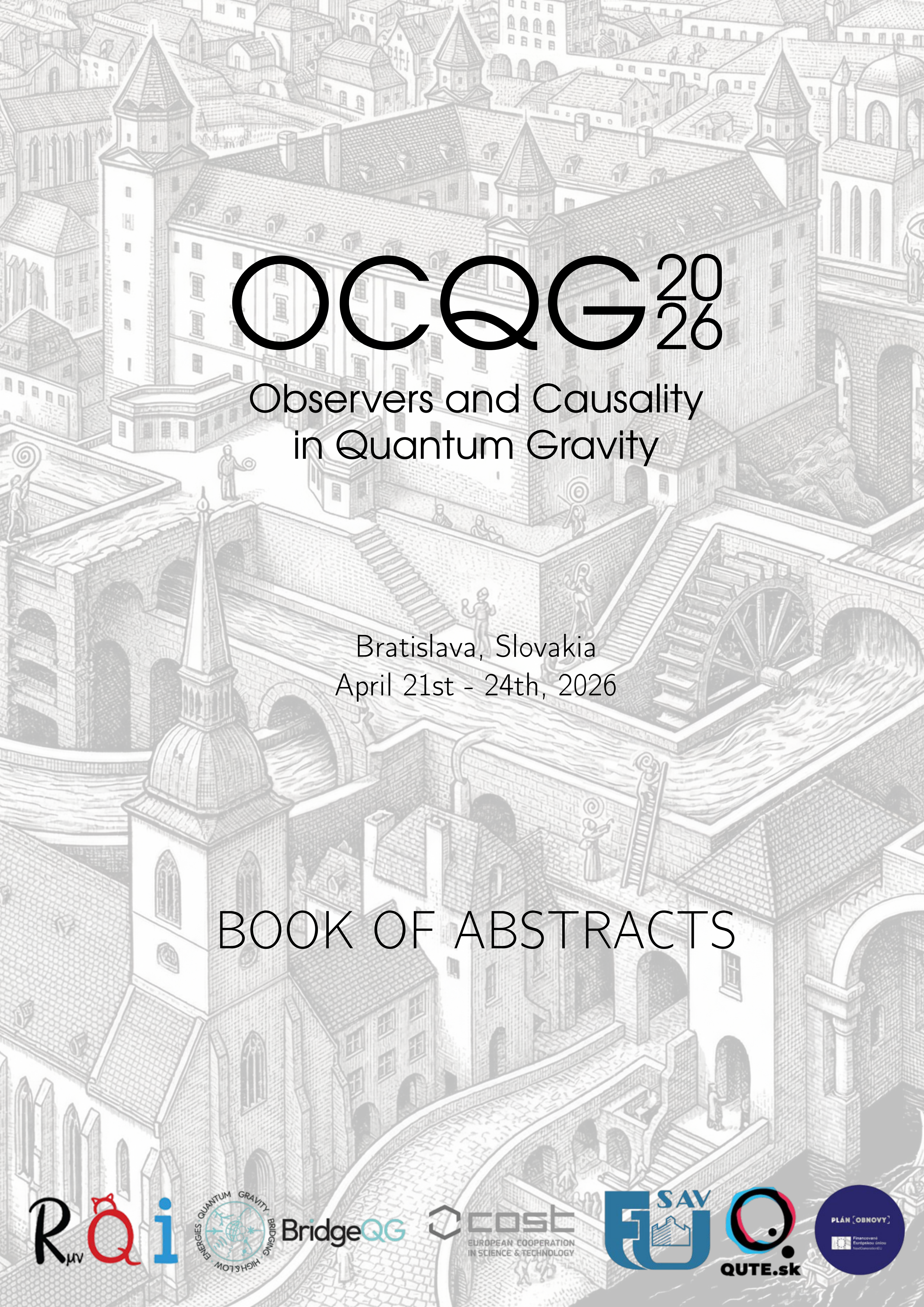

OCQG 2026

Observers and Causality in Quantum Gravity

Bratislava, Slovakia
April 21st - 24th, 2026

BOOK OF ABSTRACTS

Contents

Invited talks

Charis Anastopoulos

Final conditions in quantum cosmology

Standard quantum theory admits naturally formulations with statistical ensembles that are both pre-selected and post-selected. Pre-selection is often viewed as more fundamental, as it is compatible with the arrow of time of external observers. However, this argument does not work at the level of quantum cosmology, where the quantum description is supposed to be more fundamental than the arrow of time. In this talk, we describe the role of final conditions in quantum cosmology, showing that quantum post-selection leads to an effective quasiclassical dynamics that generates accelerated expansion in homogeneous and isotropic cosmologies without introducing a cosmological constant, dark energy, or modifications of general relativity. The resulting cosmological model is competitive with ΛCDM on supernova and cosmic chronometer data, reduces the Hubble tension, and avoids the coincidence and cosmological constant problems.

Časlav Brukner

Quantum incompatibility of relative frequencies

In standard quantum theory, unlike the individual outcomes of all possible measurements, their probabilities are treated as jointly well defined. I will show that this need not remain true when measurements are defined relative to finite, non-ideal quantum reference frames. In that case, relative frequencies themselves can become non-commuting and Bell-incompatible, suggesting that operationally accessible probabilities may themselves be genuinely context-dependent quantum objects. I will conclude by discussing why such a possibility may be relevant, and perhaps even necessary, in quantum gravity.

Esteban Castro-Ruiz

The perspective of a non-ideal quantum reference frame

After motivating why it is important to study non-ideal quantum reference frames, I will introduce a general operational framework defining their perspective and the transformations between them. I will then discuss how the perspective relative to a non-ideal QRF differs from that of an ideal one, and comment on what are the consequences that the non-ideal character of our frames have for our notions of system and subsystem.

Fay Dowker

Quantum causality without observers

Bell's condition of "local causality" results in the Bell inequalities for correlations between experimental results. I will argue that the condition can usefully be divided into two separate conditions of "locality" and "relativistic causality". The former means a cause cannot affect an event outside its local spacetime neighbourhood and the latter means that a cause cannot affect an event outside its future lightcone. I will argue that we can maintain the position that relativistic causality holds in quantum theory if we give up locality. But "relativistic causality" by itself then becomes a rather weak condition and it cannot, by itself, explain why correlations allowed by quantum mechanics are bound by the T'sirelson inequalities. I will introduce a relativistic causality condition that is intrinsic to quantum theory –i.e. that doesn't use any concept of observer or agent or measurement– and that implies the T'sirelson inequalities. The condition requires a background causal structure however, so the question of how and why and if quantum gravity is causal remains wide open. I will speculate on this question using the example of causal set quantum gravity.

Kristina Giesel

Relational Dynamics in Quantum Gravity: The Role of Dynamical Reference Frames

TBA

Giulia Gubitosi

TBA

TBA

Eleni-Alexandra Kontou

Restrictions on wormholes from energy conditions

Wormhole solutions, bridges that connect different parts of spacetime, were proposed early in the history of General Relativity. Soon after, it was shown that all wormholes violate classical energy conditions, which are non-negativity constraints on contractions of the stress-energy tensor. Since these conditions are violated by quantum fields, it was believed that wormholes can be constructed in the context of semiclassical gravity. But negative energies in quantum field theory are not without restriction: quantum energy inequalities control renormalized negative energies averaged over a geodesic. Thus, quantum energy inequalities provide restrictions on the construction and maintaining of wormholes. In this talk, I will review these restrictions and how they can prevent causality violations in semiclassical gravity.

David Kubiznak

Pushing the limits of black hole thermodynamics

After reviewing the foundations of black hole thermodynamics, I will describe its remarkable success in describing complicated black hole spacetimes, questioning what it all means.

Fedele Lizzi

Quantum observers and reference frames for quantum spacetime

In the theory of gravitation the dynamical variable is spacetime itself. This suggests that a theory of quantum gravity necessitates a quantum spacetime. Likewise symmetry transformations will be deformed (quantum groups). Implicitly there will be the need to quantize reference frames, or observers, to accommodate the quantum transformations. We will show, with examples, how a theory of quantum gravity leads to quantum reference frames.

Daniele Oriti

Causality and emergent relational dynamics from discrete quantum gravity

In the context of spin foam and group field theory models for quantum gravity, in which spacetime and cosmological physics emerge from the collective dynamics of discrete and algebraic quantum structures, I will discuss: a) how the seeds of causal evolution can be encoded in the fundamental dynamics and how causal propagation can be seen to emerge; b) how quantum relational observables can be introduced, at the fundamental "pre-geometric" level, and how their emergent cosmological dynamics can then be extracted.

T. Rick Perche

Local quantum information protocols in QFT: Theoretical, Operational, and Experimental progress in vacuum entanglement

TBA

Kasia Rejzner

Quantum reference frames and semi-local observables in QFT

The importance of including the observer and the operational description of measurement into the QFT framework has become increasingly clear in the recent years. In this talk, I will describe how operation quantum reference frames (QRFs) provide a convenient setting for this task. Starting from a local net of observables, as studied in algebraic quantum field theory (AQFT), one can construct relational observables, when coupling to a QRF. The resulting observables are typically no longer local (they are semi-local) and have some interesting mathematical and physical properties.

Renato Renner

The paradox of the third particle is classical

TBA

V. Vilasini

How to model quantum observers consistently: implications for relative notions of events, localisation and causality

Quantum theory, if universally valid, must extend consistently to observers (or gents) themselves and to systems with gravitating masses. These are two frontiers often studied in isolation despite deeper connections, in particular, both demand relational, perational frameworks: modelling agent as quantum systems, as in Wigner's Friend Scenarios (WFS), makes measurement events inherently agent-dependent and non-absolute, which standard quantum frameworks cannot capture; while the absence of a classical spacetime background in quantum gravity leaves open the question of relative to what structure an event or its localisation can even be defined. The first part of the talk will address the former challenge by presenting a generalised quantum circuit framework for arbitrary WFS that formalises Heisenberg cuts as explicit quantum channels. This fully resolves apparent logical paradoxes (including those first highlighted by Frauchiger and Renner) through explicit logical and causally consistent reasoning rules for quantum agents that do not assume absoluteness of measurement events. Despite this fundamental relationalism, the framework also shows how absolute measurement events and stable classical records nevertheless emerge in real-world quantum experiments. The second part will address the latter question by introducing an operational definition of events and their localisation relative to a structure called a Lab, equipped with a physical reference system, without assuming a background spacetime. Applied to the quantum switch (a so-called indefinite causal order process) this framework dissolves a longstanding interpretational debate by tracing differing conclusions to distinct assumptions about Labs and their references, and highlights key distinctions between classical and quantum spacetime realisations linked to the role of agents' interventions. The talk will conclude by discussing the outlook for a more unified understanding of quantum observers and quantum causality, even in the absence of a background spacetime, acyclic causal order, or absolute measurement events. Based on joint works with Mischa Woods (https://arxiv.org/abs/2209.09281) and with Lin-Qing Chen, Liuhang Ye and Renato Renner (https://arxiv.org/abs/2505.21797).

Nelson Yokomizo

Proper time, events and indefinite order in a superposition of geometries

This talk consists of a brief review of indefinite causal order in gravitational settings. I will introduce the basic concepts underlying the construction of models that exhibit an indefinite order of events and discuss explicit examples, with a focus on the quantum switch. These examples will be used to illustrate how the key notion of an operational physical event is implemented across different proposed realizations of the quantum switch.

Ying Zhao

The Hartle–Hawking state and quantum mechanics for de Sitter observers

The one-state statement for closed universes has sparked considerable discussion. In this talk, we examine its physical meaning in the context of the Hartle–Hawking state and de Sitter space. We argue that the one-state property of closed universes is fully compatible with the finite-dimensional quantum mechanics experienced by observers inside de Sitter space, and that this compatibility requires neither mixing of -sectors nor any modification of the rules of the gravitational path integral. The apparent tension is resolved by sharply distinguishing the baby-universe Hilbert space (the space of closed universes viewed from the outside) from the bulk Hilbert space that governs quantum mechanics for an observer inside a single de Sitter universe.

Contributed talks

Adrian Kent

Problems and possibilities for semi-classical gravity theories

Moller-Rosenfeld semi-classical gravity postulates a classical metric coupled to the expectation value of the quantum matter stress-energy via the Einstein equations. It continues to attract attention given the many problems of standard quantum gravity theories. However, semi-classical gravity also has many apparent problems. If we assume unitary (Everettian) quantum theory, as originally proposed, it is inconsistent with astronomical observation and terrestrial experiment. If quantum theory is combined with some measurement or collapse postulate, stress-energy conservation is generally violated. Unless this can be avoided or otherwise handled, it leads to an inconsistency in the Einstein equations. Semi-classical gravity theories are also nonlinear, and it is often claimed that such theories necessarily violate causality via superluminal signalling and also violate the second law of thermodynamics. I discuss these problems, describe how some of them can be resolved and others might be, and describe experimental tests that test semi-classical gravity theories in new regimes.

Amrapali Sen

Superluminal transformations and indeterminism

Quantum theory is widely regarded as fundamentally indeterministic, yet classical frameworks can also exhibit indeterminism once infinite information is abandoned. At the same time, relativity is usually taken to forbid superluminal signalling, yet Lorentz symmetry formally admits superluminal transformations (SpTs). Dragan and Ekert have argued that SpTs entail indeterminism analogous to the quantum type. Here, we prove a no-go theorem based on natural assumptions of consistent causal embedding of events across reference-frame transformations in a world with finite information. One way to interpret this is that superluminal transformations (SpTs) and finite information cannot coexist. Any theory accommodating SpTs must therefore allow unbounded information content, leading to a deterministic ontology akin to that of classical theories formulated over the real numbers. Thus, any apparent indeterminism arising from superluminal transformations reflects only probabilities arising from subjective ignorance, unlike the objective nature of probabilities in quantum theory, indicating that the claimed indeterminacy from superluminal extensions is not quantum.

Anne-Catherine de la Hamette

Information trade-offs between observers in quantum reference frames

Research on quantum reference frames has shown that properties assigned to quantum systems — including coherence, entanglement, and even subsystem structure — can depend on the chosen perspective. Recent developments further suggest that gravitational entropies may likewise exhibit observer dependence.

In this work, I analyse information trade-offs in networks of multiple observers describing a common quantum system. I generalise a recently established coherence-entanglement trade-off to arbitrarily many frames, including non-ideal ones, and derive structural constraints governing changes of perspective. These constraints restrict how information can be redistributed between observers and yield quantitative bounds on the extent to which the entropy assigned to a system depends on the observer and on the quality of their reference frame.

Taken together, the results place fundamental limits on how entropy can vary across observers and speak directly to recent discussions of observer-dependent entropy in gravitational contexts, including black holes.

Carla Ferradini

Emergent causal order and time direction: bridging causal models and tensor networks

Can the direction of time and the causal structure of space-time be inferred from operational principles? Causal models and tensor networks offer complementary perspectives: the former encodes cause-effect relations via directed graphs, with intrinsic ordering; the latter describes multipartite systems on undirected graphs, without presupposing directionality. We construct two-way mappings between these two frameworks, linking direction agnostic correlation functions and operational notions of signalling. This clarifies the operational meaning of causal influence in tensor networks and introduces discrete "space-time rotations" of causal models which preserve signalling relations. Applying our framework to holographic tensor networks, we use tools from causal inference, like graph-separation, to analyse emergent causal structures. By permitting cyclic and indefinite causal structures, our results enable transfer of techniques across tensor networks and a range of causality frameworks.

Giacomo Rosati

Observers and locality in relativistic quantum spacetime

Several approaches to quantum gravity point toward a Planck-scale structure of spacetime characterized by a minimal localization scale. Within these approaches, relativistic symmetries are naturally described by quantum groups, viewed as deformations of Poincaré symmetry that incorporate an observer-invariant length. Such deformations profoundly affect the notion of observer and challenge standard relativistic concepts, in particular the locality of measurements. In this presentation, I will review key results in this direction and discuss how the action of deformed boosts and translations between observers affects the operational notion of locality, yielding a Planck-scale contribution to the fuzziness of particle states.

Matt Wilson

The spatio-temporal logic of agents, actions, and observations

The framework of higher-order quantum operations (process matrices/supermaps) is primarily motivated by providing an information-theoretic abstraction of a spacetime environment. In doing so, it provides a way to extract operational causal structure from quantum circuit configurations, and (regarding quantum gravity) a way to formalise quantum (indefinite) causal structures, which have been proposed as a salient information-theoretic feature of quantum gravity. Furthermore, this informational abstraction connects to the spatio-temporal logic BV, generating a shared conceptual language for spacetime across geometric, informational, and logical disciplines. This cross-pollination is fruitful: BV was, until the advent of higher-order quantum operations, short on well-motivated examples, and conversely the compositional structure of higher-order quantum operations presented a serious challenge, witnessed by no-go theorems for tensor products of process matrices.

The story of the above paragraph is one that had only been established for finite-dimensional quantum systems. Quantum gravity, however, when built on quantum field theory rather than quantum computation, is likely to be infinite-dimensional. In this talk I will explain how abstract categorical methods resolve this problem, giving a construction which builds a BV-logic of agents, actions, and observations from any circuit model. This generalises what was established for finite-dimensional quantum theory to genuinely infinite-dimensional systems of quantum field theory, and so towards quantum gravity. Moreover, because it applies to any circuit model, it provides a way to construct agents/interventions and their spatio-temporal logic from any operational probabilistic theory, giving a stable foundation for the theory-independent study of agency in the foundations of physics. Whilst the associated preprint is very abstract, the talk will focus on the conceptual takeaways and a concrete presentation of the infinite-dimensional case in familiar linear-algebraic (and functional-analytic) terms.

Nadia Koliopoulou

Measurement, causality, and the emergence of time in relativistic quantum fields: A QTP approach

The formulation of a consistent measurement theory for relativistic quantum fields is closely tied to foundational questions concerning observers, causality, and localization. Standard non-relativistic measurement schemes fail to incorporate key relativistic principles, such as locality, causal structure, and Lorentz covariance, and are therefore inadequate for quantum field–theoretic settings.

In this work, we employ the Quantum Temporal Probabilities (QTP) framework to develop an operational approach to measurement in relativistic quantum field theory. The framework enables a consistent description of detection events in spacetime while explicitly incorporating the role of the observer and the causal structure of the interaction. We apply this formalism to electromagnetic, Dirac, and internally structured scalar fields, with particular emphasis on spin, polarization, and internal degrees of freedom.

Within this setting, we derive time-of-arrival probability distributions that respect relativistic causality, obtain generalized photodetection formulas beyond Glauber's theory, and provide a first-principles derivation of particle oscillation formulas together with a clarification of their domain of validity. We also discuss the description of relativistic qudits, highlighting the interplay between internal degrees of freedom and spacetime localization.

Our results contribute to a coherent operational framework for relativistic quantum measurements, with direct implications for the role of observers and the emergence of causal structure in quantum field theory.

Sotirios Mygdalas

Spacetime Quasicrystals: a New Kind of Possible Causal Sets

Self-similar quasicrystals (like the famous Penrose tilings) are exceptional geometric structures in which long-range order, quasiperiodicity, non-crystallographic orientational symmetry, and discrete scale invariance are tightly interwoven in a beautiful way. This work shows how such structures may be generalized from Euclidean space to Minkowski spacetime, where causality is fundamental. We construct the first examples of such Lorentzian quasicrystals (the spacetime analogues of the Penrose tilings), and point out key novel features of these structures (compared to their Euclidean cousins). Among them is the fact that spacetime quasicrystals actually preserve a dense subgroup of the Lorentz group (rather than breaking it altogether), retaining "almost all" of the underlying continuous spacetime symmetry despite being fundamentally discrete. The spacetime nature of our quasicrystals opens the door to applications in gravity, in particular quantum gravity, where spacetime is thought to be fundamentally discrete. In this talk, we emphasize that spacetime quasicrystals are a novel class of causal sets: while traditional causal sets are random and unstructured, our quasi-crystalline causal sets are highly symmetric and ordered. We comment on the rich phenomenology that arises from this new kind of causal sets and report key findings from bench-marking them against their traditional counterparts.

Veronika Baumann

Interventions and causality across multiple temporal reference frames

In relational quantum dynamics evolution emerges via the correlations of the evolving system with a temporal reference frame or clock. The combined physical state, a solution to a Wheeler-de Witt-like constraint equation, of clock and system does not evolve, similar to a four dimensional block universe. Talking about causality in such a setting requires a clearly defined notion of interventions. In quantum theory the operational approach to causality identifies interventions with sets of quantum operations and causal influences with signaling correlations between them. In relational dynamics there are two approaches towards operations in general and measurements in particular. One considers relational observables on the physical states, the other incorporates the observable into the constraint equation. In this talk I want discuss and compare these two approaches with respect to causality, more concretely for trying to embed operational causality into relational quantum dynamics. For a single clock, both approaches allow for incorporating operational causality into relational dynamics. However, for multiple temporal reference frames only incorporating interventions into the constraint gives a consistent picture regarding the causal relations. Moreover, this approach towards interventions in relational dynamics naturally allows for scenarios with indefinite causal order, a well-known quantum feature of operational causality.

Vittorio D'Esposito

Doubly Quantum Mechanics and Indefinite Probabilities

Motivated by the expectation that relativistic symmetries might acquire quantum features in Quantum Gravity, we take the first steps towards a theory of "Doubly" Quantum Mechanics, a modification of Quantum Mechanics in which the geometrical configurations of physical systems, measurement apparatuses, and reference frame transformations are themselves quantized and described by "geometry" states in a Hilbert space. This is achieved by replacing a standard Lie group symmetry with a quantum group symmetry. We develop this formalism for spin measurements, hence promoting the SU(2) rotational symmetry to a SU_q(2) quantum symmetry. As a consequence of this, the probability of obtaining a result in a measurement becomes a self-adjoint operator acting on the Hilbert space of geometry states, hence acquiring novel non-classical features. We find that probability measurements are affected, in general, by intrinsic uncertainties stemming from the quantum properties of the SU_q(2), which make probabilities indefinite. This feature translates into an unavoidable fuzziness for observers attempting to align their reference frames by exchanging spin systems, even when the number of exchanged spins approaches infinity, contrary to the standard case.

Posters

Alberto Spalvieri

Local Operations and Field Mediated Entanglement without a Local Tensor Product Structure

Quantum information has become a powerful tool for probing the structure of quantum field theories, yet its application to gauge theories remains subtle. On the one hand, quantum information theory assumes subsystem locality, i.e. the factorization of the total Hilbert space into subsystems. On the other hand, gauge constraints prevent the total Hilbert space to decompose into a spacetime-local tensor product structure. Because the Hilbert space structure of gauge theories does not accommodate the subsystem decomposition used in quantum information theory, standard information-theoretic results, such as the Local Operations and Classical Communication (LOCC) theorem, cannot be used straightforwardly in the context of gauge theories. In this work, we bridge this gap in the case of a two-dimensional lattice gauge model that captures key features of electromagnetism. In particular, we construct gauge-invariant local algebras and derive a physically meaningful decomposition of the Hilbert space, providing an operationally consistent notion of locality in the absence of a local tensor-product structure. We apply this framework to field-mediated entanglement protocols relevant to proposed tests of the quantum nature of gravity. We show that the discretized version of electromagnetism satisfies an analogue of the LOCC theorem: entanglement cannot be generated without genuine quantum field interactions, even in the absence of a spacetime-local tensor product factorization of the Hilbert space. This may point towards an operational way to define a subsystem structure for gauge theories.

Aleksandra Gočanin

Spacetime Tomography: Probing Spacetime Geometry with Entangled Particles

Building on previous work by Perche [Phys. Rev. D 106, 025018 (2022)], we present an operational analysis of two localized, nonrelativistic quantum particles propagating along timelike geodesics in curved spacetime. We compute Peres sojourn times $T_P^{(1)}$ and $T_P^{(2)}$. Using the Fermi-normal-coordinate construction and the effective Hamiltonian derived by Perche we show that Gaussian wavepackets obey inverted-harmonic-oscillator dynamics with curvature-enhanced spreading.

For a maximally entangled initial state of two non-interacting particles we compute

the Peres-time covariance to leading order in curvature and show that it is able to distinguish between the entangled state and the corresponding classical mixture with the same marginal densities. Thus, entanglement produces effective interaction-like corrections in observable two-particle temporal correlations, in a way that is analogous to the virial corrections of quantum ideal gases. Although our conclusions also apply to the flat spacetime, we point out the pivotal role played by gravity based on which the Peres-time covariance could be used as a quantum probe of spacetime geometry.

Alessandro Capurso

Time as a Quantum Memory, Causality as a Resource: The Minkowski Metric from an Information-Theoretic Axiom

The operational definition of an observer and the treatment of causality as a physical resource are central open questions at the intersection of quantum gravity and quantum information.

We present a framework in which these two concepts, together with an information-theoretic axiom, are sufficient to recover the kinematic structure of special relativity without assuming a background spacetime manifold.

Our starting point is a presentist ontology: reality is restricted to an atomic present instant, modeled as a quantum memory encoding spatial and temporal entanglement resources. Our elementary observer is a massive particle, described within the process matrix formalism in terms of non-local and acausal processes within this memory. We assume that, in the evolution between collapse events, each observer accumulates resources in its internal degrees of freedom in terms of spatial non-locality and temporal order indefiniteness. The central postulate states that the information capacity accessible to a particle-observer within its causal cone scales with the cone's surface area and decomposes across the two orthogonal resource channels. From this capacity constraint, we recover the Lorentz factor as a resource trade-off and derive proper time as an observer's subsampling of the global update cycles induced by the information-theoretic cost of its non-locality. The construction is purely kinematic and identifies a minimal set of operational assumptions under which the Minkowski metric follows from an information-capacity constraint. Multi-observer consistency and global causal order follow as derived consequences, without additional assumptions.

This result demonstrates that spacetime can emerge from the resource trade-off of quantum information. The talk invites discussion on the generalization of the information-capacity postulate and on the relevance of quantum information in the collapse dynamics and the gravitational sector.

The preprint is available at doi.org/10.5281/zenodo.18674943, as part of an ongoing framework developed in Entropy (2022), J. Phys.: Conf. Ser. (2023), and Int. J. Quantum Inf. (2026).

Andreas Leitherer

Paradox-free classical non-causality and unambiguous non-locality without entanglement are equivalent

Closed timelike curves (CTCs) challenge our conception of causality by allowing information to loop back into its own past. Any consistent description of such scenarios must avoid time-travel paradoxes while respecting the no-new-physics principle, which requires that the set of operations available within any local spacetime region remain unchanged, irrespective of whether CTCs exist elsewhere. Within an information-theoretic framework, this leads to process functions: deterministic classical communication structures that remain logically consistent under arbitrary local operations, yet can exhibit correlations incompatible with any definite causal order—a phenomenon known as non-causality. In this work (arXiv:2512.23599), we provide the first complete recursive characterization of process functions. We use it to establish a correspondence between process functions and unambiguous complete product bases (UAPBs), i.e., product bases in which every local state belongs to a unique local basis. This equivalence implies that non-causality of process functions is exactly mirrored by quantum nonlocality without entanglement (QNLWE)—the impossibility of perfectly distinguishing separable states using local operations and causal classical communication—for such bases. Our results generalize previous special cases to arbitrary local dimensions and any number of parties, enable systematic constructions of non-causal process functions and unambiguous QNLWE bases, and reveal an unexpected connection between certain non-signaling inequalities and causal inequalities. Notably, the projective measurements build from UAPBs define events (i.e., pairs of measurement settings and outcomes), where local states require fine-grained event labeling (both measurement setting and outcome), while global states require coarse-grained labeling (only outcome), i.e., the identification of local events is setting-dependent, whereas the identification of the global events they compose is setting-independent. Viewed from this angle, non-causality arises when for any party there is no local event that can be identified in a coarse-grained, setting-independent manner from outputs alone. Finally, we discuss a correspondence between process functions and measurements defined by generalized probabilistic theories.

Anna Horváth

Quantum effects of strong gravity in the Kaluza-Klein theory

A modified dispersion relation for massive particles within the frameworks of five-dimensional Kaluza-Klein theory and general relativity is derived, taking into account strong gravitational effects. The resulting effective mass depends on the curvature of the underlying phase space. Notably, in regions with strong gravitational fields, the effective mass may become imaginary, implying the possibility of particle decay induced by spacetime curvature. The effect is studied from the point of view of different observers.

Antoine Soulas (Choups)

The measurement problem = the quantum gravity problem: building a physics of finite resources

In this talk, I do not try to solve the quantum measurement problem, but rather to properly define it, in order to clarify its links with quantum gravity. I first propose an interpretation-independent formulation of it (as a property of the empirical statistics only) and derive its philosophical consequences. The key point is the impossibility to describe quantum matter by a Kolmogorovian probabilistic theory. Because Kolmogorov's axioms are the axioms of epistemic ignorance, I define the measurement problem as the existence of ontic ignorance. Said differently, there exists no 3rd person, external, God's-eye view on quantum systems. The God's-eye view lies at the heart of classical physics, but also of Einstein's relativity, where the spacetime manifold is indeed seen externally, from "nowhere", and where the notion of event is absolute. This, I argue, is the fundamental reason for the incompatibility between QM and GR. In the history of physics, QM appears to be the first theory potentially free from any God's-eye view; the only 3rd person structure that remains is its absolute spacetime, and this is precisely the task of quantum gravity to get rid of it.

In order to remove the 3rd person point view, physics has to introduce the 1st person ones. Our instruments, our laboratories, our organs, are made of such a large number of particles, so subtly arranged that the notion of physical unit, allowing certain sensations to be quantified in a stable and objective way, makes sense at our scale—this is the situation of (virtually) infinite resources. Conversely, from the perspective of a particle, the resources for producing decoherence are so limited that the very notion of a physical unit is ill-defined. Thus, taking seriously the finiteness of resources in physics leads to deconstruct the notion of objective physical units (especially of space and time); in other words, it amounts to build a theory with no absolute spacetime (the aim of quantum gravity), which is in turn equivalent to replace the God's-eye view by the 1st person views (the lesson of the measurement problem).

Ardra Ajitha Vijayan

Unambiguous cloning of unitary channels

We investigate the problem of optimal perfect probabilistic cloning of unitary channels from a single use to two copies in qubit systems. Focusing on the scenario where the unknown unitary is selected from a set of two unitaries with equal prior probabilities, we derive upper and lower bounds on the success probability of the cloning strategy. Notably, when the success probability is plotted as a function of the angular spread of the relative unitary, the bounds coincide in the interval [/4,/2], indicating that the optimal strategy in this regime is the measure-and-prepare approach. We also explore analytical methods to estimate the optimal success probability across the entire interval.

Carlo Cepollaro

Aumann's theorem beyond ontology

Quantum, postquantum, and indefinite causal order. Abstract: Agreement theorems are no-go results about rational disagreement: if two agents start from a common prior and their posterior beliefs are common knowledge, they cannot assign different probabilities to the same event. Standard treatments of the result have the agents reason about an underlying state of the world, which has lead some to ask whether the result can extend to quantum or postquantum phenomena, where such a description may no longer be appropriate. I'll present an operational version of Aumann's agreement theorem without assuming an objective state of the world and instead focusing only on what is observed. This allows to establish the theorem's validity in quantum theory and even in situations with indefinite causal order or involving hypothetical postquantum phenomena. I'll comment on seemingly contradictory results in the literature and point to the one place where the theorem might fail: Wigner's friend-type situations.

Caroline Lima

On sufficient conditions for holographic scattering.

Holography implies scattering in the bulk can be mediated by entanglement on the boundary. The connected wedge theorem (CWT) of May, Penington, and Sorce is a concrete example where bulk scattering implies correlation between certain boundary regions. However the converse does not hold. We investigate a recent proposal of Leutheusser and Liu for a generalization of the CWT with converse. We prove the forward direction: having pairs of CFT "input" (and likewise "output") regions in a phase with connected entanglement wedge implies that a particular bulk subregion (the intersection of "input" and "output" entanglement wedges) is non-empty. We then establish a modified version of the proposal which has a converse, and identify counter-examples to the stronger conjecture.

David Amaro-Alcalá

Group functions in filtered randomized benchmarking for passive bosonic devices

We reduce the cost of the current bosonic randomized benchmarking proposal. First, we introduce a filter function using immanants and characters of the unitary group. With this filter, which uses entries of the irreps of the unitary group, we avoid computing Clebsch-Gordan coefficients.

Our filter uses the same data as the original scheme, but we propose a distinct data-collection process that requires only a single measurement type. Furthermore, we argue that weak coherent states and intensity measurements are sufficient to proceed with the characterization. Our work could then allow simpler platforms to be characterized and simplify the data analysis process.

Dominik Šafránek

Work and entropy of mixing in isolated quantum systems

The mixing of two different gases is among the most common natural phenomena. Most mixing scenarios involve thermal baths, which in quantum physics renders the situation effectively classical, allowing known classical results to carry over straightforwardly. In contrast, describing mixing in isolated quantum systems is less clear. We show that, for isolated systems, the entropy of mixing can be captured using observational entropy with an appropriately chosen coarse-graining. This entropy naturally quantifies the minimal energy required to unmix the gases. Using this framework, we address the Gibbs mixing paradox, demonstrating that two observers—one who can distinguish the gases and one who cannot—predict different amounts of extractable work. Moreover, we show that this description is operationally consistent: if the observer who cannot distinguish the gases is unaware of their internal degrees of freedom, and no experimental signature of their existence is accessible given their measurement limitations, then the amount of work they predict they can extract is exactly the amount they will extract.

Dragoljub Gočanin

Rotating frames from quantum deformed spacetime

In a sense of deformation quantization, noncommutative (NC) geometry introduces a quantum structure of spacetime. Using the twist-deformation formalism, we show that the dynamical effects of spacetime noncommutativity can amount to a transition to a rotating frame of reference. In particular, we study the dynamics of charged matter (scalars and spinors) on the curved background of Melvin's electric universe in the framework of NC gauge field theory. Melvin's electric/magnetic universe is an exact sourceless solution of the Einstein-Maxwell field equations that is both static and axially symmetric, and it represents a parallel bundle of self-gravitating electric/magnetic flux. Due to its axial symmetry, it allows for a special kind of Killing twist that does not affect the coupling of the matter fields to the background metric. Focusing on the perturbative NC equations of motion for charged scalars and Dirac spinors coupled to Melvin's electric background, we show that they have the same form as the corresponding classical (undeformed) equations of motion coupled to the same geometric background but in a uniformly rotating frame whose angular velocity is determined by the NC scale and the electric charge of the matter field. In principle, this NC rotation effect can be experimentally tested by setting up the Sagnac interferometry apparatus to measure the Sagnac phase shift for charged versus electrically neutral particles, thus placing a bound on the scale of spacetime noncommutativity.

Elias Rothlin

Quantum Reference Frames for Quantum Error Correction with lattice QED

Gauge systems share a key feature with quantum error correction codes (QECCs): In both cases, the relevant information is redundantly encoded in a larger space. In gauge theories, this ensures invariance under certain gauge symmetry transformations, while in QECCs, it protects logical data against noise by distributing it as entanglement across many subsystems.

To bridge the two frameworks, the perspective-neutral construction of quantum reference frames (QRFs) is a convenient tool because it provides a physically illuminating way of separating redundant from non-redundant information in systems with gauge symmetry.

This connection has been made precise in prior work in the context of stabilizer QECCs, whose symmetry group acts like a gauge group. Here, we apply this approach to analyze general gauge systems and their ties to error correction. Identifying perspective-neutral QRFs in such systems yields sets of correctable errors consisting of certain gauge-fixing operators which, in the QRF picture, freeze the orientation of the reference frames.

As an example, we study lattice quantum electrodynamics (QED). We construct two types of QRFs consisting either of the links of a spanning tree on the lattice or of a staggered fermionic field on the sites. Treating lattice QED as a QECC, we use these QRFs to identify correctable errors corresponding to certain changes in electric flux or errors in particle number for the staggered fermionic field. Our results show that the connection between gauge theory and QECCs yields concrete insight into the error correction properties of gauge systems.

Emil Broukal

Observables are glocal

While the gravitational field has local degrees of freedom, its observables (diffeomorphism invariant functions of the field) are global, they can not depend on single manifold points. All local information about the gravitational field must therefore be completely encoded in global objects. How precisely does this take place?

In this talk I will discuss how this aspect of the problem of observables is resolved for background independent theories defined on finite graphs. I will argue that the correct analogue of coordinate independence in this setting is the invariance under changes of node labels, a kind of permutation invariance. Then, observables are formed by group averaging and thus probe the entire graph—they are global in this sense. Strikingly, sets of complete observables can be constructed so that each seeks a connected subgraph structure—local correlations. Geometrical information is fully encoded in these background-independent observables through this subtle interplay of global and local graph notions, a behavior we term glocal. This provides physically meaningful complete sets of observables for discrete general relativity, suggests a reformulation of the spin networks state space of loop quantum gravity, and reveals deep connections between the problem of observables and the graph isomorphism problem.

Emilien de Bank

A Fine-Grained Perspective on Higher Order Operations: Modelling Agents in Spacetime

Causality is a fundamental concept that takes on markedly different forms in quantum and relativistic theories. Yet in quantum information protocols implemented in spacetime, both notions must coexist consistently (Vilasini, 2024). This raises compelling questions: How can we describe a measurement on a quantum system that is in a superposition of spacetime locations? Can an agent locally extract an outcome from such a system without collapsing its spatiotemporal coherence?

We explore how such measurements can be modelled within quantum information theory in a manner consistent with relativistic causality.

This connects closely to questions about the physicality of indefinite causal order (ICO) processes, where the ordering of agents' operations is not fixed or acyclic. Broadly, two categories of approaches exist in this context:

(1) A coarse-grained perspective which exhibits indefinite causal order. For example, the framework of quantum circuits with quantum control of causal order (QC-QCs) (Wechs, 2021) captures scenarios in which a quantum system coherently controls the order of operations. The canonical example for such class is the quantum switch (QS) (Chiribella, 2013).

(2) A fine-grained perspective (Vilasini, 2024) in which such processes are embedded in spacetime in a way that respects relativistic causality, where the process can be unravelled into one with a definite and acyclic causal order between operations. The process box framework (Vilasini, 2020; Salzger, 2023, 2025, In preparation) is representative of this approach.

Here we propose a modelling of quantum measurements in spacetime that informs how agents' interventions can be described within the fine-grained, definite-order picture, while still capturing the operational correlations found in the coarse-grained ICO framework, ensuring that each agent acts once and only once on a quantum system that may be non-localised in spacetime.

While QC-QCs and process boxes have been linked before (Salzger, 2023, 2025, In preparation), we build on this connection for deriving the structure of QC-QC's causal correlations from relativistic principles by explicitly modelling measurements of systems lacking localisation in spacetime.

This sheds light on the limits of correlations attainable with quantum protocols in spacetime.

Finally, considering recent experimental claims for certifying non-classical correlations in ICO processes, we analyse how they align with a fine-grained, spacetime-consistent interpretation which can involve superpositions of arrival times. This can enable a better understanding of the physical resources responsible for these non-classical features in the fine-grained picture, which accounts for both quantum information and relativistic aspects.

Everett A. Patterson

Perspectival Entanglement Degradation: What Alice and Rob might see using quantum reference frames

One of the canonical results from the field of Relativistic Quantum Information (RQI) is the degradation of entanglement between a pair of relatively accelerated observers, typically described from a 'global' perspective. But how might this degradation be manifest from the perspective of the 'quantum observers' that comprise this set-up?

In this presentation, we make use of the Perspectival Quantum Reference Frame (QRF) formalism to revisit the problem of entanglement degradation between an inertial observer Alice and a non-inertial observer Rob. We find many interesting connections between our perspectival approach and the typical 'global' approach. We derive explicit relationships for these, noting that they sometimes require quantum resources beyond entanglement. In particular, we find that the sum of perspectival entanglement and coherence, previously studied by Cepollaro et al. can be exactly related to the entanglement of the 'global' system.

These results not only serve as a stepping stone towards understanding QRFs and quantum resources in a fully relativistic picture, but also suggest that QRFs may be a useful tool for better understanding quantum resources more broadly.

Filip Pozar

Isometry and gauge invariance on quantum spaces implies metric signature

In this talk I will present a new result where for various noncommutative spaces (of Lie algebraic type) the metric structure on them is uniquely determined from the conditions that these quantum spaces admit theories with both gauge and isometry symmetries. Most notably, Euclidean signature with deformed Euclidean algebra, Minkowski signature with deformed Poincaré algebra and Galileian signature with deformed Bargmann algebra appear as only 4D geometries satisfying our conditions.

Gaetano Fiore

Generalized group structures for changes of quantum reference frames: the ϑ-Poincare case

An ordinary change between two classical reference frames (RF) A, B can be seen as a point g in a Lie group manifold G; g sharply specifies the orientation and motion (of the origin) of B relative to A, while the group product encodes the composition of two changes into a third one. So far, fundamental physical theories are characterized by their covariance under a suitable G. If A, B are classical RFs but the state of B relative to A is mixed (i.e., a classical statistical distribution), or more generally if A and/or B are quantum RFs (i.e., use "clocks" and "rulers" that are themselves quantum systems), then in general one cannot describe the associated "unsharp" changes of RF without some generalized group (GG) structure. In the talk I will discuss some general requirements for GGs and how Hopf algebras (socalled "quantum groups") H may fulfill the latter .Remarkably, covariance under H allows for noncommutative (NC) spacetime coordinates. As a non-trivial example of a quantum group H I will consider the "ϑ-Poincare group" of covariance of the NC Minkowski spaces with coordinates fulfilling commutation relations of the type $[x_\mu, x_\nu] \equiv i\vartheta_{\mu\nu} = const$. Work in collaboration with F. Lizzi.

Giovanna Fernandes do Valle

Bose-Einstein condensates to detect the quantum nature of gravity

In this work, we propose a non-linear interferometer experiment using Bose-Einstein condensates to detect the quantum nature of gravity. The detection of a gravitational signal is typically limited by the extreme weakness of the gravitational constant, which often leads to second-order effects that fall below the noise floor of modern sensors. To address this, we present a protocol that employs magnetic dipolar self-interactions as a high-gain amplification mechanism. We show that the cross-coupling between the gravitational and dipolar potentials enables the weak gravitational influence to be carried by the stronger electromagnetic interaction. By monitoring the evolution of the interference signal variance over time, we identify quantum non-Gaussianity as a definitive witness of a quantized mediator. This approach allows for a clear distinction between quantized gravity and semiclassical models that preserve the Gaussian distribution of the state. This methodology provides a future pathway for enhancing gravitational signatures in laboratory settings using current ultracold-atom technology.

Giovanni Scala

TBA

TBA

Hristu Culetu

On a traversable wormhole with a stress tensor of a massless antiscalar field

A static spherically symmetric geometry with no horizon is investigated. The metric is asymptotically flat with the radial coordinate $r > 1/a$, where a ia a constant acceleration. One finds that the metric represents a traversable wormhole, with the shape function $b(r) = 1/(a^2r)$ and where the flare out condition [1] is satisfied and the energy density $\epsilon = -1/(8\pi a^2r^4) < 0$ (exotic matter).

One finds that the only nonzero component of the Ricci tensor may be written in the form $R_{mn} = -2\Psi_{,m}\Psi_{,n}$, with $\Psi(r) = \arctan(\sqrt{a^2r^2 - 1})$ (see [2, 3]), where Ψ represents a massless scalar field with negative kinetic energy (antiscalar field).

[1] M. S.Morris and K. S. Thorne, Am. J. Phys. 56, 395 (1988).

[2] P. Boonserm et al., Phys. Rev. D 98, 084048 (2018) (arXiv: 1805.03781).

[3]. H. G. Ellis, J. Math. Phys. 14, 104 (1973).

Iason Vakondios

Time of arrival on the circle and relativistic quantum clocks

We analyze time of arrival measurements of quantum relativistic particles constrained to move in a ring. We construct the relevant probabilities, giving particular emphasis to the quantum-classical correspondence. This system defines a simple model for a quantum clock, based on local relativistic QFT, that can be used to explore the consequences of quantum effects such as superposition and entanglement. Furthermore, we analyze the system in presence of rotation, showing that the rotational Unruh effect is manifested as noise in the time-of-arrival measurements.

Ieline Ahmed

Multipartite Bell inequalities with interferometric multiports

We propose a characteristic–function approach to Bell inequalities implemented with interferometric multiport measurements. By encoding d-valued outcomes as roots of unity, Bell functionals become linear combinations of Fourier correlators. This unified scheme reproduces CHSH, CGLMP, and MABK inequalities, and systematically generates new ones in higher-dimensional and multi-setting scenarios. Optimizing over entangled states and multiport phase shifts provides explicit quantum strategies. Our framework thus offers a compact, experimentally natural route to Bell tests beyond the standard families.

James Robinson

A formal refinement for operator size of qudits

We study operational definitions for quantum gravity that are testable on a quantum computer.

Operator size (the amount of simple operators that constitute a Heisenberg-picture operator) quantifies quantum chaos and is useful for characterizing systems in which all degrees of freedom are coupled and no notion of spatial locality exists. Operator size has been applied in several areas, including many-body teleportation, the eigenstate thermalization hypothesis and information scrambling.

We provide a formal refinement of operator size in qudit systems. Exploiting the fact that a unitary basis for finite-dimensional linear endomorphisms is a 1-design, we show that the thermally renormalized unit of size (the natural unit of size at finite temperature) agrees with expectations from studies of size using Majorana zero modes.

We define cosize as the complementary definition for size. In the Liouville representation, the cosize operator is equivalent to a uniformly random single-site fully depolarizing channel, linking operator size and depolarising noise. This relationship suggests an alternative method to measure the Lyapunov exponent on quantum computers.

Jerzy Paczos

Measuring quantum time dilation with delocalised atoms

Gravitational time dilation is normally defined along a definite worldline. Quantum theory, however, allows a clock to be prepared in a coherent superposition of locations corresponding to different proper times. Building on earlier discussions of quantum time dilation, we investigate how quantum corrections to the experienced time dilation appear operationally in a concrete, experimentally motivated model. We study a decaying two-level atom prepared in a spatial superposition of heights in a weak gravitational field, treating the atom–field interaction fully quantum mechanically. We find that the spontaneous emission rate for a coherent superposition of separated wave packets differs from that of a classical mixture with the same spatial marginals, isolating the role of spatial coherence. The same physics can be expressed as a fractional shift of the internal transition frequency and as coherence-dependent modifications of the emission spectrum. These signatures are defined through standard radiative observables accessible to external detection, within the weak-field, semiclassical domain.

Jorge Escandón-Monardes

Multiparameter estimation with a photonic quantum switch

Several experiments have demonstrated the advantages that indefinite causal order offers for quantum information. For instance, the quantum switch, which is the most prominent example of an indefinite causal order process, has been shown to enhance the precision of some metrological tasks compared to fixed order strategies. In this work, we experimentally demonstrate the advantages of indefinite causal order for multiparameter estimation in a photonic quantum switch. Our setup uses multicore optical fibers technology to coherently control the order of three quantum operations, two of them being noisy channels with variable noise strength. Our setup can estimate parameters even in noisy regimes where the consecutive application of the operations in a fixed order would make it unattainable. Additionally, we assess the Fisher information matrix for different configurations of the setup and different amounts of noise, showing that the best configuration of the quantum switch depends on a priori information and weighing of the parameters. Our results highlight the pertinence of indefinite causal order for quantum information under noisy conditions.

Jozef Genzor

Thermodynamic social influence on hyperbolic and fractal lattices: a tensor-network study

We study equilibrium models of social influence on non-Euclidean lattices using tensor-network methods. Each agent is represented by a small number of discrete "features" (opinions, cultural traits), leading to an effective multi-component Potts/clock-type spin model. We apply the corner transfer matrix renormalization group (CTMRG) and the higher-order tensor renormalization group (HOTRG) to compute thermodynamic quantities on Euclidean square lattices, regular hyperbolic tilings, tree-like limits, and a fractal Nishino-type lattice.

Kartik Kakade

Maximum Entropy Principle for Quantum Channels

The primary objective of this study is to extend and implement the principle of maximum entropy within the context of incomplete quantum process estimation tasks. We use the process entropy function defined as the von Neumann entropy of the state associated with the quantum process via Choi-Jamiolkowski isomorphism. Utilizing this definition of channel entropy, and given only partial information regarding the mean values of projective measurements on both input and output states, we aim to identify the channel that maximizes entropy. We find that the channels that transform pure states into the maximally possible mixed state, consistent with the provided constraints, constitute the set of channels having maximum entropy.

Ladina Hausmann

What Wigner's friend teaches us about black holes

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. Experiments involving observers with fundamentally different perspectives were also considered independently in quantum foundations. These are the so-called Wigner's friend experiments, which do not involve gravity. Recent versions of these experiments have shown that different perspectives are difficult to combine: even mild assumptions about how they might be combined are inconsistent with quantum theory. A careful analysis of the firewall paradox reveals that it, too, relies on such assumptions. 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.

Maarten Grothus

Impossibility of superluminal signalling rules out causal loops in conical spacetimes only

Contrary to popular belief, in PRL 129, 110401 it was shown that it is theoretically possible to have operationally detectable causal loops without violating the relativistic principle of no superluminal signalling (NSS) in 1+1-Minkowski spacetime.

Whether or not such causal loops compatible with NSS are also possible in $d > 1$ spatial dimensions, has remained a key open question. In another recent work, we introduced the spacetime property of conicality, proving it to be satisfied in $d > 1$ dimensional Minkowski spacetimes but violated in $d = 1$.

Building on this, together with techniques for causal inference in presence of operational redundancies and fine-tuning, the current submission resolves that question. We show that in any conical spacetime, NSS does rule out all operationally detectable causal loops, in classical, quantum and post-quantum theories.

Hence, the relationship between NSS and causal loops depends inherently on the spacetime geometry. Moreover, our results highlight that any such compatible causal loop necessarily requires both a fine-tuned causal model and a fine-tuned spacetime embedding, where the latter is defined via the notion of conicality.

Marek Liška

I discuss how gravitational dynamics emerges from equilibrium conditions applied to local causal horizons. I focus on the central role causality and observer-dependence play in this framework. As a particular example, I discuss the emergence of semiclassical JT gravity in 2D from local entanglement equilibrium. I am also going to comment on our ongoing effort to employ quantum reference frames for defining entropy in 2D gravity. Ultimately, this research programme aims to merge the entanglement equilibrium framework with quantum reference frames, leading to a new outlook on the role of observers in quantum gravitational dynamics.

Marina Pisaturo

Entanglement dynamics in a curved spacetime

The topic of my master thesis could fit very well in the treated topics. I could expose a still theoretical experiment where a single photon (clock state) is delocalized in a three-arms interferometer, and interacts with Earth's curved spacetime (in a post-Newtonian approach) through storage in Quantum Memories. Due to time dilation, the photon acquires a path-dependent phase, therefore correlations between internal and external DOFs. These cause complex and interesting trends of the interference contrast after recombination. This shows not only how time is not an independend background and that gravity causes decoherence, but also how the entanglement beautifully redistributes and the coherence is recovered via quantum revivals. What is new about this setup (that can be considered as a 3-slit experiment in gravity) is that we can prove Born rule, study frustrated entanglement, probe the dynamics complexity (by plotting the first fourier moment) and perform causality tests.

Matej Moško

Tensor-Network study of Ising model on infinite hyperbolic dodecahedral lattice

We propose a tensor-network-based algorithm to study the classical Ising model on an infinitely large hyperbolic lattice with a regular 3D tesselation of identical dodecahedra. We reformulate the corner transfer matrix renormalization group (CTMRG) algorithm from 2D to 3D to reproduce the known results on the cubic lattice. We subsequently generalize the CTMRG to a hyperbolic lattice with dodecahedral cells, which is an infinite-dimensional lattice. We analyze the spontaneous magnetization, von Neumann entropy, and correlation length to find a continuous non-critical phase transition on the dodecahedral lattice. We estimate the phase-transition temperature and find the magnetic critical exponents $\beta = 0.4999$ and $\delta = 3.007$, which confirm the mean-field universality class, in accord with predictions from Monte Carlo and high-temperature series expansions. The algorithm can be applied to arbitrary multi-state spin models.

Matthias Salzger

Higher-order quantum processes respecting closed labs in a spacetime have quantum controlled causal order

In quantum causality and quantum information, there is a vast landscape of abstract quantum protocols that permit cyclic or non-acyclic causal structures between quantum operations. This includes widely studied frameworks for indefinite causal order and higher-order quantum processes, such as process matrices. However, a longstanding open question has been which is the largest class of such abstract processes that admit physical realisations without post-selection. In this work, we provide a rigorous answer by adopting a top-down approach grounded in relativistic causality principles, motivated by the fact that physical experiments are implemented consistently with such principles in spacetimes with acyclic lightcone structures. Building on the framework of causal boxes, which characterise the most general quantum information-processing protocols compatible with fixed background spacetimes, we formalise additional physically motivated constraints (Acting Once + Local Order) capturing the closed-laboratory assumptions of the process matrix framework at a fine-grained spacetime level. We prove that any protocol realisable in a classical acyclic spacetime and satisfying these spatiotemporal closed-lab conditions is behaviourally equivalent to a quantum circuit with quantum control of causal orders (QC-QC), providing a top-down derivation of QC-QCs from physical principles. Our results therefore show that QC-QCs constitute precisely the class of higher-order quantum processes, including those with indefinite orders, that can be physically realised within classical spacetime, clearly ruling out the possibility of any experiment in this regime that could realise more general non-causal processes under such a closed-labs assumption. This clarifies the relationship between abstract higher-order process matrix frameworks and experimentally accessible quantum protocols, as well as the interplay between coarse-grained cyclic and fine-grained acyclic operational causal structures. We also develop characterisation techniques and results for process box protocols that lead to new causality-based open questions concerning spacetime quantum protocols and relativistic quantum experiments.

Max Joseph Fahn

Relational observables and quantum master equations for bosonic matter coupled to linearised gravity

On the poster, we discuss the application of the relational formalism to construct suitable Dirac observables for a classical field theory of scalar or photon fields coupled to linearised gravity. This includes in particular the formulation of suitable classical reference fields and a comparison of the effects of different choices of Dirac observables on the algebra and Hamiltonian of the system. The application of both an observable map, which yields Dirac observables that commute with all constraints present in the system, and a dual observable map, which leads to quantities that commute with all reference fields, provides direct access to the physical degrees of freedom of the system. The use of the relational formalism furthermore enables a physical interpretation of temporal and spatial coordinates.

In the next step, a quantum master equation is derived which encodes the effective evolution of the matter field, treating the gravitational part of the system as an environment whose dynamics are not solved in detail. Relating the individual contributions of the master equation to the Feynman rules of the underlying effective quantum field theory facilitates the interpretation of the specific terms of the Hamiltonian and the renormalisation of UV divergences present in the master equation. This procedure is applied to the single-particle projection of the master equation for a scalar field in order to obtain the dynamics of a single scalar particle in a linearised gravitational environment.

Michał Piotrak

Quantum estimation of cosmological parameters

Understanding how well future cosmological experiments can reconstruct the mechanism that generated primordial inhomogeneities is key to assessing the extent to which cosmology can inform fundamental physics. In this talk, I will explain how to apply a quantum metrology tool — the quantum Fisher information — to the squeezed quantum state describing cosmological perturbations at the end of inflation. This quantifies the ultimate precision achievable in parameter estimation, assuming ideal access to early-universe information. I will also show how this can be used to assess how close current observations come to the quantum limit by comparing quantum Fisher information to classical Fisher information for homodyne detection. For the case of the tensor-to-scalar ratio, this comparison shows the existence of a highly efficient (but presently inaccessible) optimal measurement that yields exponentially better precision in late times.

Michał Popiel

Combining boost and translation transformations in κ-Poincare Deformed Special Relativity

TBA

Miloš Milovanović

Mathematical Metrology and Information Processing

The author argues that classical states might be represented by uniform distributions which satisfy the uncertainty principle as well, due to an infinite deviation. For that aim, the quantum mechanics is expanded to involve classical in a non-trivial manner. The position operator in quantum mechanics corresponds to linear time in classical one and the momentum has corresponded to classical velocity. In that regard, the mass is eliminated and quantum dynamics has reduced to classical kinematics. In order to involve classical dynamics, one requires statistical mechanics of quantum ensembles wherein canonical coordinates are represented by superoperators. A generalization to relativistic mechanics is indicated, as well as the measurement problem of a conscious observation which emerges due to existence of the intrinsic time superoperator acting upon densities.

The measurement is regarded to be a stochastic process corresponding to the time series of binary digits, which has unified classical and quantum information in a procedure that takes place step by step. The time continuum which has emerged in that manner is a skeletal category of mathematical physics. The inference provides a consistent realization of metrology which is considered mathematically notwithstanding any physical conception. It contributes to the definition of information and foundation of mathematics upon such a measurement procedure.

Miquel Jorquera Riera

Uncertainty Relations Relative to Phase-Space Quantum Reference Frames

We study Heisenberg's uncertainty relation relative to a quantum reference frame (QRF). We introduce the QRF as a covariant phase-space observable, show that when described relative to it, position and momentum appear compatible, and derive novel, frame-relative uncertainty relations. We then verify that in the classical limit of the QRF, the standard uncertainty relations are recovered, fortifying claims that standard quantum theory must be understood relative to an external, classical frame.

Nathan Cohen

The Spin-Geometry Theorem

We revisit Penrose's program of "combinatorialising" quantum theory by developing its finite-resource formulation called "spin network" and present the Spin-Geometry Theorem within this framework. Starting from the pure logic of pairings, we construct spin networks without assuming any background space, Hilbert space, or continuum of parameters. This combinatorial setting naturally carries a rational probability rule, which we interpret as a "proto-probability" encoding a degradable notion of predictability. We introduce the δ-classicality condition that characterises regimes of effectively unbounded resources, in which repeated applications of a spin network operation yield stable probabilities, thereby enabling an operational notion of repetition of the same experiment and justifying an emergent separation between "system" and "classical context". In this δ-classical regime, the Spin-Geometry Theorem holds: for a spin network with sufficiently large open ends, the probabilities associated with a simple spin-$\frac{1}{2}$ exchange operation define angles that satisfy, up to small corrections, all constraints of three-dimensional Euclidean geometry, and the spin network probability rule reduces to the Born rule for spin. This realises Penrose's idea that both spatial geometry and quantum theory emerge jointly in an appropriate large-resource limit and provides a concrete way in which standard quantum mechanics can be viewed as the infinite-resource limit of a more primitive, discrete theory.

Nicolas Boulle

Subsystems (in)dependence in GIE proposals

Recent proposals suggest that detecting entanglement between two spatially superposed masses would establish the quantum nature of gravity. These gravitationally induced entanglement (GIE) experiments rely on assumptions about subsystem independence, measurement, and observables inherited from quantum information theory. In this talk, we examine GIE proposals through the lens of algebraic quantum field theory (AQFT), distinguishing operational and algebraic notions of independence. We focus on how gauge constraints and gravitational dressings impact the notion of subsystem independence, essential to the experimental logic. Using gravitationally dressed fields, we recall that commutation relations between spacelike separated observables can fail, undermining strict Hilbert space factorization. We discuss the implications for entanglement witnesses, showing how standard bounds can persist even when subsystem algebras fail to commute. Finally, we derive estimates for dressing-induced microcausality violations. Although these effects are negligible for current experimental regimes, they sharpen the conceptual interpretation of entanglement-based probes of quantum gravity and point to complementary ways of testing its quantum nature.

Nicolas Medina Sanchez

States of Random Gravity

Traditionally, general relativity is formulated in terms of smooth differentiable manifolds endowed with Lorentzian metrics, where the physical content of a spacetime is encoded in geometric data invariant under diffeomorphisms. These diffeomorphisms represent arbitrary coordinate transformations, reflecting the principle that physics should not depend on the particular choice of coordinates. The true gravitational degrees of freedom are therefore not individual metric tensors on a manifold, but equivalence classes of metrics under the action of the full diffeomorphism group.

Characterizing such gravitational states, namely describing spacetime geometries modulo diffeomorphism, is a highly nontrivial problem. In precise terms, one seeks invariants capable of separating and completely characterizing equivalence classes of configurations that are physically indistinguishable. This is closely related to the long-standing issue of constructing complete sets of observables in generally covariant theories [Kuchar]. The mathematical difficulty lies in the fact that the quotient space of metrics by diffeomorphisms is extremely singular and lacks a simple measurable or topological structure.

Recent results in descriptive set theory and the theory of classification problems indicate that, in general, constructing separating invariants as functions on the space of equivalence classes may be impossible in a strong sense. In certain settings, even when complete invariants exist abstractly, they may fail to be Borel definable. Moreover, the nonexistence of such definable complete invariants can be consistent with Zermelo–Fraenkel set theory [Panagiotopoulos et. al.]. These findings suggest that the problem of classifying spacetimes up to arbitrary diffeomorphism may transcend standard measurable frameworks and may not admit a satisfactory solution in terms of conventional invariants.

In this work, we pursue a different direction. Instead of quotienting by the full diffeomorphism group, we restrict attention to the subgroup of measure-preserving diffeomorphisms. Concretely, we fix a reference measure on the spacetime manifold and consider only those diffeomorphisms that preserve this measure. This restriction significantly alters the structure of the equivalence relation. While it remains nontrivial, the resulting classification problem becomes more tractable [Vershik].

Under this reduced symmetry group, it becomes possible to construct quantities that separate equivalence classes effectively. In particular, one can encode the physical information of a spacetime in terms of probability distributions derived from geometric data. These distributions capture the relevant invariant content up to sets of measure zero. From this perspective, the essential gravitational information is contained in measure-theoretic invariants rather than in pointwise geometric data.

Operationally, this amounts to randomizing the points of spacetime with respect to the chosen measure. By focusing on statistical features of the geometry rather than on individual points, one obtains a probabilistic characterization of gravitational states. Within this framework, equivalence classes under measure-preserving diffeomorphisms can be completely separated by distributional data, providing a well-defined and constructive description of the physical configuration. In this sense, once spacetime points are treated as random variables, the classification of gravitational states becomes fully achievable within a measurable setting, up to null sets.

Panagiotopoulos, A., Sparling, G. A. J., & Christodoulou, M. (2023). Incompleteness Theorems for Observables in General Relativity. PRL, 131(17), 171402. arXiv:2305.04818.

Vershik, A. M. (2004). Random metric spaces and universality. Russian Mathematical Surveys, 59(2), 259–295.

Kuchař, K. V. (1992). Time and interpretations of quantum gravity. In G. Kunstatter, D. E. Vincent, & J. G. Williams (Eds.), Proceedings of the 4th Canadian Conference on General Relativity and Relativistic Astrophysics (pp. 211–314). World Scientific.

Nikolaos Mitrakos

When does entanglement through gravity imply gravitons?

Detection of entanglement through the Newtonian potential has been claimed to support the existence of gravitons, by extrapolating to a thought experiment which demonstrates that complementarity and causality would be in conflict unless quantum fluctuations exist. We critically assess this consistency argument using scalar field models. We show that whether complementarity or no-signalling is violated when quantum fluctuations are neglected, depends on how this approximation is taken, while in both cases entanglement is generated locally in spacetime. We clarify that the correct reading of the paradox requires making a clear distinction between two notions of causality violation: Newtonian action-at-a-distance and quantum mechanical signalling at spacelike separation; the latter is pertinent while the former is not. We conclude that the thought experiment (a) does not add to the epistemological relevance of entanglement through Newtonian potentials (b) lends support for the existence of gravitons, if retardation effects are detected in entanglement through gravity.

Nitesh Kumar Dubey

Memory Effects and Entanglement Dynamics of Finite time Acceleration

We present a smooth class of trajectories in Minkowski spacetime that are inertial in the asymptotic past and future, while undergoing approximately uniform acceleration for a finite time interval. In an appropriate limit, these trajectories reduce to the standard Rindler trajectory, recovering the expected Bogoliubov transformations and results consistent with the thermal time hypothesis. Using this setup, we study the response of an Unruh–DeWitt detector and analyze how complete positivity (CP) divisibility depends on the detector's frequency, the acceleration, and the duration of the accelerated phase. We find that a finite acceleration period induces a clear memory effect in the detector's dynamics, which we further quantify using Fisher information. Extending the analysis to two detectors following various combinations of trajectories, we show that—unlike the transition rate—both the total correlations and the harvested entanglement smoothly return to their initial values after the acceleration–deceleration cycle. These correlation measures exhibit similar behavior during both accelerating and decelerating segments. Remarkably, neither negativity nor mutual information is sensitive to the memory effect for such trajectories. Finally, we discuss the physical interpretation of the sign of the flux associated with acceleration-induced radiation.

Paul Erker

Entropic costs of extracting classical ticks from a quantum clock

We experimentally realize a quantum clock by using a charge sensor to count charges tunneling through a double quantum dot (DQD). Individual tunneling events are used as the clock's ticks.

We quantify the clock's precision while measuring the power dissipated by the DQD and, separately, the charge sensor in both direct-current and radio-frequency readout modes. This allows us to probe the thermodynamic cost of creating ticks microscopically and recording them macroscopically. Our experiment is the first to explore the interplay between the entropy produced by a microscopic clockwork and its macroscopic measurement apparatus. We show that the latter contribution not only dwarfs the former but also unlocks greatly increased precision, because the measurement record can be exploited to optimally estimate time even when the DQD is at equilibrium. Our results suggest that the entropy produced by the amplification and measurement of a clock's ticks, which has often been ignored in the literature, is the most important and fundamental thermodynamic cost of timekeeping at the quantum scale.

Paul Schneidewind Telge

Scattering in a Holographic Quantum Field Theory

I explore scattering amplitudes in a model that considers shrinking the Hilbert space of a lattice-regularized quantum field by overlapping different Fourier modes, in order to achieve area-scaling of the dimension of the Hilbert space. This area scaling of degrees of freedom is motivated by the Holographic principle.

Philip Kurian

Superradiant life: The Heisenberg cut within the observer?

Addressing the extent of life's quantumness presupposes an answer to the equally fraught question, "What is life?", which became the essential focus of Erwin Schrödinger's 1943 Trinity College lectures. New science from quantum optics is pointing to how the "unsurveyably intricate" architectures of life—as Schrödinger observed—harness ordered collections of photoexcited molecular qubits in protein fibers for exquisite information processing, above thermal noise, which Schrödinger had not anticipated but which his contemporary Niels Bohr hinted at just a decade before in his essay "Light and Life". Answering how these photons shape the processes of life, and its sentient behaviors, requires a journey from life's origins in light, to the quantum-coherent union of light and matter in the evolving cosmos. As these vast interconnected webs of information flowing through life point to shadows of the mind, they will return us to the nontrivial placement of the elusive Heisenberg cut between observer and system–or perhaps within the observer–in quantum measurement.

Philip LeMaitre

Particle Detectors Witness the Non-Classicality of the Vacuum with Contextuality

Quantum contextuality is the notion that certain measurement scenarios do not admit a global description of their statistics. It generalizes the concepts of nonlocal entanglement and magic, and is an equivalent notion of nonclassicality to Wigner negativity. In this talk, I introduce the protocol of contextuality harvesting and show that Unruh-DeWitt models are capable of harvesting quantum contextuality from the vacuum of a massless scalar quantum field. In particular, I show that gapless systems can be made to harvest contextuality given a suitable choice of measurements and parameters. An Unruh-DeWitt qubit-qutrit system is also investigated, where I show that certain tradeoffs exist between the harvested contextuality of the qutrit and the harvested entanglement between the systems, and that there are regimes where the two resources can both be present. To quantify the harvested contextuality, the contextual fraction is imported and used as a general measure for any form of harvested contextuality, including nonlocal entanglement and magic. New criteria for genuine harvesting are also put forward that additionally apply to individual systems, revealing new permissible harvesting parameter regimes. Finally, I discuss the impact of this acquired contextuality on the possible observer dependence of quantum theory in spacetime.

Pop Nicolina

Some properties of coherent states representation with applications in the Quantum Information

The qubits and density operators are described in the framework of coherent states in this work. We have expressed a qubit as a coherent state, and thus a sequence of qubits becomes the tensor product of the coherent states. For the ensembles of qubits, it could be used the density operator, in order to describe the information content of the ensemble. The coherent states representation may play an important role in the quantum information theory and the use of this formalism is not only theoretical, but also, due to its applications, of some practical relevance

Riccardo Falcone

An inequality for relativistic local quantum measurements

We investigate the trade-off between vacuum insensitivity and sensitivity to excitations in finite-size detectors, taking measurement locality as a fundamental constraint. We derive an upper bound on the detectability of vacuum excitation, given a small but nonzero probability of false positives in the vacuum state. The result is independent of the specific details of the measurement or the underlying physical mechanisms of the detector and relies only on the assumption of locality. Experimental confirmation or violation of the inequality would provide a test of the axioms of algebraic quantum field theory, offer new insights into the measurement problem in relativistic quantum physics, and establish a fundamental technological limit in local particle detection.

Robin Simmons

Lessons for quantum gravity from quantum field theory

In recent years, operator algebras have become a key framework for describing quantum gravity. As well as being key in proofs of the generalised second law and in some accounts of black hole evaporation, they also promise an abstraction beyond spacetime. However, there are several lessons from algebraic QFT that suggest that operator algebras are more subtle than meets the eye. I will present two of these: Sorkin's impossible operations and backreaction, and comment on their importance in applications of operator algebras to quantum gravity.

Ryshard-Pavel Kostecki

Causal logics revisited

Orthogonality spaces, used to define the notion of a causal complement/nonsignalling in the theory of 'causal logics' and in algebraic quantum field theory (not necessarily over lorentzian spacetimes), exhibit some structural limitations. As a result, the research on causal logics does not apply tools of mathematical logic, and nearly exclusively restricts the domain of interest to the lattices of causally closed sets, which is too restrictive for many models of algebraic quantum field theory. We develop a new approach to the theory of causal logics (including old one as a special case), based on a family of logical calculi that are equivalent with varietes of lattices equipped with a negative modal operator of impossibility. We also introduce representations of these logics in terms of lattices of *- and von Neumann subalgebras, and apply them to the study of causal copresheaves ('causal nets') of *- and von Neumann algebras, including algebraic quantum field theories over globally hyperbolic spacetimes with noncompact Cauchy surfaces.

Saadat Salman Shariff

Probing quantum superposition of spacetime using Unruh DeWitt detectors

Recent developments in quantum information and tabletop quantum experiments have renewed interest in operational approaches to the interface of quantum theory and gravity. In this poster, I explore how Unruh–DeWitt particle detectors can be used as probes of spacetime structure through their interaction with quantum field vacuum fluctuations. As a case study, I discuss how a detector placed inside a massive hollow shell can detect the shell's presence through changes in its transition probability, despite the local spacetime being flat and classical experiments being unable to distinguish the two situations on short timescales. This illustrates how the quantum vacuum encodes global gravitational information accessible through local measurements. Building on this idea, I outline my ongoing research directions involving quantum-controlled detectors and the phenomenology of spacetime superpositions, aiming to develop operational probes of quantum gravitational effects.

Samgeeth Puliyil

Semi-Device-Independent Channel Identification with Communication Matrices

We look into the task of differentiating between any two quantum channels and reconstructing them from the obtained measurement statistics with possibly limited information about the experimental set-up. We employ the communication matrix formalism where the measurement statistics of a prepare-and-measure scenario is represented as a stochastic communication matrix. In order to differentiate between any two quantum channels, the informational completeness of the set-up is both necessary and sufficient. On the other hand, if we want to uniquely characterize any quantum channel, in addition we also need to have a complete description of the set-up. We show that in many important cases we can deduce this information directly from the communication matrix of the set-up before applying the channel. Given that we trust the dimension of the system, we show that we can deduce the information completeness of the set-up directly from the rank of the communication matrix. Furthermore, we show that another quantity of the communication matrix, called the information storability, can be used to self-test the set-up (up to unitary or antiunitary freedom) for an important class of states and measurements. This provides us a semi-device-independent way to identify quantum channels from the prepare-and measure statistics. Lastly, we consider scenarios where we might have some additional information about the channels or additional resources at our disposal which could help us relax some of the assumptions of the proposed scenario.

Samuel Fedida

Foundations of Relational Quantum Field Theory

We develop foundations for a relational approach to quantum field theory (RQFT) based on the operational quantum reference frames (QRFs) framework considered in a relativistic setting. Unlike other efforts in combining QFT with QRFs, we use the latter to provide novel mathematical and conceptual foundations for the former. We focus on scalar fields in Minkowski spacetime and discuss the emergence of relational local observables and quantum fields from the consideration of Poincaré-covariant frame observables defined over the space of inertial reference frames. We recover a relational notion of Poincaré covariance, with transformations on the system directly linked to the state preparations of the QRF. We introduce and analyse various causality conditions, and construct an explicit example of a covariant scalar relational quantum field which is causal relative to operationally meaningful preparations of a relativistic QRF. The theory makes direct contact with established foundational approaches to QFT: we demonstrate that the vacuum expectation values derived within our framework reproduce many of the essential properties of Wightman functions, carry out a detailed comparison of the proposed formalism with Wightman QFT with the frame smearing functions describing the QRF's localisation uncertainty playing the role of the Wightmanian test functions, and show how the properties of algebras generated by relational local observables suitably extend the core axioms of Algebraic QFT. This work is an early step in revisiting the mathematical foundations of QFT from a relational and operational perspective.

Sebastian Schuster

Canonical Quantum Gravity without Canonical General Relativity

Canonical quantum gravity has its origins in the Hamiltonian formulation of general relativity. Similar, canonical approaches have also started from Hamiltonian formulations of other theories of gravity. However, this bakes in severe restrictions, notably causal properties compatible with a (unique) initial value formulation and other topological limitations. However, as with any change in theory, new phenomenology beyond that considered sensible in the precursor theory is to be expected. Here, I will discuss our ongoing efforts to study such phenomenology through toy models. Concretely, how the Page–Wootters formalism of a relative notion of time would work out when applied to periodic systems with a periodic clock reinterpreted as self-consistent time travel.

Soham Sau

Sequential realization of Quantum Instruments

Most of the currently developed devices for quantum technologies aim to implement quantum circuits, in which measuring a qubit at the end of the circuit is a necessary part. In many practical scenarios, measuring, resetting, and reusing many qubits over time are necessary, although the qubits are still in relatively short supply. Mid-circuit measurements are a technique that allows for the extraction of information from qubits and the alteration of their state without necessarily destroying or collapsing their state entirely.

Quantum instruments form the mathematical backbone of mid-circuit measurements. It describes a measurement procedure that, in addition to capturing measurement statistics, also captures the post-measurement state. We show that any quantum instrument (T) can be realized as an adaptive sequence of two instruments, where the first instrument is the Lüders instrument of postprocessing of the induced POVM of the given instrument (T). We generalize this result for any finite number of instruments. Furthermore, we investigate the resources required for sequential implementation in terms of the ancillary dimension needed and demonstrate that one can save resources (through qubit reuse) using sequential implementations for a specific class of instruments. Finally, we provide some examples that help build a better understanding of our results.

Sourav Ballav

Semi-Causality and Information Leakage in a Quantum Circuit Model of Black Hole Evaporation

Causal structure plays a central role in the standard description of black holes: information can fall into the horizon but cannot escape from the interior. Several quantum-circuit models of black hole evaporation incorporate this principle through a constraint known as *semi-causality*, which allows information flow from exterior degrees of freedom into the black hole interior while forbidding the reverse direction.

From the perspective of quantum gravity, however, it is plausible that strict horizon causality is only approximate and may be modified by quantum fluctuations or backreaction effects. In this talk I present a minimal four-qubit circuit model of black hole evaporation in which semi-causality can be continuously deformed.

The deformation is implemented through a parametric controlled-unitary gate $\mathrm{CU}(\sigma)$ that allows a tunable leakage of quantum information from the black hole interior to exterior degrees of freedom while preserving global unitarity. By tracking the evolution of von Neumann entropy, mutual information, and entanglement negativity, we analyze how small violations of semi-causality modify the flow of information during evaporation. We find that even arbitrarily small causal leakage generates a nonzero late-time entropy plateau and persistent entanglement across the horizon, preventing complete purification of the radiation.

In the small-σ regime the residual entropy exhibits a characteristic $-\sigma^2 \log \sigma^2$ scaling, reminiscent of logarithmic quantum-gravity corrections.

These results suggest that minimal deviations from classical horizon causality can leave long-lived imprints on black hole information dynamics.

Stanislav Filatov

Definite Order, Delocalized Processes: A Reframing of the Quantum Switch

We propose a reframing of the quantum switch in which the target qubit traverses processes in a definite order — but the processes themselves are spatially delocalized. The analogy is with the double-slit experiment: rather than saying a photon goes through both slits, one can say it goes through one slit whose name is (A+B)/2. The slit is definite; its label is quantum. By the same logic, the apparent indefiniteness of the quantum switch is reread as definite traversal of delocalized processes. We present this as an open intuition and invite discussion with the participants on how to make it precise.

Tadeusz Adach

κ-deformed Discrete Symmetries

The κ-deformation of spacetime symmetries underlying -Minkowski spacetime introduces a certain degree of ambiguity in the definition of C, P, and T transformations. In most formulations, at least one of these symmetries is inevitably broken, often implying CPT violation. I will present a recent proposal for deformed discrete symmetries in -deformed field theory that, while sacrificing C and T invariance, preserves CPT as an exact symmetry. The approach will be demonstrated for spin-1/2 fields, providing a viable avenue for quantum gravity phenomenology.

Tamal Guha

Minimal Assistance from Environment Unlocks the Encoding Strength

For any quantum transmission line, with smaller output dimension than its input, the number of classical symbols that can be reliably encoded is strictly suboptimal. In other words, if the channel outputs a lesser number of symbols than it intakes, then rest of the symbols eventually leak into the environment, during the transmission. Can these lost symbols be recovered with minimal help from the environment? While the standard notion of environment-assisted classical capacity fails to fully capture this scenario, we introduce a generalised framework to address this question. Using an elegant example, we first demonstrate that the encoding capability of a quantum channel can be optimally restored with a minimal assistance from environment, albeit possessing suboptimal capacity in the conventional sense. Remarkably, we further prove that even the strongest two-input-two-output no-signalling correlations between sender and receiver cannot substitute for this assistance. Finally, we show that minimal environmental assistance unlocks encoding strength optimally for all quantum channels whose environment assisted capacity is known to be suboptimal.

Tomasz Bazylewicz

Decoherence from the light bending interaction

We analyse a decoherence effect, caused by the gravitational interaction between a massive body and the electromagnetic field. Assuming a quantum version of the light bending interaction, we show that it leads to decoherence of the mass if the light is not observed. Using the extreme weakness of the gravitational coupling, we derive explicitly the decoherence lengthscales for general states of the central mass and for both thermal and coherent light. Predictably, the effect is very faint for anything but hugely energetic light, however from the fundamental point of view of co-existence of both gravitation and quantum theories, it is there. Since effectively the studied system is a quantum optomechanical system, we hope our results, properly rescaled, will be also useful in optomechanics.

Varun Kushwaha

How Many Degrees of Freedom Does Field Theory Dynamics Use? Dynamical Compression Before Gravity

Gravitational entropy bounds suggest that far fewer independent degrees of freedom may be physically relevant in a region than suggested by the kinematics of local field theory. A natural question is whether part of this reduction already arises at the level of ordinary Hamiltonian dynamics.

In this talk, I study this question in a regulated classical scalar field theory. I introduce the notion of a minimal symplectic dimension: the smallest number of canonical degrees of freedom required for an autonomous Hamiltonian system to reproduce a given trajectory over a finite time window. This quantity measures how many phase-space directions are dynamically explored, rather than how many exist kinematically.

Using symplectic model order reduction and action–angle methods, I show that this minimal dimension is controlled by the number of distinct normal-mode frequencies and exhibits area-type scaling in flat space, with controlled curvature corrections. The resulting reduced dynamics also induces a systematic redundancy among apparent field modes, which become functions of a smaller set of canonical variables.

These results provide a controlled setting in which dynamical accessibility and redundancy can be analysed prior to quantisation and gravity, and may help clarify which aspects of holographic and information-theoretic constructions are already present in ordinary field dynamics.