Banff International Research Station
for Mathematical Innovation and Discovery

Entanglement in Curved Spacetime

(13w5153)

22-27 September 2013

MEALS

*Breakfast (Buffet): 7:00 – 9:30 am, Sally Borden Building, Monday – Friday
*Lunch (Buffet): 11:30 am – 1:30 pm, Sally Borden Building, Monday – Friday
*Dinner (Buffet): 5:30 – 7:30 pm, Sally Borden Building, Sunday – Thursday
Coffee Breaks: As per daily schedule, in the foyer of the TransCanada Pipeline Pavilion (TCPL)
***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in the TransCanada Pipelines Pavilion (TCPL). LCD projector and blackboards are available for presentations. Ceiling-mounted video cameras are installed in the main lecture room of 201, TCPL. But do bring your own laptop. There are two lecture rooms and BIRS will run two workshops in parallel. Our workshop has all lectures in the morning in room 202 and those in the evening in room 201.

We will not have lectures in the afternoons. This is to enable informal discussions and collaborations. *For collaborations, the two breakout rooms 106 and 107 on the lower level are reserved for us.* The breakout room 102 may also be available, though the parallel workshop has priority there. These breakout rooms each accommodate up to 6 people and have blackboards and white boards. Also the reading room in the Corbet Hall is available. It has computer, printer, scanner and white board. Permanently available to us is also the seminar room 202.

SCHEDULE

Sunday

16:00 Check-in begins (Front Desk – Professional Development Centre - open 24 hours)
17:30-19:30 Buffet Dinner
20:00 Informal gathering in 2nd floor lounge, Corbett Hall
Beverages and small assortment of snacks are available on a cash honor system.

Monday

7:00-8:45 Breakfast
8:55-9:00 Introduction and Welcome by BIRS Station Manager, TCPL
9:00-9:30 Lecture 1 (Mann)
9:30-10:00 Lecture 2 (Donnelly)
10:00-11:00 Coffee Break, TCPL
11:00-11:30 Lecture 3 (Hotta)
11:30-13:00 Lunch
13:00-14:00 Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall
Time for walks, discussions and collaborations (talk and walk)

15:00-15:30 Coffee Break, TCPL
Talk and walk
17:30-19:30 Dinner
19:45-20:15 Lecture 4 (Unruh)

Tuesday

7:00-9:00 Breakfast
9:00-9:20 Lecture 5 (Jonsson)
9:20-9:40 Lecture 6 (Ahmadzadegan)
9:40-10:00 Lecture 7 (Brown)
10:00-11:00 Coffee Break, TCPL
11:00-11:30 Lecture 8 (Martin-Martinez)
11:30-13:00 Lunch
13:00-13:15 Group photograph (meet in foyer of TCPL, then picture to be taken outdoors)
Talk and walk
15:00-15:30 Coffee Break, TCPL
Talk and walk
17:30-19:30 Dinner
19:45-20:15 Lecture 9 (Leon)

Wednesday

7:00-9:00 Breakfast
9:00-9:30 Lecture 10 (Dragan)
9:30-10:00 Lecture 11 (Schuetzhold)
10:00-11:00 Coffee Break, TCPL
11:00-11:30 Lecture 12 (Myers)
11:30-13:00 Lunch
Free afternoon
17:30-19:30 Dinner
19:45-20:15 Lecture 13 (Ralph)

Thursday

7:00-9:00 Breakfast
9:00-9:30 Lecture 14 (Kempf)
9:30-10:00 Lecture 15 (Reznik)
10:00-10:15 Lecture 16 (Reznik)
10:15-11:00 Coffee Break, TCPL
11:00-11:30 Lecture 17 (Hu)
11:30-13:00 Lunch
Talk and walk
15:00-15:30 Coffee Break, TCPL
Talk and walk
17:30-19:30 Dinner
19:45-20:15 Lecture 18 (Louko)

Friday

7:00-9:00 Breakfast
9:00-9:30 Lecture 19 (Sanders)
9:30-10:00 Lecture 20 (Menicucci)
10:00-10:30 Coffee Break, TCPL
10:30-11:00 Lecture 21 (Martin-Benito)
11:00-12:00 Checkout to be completed by noon
11:30-13:00 Lunch

Checkout Friday by 12 noon.

Please note: Participants are welcome to use BIRS facilities (BIRS 2nd floor lounge, TCPL and Reading Room) until 3 pm on Friday, although participants are still required to checkout of the guest rooms by 12 noon.

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TITLES & ABSTRACTS

Monday morning:

1.
Speaker: Robert Mann
Title: Invisibility: Seeing the Unseeable with RQI
Abstract: The methods of Relativistic Quantum Information are now being employed in a variety of ways to probe physical properties that are out of reach by standard (classical) means. Here I discuss how such "invisibility" can be exploited using RQI methods to detect phenomena as disparate as single photons in cavities to the topological structures inside black holes.

2.
Speaker: William Donnelly
Title: Sustainably farming a quantum field
Abstract: Entanglement can be transferred into localized detectors in a procedure that has been called entanglement harvesting. Here we study repeatedly re-using the same cavity for entanglement harvesting: we call the resulting protocol entanglement farming. Intuitively one might expect excitations to accumulate in the cavity and spoil its ability to impart entanglement. Remarkably, we find that the opposite is often true: repeated iterations drive the system toward a metastable state in which the cavity's entangling ability is actually enhanced. The impact of entanglement farming on the cavity will be described, from its initial convergence toward the metastable state, to the eventual exhaustion of the cavity due to the effects of off-resonant modes. Joint work with Eduardo Martin-Martinez, Eric Brown and Achim Kempf.

3.
Speaker: Masahiro Hotta
Title: Quantum energy teleportation
Abstract: The development of techniques for manipulation of quantum information has opened the door to a variety of protocols for accomplishing unprecedented tasks. In particular, a new protocol of quantum teleportation was proposed in 2008 to achieve effective energy transportation simply via local operations and classical communication —without breaking any known physical laws. This is achieved by extracting zero-point energy of entangled many-body systems by local operations dependent on information obtained by a distant measurement. QET can be implemented, at least theoretically, to various physical systems, including spin chains, cold trapped ions, harmonic chains, and quantum fields. Besides, it has

been recently presented that QET would be experimentally verified by using quantum Hall edge currents. QET provides a new method extracting energy from black holes: Outside a black hole, we perform a measurement of quantum ...fields and obtain information about the quantum fluctuation. Then positive-energy wave packets of the ...fields are generated during the measurement and fall into the black hole. Even after absorption of the wave packets by the black hole, we can retrieve a part of the absorbed energy outside the horizon by using QET. This energy extraction yields a decrease in the horizon area, which is proportional to the entropy of the black hole. However, if we accidentally lose the measurement information, we cannot extract energy anymore. The black-hole entropy is unable to decrease. Therefore, the obtained measurement information has a very close connection with the black hole entropy. This line of argument is expected to lead to further understanding of the origin of black hole entropy, which is often discussed in string theory. An introductory review of QET is available on WEB; http://www.tuhep.phys.tohoku.ac.jp/~hotta/extended-version-qet-review.pdf

Monday evening:

4.
Speaker: Bill Unruh
Title: The Accelerated Sponge.
Abstract: An accelerated sponge (something designed to soak up garbage-- eg thermal radiation) will absorb the thermal radiation seen by an accelerated observer. This leaves behind a trail of negative energy, which seems in conflict with the fact that the vacuum state is the state of minimum energy. This is resolved by transients. This also illustrates the effect on energy transport of breaking the entanglement of the vacuum, and has relevance to the "firewall" controversy.

Tuesday morning:

5.
Speaker: Robert Jonsson
Title: Quantum Signalling with Unruh-DeWitt detectors
Abstract: In information theoretical terms, the interaction between two particle detectors can be understood as communication. It can be described by means of the quantum communication channel between the detectors and its strength can be quantified in terms of the channel capacity. The first question in this context is what the optimal input states are for signalling between two UdW-detectors. Intuitively one might expect, that the energy eigenstates would be the best choice. However we find that, perhaps surprisingly, superposition states (like the |+>,|-> states) are in general a much stronger choice in the relativistic regime. We go on to discuss recent results on the quantum channel for fields inside cavitites. They concern both the theoretical description of quantum fields inside cavities (finite-mode approximations) and effects that are related to the strong Huygens principle. These effects should, e.g., become relevant for relativistic scenarios in cavity QED. [1] RHJ, Eduardo Martín-Martínez, Achim Kempf, Quantum Signalling in cavity QED, arXiv:1306.4275 (2013)

6.
Speaker: Aida Ahmadzadegan
Title: Approximate methods to compute the response of UdW detectors in cavities in curved spacetimes
Abstract: We introduce a method to compute particle detector transition rates in spacetime regions of general curved spacetimes provided that the curvature is not above a maximum threshold. In particular we use this method to compare the response of two detectors one in a spherically symmetric gravitational field and the other one in Rindler spacetime to compare the Unruh and Hawking effects: We study the vacuum response of a detector free falling through a stationary cavity setting in Schwarzschild background as compared with the transition rate of an equivalently accelerated detector traveling through an inertial cavity in the absence of curvature. We find that as we set the cavity in further radiuses from the black hole, the thermal radiation measured by the detector approaches the quantity recorded by the detector in Rindler background showing in which way and at what scales the equivalent principle is recovered in the Hawking-Unruh effect. I.e. when the Hawking effect in a Schwarzschild background becomes equivalent to the Unruh effect in Rindler spacetime.

7.
Speaker: Eric Brown:
Title: On translational invariance and the thermal amplification of correlation harvesting
Abstract: I will discuss work on the harvesting of quantum and classical correlations (entanglement, discord, and mutual information) by a pair of harmonic oscillator detectors placed in a periodic cavity field. By the use of oscillator detectors this study is done both non-perturbatively and exactly (non-numerically). I will introduce a new perspective on correlation harvesting stemming from the translational invariance of the cavity field, and will explain how the detectors' harvesting ability is deeply connected to the correlating properties of passive, Gaussian operations. We will go on to see how this perspective is used to explain a surprising result: even though thermal fluctuations in the field rapidly reduce the amount of entanglement that can be harvested from it, they can also vastly improve the harvesting of mutual information as well as of quantum discord. I finish by noting the experimental and practical applications that this realization may have.

8.
Speaker: Eduardo Martin-Martinez
Title: Processing quantum information with relativistic motion of atoms
Abstract: We show that particle detectors, such as 2-level atoms, in non-inertial motion (or in gravitational fields) could be used to build completely universal quantum gates for the processing of quantum information. Concretely, we show that through suitably chosen non-inertial trajectories of the detectors the interaction Hamiltonian's time dependence can be modulated to yield arbitrary rotations in the Bloch sphere due to relativistic quantum effects.

Tuesday evening:

9.
Speaker: Juan Leon
Title: Towards localized elementary quanta
Abstract: Some properties of the standard formulation of QFT, which does not permit us to speak of the location of any individual particle , or the cyclic nature of the vacuum, play a crucial role in the interpretation and applications of the theory. I will present states for localized elementary quanta, whose representation turns out to be non-unitarily equivalent to the standard Fock space construction, will give the Bogoliubov coefficients relating global to local, and will discuss some properties of the local vacuum and localized states as seen using the standard tools of QFT. These localized states may be of relevance beyond flat space-time backgrounds, for local quantum physics, and for the construction of qubits useful for RQI tasks.

Wednesday morning:

10.
Speaker: Andrzej Dragan
Title: What do we really know about the entanglement degradation in non-inertial frames?
Abstract: We will summarize our findings on this seminal topic and clarify how numerous results concerning the problem of entanglement degradation should be interpreted. We will also present a method of approaching to this problem that provides a clear and unambiguous physical interpretation of the results and point out several further applications.

11.
Speaker: Ralph Schuetzhold
Title: Hawking radiation with dispersion versus breakdown of WKB
Abstract: Inspired by the condensed matter analogues of black holes (a.k.a.~dumb holes), we study Hawking radiation in the presence of a modified dispersion relation which becomes super-luminal at large wave-numbers. In the usual stationary coordinates (t,x), one can describe the asymptotic evolution of the wave-packets in WKB, but this WKB approximation breaks down in the vicinity of the horizon, thereby allowing for a mixing between initial and final creation and annihilation operators. Thus, one might be tempted to identify this point where WKB breaks down with the moment of particle creation. However, using different coordinates (τ,U), we find that one can evolve the waves so that WKB in these coordinates is valid throughout this transition region -- which contradicts the above identification of the breakdown of WKB as the cause of the radiation. Instead, our analysis suggests that the tearing apart of the waves into two different asymptotic regions (inside and outside the horizon) is the major ingredient of Hawking radiation.

12.
Speaker: Casey Myers
Title: Simulating Closed Timelike curve Interactions
Abstract: In this talk we present recent progress in the simulation of Deutschian closed timelike curve (CTC) interactions. We first investigate the simulation of qubit interactions along a CTC, proposing a non-orthogonal state discrimination

simulation and determine the minimal experimental requirements for such a simulation. Next, we investigate the simulation of photonic interactions along a CTC, examining the use of feedback loops to simulate the CTC interactions and determine the experimental resources required for such a simulation.

Wednesday evening:

13.
Speaker: Tim Ralph
Title: Quantum Connectivity of Curved Space-Time and Entanglement
Abstract: We discuss a non-linear extension of quantum mechanics called the event operator formalism [1] that does not exhibit the usual pathologies of such extensions, such as faster-than-light signalling. The theory introduces a novel decay term to the space-time commutator between time-like separated events which can lead to observable consequences for entanglement in curved space [2]. We will discuss the motivation for the theory and potential for testing its predictions with space-based experiments.

Thursday morning:

14.
Speaker: Achim Kempf
Title: Curvature expressed in terms of entanglement
Abstract: EPR-type measurements on spatially separated entangled spin qubits allow one, in principle, to detect curvature. Also the entanglement of the vacuum state is affected by curvature. Here, we ask if the curvature of spacetime can be expressed entirely in terms of the spatial entanglement structure of the vacuum. This would open up the prospect quantum information techniques could be fully employed in the study of quantum gravity.

15.
Speaker: Benny Reznik
Title: Superoscillations and Reeh-Schlieder's theorem

16.
Speaker: Benny Reznik
Title: TBA (related to effective lattice gauge theory simulations)

17.
Speaker: Bei-Lok Hu
Title: Boundary and Topology Effects on Quantum Entanglement
Abstract: We study the quantum entanglement between a physical object and a quantum field with a boundary present or in a space with nontrivial topology. Put in a more playful way, we ask these two questions 1) “Looking into a mirror -- can one get entangled with one's own image?" 2) “A cat chasing his own tail – how stupidly entangled can he get?” Based on these papers: [1] Rong Zhou, Ryan Orson Behunin, Shih-Yuin Lin, Bei-Lok Hu, “Boundary Effects on Quantum Entanglement and its Dynamics in a Detector-Field System”, JHEP (2013) [arXiv:1301.0073] “Autangle: A case of Quantum Narcissism?” [arXiv:1201.0541v2], [2] C. H. Chou, S. Y. Lin, Rong Zhou and B. L. Hu, “Spacetime Topology and Entanglement Dynamics” (in preparation), [3] Shih-

Yuin Lin, Bei-Lok Hu "Temporal and Spatial Dependence of Quantum Entanglement from a Field Theory Perspective", Phys. Rev. D79 (2009) 085020

Thursday evening:

18.
Speaker: Jorma Louko
Title: Particle detectors near and beyond black hole horizons
Abstract: We analyse stationary and nonstationary particle detectors of the Unruh-DeWitt type in 3+1 and 1+1 black hole spacetimes, including a detector falling from infinity through the horizon. We focus on the sense in which the detector sees thermality maintained, lost, and (possibly) regained. (Based on work with Lee Hodgkinson, Adrian Ottewill and Benito Juarez.)

Friday morning:

19.
Speaker: Barry Sanders
Title: Quantum Frameness for CPT Symmetry
Abstract: We develop a theory of charge-parity-time (CPT) frameness resources to circumvent CPT superselection. We construct and quantify such resources for spin-0, 1/2, 1, and Majorana particles and show that quantum information processing is possible even with CPT superselection. Our method employs a unitary representation of CPT inversion by considering the aggregate action of CPT rather than the composition of separate C, P, and T operations, as some of these operations involve problematic antiunitary representations.

20.
Speaker: Nicolas Menicucci
Title: Acceleration-assisted entanglement harvesting and rangefinding
Abstract: I will present revised and now complete results for harvesting of entanglement from a quantum field through local detector interactions. Unlike the usual case analyzed in the literature, we do not require that the distance between the accelerating detectors be functionally related to the rate of acceleration. While parallel acceleration hinders entanglement harvesting, antiparallel acceleration enhances it over the inertial case -- quite significantly, even, in some regions of parameter space. I will highlight several methods by which the amount of entanglement harvested can be used as a measure of the distance between the detectors.

21.
Speaker: Mercedes Martin-Benito
Title: Particle creation in quantum gravity: the echo of the quantum bounce
Abstract: We identify a signature of quantum gravity effects that survives from the early universe to the current era: fluctuations of quantum fields as seen by comoving observers are influenced by the history of the early universe. In particular we study how the existence (or not) of a quantum bounce leaves a trace in the background quantum noise that is not damped and would be non-negligible even nowadays. Furthermore, we estimate an upper bound to the typical energy and length scales where quantum effects are relevant.