Analogue Models of Gravity and Fluctuation-Induced phenomena

Higgs Centre Workshop

Edinburgh, 27-29 June 2022

Organizers

Salvatore G. Butera
University of Glasgow

Suddhasattwa Brahma
University of Edinburgh

Iacopo Carusotto
INO-CNR & BEC Center

LEVERHULME TRUST

University of Glasgow
Quantum Theory Group

Relevant information

- **Venue** – The workshop will be held in the Lecture Theatre A, James Clerk Maxwell Building, Peter Guthrie Tait Road EH9 3FD which is located at King's Building Campus. For information on getting to Edinburgh and campus locations please use the following [link]
- The **social dinner** will take place at the **Amber restaurant**, 354 Castlehill, Edinburgh, on Tue 28 at 7.30pm.
- **Covid guidelines** – Please consider that the pandemic is not over yet, and there are vulnerable people among the colleagues attending the workshop. Current Edinburgh University covid regulations can be viewed here. Masks are no longer mandatory but the University encourages staff and students to continue to wear a face covering in indoor or communal areas. We will have a supply of masks available for delegates. We also request that you complete a lateral flow covid test before the start of the workshop. This is not mandatory but just a polite request to help curb any spread of covid to other delegates.

Program

Monday, 27/06/2022	
Session 1 - Chair: Suddho Brahma	
9:00 - 9:30	**Welcome**
9:30 - 10:15	**William Unruh** - University of British Columbia; Vancouver, Canada. *Detection of acceleration temperature in BEC*
10:15 - 11:00	**Martin Bojowald** - Pennsylvania State University; University Park, United States *A moment approach to non-adiabatic quantum dynamics*
11:00 - 11:30	Coffee break
11:30 - 12:00	**Julien Grain** - Paris-Saclay University - CNRS; Orsay, France *Stochastic inflation: modeling the back reaction of quantum fluctuations in cosmology*
12:00 - 12:30	**Ivan Agullo** - Louisiana State University; Baton Rouge, United States *Quantum aspects of stimulated Hawking radiation on an analog white-black Hole pair*
12:30 - 14:00	Lunch
Session 2 - Chair: Patrik Öhberg	
14:00 - 14:45	**Bei-Lok Hu** - University of Maryland; College Park, United States *Quantum Fluctuations in Gravity: Gravitational Cat State, Graviton Noise and Stochastic Gravity*
14:45 - 15:15	**Luca Giacomelli** - University of Paris; Paris, France. *Toy-model black holes in BECs: quantum superradiance and more*
15:15 - 15:45	Coffee break
15:45 - 16:30	**Larry Ford** (Remote talk) - Tuft University; Medford, United States *Analog Models for Quantum Stress Tensor Fluctuations*
16:30 - 17:00	**Maxime Jacquet** - Laboratoire Kastler Brossel - Sorbonne University; Paris, France. *Vacuum quantum excitation of the quasi-normal modes of an analogue black hole in a polariton fluid*
17:00 - 18:00	**Poster session**
	Bettina Beverungen, Humboldt University of Berlin - *Fluctuation-induced interactions in non-trivial geometries* **Hugo Candan**, University of Edinburgh - *Detecting quantum noise in primordial gravitational waves* **Riccardo Falcone**, Sapienza Roma - *Observing single-particles beyond the Rindler horizon* **Kevin Falque**, Kastler Brossel Laboratory - *Experimental investigation of quasi-normal modes and Hawking effect in a polariton fluid* **Moatasem Hassan**, University of Edinburgh - *Entangelment Entropy in the Early Universe* **Haruna Katayama**, Hiroshima University - *A soliton black hole using SNAILs* **Gerard Valenti-Rojas**, Heriot-Watt University - *Quantum Simulation of Liouville Gravity coupled to Fermions*

Tuesday, 28/06/2022	
Session 3 - Chair: Daniele Faccio	
9:00 - 9:45	**Jeff Steinhauer** - Technion; Haifa, Israel. *Hawking radiation in the presence of two analogue horizons*
9:45 - 10:30	**Ian Moss** - Newcastle University; Newcastle upon Tyne, United Kingdom *The hot big bang in a cold gas*
10:30 - 11:00	**Elisabeth Giacobino** - Laboratoire Kastler Brossel - Sorbonne University; Paris, France. *Analog gravity and Hawking effect in a quantum fluid of light*
11:00 - 11:30	Coffee break
11:30 - 12:00	**Fabio Biancalana** - Heriot-Watt University; Edinburgh, United Kingdom *Nonlinear Optics and the Holographic Principle*
12:00 - 12:30	**Gregory Kaplanek** - Imperial College London; London, United Kingdom *Decoherence in de Sitter space*
12:30 - 14:00	Lunch
Session 4 - Chair: Iacopo Carusotto	
14:00 - 14:45	**Gabriele Ferrari** - University of Trento; Trento, Italy *Observation of Massless and Massive Collective Excitations in a Two-Component Superfluid*
14:45 - 15:15	**David Bermudez** - Cinvestav; Mexico City, Mexico *Effective Michelson interference observed in fiber-optical analogue of Hawking radiation*
15:15 - 15:45	Coffee break
15:45 - 16:30	**Daniele Faccio** - University of Glasgow; Glasgow, United Kingdom *Fundamental phenomena in a rotating world*
16:30 - 17:00	**Cisco Gooding** - University of Nottingham; Nottingham, United Kingdom *Detecting the Unruh Effect in an Analogue*
17:00 - 17:30	**Friedrich König** - University of St. Andrews; St. Andrews, United Kingdom *Optical Soliton Analogue of Black Hole Quasinormal Mode Oscillations*
19:30	Social dinner @ Amber restaurant, 354 Castlehill, Edinburgh

Wednesday, 29/06/2022	
Session 5 - Chair: Salvatore Giulio Butera	
9:00 - 9:45	**Miles Blencowe** - Dartmouth College; Hanover, United States *Analogue gravity with optomechanical circuit systems*
9:45 - 10:30	**Silke Weinfurtner** - University of Nottingham; Nottingham, United Kingdom *Preheating experiments*
10:30 - 11:00	**Francesco Intravaia** - Humboldt University of Berlin; Berlin, Germany *On the physics of Quantum Friction*
11:00 - 11:30	Coffee break
11:30 - 12:00	**Jibril Ben Achour** - Arnold Sommerfeld Center for Theoretical Physics; Munich, Germany *From gravity to fluid mechanics via dynamical symmetries*
12:00 - 12:30	**Thomas Colas** - Paris-Saclay University; Paris, France. *Cosmological Master Equations*
12:30 - 13:00	**Final discussions & Conclusions - Chairs: Iacopo Carusotto, S. Giulio Butera, Suddho Brahma**
13:00 - 14:00	Lunch

Participants

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Presentations

- *From gravity to fluid mechanics via dynamical symmetries*
  Jibril Ben Achour – Arnold Sommerfeld Center for Theoretical Physics; Munich, Germany.

- *Quantum aspects of stimulated Hawking radiation on an analog white-black Hole pair*
  Ivan Agullo – Louisiana State University; Baton Rouge, United States.

- *Effective Michelson interference observed in fiber-optical analogue of Hawking radiation*
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  Thomas Colas – Paris-Saclay University; Paris, France.

- *Fundamental phenomena in a rotating world*
  Daniele Faccio – University Of Glasgow; Glasgow, United Kingdom.

- *Observing single-particles beyond the Rindler horizon*
  Riccardo Falcone – Sapienza University of Rome; Rome, Italy.

- *Experimental investigation of quasi-normal modes and Hawking effect in a polariton fluid*
  Kevin Falque – Laboratoire Kastler Brossel; Paris, France.

- *Observation of Massless and Massive Collective Excitations in a Two-Component Superfluid*
  Gabriele Ferrari – University of Trento; Trento, Italy.

- *Analog Models for Quantum Stress Tensor Fluctuations*
  Larry Ford – Tuft University; Medford, United States.

- *Analog gravity and Hawking effect in a quantum fluid of light*
  Elisabeth Giacobino – Laboratoire Kastler Brossel - Sorbonne University; Paris, France.

- *Toy-model black holes in BECs: quantum superradiance and more*
  Luca Giacomelli – University of Paris; Paris, France.

- *Detecting the Unruh Effect in an Analogue*
  Cisco Gooding – University of Nottingham; Nottingham, United Kingdom.

- *Stochastic inflation: modeling the back reaction of quantum fluctuations in cosmology*
  Julien Grain – Paris-Saclay University - CNRS; Orsay, France.

- *Entangelment Entropy in the Early Universe*
  Moatasem Hassan – University of Edinburgh; Edinburgh, United Kingdom.

- *Quantum Fluctuations in Gravity: Gravitational Cat State, Graviton Noise and Stochastic Gravity*
  Bei-Lok Hu – University of Maryland; College Park, United States.

- *Rubbing without Touching: On the physics of Quantum Friction*
  Francesco Intravaia – Humboldt University of Berlin; Berlin, Germany.

- *Vacuum quantum excitation of the quasi-normal modes of an analogue black hole in a polariton fluid*
  Maxime Jacquet –Laboratoire Kastler Brossel - Sorbonne University; Paris, France.

- *Decoherence in De Sitter Space*
  Gregory Kaplanek – Imperial College London; London, United Kingdom.

- *A soliton black hole using SNAILs*
  Haruna Katayama – Hiroshima University; Hiroshima, Japan.

- *Optical Soliton Analogue of Black Hole Quasinormal Mode Oscillations*
  Friedrich König – University of St. Andrews; St. Andrews, United Kingdom.

- *The hot big bang in a cold gas*
  Ian Moss – Newcastle University; Newcastle upon Tyne, United Kingdom.

- *Hawking radiation in the presence of two analogue horizons*
  Jeff Steinhauer – Technion; Haifa, Israel.

- *Detection of acceleration temperature in BEC*
  William Unruh – University of British Columbia and Texas; Vancouver, Canada.
- *Quantum Simulation of Liouville Gravity coupled to Fermions*
  Gerard Valenti-Rojas – Heriot-Watt University; Edinburgh, United Kingdom.
- *Preheating experiments*
  Silke Weinfurtner – University of Nottingham; Nottingham, United Kingdom.

Abstracts

Detection of acceleration temperature in BEC

Mon 27
9:30–10:15
Session 1

William Unruh
University of British Columbia – Vancouver, Canada

Using circular acceleration by a rotating detector we hope to be able to measure the accelration temperature of a revolving spot of laser light on a BEC. The proposal suffers from a variety of challenges but also offers both novel broadband detector of phonons, (basically a microphone converting phonons to electromagnetic photons) and a novel inteferometer in frequecies rather than in space.

A moment approach to non-adiabatic quantum dynamics

Mon 27
10:15–11:00
Session 1

Martin Bojowald
Pennsylvania State University – University Park, United States

This talk introduces dynamical and geometrical properties of moments that characterize a quantum state. The geometry suggests quasiclassical models for quantum phenomena implied by fluctuations and correlations. Applications include tunneling dynamics and various questions in cosmological backreaction.

Stochastic inflation: modeling the back reaction of quantum fluctuations in cosmology

Mon 27
11:30–12:00
Session 1

Julien Grain
Paris-Saclay University – Orsay, France

Cosmic inflation provides a causal mechanism for producing inhomogeneities that later seed the formation of cosmic structures in the universe. Such primordial inhomogeneities are extracted out of the quantum fluctuations of the matter and gravitational fields and stretched to astronomical scales. Hence, there is a constant inflow of small-scale fluctuations towards large-scale perturbations, which then react back on the dynamics of the universe. Such a back reaction can be investigated by means of the stochastic inflation formalism, an effective theory for the long-wavelengths part of the fields which is treated stochastically once the small-wavelengths have been integrated out. It gives a way to describe an inflating universe that is randomly corrected by the quantum fluctuations reaching the largest scales. After a brief review of the formalism, I present and discuss the assumptions this approach relies on. These include the quantum-to-classical transition of quantum fluctuations and the validity of the separate universe approach, which has been demonstrated to hold beyond slow-roll inflation. Then, I illustrate the use of this formalism considering the example of the unavoidable shear generated by the quantum back reaction. Indeed, vacuum quantum fluctuations inevitably provide a stochastic source of anisotropic stress with non-vanishing fluctuations that imprint large-scale anisotropies in the early universe. The minimum amount of shear built up by quantum fluctuations is computed using the stochastic formalism. In practice, I consider a massless test scalar field in slow-roll inflation and in contracting cosmologies. The latter is known to be flawed with a shear instability and I will show that the stochastic shear is small enough for a wide range of values of the equation-of-state parameter. Finally, I conclude by highlighting future theoretical developments and phenomenological applications of the stochastic inflation formalism.

Quantum aspects of stimulated Hawking radiation on an analog white-black Hole pair

Mon 27
12:00–12:30
Session 1

Ivan Agullo

Louisiana State University – Baton Rouge, United States

The stimulated Hawking effect is commonly regarded as a classical process, of little value to study the quantum aspects of the Hawking process in analog systems (e.g., the generation of entanglement). In this talk we will argue otherwise, and describe a protocol to amplify and observe these quantum features based on stimulating the process with a single-mode squeezed input. Although our ideas are general, we formulate them in the context of optical systems containing the analog of a pair white-black hole, based on the advantages these systems offer to prepare, manipulate and observe quantum states. Our results open the door to new possibilities of experimental verification of the Hawking effect.

Quantum Fluctuations in Gravity: Gravitational Cat State, Graviton Noise and Stochastic Gravity

Mon 27
14:00–14:45
Session 2

Bei Lok Hu

University of Maryland – College Park, United States

The intersections or unions of gravity (G), quantum (Q) fields and quantum information (I) have sparked many interesting new directions of research in fundamental physics in the last decade, black hole information and wormhole physics are amongst the better known examples. In this talk I want to present two classes of low energy quantum fluctuation phenomena amenable to earth-environment laboratory or outer-space tests. One is gravitational cat state, representing quantum entanglement in gravitating systems; the other, graviton noise, signifying the quantum

nature of perturbative gravity. In a quantum description of matter a single motionless massive particle can in principle be in a superposition state of two spatially-separated locations. This superposition state in gravity, or gravitational cat state, would lead to fluctuations in the Newtonian force exerted on a nearby test particle [CQG 32, 165022 (2015)]. The centerpiece is the energy density correlation, corresponding to the noise kernel in stochastic semiclassical gravity theory [Liv. Rev. Rel 11, 3 (2008)], evaluated in the weak-field nonrelativistic limit. It may come as a surprise that such a theory originally developed to describe quantum field effects in black holes and the early universe is actually needed for the description of gravitational entanglement in laboratory settings. For the graviton noise problem [PRL 127, 081602; PRD 104, 083516 (2021)], we [PRD 105, 086004 (2022)] consider the effects of gravitons and their fluctuations on the dynamics of two masses using the Feynman-Vernon influence functional formalism. The Hadamard function of the gravitons yields the noise kernel acting as a stochastic tensorial force in a Langevin equation governing the motion of the separation of the two masses. The fluctuations of the separation due to the graviton noise are then solved for various quantum states including the Minkowski vacuum, thermal, coherent and squeezed states, generalizing previous results of Parikh et al [PRL 127, 081602]. We end with a discussion of what would constitute a demonstration of the quantum nature of perturbative gravity, and a comment on the prospect of detecting these fluctuations in primordial gravitons using interferometers with long baselines in deep space experiments.

Toy-model black holes in BECs: quantum superradiance and more

Mon 27
14:45–15:15
Session 2

Luca Giacomelli
University of Paris – Paris, France

An interesting perspective with which Analogue Gravity can be approached is by taking advantage of the tunability of the hosting medium to construct simplified spacetimes that have minimal features to display the phenomena one is interested in studying. This point of view differs from the one of a "quantum simulation" of fields in curved spacetimes, and is instead aimed at a conceptual understanding through toy models, that in the analogue framework can also be experimentally realized. In this talk I will show how such minimal toy spacetimes can be used to understand black hole superradiance by using the tool of synthetic gauge fields for Bose-Einstein condensates. This allows to investigate classical superradiant scattering and spontaneous quantum superradiant emission, that is characterized via density-density correlations. By also tuning the atom interactions, one can build a toy model for quantum fields around a rotating black hole, that displays the symultaneous occurrence of Hawking and superradiant emission. This also displays an interesting interplay between quantum emission from the vacuum and the presence of quasinormal modes in the analogue spacetime. Connection of the results presented with configurations that can be experimentally obtained with quantum fluids of light are also discussed.

Analog Models for Quantum Stress Tensor Fluctuations

Mon 27
15:45–16:30
Time
Session 2

Larry Ford
Tuft University – Medford, United States

Recent work has shown that the probability of large fluctuations of space and time averaged stress tensor components of a quantized field, such as the energy density and flux, are very sensitive to the details of the averaging. This averaging is viewed as arising from the measurement process. Here two analog models which may be experimentally accessible will be described. The first involves light scattering from large zero point density fluctuations in a fluid. It is argued that this is analogous to vacuum energy density fluctuations of a quantum field. The second model involves vacuum radiation pressure fluctuations on a Rydberg atom. It is suggested that there may be an observable recoil of the atom which depends upon the details of how the atom is excited and de-excited.

Vacuum quantum excitation of the quasi-normal modes of an analogue black hole in a polariton fluid

Mon 27
16:30–17:00
Session 2

Maxime Jacquet
Laboratoire Kastler Brossel & Sorbonne University – Paris, France

Quantum fluctuations in the vicinity of horizons yield correlated emission by the Hawking effect. Here we use a quantum fluid of microcavity polaritons (a driven-dissipative system) to show how, in addition to the Hawking effect at the sonic horizon, quantum fluctuations perturb the spacetime that rings down. This populates a state bound to the horizon region that also couples to propagating modes, i.e. we show how quantum fluctuations result in a sizeable stationary excitation of the quasi-normal mode of the effective spacetime. Observable signatures of the quantum excitation of the quasi-normal mode are found in the correlation diagram of density fluctuations as well as in the spectrum of Hawking emission. This opens the way for studies of zero-point perturbations of the spacetime and their influence on quantum emission

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Hawking radiation in the presence of two analogue horizons

Tue 28
9:00–9:45
Session 3

Jeff Steinhauer
Techion – Haifa, Israel

There is an important class of real and analogue black holes with both outer and inner horizons. We discuss the implications of the two horizons for both spontaneous and stimulated Hawking radiation in the analogue case. The finite distance between the horizons creates an infrared cutoff for the partner quasiparticles of the spontaneous Hawking radiation emitted by the outer horizon. Furthermore, the inner horizon can spontaneously emit so-called white hole radiation, which can trigger the black hole lasing effect. The exponential growth rate of the black hole lasing is limited by the infrared cutoff of the partners. We study these issues by numerical simulations, and apply the lessons learned to experiments in Bose-Einstein condensates.

The hot big bang in a cold gas

Tue 28
9:45–10:30
Session 3

Ian Moss
Newcastle University – Newcastle, United Kingdom

There are plans afoot to simulate early universe phase transitions in the laboratory using cold gases. The most interesting examples represent a universe that supercooled into a metastable phase, or even into a 'false vacuum' state. I will describe how a cold gas can behave like a relativistic quantum system and undergo first order phase transitions, and how we might model this.

Analog gravity and Hawking effect in a quantum fluid of light

Tue 28
10:30–11:00
Session 3

Elisabeth Giacobino
Laboratoire Kastler Brossel & Sorbonne University – Paris, France

Quantum fluids are very promising tools for simulation of many systems, from condensed matter physics to astrophysics and analog gravity. Here we use a polariton fluid in a semiconductor microcavity to create an acoustic horizon, which allows simulating a Black Hole. We study the Hawking effect, coming from quantum vacuum fluctuations scattering at the horizon that generates correlated waves on both sides of the horizon. The out-of-equilibrium physics characterising the polariton fluid affects the emission and propagation of the correlated waves. We analytically and numerically study the influence of the fluid properties on the Hawking effect and we explore the characteristics of the fluid in order to optimize the emission. This opens new avenues for the observation of the Hawking effect in out-of-equilibrium systems as well as for the study of new phenomenology of fields on curved spacetimes.

Nonlinear Optics and the Holographic Principle

Tue 28
11:30–12:00
Session 3

Fabio Biancalana
Heriot-Watt University – Edinburgh, United Kingdom

I will give a review of the possible applications of the Holographic Principle (borrowed from String Theory) to condensed matter physics and optics. In particular, I am interested in the non-perturbative description of 2D materials such as graphene, something that is not achievable by using conventional methods based on quantum mechanics. On the contrary, the holographic principle could describe the quantum-mechanical and optical properties of graphene and other materials in an EXACT, fully non-perturbative fashion .

Decoherence in De Sitter Space

Tue 28
12:00–12:30
Session 3

Gregory Kaplanek
Imperial College London – London, United Kingdom

We assess the minimum, inevitable amount of decoherence induced by gravitational coupling between observable cosmological perturbations and small wavelength fluctuations. This is done by treating the long wavelength fluctuations as an open system, whose decoherence is driven by cubic interaction terms in the standard EFT of single-field inflation. At late times we find that the evolution of the reduced density matrix is Markovian (or time-local), and we make a prediction for the timescale of decoherence for each mode k of the field. We find that quantum coherence cannot survive for any range of modes visible in the CMB today.

Observation of Massless and Massive Collective Excitations in a Two-Component Superfluid

Tue 28
14:00–14:45
Session 4

Gabriele Ferrari
University of Trento – Trento, Italy

I will report on the experimental measurement of the dispersion relation of the density and spin collective excitation modes in an elongated two-component superfluid of ultracold bosonic atoms. The parametric spectroscopic technique is based on the external modulation of the transverse confinement frequency, leading to the formation of density and spin Faraday waves. I will show that the application of a coherent coupling between the two components reduces the phase symmetry and gives a finite mass to the spin modes.

Effective Michelson interference observed in fiber-optical analogue of Hawking radiation

Tue 28
14:45–15:15
Session 4

David Bermudez

Cinvestav – Mexico City, Mexico

We experimentally observe the stimulated analogue of Hawking radiation produced in a photonic-crystal fiber, with a pulsed pump and a continuous-wave probe. In particular, we propose and demonstrate an innovative method to boost the efficiency and probe the coherence characteristics of the analogue Hawking effect relying on a double pump pulse with a controlled temporal delay. We show that the emitted analogue Hawking radiation corresponds to the coherently-added, interfering Hawking signals resulting from the probe interacting with each pump pulse. We introduce a simple effective Michelson interference model, and demonstrate excellent agreement between our experimental data and the predictions derived from this model. Importantly, while naively increasing the pump power in an attempt to boost the Hawking- radiation generation efficiency results in the distortion of the output signal, we show that at the maxima of the observed Hawking-signal interference pattern, the signal can be increased by a factor of ¿3 (up to 4 under ideal experimental conditions). This approach could be extended to the use of sequences of m pulses, resulting in a Hawking-signal enhancement of m^2.

Fundamental phenomena in a rotating world

Tue 28
15:45–16:30
Session 4

Daniele Faccio

University of Glasgow – Glasgow, United Kingdom

We will overview a series of experiments, including "work in progress" aimed at studying fundamental phenomena associated to non inertial motion. Specifically, we will discus recent success in the study of Penrose superradiance from a rotating photon fluid, and Zel'dovich amplification from a rotating absorbing cylinder in acoustics and experiments moving towards the first demonstration with electromagnetic waves. We will also overview our attempts to demonstrate a direct connection between entanglement and its control or generation through mechanical rotation.

Detecting the Unruh Effect in an Analogue

Tue 28
16:30–17:00
Session 4

Cisco Gooding

University of Nottingham – Nottingham, United Kingdom

Discovered soon after black hole evaporation, the closely-related Unruh effect predicts a thermal response for a detector accelerating through the vacuum. The small magnitude of this temperature under achievable experimental conditions has hindered attempts to observe the effect, though a recent proposal indicates that an analogue of the circular Unruh effect should be observable in a cold-atom system. In this talk, I describe conceptual aspects of detection and signal extraction for the analogue Unruh effect.

Optical Soliton Analogue of Black Hole Quasinormal Mode Oscillations

Tue 28
17:00–17:30
Session 4

Christopher Burgess and Friedrich König
University of St. Andrews – St. Andrews, United Kingdom

Black hole spacetimes generally produce gravitational waves when subject to perturbations of the underlying metric. For late times, the gravitational waves are dominated by damped oscillations. The signature of these waves is exponential decay with discrete characteristic frequencies. These waves can be understood via quasi-normal modes (QNMs), which comprise the set of quasi-stationary oscillations of a dissipative system. The oscillations have a complex frequency spectrum that uniquely characterises the mass and spin of the black hole. The low-lying (slowest decaying) QNMs of black holes are determined by the curvature at the peak of the effective radial gravitational potential for massless particles.

In tortoise co-ordinates, which map the radial co-ordinate for the event horizon and spatial infinity onto the real line, the QNM perturbation equation for Schwarzschild and Kerr black holes takes the form of a Schrödinger equation in the radial part of the perturbation with the boundary conditions of purely outgoing waves at the horizon and spatial infinity. Any bell-shaped potential can serve as a good approximation for the low-lying QNM frequencies [Rev. Mod. Phys. **83**, 793 (2011)]. Often, a sech2 shape potential, an inverted Pöschl-Teller potential, is chosen, as the problem then has analytical solutions.

Astrophysical black holes are difficult to probe experimentally. Therefore, we propose an analogue using optical solitons in fibres, as follows. The propagation of pulses in optical fibres is described by the non-linear Schr odinger equation (NLS) [G. Agrawal. *Nonlinear Fiber Optics* (2006); Opt. Expr. **83**, 5538 (2012)]. The NLS supports fundamental optical solitons, pulses that maintain their shape during propagation as a result of the influence of fiber dispersion balancing that of the non-linear refractive index. The intensity of the fundamental soliton has a ^{2} shape.

We consider linear quasi-monochromatic, single-wavenumber perturbations around the fundamental soliton solution of the NLS. We find our perturbation equation takes the form of a Schrödinger equation if we choose these perturbations to be approximately group-velocity matched to the soliton, and limit dispersion to second-order. The potential appearing in this equation has the shape of the intensity profile of the background soliton, i.e. the shape of an inverted P oschl-Teller potential. This means that the linear monochromatic perturbations of the fundamental soliton are analogous to those of the astrophysical black hole. We solve the soliton perturbation equation, subject to the QNM boundary conditions, and calculate the QNM frequencies and damping constants of the fundamental soliton, for typical fibre parameters. We find a discrete and finite spectrum of soliton QNMs, with the number of QNMs given in closed form. We also discuss limits of the analogy.

This novel analogue platform can be used to experimentally investigate QNMs in the classical regime. In future, the quantum properties of QNMs can be probed, as well as the back-action onto the background fields, beyond the semiclassical regime.

Analogue gravity with optomechanical circuit systems

Wed 28
9:00–9:45
Session 5

Miles Blencowe
Dartmouth College – Hanover, United States

We describe our recent work exploring analogues of photon production processes from vacuum (Unruh and Hawking effects), as well as of gravitationally induced decoherence and entanglement, by utilizing superconducting microwave circuit systems that incorporate rapidly oscillating (i.e., accelerating), micromechanical elements.

Preheating experiments

Wed 29
9:45–10:30
Session 5

Silke Weinfurtner
University of Nottingham – Nottingham, United Kingdom

TBA

On the physics of Quantum Friction

Wed 29
10:30–11:00
Session 5

Francesco Intravaia
Humboldt University of Berlin – Berlin, Germany

The motion of objects in the fluctuating quantum vacuum has fascinated scientists for decades. Understanding the physics at work in these dynamics and the effects they produce has wide fundamental implications, ranging from nanosciences to cosmology. In addition, due to the lightening progress of quantum technologies, it is not unlikely that future devices can also be confronted with some of these phenomena or at least many of the related concepts.

In particular, the last ten years have witnessed an increasing number of investigations addressing the interactions between two or more neutral nonmagnetic bodies moving in vacuum at relative constant velocity. Special attention has been devoted to a phenomenon often called quantum friction. In the prototypical setup consisting of an atom moving near a macroscopic body, quantum friction hinders the atomic motion aiming at bringing it to rest. Contrary to its classical counterpart, this nonconservative drag is contactless and mediated by the fluctuations of the quantum electromagnetic field. Interestingly, the theoretical description of quantum friction revealed to be challenging and predictions have varied widely in the past. Recently, consensus is emerging and many analyses have brought to light the richness of the physics acting behind the scenes of this effect. In this talk I give an overview of some recent results concerning the study of the quantum frictional interaction, highlighting some interesting connections with other fields of research.

From gravity to fluid mechanics via dynamical symmetries

Wed 29
11:30–12:00
Session 5

Jibril Ben Achour
Arnold Sommerfeld Center for Theoretical Physics – Munich, Germany

In this talk, I will discuss how the non-relativistic conformal symmetries of fluid mechanics are realized in cosmology and black hole theory. These physical symmetries fully encode the gravitational system and algebraically characterize the underlying geometry. I will discuss how these shared symmetries in gravity and fluid mechanics might allow us to revisit our understanding of analogue gravity from a symmetry-based approach.

Cosmological Master Equations

Wed 29
12:00–12:30
Session 5

Thomas Colas
Paris-Saclay University – Paris, France

Nearly scale-invariant, Gaussian and adiabatic scalar perturbations from quantum mechanical origin have been extensively tested using CMB and LSS data. Effective field theories aim at providing a systematic way to consider extensions to this adiabatic evolution, incorporating the knowledge of unknown physics in a parametrically controlled manner. In order to grasp the implications of some hidden sector at the quantum level, the formalism needs to incorporate non-unitary effects such as dissipation and decoherence. To achieve this goal, master equations can be a valuable tool. Ubiquitous in quantum optics where they describe the effects of an almost unspecified environment on the evolution of measurable degrees of freedom, they rely on assumptions that do not straightforwardly extend to cosmology where the background is dynamical, the Hamiltonian time-dependent and the environment out-of-equilibrium. In this talk, I will present their implementation in cosmology and benchmark their efficiency on solvable models.

Posters

Fluctuation-induced interactions in non-trivial geometries

Mon 27
17:00–18:00

Bettina Beverungen
Humboldt University of Berlin – Berlin, Germany

In a system in thermal equilibrium, fluctuations and dissipation are inextricably related via the fluctuation-dissipation theorem. This result holds even in the limit of zero temperature due to the irreducible nature of quantum fluctuations. A notable manifestation of this behavior is the emergence of quantum fluctuation-induced interactions such as the Casimir-Polder force, which describes the interaction between a neutral atom or nanoparticle and a macroscopic object. Since this force becomes especially relevant at short distances, in the past years this effect has received increasing attention with regard to nanotechnological applications. Both the quantitative and qualitative behavior of the interaction is influenced by the physical properties of all involved objects, in particular their geometry and material properties. Since analytical calculations are only possible for a limited amount of cases, it is of interest to use numerical methods to broaden the range of potential setups to be studied. Here, we discuss a finite-element-based numerical method that enables high-accuracy calculations of fluctuation-induced interactions. Our scheme permits the evaluation of the force for very general geometries and material models.

Detecting quantum noise in primordial gravitational waves

Mon 27
17:00–18:00

Hugo Candan
University of Edinburgh – Edinburgh, United Kingdom

We will investigate the quantum nature of gravitons using tools from the theory of open quantum systems. We treat an idealized gravitational wave detector as our open quantum system which interacts with an environment constituting of primordial gravitational waves. Our goal is to establish an evolution equation for our system, which can take into account non-Markovian and non-time local effects. We eventually solve this equation in order to quantify a possible quantum noise that could arise in the measurement, giving a signature of the (perturbative) quantum nature of gravity.

Observing single-particles beyond the Rindler horizon

Mon 27
17:00–18:00

Riccardo Falcone
Sapienza University of Rome – Rome, Italy

We have shown that Minkowski single-particle states localized beyond the horizon modify the Unruh thermal distribution in an accelerated frame. This means that, contrary to classical predictions, accelerated observers can reveal particles emitted beyond the horizon. The method we have adopt is based on deriving the explicit Wigner characteristic function for the complete description of the quantum field in the non-inertial frame and which can be generalized to general states.

Experimental investigation of quasi-normal modes and Hawking effect in a polariton fluid.

Mon 27
17:00–18:00

Kevin Falque
Laboratoire Kastler Brossel – Paris, France

Quantum fluids of light enginered with strong non linear interactions are well suited systems for complex quantum simulations. Here we use quantum fluids made of polaritons in a 1D semiconductor microcavity in order to carry out analogue gravity experiments : the all optical control of the fluid allows to generate an effective black-hole spacetime and to measure remarkable effects at the sonic horizon such as Hawking radiation as well as the so called Quasi Normal Modes. Based on the theoretical work made in the team, we aim at performing a correlation diagram of the density fluctuations of the fluid and observe the signature of the above mentioned phenomena. Due to the high non linearity coupled to the driven dissipative nature of our system, those signatures are expected to be intense enough to be easily measured on macroscopic distances and provide a non ambiguous proof of analogue Hawking radiation modulated by the intrinsic ringing of our black-hole effective spacetime.

Entangelment Entropy in the Early Universe

Mon 27
17:00–18:00

Moatasem Hassan
University of Edinburgh – Edinburgh, United Kingdom

Most models of the early universe predict that quantum fluctuations were the source of the cosmological density perturbations. Given this quantum origin, we can gain insight by studying what effects entanglment between these perturbations could have had. We do this by assuming that spacetime is approximatley de Sitter in the very early universe, we can then calculate the entangelment entropy caused by cubic interactions between sub- and super-Hubble modes at that time. This requires quantum field theory involving time-dependent perturbations in a curved background.

A soliton black hole using SNAILs

Mon 27
17:00–18:00

Haruna Katayama
Hiroshima University – Hiroshima, Japan

Hawking radiation is a rare phenomenon in which gravity and quantum mechanics encounter each other. The observation of Hawking radiation is the key to unifying the two. However, it is unlikely to be measured because it is much weaker than cosmic background radiation. Therefore, it has been proposed to establish the basic principle of Hawking radiation using analogue black holes artificially created in various laboratory systems. Superconducting circuits that are capable of high-precision, quantum-limited electromagnetic wave measurements are a promising candidate among them; analogue black holes have been proposed by spatially varying the velocity of electromagnetic waves propagating in the circuits. So far, we proposed an analogue black hole induced by a soliton in Josephson-junction transmission lines. A soliton is a solitary wave formed by the balance between nonlinearity and dispersion effects that propagates stably at a fixed velocity. In particular, we have successfully formulated a theory of analogue black holes with stable event horizons using solitons induced by the Kerr nonlinearity of Josephson junctions and found that the Hawking temperature is large enough to be observed in the transmission line. However, the four-wave mixing process caused by the Kerr nonlinearity is not favorable for observing the Hawking radiation because the Hawking particle and its partner have close frequencies to that of the pump. In this presentation, we propose an analogue black hole in which Hawking radiation occurs through a three-wave mixing process to overcome the above-mentioned issue. We achieve this through the use of a transmission line with superconducting nonlinear asymmetric inductive elements (SNAILs). A SNAIL has a third order nonlinear effect in addition to the previous fourth order nonlinear effect, and either nonlinearity can be selected by controlling the external magnetic flux. Transmission lines involving SNAILs have recently been experimentally demonstrated as sources of multimode, entangled microwave photons. We found that the phase difference field coordinate of SNAILs obeys the nonlinear evolution equation called Korteweg-de Vries equation with soliton solutions by using reductive perturbation techniques. The obtained solitons spatially modulate the nonlinear inductance of the transmission line, hence resulting in a spatial modulation of the electromagnetic wave velocity and the formation of an analogue black hole. We also report the parametric amplification by the three-wave mixing process of Hawking radiation in our proposed system.

Quantum Simulation of Liouville Gravity coupled to Fermions

Mon 27
17:00–18:00

Gerard Valenti-Rojas

Heriot-Watt University – Edinburgh, United Kingsom

One of the most outstanding challenges both in quantum simulation of gauge theories and gravity is the incorporation of consistent backaction between the matter degrees of freedom and the gauge/gravitational fields. A concrete example would be a dynamical creation and evaporation of Black Holes due to Hawking emission. Not only the experimental implementation becomes extremely challenging but also the encoding or mapping, to the point that there are not many realistic proposals for the quantum simulation of toy models of semiclassical or quantum gravity. We propose the study of 1+1D dilaton gravity coupled to conformal matter, in particular to massless Dirac fermions. Our approach relies on the fact that General Relativity is, by construction, a gauge theory. The dynamical behaviour of spacetime is present even in the absence of a curved gravitational background. This could open the door to the exploration of semiclassical models of gravity in table-top experiments where backaction is incorporated in a natural way.
