International Workshop on: Simulating gravitation and cosmology in condensed matter and optical systems

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ECT* - Villa Tambosi

Book of Abstracts

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Constructing superconductors by graphene Chern-Simons wormholes

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We propose a model describing the evolution of free electron current density in graphene giving rise to wormhole solutions. Based on the concept of M-branes, we perform the analysis using the difference between curvatures of parallel and antiparallel spins. In such a framework an effective graviton emerges in the form of gauge field exchange between electrons. In a plain graphene system, the curvatures produced by both kinds of spins neutralize each other. However, in the presence of geometrical defects of the graphene sheets, the inequality between curvatures leads to the emergence of current densities and conductivity. Depending on the type of the defects, the resulting current density can be negative or positive. Possible applications are discussed.

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Imperfect fluid description of modified gravities

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Scalar-tensor and f(R) gravity can be described as general relativity plus an effective imperfect fluid corresponding to the scalar field degree of freedom of these theories. A symmetry of electrovacuum Brans-Dicke gravity translates into a symmetry of the corresponding effective fluid. We present the formalism and an application to an anomaly in the limit of Brans-Dicke theory to Einstein gravity. The case of a null dust effective fluid is briefly discussed.

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Black holes with unusual horizons

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We give an overview on the possibile horizon geometries of black holes in four and five dimensions. In the four-dimensional case, we show that in presence of a cosmological constant or, more generally, of a scalar potential, there can exist actually more possibilities for the horizon geometry than the hitherto known spherical, hyperbolic or flat cases. In particular, there are black holes whose event horizons are noncompact manifolds with finite volume, which are topologically spheres with two punctures. In five dimensions, we discuss in some detail the case when the horizon is a homogeneous but not isotropic space.

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Towards accurate confirmation of spontaneous Hawking radiation in degenerate atomic gases via interference of Hawking pairs

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Distinguishing spontaneous Hawking radiation from different thermal effects is possible by measuring correlations of Hawking pairs. However, measuring the local density is expected to be substantially more accurate than measuring density correlations. In our proposed sonic analogue, Hawking temperature can be extracted directly by studying the amplitude of a density modulation originated by the interference of Hawking pairs. In fact, in the proposed sonic analogue in degenerate atomic gases, Hawking partners meet again at some time and interfere. The produced modulation in the density can be as high as one quarter of the density and implies also reduced atom number fluctuations compared to the case of zero temperature and negligible Hawking radiation. By discussing the details of a possible realistic experimental realization we illustrate the accuracy and power of the proposal in order to confirm Hawking radiation.

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Entanglement measure for the characterisation of Hawking emission

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Quantum fluctuations on curved spacetimes cause the emission of entangled pairs, as in the Hawking effect from black hole horizons. We use an optical analogue to gravity to investigate the influence of the spacetime curvature on quantum emission. We calculate the mode conversion analytically for all frequencies. Due to dispersion, the spacetime curvature varies as a function of frequency and the radiation is not described by a single temperature. We find that the measurable photon number correlations transition from complex multimode to two-mode when horizons are formed. We use the Logarithmic Negativity to measure the two-mode entanglement and find that its magnitude is enhanced with a characteristic shape in the presence of horizons. The spacetime curvature rules the kinematics and the quantum state that is generated. These are genuine features of optical and non-optical analogue systems.

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Effective friction induced by the dynamical Casimir emission and its fluctuations

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We consider an optical cavity enclosed by a freely moving mirror attached to a spring and we study the quantum friction exerted by the dynamical Casimir emission on the mechanical motion of the mirror at the mean-field level. Observable signatures of this simplest example of back-reaction effect are studied in both the ring-down oscillations of the mirror motion and in its steady-state motion under a monochromatic force. We go beyond the study of the mean-field dynamics of the mirror and investigate the strictly quantum feature of the damping and the relative quantum fluctuations. This simple model is reminiscent of the pre-heating mechanism by which matter could have been created by the decay of the inflaton field into its true ground state.

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BEC Analog Black Holes With Massive Phonons

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The original Bose Einstein Condensate, BEC, black hole analog models and the experiments to date have been for BECs which are effectively one-dimensional and for which the mode functions have only longitudinal excitations. In this case, the corresponding phonons are massless. However, it is possible to have situations in which one or more transverse modes are excited with the result that a masslike term appears in the mode equation that is still effectively 1+1 dimensional. Thus, the phonons acquire a mass. It is shown that the presence of a mass term in the mode equation has profound effects on both the two-point function and the density density correlation function for a BEC analog black hole.

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Modified Unruh effect from generalized uncertainty principle

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We compute corrections to the Unruh effect and related Unruh temperature from the generalized uncertainty principle. First, by following a heuristic derivation, and then a more standard calculation in deformed QFT.
In the limit of small deformations, we recover the thermal character of the Unruh radiation. Corrections to the temperature at first order in the deforming parameter are compared for the two approaches, and found to be in agreement as for the dependence on the cubic power of the acceleration of the reference frame. The dependence of the shifted temperature on the frequency is also pointed out and discussed.

Reference paper: Eur.Phys.J. C78 (2018) no.9, 728 [arXiv:1804.05282 hep-th]

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Backreaction Problems in Moving Atoms, Radiating Black Holes and the Early Universe via Generalized Fluctuation-Dissipation Relations

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"Backreaction" in gravitation and cosmology is a difficult yet important class of problems imbued with many challenging issues of theoretical physics. It studies how quantum field processes like cosmological particle creation affect the dynamics of the early universe, how Hawking radiation back-reacts and changes the fate of a black hole. Research in this field began in the late 70's, with tools from quantum field theory in curved spacetime and its higher level extensions, semiclassical gravity of the 80's and stochastic gravity of the 90's [1]. New insights were added since then from nonequilibrium quantum field theory [2] using open quantum system ideas and techniques. An interesting theme is the use of fluctuation-dissipation relations (FDR) to capture the backreaction of quantum fields and their fluctuations on the dynamics of the background spacetime and its fluctuations, known as metric fluctuations or spacetime foams. In this talk I first mention samples of important work on this topic, exposing the insufficiency of linear response theory [3] and the mismatches in earlier proposals [4], then summarize the results of Raval, Hu and Anglin [5] based on stochastic field theory methods. While studying N moving Unruh-DeWitt detectors or harmonic atoms in a quantum field, these authors showed the existence of FDR between any one detector and the quantum field. They also discovered a new set of relations called the correlation-propagation relations (CPR) between two moving detectors via the quantum field. We then describe recent results by J. T. Hsiang et al [6][7] in the derivation of the FDR-CPR combination for moving detectors. This matrix relation, called the generalized FDR, ensures self-consistency in the backreaction of quantum field processes on the detectors. Interpreting these results in the open quantum system perspective, with the detectors playing the role of atoms, or quantum black holes as atoms, these relations provide rare physical insights into the backreaction problems of quantum processes in moving atoms, radiating black holes and the early universe.
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Black-hole superradiance: probing ultralight bosons with compact objects and gravitational waves

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Ultralight bosonic fields (e.g. stringy axions, axion-like particles, dark photons, light spin-2 fields) are compelling dark-matter candidates and provide a serious alternative to the WIMP paradigm. These fields have eluded particle detectors so far, but can dramatically affect the strong-gravity dynamics of compact objects (black holes and compact stars) in various detectable ways. Light bosonic fields can trigger superradiant instabilities which have peculiar signatures, e.g. they produce "gaps"

in the mass-spin diagram of astrophysical black holes and predict a measurable spin-down rate of pulsars. These effects can be used to constrain axion-like particles, to derive bounds on dark photons and on the mass of the graviton, as well as to constrain the fraction of primordial black holes in dark matter. Because of their tiny mass and coupling to the Standard Model, detecting axions and other light bosons in the lab is extremely challenging. However, boson condensates formed through superradiance would emit a periodic gravitational-wave signal (whose frequency is related to the boson mass) which can be detected with present and future gravitational-wave interferometers, either as stochastic background or as continuous resolvable sources. The theoretical potential of these phenomena as almost-model-independent smoking guns for physics beyond the Standard Model are presented.

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First M87 Event Horizon Telescope Results: The Shadow of the Supermassive Black Hole

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The Event Horizon Telescope (EHT) has mapped the central compact radio source of the elliptical galaxy M87 at 1.3 mm with unprecedented angular resolution. These images show a prominent ring with a diameter of ~40 micro-arcsecond, consistent with the size and shape of the lensed photon orbit encircling the "shadow" of a supermassive black hole. The ring is persistent across four observing nights and shows enhanced brightness in the south. Here we consider the physical implications of the asymmetric ring seen in the 2017 EHT data. To this end, we construct a large library of models based on general relativistic magnetohydrodynamic simulations and synthetic images produced by general relativistic ray tracing. We compare the observed visibilities with this library and confirm that the asymmetric ring is consistent with earlier predictions of strong gravitational lensing of synchrotron emission from a hot plasma orbiting near the black hole event horizon. Overall, the observed image is consistent with expectations for the shadow of a spinning Kerr black hole as predicted by general relativity. If the black hole spin and M87's large scale jet are aligned, then the black hole spin vector is pointed away from Earth. Models in our library of non-spinning black holes are inconsistent with the observations as they do not produce sufficiently powerful jets. We also briefly discuss the possibility of the alternatives to a black hole for the central compact object.

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Superradiant effects in Bose-Einstein condensates: amplification and instabilities

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Superradiance is a radiation enhancement effect occurring by energy extraction from a rotating spacetime. Being a kinematical effect it can also happen in gravitational analogues, where the energy for the amplification is extracted from the fluid motion. We discuss such an effect in Bose-Einstein condensates with different geometries and show that the well known instability of multiply quantized vortices can be attributed to a dispersive version of the ergoregion instability based on superradiant amplification in rotating spacetimes with no horizon.

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Non-linear effects in modulated 1D atomic BEC

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We study the dynamical effects following a sudden change of the transverse trapping frequency in an elongated BEC, which induces periodic oscillations of the radial density (the breathing mode). At early times, we observe an exponential growth of resonant longitudinal phonons, in agreement with the BdG predictions. We then observe an ordered sequence of phenomena induced by nonlinearities. The first is a loss of the nonseparability of the resonant phonon pairs. This is followed by the saturation of the exponential growth and a strong depletion of condensed atoms, which abruptly reduces the correlation length of the order parameter. Finally, the atomic spectrum becomes broad, featureless and almost incoherent, in agreement with experimental results. The link between this sequence and the preheating scenario in inflationary cosmology is striking, as is the similarity of techniques used to study them.

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Four-wave mixing and enhanced analog Hawking effect in a nonlinear optical waveguide

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We have studied the scattering of light on a soliton propagating in a waveguide, which has been proposed as an experimental system in which one could observe the analog Hawking effect. The linearized wave equation governing perturbations is shown to have the same structure as that governing phonon propagation in an atomic Bose condensate. By taking into account the full dispersion relation, the scattering coefficients encoding the production of photon pairs are shown to be amplified by a resonance effect related to the modulation instability occurring in the presence of a continuous wave. On the other hand, the scattering coefficients not subject to this enhancement behave similarly to those encoding the analog Hawking effect in subcritical flows. When using a realistic example of a silicon nitride waveguide on a silica substrate, we find that a soliton of duration 10 fs would spontaneously emit about one photon pair for every cm it travels. This rate is about six orders of magnitude larger than in previous works, making the effect readily observable.

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Scattering of co-current surface waves on an analogue black hole

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In Poitiers has been realized a stationary transcritical flow of water in a flume that possesses the analogue of a black hole horizon for long-wavelength surface waves. The horizon has been probed via the scattering of an incident co-current wave, which partially scatters into counter-current waves on either side of the horizon, yielding three outgoing waves (of which one has negative energy) rather than two in the absence of transcriticality. The measured scattering coefficients are in good agreement with the prediction of the non-dispersive theory, where the kinematical description in terms of an effective spacetime metric is exact. The data is also used to construct the two-point correlation function of free surface deformations, where the emergence of characteristic peaks is observed.

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Exploring a superradiant laser of Ginzburg phonons

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Building on the analogy with superradiant amplification of waves scattered from a rotating black hole, this investigation considers the problem of a rotating detector embedded into a weakly interacting Bose gas. We observe a qualitative transition in the amplification of the ground state excitation rate of the detector at supersonic speeds. This results from the scattering of co-rotating cylindrical Bogoliubov waves impinging upon the detector, and it resides in a mechanism similar to Ginzburg radiation. In our exploration, we also show that the mechanism can be employed to manufacture a laser of Ginzburg phonons: by confining the system inside a cylindrical mirror, we show that population inversion can be realized for broad intervals of supersonic speeds. This effect has root in the amplification of the quantized Bogolyubov modes of the cavity, and it is therefore absent in the simpler case of a rotating quantum emitter in free space.

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HELIOS, or the need for a CERN for analogs

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I shall present two orders of arguments in favor of the realization of a facility where to explore, with analogs, territories of the theoretical landscapes, otherwise unreachable. There, theorists (both of the HEP-TH and of the COND-MAT types) should sit next to experimentalists (mostly of the COND-MAT type). I shall call this facility HELIOS, an evocative name for something that should shed light on the darkness of the unknown, and an acronym for ‘’High Energy Laboratory for Indirect ObservationS”.

The first type of arguments are scientific/epistemological (what is it we are looking for with analogs?). The second type of arguments are practical (financial, logistics and timeliness aspects).

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Testing tunnelling with gravity

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This is the first of three talks exploring the feasibility building a quantum simulator for vacuum decay.

Vacuum decay is an important quantum phenomenon that could have occurred in the early universe, and has current importance due to the metastability of the Standard Model. I will review the toolkit we use in QFT and Gravity for computing the probability of vacuum decay, also showing how impurities can catalyse decay, and discuss the implications for the Higgs vacuum. I will argue that it is extremely timely to revisit our description of tunnelling in field theory, and important to explore the possibility of experimental tests.

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Pulse dynamics for the optical analogue of Hawking radiation

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The optical analogue of the Hawking radiation is based on the interaction between a pump and a probe through the optical Kerr effect. The phase-matching condition has been obtained previously by considering the conservation of energy in a frame co-moving with the pump. However, the origin of this interaction in nonlinear optics was not clear. In this work, we derive the conditions for the interaction of positive and negative frequencies, including analogue Hawking radiation, based on the method by *Skryabin, Yulin* and a similar explanation for the negative resonant radiation by *Biancalana et al.*

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Testing tunnelling with gravity: quantum simulators

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This is the second of three talks exploring the feasibility building a quantum simulator for testing vacuum decay.

I will describe some of the basic features that a BEC system would need in order to simulate cosmological vacuum decays in the laboratory. These include Klein-Gordon like behaviour and a ground state structure with metastable phases. Up to now, the proposals have suffered from a parametric growth of instabilities. I will indicate a way forward, and outline how the theory of bubble nucleation can be adapted to BEC's at zero and slightly non-zero temperature.

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Testing seeded vacuum decay with cold atoms

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This is the third of three talks exploring the feasibility of building a quantum simulator for vacuum decay.

In this presentation I will briefly explain how the usual treatment of vacuum decay in relativistic field theories can be adapted to the case of a two-components, non-relativistic Bose-Einstein condensate, focusing on the contribution of defects and potential walls. I will motivate that these effects are crucial to correctly estimate the decay rate, and illustrate this by showing results of stochastic simulations.

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The information loss problem: an analogue gravity perspective

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Analogue Gravity can be used to reproduce the phenomenology of Quantum Field Theory in Curved Spacetime and in particular phenomena such as cosmological particle creation and Hawking radiation.
In black hole physics, taking into account the backreaction of such effects on the metric requires an extension to semiclassical gravity and leads to an apparent inconsistency in the theory: the black hole evaporation induces a breakdown of the unitary quantum evolution leading to the so called information loss problem. Here we show that, albeit the back reaction in analogue systems is not described by semiclassical Einstein equations, analogue gravity can provide an interesting perspective on the resolution of this problem. In particular, by looking at the simpler problem of cosmological particle creation, we show, in the context of BEC analogue gravity, that the emerging analogue geometry and quasi-particles have correlations due to the quantum nature of the atomic degrees of freedom underlying the emergent spacetime. As a consequence the quantum evolution is always unitary on the whole Hilbert space which cannot be exactly factorised a posteriori in geometry and quasi-particle components.
In analogy, in a black hole evaporation one should expect a continuous process creating correlations

between the Hawking quanta and the microscopic quantum degrees of freedom of spacetime, implying so that only a full Quantum Gravity treatment would be able to resolve the information loss problem by proving the unitary evolution on the full Hilbert space.

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Forging graphene pseudospheres to mimic curved space–times

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In a previous work it was shown that the realization of the graphene topology on a Beltrami pseudosphere can lead to the analogue realization of the Hawking-Unruh effect [1]. This effect predicts that quantum fields in curved space-time with an horizon exhibit a thermal character due to the quantum vacuum and to the relativistic process of measurement.
Here we construct a computational model of a solid-state black-hole analogue consisting of a graphene membrane characterised by a three-connected tessellation engineered to shape it in the form of the Beltrami's pseudosphere, which is a surface with constant negative Gaussian curvature. Heptagonal and pentagonal defects emerge on the surface due to the negative curvature [2]. We devise a new algorithm to scale-up the pseudosphere dimensions reaching a radius R ~ 100 nm of the event horizon. Furthermore, we elaborate a tight-binding (TB) approach to calculate the local density of states (LDOS) for these extended curved structures. Comparison between the numerically evaluated LDOS [3] and the theoretically predicted one [1] shows, within uncertainties, its thermal nature, establishing the presence of a black hole type horizon in the system.

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Quantum analog of Kerr black hole and Penrose effect in a Bose-Einstein condensate

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We propose to use quantum vortices for analog gravity. We implement an acoustic Kerr black hole with quantized angular momentum in a Bose-Einstein condensate. We show that the condensate's metric is equivalent to the Kerr's one, exhibiting a horizon and an ergosphere. We confirm that this metric is obeyed not only by weak density waves, but also by quantum vortices which behave as massive test particles. We use these topological defects to demonstrate a quantum Penrose effect, extracting the rotation energy of the black hole by quanta of angular momentum. The particle trajectories are well described by the time-like geodesics of the Kerr metric, confirming the potential of analog gravity.

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Observation of thermal Hawking radiation and its temperature in an analogue black hole

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We study the Hawking radiation in an analogue black hole, in which sound plays the role of light. We find that the correlation spectrum of Hawking radiation agrees well with a thermal spectrum, and its temperature is given by the surface gravity. This confirms the predictions of Hawking's theory. The Hawking radiation is in the regime of linear dispersion, in analogy with a real black hole. Furthermore, the radiation inside of the analogue black hole is seen to be composed of negative-energy partners only.

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Wave amplification in rotating reference frames

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Superradiant gain is the process in which waves are amplified via their interaction with a rotating body, examples including evaporation of a spinning black hole and electromagnetic emission from a rotating metal sphere.
We will first discuss the case of photon fluids, i.e. room temperature superfluids generated by a laser beam propagating in a nonlinear defocusing material. Prior work has already demonstrated the superfluid nature of the 2D beam profile in this setting and we have recently studied that by injecting a vortex pump beam, it is possible to generate a rotating spacetime metric and experimentally identify the horizon and ergosphere. Numerical studies based on the Nonlinear Schrodinger equation now illustrate the conditions under which experiments are expected to observe superradiance by analyzing the optical currents in the system.
Finally, we will examine a different scenario, more akin to the sutation examined in 1971 by Zel'dovich, i.e. a rotating cylinder. We elucidate theoretically how superradiance may be realized in the field of acoustics, and predict the possibility of non-reciprocally amplifying or absorbing acoustic beams carrying orbital angular momentum by propagating them through an absorbing medium that is rotating. We discuss a possible geometry for realizing the superradiant amplification process using existing technology.

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Cosmology in the laboratory

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Bekenstein and Hawking predicted that black holes are not black, but radiate due to the quantum physics of the vacuum. Fulling, Davies and Unruh predicted that an accelerated observer perceives the quantum vacuum as thermal radiation. Both effects draw tantalizing connections between general relativity, quantum mechanics and thermodynamics, and both effects have never been observed yet. The lecture shows how laboratory analogues of the event horizon and of relativistic acceleration can, literally, shed light on such and similar phenomena.

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Emulating Hawking physics with cavity polaritons

Over the last decade, cavity polaritons have emerged as a powerful platform to explore the physics of quantum fluids of light [1]. They are quasi-particles arising from the strong coupling regime between photons trapped in a cavity and excitons confined in quantum wells. They propagate like photons but show strong interactions thanks to their matter part. Several theoretical works propose to make use of cavity polaritons for the emulation of Hawking physics [2-3] based on the design of an abrupt interface between a supersonic and a superfluid region.
In this talk I will describe how, making use of nanotechnology, it is indeed possible to engineer the shape of a 1D channel and to realize an acoustic black hole for cavity polaritons [4]. I will also address the possibility of engineering exotic types of Dirac cones with honeycomb polariton lattices [5], which are also relevant for the realization of analogue black holes [6].

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Hawking radiation in an exactly solvable BEC model

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In the past years the experimental detection of the Hawking radiation in Bose-Einstein condensates (BECs) has taken a remarkable leap forward (J. Steinhauer, *Nature Physics* **12**, 2016 and J.R.M. De Nova et al., *Nature* **569**, 2019). Exploiting the particular features of hard core bosons in 1D, i.e. the Tonks-Girardeau gas (S. Giovanazzi, *Phys. Rev. Lett.* **94**, 2005), we are able to obtain the exact solution of a BEC flowing against an obstacle and we examine it in the framework of sonic black holes; in this limit we recover Hawking result without making use of the gravitational analogy and we find that a precise correspondence between the emission of phonons in the upstream region and the Hawking-like mechanism requires additional conditions to be met (A. Parola, M. Tettamanti and S. L. Cacciatori *EPL* **119**, 2017). Moreover, we investigate the correlations between the Hawking

quanta and the in-falling partner and we describe the model also from a semiclassical perspective (M. Tettamanti, S. L. Cacciatori and A. Parola, *Phys. Rev. D* **99**, 2019).

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Towards analog reheating of the universe in the laboratory

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The early universe has undergone a transition from a super-cooled state after cosmic inflation to a hot and thermal one. We propose an analog experimental implementation of this cosmic reheating dynamics using an ultra-cold Bose gas. In our mapping, a Bose-Einstein condensate plays the role of the inflaton field, which describes the state of the universe after inflation. The expansion of the universe as well as the dynamics of the inflaton field are encoded in the time-dependence of the atomic interaction, which can be tuned via Feshbach resonances. By means of classical-statistical simulations we illustrate that the dynamics of the system involves the known stages of reheating. At early times, parametric instabilities lead to the production of Bogoliubov quasi-particles as excitations on top of the condensate, mimicking cosmological particle production by the decaying inflaton field. At later times, the system develops a turbulent cascade transporting energy to higher momenta in a self-similar way. The final stage of the dynamics, where the system relaxes to thermal equilibrium, is dominated by quantum fluctuations and therefore not captured by the classical-statistical approximation, which motivates an experimental study of this process using a quantum simulator."

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Universal Dynamics near Non-Thermal Fixed Points

Author: Thomas Gasenzer[1]

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Quenched or continuously driven quantum systems can show universal dynamics near non-thermal fixed points, generically in the form of scaling behaviour in space and time. Systems where such fixed points can be realized encompass post-inflationary evolution of the early universe, cold dark matter, dense neutron stars, heavy-ion collisions, to low-energy dynamics in cold gases. Key aspects of the theory of non-thermal fixed points will be briefly summarized [1,2], as well as recent experimental results for quenched systems [3,4]. Considering scaling transport of excitations to larger wave numbers similar to an inverse cascade, the underlying excitations can be either irregular phase excitations or (quasi) topological defects [5] exhibiting implications for quantum turbulence.

[1] C.-M. Schmied, A. N. Mikheev, T. Gasenzer, Non-thermal fixed points: Universal dynamics far from equilibrium, arXiv:1810.08143 [cond-mat.quant-gas]

[2] A. N. Mikheev, C.-M. Schmied, T. Gasenzer, Low-energy effective theory of non-thermal fixed points in a multicomponent Bose gas, Phys. Rev. A 99, 063622 (2019); arXiv:1807.10228 [cond-mat.quant-gas]
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[5] M. Karl and T. Gasenzer, Strongly anomalous non-thermal fixed point in a quenched two-dimensional Bose gas, New J. Phys. 19, 093014 (2017).

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Substantiating analog Hawking radiation by inspecting the close vicinity of the acoustic horizon

Authors: Mathieu Isoard[1]; Nicolas Pavloff[1]

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We compute the density-density correlation function near an acoustic horizon realized in a Bose-Einstein condensate.
A correct normalization of the field of Bogoliubov excitations necessitates to account for the contribution of zero modes.
Once this is achieved, one obtains a very good description of the recent experimental results of Technion's group.

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Breakdown of Quasilocality in Long-Range Quantum Lattice Models

Author: Salvatore Manmana[1]

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I will discuss how one can use tensor network state techniques, in particular matrix product states in 1D, to study the nonequilibrium dynamics of correlations in quantum lattice models in the presence of long-range interactions. For exponents larger than the lattice dimensionality, a Lieb-Robinson-type bound effectively restricts the spreading of correlations to a causal region, but allows supersonic propagation. I will present numerical results for the XXZ spin chain, which reveal the presence of a sound cone for large exponents and supersonic propagation for small ones. This addresses the issue of propagation of information in the quantum realm in the presence of long-range interactions, which could be realized by gravitational interactions in a cosmology context.

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Rapidly expanding BEC ring: analog cosmology in a lab

Authors: Stephen Eckel[None]; Avinash Kumar[None]; Ted Jacobson[None]; Ian Spielman[None]; Gretchen Campbell[None]

I will describe an experiment and some theory of an expanding, ring-shaped Bose-Einstein condensate. The expansion redshifts and damps long-wavelength excitations, as in an expanding universe. After expansion, energy in the radial mode leads to the production of bulk topological excitations—–solitons and vortices—driving the production of a large number of azimuthal phonons and, at late times, causing stochastic persistent currents. These complex nonlinear dynamics, fueled by the energy stored coherently in one mode, are reminiscent of a type of "preheating" that may have taken place at the end of inflation.

Based on https://arxiv.org/abs/1710.05800

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Experimental Quantum Cosmology: Probing Analogue Trans-Planckian Physics in Dipolar Bose-Einstein Condensates

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The talk will describe proposals for the quantum simulation of possible trans-Planckian effects on two fundamental phenomena in effective curved spacetime:
1. Scale Invariance of the Inflationary Power Spectrum. We consider an analogue de Sitter cosmos in an expanding quasi-two-dimensional Bose-Einstein condensate with dominant dipole-dipole interactions between the atoms or molecules in the ultracold gas. It is demonstrated that a hallmark signature of inflationary cosmology, the scale invariance of the power spectrum of inflaton field correlations, experiences strong modifications when, at the initial stage of expansion, the excitation spectrum displays a roton minimum. Dipolar quantum gases thus furnish a viable laboratory tool to experimentally investigate, with well-defined and controllable initial conditions, whether primordial oscillation spectra deviating from Lorentz invariance at trans-Planckian momenta violate standard predictions of inflationary cosmology.
2. Cosmological Particle Production aka Dynamical Casimir Effect. A rapid quench in the dipolar gas, performed on the speed of sound of excitations propagating on the condensate background, leads to the dynamical Casimir effect (and hence analogue cosmological particle production), which can be characterized by measuring the density-density correlation function. For both zero and finite initial temperatures, the continuous-variable bipartite quantum state of the created quasiparticle pairs with opposite momenta, resulting from the quench, displays an enhanced potential for the presence of entanglement (represented by nonseparable and steerable quasiparticle states), when compared to a gas with solely repulsive contact interactions. Steerable quasiparticle pairs contain momenta from close to the roton, and hence quantum correlations significantly increase in the presence of a deep roton minimum.

References

1. Seok-Yeong Chä and Uwe R. Fischer: Probing the scale invariance of the inflationary power spectrum in expanding quasi-two-dimensional dipolar condensates, Phys. Rev. Lett. 118, 130404 (2017)
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Welcome by the organizers

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Analogue stochastic ”gravity” in Bose-Einstein condensates

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Application of the black hole-fluid analogy: identification of a vortex flow through its characteristic waves

Black holes are like bells; once perturbed they will relax through the emission of characteristic waves. The frequency spectrum of these waves is independent of the initial perturbation and, hence, can be thought of as a 'fingerprint' of the black hole. Since the 1970s scientists have considered the possibility of using these characteristic modes of oscillation to identify astrophysical black holes. With the recent detection of gravitational waves, this idea has started to turn into reality. Inspired by the black hole-fluid analogy, we demonstrate the universality of the black-hole relaxation process through the observation of characteristic modes emitted by a hydrodynamical vortex flow. The characteristic frequency spectrum is measured and agrees with theoretical predictions obtained using techniques developed for astrophysical black holes. Our findings allow for the first identification of a hydrodynamical vortex flow through its characteristic waves. The flow velocities inferred from the observed spectrum agree with a direct flow measurement. Our approach establishes a non-invasive method, applicable to vortex flows in fluids and superfluids alike, to identify the wave-current interactions and hence the effective field theories describing such systems.

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Round Table: theories vs experiments

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Round Table: theories vs experiments

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Neutron Stars and Gravitational Waves

Author: Konstantinos Kokkotas[1]

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Neutron stars are the densest objects in the present Universe. These unique and irreproducible laboratories allow us to study physics in some of its most extreme regimes. The multifaceted nature

of neutron stars involves a delicate interplay among astrophysics, gravitational physics, and nuclear physics. The recent direct detection of gravitational waves by merging black-holes and neutron stars turned gravitational physics into an observational science. Gravitational Waves by tight binary neutron star systems, supernovae explosions, non-axisymmetric or unstable spinning neutron stars will provide us with a unique opportunity to make major breakthroughs in gravitational physics, in particle and high-energy astrophysics. The focus of the talk will be on neutron star as sources of gravitational waves and their impact on astrophysics and nuclear physics.

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Many-Body Entanglement in Fermi Gases for Quantum Metrology

Authors: Maria Luisa Chiofalo[1]; Leonardo Lucchesi[2]

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We explore many-body entanglement in spinful Fermi gases with short-range interactions, for metrology purposes. We characterize the emerging quantum phases via Density-Matrix Renormalization Group simulations and quantify their entanglement content for metrological usability via the Quantum Fisher Information (QFI). Our study establishes a method, promoting the QFI to be an order parameter. Short-range interactions reveal to build up metrologically promising entanglement in the XY-ferromagnetic and cluster ordering, the cluster physics being unexplored so far.

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Dissipative phase transition in a BEC with local losses

Author: Dries Sels[None]

Co-author: Eugene Demler

I will discuss the dynamics of a BEC subject to local loss of particles. We show there is a critical loss rate at which the system undergoes a continuous dissipative phase transition from a homogenous state into a state which contains a sonic horizon. The latter drastically alters the behavior of the system by screening the drain. Dissipation leads to two types of fluctuations. First, fluctuations are generated by particles emitted in the reservoir. Both above and below the critical loss, these result in thermal emission of phonons with a temperature set by the loss rate and the chemical potential. The second type of fluctuation results from scattering on the drain and gives rise to a particular correlation pattern that can be observed in the density-density correlation. Aside from correlations between in an out scattered modes, outgoing particles are correlated with localized modes through a process that is reminiscent of Hawking radiation.

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Cosmology, theory vs. observations: an overview and some ideas

Author: Sabino Matarrese[1]

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In this talk I will review the present status of the standard theoretical framework of cosmology and how it confronts observations, paying particular attention to the Early Universe physics (inflation models) and its observational probes (power-spectrum, non-Gaussian features, etc), possible connections between dark matter, dark energy and potential modifications of gravity, also accunting for cosmological gravitational-wave signals and their propagation.

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An atomic vapor medium for analogue gravity in a fluid of light.

Author: Quentin Glorieux[None]

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During this presentation I will introduce the basics of warm rubidium vapors for generating a fluid of light. Using the analogy between the non-linear Schrodinger equation and the Gross-Pitaevskii equation, I will answer the question about "Can we observe superfluidity with light ?"
I will also discuss recent non-linear and quantum optics experiments through the perspective of hydrodynamics and I will show what are the surprising consequences of this approach (shock formation, vortex generation…)
Finally, I will open the discussion about the possibility to observe analogue gravity physics in a fluid of light.

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Probing Quantum Fields in the lab

Authors: Sebastian Erne[1]; Jörg Schmiedmayer[2]

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Ultra cold quantum gases are an ideal model system to quantum simulate field theories in the lab. Matter wave interferometry gives direct access to the quantum field and thereby offers an unprecedented view on its equilibrium properties and non-equilibrium evolution. We experimentally illustrate the particle creation when cutting a quantum field in two halfs, and demonstrate the establishment of a new (pre) thermal equilibrium within a light cone horizon. In our system the quantum sine-Gordon model is realized with high accuracy through two tunnel-coupled 1d superfluids as verified by an analysis of the connected correlations in the quantum field up to 10th order. Finite time quenches in the tunnelling coupling can be used to simulate inflationary physics within the sine-Gordon model, seeded by quantum fluctuations.

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Welcome and Presentation of ECT*

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Towards exotic gravitational analogue in quantum fluids of light

Author: Maxime Richard[1]

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Exciton-polaritons in semiconductor microcavities can be understood essentially as interacting photons that are confined into a bidimensional degree of freedom. Collectively, polaritons behave as a quantum fluid, with its typical features such as a superfluid state with sonic excitations. As such, and considering their photonic character, polaritons offer an exciting platform to simulate the physics of gravitational structures, such as black holes.

In this context, the main peculiarity of polariton fluids, i.e. their its driven-dissipative character, offers original physical situations and resources that are not readily available in equilibrium system. I will illustrate this idea with a few recent experimental investigations. I will show for instance that a polaritonic black hole, featuring a maximal surface gravity, can be engineered by exploiting their hysteretic dynamics. I will also present preliminary results towards the realization of a quantum fluid of polaritons in the analogue of the relativistic regime, i.e. in which the free particle effective mass $m_{\text{eff}}c^2$ in the condensate is comparable or smaller than the interaction energy gn.

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Exploring nonequilibrium field theories with cold atoms and solid state systems

Authors: Daniel Podolsky[1]; Dries Sels[1]; Eugene Demler[1]

[1] *Harvard University*

Generation of entangled particle pairs underlies several important phenomena in non-equilibrium field theories including Hawking radiation and dynamical Casimir effect. I will discuss application of these ideas to understanding pump and probe experiments in condensed matter systems and ultracold atoms. Examples include superconducting Higgs amplifiers, phonon-polariton lasing, shaken one dimensional condensates, and dynamics of a BEC with local loss.