Atlantic GR 2022 : List of Contributed Abstracts

Geometry of embedded spacelike hypersurfaces

Abbas Mohamed Sherif
IBS Center for Geometry and Physics

We study the geometry of spacelike hypersurfaces via their conformal structure, embedded in spacetimes admitting a certain decomposition of their tangent spaces. The aim is to apply these global geometrical results to dynamical horizons in these spacetimes.

Binary black hole system at equilibrium

Adriano Viganò
Universit degli Studi di Milano

I present an exact solution of four-dimensional vacuum General Relativity, which represents a system of two black holes at equilibrium. The balance between the two black holes is granted by an external gravitational field, without the need of extra matter fields besides gravity, nor conical singularities. I analyse some geometric properties and the thermodynamics of the system, and briefly discuss the generalization to an arbitrary number of black holes and the accelerating version of the solution.

Very Special Linear Gravity: A gauge invariant Graviton mass

Alessandro Santoni
Pontificia Universidad Catlica de Chile

Linearized gravity in the Very Special Relativity (VSR) framework is considered. We prove that this theory allows for a non-zero graviton mass m_g without breaking gauge invariance nor modifying the relativistic dispersion relation. We find the analytic solution for the new equations of motion in our gauge choice, verifying as expected the existence of only two physical degrees of freedom. Finally, through the geodesic deviation equation, we confront some results for classic gravitational waves (GW) with the VSR ones: we see that the ratios between VSR effects and classical ones are proportional to $(m_g/E)^2$, E being the energy of a graviton in the GW. For GW detectable by the interferometers LIGO and VIRGO this ratio is at most 10^{-20}. However, for GW in the lower frequency range of future detectors, like LISA, the ratio increases signficantly to 10^{-10}, that combined with the anisotropic nature of VSR phenomena may lead to observable effects.

Local foliations of surfaces characterizing the center of mass.

Alejandro Penuela Diaz
University of Potsdam / Max Planck institute for gravitational physics

Inspired by the definition of center of mass given by Cederbaum and Sakovich and by the small sphere limit for quasi-local masses and, we study local foliations of constant spacetime mean curvature surfaces (surfaces characterizing the center of mass in general relativity) and also foliations of constant expansion surfaces. Using a Lyapunov Schmidt reduction in an hypersurface of a $N+1$-spacetime, we construct the foliations around a point, prove their uniqueness and show which conditions a point must fulfill to have a concentration of such surfaces. Joint work with J. Metzger.

Averaging and Stability analysis in Scalar Field Cosmologies

Alfredo Millano
Universidad Catlica del Norte

In this presentation we apply tools from ODE Theory, Singular and regular Perturbation Theory and Averaging Theory to Scalar Field Cosmologies and problems modeled by ODE's with oscillatory behaviour. We show the failure of the regular perturbation theory approach and apply averaging methods to show that the solutions of the "averaged" dynamical systems behave in the same way as the solutions of the "original" dynamical systems. We present results for different models including: Open, closed and flat FLRW, Bianchi I,III and Kantowski-Sachs.

Fractional Newtonian Gravity and Galactic Dynamics

Andrea Giusti
ETH Zurich

In this presentation I provide a derivation of some characteristic effects of Milgrom?s modified Newtonian dynamics (MOND) from a fractional version of Newton?s theory based on the fractional Poisson equation. Specifically, I employ the properties of the fractional Laplacian to investigate the features of the fundamental solution of the proposed model. Then, taking advantage of the Tully-Fisher relation, as the fractional order s approaches 3/2, I relate the typical length scale emerging from this modification of Newton?s gravity with the critical acceleration a0 of MOND. Finally, I explain the need for a variable-order version of the proposed model in order to properly capture the phenomenology of galactic dynamics.

Tidally perturbed isolated horizons

Ariadna Ribes Metidieri
Radboud University

It is generally believed that tidal deformations of a black hole in an external field, measured using the gravitational field multipoles, vanish. However, this does not mean that the black hole horizon is not deformed. In this talk, I shall discuss the deformations of a black hole horizon in the presence of an external field using a new method based on the characteristic initial value formulation. Unlike standard methods, the starting point here is the black hole horizon itself. The presence of the companion binary responsible for the tidal deformation is encoded on the geometry of the spacetime in the vicinity of the horizon, which is obtained by integrating the Einstein fields equations analytically outwards starting from the horizon. This method yields a powerful reformulation of black hole perturbation theory in a neighborhood of the horizon, which is quasi-local, geometrical, and completely general. For instance, by specializing the horizon geometry to be a perturbation of Kerr yields the metric for a tidally deformed Kerr black hole with arbitrary spin.

Aspects of the standard model from a new spacetime geometry

Charlie Beil
University of Graz

I will present an approximate spacetime model of quantum theory based on a new geometry where time does not advance along the worldlines of dust particles. In this framework, the tangent vector along such a worldline is replaced by its Hodge dual 3-form. I will show how this implies that dust particles have spin 1/2, and how the orientation of the 3-form may be associated with electric charge. This identification gives rise to a free Dirac Lagrangian with a new adjoint spinor. I will describe how this Lagrangian in turn gives rise to a composite model of the standard model particles.

Theories of non-linear electrodynamics: solutions beyond spherical symmetry

David Kubiznak
Charles University

After reviewing some basic facts about theories of non-linear electrodynamics, I will discuss recent progress towards obtaining their self-gravitating solutions that go beyond spherical symmetry.

Shock Waves in Quantum Black Holes: Numerics

Edward Wilson-Ewing
University of New Brunswick

I will present some numerical solutions for the quantum gravitational collapse of spherically symmetric pressureless dust. Using an effective equation derived from a loop quantization, for a variety of initial dust configurations the numerical solutions show 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.

Probing new physics on the horizon of black holes with gravitational waves

Elisa Maggio
Imperial College London

Black holes are the most compact objects in the universe. According to general relativity, black holes have a horizon that hides a singularity where Einstein?s theory breaks down. Recently, gravitational waves opened the possibility to probe the existence of horizons and investigate the nature of compact objects. This is of particular interest given some quantum-gravity models which predict the presence of horizonless and singularity-free compact objects. Such exotic compact objects can emit a different gravitational-wave signal relative to the black hole case. In this talk, we infer how extreme mass-ratio inspirals observable by future gravitational-wave detectors will allow for model-independent tests of the black hole paradigm.

Slowly rotating black holes and exact hidden symmetries

Finnian Gray
Perimeter Institute/University of Waterloo

We present a novel family of slowly rotating black hole solutions in four, and higher dimensions, that extend the well known Lense-Thirring spacetime and solve the field equations to linear order in rotation parameters. This generalization lets us study slowly rotating spacetimes in various higher curvature gravities as well as in the presence of non-trivial matter. As "exact metrics" in their own right, the new (non-vacuum) spacetimes feature the following two remarkable properties: i) near the black hole horizon they can be cast in the, manifestly regular, Painlevé-Gullstrand form and ii) they admit exact Killing tensor symmetries. Remarkably, in higher dimensions the novel generalized Lense-Thirring spacetimes provide a first example of a physical spacetime with more hidden than explicit symmetries. Finally we show that in four dimensions Einstein gravity is the only non-trivial theory amongst all up to quartic curvature gravities that admits a Lense–Thirring solution characterized by a single metric function.

Time-averaging axion-like interacting scalar fields models

Genly León Torres
Universidad Católica del Norte

We study a cosmological model inspired in the axionic matter with two canonical scalar fields ϕ_1 and ϕ_2 interacting through a term added to its potential. Introducing novel dynamical variables, and a dimensionless time variable, the resulting dynamical system is studied. The main difficulties arising in the standard dynamical systems approach, where expansion normalized dynamical variables are usually adopted, are due to the oscillations entering the nonlinear system through the Klein?Gordon (KG) equations. This motivates the analysis of the oscillations using methods from the theory of averaging nonlinear dynamical systems. We prove that time-dependent systems, and their corresponding time-averaged versions, have the same late-time dynamics. Then, we study the time-averaged system using standard techniques of dynamical systems. We present numerical simulations as evidence of such behaviour.

Towards a viable compact-object scalarization model

Georgios Antoniou
University of Nottingham

A reasonable extension to the theory of general relativity involves the introduction of an extra degree of freedom in the form of a scalar field. It has been shown that very compact objects can exhibit a phenomenon known as spontaneous scalarization in which they spontaneously develop a non-trivial scalar hair profile. In this talk we discuss recent progress made towards the direction of a viable scalarization model, describing stable solutions while being compatible with cosmological observations.

Page Curves of Reissner-Nordström Black Hole in HD Gravity

Gopal Yadav
Indian Institute of Technology Roorkee

We obtain the Page curves of an eternal Reissner-Nordström black hole in the presence of higher derivative terms in four dimensions. We consider the two cases: gravitational action with general $\mathcal{O}(R^2)$ terms plus Maxwell term and Einstein-Gauss-Bonnet gravity plus Maxwell term. In both the cases entanglement entropy of the Hawking radiation in the absence of island surface increases linearly with time. After including contribution from the island surface, we find that after the Page time entanglement entropy of the Hawking radiation in both the cases reaches a constant value which is the twice of the Bekenstein-Hawking entropy of the black hole and we obtain the Page curves. Further we find that Page curves appear at later or earlier time when the Gauss-Bonnet coupling increases or decreases. As a consistency check, in the limit of vanishing GB coupling we obtain the Page curve of the Reissner-Nordström black hole obtained in arXiv:2101.06867.

Trapped gravitational waves in Jackiw Teitelboim gravity

Ido Ben-Dayan
Ariel University, UC Berkeley

We discuss the possibility that gravitational fluctuations ("gravitational-waves") are trapped in space by gravitational interactions in two dimensional Jackiw?Teitelboim gravity. In the standard geon (gravitational electromagnetic entity) approach, the effective energy is entirely deposited in a thin layer, the active region, that achieves spatial self-confinement and raises doubts about the geon's stability. In this paper we relinquish the "active region" approach and obtain self-confinement of "gravitational waves" that are trapped by the vacuum geometry and can be stable against the backreaction due to metric fluctuations.

Nonperturbative backreaction models: lessons for quantum gravity

Irfan Javed
University of New Brunswick

Between the regimes of quantum gravity and quantum fields on curved spacetime, there is an intermediate semiclassical regime where classical gravity is dynamically coupled to quantum matter. This is an example of a classical-quantum system. I will describe a toy model that provides some lessons for semiclassical and quantum gravity.

Beyond the Zel'dovich Approximation in relativistic cosmology

Ismael Delgado Gaspar
National Centre for Nuclear Research

Motivated by the correspondence between the Relativistic Zel'dovich Approximation (RZA) and Szekeres Class II exact solutions, we propose a generalization of RZA that includes the entire Szekeres family. In contrast to RZA, which retains a global cosmological background, the proposed method contains a space-dependent reference model obeying Friedmann-like evolution equations. The overall approach is then interpreted as the evolution of a deformation field on an inhomogeneous Friedmann-like reference model that includes backreaction. In this scheme, the most relevant exact cosmological solutions emerge as particular sets of the initial data. Finally, some numerical examples illustrate the application potential of this approach.

Cosmological tensions guiding the path beyond LCDM

Jann Zosso
ETHZ

Cosmology is one of the most promising testing grounds for fundamental physics and in recent years the growing evidence for the mismatch between the value of the Hubble constant H0 inferred from the CMB and the value measured by theory independent local measurements could indeed seriously require a departure form the GR based LCDM cosmological standard model. While an abounding amount of models have already been proposed to address this so called H0-tension, many of these alternatives are not viable at a closer look and in particular alleviate the H0-tension only at the cost of increasing the tension with other cosmological parameters, such as the clustering amplitude sigma8. After pedagogically introducing the H0 and sigma8 tensions, I will present in this talk recent work in which we derive generic analytical conditions any late-time modification to LCDM must satisfy in order to simultaneously solve both these tensions. Our model independent approach therefore provides necessary requirements which can be viewed as preliminary guiding principles towards a consistent extension of the cosmological standard model with the hope of discovering the next steps in fundamental physics.

Quantum gravity of dust collapse

Jarod Kelly
University of New Brunswick

In this talk, I will present a model for the quantum dynamics of spherically symmetric pressureless dust collapse. Starting from a canonical description of the system (in Ashtekar variables), the model is derived via a polymer quantization based on loop quantum cosmology that incorporates fundamental discreteness. Using one of the analytical solutions of the effective equation derived from this quantization, I will demonstrate some of the main features of the model including: singularity resolution and a black hole lifetime proportional to the square of its mass.

Zero-damped Modes and Nearly Extremal Horizons

Jason Joykutty
University of Cambridge

Quasinormal modes are the gravitational wave analogue to the overtones heard after striking a bell. They dominate the signal observed during the ringdown phase after a dynamical event and are characterised by complex frequencies, which encode oscillation and exponential decay in time. As horizons become extremal, various computations (both analytic and numerical) have shown that in many cases, there exists a sequence of frequencies which become purely oscillatory in the limit and cluster on a line in the complex plane. These are zero-damped modes and are conjectured to exist generically for near-extremal horizons. In this talk, we shall discuss results that can be obtained toward resolving this question; for example, one can show that these modes do arise for the conformal Klein-Gordon equation on a class of spherically symmetric black hole spacetimes.

Allowable complex metrics in quantum cosmology

Jerome Quintin
Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam

A contemporary challenge when attempting to perform gravitational path integrals in minisuperspace quantum cosmology is to determine the physically relevant and appropriate saddle points and integration contours. This is a quantum problem, where the usual Lorentzian metric of classical general relativity can now be complex. However, not all complex metrics in quantum physics lead to a physically meaningful action for matter fields. This results in a bound (known as the Kontsevich-Segal bound) on the complex arguments of the diagonal elements of the metric, whose implications in quantum gravity are only starting to be explored. In quantum cosmology, it was realized that the Kontsevich-Segal bound has the potential of resolving many issues with regard to which integration contours may or may not be allowed when performing path integrals. I will present our recent developments on this topic for various models (no-boundary, de Sitter, FLRW).

Schrödinger symmetry in black hole mechanics

Jibril Ben Achour
Arnold Sommerfeld Center for Theoretical Physics - LMU - Munich

In this talk, I will discuss recent results revealing new conformal symmetries in black hole mechanics. These new symmetries provide a new algebraic point of view on the black hole geometry and its thermodynamical (or fluid) interpretation. Along this talk, I will focus on the Schwarzschild-(A)dS system. First, I will show that the Schwarzschild mechanics possesses a hidden dynamical conformal symmetry under the two dimensional Schrodinger group. This new symmetry fully encodes the geometry of both the exterior and the interior of the black hole. I will then present a new map which allows one to generate the Schwarzschild-(A)dS mechanics from the Schwarzschild one, and I will discuss how the symmetry is affected when turning on the cosmological constant. I will also comment on the interpretation of the central charge in this context. This talk is based on ArXiv:2110.01455 [gr-qc] and on-going work.

The dynamics of scalar-field Quintum cosmological models

Jonathan Tot
Dalhousie University

We present a complete (compactified) dynamical systems analysis of the Quintom model comprised of an interacting quintessence scalar field and a phantom scalar field. We find that there is a range for the model parameters ?, ? such that there are expanding Quintom cosmologies that undergo two inflationary periods, and that this behaviour is not destabilized by spatial curvature. We also discuss a class of bouncing cosmologies.

The curious case of the Buchdahl-Land-Sultana-Wyman-Ibaez-Sanz spacetime

Jose Sonia
Bishop's University

We revisit Wyman's "other" scalar field solution of the Einstein equations and its Sultana generalization to positive cosmological constant, which has a finite 3-space and corresponds to a special case of a stiff fluid solution proposed by Buchdahl and Land and, later, by Ibaez and Sanz to model relativistic stars. However, there is a hidden cosmological constant and the peculiar geometry prevents the use of this spacetime to model relativistic stars.

The Holst action is just GR

Juan Margalef
Memorial University of Newfoundland

In this talk I will introduce a generalization of the Holst action in manifolds with timelike boundaries (both in the metric and tetrad formalism), where we consider a completely general connection i.e. with nonmetricity and torsion. I will prove that its space of solutions is equal to the one given by the Palatini action which in turn is equal, up to some gauge degeneracy, to standard GR. This is somewhat surprising since the Palatini and (the generalized) Holst Lagrangians are not cohomologically equal! In particular, despite having the same space of solutions, their presymplectic structure and charges provided by the Covariant Phase Space method might differ. However, using the relative bicomplex framework, I will show their on-shell equivalence, clarifying some open problems regarding dual charges and their equivalence in different formulations.

Appearance (and disappearance) of self-intersecting surfaces in black holes

Kam To Billy Chan
Memorial University of Newfoundland

The advent of gravitational wave detectors had facilitated a constant stream of black hole merger observations. Despite this, black hole mergers are not fully understood. The details of the two apparent horizons becoming one is unclear due to the non-linear nature of the merger process. Recent numerical work has shown that there is an appearance of self-intersecting marginally outer-trapped surfaces (MOTS) during the black hole merger [Pook-Kolb et. al. arXiv:1903.05626]. Following papers have found similarly behaving MOTS in a simpler and static scenario, that of a Schwarzschild black hole, where a seemingly infinite number of self-intersecting MOTS were found [Booth et. al., arXiv:2005.05350]. This talk introduces new phenomena that occur in the presence of an inner horizon. For Reissner-Nordstrom and Gauss-Bonnet black holes, we find that the maximum number of self-intersections becomes finite with the MOTS parameter space deeply dependent on the interior structure of the black hole and in particular the stability of the inner horizon [Hennigar et. al., arXiv:2111.09373].

Nonspherical gravitational collapse

Karim Mosani
BITS Pilani, Goa

We investigate here the final state of gravitational collapse of a non-spherical and non-marginally bound dust cloud as modelled by the Szekeres spacetime. We show that a directionally globally naked singularity can be formed in this case near the collapsing cloud boundary, and not at its geometric center as is typically the case for a spherical gravitational collapse. This is a strong curvature naked singularity in the sense of Tipler criterion on gravitational strength. The null geodesics escaping from the singularity would be less scattered in this case in certain directions since the singularity is close to the boundary of the cloud as is the case in the current scenario. The physical implications are pointed out.

A simple proof of Birkhoff's theorem for Gauss Bonnet gravity

Kristin Schleich
University of British Columbia

A simple proof of the generalization of Birkhoff?s theorem to Einstein-Gauss-Bonnet gravity in n dimensions is provided for all values of the cosmological constant and Gauss-Bonnet coupling constant.

Gauging the CPT Symmetry as an Extension of General Relativity

Kurt Koltko
Independent Theoretical Physicist

We outline the gauge theory of CPT transformations as a natural extension of general relativity (GR). First, we discuss the motivation: 1) The global CPT symmetry physically exists. 2) Because CPT is born from the union of special relativity with quantum theory, it would seem natural to view this as a "bridge" between GR and quantum theory and, therefore, include local CPT when gauging Lorentz transformations. This results in a natural (not ad-hoc) complex extension of the spin connection formulation of GR. Second, we discuss the derivation of the two fundamental local CPT transformations acting on vierbein and Dirac spinors. Finally, we discuss the reasons for the choice of Lagrangian and present the field equations for the extended spin connection.

The evolution of marginally stable MOTS in spherically symmetric spacetimes

Liam Bussey
Memorial University of Newfoundland

The definition of a black hole is global and requires knowledge of the full evolution of the spacetime. In practice, one uses a quasi-local characterization called a marginally

outer trapped surface (MOTS) that captures the idea that a horizon is the boundary of a region from which light cannot escape, and frames black holes in an initial data formulation. This characterization provides a framework to study the time evolution of dynamical black holes.

Recent numerical works simulating a black hole merger event have observed that as two disjoint MOTSs corresponding to the distinct black holes get closer, they influence each other and cause bizarre phenomena such as the MOTSs merging or the sudden appearance of a common outer horizon enclosing the original MOTSs. Although such behaviour has been observed numerically, they correspond to non-smooth evolutions of the MOTS and are not well understood analytically. In this talk, while working in the context of a spherically symmetric spacetime, I will construct a necessary geometric condition for such non-smooth evolutions.

Self-Intersecting Surfaces Within a Static Black Hole With Kruskal-Szekeres Extension

Liam Newhook
Memorial University of Newfoundland

Black hole mergers have become a popular research area in general relativity with the detection of gravitational waves. The evolution of which two horizons become one during the merger is not well understood. While numerically computing marginally outer-trapped surfaces (MOTS) to clarify this process, self-intersecting MOTS were found and play a key role [Pook-Kolb et. al. arXiv:1903.05626]. Examining a single, static, black hole then led to the discovery of an infinite amount of self-intersecting MOTS [Booth et. al., arXiv:2005.05350]. Further work has shown that these surfaces are more robust than simply artifacts of the coordinate system [Hennigar et. al., arXiv:2111.09373]. This talk presents results found when examining the maximal extension to the Schwarzschild black hole, the Kruskal-Szekeres extension. This set of coordinates features an Einstein-Rosen bridge of which the self-intersecting MOTS stretches into and through the wormhole, depending on the size of the wormhole throat.

Evolution of exotic MOTS in an accreting black hole

Matin Tavayef
Memorial University of Newfoundland

Marginally outer trapped surfaces (MOTS), (closed surfaces of vanishing outward null expansion) provide a useful tool to study the local and global dynamics of black holes. They can be used both to locate black hole boundaries as well as study their internal geometry. Understanding the evolution of these objects can play an important role in understanding realistic black dynamics: in particular their complex dynamics has recently been studied in black mergers. In this talk, I summarize a method that can be used to identify axisymmetric MOTSs with arbitrarily complicated geometries in arbitrary axisymmetric spacetimes. Using this method, I find new MOTSs in dynamical

Lemaitre-Tolman-Bondi spacetimes, focusing on the case of a large dust shell falling into an existing black hole. I will present the evolution of the many MOTS (both standard and exotic) that can be observed during this process.

The Third Way to Gauge and Gravitational Theories

Matteo Broccoli
Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

In three spacetime dimensions certain gravitational and gauge theories are 'third way' consistent. This means that their equations of motion are only on-shell consistent and do not come from the variation of an action which contains the dynamical field alone. Although this mechanism is not special to 3d, no higher dimensional third way consistent theory was known. In this talk, I will introduce the third way by presenting the 3d theories and show how we recover them by shifting a flat gauge connection. Applying the same method in higher dimensions, we find a new class of interacting $(d-2)$-form theories and I will discuss various generalisations of them. Our result proves that the third way can be realised in dimensions higher than three, and I will conclude by discussing the possibility of constructing new third way consistent theories of gravity.

Cosmological Constraints on First-Order Phase Transitions

Mrunal Korwar
University of Wisconsin-Madison

First-order phase transitions exist in many models beyond the Standard Model and can generate detectable stochastic gravitational waves for a strong one. Using the cosmological observables in big bang nucleosynthesis and cosmic microwave background, we derive constraints on the phase transition temperature and strength parameter in a model-independent way. For a strong phase transition, we find that the phase transition temperature should be above around 2 MeV for both reheating photon and neutrino cases. For a weak one with the temperature below 1 MeV, the phase transition strength parameter is constrained to be smaller than around 0.1. Implications for using a first-order phase transition to explain the NANOGrav observed gravitational wave signal are also discussed.

Spacetime entanglement entropy with examples

Nomaan X
University of New Brunswick

A manifestly covariant "spacetime entanglement entropy" will be discussed. This formulation is useful in working with spacetime regions as opposed to spacelike Cauchy surfaces and might be an alternative to the Ryu - Takayanagi formulation. Some exam-

ples of it's application to free scalar field theory in Minkowski, de Sitter and de Sitter - Schwarzschild spacetimes will be shown.

Type V singularities in non-standard cosmological backgrounds

Oem Trivedi
Ahmedabad University

While there has been an expansive literature which has discussed the occurrence of Type I-IV singularities in many non-standard cosmologies, w/Type V singularities have not yet been explored in exotic cosmological settings. So in this work we pursue the same and discuss the occurrence of w-singularities in a variety of non-standard cosmologies. We consider the RS-II Braneworld cosmology, an F(R) gravity cosmology which gives viable late time acceleration and we also consider cosmologies due to modified area-entropy relations, generalized uncertainty principles, holographic renormalization and Chern-Simons gravity(all of which can be coincidentally described by the same form of the modified Friedmann equation). We show that w-singularities will occur in exactly the same conditions in all these cosmological settings as they do in the usual general relativistic cosmology if one considers a power series expansion ansatz for the scale factor. We also show that if one considers an exponential form of the scale factor then almost the same results hold, except there is a significant difference in the occurence conditions when one considers the f(R) gravity case.

Cosmological Standard Timers from Unstable Primordial Relics

Qianhang Ding
The Hong Kong University of Science and Technology

We study a hypothetical possibility of tracking the evolution of our Universe by introducing a series of the so-called standard timers. Any unstable primordial relics generated in the very early Universe may serve as the standard timers, as they can evolve through the whole cosmological background until their end while their certain time-varying properties could be a possible timer by recording the amount of physical time elapsed since the very early moments. Accordingly, if one could observe these quantities at different redshifts, then a redshift-time relation of the cosmic history can be attained. To illustrate such a hypothetical possibility, we consider the primordial black hole bubbles as a concrete example and analyze the mass function inside a redshifted bubble by investigating the inverse problem of Hawking radiation. To complete the analyses theoretically, the mass distribution can serve as a calibration of the standard timers.

A comprehensive study of Modulation effects on CMB Polarization

Rahul Kothari
The University of the Western Cape

The Cosmic Microwave Background is characterized by temperature and linear polarization fields. Dipole modulation in the temperature field has been extensively studied in the context of hemispherical power asymmetry. In this article, we show that a dipole modulation, and in general, any kind of modulation isn't allowed in the E and B modes. This is the main result of this paper. This result explains why no evidence of modulation in E mode has been found in the literature. On the contrary, the linear polarization fields Q and U have no such restrictions. We show that modulation under certain situations can be thought of as local $U(1)$ gauge transformations on the surface of a sphere. As far as the modulation function is concerned, we show that physical considerations enforce it to be (i) a spin 0 field and (ii) a scalar under parity. As masking is a specific type of modulation, our study suggests that a direct masking of E mode isn't also possible. Masking in E map can only be applied through Q and U fields. This means that in principle, leaking of E and B mode powers into each other is unavoidable.

Canonical Description of LTB Spacetimes

Robert Santacruz
University of New Brunswick

Lemaitre-Tolman-Bondi models describe the dynamics of a pressureless dust in spherically symmetric spacetimes. This system is widely known and used in models of dust collapse. In this talk, we will describe this scenario using a canonical formalism via Ashtekar Variables. In such a formalism, diffeomorphism invariance is encoded in certain constraints that conform the Hamiltonian. Nonetheless, the implementation of several Gauge Fixings in the theory will let us trivialize these constraints and retrieve a certain class of spacetimes known as marginally trapped solutions. The aim here will be: introduce a canonical description of gravity and show that we can simplify the theory avoiding the constraints.

Generalizations of Painleve-Gullstrand Coordinates

Robie Hennigar
University of Barcelona

While there has been an expansive literature which has discussed the occurrence of Type I-IV singularities in many non-standard cosmologies, w/Type V singularities have not yet been explored in exotic cosmological settings. So in this work we pursue the same and discuss the occurrence of w-singularities in a variety of non-standard cosmologies. We consider the RS-II Braneworld cosmology, an F(R) gravity cosmology which gives viable late time acceleration and we also consider cosmologies due to modified area-

entropy relations, generalized uncertainty principles, holographic renormalization and Chern-Simons gravity(all of which can be coincidentally described by the same form of the modified Friedmann equation). We show that w-singularities will occur in exactly the same conditions in all these cosmological settings as they do in the usual general relativistic cosmology if one considers a power series expansion ansatz for the scale factor. We also show that if one considers an exponential form of the scale factor then almost the same results hold, except there is a significant difference in the occurence conditions when one considers the f(R) gravity case.

Quantum gravitational corrections to the entropy of black holes

Ruben Campos Delgado
University of Bonn

This talk is mainly based on my publication
`https://link.springer.com/article/10.1140/epjc/s10052-022-10232-0`.

Underdamped Axionic Blue Isocurvature Perturbations

Sai Chaitanya Tadepalli
University of Wisconsin-Madison

Previous computations of strongly blue tilted axionic isocurvature spectra were computed in the parametric region in which the lightest time-dependent mass is smaller than the Hubble expansion rate during inflation, leading to an overdamped time evolution. Here, we present the strongly blue tilted axionic isocurvature spectrum in an underdamped time evolution parametric regime. Somewhat surprisingly, there exist parametric regions with a strong resonant spectral behavior that leads to rich isocurvature spectral shapes and large amplitude enhancements. We focus on computing this resonant spectrum analytically in parametric regions amenable to such computations. Because the spectrum is sensitive to nonperturbative classical field dynamics, we will focus on a wide variety of analytic techniques that are used like decoupling, nonlinear field redefinition, a time-space effective potential obtained by integrating out high-frequency fluctuations, and a piecewise mass-model.

On dynamical system approaches in f(R) gravity

Saikat Chakraborty
North-West University, South Africa

Dynamical system formulation is an important qualitative tool now widely used in cosmology to understand the cosmological solution space of a theory. A number of dynamical system formulations have been proposed over the last few years to analyse cosmological solutions in f(R) gravity. I will try to give a brief introduction to the different approaches, presenting them in a chronological order as they appeared in the history of the relevant scientific literature. I will particularly illuminate how the shortcoming(s) of an existing formulation encouraged the development of an alternative formulation. I will also try to emphasize the utility of the dynamical system formulation in to study various aspects of cosmological perturbations.

Marginally Outer Trapped (Open) Surfaces in 5D Rotating Spacetimes

Sarah Muth
Memorial University of Newfoundland

In astrophysically realistic black holes ? for instance, binary black hole mergers ? the surface of most obvious interest is the Event Horizon. However, this surface is often computationally difficult to locate due to its global definition. Instead, it is useful to turn to quasi-local characterizations of black hole boundaries, such as Marginally Outer Trapped Surfaces (MOTS), which have the benefit of being defined for a single time slice, while the outermost of which is also (generally) the apparent horizon. My talk will describe work which seeks to understand MOTS in the interior of five-dimensional black holes; in particular, I will focus on our results in studying the rotating case (Myers-Perry). Similar to the four-dimensional Schwarzschild case studied by my collaborators, and the five-dimensional static case I presented last year, we find self-intersecting MOTS, and in doing so provide further support for the claim that self-intersecting behavior is rather generic. I will conclude by discussing new oscillating MOTS-like surfaces, first seen in this study of 5D rotating black holes, and now reproduced for other types of rotating black holes in other dimensions.

Probing quantum effects near black hole with gravitational wave

Sayak Datta
Albert Einstein Institute, Hannover

I will discuss the impact of the quantum effects near black holes on the gravitational waves emitted by an inspiring binary black hole. These contributions manifests via tidal effects. According to Bekenstein?s quantization, we find that black hole area discretization can have observable imprints on the gravitational wave signal from an inspiraling binary black hole. We model the absorption lines and compute gravitational wave flux due to tidal heating in such a case. By including the quantization we find the dephasing of the gravitational wave. We discuss the observability of the phenomena in different parameter ranges of the binary. We discuss that it can be used to rule out area quantization with GW. Alongside I will also discuss how tidal deformability also can shed light on the quantum effects near horizon. This talk will be primarily based on PhysRevD.104.124062 and arXiv:2107.07258.

Probing Black Holes with Quasi-Normal Modes and Shadows

Sebastian Völkel
SISSA & IFPU

Ongoing improvements of the LIGO-Virgo-KAGRA gravitational wave detectors and the Event Horizon Telescope will allow to test gravity in complementary ways. In this talk I will outline how gravitational waves, in particular quasi-normal modes, and images of black holes can in principle be used to infer possible deviations from general relativity. Special attention will be devoted to the role of so-called theoretical priors that enter theory agnostic, as well as theory specific frameworks. Bounds and correlations that can be found for different parametrizations are quantified using principal component analysis (PCA) and Markov-chain Monte Carlo (MCMC) techniques.

The talk is based on a series of recent and ongoing works on the topic [1,2,3].

[1] SV and Enrico Barausse, Phys.Rev.D 102 (2020) 8, 084025, https://arxiv.org/abs/2007.02986

[2] SV, Enrico Barausse, Nicola Franchini and Avery E. Broderick, Class.Quant.Grav. 38 (2021) 21, 21LT01, https://arxiv.org/abs/2011.06812

[3] SV, Nicola Franchini and Enrico Barausse, Phys.Rev.D 105 (2022) 8, 084046, https://arxiv.org/abs/2202.08655

The meaning of speed of light in the FLRW universe

Seokcheon Lee
Sungkyunkwan University

This is a review of the speed of light both in Minkowski spacetime and in the Friedmann-Lemaitre-Robertson-Walker universe. The local Lorentz frame is defined simply as a lattice of space and time coordinates. Anything that happens (i.e., an event) is automatically assigned space and time coordinate in every frame, independent of any observer. Any finite interval can be built up from a series of many infinitesimal ones. Sometimes unclear notation between finite and infinitesimal causes confusion to define the speed of light in the local Lorentz frame. We make this clear in this review.

A new approach to the thermodynamics of modified gravity

Serena Giardino
Max Planck Institute for Gravitational Physics

Jacobson showed that the Einstein equations can be derived as an equation of state, leading to the identification of GR with an equilibrium state of gravity and f(R) gravity with a non-equilibrium one. This breakthrough made the relationship between gravity and thermodynamics even more intriguing. I will present a new approach to the thermodynamics of modified gravity which is inspired by these results, but follows a starkly different path, starting with minimal assumptions. Specifically, I will describe how an understanding of the approach to the equilibrium state, missing in the thermodynamics of spacetime approach, naturally emerges from the application of Eckart's first-order irreversible thermodynamics to the effective dissipative fluid describing scalar-tensor gravity.

Spherical Einstein Field Equations on Hyperboloidal Slices

Shalabh Gautam
International Centre for Theoretical Sciences (ICTS), Bengaluru, India

One of the challenges in numerical relativity is to include future null infinity in the computational domain with a well-posed formulation. Success will not only enable us to evolve any system of astrophysical interest, e.g. binary black holes and extracting the gravitational wave signal at future null infinity, with any desired accuracy, but also help in studying various phenomena of fundamental interest. One proposal is to use hyperboloidal slices. In this talk, I will present our ongoing efforts for obtaining a well-posed formulation of the Einstein Field Equations on hyperboloidal slices, all in spherical symmetry. The natural extension will be to generalize these methods to full 3d.

The characteristics of the remnant from compact binary mergers.

Sourav Roy Chowdhury
Southern Federal University

The binary black hole coalescences GW150914 and GW151226 observed by the LIGO started the era of gravitational-wave astronomy. It enabled us to investigate gravity in the strong-field regime. During the second half of the third observing run (O3b), 35 compact binary coalescence candidates were identified. One of the critical issues was determining the final mass and spin of the compact binary coalescences' remnant. We present the analytical model with nonprecessing spins. Within a parametric range, we define a model that predicts the final mass as well as the spin of the system. The remnant of compact binary coalescences of the third observation has been researched extensively. In addition, we also surveyed the rotational energy of the merger. A circular binary is used to calculate the changes in the black hole's mass, spin, and horizon area as it spirals.

The Strong Cosmic Censorship Conjecture in Anti-de Sitter Spacetimes

Subhodeep Sarkar
Indian Institute of Information Technology, Allahabad

Determinism is the cornerstone of any successful theory of nature. The internal structure of black holes holds the key to answering this question of determinism in general relativity which is supposedly guaranteed by the Strong Cosmic Censorship (SCC) conjecture. It is therefore imperative to use theoretical tools to probe the stability of the inner horizons of various black holes and verify if SCC is indeed respected. Over the years, we have gained reasonable experience in this area, and have managed to answer the question in the context of asymptotically flat and de Sitter spacetimes. We have turned our attention to anti-de Sitter (AdS) spacetimes fairly recently. In this talk, I will discuss the validity of SCC in $(2+1)D$ and $(1+1)D$ AdS spacetimes. We will see that a non-extreme BTZ black hole respects cosmic censorship. A simple toy mass inflation model is able to capture the subtle physics involved near the Cauchy horizon. We also show how similar considerations hold for 2D AdS black holes in JT gravity. Along the way, we shall also mention how one can analytically compute the quasinormal mode frequencies of 2D AdS black holes.

Family of solutions for the null-surface formulation of general relativity

Tina Harriott
Mount Saint Vincent University

The null surface formulation (NSF) is equivalent to standard general relativity but uses null surfaces, instead of a metric or a connection. These are specified by a function Z, which depends on the spacetime coordinates. The field equations of the NSF form a coupled system of highly nonlinear partial differential equations and are extremely

challenging to solve exactly, with only three solutions having so far been found. Here, the assumption that the solution be additively separable is shown to be naturally adapted to the structure of the NSF. Using this assumption, a new family of solutions is derived. The eigenvalues of the Cotton-York tensor are presented and it is shown how the associated general relativistic spacetimes cover a range of Petrov types: I, II, and D. Two of the previously known solutions are shown to be special cases. For one solution, the function Z that specifies the surfaces is explicitly constructed. The physical interpretation is discussed, and possible sources are examined. The assumption of additively separability opens up the possibility of generalization to 3+1?where no NSF solutions have been found to date. This possibility is also discussed.

New BPS Gravitational Solitons in Anti-de Sitter Spacetimes

Turkuler Durgut
Memorial University of Newfoundland

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.

Recent progress in the thermodynamics of scalar-tensor gravity

Valerio Faraoni
Bishop's University

A new approach describes general relativity as the zero-temperature state of gravity, while scalar-tensor (including Horndeski) gravity is an out-of-equilibrium state. The "temperature of gravity" and its "diffusion" toward the GR equilibrium are described using Eckart's thermodynamics for the effective imperfect fluid obtained by rewriting the scalar-tensor field equations as effective Einstein equations. Thus far, the new formalism has been applied to Horndeski gravity, FLRW cosmology, non-GR (trivial) equilibrium states, and black holes, and shown to remain consistent. These aspects will be briefly reviewed.

A tale of quantum black holes

Viqar Husain
University of New Brunswick

Quantum gravity should resolve spacetime curvature singularities. If so, gravitational collapse with singularity avoidance should look very different from classical physics. I will survey past ideas and describe a new picture of a dynamical quantum black hole.

Can One Hear the Shape of a Quantum Spacetime?

Yasaman Yazdi
Imperial College London

Spectral geometry offers a new and powerful means to describe quantum spacetimes using the spectra of operators defined on them. I will review the study of Lorentzian spectral geometry using discrete spacetimes in the framework of causal set quantum gravity. I will discuss what geometric information can be gleaned from the spectra of various operators on causal sets describing various spacetimes. I will show recent results indicating that one can "hear" a spacetime's dimension and manifoldlike nature.