Titles and Abstracts of invited talks

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Yasunori Nomura

Title: Quantum Gravity from a Semiclassical Perspective

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Philipp Andres Hoehn

Title: Dynamical frames in gauge theory and gravity

Abstract: Though often not spelled out explicitly, dynamical reference frames appear ubiquitously in gauge theory and gravity. They appear, for example, when constructing dressed/relational observables, describing physics relative to the frame in a gauge-invariant way. In this talk, I will sketch a general framework for constructing such frames and associated relational observables. It unifies previous approaches and encompasses the transformations relating different frame choices. In gravitational theories, this gives rise to an arguably more physical reformulation of general covariance in terms of dynamical rather than fixed frames. I will then discuss an ensuing relational form of locality, including bulk microcausality and local subsystems associated with subregions, both of which can be defined gauge-invariantly relative to a dynamical frame. In the latter case, the frame incarnates as an edge mode field, linking with recent work on finite subregions. In particular, the corresponding boundary charges and symmetries can be understood in terms of reorientations of the frame. Notably, the resulting notion of a subsystem is frame-dependent, as are therefore correlations, thermal properties and specifically entropies. I will conclude with an outlook on the quantum realm and connections with recent developments on quantum reference frames. [Based on 2206.01193, 2205.00913, JHEP 172 (2022), PRL 128 170401.]

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Pisin Chen

Title: Information loss paradox and the AnaBHEL experiment

Abstract: 40 some years since Hawking's seminal discovery, the question of whether black hole evaporation will result in the loss of information remains unresolved. An equally, if not more, challenging issue is how would the information be recovered if the unitarity is indeed preserved. So far the investigations remain essentially theoretical. It would be highly desirable if some aspects of this important issue can be revealed

through experimental means. Accelerating relativistic mirror has long been recognized as a viable setting where the physics mimics that of black hole Hawking radiation. In 2017, Chen and Mourou proposed a novel method to experimentally realize such a system by traversing an ultra-intense laser through a plasma target with a decreasing density. Based on this concept, an international AnaBHEL (Analog Black Hole Evaporation via Lasers) Collaboration was formed with the objectives of observing the analog Hawking radiation and shedding lights on the information loss paradox. In this talk, we review the physics of the information loss paradox with some new theoretical insights, and describe the vision, the design, and the progress of the AnaBHEL experiment.

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Geoff Penington

Title: TBA

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Andreas Karch

Title: "A top-down dictionary for double holography"

Abstract: "Holographic interpretations of Randall-Sundrum (RS) branes provide a laboratory to explore the way quantum information evolves in field theories coupled to gravity. Despite this importance, the holographic interpretation of RS branes in terms of a theory of gravity coupled to a CFT is rather ad-hoc. In this talk, we use top-down constructions of RS branes in order to work out a precise dictionary for this "intermediate" holographic prescription, resolving serious causality problems of the naive picture often used in the literature while preserving many of the successes of the RS construction."

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Monika Schleier-Smith

Programmable Interactions and Emergent Geometry with Atoms and Photons

Advances in engineering and probing quantum many-body systems in the laboratory open the door to experimental investigation of holographic duality. Motivated by this vision, I will report on experiments demonstrating versatile control over the graph of interactions in an array of atomic spin ensembles. By letting photons convey information between distant atoms, we access nonlocal coupling graphs, where the dependence of interactions on distance is fully programmable via the spectrum of an optical control field. We apply this method to realize and probe a toy model inspired by the p-adic AdS/CFT correspondence, in which the holographic bulk geometry is embodied by a tree graph constituting a discretization of hyperbolic space. In our experiment, the treelike bulk geometry emerges from a coarse-graining procedure

based on measured spin correlations. I will also present complementary results on engineering and detecting the spatial structure of entanglement among atomic ensembles, opening prospects for directly probing the emergence of geometry from entanglement in future work.
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Hosho Katsura

Title: Constructing frustration-free models via Witten's conjugation

Abstract:
Witten's conjugation is a powerful method to construct a family of inequivalent Hamiltonians with the same number of zero-energy ground states [1]. This method provides a means to map a complicated Hamiltonian to a simple one, in which the counting of the ground states is rather trivial. Although the method was originally introduced in the context of supersymmetric quantum mechanics, the same idea applies to frustration-free models, which are not necessarily supersymmetric. In this talk, I will show that this conjugation approach allows us to construct a family of frustration-free models starting from a simple model, e.g., the classical Ising model [2]. The method not only provides a unified framework to treat different models scattered in the literature but also allows us to construct new models with exact ground states.

[1] E. Witten, Nucl. Phys. B 202, 253 (1982).
[2] J. Wouters, H. Katsura, and D. Schuricht, SciPost Phys. Core 4, 027 (2021) [arXiv:2005.12825].

Pawel Caputa

Title: "Quantum Complexity in the Krylov basis".

Abstract: I will review a recent progress on defining a universal measure of quantum complexity based on the Krylov basis. In particular, after introducing some of the Krylov basis techniques, I will discuss the “Spread Complexity” measure for quantum states and its main properties. The talk will be based on our recent results:
https://arxiv.org/abs/2202.06957
https://arxiv.org/abs/2109.03824

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Ignacio Cirac

Title: Quantum Circuits, Cellular Automata and Tensor Networks

Abstract: Quantum computers employ quantum circuits to implement algorithms. They are composed of quantum gates that act on near neighbors according to some spatial geometry. They are particular instances of quantum cellular automata (QCA), the set of operators whose action respects both locality and causality. I will show that QCAs can be effectively represented in terms of tensor networks in any spatial dimension.
As a result, they obey an area law for the entanglement entropy they can create.
Then, I will generalize these notions in two different ways: (i) by replacing unitary operators by quantum channels, i.e., operations that do not preserve the purity of states; (ii) by including local measurements assisted by classical communication.
In the first case, the resulting operations still comply with an area law for the mutual information they can create but, in general, cannot be efficiently expressed as tensor networks. In the second, they can still give rise to unitary dynamics but cannot be described in terms of QCA in general.

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Tzu-Chieh Wei

Title: AKLT states as information processing tensor-network states and ground states of gapped Hamiltonians

Absract: Haldane's conjecture on the spectral gap of integer chains led Affleck, Kennedy, Lieb, and Tasaki (AKLT) to construct one- and higher-dimensional spin models invariant under spin rotation, where their 1D spin-1 model provided an example of a gapped isotropic chain with a unique ground state and thus supported the conjecture. These models' ground-states---the AKLT states---are among the earliest examples of tensor-network quantum states and were recognized to possess symmetry-protected topological order. In this talk, I will explain some of the interesting features of AKLT states, including the magnetic ordering/disordering, the capability for quantum computation, and the existence of nonzero spectral gap for several two- and three-dimensional AKLT models. It turns out tensor networks provide a useful tool to study many of these features.

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Robert Wald

Title:
Quantum Superpositions of Massive Bodies and Gravitationally Mediated Entanglement

Abstract:
In order to avoid contradictions with complementarity and causality in a gedankenexperiment involving a quantum superposition of a massive body, it was previously shown (in arXiv:1807.07015) that it is necessary for there to be both quantized gravitational radiation and local vacuum fluctuations of the spacetime metric We review this gedankenexperiment and the previously given "back of the envelope" arguments that resolve it. We then improve upon this analysis by providing a precise and rigorous description of the entanglement and decoherence effects (given in arXiv:2112.10798). As a by-product of our analysis, we show that under the protocols of the gedankenexperiment, there is no clear distinction between entanglement mediated by the Newtonian gravitational field of a body and entanglement mediated by on-shell gravitons emitted by the body. This suggests that Newtonian entanglement implies the existence of graviton entanglement and supports the view that the experimental discovery of Newtonian entanglement—as envisioned in proposed experiments—may be viewed as evidence for the existence of the graviton.

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Ying Zhao

Title: Collisions of localized shocks and quantum circuits

Abstract: We study collisions between localized shockwaves inside a black hole interior. We give a holographic boundary description of this process in terms of the overlap of two growing perturbations in a shared quantum circuit. The perturbations grow both exponentially as well as ballistically. Due to a competition between different physical effects, the circuit analysis shows dependence on the transverse locations and exhibits four regimes of qualitatively different behaviors. On the gravity side we study properties of the post-collision geometry, using exact calculations in simple setups and estimations in more general circumstances. We show that the circuit analysis offers intuitive and surprisingly accurate predictions about gravity computations involving non-linear features of general relativity.

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Etsuko Itou

Title: Quantum computation and tensor network analyses on the Schwinger model

Abstract: Quantum computation and tensor network have attracted attention as new computational approaches for quantum field theories with the infamous sign problem. In this talk, I will introduce some results of these methods on the

Schwinger model, which describes Quantum electromagnetic dynamics(QED) in
1+1 dimensions.

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Koji Azuma

Title:Do black holes store negative entropy?

Abstract: Bekenstein proposed that black holes should have entropy proportional to the area of their horizon in order to make black-hole physics compatible with the second law of thermodynamics. Hawking strengthened this argument by showing that black holes emit thermal radiation. As a result, they established the Bekenstein-Hawking equation. However, the heuristic picture of the microscopic process for this Hawking radiation—creation of entangled pairs of positive- and negative-energy particles—leads to an inconsistency among the first law for black holes, the conservation law for entropy, and the Bekenstein-Hawking equation. The conventional resolution of this inconsistency has been to throw Hawking's heuristic picture out as incorrect, although this heuristic has its own advantages, such as directly associating the temperature of the radiation with the surface gravity of the black hole. In this talk, we show an alternative possibility where Hawking's pair-creation picture can be kept as correct, by adding a correction term to the Bekenstein-Hawking equation. This modified equation not only reproduces the original Bekenstein-Hawking equation in the suitable limit, but also suggests that a black hole stores quantum entanglement, and its horizon area represents how many entangled Bell pairs can be distilled between the interior and exterior of the black hole. This talk is based on a joint work with Sathyawageeswar Subramanian (University of Warwick, UK) and Go Kato (National Institute of Information and Communications Technology, Japan). I also acknowledge the support, in part, from PRESTO, JST JP-MJPR1861, from CREST, JST JP-MJCR1671, from Moonshot R&D, JST JPMJMS2061, and from MEXT-JSPS Grant-in-Aid for Transformative Research Areas (A), No. 21H05183.

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Tomaž Prosen

Exactly solved models of many-body quantum chaos

I will discuss the problem of unreasonable effectiveness of random matrix theory for description of spectral fluctuations in extended quantum lattice systems. A class of locally interacting spin systems has been recently identified where the spectral form factor is proven to match with gaussian or circular ensembles of random matrix theory, and where spatiotemporal correlation functions of local observables as well as some measures of dynamical complexity can be calculated analytically. These, so-called dual unitary systems, include integrable, non-ergodic, ergodic, and generically, (maximally) chaotic cases. After reviewing the basic properties of dual unitary Floquet circuits, I will argue that correlation functions of these models are generally perturbatively stable with respect to breaking dual-unitarity, and describe a simple result within this framework.

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Francesco Buscemi

Title: Observational entropy, coarse-grainings, and Petz recovery

Abstract: Besides the quantity that is nowadays eponymously known as the von Neumann entropy, in his 1932 book von Neumann introduces also another entropic quantity, which he calls "macroscopic", arguing that it is the latter, and not the former, the relevant quantity to use when analyzing thermodynamic systems. However, for a long time, this von Neumann's "other" entropy has been largely forgotten and appeared only sporadically in the literature, overshadowed by its more famous sibling. In this talk I will discuss a recent generalization of von Neumann's macroscopic entropy, called "observational entropy", which has been argued to provide a useful measure of out-of-equilibrium thermodynamic entropy. In particular, I will explore the mathematical properties of observational entropy from an information-theoretic viewpoint, making use of recently strengthened forms of relative entropy monotonicity, approximate recovery, and Petz's transpose map. This is work in collaboration with Dominik Safranek and Joseph Schindler.

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Masaki Shigemori

Title: Fractional modes and superstrata

Abstract: Superstrata are black hole microstates that are represented by smooth horizonless solutions of classical supergravity. They are not typical microstates of a black hole ensemble because their number is insufficient for reproducing the black hole entropy. Holography suggests that typical states must involve "fractional modes" in the CFT language. Here we point out that superstrata on an orbifolded AdS space contain particular types of fractional mode, and discuss the properties of the resulting geometries.

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Časlav Brukner

Title: Quantum reference frames for indefinite space-time metrics

Abstract: The current theories of quantum physics and general relativity alone do not allow us to study situations where the gravitational source is quantum, i.e. where the space-time metric is indefinite. In my talk, I will propose a strategy to determine the dynamics of probe quantum systems in the presence of an indefinite spacetime metric, using quantum reference frame (QRF) transformations. In particular, I will establish the formalisms that allow us to move from a QRF where the metric is indefinite to a QRF where the metric is definite. Assuming the covariance of the dynamical laws under the QRF transformation
, this will transform the problem of the dynamics of probe quantum systems in indefinite

metrics into a physically equivalent problem of the dynamics in a definite metric.

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Xiao Chen

Tiitle: Measurement induced entanglement phase transition

Abstract: Monitoring a unitary quantum dynamics can induce an entanglement phase transition. In this talk, we consider two types of analytically solvable quantum circuits and provide two different physical pictures to understand this phase transition. In the quantum automaton circuit, we analyze the entanglement entropy dynamics in terms of a classical stochastic particle model and show that the entanglement phase transition belongs to the directed percolation universality class. In the large N non-unitary Schadev-Ye-Kitaev chain model, we show that the entanglement entropy can be treated as the free energy of the domain wall of a magnet and the phase transition maps to a symmetry breaking phase transition in the enlarged replica space.

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Juan Maldacena

Title : Time without a Hamiltonian, the curious case of supersymmetric extremal black holes.

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Chi Fang Chen

Title: Fast Thermalization from the Eigenstate Thermalization Hypothesis

Abstract: The Eigenstate Thermalization Hypothesis (ETH) has played a major role in explaining thermodynamic phenomena in closed quantum systems. However, no connection has been known between ETH and the timescale of thermalization for open system dynamics. We show that ETH indeed implies fast thermalization to the global Gibbs state.

The critical feature of ETH we exploit is that operators in the energy basis can be modeled by independent random matrices in a near-diagonal band. We show this gives quantum expander at nearby eigenstates of the Hamiltonian. This implies fast convergence to the global Gibbs state by mapping the problem to a one-dimensional classical random walk on the energy eigenstates. Our results explain finite-time thermalization in chaotic open quantum systems and suggest an alternative formulation of ETH in terms of quantum expanders.

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Takashi Mori

Title: Relaxation times in open quantum many-body systems

Abstract:Markovian open quantum systems display intriguing relaxation dynamics. The spectral gap of the Liouvillian characterizes the asymptotic decay rate towards the stationary state, but it is pointed out that the spectral gap does not necessarily determine the overall relaxation time [1-3]. Our understanding on the relaxation process before the asymptotically long-time regime is still limited. In this talk, I talk about our recent work [2] on the discrepancy between the relaxation time and the Liouvillian gap. It is shown that explosive large expansion coefficients, which are ubiquitous in many-body Markov processes, explain the discrepancy. I also explain our recent attempt to understand the instantaneous decay rate in the transient regime before entering the long-time asymptotic regime.

[1] M. Znidaric, Phys. Rev. E 92, 042143 (2015)

[2] T. Mori and T. Shirai, Phys. Rev. Lett. 125, 230604 (2020)

[3] T. Haga, M. Nakagawa, R. Hamazaki, and M. Ueda, Phys. Rev. Lett. 127, 070402 (2021)

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Keisuke Izumi

Title: Area inequality in weak gravity region

Abstract: Penrose gave a conjecture that, in the asymptotically flat spacetime with general relativity satisfied and with the dominant energy condition satisfied, the area of an apparent horizon is bounded by the ADM mass squared. The inequality implying this is called Penrose inequality, and it would show the maximum of entropy. On the time symmetric hypersurface (supposing its existence), this conjecture has been proved. Then, the statement is reduced to “in the asymptotically flat SPACE with NONNEGATIVE RICCI SCALAR, the area of a MINIMAL SURFACE is bounded by the ADM mass squared.” This version of Penrose inequality is called Riemannian Penrose inequality. Note that this inequality is applicable in any asymptotically flat spacetime, although then the minimal surface does not coincide with the apparent horizon.

In this talk, I will show our new result, a generalization of Riemannian Penrose inequality applicable to a surface in a weak gravity region. We introduce a parameter describing the strength of the gravitational field, and prove the inequality with the parameter. Our inequality can be applied even in the asymptotic region of space.

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Sougato Bose

Title: Quantum Coherent Nature of Gravity through a Table-Top Experiment

Abstract: We will discuss a laboratory experiment to reveal the ``qualitatively'' quantum nature of gravity. Along with justifications, we will explore a methodology and the main challenges to meet in order to make such an experiment a reality.

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Edward Witten

Title: An Algebra of Observables For De Sitter Space.

Abstract: In ordinary quantum mechanics, we can consider an observer to be external to the system being observed. In the presence of gravity, the observer inevitablygravitates and the observer is part of the system. In an open universe, the gravitation of the observer can be unimportant, but in a closed universe, it is essential to take into account the gravity of the observer. De Sitter space is a simple example of a closed universe. To define a sensible algebra of observables for de Sitter space, it is necessary to take into account the observer who is making the measurements and the gravity of this observer. When this is done, one can define avon Neumann algebra of Type II_1, which comprises the operators accessible to the observer and gives a sensible account of de Sitter entropy. Based on a recent paper with Chandrasekharan, Longo, and Penington.