The University of Nottingham
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FGI

Quantum Fields, Gravity and Information

Joint Efforts and New Directions in Mathematical Physics

Highfield House, University of Nottingham
3-5 April 2013

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IOP Institute of Physics
Gravitational Physics Group
Mathematical and Theoretical Physics Group
Quantum Optics, Quantum Information and Quantum Control Group

Institute of mathematics & its applications

Welcome

Welcome everyone! We are pleased to have you all here in Nottingham.

As you know, this conference was designed to bring together postgraduate researchers from inside and outside the UK to exchange ideas on the mathematical aspects of relativistic quantum physics. A special focus of this workshop lies on relativistic quantum information, a young field which combines techniques from quantum field theory, quantum gravity, quantum information and quantum optics. We hope the morning lectures will help everyone engage with fields that might not be exactly their own.

Don't hesitate to get in touch with any of us if there's something you need. That's what we're here for.

David, Nicolai, Antony and Sara

Funding

We gratefully acknowledge funding from a Scheme 8 Grant of the **London Mathematical Society** without which this meeting would not be held. We also thank the **CAP** research network and the **Science and Technology Facilities Council** who helped us make this meeting truly international. We further thank the **Edinburgh Mathematical Society** and the **Institute of Mathematics & its Applications** for their generous support. Finally we cannot forget the **Institute of Physics** sponsorship through three of its groups: Gravitational Physics, Mathematical and Theoretical Physics, and Quantum Optics, Quantum Information and Quantum Control.

Acknowledgements

We acknowledge the support of the administrative team at Nottingham, particularly Mrs Andrea Blackbourn and Dr David Hawker. We reserve a special thanks to Prof David Riley and Dr Jorma Louko who provided guidance and support throughout the months of preparation for this workshop. Finally, we cannot forget the RQI local group to which we are grateful for all the advice, support and for sponsoring our conference prize.

Programme

The conference will be held on the University Park Campus of the University of Nottingham, beginning with registration at 8.00 on Wednesday 3rd of April and finishing at 18.15 on Friday 5th of April. The full programme is below. All talks will take place in Highfield House (10 on the back cover map), Seminar Room A11. Posters will be displayed in the building's cloisters, where lunches and refreshments will also be served.

Wednesday 3 April

8.00	Registration and Welcome	
9.00	**Ivette Fuentes** (Nottingham)	***Quantum information processing in spacetime***
11.00	Tea/Coffee Break	
11.30	**Bob Coecke** (Oxford)	***Quantum Information Flow (Part I)***
12.30	Lunch Break	
14.00	Valentina Baccetti (Wellington)	*Clausius entropy for bifurcate null surfaces*
14.20	Tanapat Deesuwan (Imperial)	*On heat in a quantum mechanical process*
14.40	Hal Haggard (Marseille)	*Death and resurrection of the zeroth principle of thermodynamics*
15.00	Questions	
15.15	Michel Buck (Imperial)	*Physical and unphysical interventions on quantum fields*
15.35	Veiko Palge (Leeds)	*Generation of maximally entangled states with sub-luminal Lorentz boosts*
15.55	Dominic Hosler (Sheffield)	*Parameter estimation using NOON states over a relativistic quantum channel*
16.15	Questions	
16.30	**Poster Session** (Refreshments served)	
	Mohammed Akram Fellah (Annaba)	*Perturbative renormalization and cosmology in Horava-Lifshitz gravity*
	Jack Binysh & Felix Pollock (Oxford)	*Twisted Correlations from Acceleration*
	Fabio Costa (Vienna)	*Quantum correlations with no causal order*
	Vedran Dunjko (Edinburgh)	*Composability of secure delegated quantum computation*
	Joel Lindkvist (Chalmers)	*Relativistic motion of cavities in circuit QED*
	Christiana Panayi (Leeds)	*Measurement-Device-Indep. Q. Key Distribution with Realistic Q. Memories*
	Magdalena Zych (Vienna)	*General relativistic effects in quantum interference of "clocks"*
18.30	Close	

Thursday 4 April

9.00	**Tim Ralph** (Brisbane)	***Quantum Optics on Curved Space-Time***
11.00	Tea/Coffee Break	
11.30	**Bob Coecke** (Oxford)	***Quantum Information Flow (Part II)***
12.30	Lunch Break	
14.20	Miriam Backens (Oxford)	*The ZX-calculus is complete for stabilizer quantum mechanics*
14.40	Rui Soares Barbosa (Oxford)	*Structural reason for monogamy and local macroscopic correlations*
15.00	Questions	
15.15	Christoph Spengler (Innsbruck)	*Composite parameterization and Haar measure for all unitary and special unitary groups*
15.35	Michael Skotiniotis (Innsbruck)	*Quantum frameness for charge-parity-time inversion symmetry*
15.55	Sergii Strelchuk (Cambridge)	*Entanglement recycling and generalized teleportation*
16.15	Questions	
16.30	Tea/Coffee Break	
17.00	Benjamin Lang (York)	*A Hitchhiker's Guide to Quantum Field Theory*
17.20	Shane Mansfield (Oxford)	*Are observable properties physical?*
17.40	Emanuele Levi (London)	*Entanglement entropy in integrable quantum field theory*
18.00	Questions	
18.15	Close	

Friday 5 April

9.00	**Etera Livine** (Lyon)	***Loop Quantum Gravity and Spinor Networks***
11.00	Tea/Coffee Break	
11.30	Raphael Lopes (LCF)	*An acoustic analogue to the dynamical Casimir effect*
11.50	Marcilio Santos (Aberdeen)	*Towards quantum gravity measurement by cold atoms*
12.10	Questions	
12.20	Lunch Break	
14.00	Ricardo Camões de Oliveira (Nottingham)	*EPRL/FK asymptotics and the flatness problem*
14.20	Nadish de Silva (Oxford)	*Extensions: from classical to noncommutative*
14.40	Philipp Köhler (Vienna)	*Physics on the boundary between quantum mechanics and general relativity*
15.00	Questions	
15.15	Jos Gibbons (York)	*Does cosmological particle creation alter the emission process by a local source?*
15.35	Miguel Montero Muñoz (Madrid)	*Wavepacket detection with the Unruh-DeWitt model*
15.55	Questions	
16.05	Coffee Break	
16.35	Benito Alberto Juarez Aubry (Nottingham)	*Detector for a massless (1+1) field: Hawking effect without infrared sickness*
16.55	Luis C. Barbado (Granada)	*Hawking radiation as perceived by different observers*
17.15	Questions	
17.25	**Goodbye** (Tea/Coffee served)	
18.15	Close	

Abstracts

Introductory Lectures

Bob Coecke (University of Oxford, UK)
Quantum Information Flow

Much of the mathematics of quantum information can be cast in terms of symmetric monoidal categories (SMCs), which themselves admit a sound and faithful diagrammatic calculus [1-3]. For important fragments of the Hilbert space formalism [1,4,5], this calculus is complete [6-7], that is, whatever can be proven using the Hilbert space formalism can be proven diagrammatically. We will explain this language on several important examples from quantum information. We also show how SMCs already carry a shadow of causal structure [8], and explain the connection between the diagrammatic formalism and topological quantum field theories [9].

[1] Abramsky and Coecke, A categorical semantics of quantum protocols, Proc. of 19th IEEE conf. on Logic in Comp. Sci., (IEEE Press, 2004)
[2] Coecke, Quantum picturalism, Contemporary Physics 51, 59 (2010), e-print arXiv:0908.1787 (2009)
[3] Coecke, The logic of quantum mechanics - Take II, arXiv:1204.3458 (2012)
[4] Coecke and Duncan, Interacting quantum observables, Proc. of the 35th ICALP, Lecture Notes in Comp. Sci. 5126 (Springer, Berlin, 2008)
[5] Coecke and Duncan, Interacting Quantum Observables: Categorical Algebra and Diagrammatics, New J. Phys. 13, 043016 (2011)
[6] Selinger, Finite dimensional Hilbert spaces are complete for dagger compact closed categories, Elect. Notes in Theo. Comp. Sci. 270, 113 (2011)
[7] Backens, The ZX-calculus is complete for stabilizer quantum mechanics, e-print (2012).
[8] Coecke, A Universe of Processes and Some of its Guises, Deep Beauty: Underst. the Quant. World through Math. Innov., Halvorson (CUP, 2010)
[9] Baez and Dolan, Higher-dimensional algebra and topological quantum field theory, J. Math. Phys. 36, 6073 (1995)

Ivette Fuentes (University of Nottingham, UK)
Quantum information processing in spacetime

Cutting-edge experiments in quantum communications are reaching regimes where relativistic effects can no longer be neglected. For example, there are advanced plans to use satellites to implement teleportation and quantum cryptographic protocols. Relativistic effects can be expected at these regimes: the Global Positioning System (GPS), which is a system of satellites that is used for time dissemination and navigation, requires relativistic corrections to determine time and positions accurately. Therefore, it is timely to understand what are the effects of gravity and motion on entanglement and other quantum properties exploited in quantum information. In these lectures I will show that entanglement can be created or degraded by gravity and non-uniform motion. While relativistic effects can degrade the efficiency of teleportation between moving observers, the effects can also be exploited in quantum information. I will show that the relativistic motion of a quantum system can be used to perform quantum gates. Our results, which will inform future space-based experiments, can be demonstrated in table-top experiments using superconducting circuits.

Etera Livine (École Normale Supérieure de Lyon, France)
Loop Quantum Gravity and Spinor Networks

I will review the basics of loop quantum gravity and spinfoam models. Loop quantum gravity proposes a background independent framework for quantum gravity and geometry and defines quantum states of space geometry - the spin networks. Then spinfoam models define their transition amplitude from a discretized path integral for general relativity formulated as an "almost-topological" field theory. I will further review the main results of the spinfoam framework, about the link with Regge calculus at large scale and the computation of correlations such as the graviton propagator. After this introduction, I will show how to understand the geometry of spin networks in terms of classical spinor networks and twisted geometries representing polyhedra loosely glued together. I will explain the applications of this formulation to coarse-graining quantum states of geometry, to black hole entropy and to the development of cosmological toy models of loop gravity. I will conclude with the recent work towards the continuum regime (at large scale) of spinfoams and loop quantum geometry through the analysis of the renormalisation of tensor models (and group field theory).

Tim Ralph (University of Queensland, Brisbane, Australia)
Quantum Optics on Curved Space-Time

Quantum optics has been incredibly successful in describing and testing fundamental effects in quantum mechanics that once had the status of "thought experiments". An impressive array of theoretical tools and experimental techniques have been built up over the past few decades. An exciting new quest is to use quantum optics to explore and test the principles of relativistic quantum field theory. In the first lecture I will introduce quantum optical techniques and look at some simple examples of situations in which general relativistic and quantum effects occur simultaneously. In my second lecture I will discuss the problems of communication between non-inertial observers and extracting vacuum entanglement.

Contributed Talks and Poster Presentations

Mohammed Akram Fellah (Badji Mokhtar University, Annaba, Algeria)

Perturbative renormalization and cosmology in the Horava-Lifshitz gravity (Poster)

In this poster, we aim to conduct an in-depth study of a novel gravitational theory which goes under the name of Horava-Lifshitz gravity. The main thrust of the research will be to exhibit the claimed renormalizability of this theory explicitly either in renormalized perturbation theory or using the non-perturbative renormalization group. The second goal is to formulate cosmological models as well as quantum cosmology based on this new theory of gravity, and to pin down precisely the relationship of this gravity to Lifhsitz field theory. We will also try to formulate Horava-Lifshitz gravity in 2 and 3 dimensions and investigate their connections to topological field theory and matrix models.

Valentina Baccetti (Victoria University of Wellington, New Zealand)

Clausius entropy for bifurcate null surfaces (Talk)

A crucial question that has been recently at the center of heated debates is the objective reality of entropy or its possible observer-dependence. Part of such an ambiguity is due to the several definitions of entropy present in the literature, and the extent to which they may be considered as equivalent. This question is particularly pressing when it comes to understanding Bekenstein entropy. In this talk we shall address such a question by exploring the nature of the Clausius entropy for a bifurcate null surface. In particular we shall demonstrate that one can assign a notion of differential Clausius entropy to the matter crossing a bifurcate null surface, therefore defining a “virtual Clausius entropy” for an arbitrary “virtual causal horizon”.

Miriam Backens (University of Oxford, UK)

The ZX-calculus is complete for stabilizer quantum mechanics (Talk)

The ZX-calculus is a graphical formalism for categorical quantum mechanics. It is known to be universal and sound for pure state quantum mechanics. Focussing on the fragment of the calculus representing pure stabilizer quantum mechanics, we introduce a normal form for diagrams based on graph states and local Clifford operations. The normal form is not unique, but it does allow equality of diagrams to be tested easily. From this we deduce that the ZX-calculus is complete for stabilizer quantum mechanics.

Luis C. Barbado (Instituto de Astrofisica de Andalucia, Granada, Spain)

Hawking radiation as perceived by different observers (Talk)

In this talk, I will introduce a method for studying the perception of Hawking radiation by different observers outside a black hole, and for different vacuum states of the radiation field. The analysis is performed in terms of an effective-temperature function that varies along the trajectory of each observer. Among other results, I will show that it is not necessary to strictly form an horizon for obtaining Hawking radiation; Not all observers crossing the horizon of a black hole in free-fall will fail to detect radiation; The radiation temperature perceived by a generic observer outside the black hole (when it is possible to talk about a temperature) can be calculated directly from the local characteristics of its trajectory in a way which has a clear physical interpretation.

Jack Binysh (University of Oxford, UK)

Twisted Correlations from Acceleration (Poster, together with Felix Pollock)

The twist is a SLOCC-invariant measure of the asymmetry of bipartite correlations in a multi-partite quantum state. We investigate how such asymmetries can arise between photon modes in a cavity which has undergone a period of constant acceleration. In addition, we consider how correlations can build up between different spatial regions within the cavity for different initial states.

Michel Buck (Imperial College London, UK)

Physical and unphysical interventions on quantum fields (Talk)

When we use relativistic quantum fields in information processing schemes, an important question is: which types of interventions are physically possible? We consider a sequence of interventions on a scalar field in a relativistic spacetime to investigate this question. We find that the ideal measurement of a wave packet state in flat spacetime leads to a violation of relativistic causality. The result holds for a measurement that takes place over an intervention region in spacetime whose extent in time in some frame is longer than the light crossing time of the packet in that frame. We will discuss some consequences of this result.

Ricardo Camões de Oliveira (University of Nottinhgam, UK)

EPRL/FK asymptotics and the flatness problem (Talk)

Since the introduction of the EPRL/FK spin foam model, one of the highest priorities in its study has been to obtain a semiclassical limit and compare it to what is expected from General Relativity, more specifically its discrete version in Regge calculus. While some promising results were obtained, mostly in the form of the "reconstruction theorem" which maps an asymptotic spin foam configuration to a geometric triangulated manifold, several issues have arisen. Important ones are the lack of triangulation independence in the full theory and the "flatness problem", which is a claim that the reconstructed triangulated manifolds are restricted to be Regge-flat. We discuss several considerations on the model's asymptotics and the aforementioned issues, illustrated by example computations on small triangulated manifolds.

Fabio Costa (University of Vienna, Austria)

Quantum correlations with no causal order (Poster)

The correlations considered in quantum mechanics are typically assumed to arise from operations performed at specific space-time locations. This assumption puts restrictions on the possibility of signalling: no signal can be exchanged between space-like separated observers, while time-like separation allows signalling only in one direction, from the past to the future. We pose the question whether the observed causal order between events is a necessary element of quantum theory. We first develop a formalism for multipartite quantum correlations that does not assume any underlying space-time or causal structure, but only that local agents are free to perform arbitrary quantum operations. All known situations, including non-signalling correlations between space-like separated observers, signalling ones between observers connected by a channel, as well as probabilistic mixtures of these, can be expressed in this formalism. We show that there exist situations allowed by the formalism where two experiments are neither causally ordered nor in a mixture of causal orders.

Nadish de Silva (University of Oxford, UK)

Extensions: from classical to noncommutative (Talk)

I will define the elementary concept of an extension of a topological functor which is a method of taking functors defined on topological spaces (i.e. classical state spaces or, dually, commutative algebras of observables) and systematically producing functors on noncommutative algebras. It is shown that these extensions provide elegant restatements, and conceptual insight, into the Kochen-Specker theorem and Gleason's theorem, e.g, the extension of classical probability distributions yields the quantum state space. Progress on defining noncommutative geometric invariants such as K-theory as extensions of their topological counterparts will be reported. I will discuss noncommutative geometry as well as the topos approach to quantum mechanics, two directions taken in quantum gravity research, and how this work connects ideas from both.

Tanapat Deesuwan (Imperial College London & UCL, UK)

On heat in a quantum mechanical process (Talk)

Heat is the portion of energy exchange between systems in thermodynamic process which, unlike work, is always associated with the change of the entropies of the systems. In the context of quantum thermodynamics, heat process is described by an incoherent generalised quantum evolution, which is a map between two quantum states that does not preserve the entropy. Based on an information-theoretic reasoning, we propose that heat involving in a general quantum thermodynamic process can be separated into two types: one that is due to the unital subclass of the evolutions and another one that is due to the others. According to these categories, we show how the former type of heat can be incorporated into Jarzynski equality, resulting in a generalised version of the equality. We also derive a Jarzynski inequality which incorporates all heat into the picture and show that this situation is just equivalent to the presence of Maxwell's demon as presented in.

Vedran Dunjko (University of Edinburgh, UK)

Composability of secure delegated quantum computation (Poster)

Delegating difficult computations to remote large computation facilities, with appropriate security guarantees, is an important solution for the ever-growing needs for personal computing power. For delegated computation protocols to be usable in a larger context (or simply to run two protocols in parallel) the security definitions need to be composable. Here, we define composable security for delegated quantum computation, and prove that several known protocols are composable, including Broadbent, Fitzsimons, Kashefi's Universal Blind Quantum Computation protocol.

Jos Gibbons (University of York, UK)

Does cosmological particle creation alter the emission process by a local source? (Talk)

It has long been known that cosmological expansion creates particles. One might expect that the presence of these particles would alter the emission and absorption processes of a local source. There are two important cases to consider, one in which the source back-reacts and one in which it does not because it is classical. If the source is classical, one can readily show the spectrum of emitted particles is the same with or without cosmologically created particles. (The case without them can be calculated in classical field theory.) In the interaction picture, this agreement is apparently due to interference between the classical source’s absorption and emission processes; this coherent case is amenable to an exact calculation we present. The absorption and emission processes instead decohere if the emitter back-reacts. The natural question is whether for a back-reacting source the spectrum of emitted particles remains the same under decoherence. We have computed the decoherent case to lowest non-trivial order, and have found that the spectrum with cosmologically created particles still agrees with that obtained without them. We are investigating whether this agreement persists to all orders. It is conjectured it does, and our sketch proof proposes a mathematically simple reason why this occurs, which does not require an explicit calculation of the terms introduced at each order.

Hal Haggard (Centre de Physique Théorique, Marseille, France)

Death and resurrection of the zeroth principle of thermodynamics (Talk)

The zeroth principle of thermodynamics in the form "temperature is uniform at equilibrium" is notoriously violated in relativistic gravity. Temperature uniformity is often derived from the maximization of the total number of microstates of two interacting systems under energy exchanges. Here we discuss a generalized version of this derivation, based on informational notions, which remains valid in the general context. The result is based on the observation that the time taken by any system to move to a distinguishable (nearly orthogonal) quantum state is a universal quantity that depends solely on the temperature. At equilibrium the net information flow between two systems must vanish, and this happens when two systems transit the same number of distinguishable states in the course of their interaction.

Dominic Hosler (University of Sheffield, UK)

Parameter estimation using NOON states over a relativistic quantum channel (Talk)

We study the effect of communication with an accelerated observer on the parameter estimation of a quantum state. An inertial observer, Alice, prepares a parameterized state which she then sends to an accelerated observer, Rob, using Unruh modes of a quantum field. We calculate the Fisher information of the state Rob receives to find the amount of information he can extract about the parameter. We find the counter-intuitive result that the single rail encoding outperforms the dual rail. Using NOON states, there is an optimal N for maximum information extractable by Rob, contradicting the standard notion that a higher N performs better. This optimal N decreases with increasing noise.

Benito Alberto Juarez Aubry (University of Nottingham, UK)

Detector for a massless (1+1) field: Hawking effect without infrared sickness (Talk)

We modify the Unruh-DeWitt particle detector by coupling the detector's monopole moment to the derivative of a (1+1)-dimensional scalar field, rather than the field itself. We show that issues of time-dependency in the trajectory, the quantum state and the switching can be handled within first-order perturbation theory essentially as for a non-derivative coupling in 3+1 dimensions. Crucially, we present evidence that the detector remains well-behaved in the limit of a massless field, despite the divergence in the two-point function, and we use the detector to analyse the onset of the Hawking and Unruh effects in strongly time-dependent situations.

Philipp Köhler (University of Vienna, Austria)

Physics on the boundary between quantum mechanics and general relativity (Talk)

The last century in physics was governed by two highly successful theories, namely quantum mechanics and general relativity. Both of these theories had tremendous influence not only in the realm of physics but also in fundamental philosophical questions, such as the nature of time or the meaning of reality. Both of these theories are well tested within their regimes. However, basic concepts of these theories are not compatible. Thus, a combination of those two theories has not been accomplished as of yet. This is not only due to the partly contradictory predictions but also to an absence of experiments within regimes, where both theories have to be taken into account. One starting point for an investigation is to describe the transition from quantum mechanics to classical physics. There is lots of models that try to predict quantum mechanical behaviour in macroscopic system, so called collapse models, to account for the fact that quantum mechanics seems to be absent in our everyday world. One prominent model is that of Penrose, which states that gravitational influences may be responsible for decoherence effects that annihilate quantum superpositions at certain mass scales. Another aspect is the localization of a macroscopic object. Following Diosi, and again Penrose, this localization can also be related to a gravitational effect, which directly modifies the Schrödinger equation. In this talk I want to present why it might be a good idea to have a closer look at these models, as well as the difficulties that one encounters in them. Also, we will look at possible regimes for experiments in which these models may give new predictions.

Benjamin Lang (University of York, UK)

A Hitchhiker's Guide to Quantum Field Theory (Talk)

Despite its great and recent successes, quantum field theory is far from being a mathematical sound or well-understood theory. In this talk, I aim to talk about the framework of quantum field theories rather than discussing a specific model. In doing so, I will present the algebraic approach due to R. Haag and D. Kastler as well as the locally covariant approach due to R. Brunetti, K. Fredenhagen and R. Verch, which both have led to major progresses.

Emanuele Levi (City University London, UK)

Entanglement entropy in integrable quantum field theory (Talk)

In the first part of this talk I will review the motivations and methods used in the study of entanglement entropy in two dimensional QFT. I will focus particularly on the connections between two dimensional QFT and one dimensional quantum lattice systems (e.g. quantum spin chains) near criticality. I will then present the main results achieved by my collaborators and me in the context of CFT and integrable QFT. I will eventually give numerical evidence of the results obtained so far in massive QFT.

Joel Lindkvist (Chalmers University of Technology, Gothenburg, Sweden)

Relativistic motion of cavities in circuit QED (Poster)

Relativistic quantum information typically deals with cavities accelerating and moving in the relativistic regime. Naturally, testing the various predictions experimentally with massive accelerated cavities is extremely difficult. In the field of circuit quantum electrodynamics (circuit QED), superconducting circuits are used to study quantum optics in the microwave regime. In these systems, a coplanar waveguide terminated at both ends works as a one dimensional cavity where photons can be stored. Terminating the waveguide using superconducting quantum interference devices (SQUIDs), the effective positions of the cavity walls can be modified by tuning the external magnetic fluxes in the system. Physically, the magnetic flux through the SQUID loops determines their effective inductances, which translates to an effective length through the characteristic inductance per unit length of the waveguide. This setup was recently used to demonstrate the dynamical Casimir effect [1]. Rapidly tuning the fluxes, a system equivalent to a relativistically moving cavity can be designed, enabling us to experimentally study phenomena in relativistic quantum information. Recently a proposal for studying relativistic quantum teleportation in circuit QED was made [2] and in this poster I will briefly discuss a demonstration of the twin paradox using a similar setup.

[1] Wilson *et al*, Observation of the dynamical Casimir effect in a superconducting circuit, Nature 479 (2011).
[2] Friis *et al*, Relativistic Quantum Teleportation with superconducting circuits, to appear in Phys. Rev. Lett. 110 (2013), e-print arXiv:1211.5563.

Raphael Lopes (LCF, Institut d'Optique, Palaiseau, France)

An acoustic analogue to the dynamical Casimir effect (Talk)

In this talk we'll present an analog to the dynamical Casimir effect in a metastable helium Bose-Einstein condensate. By changing the trap stiffness, we change the atomic density thereby modulating the speed of sound in our cloud. This modulation induces elementary excitations, both particle-like and phonon-like, that we detect after time of flight due to our single atom detection. We demonstrate that the excitations are pairwise, that each excitation is correlated with its pair and that for a well-defined modulation frequency, the excitation frequency is half that of the trap modulation frequency.

Shane Mansfield (University of Oxford, UK)

Are observable properties physical? (Talk)

A recent result from Pusey, Barrett and Rudolph gives an argument for the reality of the quantum wavefunction. We consider the question of whether the observable properties of a quantum system can be considered physical in a similar sense. This also provides a novel viewpoint on the Bell and EPR theorems.

Miguel Montero Muñoz (Universidad Autónoma de Madrid, Spain)

Wavepacket detection with the Unruh-DeWitt model (Talk)

In its original formulation as a point-like detector, the Unruh-DeWitt model has been used to study extensively the physics of quantum fields in presence of accelerations or curved backgrounds. Natural extensions of the model have tried to take into account the spatial profile of such detectors but all of them show some properties in their spectral response which render them not quite useful to study some of the most interesting physical scenarios. In this talk we will review the spectral response of spatially smeared Unruh-DeWitt detectors, discuss the kind of spatial profiles which can be especially useful in relativistic quantum information, and establish under which circumstances the Unruh-DeWitt model can be effectively used to describe two-level atoms interacting with the EM field.

Veiko Palge (University of Leeds, UK)

Generation of maximally entangled states with sub-luminal Lorentz boosts (Talk)

Quantum entanglement is widely held to be the crucial feature that discriminates between quantum and classical physics; it is also at the heart of quantum information theory. While most of the theory of entanglement is non-relativistic, a complete account of entanglement requires that we understand its behaviour in the relativistic regime. Studies in relativistic quantum information have found that in contrast to non-relativistic regime, single and two particle entanglement becomes an observer dependent phenomenon when viewed from different Lorentz boosted frames. Recent work has also investigated entanglement between the spin and momentum components of a single particle and showed that it reaches a maximum value only when boosts approach the speed of light. In this paper, however, we demonstrate that maximal entanglement can be obtained for realistic quantum states with boosts less than the speed of light. We furthermore show that this behaviour can be given a natural geometric explanation.

Christiana Panayi (University of Leeds, UK)

Measurement-Device-Independent Quantum Key Distribution with Realistic Quantum Memories (Poster)

Quantum memories are used to improve the rate-versus-distance behaviour in measurement-device-independent quantum key distribution (QKD) systems. By relying on entanglement swapping techniques, which can be performed by any untrusted parties, such systems are immune to detection loopholes and offer a practical approach to secure communications. Here, we present a secret key rate analysis, when quantum memories are employed before the entanglement-swapping stage. Our analysis accounts for various sources of imperfections in the system and in the quantum memory units. The required specifications in term of reading and writing times for such memories, as well as their coherence times, are obtained. We show that the faster the access times are, the higher the repetition rates and the lower the required coherence times would be. As opposed to being mainly distance dependent in quantum repeaters, the required coherence time for quantum memories, in our protocol, is proportional to memories' access times. This has the prospect of implementing QKD systems, with current growing technology for quantum memories that beat, in rate and distance, existing QKD setups.

Felix Pollock (University of Oxford, UK)

Twisted Correlations from Acceleration (Poster, together with Jack Binysh)

The twist is a SLOCC-invariant measure of the asymmetry of bipartite correlations in a multi-partite quantum state. We investigate how such asymmetries can arise between photon modes in a cavity which has undergone a period of constant acceleration. In addition, we consider how correlations can build up between different spatial regions within the cavity for different initial states.

Marcilio Santos (University of Aberdeen, UK)

Towards quantum gravity measurement by cold atoms (Talk)

We propose an experiment for the measurement of gravitational effect on cold atoms by applying a one-dimensional vertically sinusoidal oscillation to the magneto-optical trap, and observe the signature of low quantum energy shift of quantum-bound states as a consequence of gravitational fluctuation. To this end, we present brief details of the experiment on a Bose–Einstein condensate (BEC), and a simplistic calculation of the Gross–Pitaevskii solution using the Thomas–Fermi approximation with focus on the density of the BEC for the time-dependent perturbation. Moreover, we calculate the power induced by quantum gravity on a generic atomic ensemble. We also address the possible challenges for the measurement of the expected results. Finally, we discuss the prospect of further developing this experiment toward measuring the effect of quantum spacetime fluctuations on cold atoms.

Michael Skotiniotis (University of Innsbruck, Austria)

Quantum frameness for charge-parity-time inversion symmetry (Talk)

Due to Lorentz invariance and linearity, physical laws are invariant under simultaneous charge-parity-time (CPT) inversion making this symmetry one of the most fundamental ones in the universe. We consider the superselection rule that arises from CPT symmetry, and develop a theory of CPT frameness resources. We show that even for this fundamental symmetry, superselection can be circumvented using appropriate resources, which we construct and quantify for the case of spin-0, -1/2, -1, and Majorana particles. In addition, we show that spin-0 particles only allow for classical information processing whereas particles of higher-dimensional spin allow for quantum information processing even in the presence of CPT-superselection. We treat CPT inversion unitarily by considering the aggregate action of CPT rather than the composition of C, P and T, which results in an anti-unitary representation of CPT. This work is a joint collaboration with Borzu Toloui, Ian T. Durham, and Barry, C. Sanders.

Rui Soares Barbosa (University of Oxford, UK)

Structural reason for monogamy and local macroscopic correlations (Talk)

We consider the emergence of classical correlations in macroscopic quantum systems, and its connection to monogamy relations for violation of Bell-type inequalities. We work within the sheaf-theoretic framework of Abramsky and Brandenburger [1], which provides a unified treatment of non-locality and contextuality in the general setting of no-signalling empirical models. General measurement scenarios are represented by simplicial complexes that capture the notion of compatibility of measurements. Monogamy and locality/noncontextuality of macroscopic correlations are revealed by our analysis as two sides of the same coin: macroscopic correlations are obtained by averaging along a symmetry (group action) on the measurements, while monogamy relations are exactly the inequalities that are invariant with respect to that symmetry. Our results exhibit a structural reason for monogamy relations and consequently for the classicality of macroscopic correlations in the case of multipartite scenarios, shedding light on and also generalising the results in [2,3]. More specifically, we show that, however entangled the microscopic state of the system, and provided the number of particles in each site is large enough with respect to the number of allowed measurements, the macroscopic correlations (of the kind considered) will be local realistic. The result depends only on the compatibility structure of the measurements, hence it applies generally to any no-signalling empirical model. The macroscopic correlations can be defined on the quotient of the simplicial complex by the symmetry that lumps together like microscopic measurements into macroscopic measurements. Given enough microscopic particles, the resulting complex satisfies a structural condition due to Vorob'ev [4] that is necessary and sufficient for any probabilistic model to be classical. The generality of our scheme suggests a number of promising directions. In particular, they can be applied in more general scenarios to yield monogamy relations for contextuality inequalities and to study macroscopic non-contextuality.

[1] Abramsky and Brandenburger, The sheaf-theoretic structure of non-locality and contextuality, New J. Phys. 13, 113036.
[2] Pawłowski and Brukner, Monogamy of Bell's Inequality Violations in Nonsignaling Theories, Phys. Rev. Lett. 102, 030403.
[3] Ramanathan, Paterek, Kay, Kurzyński and Kaszlikowski, Local Realism of Macroscopic Correlations, Phys. Rev. Lett. 107, 060405.
[4] Vorob'ev, Consistent Families of Measures and Their Extensions, Theory Probab. Appl. 7, 147.

Christoph Spengler (University of Innsbruck, Austria)

Composite parameterization and Haar measure for all unitary and special unitary groups (Talk)

Many quantities in quantum physics are related to optimization problems that necessitate to vary over all unitary transformations, density matrices or subspaces. In quantum information such problems arise, for instance, in the analysis of entanglement and nonlocality. Most of these tasks can be considerably simplified by using appropriate parameterizations for the central objects. In this talk, we introduce the 'composite parameterization' of the unitary and special unitary group, i.e. U(d) and SU(d). This parameterization has an insightful matrix notation and can be used to efficiently describe orthonormal vectors, density matrices and subspaces. We also consider the Haar measure in terms of the introduced parameters, which plays an important role in all kinds of unbiased randomizations. We show that the well-defined structure of the parameterization leads to a concise formula for the normalized Haar measure on U(d) and SU(d). With regard to possible applications, we point out the usefulness of the presented tools for examining the distillability of quantum states and solving unitary group integrals.

Sergii Strelchuk (University of Cambridge, UK)

Entanglement recycling and generalized teleportation (Talk)

We introduce new teleportation protocols which are generalizations of the original teleportation protocols that use the Pauli group and the port-based teleportation protocols, introduced by Hiroshima and Ishizaka, that use the symmetric permutation group. We derive sufficient conditions for a set of operations, which in general need not form a group, to give rise to a teleportation protocol and provide examples of such schemes. This generalization leads to protocols with novel properties and is needed to push forward new schemes of computation based on them. Port-based teleportation protocols and our generalizations use a large resource state consisting of N singlets to teleport only a single qubit state reliably. We provide two distinct protocols which recycle the resource state to teleport multiple states with error linearly increasing with their number. The first protocol consists of sequentially teleporting qubit states, and the second teleports them in a bulk.

Magdalena Zych (University of Vienna, Austria)

General relativistic effects in quantum interference of "clocks" (Poster)

Quantum mechanics and general relativity have been extensively and independently confirmed in many experiments. However, all experiments that measured the influence of gravity on quantum systems are still fully consistent with non-relativistic, Newtonian gravity. Here we discuss a novel effect in quantum interference experiments that can probe the interplay between quantum mechanics and general relativity. We consider interference of a “clock” – a particle with some evolving degrees of freedom - placed in a superposition of two different gravitational potentials. According to general relativity, each amplitude of the superposition will experience a different gravitational time dilation. Due to quantum complementarity the visibility of quantum interference will thus drop to the extent to which the information about the location becomes available from the “clock”. The clock can be implemented in an internal degree of freedom of a massive particle or in the position of a photon. The proposed experiment would thus provide the first test of quantum mechanics in curved background.

Participants

Name	Association	Country	Role
David Bruschi	University of Leeds	UK	Organiser
Nicolai Friis	University of Nottingham	UK	Organiser
Antony Lee	University of Nottingham	UK	Organiser
Sara Tavares	University of Nottingham	UK	Organiser
Karishma Hathlia	University of Nottingham	UK	Volunteer
Bob Coecke	University of Oxford	UK	Invited lecturer
Ivette Fuentes	University of Nottingham	UK	Invited lecturer
Etera Livine	Ecole Normale de Lyon	France	Invited lecturer
Tim Ralph	University of Queensland	Australia	Invited lecturer
Mohammed Akram Fellah	Badji Mokhtar University	Algeria	Poster
Valentina Baccetti	Victoria University of Wellington	New Zealand	Talk
Miriam Backens	University of Oxford	UK	Talk
Luis C. Barbado	Instituto de Astrofisica de Andalucia	Spain	Talk
Dionigi Benincasa	Imperial College London	Spain	Attending
Jack Binysh	University of Oxford	UK	Poster
Michel Buck	Imperial College London	UK	Talk
Ricardo Camões de Oliveira	University of Nottingham	UK	Talk
Fabio Costa	University of Vienna	Austria	Poster
Nadish de Silva	University of Oxford	UK	Talk
Tanapat Deesuwan	Imperial College London & UCL	UK	Talk
Vedran Dunjko	University of Edinburgh	UK	Poster
Jos Gibbons	University of York	UK	Talk
Hal Haggard	Centre de Physique Théorique	France	Talk
Dominic Hosler	University of Sheffield	UK	Talk
Sergio Inglima	Heriot-Watt University	UK	Attending
Philipp Köhler	University of Vienna	Austria	Talk
Benjamin Lang	University of York	UK	Talk
Emanuele Levi	City University London	UK	Talk
Joel Lindkvist	Chalmers University of Technology	Sweden	Poster
Benito Alberto Juarez Aubry	University of Nottingham	UK	Talk
Raphael Lopes	LCF, Institut d'Optique	France	Talk
Shane Mansfield	University of Oxford	UK	Talk
Miguel Montero Muñoz	Universidad Autónoma de Madrid	Spain	Talk
Veiko Palge	University of Leeds	UK	Talk
Christiana Panayi	University of Leeds	UK	Poster
Supakchai Ponglertsakul	University of Sheffield	UK	Attending
Felix Pollock	University of Oxford	UK	Poster
Benjamin Russell	University of York	UK	Attending
Marcilio Santos	University of Aberdeen	UK	Talk
Michael Skotiniotis	University of Innsbruck	Austria	Talk
Rui Soares Barbosa	University of Oxford	UK	Talk
Christoph Spengler	University of Innsbruck	Austria	Talk
Sergii Strelchuk	University of Cambridge	UK	Talk
Magdalena Zych	University of Vienna	Austria	Poster

Location

All conference events, apart from the conference dinner, are held on the University's Park Campus, in Highfield House (10). Lunches will be served in the cloister area, near the main venue, room A11. Accommodation is provided in nearby Hugh Stewart Hall. Buses to the city centre leave from outside the Portland Building.