GHENT UNIVERSITY

Course Specifications

Valid as from the academic year 2024-2025

Relativistic Hydrodynamics - from Quantum Field Theory to Black Holes (C004421)

Course size *(nominal values; actual values may depend on programme)*

Credits 6.0 **Study time 180 h**

Course offerings and teaching methods in academic year 2024-2025

A (semester 1)	English	Gent	lecture
			seminar

Lecturers in academic year 2024-2025

Heller, Michal	WE05	lecturer-in-charge
Serantes Rubianes, Alexandre	WE05	co-lecturer

Offered in the following programmes in 2024-2025	crdts	offering
Master of Science in Teaching in Science and Technology(main subject Mathematics)	6	A
Master of Science in Teaching in Science and Technology(main subject Physics and Astronomy)	6	A
Master of Science in Mathematics	6	A
Master of Science in Physics and Astronomy	6	A
Master of Science in Physics and Astronomy	6	A
Exchange Programme in Physics and Astronomy (Master's Level)	6	A

Teaching languages

English

Keywords

Relativistic hydrodynamics, Schwinger-Keldysh formalism, kinetic theory, applied holography, black holes, quark-gluon plasma, heavy-ion collisions

Position of the course

The goal of this course is to teach both fundamental concepts, as well as recent developments in non-equilibrium field theory centred around relativistic viscous hydrodynamics, its microscopic origins and questions of its applicability. This is a timely topic due to experimental studies of collective state of strong interactions — the quark-gluon plasma — at RHIC and LHC accelerators in the course of the past 20 years and associated theoretical progress. The course provides an opportunity for students to deepen their knowledge of quantum field theory by studying it in the context of collective states of matter. In a similar vein, it provides also an opportunity to train general relativity skills by studying a novel paradigm (holography) in which time-dependent black hole processes describe nonequilibrium physics of strongly-coupled quantum field theories. Finally, the students will familiarise themselves with the notion of asymptotic expansions, usually known from the perturbation theory in quantum systems, by studying their appearance in the context of non-equilibrium physics.

Contents

- Introduction
- Basics of relativistic hydrodynamics
- Relativistic hydrodynamics as an initial value problem
- Viscosity from the Kubo formula and the Schwinger-Keldysch formalism
- Black holes as a novel tool to study strongly-coupled quantum field theory
- From weakly-coupled quantum field theory to relativistic kinetic theory
- Nonequilibrium processes beyond relativistic hydrodynamics
- Relativistic hydrodynamics and asymptotic series
- Summary and discussion of some open problems in this discipline

The course will require students to participate in small groups in projects based on literature review (for example, new formulations of equations of motion for relativistic hydrodynamics, action formulations of relativistic hydrodynamics, cutting-edge applications of asymptotic series to relativistic hydrodynamics, relativistic hydrodynamics and fluctuations, higher derivative modifications of general relativity and insights from relativistic hydrodynamics, retarded correlators in free quantum field theory, hydrodynamic attractors) or simple research (for example, solving equations of relativistic hydrodynamics or simple relativistic kinetic theory numerically, studying asymptotic series for relativistic hydrodynamics in a novel setting, study of hydrodynamic attractors in a novel setting).

Initial competences

Required "Quantum field theory" and Relativity, useful but not required Quantum Black Holes and Holography

Final competences

1 Understanding of the relevance of relativistic hydrodynamics for modern theoretical physics.
2 Understanding of the challenges posed by nonequilibrium physics of interacting quantum field theories.
3 Working knowledge of relativistic hydrodynamics and related topics that reflects their contemporary understanding.
4 Enhancement of understanding of other important contemporary theoretical physics topics, such as asymptotic series, effective field theory or modifications of general relativity, via their appearance in the context of relativistic hydrodynamics.
5 Building or strengthening the ability to a) read scientific papers discussing current developments in theoretical physics and b) start research in this area, or in theoretical physics in general.
6 Building or strengthening the ability to work in a group with a focus on scientific collaboration.
7 Building or strengthening the ability to present the results of group research (which includes scientific writing).

Conditions for credit contract

Access to this course unit via a credit contract is determined after successful competences assessment

Conditions for exam contract

This course unit cannot be taken via an exam contract

Teaching methods

Seminar, Lecture, Independent work

Extra information on the teaching methods

Project: students form teams to prepare a literature review or participate in a computational exercise.
Teams present their outcomes both in the form of reports, as well as presentations.

Study material

None

References

Freely available on the web:

https://arxiv.org/abs/1205.5040

https://arxiv.org/abs/0909.0518

https://arxiv.org/abs/1707.02282

https://arxiv.org/abs/1712.05815

Course content-related study coaching

Outside lecture hours, the teacher will be available for further explanation during consultation hours and upon an appointment.

Assessment moments

end-of-term and continuous assessment

Examination methods in case of periodic assessment during the first examination period

Oral assessment

Examination methods in case of periodic assessment during the second examination period

Oral assessment

Examination methods in case of permanent assessment

Assignment

Possibilities of retake in case of permanent assessment

examination during the second examination period is possible

Calculation of the examination mark

- 35% continuous assessment (project)
- 65% end-of-term evaluation (oral examination)