15th annual conference on Relativistic Quantum Information (North)

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Università degli Studi Federico II, Napoli

Book of Abstracts

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Monday Plenary Session / 158

Philosophy and history of QFT

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I will survey a few topics in philosophy and history of QFT that are relevant to RQI, and then focus on a central topic: the Measurement Problem. In non-relativistic QM, one version of the Measurement Problem is that the measurement theory (i.e., the Born rule and state update rules) cannot be derived from the application of the dynamics (e.g., Schrodinger equation) to a measurement scenario. Recent work on local measurement theories for QFT introduces new relativistic state update rules and relies on relativistic representations of the dynamics in QFT. As a result, the Measurement Problem takes a different form in QFT than in non-relativistic QM. This is of interest because a satisfactory interpretation of quantum theory must solve the Measurement Problem.

Monday Plenary Session / 159

Weighing the vacuum with the Archimedes experiment

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Archimedes is an experiment designed to measure the discussed interaction between vacuum fluctuations and the gravitational field. It is based on the measurement of the weight variation of a suitable stack of Casimir cavities whose vacuum energy is varied thanks to a suitable superconducting phase transition. The experiment is currently being installed and commissioned at the Sos Enattos site in Sardinia, chosen for its properties of extreme seismic and anthropic quiet. The theoretical aspects are briefly recalled, the state of the art of the experiment is discussed, and some experimental implications in the geophysical and astrophysical fields are also presented.

Monday Plenary Session / 166

Space and time correlations in quantum histories

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The formalism of generalized quantum histories allows a symmetrical treatment of space and time correlations, by taking different traces of the same history density matrix. We characterize spatial and temporal entanglement in this framework. An operative protocol is presented, to map a history state into the ket of a static composite system. We show, by examples, how Leggett-Garg and temporal CHSH inequalities can be violated in our approach.

Monday Plenary Session / 167

Causality in relativity, philosophy and causal modeling

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In this talk, I will discuss the ways in which philosophical work on causation and physics research in quantum foundations can usefully inform and influence each other. I will introduce some important philosophical ideas about causation, including the asymmetry of causation and its relation to time-symmetry in macroscopic and microscopic physics. I will also discuss the causal modelling approach and its philosophical motivations. I will then discuss the notion of causation as it appears in the process matrix formalism, and argue that these results can help us understand type of causal or quasi-causal structure might be present in the microscopic world. I will comment on some important lessons for both philosophy and physics.

Monday Plenary Session / 187

Measurement and preparation protocols for QFT on curved space-times

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"I will review the framework for measurement in QFT introduced in joint work with Rainer Verch [1], which provides a covariant and consistent description of measurements and state updates and (as an application) resolves the ""impossible measurement"" problems raised by Sorkin long ago [2]. The framework is also known to be comprehensive in the sense that there are classes of QFTs for which all local observables can be obtained in an asymptotic sense from local measurement schemes [2]. I will describe work in progress that gives exact local measurement schemes for all observables, and also gives a preparation procedure for local product states.
[1] Quantum fields and local measurements, CJ Fewster and R Verch, Commun. Math. Phys. 378 (2020) 851-889 arXiv:1810.06512
[2] Impossible measurements require impossible apparatus, H Bostelmann, CJ Fewster and MH Ruep, Phys. Rev. D 103 (2021) 025017 arXiv:2003.04660
[3] Asymptotic measurement schemes for every observable of a quantum field theory, CJ Fewster, I Jubb and MH Ruep, Annales Henri Poincaré 24 (2023) 1137–1184. arXiv:2203.09529"

Monday Plenary Session / 169

Harvesting stabilizer entropy and non-locality from a quantum field

Author: Stefano Cusumano[1]

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The harvesting of quantum resources from the vacuum state of a quantum field is a central topic in relativistic quantum information. While several proposals for the harvesting of entanglement from the quantum vacuum exist, less attention has been paid to other quantum resources, such as non-stabilizerness, commonly dubbed magic and quantified by the Stabilizer Rényi Entropy (SRE). In this work, we show how to harvest SRE from the vacuum state of a massless field, using accelerated Unruh-DeWitt detectors in Minkowski spacetime. In particular, one can harvest a particular non-local form of SRE that cannot be erased by local operations. We conclude our work with an analysis of the CHSH inequalities: one cannot extract a violation from the quantum field unless these resources are already there.

Monday Parallel Session F / 182

Reading off correlation of spacetime fluctuations from interferometric output

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To understand the fundamental nature of gravity, high-precision interferometers, namely, Holometer (Fermilab), QUEST (Cardiff) and GQuEST (CalTech), seek possible evidence of spacetime fluctuations. These spacetime fluctuations, a feature common to both quantum and semiclassical models of gravity, could be characterised by two-point correlation functions. A two-point correlation function of any typical physical process dictates the correlation to decay as the separation increases, with the decay being either exponential or an inverse power law. This leads to two possible classes of correlation functions. We compute the spectral densities of interferometric output signal from a single Michelson interferometer, corresponding to when the light beam traverses through spacetime fluctuations with different correlation functions. From the high and low frequency behaviours of such spectral densities, we identify the characteristic signatures of each class of these correlation functions. We show that detection of these characteristic signatures in the interferometric output, in turn, will help identifying the underlying correlation function. To fully capture these signatures, we find that interferometers require sensitivity in a frequency range between O(0.1) and O(10) times the light round-trip frequency $c/2\mathcal{L}$, for an interferometer with arm length $\mathcal{L}$. We also find the high and low frequency trends of the spectral density for more sophisticated setups such as Holometer-type colocated interferometers and LIGO-type interferometers with Fabry-Perot arm cavities. Comparing such findings allow us to identify from current interferometers, setups best suited for investigating spacetime fluctuations. Our work can also be used to guide the design of future interferometers.

Monday Parallel Session C / 170

Quantum features from classical entropies

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Local quantum entropies are of utmost interest in characterizing quantum fields, many-body systems, and gravity. Despite their importance, being nonlinear functionals of the underlying quantum state hinders their theoretical as well as experimental accessibility. Here, we show that suitably chosen classical entropies of standard measurement distributions capture many features of their quantum analogs while remaining accessible even in high-dimensional Hilbert spaces. We demonstrate the presence of the celebrated area law for classical entropies of typical states, such as ground

and excited states of a scalar quantum field. Further, we consider the post-quench dynamics of a Bose-Einstein condensate from an initial product state, in which case we observe the dynamical build-up of quantum correlations signaled by the area law, as well as local thermalization indicated by a transition to a volume law – both in regimes characterized by non-Gaussian quantum states and small sample numbers. With the classical entropy method, we set out a novel paradigm for describing local information in quantum many-body systems and analyzing experimental data beyond correlation functions.References: arXiv:2404.12320, 2404.12321, 2404.12323.

Monday Parallel Session C / 171

Observers in relativistic quantum spacetime

Author: Giacomo Rosati[None]

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I will review some recent progresses in the characterization of the properties of spacetimes with relativistic symmetries deformed at the Planck scale (DSR), relying on the exchange of signals between DSR relativisitc observers.

Monday Parallel Session F / 183

Probing Quantum Collapse with Rotational Dynamics

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Spontaneous wavefunction collapse models, such as the Continuous Spontaneous Localization (CSL) model, provide a promising approach to address the quantum measurement problem by introducing stochastic, nonlinear modifications to the Schrödinger equation. We present new experimental constraints on the CSL model derived from recent high-precision measurements of optomechanical systems rotational motion. Using data from both the LISA Pathfinder mission and a state-of-the-art table-top short-distance gravity experiment, we show that rotational noise can place competitive, and in some regimes stronger, bounds on CSL parameters compared to translational tests. Our analysis highlights the conditions under which rotational degrees of freedom offer enhanced sensitivity to collapse-induced noise. Additionally, we design an optimized geometry of the test mass to amplify the CSL effect and access previously unexplored regions of the parameter space. These findings underscore the potential of rotational tests as a powerful tool for future dedicated experimental investigations of collapse models.

Monday Parallel Session C / 172

Decoherence due to vacuum fluctuations

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The existence of zero-point modes, or the so-called vacuum fluctuations, is one of the fundamental predictions of quantum field theory. From an open quantum system perspective, they constitute an omnipresent and an unavoidable environment of a charged particle. In this talk I would like to discuss if such an environment can lead to observable decoherence and compare it with fundamental decoherence predicted by other theories, concerning the foundations of quantum mechanics. The talk is based on my publications arXiv:2501.17928, Phys. Rev. D 110, 116001 and Phys. Rev. A 107, 062801.

Monday Parallel Session F / 207

A New Experimental Proposal to Test the Nonclassicality of Gravity

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A defining signature of classical systems is "in principle measurability"without disturbance: a feature manifestly violated by quantum systems. We describe a multi-interferometer experimental setup that can, in principle, reveal the nonclassicality of a spatial superposition-sourced gravitational field if an irreducible disturbance is caused by a measurement of gravity. While one interferometer sources the field, the others are used to measure the gravitational field created by the superposition. This requires neither any specific form of nonclassical gravity, nor the generation of entanglement between any relevant degrees of freedom at any stage, thus distinguishing it from the experiments proposed so far. This test, when added to the recent gravity-induced entanglement-witness based proposals, enlarges the domain of quantum postulates being tested for gravity. Moreover, the proposed test yields a signature of quantum measurement induced disturbance for any finite rate of decoherence, and does not require trusted measurement devices (unlike witnessing gravity-induced entanglement). Ref.: Phys. Rev. Lett. 133, 180201 (2024).

Monday Parallel Session F / 208

A multimodal probe for general holographic coherence of quantum space-time states on causal horizons

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Gravitational-wave observatories such as LIGO and Virgo have enabled a new era in multimessenger astronomy. In recent years, predictions of quantum gravity signatures in interferometers by Craig Hogan, Tom Banks, Eric Verlinde, Frank Wilczek, and Kathryn Zurek have inspired multiple new experiments deploying precision laser interferometry at smaller scales to probe such phenomena, such as the Holometer at Fermilab, QUEST at Cardiff, GQuEST at Caltech, and a prototype interferometer at INRiM. Many such models of holographic quantum space-time phenomena are inspired by 't Hooft's algebra of black hole information, which shows large-scale spacelike coherence on causal horizons. This talk will report on efforts to generalize such holographic coherence to the inflationary horizon and causal diamonds in flat space-time (conformal Killing horizons), enabling a multimodal probe connecting primordial signatures in the Cosmic Microwave Background to concordant spectra predicted for tabletop interferometric searches in laboratory space-times. Future expansions of this multimodal research program are explored, with 3D correlations of galaxy distributions in large-scale structure surveys that show intriguing parity violations, and with future experiments in gravitationally mediated entanglement that can shed light on the excited states of quantum gravity if the current experiments detect signatures for the ground state of gravitational entanglement.

Monday Parallel Session C / 173

Quantum entanglement among axions, photons, and gravitons from inflation

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Recent results on electron tunneling across a potential barrier, inferred from experimental observations or obtained from theoretical models, have suggested superluminal or instantaneous barrier traversal times. We will argue, by linking the QFT property of microcausality to the wave-packet second quantized state that the tunneling dynamics is fully causal, precluding instantaneous or superluminal effects. This holds for regular or Klein tunneling across a standard or a supercritical potential: the transmitted wave packet remains in the causal envelope of the propagator, even when its average position lies ahead of the average position of the corresponding freely propagated wave packet. We will also present some numerical illustrations obtained by employing a space-time resolved QFT framework for Klein-Gordon and Dirac fields. Ref: M. Alkhateeb, X. Gutierrez de la Cal, M. Pons, D. Sokolovski, and A. Matzkin, Phys. Rev. A 111, 012222 (2025).

Monday Parallel Session C / 174

Quantum entanglement among axions, photons, and gravitons from inflation

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It is believed that quantum fluctuations of various fields including electromagnetic and gravitational fields are generated during inflation. On top of those, quantum fluctuations of ultralight axion fields could be generated. These fields can be naturally mixed in the history of the universe. Moreover, because of the rapid expansion of the universe, the quantum fluctuations lead to the squeezed state. In this talk, I will show how the quantum states of those fields are entangled. I will also discuss how to characterize the entanglement with Bell-Mermin inequality. I will also mention how to observe entanglement through Hanbury-Brown-Twiss interferometry.

Monday Parallel Session F / 209

An experiment to search for signatures of quantized space-time: QUEST

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We report on the 'QUantum-Enhanced Space-Time experiment' (QUEST), which consists of two co-located Michelson interferometers with the ultimate goal of searching for signatures from the quantization of space-time. We have performed a first engineering run with QUEST which already sets new upper limits for stochastic gravitational waves in the range 13 to 80 MHz, an auxiliary result from the fact that our experiment resembles a table-top scale gravitational-wave detector. We will also report on the planned future version of this experimental paradigm, in which we plan to employ single-photon detection readout on a larger-scale set of Michelson interferometers with 5 m long arms. In this planned version of the experiment (SPI-QG), single photon readout is expected to increase sensitivity to stochastic signal sources, such as from quantization of space-time. With this we should be able to test existing predictions of quantized space-time signatures.

Monday Parallel Session C / 175

How Much Vacuum Entanglement is there between Two Finite Spacetime Regions?

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Studies of extraction of entanglement from quantum fields usually consider probes that couple to independent degrees of freedom of the field, in an attempt to harvest entanglement. These studies usually rely on the specific properties of the probes and perturbative results, resulting in a nearly negligible extraction of entanglement. In this talk we will first quantify the distillable (extractible) entanglement between degrees of freedom localized in two finite spherical regions for a massless real scalar field without utilizing probes or perturbative approximations. Using techniques introduced by Natalie Klco and collaborators, we will then find the most entangled modes between the two regions and discuss which probes could directly couple to these degrees of freedom, optimizing entanglement extraction from a massless quantum field.

Monday Parallel Session F / 210

Operator Ordering in Relativistic Quantization: A Case Study of Specific Heat in Rindler Space

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How do quantum systems behave in a gravitational field, and what role does operator ordering play in their quantization? This work presents a consistent framework for relativistic quantization, tackling the longstanding operator ordering problem through the introduction of arbitrary constants and by coupling internal quantum and external gravitational degrees of freedom. A general, relativistically invariant Hamiltonian is derived, capturing leading-order quantum and relativistic corrections, and allowing for operator ordering parameters that may be probed experimentally. Using perturbation theory, we compute the corrected energy spectrum and apply it to evaluate thermodynamic properties, focusing on the specific heat of a bosonic gas in Rindler coordinates. The resulting relativistic quantum corrections to specific heat could be accessible in state-of-the-art setups, such as counterpropagating laser traps generating strong accelerations. These findings offer a realistic path toward testing gravitational quantum effects through thermodynamic observables.

Monday Parallel Session C / 176

Dynamic Localization of a Free Quantum Field

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In this presentation we will discuss our work on the evolution of a quantum field subject to a time-dependent, confining potential well. In particular we focus on the entanglement dynamics in the process of the construction of a confined field in a finite region (that can be seen as the construction of an optical cavity) from the field vacuum in flat free space. Furthermore, we will discuss that this scenario can model the construction of a covariant particle detector model, and in what way the entanglement present in the field can affect these detectors.

Monday Parallel Session F / 211

Cosmological tests for hybrid classical-quantum gravity

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A way to reconcile general relativity and quantum field theory without quantizing the geometry is requiring that the metric evolves stochastically. In this talk, I will first review the main ideas and motivations around hybrid theories that handle the interaction between classical and quantum degrees of freedom in a consistent manner. In the second half of the talk, I will describe how spacetime diffusion can produce experimentally falsifiable predictions, both at the level of tabletop experiments and of cosmological observables.

Monday Parallel Session C / 177

Conceptual differences between mechanics and field theory, including gravity

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While there are many similarities between mechanics and field theory (both classical and quantum), there are also some fundamental conceptual differences. Examples include (i) the existence of derivatives in directions of 3-space (not to be confused with the configuration space directions), (ii) nonlocality of the evolution operator, (iii) different (and inequivalent) notions of "particle", (iv) the Unruh effect, as well as (v) formal results such as the Haag's theorem (QFT) versus the Stone-von Neumann theorem (QM). Given these and other differences, we will discuss whether the toolbox of quantum information theory (historically constructed within the ontology of mechanics) needs to be reexamined to some extent, in order to render it more compatible with the ontology of field theory.

Monday Parallel Session F / 212

Causal consistency requirements for gravity-induced entanglement in systems with internal energy

Authors: Andre Grossardt[1]; Linda van Manen[2]

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I will present the effects of changes in internal energy on gravity-induced entanglement in interference experiments, which in principle allows for faster-than-light communication. By including a change in internal mass-energy due to photon absorption, we show that previous solutions to the thought experiment are insufficient, and we propose new requirements to save causality and complementarity. The nonrelativistic treatment of the problem is expected to neglect the effects that render the gravitational phase shift unobservable. One such effect could be that decoherence destroys the interferometric superposition at a rate that prevents the detection of the phase shift. Such a decoherence effect is expected from the created virtual quadrupole when exciting the superposed particles, and is similar to decoherence from gravitational radiation due to acceleration.

Monday Parallel Session C / 178

Causal maps in quantum field theory

Author: José Polo-Gómez[1]

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In this talk, we define and characterize localized causal operations in a real scalar quantum field theory, and we will show that these operations exactly correspond to those satisfying various equivalent no-signalling conditions proposed in previous works. The simplicity of this characterization allows us to define a faithful quantifier of how much a map enables faster-than-light signalling in a given field state. Finally, we will apply our results to revisit relevant examples, providing straightforward proofs of their causal (or acausal) behaviour.

Monday Parallel Session F / 213

Bridging Gravitational and Quantum Worlds Using Coherent Atom Arrays

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Relativistic gravitational and many non-gravitational effects are intrinsically weak in their coupling to quantum systems and, therefore, require suitable amplification. To this end, we have identified coherent collections of quantum systems, such as atom arrays, as novel coupling interfaces between relativistic, gravitational, and quantum physics. To illustrate their potential, we shall discuss two recently reported phenomena: (a) *Gravitational Wave-Induced Photon Superradiance in Atoms* and

(b) *Time-resolved and Super-radiantly Amplified Unruh Effect.* References: (a) arXiv:2408.12436 (b) arXiv:2501.16219 Authors List:- Ref. (a): **Navdeep Arya**, Magdalena Zych Ref. (b): Akhil Deswal, **Navdeep Arya**, Kinjalk Lochan, Sandeep K. Goyal

Monday Parallel Session C / 179

Quantum Scalar and Vector Evanescent Particles

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The possibility of quantizing fields in neighborhood of arbitrary spacetime hypersurfaces, not necessarily of Cauchy nature, lies at the core of the so called General Boundary Formulation (GBF) of quantum theory. The GBF provides a novel perspective on quantum dynamics and offers the opportunity to address problems that are challenging (or even impossible) to solve within the standard formulation. In this presentation, we will discuss some recent findings regarding the quantization of evanescent modes of the field, a process that necessitates a new quantization scheme. We will explore this in various contexts, including a massive scalar field within the hypercylinder region in Minkowski spacetime and the electromagnetic field within a waveguide (a spatially cylindrical region extended over all time).

Monday Parallel Session F / 214

Simulating a superposition of spacetimes with optical media

Authors: Germain Tobar[None]; Magdalena Zych[1]; María Rosa Preciado-Rivas[2]

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Superpositions of spacetimes have received considerable attention from the Relativistic Quantum Information community. The standard RQI protocol involves calculating the response of an Unruh-DeWitt detector that is coupled to a quantum field whose background spacetime exists in a quantum superposition of geometries. In this work, we propose a method to simulate such a superposition of spacetimes using optical media. The approach builds on the established analogy between the electromagnetic field in an arbitrary spacetime and the electromagnetic field in an equivalent optical medium. Since permittivity determines the speed of light propagation in an optical medium, controlling it allows us to mimic different spacetime geometries. By analyzing an optical cavity under quantum control—where its permittivity depends on the state of a quantum system—we analyze in-principle measurable quantities in a scenario describing a superposition of effective metrics. We draw analogies between our setup and the standard RQI protocol, and outline how such an approach could be used to simulate quantum superpositions of spacetimes in a laboratory setting.

Monday Parallel Session F / 215

Cascaded Optomechanical Sensing

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We present a novel approach for detecting the weak gravitational field generated at the Large Hadron Collider (LHC) using cascaded optomechanical cavities. Our methodology exploits coherent averaging to potentially reach Heisenberg-limited sensitivity without entangled resources. In this configuration, N sequentially arranged optomechanical cavities interact with a single laser pulse in the stroboscopic regime. This approach overcomes Standard Quantum Limit constraints, enabling distributed sensing across multiple LHC locations. Our analysis addresses implementation challenges including thermal noise and transmission losses. Beyond LHC applications, this methodology shows promise for other fundamental physics investigations requiring unprecedented force sensitivity, including dark matter detection and tests of quantum collapse models.

Monday Parallel Session C / 180

Gravitationally induced decoherence of scalar particles from field theory

Authors: Kristina Giesel[1]; Max Joseph Fahn[2]

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The formalism of open quantum systems provides a way to derive evolution equations, called master equations, for a quantum system of interest that is coupled to an environment, without the need to solve the dynamics of the environment in detail. The starting point of this talk is a master equation for a scalar field as system of interest in an environment of quantised linearised gravity from arXiv:2206.06397. The main focus is on considering its projection onto the one-particle space in order to obtain the decoherence induced by the gravitational environment on a single scalar particle. Special emphasis is put on the renormalisation of the resulting one-particle master equation which contains UV-divergent terms. To this end, the individual contributions of the master equation are linked to the underlying effective QFT and its Feynman diagrams, allowing an analysis of the origin of the divergent terms and a way how to renormalise them. Finally, the model is applied as a toy model to a neutrino in order to gain some insights into gravitationally induced decoherence in neutrino oscillations.

Monday Parallel Session F / 216

Quantum signatures of proper time in optical atomic clocks

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Optical clocks based on atoms and ions probe relativistic effects with unprecedented sensitivity by resolving time dilation through frequency shifts. However, all measurements of time dilation so far are effectively classical, stemming from classical motion. Here we show that the first tests of time dilation where the proper time is no longer a single classical parameter can be achieved with atomic clocks. We apply a Hamiltonian formalism to derive time dilation effects in atomic clocks from first principles, and show how second-order Doppler shifts (SODS) due to the vacuum energy arise (vSODS). We then isolate the quantum-second-order-Doppler-shift (qSODS), a new effect for which a semiclassical description of proper time is insufficient, and which arises due to interference

of relativistic effects in both time and length. We show that both vSODS and qSODS are within reach of near-future experiments with trapped ion clocks.

Monday Parallel Session C / 181

Probing Gravitationally Induced Entanglement via Dynamical Superpositions of Quantum Matter

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Gravitationally Induced Entanglement (GIE) between two levitated objects in quantum states can investigates the quantum nature of the gravitational field in a tabletop experiment. To formally treat the entangling dynamics —both unitary and open —between superpositions of quantum states of matter entangled with a qubit, the Gaussian formalism of continuous-variable systems can be extended to include non-Gaussian states. This is achieved by considering a "superposition of phase spaces,"each characterized by an associated covariance matrix and a vector of first moments. Thus, we propose a protocol to exponentially delocalize a cat state of a massive object, which can be successfully recombined to complete an interferometer. When two such interferometers interact via gravity, GIE can be sensed exponentially fast in the expansion time —if gravity is not classical. The introduced formalism allows noise analysis of the protocol.

Tuesday Plenary Session / 184

Table-top tests of quantum gravity: to entanglement and beyond

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In this talk, I will give an overview of the state of the art and key open questions of this research programme and describe the related activities of the COST Action BridgeQG (Bridging high and low energies in search of quantum gravity).

Tuesday Plenary Session / 185

Waiting around for Unruh

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In the ongoing work towards observing the circular motion Unruh effect in (2+1)-dimensional analogue spacetime systems, one challenge is that the effective temperature experienced by a local detector is much smaller than the linear acceleration prediction when the detector's energy gap

is small and the interaction time is long. We show that an effective temperature of the order of the linear acceleration prediction can be regained via a controlled long-time-small-gap double limit, provided the detector's coupling to the field is allowed to change sign. Such sign changes may be naturally implementable in experiments where a laser beam plays the role of the detector. We further provide a new mathematical characterisation of the long interaction time limit, with a precise asymptotic control of both the coupling strength and its Fourier transform. (Based on joint work with Christopher J Fewster, Leo J A Parry and Diego Vidal-Cruzprieto.)

Tuesday Plenary Session / 186

Stimulated emission or absorption of gravitons by light

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We study the exchange of energy between gravitational and electromagnetic waves in a Sagnac type geometry, in analogy to an "optical Weber bar." In the presence of a gravitational wave (such as the ones measured by LIGO), we find that it should be possible to observe signatures of stimulated emission or absorption of gravitons with present day technology. Apart from marking the transition from passively observing to actively manipulating such a natural phenomenon, this could also be used as a complementary detection scheme. Non-classical photon states may improve the sensitivity and might even allow us to test certain quantum aspects of the gravitational field.

Tuesday Plenary Session / 168

Testing quantum gravity

Author: Daniel Carney[1]

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I will give a brief overview of proposals to test the quantization of the gravitational field, particularly in terrestrial experiments. This will include entanglement experiments and "single-graviton detection". As a particular example of a non-standard gravity model that could be tested, I will discuss a recent phenomenological model of "entropic gravity" and its experimental signatures.

Tuesday Plenary Session / 188

Atom interferometry applied to gravitational measurements

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"Atom interferometry has emerged as a powerful tool to probe gravitational physics with unprecedented precision. In this talk, I will present two distinct experimental efforts that, while targeting

different fundamental questions, share this common methodology.
The first experiment, MEGANTE, addresses a long-standing challenge in metrology: the precise determination of the gravitational constant G. Unlike approaches based on classical instruments, MEGANTE uses cold rubidium atoms and atom interferometry to achieve a target precision of 10 ppm. After a brief introductory overview of the experiment's concept, I will present the recent results concerning the design and implementation of the experimental apparatus.
The second part of the talk will focus on the QUPLAS experiment, which aims to test the Einstein Equivalence Principle and CPT symmetry by measuring the gravitational acceleration of positronium in free fall, which represent an interesting probe mass, alternative and complementary to antihydrogen. In this context I will discuss the design, simulation and optimization of a Large Momentum Transfer (LMT) Mach-Zehnder interferometer used to reveal the influence of the Earth's gravitational field through the relationship that binds the phase shift of the wave function of Ps to the gravitational acceleration. "

Tuesday Plenary Session / 189

BridgeQG: Bridging high and low energies in search of quantum gravity

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The interplay between quantum mechanics and general relativity is one of the most profound open problems in fundamental physics. After decades of purely theoretical investigations, recent experimental advances turned the prospect of a phenomenological approach into a realistic possibility. On one hand, searches for quantum gravity effects in astrophysical signals constitute nowadays an established field of basic research. On the other hand, table-top experiments with quantum systems are now advancing fast towards understanding the role of gravity in quantum systems and testing the possibility that gravity itself is quantized. Investigating the interface between high-energy quantum gravity and quantum aspects of gravity in the low-energy regime, using both theoretical and experimental tools, can provide complementary clues towards the construction of a phenomenologically viable theory of quantum gravity at all scales.

Tuesday Parallel Session F / 217

Quantum decoherence of gravitational waves

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The quantum nature of gravity remains an open question in fundamental physics, lacking experimental verification. Gravitational waves (GWs) provide a potential avenue for detecting gravitons, the hypothetical quantum carriers of gravity. However, by analogy with quantum optics, distinguishing gravitons from classical GWs requires the preservation of quantum coherence, which may be lost due to interactions with the cosmic environment causing decoherence. We investigate whether GWs retain their quantum state by deriving the reduced density matrix and evaluating decoherence, using an environmental model where a scalar field is conformally coupled to gravity. Our results show that quantum decoherence of GWs is stronger at lower frequencies and higher reheating temperatures. We identify a model-independent amplitude threshold below which decoherence is negligible, providing a fundamental limit for directly probing the quantum nature of gravity. In the standard

cosmological scenario, the low energy density of the universe at the end of inflation leads to complete decoherence at the classical amplitude level of inflationary GWs. However, for higher energy densities, decoherence is negligible within a frequency window in the range 100 Hz-100 MHz, which depends on the reheating temperature. In a kinetic-dominated scenario, the dependence on reheating temperature weakens, allowing GWs to maintain quantum coherence above 10 MHz.

Tuesday Parallel Session C / 229

Thermodynamic properties of regular black holes from pure gravity

Authors: David Kubizňák[1]; Fil Simovic[2]; Ioannis Soranidis[2]; Robie A. Hennigar[3]; Sebastian Murk[4]

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Candidate theories of quantum gravity are widely expected to resolve the singularities predicted by general relativity. In the absence of a complete theory, singularity-free models —often referred to as regular black holes —have emerged as a compelling alternative, sidestepping the problematic causal structure of their classical counterparts. A rather ubiquitous prediction across various quantum gravity frameworks is the presence of higher-order curvature corrections to the gravitational action. We show that, within quasitopological gravity, an infinite series of such terms can generically lead to singularity resolution in D
$geqslant5$ dimensions. We also perform a detailed analysis of the resulting black hole thermodynamics, which lies at the intersection of quantum gravity, information theory, and geometry. Notably, the equation of state displays features reminiscent of fluids with finite molecular volume. In addition, we investigate singularity resolution in $D = 4$ through nonlinear electrodynamics with magnetic charge, comparing the relevant phase structure of and discussing implications for relativistic quantum information and the internal geometric structure of regular black holes. [1] R. A. Hennigar, D. Kubizňák, S. Murk, and I. Soranidis, Thermodynamics of regular black holes in anti-de Sitter space (in preparation) [2] F. Simovic and I. Soranidis, Euclidean and Hamiltonian thermodynamics for regular black holes, https://doi.org/10.1103/PhysRevD.109.044029

Tuesday Parallel Session C / 230

Evaporating regular black holes in 2D gravity

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Quantum field theory in curved spacetime famously predicts that information is lost as a black hole evaporates through Hawking radiation. While many resolutions have been proposed, we consider the role of singularities in black hole evaporation. This talk will present a general model of evaporating black holes in 2D dilaton gravity, with a focus on a Bardeen-like regular black hole model. The formation and evaporation of a black hole, including backreaction, is simulated numerically. We find that the apparent horizons evaporate smoothly in finite time and that the final spacetime is free of pathologies such as singularities, event horizons, or Cauchy horizons. This suggests that the evaporation of regular black holes is a unitary process and that resolving the singularity can be a viable solution to the black hole information loss problem

Tuesday Parallel Session F / 218

Sudden Decoherence by Resonant Particle Excitation for Testing Gravity-Induced Entanglement

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Aiming to explore quantum gravity, low-energy experiments have been proposed to test whether Newtonian gravity can generate quantum entanglement or not. However, the weakness of gravity hinders experimental realization. In this talk, we propose a novel optimal method to probe gravity-induced entanglement. We consider the gravitational interaction between a particle trapped in a shallow potential and a harmonic oscillator. The harmonic oscillator is in a quantum superposition of two frequencies and only one of these states can excite the trapped particle via resonance. Once the excited particle is detected, the quantum state of the oscillator is collapsed, which can be observed as the sudden disappearance of the superposition of oscillator frequencies. Thus, the sudden decoherence, which is only triggered by particle detection, can be a smoking gun evidence of gravity-induced entanglement. Since the probability of particle excitation increases linearly with time, the total probability is multiplied by repeating experiments. We will also discuss experimental implementations using optomechanics. This talk is based on arXiv: 2501.18147.

Tuesday Parallel Session C / 231

New interpretation of the original charged BTZ black hole spacetime

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In their seminal 1992 paper, Bañados, Teitelboim and Zanelli (BTZ) proposed a simple charged generalization of what is now known as the spinning BTZ black hole. However, it soon became clear that this spacetime does not satisfy Maxwell equations and was thus discarded. In this talk, we will see that this incorrect original BTZ metric can actually be redeemed - it can be interpreted as a solution of recently discovered Deshpande-Lunin theory which enables us to construct charged and spinning black holes in all odd dimensions by slightly modifying the action with special topological term.

Tuesday Parallel Session F / 219

Detecting post-Newtonian classical and quantum gravity via quantum clock interferometry

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Understanding physical phenomena at the intersection of quantum mechanics and general relativity remains one of the major challenges in modern physics. Among various approaches, experimental tests have been proposed to investigate the dynamics of quantum systems in curved spacetime and to examine the quantum nature of gravity in the low-energy regime. However, most previous studies have considered only Newtonian gravity, leaving the post-Newtonian regime largely unexplored. Developing an experimental test to probe how gravitational and quantum mechanical effects interact in this regime would provide valuable insights into the physics bridging quantum mechanics and general relativity. In this study, we propose an experimental test to investigate how post-Newtonian gravity affects quantum systems and to examine its quantum nature. Specifically, we design and analyze two types of experiments: one using a quantum clock interferometry setup to detect the gravitational field generated by a rotating mass, and another leveraging this effect to generate gravity-mediated entanglement. Although the proposed experiments are extremely challenging to implement, they are inherently suited for probing post-Newtonian gravity. This is because, due to the symmetry of the configuration, the setup is insensitive to the Newtonian gravitational contribution while sensitive to the frame-dragging effect. Moreover, assuming the universality of gravitational redshift, our approach may offer a possible way not only to probe the quantum nature of gravity but also to investigate whether spacetime itself exhibits quantum features. The results of this study open up new avenues for investigating physical phenomena in the regime where quantum mechanics and general relativity converge.

Tuesday Parallel Session F / 220

Control, sensing and gravitational coupling of milligram pendulums: towards interfacing quantum and gravity

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Can we test the quantum mechanical nature of gravitational fields? Milligram-scale optomechanical experiments present a frontier for bridging quantum mechanics and gravitational physics by aiming to strike a balance between 1) making gravitational couplings of the controlled objects dominant and 2) making the motions of these objects quantum noise dominated. Required systems necessitate low-frequency dynamics that is typically considered quantum-unfriendly, but seems to be needed to achieve a large figure-of-merit in the problem, quantifying the ability to generate quantum entanglement gravitationally. In this talk, I will first focus on our 1-milligram suspended torsional pendulum operating at 18 Hz, and the successful laser cooling of its motion to 240~microkelvins. I will elucidate the resulting boost in the quantum coherence length of this pendulum, benchmarking a state-of-the-art quantum-gravity figure-of-merit with a vast improvement potential [1]. I will outline a realistic path to enter a regime where gravitational entanglement could be generated utilizing our zig-zag optical cavities [2] to boost the interactions of light and torsional pendulums. I will conclude with the ongoing effort of achieving gravitationally-limited coupling between two free running ~1 milligram pendulums –aiming to push observable inter-particle gravitational couplings down by 3 orders of magnitude relative to current state of the art. [1] "1-milligram torsional pendulum for experiments at the quantum-gravity interface", S. Agafonova, P. Rossello, M. Mekonnen, O. Hosten, arXiv:2408.09445 (2024). [2] "A zigzag optical cavity for sensing and controlling torsional motion", S. Agafonova, U. Mishra , F. Diorico , and O. Hosten, Phys. Rev. Research 6, 013141. (2024)

Tuesday Parallel Session C / 266

Covariant non-perturbative pointer variables for quantum fields

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In this talk I will discuss how modelling local, nonperturvative measurements in relativistic field theories has traditionally led to a choice between mathematical untractability and frictions with covariance, locality and causality. In this context I will argue that there is a class of detector models in which nonperturbative, local and convariant, as well as mathematically tractable results can be achieved. Our approach combines several features of other models encountered in the literature of relativistic quantum nformation, namely scattering processes, quantum Brownian motion models, and Gaussian dynamics. I will argue that, when it comes to causality and covariance, pointlike, ill-defined interactions are necessary, but these can be renormalized consistently a la Epstein Glasser. I will further analyze the model in the context of quantum measurement theory and argue that these models generate well-defined induced observables. Our formalism can be used to detect non-Gaussianities present in the field's state in a local and covariant way, and the nonperturvative nature of the problem provides an operational framework to discuss Bell inequalities in of quantum field theory. arXiv:2502.01283

Tuesday Parallel Session C / 233

What quantum foundations teach us about black holes

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Black holes provide a setting to test assumptions about the interplay of quantum theory and gravity. These tests have led to several puzzles, such as the xeroxing or firewall paradox. A common feature of these puzzles is that they combine the perspectives of an infalling observer and an exterior observer, who, for fundamental reasons, have access to different systems. In quantum foundations, so-called Wigner's friend experiments study observers with different perspectives, without involving gravity. Recent versions have shown that even mild assumptions about the combination of different observers'perspectives are inconsistent with quantum theory. A careful analysis of the firewall paradox reveals that it, too, relies on this assumption. Therefore, the firewall paradox may not stem from inconsistent assumptions about quantum gravity, but from quantum theory's limitations in consistently combining multiple observers'viewpoints.

Tuesday Parallel Session F / 221

Benchmarks for quantum communication via gravity

Authors: Jonatan Bohr Brask[1]; Kristian Toccacelo[1]; Ulrik Lund Andersen[1]

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We establish limitations and bounds on the transmission of quantum states between gravitationally interacting mechanical oscillators under different models of gravity. This provides benchmarks that can enable tests for quantum features of gravity. Our proposal does not require the measurement of gravitationally induced entanglement and only requires final measurements of a single subsystem. We discuss bounds for classical models based on local operations and classical communication when considering coherent-state alphabets, and we discuss the transfer of quantum squeezing for falsifying the Schrödinger-Newton model.

Tuesday Parallel Session C / 234

Black hole thermodynamics probes the equivalence principle

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The equivalence principle imposes stringent constraints on both kinematics and dynamics of the spacetime. In my talk, I discuss how these constraints manifest in the context of black hole thermodynamics. I introduce a thought experiment involving a small black hole which uncovers violations of the strong equivalence principle. I then explore its outcomes in several gravitational theories of interest. In particular, I show that all Lanczos-Lovelock theories except general relativity violate the strong equivalence principle. I also comment on the application of the thought experiment in the context of semiclassical gravity and AdS/CFT correspondence.

Tuesday Parallel Session F / 222

Quantum dynamics of indefinite fields and spacetimes

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The dynamics of quantum systems in indefinite spacetimes—such as superpositions of macroscopically distinct semiclassical geometries—have been studied extensively in the contexts of quantum reference frames and quantum field theory in curved spacetimes. These studies typically assume that quantum states associated with different spacetimes (i) form a complete orthonormal basis and (ii) possess no intrinsic dynamics. Motivated by arguments from the quantum gravity community, we relax the first assumption and treat different spacetimes as partially distinguishable. This leads to novel dynamical effects arising from the nonorthogonality of spacetime states. We explore the consequences of this framework and predict several new phenomena, including a thought experiment that constrains the inner product between distinct metric states.

Tuesday Parallel Session F / 223

Acceleration-induced radiation from a qudit particle detector model

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We nonperturbatively examine the emission rate of acceleration-induced radiation from a uniformly accelerated gapless qudit-type Unruh-DeWitt detector. We find that the emission rate can be written as Larmor's formula multiplied by a factor that depends on the detector's initial state. In particular, certain initial states of integer-spin detectors do not produce radiation. Although the appearance of Larmor's formula may suggest a classical phenomenon, we argue that the resulting radiation is fundamentally distinct from that of structureless classical sources, as it evolves into a multimode

coherent state correlated with the detector's internal degree of freedom. Thus, gapless detectors cannot be treated as structureless sources, as previously proposed.

Tuesday Parallel Session C / 235

Entanglement entropy area law in dynamical and quantum-corrected black holes

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Entanglement entropy in dynamical and quantum-corrected black hole spacetimes offers a key diagnostic of quantum correlations across horizons, motivating studies of its scaling and time evolution near these critical surfaces. We investigate the entanglement entropy scaling with the horizon area in two settings. In the first analysis, we consider a massive scalar field with nonminimal curvature coupling in Schwarzschild-like quantum-corrected metrics, employing a spherical-shell discretization and parameter estimation anchored in uncertainty-principle constraints and quantum-gravity models. We find entropy suppression near the regularized singularity and the asymptotic restoration of the area law. In the second study, we discretize a massless scalar field on a time-dependent Oppenheimer–Snyder collapse background. We observe nontrivial time-dependent deviations from the canonical area law as the collapse goes on. Together, these results elucidate the interplay between dynamical evolution, UV regularization, and horizon entanglement.

Tuesday Parallel Session F / 224

A novel approach to particle production via communication between quantum particle detectors

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Recent work has shown that communication channels between Unruh–DeWitt detectors are sensitive not only to the initial particle content of a quantum field but also to the spacetime history prior to the communication protocol. In particular, a cosmological expansion occurring before the protocol begins reduces the channel's capacity. This implies that the noise experienced by the receiver encodes information about the universe's past. Additionally, if a thermal particle spectrum is present at the start of the communication, it contributes with noise, as expected. Can these two sources of noise—one from thermal particles and one from spacetime dynamics—be related? If so, this relation allows us to infer particle production resulting from cosmic expansion, even during ongoing expansion and without requiring an asymptotically flat spacetime in the far future, as is necessary in the conventional Bogoliubov coefficient approach.

Tuesday Parallel Session C / 236

Quantum entanglement of two bosonic modes in de Sitter space

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In recent years, extensive studies on quantum correlations in various scenarios, such as non-inertial frames, curved spacetime, and an expanding universe have been performed [1–7]. In the framework of the theory of open systems based on completely positive quantum dynamical semigroups, we investigate the time evolution of Gaussian quantum entanglement of two bosonic modes associated with a scalar quantum field in de Sitter space and in interaction with a thermal reservoir. We show that quantum entanglement strongly depends on the squeezing of the bimodal state, the parameters characterizing the thermal environment, the curvature parameter of de Sitter space, and the mass parameter. The thermal environment and the curvature have a destructive influence on the entanglement, whose survival time depends on the competition between the contrary effects provided by the squeezing of the bimodal state, the curvature, and the thermal bath. The entanglement is minimized for values 1/2 and 3/2 of the mass parameter, corresponding to the conformally coupled scalar field, respectively minimally coupled massless field [8]. [1] P.M. Alsing, I. Fuentes-Schuller, R.B. Mann, T.E. Tessier, Phys. Rev. A 74, 032326 (2006). [2] D.E. Bruschi, A. Dragan, I. Fuentes, J. Louko, Phys. Rev. D 86, 025026 (2012). [3] G. Adesso, S. Raga, D. Girolami, Class. Quantum Grav. 29, 224002 (2012). [4] J. Doukas, E.G. Brown, A. Dragan, R.B. Mann, Phys. Rev. A 84, 012306 (2013). [5] B. Richter, Y. Omar Phys. Rev. A 92, 022334 (2015). [6] S.M. Wu, H.S. Zeng, Quantum Inf. Process. 18, 305 (2019). [7] M. Calamanciuc, A. Isar, Results Phys. 55, 107167 (2023). [8] M. Calamanciuc, A. Isar, submitted for publication.

Tuesday Parallel Session C / 237

Quantum fermion superradiance and vacuum ambiguities on charged black holes

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Unlike a classical charged bosonic field, a classical charged fermion field on a static charged black hole does not exhibit superradiant scattering. We demonstrate that the quantum analogue of this classical process is however present. We construct a vacuum state for the fermion field which has no incoming particles from past null infinity, but which contains, at future null infinity, a nonthermal flux of particles. This state describes both the discharge and energy loss of the black hole, and we analyze how the interpretation of this phenomenon depends on the ambiguities inherent in defining the quantum vacuum.

Tuesday Parallel Session F / 225

Can spacetime fluctuations generate entanglement between co-moving accelerated detectors?

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Recent studies [Class. Quant. Grav. 42, 03LT01 (2025); Phys. Rev. D 111, 045023 (2025)] indicate that in a nested sequence of Rindler wedges, vacuum of former Rindler frame appears to be thermally populated for an observer in shifted Rindler frame. Interestingly, this thermality is independent of shift parameter as long as it is non-zero and therefore arises even if the shift parameter is as small as Planck length. Building on this insight, we propose a set-up involving two atoms accelerating with identical acceleration. We find that if their Rindler frames (consequently their trajectories) get infinitesimally separated, the atoms become entangled. Remarkably again, this entanglement, like the perceived thermality, is independent of the shift parameter, provided it is non-vanishing. We investigate the dependence of entanglement on acceleration of the detectors. The present study indicates that the entanglement between two detectors, moving on the same Rindler wedge, is possible. Moreover, small spacetime fluctuations can lead to entanglement between detectors, moving along same classical trajectory. Hence we feel that such theoretical prediction has potential to probe the Planck length nature of spacetime. arXiv: 2504.12674

Tuesday Parallel Session F / 226

Quantum thermal machines in black hole spacetime

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We present a general framework for understanding the finite-time operation of relativistic quantum thermal machines, focusing on their energy optimization. As an example, we introduce an Otto thermodynamic cycle where the working medium is a qubit Unruh-DeWitt detector interacting with a massless, conformally coupled scalar field in the Hartle-Hawking vacuum of a (2+1)-dimensional BTZ black hole spacetime. The thermal properties of the field are employed to model the heat and cold reservoirs driving the cycle. Modeling the detector as an open quantum system, we use a master equation to study its finite-time dynamics during each cycle stroke. We evaluate the output performance of the Otto heat engine and refrigerator by computing, respectively, the total work output and the cooling power. Additionally, we evaluate the optimal performance of the thermal machine by analyzing its efficiency at maximum power output and ecological impact.

Tuesday Parallel Session C / 238

Computational Quantum field theory in curved spacetimes: Fermionic and bosonic pair creation in 1+1 dimensional black holes

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Computational quantum field theory (CQFT) has been successful in studying the pair production of electron-positron pairs resulting from colliding laser pulses—an effect yet to be observed. It has also been successful in studying the dynamics of Klein tunneling for fermions and bosons. We extend the framework of CQFT to curved spacetimes and use it to investigate the dynamics of fermionic and bosonic pair production resulting from spacetime curvature. For illustration, we implement our CQFT framework to study the evolution of fermionic and bosonic vacuum states in a spacetime characterized by a Schwarzschild-like metric in 1+1 dimensions.

Tuesday Parallel Session C / 239

How to lose information with black holes: an update

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Hawking radiation is the most celebrated result of quantum field theory on a curved background. It completed the formulation of black hole thermodynamics and initiated the black hole information loss debate. Candidate theories of quantum gravity are required to demonstrate their way of entropy counting, indicate modifications to gravitational collapse, and take a stance on the issue of information loss and/or its resolution. At the same time, the pre-conditions for formulation of the paradox are often neither fully specified nor explored. We review the necessary semiclassical ingredients of the formulation of the paradox, and describe how assuming them constrains properties of black holes. Even under these conditions it is unclear if the paradox can be formulated. What is clear is that black holes must be more exotic than exotic horizonless objects, as they violate all the assumptions of the Buchdahl theorem.

Tuesday Parallel Session F / 227

A Universal Quantum Computer From Relativistic Motion

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We present an explicit construction of a relativistic quantum computing architecture using a variational quantum circuit approach that is shown to allow for universal quantum computing. The variational quantum circuit consists of tunable single-qubit rotations and entangling gates that are implemented successively. The single qubit rotations are parameterized by the proper time intervals of the qubits' trajectories and can be tuned by varying their relativistic motion in spacetime. The entangling layer is mediated by a relativistic quantum field instead of through direct coupling between the qubits. Within this setting, we give a prescription for how to use quantum field-mediated entanglement and manipulation of the relativistic motion of qubits to obtain a universal gate set, for which compact non-perturbative expressions that are valid for general spacetimes are also obtained. We also derive a lower bound on the channel fidelity that shows the existence of parameter regimes in which all entangling operations are effectively unitary, despite the noise generated from the presence of a mediating quantum field. Finally, we consider an explicit implementation of the quantum Fourier transform with relativistic qubits.

Tuesday Parallel Session C / 240

Entanglement generation and distribution in QED processes

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I will report on recent findings about the generation and distribution of entanglement in Quantum Electrodynamics (QED) scattering processes. The analysis takes advantage of the complete complementarity relations, which allow for a complete characterization of both local and nonlocal properties of these fundamental quantum processes. Remarkably, it is found that maximal entanglement is conserved in scatterings involving fermions only. References 1. M. Blasone, G. Lambiase and B. Micciola, "Entanglement distribution in Bhabha scattering with entangled spectator particle", Phys.

Rev. D 109, (2024). 2. M. Blasone, S. De Siena, G. Lambiase, C. Matrella and B. Micciola, "Complete complementarity relations in tree level QED processes", Phys. Rev. D 111 (2025). 3. M. Blasone, S. De Siena, G. Lambiase, C. Matrella and B. Micciola, "Entanglement dynamics in QED processes", Chaos Solitons Fractals 195 (2025).

Tuesday Parallel Session F / 228

Non-perturbative modelling of quadratically coupled detectors in QFT

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QFT models involving detectors are usually modelled perturbatively out of necessity, however, there are certain situations when non-perturbative methods can be used. When the detector is a finite dimensional qudit, non-perturbative modelling is possible if the detector interacts suddenly and very quickly (δ-switching) or if the detector is degenerate (zero energy gap). When the detector couples linearly to the field, numerical evaluation of the model requires an understanding of the Lie Group of (Glauber) coherent states and linear displacement operators, including the exact evaluation of the inner product between two different coherent states. Fortunately, coherent states are frequently used in quantum optics and their algebraic properties are well known. When the detector couples quadratically to the field, we require an understanding of the Lie Group of quadratic displacement operators. Whilst these operators are used in quantum optics, there are some gaps in knowledge, specifically the exact evaluation (including complex phase) of the inner product between two different quadratically displaced states. In this talk I will be introducing a technique for evaluating the inner product between two different quadratically displaced states. I shall then use this technique to model two example scenarios relevant to RQI, 1) how does the excitation probability of a detector change by the presence of another detector in its past? (Fermi problem); 2) What is the energy density of a scalar field after a detector interaction and measurement? These questions have been answered for linear detectors, although they have not previously been solved for quadratic detectors. This tool is expected to become increasingly useful in optomechanical and superconducting analogue gravity modelling. ArXiv: 2504.11799

Wednesday Plenary Session / 190

Quantum foundations and causality

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We will discuss the notion of causal influence and compare it to signalling. We will then show the conditions on a theory of elementary systems for the two notions to coincide. After introducing quantifiers of signalling and causal influence, we will calculate them for special quantum channels. The discussion will proceed reviewing the main open problems related to the notion of causal influence. We will conclude with a brief illustration of how the partial order introduced by causal influence allows for a backbone graph for an emergent geometry in a computational scenario such as a cellular automaton, confirming that this approach constitutes a viable route to the emergence of mechanical laws in a purely information-theoretic background.

Wednesday Plenary Session / 191

State updates and useful qubits in relativistic quantum information

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What happens when one measures a quantum system in a relativistic setting? We will address the challenge of consistently updating quantum states after selective measurements in a relativistic spacetime. Standard updates along the future lightcones preserve causality but break correlations between causally disconnected parties, whereas updates along the past lightcone can either imply retrocausality or not respect the causal propagation of information. We introduce a minimal extension of multipartite states to encode subsystem-specific contextual information.

Wednesday Plenary Session / 197

Sensing Superposed Spacetime

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One of the most basic expectations of quantum gravity is that gravitational fields can be placed in a state of superposition, analogous to what can be done for electromagnetic fields. However in a relativistic context a gravitational field is equivalent to a particular spacetime, and so a superposed gravitational field is a superposed spacetime. Rather than consider how such a state might emerge from a quantum theory of gravity, I will discuss instead how such states might be probed by model 2-level detectors. Examples will include flat spacetimes, expanding spacetimes, black holes, and cosmic strings. Quantum interference between the superposed spacetimes leads to qualitatively new features in the detector response. I will discuss these and close with some comments as to how these ideas can be further explored.

Wednesday Plenary Session / 193

Gravitational Decoherence from Loop Quantum Gravity

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Models for gravitationally induced decoherence can be formulated in the framework of open quantum systems, where gravity is chosen as the environment and quantized together with the system under consideration. Existing phenomenological models often take the Lindblad equation as a starting point for the master equation, while from the perspective of quantum gravity approaches, an underlying microscopic model from which a field-theoretical master equation can be derived seems to be the more accessible route. In the first part, we briefly discuss the tasks to be accomplished in principle to formulate such open quantum models in the framework of loop quantum gravity (LQG), as well as the challenges that come along with it, focusing on the similarities and differences with

existing models of gravitationally induced decoherence with linearized gravity. These include the role of physical dynamical reference frames in open relativistic quantum systems, the renormalization of the master equation, and the specific quantization method used in LQG-inspired models. In the second part, recent first steps and results on some of the relevant steps discussed in the first part are presented. This involves an open QFT model formulated in terms of Ashtekar-Barbero variables, the usual classical starting point for LQG, but which is still based on a standard Fock quantization, a special choice of so-called geometrical clocks as a reference frame, and a renormalization of the master equation based on QFT techniques.

Wednesday Plenary Session / 194

Quantum reference frames, quantum observers and quantum spacetime

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I will introduce and motivate the Hopf-algebraic (quantum group) description of isometries in noncommutative spacetimes, emphasizing the quantum nature of transformations between reference frames. In this context, the notion of reference frame itself must acquire quantum properties. I will then overview recent work describing quantum reference frames via quantum groups of frame transformations, both within noncommutative spacetimes and in more general settings. These developments provide new perspectives on the operational meaning of reference frames and observers in quantum gravity.

Wednesday Plenary Session / 195

Recent Advancements in cavity controlled Quantum Field effects

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The idea of judicious selection of boundary conditions has been recently advanced to meaningfully enhance some low cross section quantum field theoretic events. In this talk, we will discuss some recent proposals of proper selection of mode functions to identify and amplify many interesting effects like acceleration radiation, Unruh thermality, Entanglement harvesting and Field-Field interactions. Such studies advocate the idea of achieving precision boundary conditions as a potential replacement of extreme conditions in the attempts of realizing these interesting theoretical predictions.

Wednesday Parallel Session C / 253

Circular Unruh effect using coupled annular Josephson junctions at finite ambient temperatures

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The Unruh effect, a fundamental prediction of quantum field theory, postulates that a uniformly accelerated observer perceives the vacuum as a thermal bath. Direct experimental verification remains a formidable challenge due to the minuscule magnitude of the effect under linear acceleration. We have previously proposed a tabletop experiment utilizing the circular motion of fluxon-antifluxon pairs in inductively coupled annular Josephson junctions to generate a measurable Unruh temperature, estimated to be on the order of 1K. In this study, we incorporate realistic laboratory temperatures into our analysis as the initial conditions of the thermal bath. This enables a more concrete feasibility assessment for observing the circular Unruh effect in practical settings. Specifically, we investigate the impact of ambient thermal noise on the detectability of the Unruh temperature. Furthermore, we evaluate the sensitivity of our proposed thermometer, demonstrating a temperature resolution on the order of 10mK. This analysis provides crucial insights into the experimental requirements and potential challenges for the observation of the circular Unruh effect in Josephson junction systems.

Wednesday Parallel Session F / 241

Cyclic quantum causal modelling with a graph separation theorem

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Causal modelling frameworks link observable correlations to causal explanations, which is a crucial aspect of science. These models represent causal relationships through directed graphs, with vertices and edges denoting systems and transformations within a theory. Most studies focus on acyclic causal graphs, where well-defined probability rules and powerful graph-theoretic properties like the d-separation theorem apply. However, understanding complex feedback processes and exotic fundamental scenarios with causal loops requires cyclic causal models, where such results do not generally hold. While progress has been made in classical cyclic causal models, challenges remain in uniquely fixing probability distributions and identifying graph-separation properties applicable in general cyclic models. In cyclic quantum scenarios, existing frameworks have focussed on a subset of possible cyclic causal scenarios, with graph-separation properties yet unexplored. This work proposes a framework applicable to all consistent quantum and classical cyclic causal models on finite-dimensional systems. We address these challenges by introducing a robust probability rule and a novel graph-separation property, p-separation, which we prove to be sound and complete for all such models. Our approach maps cyclic causal models to acyclic ones with post-selection, leveraging the post-selected quantum teleportation protocol. We characterize these protocols and their success probabilities along the way. We also establish connections between this formalism and other classical and quantum frameworks to inform a more unified perspective on causality. This provides a foundation for more general cyclic causal discovery algorithms and to systematically extend open problems and techniques from acyclic informational networks (e.g., certification of non-classicality) to cyclic causal structures and networks. In addition, in future work in preparation, we connect this approach to the study of emergent spacetime structure, using tensor networks to explore how spatio-temporal notions might emerge from purely information-theoretic causal models.

Wednesday Parallel Session C / 254

Tunneling method for Hawking radiation in analogue gravity

Authors: Francesco Del Porro[1]; Marc Schneider[2]; Stefano Liberati[3]

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Analogue Hawking radiation from acoustic horizons is now a well-established phenomenon, both theoretically and experimentally. Its persistence, despite the modified dispersion relations characterizing phonons in analogue spacetimes, represents an evidence of the robustness of this effect against the ultraviolet non-relativistic modification of the particles' behavior. Previous theoretical explanations of this effect are based on Bogoliubov transformations, relating asymptotic states, for which an analytical treatment represents a hard challenge and usually stops at the leading order around the relativistic limit In this talk (based on ArXiv:2406.14603) I will address the analogue Hawking effect making use of the tunneling method. Within a unified treatment, I will show how the simplicity of this method allows to describe both the case of superluminal and subluminal dispersion relations, going beyond the leading order approximation. I will clarify also the mechanism behind the puzzling appearance of excitations for horizonless spacetimes, namely for a subcritical flow, which are expected in the case of subluminal dispersions.

Wednesday Parallel Session F / 242

Modular Theory, Quantisation and Quantum Space-time

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A link between quantisation and (non-commutative) geometry is uncovered via Tomita-Takesaki modular theory for complexified ortho-symplectic spaces. We suggest (following arXiv:1007.4094v1) that, in a covariant quantum theory, non-commutative space-time can be a-posteriori recovered from relativistic states over algebras of partial observables. Speculative implications for cosmology will be mentioned.

Wednesday Parallel Session C / 255

Quasinormal Modes of a Dispersive, Confined Gravity Simulator

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Gravity simulators enable the study of black-hole quasinormal modes (QNMs) in controlled experimental settings. However, realistic laboratory setups introduce two key effects absent in traditional gravitational QNM analyses: dispersion and spatial confinement. The former introduces Lorentz-breaking terms in the wave equation, as encountered in modified gravity theories, whereas the latter significantly alters the QNM spectrum, as widely explored in recent studies on spectral stability. The recent development of a rotating spacetime simulator in superfluid helium offers an ideal platform where these effects can be observed. In this talk, I show how ray tracing and spectral-stability techniques can be used to predict the resonances observed in finite-size, highly dispersive systems, providing new insights into laboratory-based black hole spectroscopy.

Wednesday Parallel Session F / 243

Quantifying Causal Influence in Quantum Mechanics

Authors: Daniel Braun[1]; Llorenç Escolà-Farràs[1]

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We generalize Pearl´s definition of causal influence from classical random variables and probability distributions to the quantum world. For two systems A, B, embedded in a common environment C that might represent quantum fields and mediate an interaction between A and B, we find the necessary and sufficient condition on a unitary U that jointly propagates A, B, C for a causal influence of A on B and vice versa. We then introduce an easily computable measure of the causal influence and use it to study the causal influence of different quantum gates, the mutuality of the causal influence, and quantum superpositions of different causal orders. We study the distribution of causal influence over an ensemble of Haar-distributed unitaries U and calculate analytically the expected value of the causal influence. Applied to two two-level atoms that dipole-interact with a thermal bath of electromagnetic waves, we find that the space-time dependence of causal influence almost perfectly reproduces the one of reservoir-induced entanglement. [1] Llorenç Escolà-Farràs and Daniel Braun, Phys. Rev. A, **106**, 062415 (2022)

Wednesday Parallel Session C / 256

Gravitational wave imprints on spontaneous emission

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Gravitational wave studies and detection efforts have traditionally focused on their effects on test masses and geodesic deviation. In contrast, we show that gravitational waves can nontrivially influence spontaneous emission from point-like atoms, inducing directionality in the emission pattern and generating sidebands in the spectrum. We examine how much information about the gravitational wave amplitude is encoded in the quantum state of the combined atom–field system, analyzing both the classical Fisher information associated with photon number measurements and the quantum Fisher information. Our results suggest that the requirements for gravitational wave detection via this mechanism are not prohibitive.

Wednesday Parallel Session F / 244

What process matrices tell us about quantum spacetime

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Considering the problems to extract near-term testable predictions from theories of quantum gravity, a promising alternative is to instead start with phenomenological approaches. One such phenomenon, that might be rather generic, is indefinite causal structure: The dynamic causal structure of general relativity gets combined with quantum indeterminism. The most established framework

to describe indefinite causal structure is the process matrix framework. However, because of its root in quantum information theory, it can be quite abstract and detached from spacetime concepts. In my presentation, I will bridge this gap by presenting projects I worked on as a PhD student. These projects extracted operational statements about spacetime. If time permits, I will take a contemporary look at the field of process matrices, and propose possible avenues to continue.

Wednesday Parallel Session F / 245

Unified Covariant GUP and Momentum-Space Geometry

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We present a unified theoretical framework that combines a covariant Generalized Uncertainty Principle with a dynamical momentum-space geometry. Using normal-coordinate methods, we show that the extrinsic curvature of constant-momentum hypersurfaces induces covariant deformations of the canonical commutators, yielding noncommutative position operators. Simultaneously, the momentum-space metric is elevated to a dynamical field governed by an Einstein–Hilbert–type action. When coupled to quantum matter fields, this construction produces systematically modified kinetic operators and dispersion relations within a self-consistent, covariant setting.

Wednesday Parallel Session C / 257

Information in quantum field theory simulators: Thin-film superfluid helium

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Experimental studies of information in continuous—variable quantum systems have thus far been highly limited due to the difficulty of accessing the full state of the system. Recently, novel reconstruction methods for Gaussian states —those fully characterised by mean and covariance — have been utilised, enabling the verification of the area-law scaling of mutual information in a one-dimensional quantum field theory (QFT) simulator [1]. Advances in the control of quantum systems now open new avenues for the development and use of (2+1)-dimensional QFT simulators. Here, we show a procedure for analysis of information-theoretic quantities in various simulator systems. We then motivate the use of superfluid helium−4 thin-film QFT simulators [2] for this purpose. Finally, we discuss remaining technical challenges and recent progress, arguing that experimental measurements of information in (2+1) dimensional, finite-size, field theory simulators may soon be within reach. **References** [1] Bunney, C. R. D., Barroso, V. S., Biermann, S., Geelmuyden, A. et al. (2024), 'Third sound detectors in accelerated motion', New J. Phys. 26, 065001. [2] Tajik, M., Kukuljan, I., Sotiriadis, S., Rauer, B. et al. (2023), 'Verification of the area law of mutual information in a quantum field simulator', Nature Physics 19(7), 175–2481.

Wednesday Parallel Session C / 280

Trajectory-protected Quantum Computing

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In this talk, I will introduce a proposal for a quantum computing model that leverages a qubit's motion to suppress decoherence while enabling quantum gates. By treating the qubit as a moving Unruh-DeWitt detector interacting with a quantum field in a cavity, we use its trajectory to eliminate dominant decoherence channels—an effect known as acceleration-induced transparency. One-qubit gates are implemented via controlled counter-rotating interactions, while two-qubit gates exploit entanglement harvesting from the vacuum, enhanced by field squeezing. Finally, I will discuss how periodicity in the qubit's trajectory is used to eliminate spurious phase accumulation during gate operations, while simultaneously preserving the transparency condition throughout the evolution.

Wednesday Parallel Session F / 246

Quantumness and memory effects in multi-time measurements

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More than a century after the birth of quantum theory, the question of which properties and phenomena are fundamentally quantum remains under active investigation. In this talk, I will discuss when and to what extent quantumness can be unambiguously associated with an open quantum system that is sequentially measured at different times. Central to our analysis are the quantum regression theorem, which defines the Markovianity of the multi-time statistics, and the Kolmogorov consistency conditions, which discriminate classical and non-classical statistics. We show that in the Markovian case the multi-time statistics cannot be accounted for by means of any classical process if and only if the dynamics generates coherences and subsequently turns them into populations [1]. On the other hand, such a direct connection between the dynamics of quantum coherences and non-classicality cannot be extended to general non-Markovian processes, where, instead, non-classicality is related to a global property of the system-environment correlations [2] that is fully captured by higher-order quantum maps, i.e., quantum combs [3]. **References** [1] A. Smirne, D. Egloff, M. G. Diaz, M. B. Plenio, and S. F. Huelga, Quantum Sci. Technol. 4, 01LT01 (2018) [2] S. Milz, D. Egloff, P. Taranto, T. Theurer, M. B. Plenio, A. Smirne, and S. F. Huelga, Phys. Rev. X 10, 041049 (2020) [3] G. Chiribella, G. M. D'Ariano, and P. Perinotti, Phys. Rev. Lett. 101, 060401 (2008).

Wednesday Parallel Session F / 247

Foundations of relational scalar quantum field theory

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Starting from operationally motivated principles, we derive a relational theory of local observables in Minkowski spacetime from which the notion of scalar quantum fields naturally emerges. We expand on quantum reference frames in spacetime and demonstrate that most properties of quantum fields arise as direct consequences of constraints on quantum reference frames – that is, quantum fields should be understood as what observers "see" in spacetime. We show that such quantum fields satisfy the usual axioms of constructive quantum field theory provided natural assumptions at the level of the quantum reference frames. We indeed highlight that analogous objects to the textbook Wightman quantum fields show up in certain classes of quantum reference frames in spacetime.

Wednesday Parallel Session C / 258

Quantum Backaction in Analogue Spacetime

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Backaction plays a fundamental role in measurements made on quantum systems. In this talk I will discuss the role of backaction in quantum simulators on analogue spacetime, presenting both a non-perturbative treatment of backaction for an analogue realization of the circular Unruh effect and a general analogy incorporating perturbative backaction for Unruh-deWitt detectors in (2+1) dimensions. I will compare the two treatments, and then comment on the role of backaction for extracting a signature of the Unruh effect beyond the standard quantum limit.

Wednesday Parallel Session F / 248

Unitarity, nonunitarity, and choice of clock observable in the Page-Wootters framework

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The Page-Wootters framework introduces a covariant observable for a physical system, allowing it to serve as a time reference—a clock—to describe the dynamics of a system of interest. Within this framework, standard Schrödinger dynamics is recovered when the clock and system do not interact. However, interactions generally lead to time-nonlocal and potentially nonunitary dynamics. We show that these effects stem from the standard choice of clock observables. Specifically, we present an example where a generalized clock observable yields unitary dynamics, while the standard choice results in nonunitarity. We then establish conditions on the joint state of the clock and system that allow for generalized clock observables that ensure unitarity. Finally, we outline a method to construct such observables when they exist.

Wednesday Parallel Session C / 259

Modelling entanglement harvesting implementations in superconducting circuits

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Implementing RQI protocols such as entanglement harvesting in superconducting circuits requires moving beyond idealized UDW detector models. These implementations use superconducting qubits tunably coupled to transmission lines, which serve as one-dimensional quantum fields. We will present a series of upgrades to UDW detector models needed to capture such experimental implementations, and examine the impact of these modifications on entanglement harvesting.

Wednesday Parallel Session C / 260

Gravitational dynamics in analogue systems: a proposal

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I review a number of theoretical results suggesting that gravitational (notably, cosmological) dynamics can be reproduced in the hydrodynamic regime of quantum many-body systems, and argue for a change in perspective (based on a relational understanding of spacetime physics and on these recent results) on what analogue simulations should strive for, to reproduce cosmology also in the lab. More precisely, I argue that hydrodynamics on minisuperspace (or a non-linear extension of quantum cosmology) represents both a coarse-grained approximation of quantum gravity physics and the starting point to describe cosmological dynamics, to be reproduced in the lab.

Wednesday Parallel Session F / 249

Relativity of Quantum Correlations: Invariant Quantities and Frame-Dependent Measures

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Viewing frames of reference as physical systems, subject to the same laws as the systems they describe, is central to the relational approach in physics. Under the assumption that quantum mechanics universally governs all physical entities, this perspective naturally leads to the concept of quantum reference frames (QRFs). In this talk, I will discuss the perspective-dependence of position and momentum uncertainties, correlations, covariance matrices, and entanglement within the spatiotemporal QRF formalism. We show that the Robertson-Schrödinger uncertainty relations are frame-dependent, and so are correlations and variances, which satisfy various constraints described as inequalities. However, the determinant of the total covariance matrix, linked to the uncertainty volume in phase space, as well as variance-based entanglement criteria, remains invariant under changes of reference frame. Under specific conditions, the purities of subsystems are also invariant for different QRFs, but in general, they are perspective-dependent. These invariants suggest fundamental, robust measures of uncertainty and entanglement that persist despite changes in observational perspective, potentially inspiring dedicated quantum information protocols as well as further foundational studies. To conclude, I will discuss the generalization and application of the presented results within relativistic frameworks.

Wednesday Parallel Session C / 261

Tachyonic media in analogue models of special relativity

Authors: James Read[None]; Nicolas Menicucci[1]; Scott Todd[None]; Sundance Bilson-Thompson[None]; Valentina Baccetti[None]

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In sonic models of relativity, observers outside the sonic medium perceive the violation of ordinary Lorentz symmetry, while agents measuring distances and durations using sound pulses within the medium don't. Surprisingly, these "sonic observers" will interpret the physics of ordinary particles (like photons) as violating their own sonic Lorentz symmetries. In previous work, we argued that scattering experiments from ordinary particles could allow sonic observers to determine (1) the existence of an ether universe and (2) the rest frame of the ether (the sonic medium). However, we contend that this isn't what these observers would reasonably conclude. Instead, they'd likely maintain their belief in the ether-free nature of sound and interpret the velocity-dependent scattering effects as reflecting the ether-bound nature of photons. While this interpretation may seem absurd from an external perspective, it would be natural to them. Since photons are supersonic, to these observers, they would appear as tachyons confined to a novel type of material, which we call a "tachyonic medium." Sonic observers would conclude that these tachyons don't create causal paradoxes due to their confinement within the medium, while external observers would argue that causal paradoxes are inherently impossible since everything occurs within a laboratory setting. We extend this reasoning to various fields with different Lorentz-invariant speeds and demonstrate that all observers have the freedom to choose which speed is invariant. This choice is influenced by the tools and methods used for measurements and a desire for simplicity in describing physical laws. (This freedom exists within ordinary relativity but is rarely discussed.) This conceptual framework suggests that the hypothetical detection of actual (superluminal) tachyons might not be as problematic as commonly believed. Specifically, if such tachyons were measured to travel as if confined to a tachyonic medium, Lorentz symmetry could be rationally maintained, and no causal paradoxes would necessarily arise. Sundance O. Bilson-Thompson, Scott L. Todd, James Read, Valentina Baccetti, and Nicolas C. Menicucci, "Tachyonic media in analog models of special relativity," Phys. Rev. D 108, 124020 (2023). DOI: 10.1103/PhysRevD.108.124020

Wednesday Parallel Session F / 250

Linking quantum error correction and gauge theory via quantum reference frames

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One of the defining features of gauge theories is that they describe physics redundantly, in a way that is insensitive to certain local details. This redundancy is akin to how quantum error correcting codes (QECCs) protect quantum information from local errors by redundantly encoding logical states into a larger physical space. In this talk, I will show that this analogy is not merely a coincidence but that there is a deeper underlying structural relationship. The key ingredient is quantum reference frames (QRFs), a universal tool for dealing with symmetries in quantum systems. A choice of QRF defines a split between redundant and physical information in gauge systems, thus establishing a notion of encoding in that context. This leads to an exact dictionary between group-based quantum error correcting codes and QRF setups. In stabilizer codes, this reveals a one-to-one correspondence between (maximal sets of) correctable errors and QRFs. This provides novel insights into the relation between correctability and redundancy through a reinterpretation of the Knill-Laflamme condition. The dictionary also reveals a novel error duality, based on Pontryagin duality, and somewhat akin to electromagnetic duality. Throughout the presentation, I will illustrate these findings through simple examples involving Pauli stabilizer codes. Based on: Sylvain Carrozza, Aidan Chatwin-Davies, Philipp A. Hoehn, Fabio M. Mele, A correspondence between quantum error correcting codes and quantum reference frames, arXiv: 2412.15317 [quant-ph]

Wednesday Parallel Session F / 251

Three lessons in temporal quantum reference frames: causality, unitarity and periodicity

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By describing the properties of one quantum system relative to another (treated as a quantum reference frame), we can construct a relational picture of physics that reduces or eliminates reliance on idealised background structures such as classical coordinates. When applied to time, this relational approach offers a compelling resolution of the "problem of time" in canonical approaches to quantum gravity. I will give a brief introduction to arguably the most famous approach to relational dynamics – the Page-Wootters formalism – and describe our investigations into: a) the modelling of causal relations in the formalism; b) the appearance of non-unitary evolution due to interactions between clock and system; c) the physical consequences of describing systems relative to periodic clocks. Each topic highlights the importance of distinguishing between structures on the kinematic (non-symmetric) and physical (symmetric) Hilbert spaces.

Wednesday Parallel Session C / 262

Geometric Event-based relativistic quantum mechanics

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We propose a special relativistic framework for quantum mechanics. It is based on introducing a Hilbert space for events. Events are taken as primitive notions (as customary in relativity), whereas quantum systems (e.g. fields and particles) are emergent in the form of joint probability amplitudes for position and time of events. Textbook relativistic quantum mechanics and quantum field theory can be recovered by dividing the event Hilbert spaces into space and time (a foliation) and then conditioning the event states onto the time part. Our theory satisfies the full Poincare' symmetry as a 'geometric' unitary transformation, and possesses relativistic observables for space (location of an event) and time (position in time of an event). Based on V. Giovannetti, S. Lloyd, L. Maccone, Geometric Event-Based Quantum Mechanics, New J. Phys. 25, 023027 (2023). doi:10.1088/1367-2630/acb793

Wednesday Parallel Session C / 263

Infinitesimal limit of teleportation

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We model relativistic equations of motion, i.e. the physics of first quantization, using a port-based teleportation protocol. The entanglement resource is found in a quantum field's vacuum, and the measurement needed for a teleportation protocol is found in the interaction between a piece of

matter and the vacuum of a quantum field. In this way, we find an interesting mapping between second-quantized physics, and first quantized physics, pointing at an information-theoretic interpretation of the Planck constant as measuring the amount of entanglement in a quantum field's vacuum. We will compare this result with results in holographic, AdS/CFT toy models.

Wednesday Parallel Session F / 252

Statistical Fluctuations in the Causal Set-Continuum Correspondence

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Causal set theory is an approach to quantum gravity that proposes that spacetime is fundamentally discrete and the causal relations among the discrete elements play a prominent role in the physics. Progress has been made in recognizing and understanding how some continuumlike features can emerge from causal sets at macroscopic scales, i.e., when the number of elements is large. An important result in this context is that a causal set is well approximated by a continuum spacetime if there is a number-volume correspondence between the causal set and spacetime. This occurs when the number of elements within an arbitrary spacetime region is proportional to its volume. Such a correspondence is known to be best achieved when the number of causal set elements is randomly distributed according to the Poisson distribution. I will discuss the Poisson distribution and the statistical fluctuations it induces in the causal set-continuum correspondence, highlighting why it is important and interesting. I will also discuss new tools and techniques that facilitate such analyses.

Thursday Plenary Session / 196

Graviton quantum noise on geodesic congruences and gravitational decoherence

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Using the Feynman-Vernon influence functional approach, we study the effects of quantum noise of gravitons on particles. These effects manifest as a stochastic tensorial force whose correlator is given by the graviton noise kernel associated with the Hadamard function of the quantized gravitational field. We solve the corresponding Langevin equation to obtain the fluctuations of particle separations due to this quantum noise for various states of the graviton. The influence of this force on the geodesic congruence through the Raychaudhuri equation is also presented. For the quantum case, we derive the master equation of the reduced density matrix of the particles and estimate the gravitational decoherence effect of gravitons on the quantum particles.

Thursday Plenary Session / 192

Quantum Simulators for Fundamental Physics

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Exploring the dynamics of the early universe and black holes unveils profound insights into the interplay between general relativity and quantum fields. Important phenomena emerge when gravitational and/or field interactions are strong, and/or when quantum effects become prominent. Notable examples include Hawking's proposal on the evaporation of black holes, Penrose's conjecture on the spin-down of rotating black holes, and Kofman's proposal on particle production during preheating. Despite their significance, observing these phenomena directly remains elusive. In this presentation, I will report on recent advancements in investigating rotating black hole processes in laboratory experiments quantum liquids.

Thursday Plenary Session / 198

Flash Talks

Authors: Aleksandar Mikovic[1]; Dario Cafasso[2]; Dominic Lewis[3]; Grzegorz Czelusta[4]; Joppe Widstam[5]; Sean Gregory[6]; Sebastian Murk[7]; Tadeusz Adach[8]

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A selection of 8 poster contributors give a "flash talk", i.e. a short talk of around 3 minutes, presenting their poster. The list is the following:
- "Cross-scale correlations and interactions in wavelet-based quantum field theory" by Dominic Lewis.
- "Kinematic and energy properties of dynamical regular black holes" by Sebastian Murk.
- "Inference and Fine-Tuning in Causal Explanations of Bell-Inequality Violations" by Joppe Widstam.
- "Spinor fields in κ-Minkowski noncommutative spacetime" by Tadeusz Adach.
- "Tracking the nonlinear formation of an interfacial wave cascade: from one to few to many" by Sean Gregory.
- "Quantum gravity generalization of the Bohmian mechanics" by Aleksandar Mikovic
- "Spin networks on quantum computers" by Grzegorz Czelusta.
- "Gravitational time dilation from quantum interactions?" by Dario Cafasso.

Thursday Plenary Session / 199

Extension of the Einstein Equivalence Principle to quantum reference frames

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"The Einstein Equivalence Principle (EEP), stating that all laws of physics take their special-relativistic form in any local inertial (classical) reference frame, lies at the core of general relativity.
Because of its fundamental status, this principle could be a very powerful guide in formulating physical laws at regimes where both gravitational and quantum effects are relevant. The formulation of the EEP only holds when both matter systems and gravity are classical, and we do not know whether we should abandon or modify it when we test it with quantum systems and/or the gravitational field is not classical. In my talk, I propose an extension of the EEP which relies on quantum reference frames, namely the possibility that reference frames can be associated to quantum systems, and hence be in a quantum superposition or entangled relative to each other. In addition, I show that this generalised principle can be tested, for classical gravity, using atom interferometry with quantum clocks. Finally, I will argue that such an extension of the EEP can overcome Penrose's argument in favour of the classicality of the gravitational field."

Thursday Plenary Session / 200

Relational Approaches toward Background-Independent Quantum Spacetimes

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Three foundational aspects will be discussed in which relational approaches offer insight into developing a background-independent description of quantum spacetime: the notions of events, diffeomorphisms and the assumption underlying quantum probability assignments. The first aspect concerns the notion of *events*and *their localisation*, which fundamentally differ in quantum theory and general relativity. We propose an operational approach drawing from quantum information and apply it to the quantum switch (QS); this analysis reveals differences between classical and quantum spacetime realisations of QS, clarifies a longstanding interpretational debate, and demonstrates how different conclusions stem from distinct assumptions. The second aspect addresses*diffeomorphisms* in regimes beyond superpositions of semiclassical spacetimes; I will briefly present a construction of quantum diffeomorphisms for linearised quantum gravity, along with their physical implications and their role in realising background independence. The third concerns a basic assumption in quantum probability assignments, that experimental data arise from an identically and independently distributed (i.i.d.) ensemble; this assumption is expected to break down in certain regimes of quantum gravity. I will outline a proposal to resolve this issue by leveraging the tool of quantum reference frames in the measurement context.

Thursday Plenary Session / 201

Causal structure, quantum memory, and relativistic particles

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Quantum non-Markovianity—the influence of an external memory on a system's dynamics—has posed longstanding technical and conceptual challenges. Recently, significant insight was transferred from the field of quantum causal structures, highlighting the role of interventions and multi-time correlations. In this talk, I will review the causal-structure approach to non-Markovian multi-time processes and present recent results characterizing system-environment interactions that lead to a specific type of classical memory. This applies to one of the classic RQI topics: relativistic quantum particles with internal structure (or interfering "quantum clocks"). Despite their non-Markovian behaviour defying standard open-system assumptions, the classical-memory nature of their dynamics can greatly simplify their analysis

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Poster Session

Beside the poster presented in the flash talk section, the other poster contributions are:
- "Conditions for Unitarity in Timeless Quantum Theory" by Simone Rijavec.
- "Using Wigner's rotation as a quantum resource in Kerr's metric parameter estimation" by Francisco Jara Lobo.
- "De Sitter Black Holes in Euclidean Quantum Gravity" by Tim Blankenstein.
- "Decoherence in non-inertial reference frames" by Clemens Jakubec.
- "The tensor product of p-adic Hilbert spaces" by Lorenzo Guglielmi.
- "Search for high-frequency gravitational waves using quantum sensing with Rydberg atoms" by Akira Taniguchi.
- "Energy Fluctuations of Massive Scalar Fields in Gaussian and Cat States" by Adriano Barreto.
- "Rotating frames from quantum deformed spacetime" by Dusan Dordevic.
- "Decoherence as Musical Composition: A Sonification Approach to Open Quantum Systems" by Vasiliki Florou and Theodora Kolioni.
- "Entropic Uncertainty and Non-Markovian Information Flow in Relativistic Detector–Field Interactions" by Theodora Kolioni.
- "Effects of superradiance on relativistic Foldy-Wouthuysen densities" by Florent Daem.
- "Testing Weak Equivalence Principle using entanglement measures" by Marco Rivera.
- "Time-Energy Uncertainty from Einstein's Box" by Sara Butler.
- "Low-Energy Test of Quantum Gravity via Angular Momentum Entanglement" by Luciano Petruzziello.
- "Emergent geometry and defects from wavelet-transformed quantum information" by Fil Simovic.
- "Towards violation of Bell inequalities by position measurements for Dirac particles" by Anuradha Tonipe.
- "Measurement of the Unruh effect through extended quantum thermometers" by Matteo Cardi.
- "Composition of local observables in quantum field theory: Towards a consistent measurement theory" by Adamantia Zampeli.
- "Two-Qubit Entanglement on Two Bloch Spheres" by Stalislav Filatov.
- "Quantum estimation in inflationary cosmology" by Michał Piotrak.
- "The Quantum Information of Cosmological Perturbations" by Simone Scarlatella.
- "Enhanced Gravitational Entanglement via Modulated Optomechanics" by Dennis Rätzel

Friday Plenary Session / 202

Quantum Position Verification, Quantum Nonlocal Computation, and Surprising Connections with Holography and classical cryptography

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"Quantum position verification (QPV) plays a crucial role in secure quantum communication and nonlocal quantum computation. It ensures that a party involved in a communication protocol is at its claimed location, which is essential for secure communication, distributed computing, and location-based services.

In 2012, we established a tight connection between the security of QPV schemes and the entanglement usage in quantum nonlocal computation. Quantum nonlocal computation is the task of performing a unitary operation U on a bipartite quantum state φ_AB held by two parties, Alice and Bob. They can simultaneously send a single message to each other, after which they should hold the state ψ_AB = Uφ_AB. It is always possible to apply U in this manner, but the entanglement usage for arbitrary U's remains unknown. The best known upper bound is exponential, while the best known lower bound is linear.
In this talk, we will discuss recent advances and surprising connections with other fields, such as holography, ADS/CFT correspondence, and classical primitives like conditional disclosure of secrets (CDS) and secure message passing (SMP)"

Friday Plenary Session / 203

What Makes an Observable? Invariance Under Quantum vs. Classical Reference Frames

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In the presence of symmetries, observables are defined as quantities that remain invariant under transformations of reference frames or coordinates. Recently, the concept of quantum reference frame (QRF) transformations has emerged, where reference frames themselves are treated as quantum systems subject to superposition and entanglement. This generalization extends the classical notion of symmetry and motivates a reconsideration of what constitutes a physically meaningful observable. While any observable invariant under classical transformations is also invariant under QRF transformations, I will show that the converse does not necessarily hold: there exist observables that are invariant under changes of QRFs but not under classical ones. What is the physical meaning of observables that are invariant only under QRF transformations? Do they reveal a deeper, genuinely relational structure of quantum theory that goes beyond the classical frame-dependent perspective?

Friday Plenary Session / 204

Generalizing Noether: the metric from energy-momentum non-conservation

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I show that a manifold's geometry can be reconstructed from its vibrational spectrum—provided one also measures the rates at which resonant modes nonlinearly excite one another under strong driving. Applied to spacetime, this yields a generalized Noether theorem: the specific pattern of energy-momentum non-conservation in quantum field theory on curved backgrounds, encoded in the scattering matrix, is sufficient to reconstruct the spacetime metric. In the context of quantum gravity, this suggests that the familiar dichotomy of spacetime versus matter can emerge from an information-theoretic framework based on only one concept: correlators. When higher-order correlators ($n>2$) are approximately jointly diagonalizable, they admit a representation as correlation functions of a local QFT on a curved background, allowing both spacetime and matter to emerge as effective constructs. However, at Planckian energies, this diagonalizability may break down, yielding a pre-geometric regime in which the correlators remain well-defined but lack an interpretation in terms of spacetime and local quantum fields.

Friday Plenary Session / 205

Checkpoints on the road to Quantum Gravity – Semiclassical insights, Thermodynamics, Entanglement, and Probes within RQI

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I will emphasise what I consider as the checkpoints on the road to quantum gravity as a part of my research program and ideology, the four points, viz., the prescription of gravity-matter interaction, observer dependence, resolution of issues and paradoxes in quantum fields in curved spacetimes (QFT in CST), and probes of quantum effects in gravity. QFT in CST has been very successful in unveiling a whole new class of physical effects from those in non-inertial frames to black holes, and in cosmology. The talk will seek to look into some of these so as to provide guide posts that any theory of quantum gravity should incorporate. I will discuss how the need to "prescribe" a back reaction inclusive gravity-matter interaction arises beyond QFT on fixed backgrounds. I will discuss the role of entanglement in contrasting a fully quantum dynamics with a certain back reaction inclusive dynamics and dynamics on a fixed background in a simple example where all three aspects are tractable. I will describe the dynamics of entanglement between a bipartite gravity-matter system within cosmology. The talk will conclude with a direction to probing quantum effects in gravity.

Friday Plenary Session / 206

Monogamy relations for relativistically causal correlations

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Non-signalling conditions are usually understood to encode minimal requirements that any (quantum) systems put into spatial arrangements must satisfy in order to be consistent with special relativity. Recent works have argued that in scenarios involving more that two parties, conditions compatible with relativistic causality do not have to satisfy all possible non-signalling conditions but only a subset of them. Here we show that correlations satisfying only this subset of constraints have to satisfy highly non-local monogamy relations between the effects of space-like separated random variables. These monogamy relations take the form of entropic inequalities between the various systems and we give a general method to derive them. Using these monogamy relations we discuss previous suggestions for physical mechanisms that could lead to relativistically causal correlations, demonstrating that such mechanisms would lead to superluminal signalling.

Friday Parallel Session F / 264

The localization problem: an antinomy between measurability and causal dynamics

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The localization problem in relativistic quantum theory has persisted for more than seven decades, yet it is largely unknown and continues to perplex even those well-versed in the subject. At the heart of this problem lies a fundamental conflict between localizability and relativistic causality, which can also be construed as part of the broader dichotomy between measurement and unitary dynamics. In this talk, I briefly review the localization problem and discuss its significance more broadly within the foundations of physics, particularly as regards the antinomy between measurability and causal dynamics.

Friday Parallel Session C / 272

Relativistic quantum Otto heat engine using a three-level Unruh-DeWitt detector

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In this study, we explore a relativistic quantum Otto heat engine with a qutrit as the working substance interacting with a quantum scalar field in curved spacetime. Unlike qubits, which extract work by simply expanding or shrinking a single energy gap, qutrits allow multiple energy gaps to be adjusted independently, enabling more versatile work extraction in the quantum Otto cycle. We derive a general positive work condition in terms of the effective temperature that each pair of energy levels perceives. Moreover, we discuss additional subtleties that are absent when using a qubit, such as the generation of coherence terms in the density matrix due to interactions.

Friday Parallel Session F / 265

Quantum Larmor formula for uniformly accelerated charges

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With the settings in JHEP04(2024)065, we calculate the quantum radiation emitted by relativistic single-electron wavepackets in Minkowski vacuum. We show that the quantum radiation of a single-electron wavepacket at rest is exactly zero. For a uniformly accelerated electron, the quantum radiated power grows in time exponentially. This indicates that our linear approximation which breaks the reparameterization symmetry of the full action would break down if the evolution time is too long.

Friday Parallel Session C / 273

An analysis of entanglement harvesting beyond perturbation theory

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A key prediction of quantum field theory that has yet to be tested experimentally is the existence of correlations between different regions in a quantum field. It is hypothesized that this phenomenon can be measured using the entanglement harvesting protocol, a process by which entanglement between detectors is induced due to their interaction with a quantum field in its vacuum state. Entanglement harvesting has been extensively researched using perturbative methods. However, experimental proposals for realizing this protocol using superconducting qubits utilize setups beyond the limits of perturbation theory. Furthermore, non-perturbative studies are very limited to particular scenarios often unfit for modeling the regimes of current experiments. Here we present results on entanglement harvesting using non-perturbative methods. We investigate the breakdown of perturbation theory as well as the non-perturbative behaviour of harvesting in realistic experimental regimes.

Friday Parallel Session F / 232

Relativistic implications of entropy and purity

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A quantum object in free fall is extended by virtue of quantum uncertainty, and therefore experiences tidal forces and other relativistic effects. As a result, entropy and purity affect geodesic motion and acquire weight, an observation that has broad implications from free-fall experiments to Hawking radiation. If the object's position is correlated in at least two directions, a complete description of its geodesic motion requires non-Riemannian geometry of a form controlled by the entropy and purity of its state.

Friday Parallel Session C / 274

Ambient temperature versus ambient acceleration in the circular motion Unruh effect

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The Unruh effect asserts that the experience of uniformly linearly accelerated observer with proper acceleration a is indistinguishable from that of a static observer in a thermal bath whose temperature is given by $T=a/(2\pi)$. This prediction of Minkowski quantum field theory continues to inspire both theoretical and experimental investigations. More generally, non-inertial trajectories—such as circular or drifted Rindler motion—yield a nonzero response to the vacuum, though the response is typically not thermal. In this talk, I examine the interplay between acceleration and ambient temperature by considering two scenarios: (i) a circularly orbiting observer in a thermal bath, and (ii) a circular trajectory around a uniformly accelerated path. These setups allow for a probe of the Unruh effect's robustness under deviations from uniform acceleration. This work is based on Phys. Rev. D 109, 065001 (2024).

Friday Parallel Session F / 267

Quantum Langevin equation for finite-time interactions

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In this talk, we consider the quantum Langevin equation for the Caldeira-Leggett model with an arbitrary time-dependent coupling constant. We solve this equation exactly by employing a train of Dirac-delta switchings. This method also enables us to visualize the memory effect in the environment. Furthermore, we compute the two-time correlation functions of the system's quadratures and show that the discrete-time Fourier transform is well-suited for defining spectral densities, as the Dirac-delta switchings turn continuous functions into discretized samples. Lastly, We demonstrate the applicability of this method in a relativistic framework.

Friday Parallel Session C / 275

Measurement-induced state updates in holography

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Detector-based measurements in QFT describe how information about a quantum field's state can be extracted through a non-relativistic system moving in spacetime. This way, the standard quantum measurement postulate can be extended to QFT. The postulate consists of two parts: the Born rule, which relates outcomes to the probability of their occurrence, and the Lüders rule, which prescribes how states update upon measurement. The latter implies that measuring a quantum field induces a state update consistent with the observed outcome. In this talk, we propose that — when the field lives on the conformal boundary of a semi-classical AdS spacetime and the measurement is interpreted holographically — the Lüders rule corresponds to an update of the bulk dual, affecting the semi-classical degrees of freedom in a way consistent with the measurement outcome. Then, we present the features of this update and propose a new entry in the holographic dictionary, relating the information extracted by the measurement to semi-classical parameters characterizing the updated bulk state.

Friday Parallel Session C / 276

Field-state back-action from pointlike detectors

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Particle detector models are widely used in quantum field theory as local probes of quantum fields. A common simplifying assumption is that the field-detector interaction is sufficiently weak that the detector's back-action on the field can be neglected. However, detectors necessarily perturb the systems they probe. In this talk, we explore the back-action of a pointlike Unruh–DeWitt detector on the state of a real massless scalar field, when the field is prepared in the vacuum or in a thermal state.

To characterise this back-action, we calculate an explicit expression for the renormalised expectation value of the field-squared, valid for a detector following an arbitrary timelike worldline and interacting via an arbitrary switching function. We examine how the back-action depends on the detector's motion, the initial state of the field, and the nature of the switching, comparing sudden and gradual coupling. Finally, we compute the renormalised expectation value of the stress-energy tensor for a static detector and show that it is not covariantly conserved, but that this non-conservation is strongly localised around the detector's worldline.

Friday Parallel Session F / 268

Routing Quantum Control of Causal Order

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In recent years, various frameworks have been proposed for the study of quantum processes with indefinite causal order. Beyond the standard quantum formalism, these processes do not only feature computational and communication advantages, but are also of foundational and philosophical interest regarding e.g. notions of physical events, quantum reference frames and potential theories of quantum gravity, which may feature a dynamical and indefinite causal structure. In this contribution, we connect two of these frameworks: Quantum Circuits with Quantum Control of Causal Order (QC-QCs) form a broad class of physical supermaps obtained from a bottom-up construction and are believed to represent all quantum processes physically realisable in a fixed spacetime; while Routed Quantum Circuits introduce quantum operations constrained by "routes" to represent processes in terms of a finer-grained routed circuit decomposition. This decomposition, being represented by a so-called routed graph, represents the information flow within the respective process. However, routed circuits have only been established for a small set of processes so far, including both QC-QCs and more exotic processes as examples. We remedy this fact by proving that for any number of parties in the process, starting from a single routed graph, one can systematically obtain any QC-QC with this number of parties by using an appropriate fleshing out. We detail this construction explicitly and consider how the topology of the routed graph impacts which processes it may represent. We conclude by pointing out how this connection can be useful to tackle various open problems in the field of indefinite causal order. These include establishing circuits representations of subclasses of QC-QCs, studies of the causal structure of QC-QCs and questions regarding the compositionality of processes.

Friday Parallel Session F / 269

Role of Derivative Coupling in the Study of Acceleration Radiation in Curved Spacetimes

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Since 1970, the phenomena of particle production in curved/ flat spacetime has been of consistent interest to many physicists. This has led us to remarkable findings such as Unruh effect, Hawking radiation, cosmological particle production and many more. Subsequently, to investigate its experimental relevance, the Unruh DeWitt (UD) detector model, based on atom-field interaction, has been widely employed in realistic setting. Aligning with this idea, Scully et al. proposed an alternative mechanism for particle production utilizing quantum optics techniques. This framework suggests

that when ground state atomic detectors are accelerated through a high-Q microwave cavity, radiation is produced, and the detector's transition probability can be enhanced by several orders of magnitude compared to that from Unruh radiation.In the context of black hole (BH) spacetime, this alternative scheme of particle production is popularly known as "horizon brightened acceleration radiation (HBAR)". In this model the atomic detectors are minimally coupled with the field such as $H_{int} \sim g\mu(\tau)\phi[x(\tau)]$, where g depicts the coupling strength and $\mu(\tau),\ \phi(x)$ represent the monopole moment for the atom and matter field respectively. Despite its several lucrative features, a minimally coupled UD detector model is plagued with infrared (IR) divergence for a massless field in $(1+1)$ dimensions. As a resolution, it was shown in the literature that this IR ambiguity can naturally be removed by considering the UD detector linearly coupled to the proper time derivative of the field amplitude. Analogous to the Unruh effect, in this work we investigate how derivative coupling influences the HBAR phenomenon in Schwarzschild spacetime for both point-like and finite size detectors. Remarkably, for the point-like detector we find the transition probability of the system is independent of the frequency of the detector. We suggest that the derivative coupling in the curved spacetime introduces an explicit coupling between the g^{tt} component of the background metric and the detector. The g^{tt} component may reflect some aspects of the gravitational fluctuations, in which case the detector will no longer be sharply tuned to a particular frequency but will be exposed to a range of frequencies due to its direct interaction with gravitational background. We predict that this in turn removes the effect of any particular frequency of the detector from the transition probability. Furthermore we show that this enhances the amplitude of the transition probability than that of the standard HBAR phenomenon as shown by Scully et al. in the context of BH. On the other hand for the finite size detector, we obtain the transition spectrum as dependent on the length/ extent (L), frequency (ω) of the detector. Deriving the equation of motion for the density matrix of the field, we find that the system has a zero steady state solution under the condition $L\omega < \sqrt{2}$. This result indicates that within this parameter space, the system exists in a non-equilibrium thermodynamic state, where standard thermal equilibrium and its consequences will no longer hold.

Friday Parallel Session C / 277

Harvesting Information Across the Horizon

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The effect of black holes on entanglement harvesting has been of considerable interest over the past decade. Research involving stationary Unruh-DeWitt (UDW) detectors near a (2+1)-dimensional Bañados-Teitelboim-Zanelli (BTZ) black hole has uncovered phenomena such as entanglement shadows, entanglement amplification through black hole rotation, and differences between bipartite and tripartite entanglement. For a (1+1)-dimensional Schwarzschild black hole, it has been shown that two infalling UDW detectors can harvest entanglement from the scalar quantum vacuum even when separated by an event horizon. In this paper, we calculate the mutual information between two UDW detectors coupled to a massless quantum scalar field, with the detectors starting at rest and falling radially into a non-rotating (2+1)-dimensional BTZ black hole. The trajectory of the detectors includes regions where both detectors are switched on outside of the horizon; where one detector is switched on inside of the horizon while the other switches on outside; and where both detectors switch on inside of the horizon. We investigate different black hole masses, detector energy gaps, widths and temporal separations of the detector switching functions, and field boundary conditions. We find that black holes–even the simplest kind having constant curvature–significantly affect the correlation properties of quantum fields in the vacuum state. These correlations, both outside and inside the horizon, can be mapped out by infalling detectors.

Friday Parallel Session F / 270

Using adaptiveness and causal superpositions against noise in

quantum metrology

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A well-established approach to enhance precision of quantum metrological protocols involves preparing multiple probes in an entangled state before interaction with the measured system. Fundamental precision limits for such entanglement-based protocols have been known for more than decade. Nevertheless, quantum mechanics permits more advanced strategies that employ quantum error correction, adaptive preparation of probe states, and even non-trivial causal structures. Specifically, preparing causal superposition of different orders in which probes interact with the system may give some metrological advantage. In our work (Phys. Rev. Lett. 131 (9), 090801), we derive fundamental, asymptotically saturable bounds for both adaptive and causal-superpositions enhanced strategies. Remarkably, we demonstrate that these sophisticated strategies achieve the same asymptotic precision precision as standard entanglement-based approaches. However, employing causal superpositions and adaptiveness can offer some advantage for a finite number of channel uses.

Friday Parallel Session C / 278

The Twin Paradox in Quantum Field Theory

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The theory of relativity fundamentally reshaped our understanding of space and time, introducing conceptual shifts often illustrated explicitly through apparent paradoxes. Among these, the twin paradox stands out by clearly demonstrating how two observers following different spacetime trajectories can experience distinct elapsed times. Physically meaningful statements about elapsed time require the use of clocks, which, as physical systems, should be modeled using our best available theories of matter. In this work, we introduce a version of the twin paradox in which clocks are modelled as Unruh-DeWitt detectors. Our results offer insights into the indefiniteness of causal structures at scales where quantum effects become significant.

Friday Parallel Session F / 282

Quantum many-body analogue black-holes and analogue cosmology

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I will discuss the existence conditions of stationary sonic black hole configurations in the presence of quantum fluctuations, assessed by computing the quantum depletion of the many-body system due to both interactions and Hawking radiation. Bogoliubov theory and the conventional neglect of backreaction in describing the analog Hawking process will thereby be validated, and the resulting limits for the experimentally attainable Hawking temperature will be explored.

Friday Parallel Session C / 279

Particle detectors in superposition in de Sitter spacetime

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Cosmological particle creation is the phenomenon by which the expansion of spacetime results in the production of particles of a given quantum field in that spacetime. In this paper, we study this phenomenon by considering a multi-level quantum particle detector in de Sitter spacetime coupled to a massless real quantum scalar field. Rather than considering a fixed classical trajectory for the detector, following recent novel approaches we consider a quantum superposition of trajectories, in particular of static trajectories which keep a fixed distance from one another. The main novel result is that, due to the quantum nature of the superposition of trajectories, the state of the detector after interaction with the field is not only a mixture of the thermal states that would be expected from each individual static trajectory, but rather exhibits additional coherences due to interferences between the different trajectories. We study these in detail and associate them with the properties of the particle absorbed by the detector from the thermal bath.