

Conformal anomalies: theory and applications

Tuesday, 31 May 2022 - Thursday, 2 June 2022

Tours Programme

Table of contents

Tuesday 31 May 2022	1
Coffee/Registration	1
Holographic 4-point functions in momentum space: renormalisation, anomalies and reduction scheme	1
Some remarks on thermal CFTs and massless Feynman graphs	1
Lunch	1
Topological Corrections and Conformal Backreaction in the Einstein Gauss-Bonnet/Weyl Theories of Gravity at D=4	1
CFT in momentum space and Anomaly Actions in Gravity	1
Coffee break	1
The Effective Theory of Gravity and Dynamical Vacuum Energy	1
Five decades of the Weyl anomaly	2
Wednesday 01 June 2022	3
Weyl Anomalies of Defects and Boundaries	3
Coffee break	3
Conformal Surface Defects in Maxwell Theory are Trivial	3
Double scaling limits for field theory defects	3
Lunch	3
New thermoelectric transport from the scale anomaly in Dirac/Weyl materials	3
Anomalous Luttinger relation for energy transport: From black hole's atmosphere to thermal quenches	3
Coffee break	4
Conformal anomaly in spin ladders	4
Chiral Magnetic Effect in Heavy Ion Collisions: Status Report on Experiment and Holography	4
Thursday 02 June 2022	5
Persistent order in CFTs	5
Coffee break	5
Boundary Conformal Anomaly in Odd Dimensions	5
Jordan Algebras and Dynamical Conformal Symmetries	5
Lunch	5
Anomaly-free scale symmetry and gravity	5
Renormalization of Horava gravity	5
Coffee break	5
Limiting curvature gravity and problem of singularities	5
Free energy and BPS Wilson loop in N=2 superconformal theories	6
Remembering Werner	6

Tuesday 31 May 2022

Coffee/Registration (09:45-10:15)

Holographic 4-point functions in momentum space: renormalisation, anomalies and reduction scheme (10:15-11:00)

- **Presenter: SKENDERIS, Kostas**

I will discuss the computation of holographic 4-point functions in momentum space, their renormalisation and the associated anomalies and beta functions. I will also present a reduction scheme that allows to explicitly compute a class of such correlators starting from a seed correlator.

Some remarks on thermal CFTs and massless Feynman graphs (11:00-11:45)

- **Presenter: PETKOU, Anastasios**

I will elaborate on a recently observed, unexpected relationship between thermal partition functions of free massive theories in odd dimensions and multiloop Feynman ladder graphs in $d=4$.

Lunch (12:00-14:00)

Topological Corrections and Conformal Backreaction in the Einstein Gauss-Bonnet/Weyl Theories of Gravity at $D=4$ (14:00-14:45)

- **Presenter: CORIANÓ, Claudio**

We investigate the gravitational backreaction, generated by coupling a general conformal sector to external, classical gravity, as described by a conformal anomaly effective action. We address the issues raised by the regularization of the topological Gauss-Bonnet and Weyl terms in these actions and the use of dimensional regularization (DR). We discuss both their local and nonlocal expressions, as possible IR and UV descriptions of conformal theories, below and above the conformal breaking scale. Our discussion overlaps with several recent studies of dilaton gravities - obtained via a certain singular limit of the Einstein-Gauss-Bonnet (EGB) theory - originally introduced as a way to bypass Lovelock's theorem. Nonlocal, purely gravitational realizations of such EGB theories, quadratic in the dilaton field, beside their local quartic forms, are possible by a finite renormalization of the Euler density.

CFT in momentum space and Anomaly Actions in Gravity (14:45-15:30)

- **Presenter: MAGLIO, Matteo**

In this talk, we present an overview of the essential features of the conformal anomaly. On general geometrical grounds, we will see how an amplitude that is both gauge and conformal invariant will contain anomalous trace contributions in the physical limit $d=4$.

Then we will discuss how to obtain the effective anomaly action and illustrate the derivation of the conformal Ward identities directly from its path-integral definition and its Weyl symmetry, which is an alternative to the standard operatorial approach used in conformal field theories in flat space. Then we will present the method to write the general structure of correlation functions in momentum space by solving the conformal constraints. We briefly discuss the procedure for scalar four-point functions to determine the dual conformal solutions, identified only by the CWIs, and related to the conformal Yangian symmetry. We will see that in correlation functions with energy-momentum tensors, evaluated around a flat spacetime, the conformal anomaly is characterized by the (non-local) exchange of massless poles in specific form factors, which has been investigated both in free field theory and non-perturbatively.

Coffee break (15:30-16:00)

The Effective Theory of Gravity and Dynamical Vacuum Energy (16:00-16:45)

- **Presenter: MOTTOLA, Emil**

Gravity and general relativity are considered as an Effective Field Theory (EFT) at low energies and macroscopic distance scales. The effective action of the conformal trace anomaly of light or massless quantum fields has significant effects on macroscopic scales, owing to its describing light cone singularities not captured by an expansion in local curvature invariants. A compact local form for the Wess-Zumino effective action of the conformal anomaly and stress tensor is given, involving the introduction of a new light scalar, which it is argued should be included in the low energy effective action for gravity. This scalar conformalon couples to the conformal part of the

spacetime metric and allows the effective value of the vacuum energy, described as a condensate of a 4-form abelian gauge field, to change in space and time. The EFT of vacuum energy thereby replaces the fixed constant Λ of the classical theory with a dynamical condensate whose natural ground state value in empty flat space is $\Lambda_{\text{eff}} = 0$ identically. In addition to the conformal anomaly, the principal physical inputs to the EFT are a topological vacuum susceptibility characterizing the coupling of the 4-form condensate to the anomaly current, in analogy to the chiral susceptibility of QCD, and the extension of the fermion anomaly to a general Einstein-Cartan space including torsion. By allowing Λ_{eff} to vary rapidly near a black hole horizon, the EFT of dynamical vacuum energy provides an effective Lagrangian framework for gravitational condensate stars, as the final state of complete gravitational collapse consistent with quantum theory. The possible consequences of dynamical vacuum dark energy in cosmology, the cosmic coincidence problem, and the role of conformal invariance for other fine tuning issues in the Standard Model are discussed.

Five decades of the Weyl anomaly (16:45-17:30)

- Presenter: DUFF, Michael

The Weyl invariance under conformal rescaling of the metric tensor, displayed by classical massless fields interacting with gravity, no longer survives in the quantum theory. Since the 1970s this Weyl anomaly has found a variety of applications in quantum gravity, black hole physics, inflationary cosmology, string/M theory, conformal field theory, quantum information theory and statistical mechanics.

Wednesday 01 June 2022

Weyl Anomalies of Defects and Boundaries (09:00-09:45)

- **Presenter: O'BANNON, Andy**

Conformal Field Theories (CFTs) in even spacetime dimensions are characterised in part by Weyl anomaly coefficients, the coefficients of curvature invariants in the stress tensor's trace. In particular, these coefficients often appear in various physical observables, such as thermal entropy, stress tensor correlators, universal contributions to entanglement entropy, and more. Many of them also obey powerful non-perturbative constraints, such as c-theorems. What if the CFT has a boundary or defect, however? How do these contribute to the Weyl anomaly? Do their Weyl anomaly coefficients appear in any physical observables, or obey any constraints? In this talk, I will summarise the state of the art and open questions in our understanding of boundary and defect Weyl anomalies, with emphasis on two- and four-dimensional boundaries and defects.

Coffee break (09:45-10:15)

Conformal Surface Defects in Maxwell Theory are Trivial (10:15-11:00)

- **Presenter: HERZOG, Christopher**

I consider a free Maxwell field in four dimensions in the presence of a codimension two defect. Reflection positive, codimension two defects which preserve conformal symmetry in this context are very limited. Only generalized free fields can exist on the defect and interact with the free Maxwell field in the bulk. This result stands in stark contrast to the codimension one case where interacting conformal boundary conditions can be found for free bulk fields, producing systems with physical relevance, for example for graphene.

Double scaling limits for field theory defects (11:00-11:45)

- **Presenter: RODRIGUEZ-GOMEZ, Diego**

Defect operators in field theory are very interesting for a number of reasons. Drawing inspiration from techniques which have been very recently applied to uncover interesting properties of sectors of operators with large charge under a global symmetry, we will study simple defects in the Wilson-Fisher fixed point near $d=4,6$ dimensions. Combining with localization, we will also introduce a novel double-scaling limit for certain Wilson loops in $N=2$ supersymmetric theories in 4d which allows to make exact statements at finite N .

Lunch (12:00-14:00)

New thermoelectric transport from the scale anomaly in Dirac/Weyl materials (14:00-14:45)

- **Presenter: VOZMEDIANO, María**

The low energy effective description of Weyl and Dirac semimetals as massless Dirac fermions has given rise to new interpretations of thermal and thermo-electric transport phenomena in these materials, associated with quantum field theory predictions. In particular, quantum anomalies - most prominently the chiral anomaly - have provided a novel theoretical frame for the understanding of new magneto transport features. More recently thermal transport has taken the lead in relation to the gravitational anomaly. In this talk we will describe novel response functions associated with the scale anomaly in Dirac and Weyl semimetals. I will try to provide the foundations and the results in a pedagogical way.

Anomalous Luttinger relation for energy transport: From black hole's atmosphere to thermal quenches

(14:45-15:30)

- **Presenter: BERMOND, Baptiste**

The idea that heat has weight led Tolman and Ehrenfest, and later Luttinger, to establish a deep, but classical, connection between gravitational fields and thermal transport. However, gravitational anomalies can introduce additional quantum energy scales, suggesting that their celebrated results can break down at the quantum level. In this work we establish the extent to which anomalies correct the Tolman-Ehrenfest and Luttinger relations, and their effect on thermal transport calculations. Our results reveal that gravitational anomalies are observable in flat-space time when the local temperature varies strongly. This condition maps to regions where the space-time curvature is sizable, including those defining the quantum atmosphere of a black-hole. These observations establish how the trace and gravitational anomalies manifest in non-linear thermal transport, propagating energy waves following a thermal quench, or the energy density of heating Floquet states induced by repeated thermal quenches. Our results offer a systematic way to find examples where to explore gravitational anomalies in flat-space time.

Coffee break (15:30-16:00)**Conformal anomaly in spin ladders (16:00-16:45)**

- Presenter: HANKIEWICZ, Ewelina

Recent theoretical and experimental advances allow for an observation of signatures of quantum anomalies in condensed matter systems. After a brief discussion of the application of chiral and parity anomalies in condensed matter [1,2], we turn our attention to the conformal anomaly in (1+1)D systems. The conformal anomaly signals itself in a breaking of scale invariance by quantum effects, visible in multi-point functions of the energy-momentum tensor. One way of extracting the conformal anomaly, which we will discuss, is to take the expectation value of the energy-momentum tensor in a thermal state of constant temperature. While this is already connected to the free energy of the system and hence the specific heat, we present here a new application. Using the conformal transformation, we relate the variance of the on-site static magnetization to the conformal anomaly and to the experiments on one dimensional systems. Moreover, we show how the deviations of static magnetization are further modulated in systems with gradient of temperature. We expect that these effects are important in spin chains and spin ladders.

Chiral Magnetic Effect in Heavy Ion Collisions: Status Report on Experiment and Holography (16:45-17:30)

- Presenter: LANDSTEINER, Karl

The Chiral Magnetic Effect (CME) is the generation of an electric current in a magnetic field due to a chirality imbalance. It is supposed to occur in non-central heavy ion collisions. I will review the experimental efforts to measure CME and especially highlight the recent results from the isobar run at RHIC. Then I present a holographic model to address the question how fast the CME builds up in an out-of-equilibrium setup. This is a relevant question since the lifetime of the magnetic field is short. Results for static and time dependent fields will be contrasted. The need for better models is evident. To improve this situation the "AdS4CME" collaboration has been formed.

Thursday 02 June 2022

Persistent order in CFTs (09:00-09:45)

- **Presenter: SMOLKIN, Michael**

I will review recent field theory constructions in three Euclidean dimensions which exhibit the phenomenon of persistent symmetry breaking. I will argue that the models under study are scale invariant and unitary. Open questions will be discussed.

Coffee break (09:45-10:15)

Boundary Conformal Anomaly in Odd Dimensions (10:15-11:00)

- **Presenter: ASTANEH, Amin Faraji**

In odd dimensions the integrated conformal anomaly is entirely due to the boundary terms. I will present the heat kernel method as well as the holographic method to compute the conformal charges in the presence of the boundaries in field theories of odd dimensions.

Jordan Algebras and Dynamical Conformal Symmetries (11:00-11:45)

- **Presenter: POPOV, Todor**

The Newton-Hooke duality between the 2D hydrogen atom and the Landau problem is explained via the Tits-Kantor-Koecher construction of the conformal symmetries of the Jordan algebra of real symmetric 2×2 matrices. The connection between the Landau problem and the 3D hydrogen atom is elucidated by the reduction of a Dirac spinor to a Majorana one in the Kustaanheimo-Stiefel spinorial regularization.

Lunch (12:00-14:00)

Anomaly-free scale symmetry and gravity (14:00-14:45)

- **Presenter: TOKAREVA, Anna**

We address the question of whether the conformal invariance can be considered as a global symmetry of a theory of fundamental interactions. To describe Nature, this theory must contain a mechanism of spontaneous breaking of the scale symmetry. Besides that, the fundamental theory must include gravity, whereas all known extensions of the conformal invariance to the curved space-time suffer from the Weyl anomaly. We show that conformal symmetry can be made free from the quantum anomaly only in the flat space. The presence of gravity would reduce the global symmetry group of the fundamental theory to the scale invariance only. We discuss how the effective Lagrangian respecting the scale symmetry can be used for the description of particle phenomenology and cosmology.

Renormalization of Horava gravity (14:45-15:30)

- **Presenter: BARVINSKY, Andrei**

I will discuss quantum properties of the projectable Horava gravity -- the first example of renormalizable, local and unitary gravity theory perturbatively consistent in UV domain and demonstrating asymptotic freedom in $(2+1)$ dimensions and possibly in $(3+1)$ dimensions. Correspondingly I will briefly dwell on gauge dependence issues, background field and heat kernel methods along with the dimensional reduction necessary for the computation of beta-functions and conformal anomalies in such a class of extraordinarily complicated Lorentz non-invariant theories. Possible dark energy and inflationary cosmology implications of this and related theories will be touched upon.

Coffee break (15:30-16:00)

Limiting curvature gravity and problem of singularities (16:00-16:45)

- **Presenter: FROLOV, Valeri**

I shall discuss a recently proposed limiting curvature theory of gravity and its application to the problem of singularities in cosmology and inside black holes. In this theory the growth of the curvature is suppressed by specially chosen inequality constraints included in the gravity action. In this model the Universe has a bounce instead of the initial Big Bang singularity. We also consider a case of a spherically symmetric four dimensional black hole and demonstrate that imposed curvature constraints modify a solution in the black hole interior. Instead of forming the curvature singularity the modified metric describes a space which is exponentially expanding in one direction and oscillating in the other two directions. The spacetime is complete and its polynomial curvature

invariants are uniformly bounded.

Free energy and BPS Wilson loop in N=2 superconformal theories (16:45-17:30)

- **Presenter: TSEYTLIN, Arkady**

I will discuss some recent work on strong-coupling expansion of leading non-planar corrections in several examples of N=2 superconformal models that are planar-equivalent to N=4 super Yang-Mills theory and dual to type II superstring in orbifolds/orientifolds of AdS5 x S5. Starting with the localization matrix model one finds that the large 't Hooft coupling asymptotics of the coefficient of non-planar correction to Wilson loop expectation value is in agreement with a universal prediction on the dual string theory side.

Remembering Werner (17:30-18:15)

- **Presenters: BARVINSKY, Andrei; BARRABES, Claude; FROLOV, Valeri**

The sad news came from Canada that Prof. Werner Israel passed away on 18th May. Werner had close relations with the gravity group in Tours and was a close friend to some participants of the workshop. A new session "Remembering Werner" is devoted to exchange of our memories about Werner.