issue, the previous work by my supervisor explored the modification of the hydrostatic constraints by incorporating relaxation terms. This lead to Drude-like behaviour, in the sense that the electric field in these stationary states is not fully counteracted by the gradient of the chemical potential.
The approach necessitates that the fluid velocity becomes itself a thermodynamic variable, such that different inertial frames correspond to distinct hydrodynamic states. The framework for describing such fluids is known as "boost-agnostic" hydrodynamics.
As in Lagrangian mechanics, the energy and momentum relaxation terms — analogous to non-conservative forces — have been introduced by hand to the equations of motion, after having derived the conservative components using a variational principle. To ensure consistency, it has been assumed that the relaxation contributions can be separated

into two types: those that can be expressed in terms of stationary tensor structures and those that vanish at stationarity. The initial paper focused on the first type, while my work extended the analysis to examine the energy and momentum relaxation terms of the second type.
Specifically, I investigated flows that achieve a steady state under the influence of an external electric field, incorporating tensor structures in the constitutive relations that are first-order in derivatives and vanish at stationarity, including entropy-generating flows. By enforcing positivity of entropy production, I constrained the relevant transport coefficients and characterised energy relaxation in terms of momentum relaxation.
I then applied the developed theory to calculate the thermo-electric conductivities of the system in the absence of microscopic time-reversal invariance. It was observed that when time-reversal invariance, i.e. Onsager reciprocity, is imposed, the AC thermo-electric conductivities assume their Drude form. Moreover, it has been found that the contribution of the incoherent conductivity to the electric conductivity vanishes.

Magnetically suppressed linearised quasihydrodynamics
I recently joined a new project where I will study the diffusion in probe brane models and their behaviour under $SL(2,\mathbb{Z})$. For this, alternative quantisation of the D3/D5 system will be used. The aim of the project is to gain a deeper understanding of non-equilibrium steady states.

Publications

- A. Amoretti, D. K. Brattan, L. Martinoia, and J. Rongen, "Dissipative electrically driven fluids," arXiv:2407.18856 [cond-mat.stat-mech].

Courses

I attended the following courses:

- Non-Abelian Gauge Theory (N. Maggiore, 3 CFU)
- Introduction to AdS/CFT (A. Amoretti, 3 CFU)
- Black hole thermodynamics (S.Giusto, 3 CFU)
- Introduction to the Foundations of Quantum Mechanics and Applications (P. Solinas and N. Zanghi, 3 CFU)

Schools and seminars

I attended the following PhD schools and seminars:

- "LACES 2023", PhD school in Florence, Italy, 27 November 2023 - 15 December 2023
- "CERN–SEENET-MTP–ICTP PhD Training program", PhD school in Thessaloniki, Greece, 9 June 2024 - 16 June 2024.
  I gave a short presentation (10 min), titled "Boost-Agnostic Hydrodynamics"

- Weekly seminars organised by INFN Genova throughout the whole year