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| Philippe Allard | **Observer-dependent locality of events in quantum causal structures**<br><br>The process matrix formalism was invented to describe multipartite quantum correlations, without requiring the assumption of a preexisting causal order. Certain correlations contained within the formalism are incompatible with the assumption of a causal ordering of the events – these correlations violate causal inequalities. However, the formalism offers no clue as to how one might physically realize such acausal correlations. We attempt to understand these processes in a more physical way by making an explicit connection with certain aspects of the relativistic description of causality. We associate to each event a "causal reference frame", which can be interpreted as an observer dependent time function, and relate the reference frames of different events via a consistency condition. We then show how these ideas occur concretely by discussing some examples of interesting non-causal processes. |
| Alessio Belenchia | **Entanglement Entropy for Quantum Fields on Discrete Spacetime**<br><br>In this talk the concept of Sorkin entropy, a covariant generalization of the usual entanglement entropy in QFT, will be introduced. It will then be used to show the difficulties in defining entropy when continuum spacetime is replaced by a discrete partial order, i.e., a causal set. Divergences of the entropy, related to "completely classical" components of the Wightman function, as well as the physical meaning of a double cut-off procedure leading to the expected area-law in the continuum limit, will be discussed. |
| Caslav Brukner | **Causality at the crossroad between quantum theory and gravity**<br><br>I will review recent efforts in describing causal relations in quantum mechanics and some quantum gravity scenarios within the process-matrix formalism. |
| Esteban Castro-Ruiz | **Entanglement of quantum clocks through gravity**<br><br>In general relativity, the picture of space–time assigns an ideal clock to each world line. Being ideal, gravitational effects due to these clocks are ignored and the flow of time according to one clock is not affected by the presence of clocks along nearby world lines. However, if time is defined operationally, as a pointer position of a physical clock that obeys the principles of general relativity and quantum mechanics, such a picture is, at most, a convenient fiction. Specifically, we show that the general relativistic mass–energy equivalence implies gravitational interaction between the clocks, whereas the quantum mechanical superposition of energy eigenstates leads to a nonfixed metric background. Based only on the assumption that both principles hold in this situation, we show that the clocks necessarily get entangled through time dilation effect, which eventually leads to a loss of coherence of a single clock. Hence, the time as measured by a single clock is not well defined. However, the general relativistic notion of time is recovered in the classical limit of clocks. |

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| Goffredo Chirco | **An information-theoretic toolkit for quantum geometry**<br><br>In background independent approaches to quantum gravity, the operational content of Einstein's theory, manifest in a group theoretic general covariant description of general relativity, translates into a relational and purely algebraic quantum spin-network description of spacetime geometry. The operational characterisation of the theory allows to recast the fundamental structure of Einstein's theory in information theoretic terms. Accordingly, giving primacy to such operational content rather then to spacetime geometry, a generalised quantum spin-network framework provides a concrete arena to investigate the emergence of classical spacetime geometry in terms of entanglement theory, quantum thermodynamics and resource theory. I will discuss some specific examples in this sense, based on some very recent work. |
| Will Donnelly | **Quantum gravity tomography**<br><br>In quantum gravity, information about the spacetime distribution of energy and momentum is encoded in the metric at spatial infinity via the gravitational constraints. I will show that in perturbative quantum gravity in flat spacetime, this information is sufficient to reconstruct the full quantum state of a single particle. The argument uses a relativistic generalisation of the quantum-mechanical Wigner function. Implications for resolution of the black hole information paradox via gravitational soft charges will be discussed. |
| Jens Eisert | **Holography and criticality in matchgate tensor networks**<br><br>The AdS/CFT correspondence conjectures a holographic duality between gravity in a bulk space and a critical quantum field theory on its boundary. Tensor networks - which are briefly introduced in the talk - have come to provide toy models to understand such bulk-boundary correspondences, shedding light on connections between geometry and entanglement. In this talk, we will introduce a versatile and efficient framework for studying tensor networks, extending previous tools for Gaussian matchgate tensors in 1+1 dimensions [1]. Using regular bulk tilings, we show that the critical Ising theory can be realized on the boundary of both flat and hyperbolic bulk lattices, and explain how critical data can be extracted. Within our framework, we also produce translation-invariant critical states by an efficiently contractible network dual to the multi-scale entanglement renormalization ansatz. Furthermore, we explore the correlation structure of states emerging in holographic quantum error correction. In fact, using a machinery of holographic Majorana dimer models [2], we are able to compute boundary second moments for arbitrary states within the error correcting subspace. If time allows, we will discuss further perspectives of the intersection of holography and quantum information theory, including notions of state preparation complexity in the context of holography [3,4].<br><br>[1] Holography and criticality in matchgate tensor networks, |

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| | A. Jahn, M. Gluza, F. Pastawski, J. Eisert,<br>arXiv:1711.03109 (2017).<br><br>[2] Holographic Majorana dimer models of quantum error correction,<br>A. Jahn, M. Gluza, F. Pastawski, J. Eisert,<br>in preparation (2018).<br><br>[3] Towards holography via quantum source-channel codes,<br>F. Pastawski, J. Eisert, H. Wilming,<br>Phys. Rev. Lett. 119, 020501 (2017).<br><br>[4] Circuit complexity for thermofield double states,<br>S. Chapman, J. Eisert, L. Hackl, M. P. Heller, R. Jefferson,<br>H. Marrochio, R. C. Myers, and F. Pastawski,<br>in preparation (2018). |
| Rodolfo Gambini | **An approach to the measurement problem based on quantum gravity considerations**<br><br>In a totally constrained theory as quantum general relativity a complete physical description should be given in terms of observables and relational properties among them. Time evolution may only be described in terms of quantum physical clocks. It is shown that this leads to fundamental modifications of the master equation for the evolution. Limitations in the measurement of time may help to address some of the problems posed by the use of environmental decoherence for the solution of the measurement problem in quantum mechanics. This analysis provides a criterion for the occurrence of events in quantum systems and it is known as the Montevideo Interpretation of quantum mechanics. |
| Flaminia Giacomini | **Quantum mechanics and the covariance of physical laws in quantum reference frames**<br><br>In physics, every observation is made with respect to a frame of reference. Although reference frames are usually not considered as degrees of freedom, in all practical situations it is a physical system which constitutes a reference frame. Can a quantum system be considered as a reference frame and, if so, which description would it give of the world? The relational approach to physics suggests that all the features of a system —such as entanglement and superposition— are observer-dependent: what appears classical from our usual laboratory description might appear to be in a superposition, or entangled, from the point of view of such a quantum reference frame. In this work, we develop an operational framework for quantum theory to be applied within quantum reference frames. We find that, when reference frames are treated as quantum degrees of freedom, a more general transformation between reference frames has to be introduced. With this transformation we describe states, measurement, and dynamical evolution in different quantum reference frames, without appealing to an external, absolute reference frame. The transformation also leads to a generalisation of the notion of covariance of dynamical physical laws, which we explore in the case of 'superposition of |

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| | Galilean translations' and 'superposition of Galilean boosts'. In addition, we consider the situation when the reference frame moves in a 'superposition of accelerations', which leads us to extend the validity<br>of the weak equivalence principle to quantum reference frames. |
| Daniel Grumiller | **QNEC - A Remarkable Inequality**<br><br>Inequalities are ubiquitous in mathematics and physics. Among the interesting ones are so-called energy conditions, since they seem plausible (energy is positive) and are useful (e.g. for proving singularity theorems). However, all local energy conditions are violated by quantum effects, so an intriguing question is whether or not there is some local quantum energy condition. Bousso et al recently proposed the Quantum Null Energy Condition (QNEC), conjectured to hold universally. I review basic features and holographic as well as quantum information aspects of QNEC. |
| Lucas Hackl | **Squeezed vacua in quantum gravity and field theory**<br><br>Squeezed vacua play an important role in many areas of physics. In this talk, I will focus on applications to quantum gravity and field theory, for which I will review a new formalism that treats bosonic and fermionic systems in a unified manner.<br>(1) We expect that a quantum theory of gravity contains semi-classical quantum states, that describe classical spacetimes plus quantum perturbations. Recently, it was conjectured that the area law of the entanglement entropy may provide an efficient criterion to identify such semi-classical states. I explain how this idea can be explored in loop quantum gravity by introducing a new class of states--squeezed spin network states--that satisfy the area law and have long-ranged correlations.<br>(2) We can use entanglement entropy to understand the dynamics of quantum correlations in quantum field theory. Many systems show a phase of linear growth of the entanglement entropy, which are related to instabilities in the underlying Hamiltonian. For squeezed vacua, I will present a theorem that relates the rate of entanglement growth to the Lyapunov exponents of these instabilities. This result plays an important role for quantum fields in cosmology and periodically driven Bose condensates.<br>If time permits, I will also comment on applications of squeezed vacua to define adiabatic vacua in cosmology and study circuit complexity of quantum field theory states. |
| Felix Haehl | **Emergence of gravitational dynamics from entanglement in CFT**<br><br>I will report on recent progress in seeing the emergence of local bulk dynamics in anti de Sitter (AdS) spacetime from perturbations of entanglement entropy in conformal field theory (CFT). I will explain how the entanglement entropy of ball-shaped regions can always be represented geometrically (via the Ryu-Takayanagi formula) by an Anti-de Sitter (AdS) geometry. I will argue that such a geometry necessarily satisfies Einstein's equations perturbatively up to second order. While this is motivated by AdS/CFT, the derivation does not assume the duality, and hence provides a window into a universal sector of |

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| | bulk emergence. I will also mention generalizations to higher curvature theories and to states with more complicated entanglement structure in the bulk, thus leading to the emergence of quantum corrections. |
| Michal Heller | **New results on QFT complexity**<br><br>Motivated by holographic complexity proposals, I will discuss complexity in free systems for pure and mixed states. I will primarily focus on time-dependent setups, which include time evolution of thermofield double states and quantum quenches. |
| Marcus Huber | **Thermodynamic limitations to quantum measurements and clocks**<br><br>While quantum mechanics assumes a continuous parameter t driving the reversible time evolution of quantum systems, it is not a direct observable. We can only indirectly infer this parameter through operational definitions, such as operational time being defined through what a clock measures. But, in a universe with a non-zero temperature background, idealised quantum measurements are just as impossible as ideal quantum clocks. Indeed, the only operational way to measure time, or any quantum system, is through harnessing out-of-equilibrium resources, i.e. spending thermodynamic work to implement that measurement. In this talk we show how the work cost of quantum measurements and quantum clocks diverges as the quality of the measurement increases. |
| Ted Jacobson | **What is the black hole information paradox?**<br><br>Much thought has been devoted to solving the black hole information problem. I'll argue that almost none of it has been asking the right question, and will explain how (what I believe is) the right question is inextricably tied up with the implications of diffeomorphism symmetry for the nature of states and observables in quantum gravity. Moreover, I'll argue that the paradox isn't really about black holes, and will present a toy model illustrating a schema for its resolution. |
| Achim Kempf | **Stone age tools for quantum gravity**<br><br>The development of relativity and of quantum theory each required the abandonment of concepts that had previously widely been considered self-evident. In the century since, the tremendous level of difficulty that has been encountered in approaches to quantum gravity indicates that it will again be necessary to challenge long-held concepts, presumably concepts that sit deep and go a long way back. The difficulty is, of course, to know how deep to dig or how far back in time to search for the origins of the misconceptions that may need to be overcome. Some conceptual tools from the stone age that we still use in physics today, such as the barbed arrow to indicate maps, are probably fine. I will discuss that others, such as the measuring stick, may need to be replaced, for example, by the notion of the correlation strength of vacuum fluctuations. |

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| Etera Livine | **Spin networks: from quantum gravity to quantum information**<br><br>I will introduce the spin network states for the quantum geometry in loop quantum gravity, presenting both their interpretation as discrete geometries and quantum circuits. In the context of the interplay between coarse-graining quantum gravity, the quantum geometry dynamics and holograpy, we'll describe the structure of entanglement on spin networks and the possibility for holographic spin network states. We'll conclude on a discussion about the dynamics and decoherence of boundary states in quantum gravity. |
| Markus Müller | **Quantum theory and the structure of spacetime in the light of operationalism**<br><br>Some approaches to quantum gravity promote the idea that spacetime can ultimately be reconstructed from the structure of (some underlying) quantum theory. In this talk, I sketch a research program that aims at studying aspects of this idea without committing to a particular model or ansatz. Namely, simple thought experiments of communicating observers, based only on what we currently know about physics, can shed light on the structural relation between quantum theory and spacetime — in both directions.<br>I will first present a simple thought experiment that shows how relativity of simultaneity constrains the structure of the quantum bit, without assuming the validity of quantum theory from the outset [1]. Then I will show that this kind of reasoning can be extended and reversed: if we assume the validity of quantum theory and the existence of certain types of “universal measurement procedures” (but make no assumptions about spacetime), then observers will automatically relate their descriptions of local laboratory physics by elements of the Lorentz group SO(3,1) [2]. Thus, taking the question of “how observers operate in a quantum world” seriously can help illuminate the relation between two seemingly separate aspects of physics.<br><br>[1] A.J.P. Garner, M.P. Mueller, and O. C. O. Dahlsten, The complex and quaternionic quantum bits from relativity of simultaneity on an interferometer, Proc. R. Soc. A 473, 20170596 (2017); arXiv:1412.7112<br>[2] P.A. Hoehn and M.P. Mueller, An operational approach to spacetime symmetries: Lorentz transformations from quantum communication, New J. Phys. 18, 063026 (2016); arXiv:1412.8462 |
| Jonathan Oppenheim | **Are there additional laws of black hole thermodynamics**<br><br>Recently, it has been shown that for out-of-equilibrium systems, there are additional constraints on thermodynamical evolution besides the ordinary second law. These form a new family of second laws of thermodynamics, which are equivalent to the monotonicity of quantum Rényi divergences. In black hole thermodynamics, the usual second law is manifest as the area increase theorem. Hence one may ask if these additional laws imply new restrictions for gravitational dynamics, such as for out-of-equilibrium black holes? After a review of these recent results from thermodynamics, we show that the Rényi divergence can be computed via a Euclidean path integral for a certain class of states. One can then study these second laws for CFTs, and using the AdS/CFT |

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| | conjecture, explore what they might mean for black holes.<br>Based on: arXiv:1803.03633 |
| Daniele Oriti | **Quantum gravity and tensor networks: first contacts**<br><br>I illustrate how quantum gravity states as appearing in group field theory and loop quantum gravity can be understood as generalised tensor networks, endowed with a local (gauge) invariance. Given this correspondence, group field theory models can be seen as defining a probability measure for random tensor networks, and, conversely, random tensor network techniques can be applied in a quantum gravity context. In particular, I present some results in the calculation of entanglement entropy for quantum gravity states, using tensor network techniques, and towards a full quantum gravity realization of the Ryu-Takayanagi entropy formula. |
| Federico Piazza | **Regions of space as quantum subsystems**<br><br>Recent insights from AdS/CFT suggest quantum entanglement at the very origin of spacial "connection" and therefore of the geometrical description of physical events.<br>I will review some—more pedantic and prosaic — proposals of more than a decade ago in the same directions, and how regions of space can be consistently described as subsystems in field theory and in the absence of gravity.<br>Some recent results will be also discussed. |
| Sukhi Singh | **Holographic spin networks from tensor network states**<br><br>The multi-scale entanglement renormalization ansatz (MERA) is a successful tensor network description for ground states of quantum critical systems. The latter are effectively described by conformal field theory (CFT) in the continuum, and it has recently been proposed that the MERA may be some sort of discrete realization of the AdS/CFT correspondence. Though how the MERA representation of a critical ground state could possibly encode a dual bulk state in one higher dimension is still an open question.<br><br>In this talk, I will introduce a candidate dual bulk state from the MERA representation of a critical ground state, guided primarily by a rule of thumb in AdS/CFT, namely, a global symmetry at the boundary appears gauged in the bulk. Applying a known procedure of directly gauging symmetries in tensor network states greatly constraints the structure of the bulk state. I will describe how the dual bulk state so obtained exhibits other interesting features, some of which are reminiscent of known properties of AdS/CFT.<br><br>Based on:<br>1) SS, "Tensor network state correspondence and holography", Phys. Rev. D 97, 026012 (2018).<br>2) SS, N. McMahon, and G. Brennen, "Holographic spin networks from |

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| | tensor network states", Phys. Rev. D 97, 026013 (2018). |
| Frank Verstraete | **Geometry and entanglement renormalization of quantum many body systems**<br><br>Abstract: TBA |