Theory Canada 15

Thursday 15 June 2023 - Saturday 17 June 2023

Mount Allison University

Book of Abstracts

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Modeling Late-Time Tails for Scalar Perturbations of Quantum Corrected Black Holes

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Abstract:

The main goal of this research is to obtain a clear and accurate model of the late-time behavior of a quantum-corrected black hole's radiative emission wave. Specifically, the focus is on late-time tail waveforms, which appear after the exponentially damped signal originating from the ring down phase of a perturbed black hole. This project focused on interpreting the effects of loop quantum corrections on black hole quasi-normal modes and radiative tails. We began with the scalar wave equation and solved for the Regge-Wheeler scalar field potential, which captures the physics of a standard Schwarzschild black hole. This solution allowed us to generate waveforms with different initial variables, such as multipole numbers and radial epsilon exponents. Next, we analyzed the divergent characteristics, oscillatory behavior, and decay rates of the late-time tails for the quantum-corrected black hole and performed a comparison with the Schwarzschild case. This research is part of an ongoing project on gravitational wave emission from quantum-corrected black holes, and how they can be modeled. It is a bid to make detection and recognition of such waveforms possible in future gravitational wave observatories.

Mathematical Physics / 2

A pedagogical approach to degrees of freedom

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As one of the fundamental concepts in physics, degrees of freedom are commonly encountered in classical mechanics, statistical physics, and QFT. However, the concept is often introduced without a careful explanation. In this talk, I will present a pedagogical approach to understanding degrees of freedom by analyzing simple (but not trivial!) mechanical systems. We will emphasize the role played by topology and geometry, and demonstrate how this approach provides a physical introduction to topology.

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The Macroscopic Mechanical Equilibrium Condition Governing and Supporting Equilibrium States: the Physical Origin of the Equation of State

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The Equation of State (EOS) has a pretty long history. The physics behind it should be explored. The main purpose of the EOS is to yield the volume of a given material system under given external temperature and mechanical condition. Since the predicted volume is fixed, the EOS is for the system in a macroscopic equilibrium state. In such a situation, the Macroscopic Mechanical Equilibrium Condition (MMEC) applies. Imagine that the system is cut into a great number of small, yet macroscopic pieces. The macroscopic equilibrium state and the MMEC hold, implying that the macroscopic internal stress at every macroscopic point of the system balances the external stress applied onto the system, and determine the equilibrium positions of all the inside microscopic particles. As a result, the MMEC determines the volume of the system as well. Since both the MMEC and the EOS determine the volume of the system but can not conflict, they should be equivalent to each other mathematically, or the MMEC is, in fact, the physical origin/foundation of the EOS. Furthermore, as they determine the geometry of the system, the MMEC/EOS can describe all thermodynamic quasi-equilibrium processes caused by the change of the external temperature and/or mechanical environment. If they cannot be satisfied, the system cannot be in an equilibrium state.

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Partition dominance ordering and fermionic interferometry

Author: Hubert de Guise[None]

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I will discuss the role of partition dominance ordering in the expression of coincidence rates in the interference of partially distinguishable fermions, and also discuss the algorithmic complexity of various functions entering in the expressions of these rates.

Relativity, Gravitation and Cosmology / 6

Tentative evidence for cosmological coupling of black holes and implications for dark energy

Author: Valerio Faraoni[None]

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Exact solutions of the Einstein equations describing black holes in cosmological backgrounds exhibit time-dependent masses over Hubble times. We report tentative evidence for such a cosmological coupling obtained by studying populations of supermassive black holes in a sequence of red elliptical galaxies spanning 9 billion years. If black holes are non-singular, they typically have de Sitter cores and interior stresses, which corrects the Einstein-Friedmann equations obtained by averaging matter over 180 Mpc. Then, the (conservative) collapse of first-generation stars converting into black holes a mere 3% of the baryons present at z=25 explains the cosmic acceleration without any dark energy outside (de Sitter-cored) black holes. This speculative model based only on GR and common ideas about black hole interiors is astrophysically testable and will be summarized in this talk.
[Based on D. Farrah et al, ApJ Lett. 944, L31 (2023)]

Relativity, Gravitation and Cosmology / 7

BPS Gravitational Solitons in Anti-de Sitter Spacetimes

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Gravitational solitons are globally stationary, geodesically complete spacetimes with positive energy. These event-horizonless geometries do not exist in the electrovacuum by the classic Lichnerowicz Theorem. However, gravitational solitons exist when there are non-Abelian gauge fields in higher dimensions. In this talk, I will present a new class of supersymmetric asymptotically globally Anti-de Sitter gravitational solitons. I will then show that they contain evanescent ergosurfaces, a timelike hypersurface where the timelike Killing vector field becomes null. The presence of this hypersurface strongly suggests nonlinear instability due to the stable trapping phenomena. I will present an analytical argument for the derivation of this nonlinear instability. This is joint work with Dr. Hari K. Kunduri.

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Conservation,Non-conservation Laws and Gravitational Energy momentum in Curved Spacetime

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The spacetime M in general relativity (GR) is curved. Parallel transportations of vectors in M depend on path. This leads to the fact that vectors distributed on different points in M can not be added up to get a sum vector unambiguously. Geometry does not allow talking about matter energy momentum distributed on (passing through) a finite or infinite spacelike (timelike) hypersurface, does not allow talking about the net increase of matter energy momentum in a finite or infinite 4-demensional spacetime region. Even for a simple physical system consisting of only two uncharged mass points, geometry does not allow talking about its energy momentum. Therefore, it is pressing to explore the meaning of conservation of matter energy momentum in GR from a geometric perspective.
We show, in a curved spacetime M, when limited to an infinitesimal spacetime region, vectors distributed at different points can still be added up to get a sum vector unambiguously, if neglecting higher order infinitesimals. For an (r,s)-tensor Q, denoting by J its flux density (r+1,s)-tensor field, the conservation law of Q in curved spacetime M is "the covariant divergence of J vanishes everywhere". It reads, "the net increase of tensor Q in any infinitesimal 4-dimensional neighborhood is zero".
In particular, "the covariant divergence of T (flux density of matter energy momentum) vanishes everywhere"is the conservation law of matter energy momentum in GR.
Noether's theorem for GR is re-visited. It is shown, all the Noether's conserved currents corresponding to generating smooth vector fields on M are vector fields on M, hence they are conservation laws of scalars. It is also shown, all these Noether's conservation laws together are equivalent to the equations of motion of GR.

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Classical-Quantum Approximation for Bipartite Quantum Systems

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We derive a "classical-quantum"approximation scheme for a broad class of bipartite quantum systems. In this approximation, one subsystem's evolution is governed by classical equations of motion with quantum corrections, and the other subsystem evolves quantum mechanically with equations of motion informed by the classical degrees of freedom. Similar approximations are common when discussing the backreaction of quantum fields on curved spacetime, as in Hawking radiation around black holes or the generation of primordial perturbations in inflation.

Relativity, Gravitation and Cosmology / 11

Negative Mass in the Universe is Relative, Repulsive and Real

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The Schwarzschild solution admits one parameter, the mass, which can be positive or negative. What is the meaning of the negative mass solution? Negative mass is an intriguing idea. Negative mass, to be physical, must satisfy the dominant energy condition. Indeed stable configurations can be found that correspond to bubbles of negative mass, however crucially, in a background energy density. It seems that positive mass attracts while negative mass repels when acting on all masses, positive or negative, due to the equivalence principle. However a simple analysis of one graviton exchange implies that the potential between like mass particles should be negative, be they of positive or negative mass, implying naively attraction. We explain how this conclusion is eschewed, and gives repulsion for negative mass particles.

Quantum Information / 12

A generalized framework for the quantum Zeno and anti-Zeno effects in the strong coupling regime

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It is well known that repeated projective measurements can either slow down (the Zeno effect) or speed up (the anti-Zeno effect) quantum evolution. Until now, studies of these effects for a two-level system interacting with its environment have focused on repeatedly preparing the excited state via projective measurements. In this paper, we consider the repeated preparation of an arbitrary state of a two-level system that is interacting strongly with an environment of harmonic oscillators. To handle the strong interaction, we perform a polaron transformation and then use a perturbative approach to calculate the decay rates for the system. Upon calculating the decay rates, we discover that there is a transition in their qualitative behaviors as the state being repeatedly prepared continuously moves away from the excited state and toward a uniform superposition of the ground and excited states. Our results should be useful for the quantum control of a two-level system interacting with its environment.

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Natural Orbital Properties for Excited States

Author: Thomas Baker[1]

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Natural orbitals are defined as the eigenvectors one-body reduced density matrix. These orbitals are a highly convergent basis for the many-body problem. Here, some exact properties of the natural orbitals are discussed, particularly their similarities and differences for excited states with varying energy differences. These results are used to justify the behavior of entanglement renormalization techniques for excited states of both fermions and bosons. The results prove an upper bound on how different density matrices can be for excitations in a system with local correlations. A discussion of the relevance of symmetry on those solutions is also discussed and some examples are provided. I conclude with an outlook of how these results can be applied to real systems.

This research was undertaken, in part, thanks to funding from the Canada Research Chairs Program. The Chair position in the area of Quantum Computing for Modeling of Molecules and Materials is hosted by the Departments of Physics & Astronomy and of Chemistry at the University of Victoria. T.E.B. is grateful for support from the University of Victoria's start-up grant from the Faculty of Science. I acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC),for RGPIN-2023-05510.

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Extending qubit dihedral benchmarking to complete the characterisation of a universal qutrit gate set

Author: David Amaro Alcala[1]

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To effectively operate a large-scale quantum computer, it is essential to thoroughly and confidently assess the performance of its components.
The gold standard for performance assessment of quantum gates is randomised benchmarking.
In particular, randomised benchmarking of universal qutrit quantum gates is needed.
In this presentation I will show how we advance from qubit dihedral benchmarking using the group D_8 to benchmarking a qutrit T gate by generalizing D_8 using the unique group for qutrits that satisfies three criteria inspired by D_8.
Using this generalization of D_8 we can complete the characterisation of a universal qutrit gate set.
I will also briefly discuss the application of our criteria to T gate benchmarking in the ququart and ququint cases.

Condensed Matter / 15

Ising-like models on black hole space

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It is known that Schwarzchild geometry exhibits thermodynamic properties and these have a statistical mechanics explanation. An interesting question to ask is if we can study the statistical mechanics of spins on this background. In this presentation we will answer this question in the positive and construct an Ising-like model on black hole space. Then we will numerically study the thermodynamic properties of spins (such as alignment and entropy) for different masses of the black hole and discuss the resultant second order phase transition.

String and Quantum Gravity / 16

Scalar cosmological perturbations from full quantum gravity

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Extracting the physics of cosmological inhomogeneities and anisotropies from full quantum gravity is a crucial step to make contact with observations. I address this problem within the group field theory (GFT) formalism for quantum gravity by studying the perturbative mean-field effective dynamics of small relational inhomogeneities of GFT condensates. I show how these perturbations give rise to local volume and matter relational inhomogeneities and compare their dynamics with that of scalar cosmological perturbations from general relativity, highlighting similarities and differences that may lead to observational consequences.

Quantum Information / 17

Quantum Coherence and Antidistinguishability

Author: Nathaniel Johnston[1]

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Given a quantum state, how can we tell how "quantum" it is? That is, can we use that quantum state to do kick-start an interesting protocol like quantum teleportation, or is it really just a classical state in disguise? Quantum coherence tries to answer this question by quantifying the amount of superposition present in a quantum state. We develop some new easy-to-compute methods of determining how much coherence is present in a quantum state, and we establish a connection with the seemingly unrelated problem of *antidistinguishability*: if we are given a pure quantum state from some fixed set, is there a measurement that determines at least one state that we were *not* given? As an application of our results, we derive a correct version of a recently-disproved conjecture about antidistinguishability of quantum states.

Quantum Information / 18

From quantum resource theories to discrete dynamical systems

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Resource theories have been widely used in quantum information as a framework for quantifying quantum resources, even of remarkably different types. However, the applicability of such a framework is far more general than quantum theory, given that its mathematical underpinning lies in category theory, which is a universal paradigm in math. In this way, resource theories can be extended beyond their traditional domain to study new phenomena arising in non-quantum scenarios. Here, for the first time, we apply resource theories to finite discrete dynamical systems. In particular, we use them to develop a rigorous theory of external influences, going beyond the perturbation paradigm, in that the external influence need not be a small contribution. The core of our work is the notion covariance influence: if we evolve a dynamical system for n time steps and then we disturb it, it is the same as first disturbing the system with the same influence and then letting the system evolve for n time steps. Using resource theories, we provide necessary and sufficient conditions for the transition between states under deterministic covariant influences and necessary conditions in the presence of stochastic covariant influences, predicting which transitions between states are forbidden.

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A five dimensional distorted black hole with a "bubble".

Authors: Hari Kunduri[1]; Ivan Booth[None]; Matin Tavayef[2]

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In general, black holes interact with external matter and fields. A four-dimensional static black hole within a static external axisymmetric gravitational field can be described by a Weyl solution of the Einstein equations. These results can be extended to higher dimensions using the generalized Weyl form. Various studies have been devoted to investigate the properties of the distorted black holes so far. These include a distorted five dimensional Schwarzschild-Tangherlini black hole, a distorted five dimensional Reissner-Nordstrom black hole and a distorted black ring. In this talk, we consider five-dimensional Weyl solutions, which are characterized by two independent axially symmetric harmonic functions in three-dimensional flat space. Using this method, we investigate distortions of a vacuum five-dimensional black hole with a "bubble' (the black hole exterior has nontrivial topology).

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Exotic Marginally Outer Trapped Surfaces are Unstable

Author: Ivan Booth[None]

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Recently, significant process has been made in the understanding of how two apparent horizons merge to become one during a black hole collision. Apparent horizons are examples of more general objects called marginally outer trapped surfaces (MOTS) and as an offshoot of the merger studies, we have learned that MOTS are much more common than had been previously realized. For example, apart from its standard horizon, the Schwarzschild spacetime contains a (likely) infinite family of MOTS contained within the black hole region. These MOTS have complicated self-intersecting geometries and so have been dubbed "exotic". However, horizons of black holes have another property beyond being MOTS: they separate regions of outer trapped surfaces (the interior of the black hole) from untapped regions (the exterior). Geometrically this corresponds to a MOTS being *stable* (in a sense closely analogous to minimal surface stability). It has been observed that all of the exotic MOTS in Schwarzschild are unstable in this sense.

In this talk I will present a mathematical proof that a MOTS that doesn't share the symmetries of a spacetime is necessarily unstable. In particular, this includes all of the exotic Schwarzschild MOTS, as well as many more that have recently been studied in the literature.

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How to recover your homework from a black hole

Author: David Wakeham[None]

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Alice is taking a course on QFT in curved spacetime, and accidentally drops her midterm into a black hole. From Hawking's famous calculation, she suspects the midterm been irreversibly thermalized, and her GPA with it. Her colleague Bob, a card-carrying unitarian, believes the midterm can be recovered from the Hawking radiation, at least in principle. Their mutual friend Charlotte is a condensed matter theorist who constructed the black hole, using matter entangled with her quantum computer, for a harebrained DARPA project. We discuss how Charlotte can recover Alice's midterm, proving Bob right and saving Alice's GPA, provided Charlotte's quantum computer is embedded into an asymptotically large Dyson sphere tuned to a critical state.

Relativity, Gravitation and Cosmology / 22

Indeterminacy in Classical Cosmology with Dark Matter

Authors: Vladimir Tasic[None]; Viqar Husain[None]

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We describe a case of indeterminacy in general relativity for homogeneous and isotropic cosmologies for a class of dark energy fluids. The cosmologies are parametrized by an equation of state variable, with one instance giving the same solution as Norton's mechanical dome. Our example goes beyond previously studied cases in that indeterminacy lies in the evolution of spacetime itself: the onset of the Big Bang is indeterminate. We show further that the indeterminacy is resolved if the dynamics is viewed relationally.

Nuclear Theory-Particles and Fields / 23

High energy probes of nuclear media: selected topics from quark gluon plasma studies

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The production of very energetic quarks and gluons (i.e., partons) and their showering in the Quantum Chromodynamical (QCD) vacuum has been well studied inside relativistic electron-proton and proton-(anti)proton collisions. Our good understanding of high energy partons in those collisions allow us to consider them as calibrated probes inside relativistic heavy-ion collisions, where they are used to study the finite temperature nuclear medium known as the quark gluon plasma (QGP). I will present a modern understanding of parton interaction with the nuclear medium, along with simulations used to describe them. Finally, I will present recent constraints on an important transport coefficient describing how partons behave inside the QGP, as well as some prospects for future improvement.

Nuclear Theory-Particles and Fields / 24

Exploring the Influence of Vector Like Quarks (VLQs) in Rare B-Decays

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The study of rare B- decays provides a unique opportunity to probe the Standard Model and search for signs of new physics. In particular, the VLQs (iso-singlet down-type), characterized by their isospin singlet nature, can play a significant role in these rare decays. We investigate the impact of the VLQ on the B ⟶ sμ+μ- decay process, starting by reviewing the theoretical framework of the Standard Model and introducing the relevant Feynman diagrams associated with the B ⟶ sμ+μ- decay and then highlighting potential implications of VLQs.

Mathematical Physics / 25

Flashpoints Signal Hidden Inherent Instabilities in Land Use Planning

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Land-use decision-making processes have a long history of producing globally pervasive systemic equity and sustainability concerns. Quantitative, optimization-based planning approaches, e.g., Multi-Objective Land Allocation (MOLA), seemingly open the possibility to improve objectivity and transparency by explicitly evaluating planning priorities by land use type, amount, and location. Here, we

show that optimization-based planning approaches with generic planning criteria generate a series of unstable "flashpoints"whereby tiny changes in planning priorities produce large-scale changes in the amount of land use by type. We give quantitative arguments that the flashpoints we uncover in MOLA models are examples of a more general family of instabilities that occur whenever planning accounts for factors that coordinate use on- and between-sites, regardless of whether these planning factors are formulated explicitly or implicitly. We show that instabilities lead to regions of ambiguity in land-use type that we term "gray areas". By directly mapping gray areas between flashpoints, we show that quantitative methods retain utility by reducing combinatorially large spaces of possible land-use patterns to a small, characteristic set that can engage stakeholders to arrive at more efficient and just outcomes.

Welcome and Introduction / **26**

Opening remarks

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