Atlantic General Relativity 2024

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University of New Brunswick

Book of Abstracts

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Session 1.4 / 1

Three years of thermodynamics of scalar-tensor gravity

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The first-order thermodynamics of scalar-tensor gravity is an analogy between scalar-tensor gravity (including viable Horndeski) and dissipative fluids. Assuming the gradient of the gravitational scalar field to be timelike and future-oriented, it contributes to the field equations like a dissipative fluid which, surprisingly, obeys Eckart's version of the Fourier law. Then, the convergence of modified gravity to General Relativity is analogous to the approach of this effective fluid to thermal equilibrium, but the situation is complicated by extra terms in the relevant equations. This formalism provides a notion of "temperature of gravity" and an explicit equation describing the approach to GR, or the departure thereof. Three years into this study, we draw a bird's eye view of this analogy and of its limitations and prospects.

Session 1.2 / 2

Power-law spacetime in terms of (2+1)-dimensional light-cone cuts and metricity conditions

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The null-surface formulation (NSF) of general relativity is equivalent to standard general relativity but uses null surfaces instead of a metric or a connection. The NSF, itself, exists in two distinct but mathematically equivalent versions: (a) Future-directed light rays leave a spacetime point and intersect null-infinity. The resulting light-cone cut encodes the properties of the spacetime; (b) The angular coordinates (Bondi coordinates) of null-infinity are used to label null surfaces, thereby producing a family of null surfaces which satisfies so-called metricity conditions. These are the NSF field equations. Any solution of these equations provides a description of spacetime and can be used, for example, to reproduce the spacetime metric (which would satisfy the Einstein equations).

The NSF is a nonlocal theory, describing nonlocal objects such as surfaces. It contrasts markedly with the usual general relativistic formalism which uses local fields, such as the metric. Minkowski spacetime is easily described within the NSF framework. However, nontrivial spacetimes have proved much more difficult to describe and, owing to the complexity of the NSF field equations, only a handful of solutions have been found. This talk presents a new exact solution that corresponds to a power-law spacetime with a dust source and everywhere positive mass-energy density. This solution is the first solution that directly links Version (a) and Version (b), thereby illustrating both versions of the NSF and demonstrating their equivalence. The new solution will be outlined at first in 2+1 dimensions. Its generalization to 3+1 will then be described.

Session 2.4 / 3

A dynamical systems formulation for inhomogeneous LRS-II spacetimes

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I will introduce a dynamical system formulation for inhomogeneous LRS-II spacetimes using the covariant 1+1+2 decomposition approach, that we recently proposed in 2404.01161. Our approach describes the LRS-II dynamics from the point of view of a comoving observer. Promoting the covariant radial derivatives of the covariant dynamical quantities to new dynamical variables and utilizing the commutation relation between the covariant temporal and radial derivatives, we have been able to show that it is possible to construct an autonomous system of first-order ordinary differential equations along with some purely algebraic constraints. I will talk about some interesting features in the LRS-II phase space with dust, one of them being that the homogeneous solutions constitute an invariant submanifold. For the particular case of LTB, I show that it is possible to recover some previously known results. The talk will be based on our recent work 2404.01161

Session 2.4 / **4**

On the impact of □ (□) gravity on the Large Scale Structure

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We investigate the exponential □ (□) symmetric teleparallel gravitation, namely □ (□) = □ + □□_0(1 − □ˆ(−□√□/□_0)) using ME-GADGET code to probe the structure formation with box sizes □_box = 10/100 Mpc/h and middle resolution □ˆ1/3 = 512. To reproduce viable cosmology within the aforementioned modified gravity theory, we first perform Markov Chain Monte Carlo (MCMC) sampling on OHD/BAO/Pantheon datasets and constrain a parameter space. Furthermore, we also derive theoretical values for deceleration parameter □(□), statefinder pair {□, □} and effective gravitational constant □eff, perform □□(□) diagnostics. While carrying out N-body+SPH simulations, we derive CDM+baryons overdensity/temperature/mean molecular weight fields, matter power spectrum (both 2/3D, with/without redshift space distortions), bispectrum, two-point correlation function and halo mass function. Results for small and big simulation box sizes are therefore properly compared, halo mass function is related to the Seth-Tormen theoretical prediction and matter power spectrum to the standard CAMB output.

Session 1.1 / **5**

Photon Surfaces and Shadows of Compact Objects

Author: Dipanjan Dey[1]

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In this talk, I will define the photon surface conditions using Cartan scalars within an invariant spin frame which offers a comprehensive description of the local spacetime geometry. By employing this approach, one can gain novel insights into the geometry and dynamics of photon surfaces, independent of the global spacetime structure. I will first discuss the photon surface conditions in a Petrov type-D spacetime manifold, and then I simplify those conditions assuming the existence of spherical symmetry. Finally, employing the simplified, spherically symmetric photon surface conditions, I will show the dynamics of photon surfaces in static spacetimes and collapsing Lemaitre-Tolman-Bondi (LTB) spacetimes and Vaidya spacetimes. Following the discussion on the local geometry of photon surfaces, I will talk about the recent advancements in comprehending the existence of shadows and relativistic photon rings, along with the necessary and sufficient conditions for their existence.

Session 2.1 / 6

Black hole Dissolution

Author: Ivan Booth[1]

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Black hole evaporation is perhaps the most commonly studied way for a black hole to end. However there is another way that is both entirely classical and whose consequences have been observed hundreds of times by LIGO/VIRGO. One can sensibly understand black hole mergers as representing the formation of a new black hole followed by the destruction of the two original ones. The destruction happens deep inside the new black hole as the original black holes “dissolve” in the intense interior gravitational fields. Instances of this have now been tracked in numerical simulations but aspects of this dissolution can also be understood from exact solutions. In this talk I will review the features common to all of these examples.

Session 1.1 / 7

Slowly evolving horizons in Einstein gravity and beyond

Author: Ayon Tarafdar[1]

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In this talk, I explore the determination of an event horizon candidate for slowly evolving dynamical black holes (BHs). Such a candidate has been termed as a *slowly evolving null surface* (SENS). Such surfaces are of interest because they coincide with the event horizon and are causal, unlike apparent horizons. Moreover, known laws of BH mechanics can be established for these slowly evolving surfaces. I discuss a few example spacetimes and the constraints that must be placed on parameters describing them to allow a physically admissible SENS. I start with spherically symmetric examples and talk about consequences when we perturbatively break free from such symmetry.

Session 1.4 / 8

Gravitational Field of an Oscillator in Proper Time

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We show that a proper time oscillator can mimic a point mass at rest in general relativity. The spacetime outside a proper time oscillator is a Schwarzschild field. Although the singularity in our model acts as a boundary for incoming geodesics, the spacetime structure inside this boundary is well-defined. The proper time oscillator is cloistered behind the singularity.

Session 2.1 / **9**

Quantum gravity of dust collapse

Author: Edward Wilson-Ewing[1]

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I will present a study on the quantum gravitational collapse of spherically symmetric pressureless dust. Using an effective equation derived from a polymer quantization in the connection-triad phase space variables of general relativity, numerics show, for a variety of initial dust configurations, that (i) trapped surfaces form and disappear as an initially collapsing density profile evolves into an outgoing shockwave; (ii) black hole lifetime is proportional to the square of its mass; and (iii) there is no mass inflation at inner apparent horizons. These results provide a substantially different view of black hole formation and subsequent evolution than found from semiclassical analyses.

Session 2.1 / **10**

How Does a Quantum State Self Gravitate?

Author: Gaia Noseworthy[1]

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Developing a Theory of Everything has been a long-standing, yet elusive goal. Even so, approaches exist that may be able to remedy this. In this presentation, we will explore one such approach: The Newton-Schrödinger System. Presented here will be numerical analysis on how such a system behaves in the domain of a circle with various Gaussian initial conditions, as well as the motion of test particles in this system.

Session 1.3 / **11**

New Static Spherically Symmetric Spacetime Teleparallel F(T) Gravity Solutions

Author: Alexandre Landry[1]

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We are interested in the static spherically symmetric geometries in F(T) teleparallel gravity with physical importance. We have found the general forms of the spherically symmetric frame with zero curvature, metric compatible and non-zero spin connection. We then analyse the antisymmetric field equations (the solutions splitting into two separate cases), and derive and analyse the resulting symmetric field equations. For studying the applications of spherically symmetric teleparallel models, we have studied the static spherical symmetric by solving the antisymmetric field equations and by setting the final static symmetric field equations to solve. Then, we solved these field equations for vacuum spacetimes and obtain a number of new F(T) solutions. Finally, we have proposed some insights and aims for perfect fluids new possible F(T) solutions in some recent works.

Session 1.2 / 12

Invariant Characterization and its Applications

Author: Nicholas Layden[None]

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We begin by discussing the Cartan-Karlhede algorithm, and its use in characterizing spacetimes, through the aid of the Newman Penrose formalism. We then introduce some ideas based on the invariant properties of a spacetime, like the geometric horizon conjecture, and how such surfaces are defined in terms of Cartan scalars, and how these are sometimes connected with the conventional notion of a marginally outer trapping surface. We then discuss an application of the invariant characterization of the collapse of a spherically symmetric perfect fluid, which was solved numerically, and discuss the formation of a geometric horizon in this system, and how the numerics can be aided by the invariant characterization. We then conclude with a brief description of another of the Cartan scalars, based on a recent paper, discussing photon surfaces in arbitrary spacetimes.

Session 1.1 / 13

Distorted static black holes with a bubble

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

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We construct a family of local static, vacuum five-dimensional solutions with two commuting spatial isometries describing a black hole with an S^3 horizon and a 2-cycle 'bubble'in the domain of outer communications. The solutions are obtained by adding distortions to an asymptotically flat seed solution. We show that the conical singularities in the undistorted geometry can be removed by an appropriate choice of distortion.

Session 2.3 / 14

Effective group field theory metric for the universe

Authors: Lisa Mickel[1]; Steffen Gielen[1]

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Group field theory (GFT) is a background independent approach to quantum gravity that exhibits a rich phenomenology in the cosmological setting. In this talk we will explore a recent proposal that reconstructs an effective metric directly from the quantum theory. This is achieved by relating metric components to the expectation values of novel operators that are based on symmetries of the GFT action. The construction relies on a relational coordinate system spanned by four massless scalar fields. We will examine the effective metric of a flat homogeneous universe with perturbations.

Session 1.2 / 15

EIGENVALUE SPECTRUM OF STABILITY OPERATORS FOR MARGINALLY OUTER TRAPPED SURFACES IN WEYL-DISTORTED SCHWARZSCHILD BLACKHOLES

Author: Chiamaka Mary Okpala[1]

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Abstract:
Marginally outer trapped surfaces (MOTS) are surfaces from which outgoing light rays neither converge nor diverge. In recent years they have been found to be a key tool for understanding black hole geometries. In particular, the stability operator provides information as to whether the MOTS bounds a trapped region. This study investigates the eigenvalue problem associated with the stability operator for MOTS in the context of Weyl-distorted Schwarzschild solutions. By solving the eigenvalue problem, we aim to understand whether these solutions can always be understood as black holes

Session 2.2 / 16

Motivating semiclassical gravity: a classical-quantum approximation for bipartite quantum systems

Authors: Viqar Husain[1]; Irfan Javed[1]; Sanjeev Seahra[1]; Nomaan X[1]

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We derive a "classical-quantum"approximation scheme for a broad class of bipartite quantum systems from fully quantum dynamics. In this approximation, one subsystem evolves via classical equations of motion with quantum corrections, and the other subsystem evolves quantum mechanically with equations of motion informed by the evolving classical degrees of freedom. Using perturbation theory, we derive an estimate for the growth rate of entanglement of the subsystems and deduce a "scrambling time"—the time required for the subsystems to become significantly entangled from an initial product state. We argue that a necessary condition for the validity of the classical-quantum approximation is consistency of initial data with the generalized Bohr correspondence principle. We illustrate the general formalism by numerically studying the fully quantum, fully classical, and classical-quantum dynamics of a system of two oscillators with nonlinear coupling. This system exhibits parametric resonance, and we show that quantum effects quench parametric resonance at late times. Lastly, we present a curious late-time scaling relation between the average value of the von Neumann entanglement of the interacting oscillator system and its total energy: ⊠~2/3ln ⊠.

Session 1.4 / 17

GR and EDI

Author: Turkuler Durgut[None]

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Is GR open to EDI concepts? Are relativists considering inclusivity in their research and teaching? In this talk, I will try to draw a picture of GR with an EDI perspective and show my students' perspective as first-time relativity learners.

Session 2.2 / 18

Semiclassical Gravity on Effective Backgrounds

Author: Muhammad Muzammil[1]

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We study the classical-quantum (CQ) hybrid dynamics of homogeneous cosmology from a Hamiltonian perspective where the classical gravitational phase space variables and matter state evolve self-consistently with full backreaction. We compare numerically the classical and CQ dynamics for isotropic and anisotropic models, including quantum scalar-field induced corrections to the Kasner exponents. Our results indicate that full backreaction effects leave traces at late times in cosmological evolution; in particular, the scalar energy density at late times provides a potential contribution to dark energy. We also show that the CQ equations admit exact static solutions for the isotropic, and the anisotropic Bianchi IX universes with the scalar field in a stationary state.

Session 2.3 / 19

Group field theories: A view from below

Author: Hassan Mehmood[1]

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It is widely believed that quantum gravity should be background independent. Perhaps the most radical way to realize this is to imagine a quantum theory in which the abode of gravity, that is to say, the fabric of spacetime itself, becomes an emergent, rather than an inherent, entity. Group field theories constitute a concrete attempt at such a formulation of quantum gravity. However, in such theories, the question of what happens to central spacetime notions pertaining to the behavior of gravity as we know it, such as diffeomorphisms, becomes quite nontrivial. Equally of interest is to explore the connections of such theories with other known background-independent approaches to quantum gravity. We argue that free group field theory is a viable model to probe these questions, since it can be regarded as a quantum theory of an interesting toy model for gravity, namely the Husain-Kuchar model.

Session 2.3 / 20

Emergent Cosmology from Quantum Gravity

Author: Luca Marchetti[1]

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In this talk, I will show how cosmological physics emerge from the collective behavior of spacetime quanta within the Group Field Theory (GFT) approach to quantum gravity. In particular, I will review key aspects of the resulting quantum cosmological physics, including the resolution of the initial singularity into a quantum bounce, the presence of a purely quantum geometric inflationary mechanism, the deep connection between cosmological perturbations and quantum gravitational entanglement, and the effects of quantum gravity on the dynamics of these perturbations.

Session 1.3 / 21

The Proper Frame In Spherically Symmetric Teleparallel Geometries

Author: Hudson Forance[None]

Modified frameworks of gravity are of growing interest in the field of cosmology, $f(\mathrm{T})$-type gravity is one such framework, where instead of curvature, we use torsion as the fundamental source field for gravitational effects.

Expanding on former work, I present the local Lorentz transformation and the general proper frame for a class of spherically symmetric teleparallel geometries.
Starting with the diagonal frame and corresponding spin connection for a general spherically symmetric teleparallel geometry, a system of matrix partial differential equations is established using the transformation laws for the spin connection. Solving these equations yields a local Lorentz transformation which can be applied to the diagonal frame, bringing it to a purely inertial(proper) frame, where the spin connection vanishes and inertial effects are absent. The torsion and field equations are computed in the proper frame and compared to those found using the diagonal frame. Additionally, physically relevant sub-cases will be discussed.

Session 1.3 / 22

The Averaging Problem in the Teleparallel Equivalent to General Relativity

Author: Robert van den Hoogen[1]

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The construction of an averaged theory of gravity based on Einstein's General Relativity is challenging due in one part to the difficulty in defining a mathematically precise covariant averaging procedure for tensor fields over differentiable manifolds. Even if one is able to address the first problem, a second problem has to deal with the non-linear nature of the gravitational field equations. Together, these two ideas have been called the averaging problem. The Teleparallel Equivalent to GR offers us a promising alternative.

Session 2.4 / 23

What do we really know about quantum gravity?

Author: Viqar Husain[None]

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I will attempt a brief overview of a few ideas about quantum gravity and what they might reveal about a final theory.

Session 2.2 / 24

Entanglement in quantum cosmology

Author: Sanjeev Seahra[None]

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We investigate the quantum entanglement between spacetime geometry and matter during a quantum cosmological bounce and a subsequent possible inflationary period. We find that entanglement entropy does not monotonically increase in the early universe and is therefore not an "arrow of time", and that the emergence of a (semi-)classical inflating universe from a quantum gravity era is not guaranteed in the model we studied.

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Opening remarks

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Closing remarks