Atlantic General Relativity Meeting 2021

Bishop's University, Sherbrooke 25-29 May 2021

ABSTRACTS

MINI-COURSES

Entering the Era of Black Hole Observations: Black Hole Imaging, Gravitational Waves, and Multi-messenger Astrophysics

Daryl Haggard (McGill University)

This short course will focus on recent advances in astrophysical observations of black holes. In the first half, we will discuss the Event Horizon Telescope discovery images of M87*, the supermassive black hole in the Virgo Cluster's brightest cluster galaxy, alongside recent polarization and multi-wavelength observations. We will also discuss how future observations of Sgr A* and a larger population of supermassive black holes targeted by EHT and the next generation EHT (ngEHT) can continue to probe accretion and jet launching near the event horizon. In the second half of the course, we will consider recent searches (and discoveries!) of electromagnetic counterparts to LIGO-Virgo gravitational wave sources, including black hole and neutron star mergers. We will consider how engineering upgrades and new gravitational wave interferometers (on the ground and in space) will change the discovery landscape for this emerging field of multi-messenger astrophysics.

Early Universe Cosmology

Matthew Johnson (York University/Perimeter Institute)

Cosmology is a smorgasgord of relativity, particle physics, statistical mechanics, and atomic physics. In this three hour mini-course I will give a sampling of this rich buffet of physics, and attempt to tell the story behind the seeds that formed structure in the Universe, how these seeds grew into galaxies, and how cosmological observables have given us an amazingly detailed picture of the early Universe. I will end by highlighting promising new lines of inquiry into the early Universe and powerful new cosmological observables that will be made possible with the next generation of cosmic microwave background experiments and enormous galaxy surveys.

Introduction to Loop Quantum Cosmology

Edward Wilson-Ewing (University of New Brunswick)

I will give an introduction to the foundations of loop quantum cosmology, with a focus on the spatially flat Friedman-Lemaître-Robertson-Walker space-time minimally coupled to a massless scalar field. I will explain how to define the operator corresponding to the Hamiltonian constraint by following as closely as possible the quantization procedure of loop quantum gravity, and then how to solve for the relational quantum dynamics by using the scalar field as a clock. I will also discuss how the effective dynamics provide a good approximation to the quantum dynamics for states that are sharply peaked. Finally, I will describe the extension to include cosmological perturbations and the predictions for the cosmic microwave background for the inflationary, ekpyrosis and matter bounce cosmological scenarios.

ORAL CONTRIBUTIONS

(The presenter's name is underlined)

Tests of General Relativity with black hole X-ray data

Askar Abdikamalov, Dimitry Ayzenberg, Cosimo Bambi (Fudan U.)

The theory of General Relativity has been thoroughly tested in the weak-field regime by various experiments. Over the past five years, significant advances have been made in the study of the strong field regime, which can now be tested using gravitational waves, X-ray data, and observations of mm Very Long Baseline Interferometry. I will present recent work to test General Relativity with black hole X-ray data using the NKBB and RELXILL-NK models, which are respectively thermal and reflection models to test the Kerr black hole hypothesis.

Reissner-Nordström geometry counterpart in semiclassical gravity

Julio Arrechea (Institute of Astrophysics of Andalusia IAA-CSIC), Carlos Barceló, Raúl Carballo-Rubio, Luis J. Garay

We compute the Renormalized Stress-Energy Tensor (RSET) of a massless minimally coupled scalar field in the Regularized Polyakov approximation, as well as its backreaction, on the classical Reissner-Nordström spacetime. The complete set of solutions of the semiclassical self-consistent equations is obtained and compared with their classical counterparts. The semiclassical Reissner-Nordström family involves three kinds of geometries We compute the Renormalized Stress-Energy Tensor (RSET) of a massless minimally coupled scalar field in the Regularized Polyakov approximation, as well as its backreaction, on the classical Reissner-Nordström spacetime. The complete set of solutions of the semiclassical self-consistent equations is obtained and compared with their classical counterparts. The semiclassical Reissner-Nordström family involves three kinds of geometries that arise depending on the charge-to-mass ratio of the spacetime. In the under-charged regime, the geometry has its external horizon replaced by a wormhole neck that leads to a singular asymptotic region at finite proper distance. The over-charged regime reveals a naked singularity surrounded by a cloud of (infinite) mass coming from the quantized field. Between both behaviours there is a separatrix solution reminiscent of the extremal black hole classical geometry. As the RSET over an extremal horizon is finite, the semiclassical backreaction does not get rid of the horizon. Nonetheless, we show that the resulting horizon is singular.

Canonical Noether and the energy-momentum non-uniqueness problem in linearized gravity

Mark Robert Baker (St. Francis Xavier U.)

Title and abstract taken from recent publication (https://doi.org/10.1088/1361-6382/abf1c9). Talk will include a more broad introduction to this area of work.
Recent research has highlighted the non-uniqueness problem of energy-momentum tensors in linearized gravity; many different tensors are published in the literature, yet for particular calculations a unique expression is required. It has been shown that (A) none of these spin-2 energy-momentum tensors are gauge invariant and (B) the Noether and Hilbert energy-momentum tensors are not, in general, equivalent; therefore uniqueness criteria is difficult to specify. Conventional wisdom states that the

various published spin-2 energy-momentum tensors can be derived from the canonical Noether energy-momentum tensor by adding ad-hoc "improvement" terms (the divergence of a superpotential and terms proportional to the equations of motion), that these superpotentials are in some way unique or physically significant, and that this implies some meaningful connection to the Noether procedure. To explore this question of uniqueness, we consider the most general possible spin-2 energy-momentum tensor with free coefficients using the Fock method. We express this most general energy-momentum tensor as the canonical Noether tensor, supplemented by the divergence of a general superpotential plus all possible terms proportional to the equations of motion. We then derive systems of equations which we solve in order to prove several key results for spin-2 Fierz-Pauli theory, most notably that there are infinitely many conserved energy-momentum tensors derivable from the "improvement" method, and there are infinitely many conserved symmetric energy-momentum tensors that follow from specifying the Belinfante superpotential alone. This disproves several recent claims that the Belinfante tensor is uniquely associated to the Hilbert tensor in spin-2 Fierz-Pauli theory. We give two new energy-momentum tensors of this form. Most importantly, since there are infinitely many spin-2 energy-momentum tensors of this form, no meaningful or unique connection to Noether's first theorem can be claimed by application of the canonical Noether "improvement" method.

Analyzing Loop Quantum Cosmology of Bianchi II Space with Numerical Methods

Timothy Blackmore (U. New Brunswick)

Loop Quantum Gravity (LQG) is one proposed approach to quantize General Relativity. In previous literature LQG effects have been applied to Bianchi II spaces. and here we numerically solve the resulting equations of motion using the fixed step 6th order Butcher-1 Runge-Kutta method. We also test, for a wide range of initial conditions, analytic transition rules for the Kasner exponents and show in which cases these transition rules hold.

Exotic MOTSs: finding unexpected "apparent horizons"

Ivan Booth (Memorial U.)

In numerical relativity, marginally outer trapped surfaces (MOTSs) (often referred to as apparent horizons) are the main tool to locate and characterize black holes. For five decades it has been known that during a binary merger, the initial apparent horizons of the individual holes disappear inside a new joint MOTS that forms around them once they are sufficiently close together. However the ultimate fate of those initial horizons has remained a subject of speculation. In this talk I will introduce new mathematical tools that can be used to locate and understand axisymmetric MOTS. In particular I will show that the MOTS equations can be rewritten as a pair of coupled second order equations that are closely related to geodesic equations and hence dubbed the MOTSodesic equations. Numerically, these are very easily solved and in the linked talks by KTB Chan, R Hennigar and S Muth they will be used to identify and study rich families of previously unknown MOTS in a variety of black hole spacetimes, including both exact solutions and binary merger simulations. I will also show that the MOTS stability operator bears the same relation to MOTSodesics as the Jacobi deviation operator does to geodesics and consider the implications.

Thermodynamics of hairy black holes in AdS

Alvaro Ballon Bordo (Perimeter Institute)

We study the thermodynamics of planar and hyperbolic black holes with scalar hair, and propose a new interpretation of the thermodynamics of black holes with variable cosmological constant.

Observation of a multimode quasi-normal spectrum from a perturbed black hole

C.D. Capano, Miriam Cabero (U. British Columbia), J. Abedi, S. Kastha, J. Westerweck, A.H. Nitz, A.B. Nielsen, B. Krishnan

We provide strong observational evidence for a multimode black hole ringdown spectrum, using the gravitational wave event GW190521. We show strong evidence for the presence of at least two ringdown modes, with a Bayes factor of $43.4^{+8.1}_{-6.8}$ preferring two modes over one. The dominant mode is the fundamental $\ell = m = 2$ harmonic, and the sub-dominant mode corresponds to the fundamental $\ell = m = 3$ harmonic. We estimate the redshifted mass and dimensionless spin of the final black hole as $332^{+31}_{-35} M_{\odot}$ and $0.871^{+0.052}_{-0.096}$ respectively. The detection of the two modes disfavors a binary progenitor with equal masses, and the mass ratio is constrained to $0.45^{+0.22}_{-0.29}$. General relativity predicts that the frequency and damping time of each mode in the spectrum depends only on two parameters, the black hole mass and angular momentum. Consistency between the different modes thus provides a test of general relativity. As a test of the black hole no-hair theorem, we constrain the fractional deviation of the sub-dominant mode frequency from the Kerr prediction to $\delta f_{330} = -0.0.001^{+0.073}_{-0.121}$.

The many marginally outer trapped surfaces of Schwarzschild spacetime

Kam To Billy Chan (Memorial U.), Ivan Booth (Memorial U.), Robie Hennigar (U. Waterloo), and Sarah Muth (Memorial U.)

Despite the constant stream of black hole merger observations, black hole mergers are not fully understood. The details of how the two apparent horizons end up as one horizon is unclear due to the non-linear nature of the merger process. Recent numerical work has shown that there is a merger of self-intersecting Marginally Outer-Trapped Surfaces (MOTS) during the black hole merger. Following papers have investigated further into MOTS in a simpler and static scenario, that of a Schwarzschild black hole. Such cases require less machinery and are solved with everyday computers. Those numerical calculations show an infinite number of self-intersecting MOTS hidden within the apparent horizon. In this talk, I will discuss the current understanding of black hole mergers as has been numerically shown and my work investigating Schwarzschild MOTS in maximally-extended Kruskal-Szekeres coordinates.

An Optomechanical Cavendish Experiment

Abdulrahim Al Balushi, Wan Cong, Robert Mann (U. Waterloo)

If a quantum particle exists in a superposition state of being at two different spatial positions, can we also consider the gravitational field to be superposed? What does this mean in terms of the spacetime geometry? There is no way of answering these questions currently, as the answers can only be provided by experiments which we do not yet have. However, advances in experimental techniques have led to various proposals which propose to prepare masses in spatial superpositions. In this talk, I will make use of one of these proposals utilizing optomechanical techniques in achieving the superposition. I will study what the observable effects are if the answer to the first question were true. More specifically, I will demonstrate what the effects on the interference visibility (a quantity measurable from the experiment) are if we describe the interaction between two superposed masses using the canonical Schrodinger evolution. I will also show that this interaction leads to quantum entanglement between the two masses. This talk is based on the paper Phys. Rev. A 98, 043811 (2018), arXiv: 1806.06008.

Nonlinear dynamics of flux compactification

Maxence Corman, Will East, Matt Johnson (Perimeter Institute)

One proposed framework for the accelerated expansion of the Universe is string/M-theory, where extra dimensions are required for consistency. One of the dominant mechanism to hide extra dimensions is the spatial compactification on small length scales. We focus on a simple model of flux compactification: Einstein-Maxwell theory in D-dimensions with a positive cosmological constant and a q-form field strength such that the extra dimensions are stabilized on a sphere. This model not only allows highly symmetric solutions, where the sphere is stabilized against collapse by a uniform field strength, but also warped solutions where the compact space is inhomogeneous. We perform a fully non-linear evolution of these stationary or homogeneous solutions. We find a regime where the perturbatively unstable homogeneous solutions evolve to the stable stationary warped solutions. Outside this range of the parameter space we find that unstable solutions evolve towards a singular state, overshooting stable solutions in some cases. We discuss cosmological implications for the effective four-dimensional universe.

Asymptotically Anti-de Sitter Gravitational Solitons

Turkuler Durgut (Memorial U.)

In this talk, I will consider the stability of asymptotically anti-de Sitter gravitational solitons. These are globally stationary, asymptotically (globally) AdS spacetimes with positive energy but without horizons. I will introduce my ongoing project investigating solutions of the linear wave equation in this class of backgrounds. I will provide analytical expressions for the behavior of the scalar field near the soliton bubble and at spatial infinity. The special BPS (supersymmetric) case will then be examined as an example of a solution where stable trapping occurs. This project is joint work with Dr. Hari K. Kunduri and Dr. Robie A. Hennigar.

Emergent GR from Yang-Mills Type Theory

Jack Gegenberg (U. New Brunwick)

I will show how GR emerges from SO(4,2) Yang-Mills type theory via spontaneous symmetry breaking.

Relational clocks in group field theory

Steffen Gielen (U. Sheffield)

Due to general covariance, a meaningful notion of time evolution in general relativity is not defined with respect to a background time (as in Newtonian physics) but relational: one can describe the dynamics of systems relative to others, and in particular choose suitable degrees of freedom as “clocks” for others. In the canonical quantisation of gravity this leads to the problem of time, and to the question of whether theories defined with respect to different relational clocks are equivalent as they would be classically. I will discuss the issue of relational clocks in the context of group field theory (GFT). As in the closely related setting of loop quantum gravity (see e.g. Edward Wilson-Ewing's mini-course), a popular approach in GFT has been to use a (free) massless scalar field as a relational clock, in particular in order to construct cosmological models. Discussing two attempts to go beyond this past work, I will first present a model with multiple identically coupled scalars, in which covariance seems broken at the quantum level: the "clock" scalar is distinguished in the quantum theory (work in collaboration with Axel Polaczek). I will then introduce a new "frozen" formalism in which theories like GFT can be quantised without choosing a clock before quantisation, similar to Dirac quantisation for finite-dimensional quantum systems.

Canonical Analysis of Brans-Dicke Theory Addresses Hamiltonian Inequivalence between Jordan and Einstein Frames

Gabriele Gionti, S.J. (Specola Vaticana-Vatican Observatory)

We analyze the Brans-Dicke theory with a Gibbons-Hawking-York (GHY) boundary term and perform ADM decomposition both in Jordan and Einstein frames. For $\omega \neq -3/2$, Hamiltonian analysis shows that, in both frames, the theory has four secondary first class Dirac's constraints whose algebra is like Einstein's geometro-dynamics. We show that, at the level of Hamiltonian variables, the Weyl (conformal) transformations from the Jordan to Einstein frames are not canonical transformations (in Hamiltonian sense). A set of canonical transformations is found. These are called Anti-Gravity or Anti-Newtonian transformations and look different respect to the transformations from the Jordan to the Einstein frames. The Brans-Dicke case for $\omega = -3/2$ with GHY boundary term is studied as well. Here, due to the presence also of the conformal invariance in the Jordan frame, the Dirac's constraint algebra of secondary first-class constraints is completely different in the Jordan frame respect to the Einstein frame. This inequivalence of the Dirac's constraint algebra between the two frames addresses, more strongly respect to the case $\omega \neq -3/2$, the non (Hamiltonian)-canonicity of the transformations from the Jordan to the Einstein frames.

Symmetry operators for the conformal wave equation in rotating black hole spacetimes

Finnian Gray (Perimeter Institute/U. Waterloo, Canada), Tsuyoshi Houri, David Kubiznak, Yukinori Yasui

We present covariant symmetry operators for the conformal wave equation in the (off-shell) Kerr–NUT–AdS spacetimes. These operators, that are constructed from the principal Killing–Yano tensor, its 'symmetry descendants', and the curvature tensor, guarantee separability of the conformal wave equation in these spacetimes. We also discuss how these operators give rise to a full set of conformally invariant mutually commuting operators for the conformally rescaled spacetimes and underlie the R-separability of the conformal wave equation therein.

Subtleties in the Near Horizon Geometry of Spherically Symmetric, Extremal Black Holes in 4D Einstein-Maxwell Theory

Jamie Griffiths (U. Calgary)

The near horizon geometry (NHG) of an extremal Reissner-Nordström (RN) black hole is known to be $AdS_2 \times S^2$, but the method for obtaining the NHG is still unclear. The limit to extremality is taken when zooming in on a coordinate patch between the horizons of a non-extremal RN black hole. This process shows that the volume between the two horizons remains finite, despite the horizons coinciding. In this talk, a novel approach to this problem that illustrates two points will be shown. First, in the extremal limit, the patch between the horizons "bubbles out" and becomes a fully disconnected spacetime. Second, there is a true near horizon geometry, also $\mathrm{AdS}_2 \times \mathrm{S}^2$, to the degenerate horizon of the extremal black hole that is still connected to the parent spacetime. This is obtained by using a new limit where extremality is reached faster than the zoom into the horizon. Both of these points have important implications for extremal black hole entropy.

Quantum dynamics under the influence of gravitational tidal forces

Fayçal Hammad (Bishop's U.), Parvaneh Sadeghi (Bishop's U.), Nicolas Fleury (U. Sherbrooke), Alexandre Leblanc (U. Sherbrooke)

Gravitational tidal forces conceal very interesting effects when combined with the extended nature of the wavefunction of a freely-falling quantum particle. The reason being that inertial properties of the particle get then mixed with the gravitational effects in such a way that, as in classical mechanics, the ratio of the gravitational mass to the inertial mass of the particle emerges in an isolated form. The equivalence principle in quantum mechanics then takes on a novel meaning thanks to the emergence of mass-independent dynamics during the free fall of the quantum particle.

Imperfect-fluid solution in the null-surface formulation of general relativity

Tina A. Harriott (Mount Saint Vincent U.), Jeff Williams (Brandon U.)

In the null-surface formulation (NSF) of general relativity, null surfaces are employed instead of a metric or a connection. Nonetheless, the NSF is equivalent to standard general relativity and, if needed, the metric can be easily constructed once the surfaces have been determined by solving the NSF field equations. However, solving the field equations has proved challenging. As yet, the field equations have not been solved in $3+1$ dimensions and only three solutions have been presented to date in $2+1$. This talk presents a fourth $(2+1)$-dimensional solution. It is the only known imperfect solution of the NSF and includes two of the previously known solutions as special cases. The curvature invariants, including the Ricci scalar, are constant. The physical properties, including the thermodynamics, are discussed.

A Pair of Pants for the Apparent Horizon

Robie A. Hennigar (U. Waterloo), Daniel Pook-Kolb (Memorial U.), Ivan Booth (Memorial U.)

The common picture of a binary black hole merger is the "pair of pants" diagram for the event horizon. However, in many circumstances, such as those encountered in numerical simulations, the event horizon may be ill-suited and it is more practical to work with quasi-local definitions of black hole boundaries, such as marginally outer trapped surfaces (MOTS). The analog of the pair of pants diagram for the apparent horizons remains to be fully understood. In this talk, I will discuss the complete picture for the merger of two axisymmetric black holes. I will begin by introducing new classes of MOTS present in Brill-Lindquist initial data. I will then discuss the role played by these and related surfaces in understanding the final fate of the apparent horizons of the initial two participants in the merger.

Quartic Hilltop-Squared Inflation

Joshua Hoffmann (U. Lancaster)

Inflation is an important aspect of modern cosmology and there are a variety of models to explain this mechanism. The Quartic Hilltop model, which is a subclass of more general Hilltop Models, is among those that best fit data from the Planck 2018 release. Quartic Hilltop Inflation, however, suffers from a number of theoretical drawbacks that could rule it out as a potential candidate model. In this talk, I present an analytical treatment of the Quartic-Hilltop-Squared model, which aims to improve upon the conceptual issues raised by Quartic Hilltop, whilst retaining its attractive features. I show that the same analytical techniques used to investigate the Quartic Hilltop model in recent work can also be applied to Quartic Hilltop-Squared to derive analogous results. In both cases this involves working outside of the parameter space of previous approximations. The results are shown to be in close agreement with numerical solutions and data from the Planck 2018 release.

Entanglement in quantum gravity

Viqar Husain, Suprit Singh (U. New Brunswick)

Gravity is a natural bipartite system with matter and gravity sectors. As the Universe evolves it is natural to expect that the entanglement entropy does too. We present a study of the evolution of initial product and entangled states in quantum cosmology. We show by numerical calculations that entanglement entropy increases as the Universe expands and ultimately saturates, and that the saturation value satisfies a First Law: $S \sim < E >$, where $< E >$ is the expectation value of the energy of the initial state.

An Alternative Way in Massive Gravity Theory

Sobhan Kazempour, Amin Rezaei Akbarieh (U. Tabriz)

In this oral presentation, initially, I review ups and downs of the massive gravity theory very briefly. Actually, I try to indicate the striking points of this theory. In the following slides, I introduce a new extension of quasi-dilaton massive gravity theory as an alternative theory. Therefore, I show the complete set of background equations of motion, in other words, I show the calculation of the Friedman and constraint equations for this theory. Moreover, I indicate the analysis of the self-accelerating background solutions. In final slides, I present the tensor perturbations analysis and I show the dispersion relation of gravitational waves for this theory.

Effective loop quantum gravity framework for vacuum spherically symmetric space-times

Jarod George Kelly, Robert Santacruz, Edward Wilson-Ewing (U. New Brunswick)

Guided by the application of loop quantum gravity (LQG) to cosmological space-times and techniques developed therein, I will present an effective framework for vacuum spherically symmetric space-times. Stationary solutions of the effective theory give an LQG corrected metric with a number of interesting properties including curvature scalars that are bounded by the Planck scale and a minimal (non-zero) mass for black hole formation. Finally, the vacuum solution we derive is only valid down to some minimum (non-zero) radial coordinate; this necessitates the inclusion of matter fields for a description of the full space-time and in particular address the question of singularity resolution.

Is there a Gauss-Bonnet gravity in four dimensions?

Robie A. Hennigar (U. Waterloo), David Kubiznak (Perimeter Institute), Robert B. Mann, Christopher Pollack (U. Waterloo/Perimeter Institute)

We comment on the recently introduced Gauss-Bonnet gravity in four dimensions. We argue that although the naive $D \to 4$ limit of the Gauss-Bonnet gravity does not work, a well-defined theory is obtained by generalizing a conformal trick employed by Mann and Ross to obtain a limit of the Einstein gravity in $D = 2$ dimensions. This yields a scalar-tensor theory of the Horndeski type that can also be obtained by dimensional reduction methods. Some properties and solutions of this theory in four and three dimensions will be discussed.

Toric gravitational instantons

Hari Kunduri (Memorial U.)

Gravitational instantons are 4d geodesically complete, non-compact Ricci flat Riemannian (positive-signature) manifolds. Simple examples arise from Wick-rotated black hole metrics such as the Schwarzschild and Kerr instantons. It was conjectured that the classic black hole uniqueness theorems extended to the Riemannian setting. However, recently Chen and Teo constructed a new instanton, thus providing an explicit counterexample. I will discuss new existence and uniqueness results for asymptotically flat, simply connected gravitational instantons.

Quantum cosmology is clock dependent

Steffen Gielen (U. Sheffield), Lucía Menéndez-Pidal de Cristina (U. Nottingham)

Quantum cosmology faces the problem of time: the Universe has no background time, only interacting dynamical degrees of freedom within it. The relational view is to use one degree of freedom (which can be matter or geometry) as a clock for the others. In this talk I discuss a cosmological model of a flat FLRW universe filled with a massless scalar field and a perfect fluid. We study three quantum theories based on three different choices of (relational) clock and show that, if we require the dynamics to be unitary, all three make drastically different predictions regarding resolution of the classical (Big Bang) singularity or a possible quantum recollapse at large volume. The talk is based on [arXiv:2005.05357] and a second paper to appear on arXiv in May 2021. I will present the construction of the theories and their main results, especially focusing on singularity resolution.

Extended Uncertainty Principle Black Holes

J. Mureika (Loyola Marymount U.)

An Extended Uncertainty Principle inspired Schwarzschild metric that allows for large scale modifications to gravitation is presented. At a new fundamental length scale L_*, the horizon is corrected by an additional term of the form $\frac{R_S^3}{L_*^2}$. This in turn modifies the characteristics of near horizon orbits. If the scale is on the order of at least 10^{13} m, such EUP modifications become relevant for black holes of mass greater than 10^6 solar masses. This would affect the characteristics of most known supermassive black holes, and thus presents a unique set of experimental signatures that could be tested by the Event Horizon Telescope and similar future collaborations. EUP modifications in the weak field limit are also addressed, and implications for galaxy rotation curves are discussed.

Marginally Outer Trapped (Open) Surfaces in 5D Black Hole Spacetimes

Sarah Muth (Memorial U.), I. Booth (Memorial U.), H. Kunduri (Memorial U.), R. Hennigar (U. Waterloo)

In the case of binary black hole mergers, the surface of most obvious interest, the Event Horizon, is often computationally difficult to locate. Instead, it is useful to turn to quasi-local characterizations of black hole boundaries, such as Marginally Outer Trapped Surfaces (MOTS), which are defined for a single time slice of the spacetime, and the outer-most of which is the apparent horizon. In this talk, I will describe ongoing work focused on understanding MOTS in the interior of a five-dimensional black hole; both static and rotating. Similar to the four-dimensional Schwarzschild case previously studied, we find examples of self-intersecting MOTS with an arbitrary number of self-intersections. This provides further support that self-intersecting behavior is rather generic. I will also discuss the second stage of our research, which is for a rotating 5D black hole spacetime. These two cases fit into a larger project involving exploration of the generality of self-intersecting behaviour in MOTS, within spacetimes of increasing diversity.

Universal p-form black holes in generalized theories of gravity

Sigbjorn Hervik, Marcello Ortaggio (Czech Academy of Sciences)

We explore how far one can go in constructing d-dimensional static black holes in vacuum or coupled to p-form and scalar fields in an arbitrary diffeomorphism invariant, higher-order (possibly non-minimally coupled) theory. A (generalized) Schwarzschild-like ansatz is shown to give rise to consistent reduced field equations and to allow for a large class of horizon geometries more general than spaces of constant curvature. Examples in particular theories such as Gauss-Bonnet, R^2 and (a sector of) Einstein–Horndeski gravity coupled to certain p-form and conformally invariant electrodynamics are presented.

Noncommutative momentum and torsional regularization

Nikodem Poplawski (U. New Haven)

We derive the quantum commutation relation for the four-momentum in the presence of spacetime torsion. In the Einstein–Cartan theory of gravity, in which the torsion tensor is coupled to the spin of fermions, this relation can be reduced to a commutation relation for the momentum components. We propose that this relation replaces the integration in the momentum space in Feynman diagrams with the summation over the discrete momentum eigenvalues. We derive a prescription for this summation that agrees with convergent integrals. We show that this prescription regularizes ultraviolet-divergent integrals in loop diagrams. We extend this prescription to tensor integrals. We derive a finite, gauge-invariant vacuum polarization tensor and a finite running coupling. Including loops from all charged fermions, we find a finite value for the bare electric charge of an electron. This regularization, originating from the torsion-generated noncommutativity of the momentum, may therefore provide a realistic, physical mechanism for eliminating infinities in quantum field theory and making renormalization finite.

Quintessential inflation in Palatini $f(R)$ gravity

Samuel Sánchez López, Konstantinos Dimopoulos (U. Lancaster)

The cosmological constant problem is one of the major unsolved puzzles in modern-day physics. In this talk I will give a brief introduction to quintessential inflation, a theoretical framework which aims to alleviate the incredible fine-tuning present in this problem. Furthermore, I will show how adding a Starobinski term in the gravitational action in the Palatini formalism can rescue a family of models - the original Peebles-Vilenkin potential particularly - otherwise ruled out by observations. The kination (a cosmological era unique to quintessential inflation) and quintessence eras remain unaffected. The talk will be largely based in our recently published paper 2012.06831.

Theory-Independent tests of General Relativity by analysing Black hole images

Saurabh (U. Delhi), Sourabh Nampalliwar (Tubingen U.)

Recent observations from the EHT of the center of the M87 galaxy [1] has opened a whole new era for testing general relativity using black hole images. Normally, the astrophysical black holes are thought to be described by the Kerr metric from General relativity, but theories beyond general relativity predict black holes that deviate from the Kerr solution [2]. To test the Kerr hypothesis and hence GR, we are developing a framework that can perform theory-independent tests of general relativity by analysing black hole images. In the talk, I will present our preliminary results on modelling the black hole neighbourhood with some accretion disk models, building and comparing black hole images, and using Bayesian analysis on the EHT data to estimate the deviation parameters that characterise deviations from the Kerr solution.

References:

1) The EHT Collaboration et al. 2019, ApJL, 875, 1

2) Y. Mizuno, Z.Younsi, C. M. Fromm, et al., Nature Astronomy 2, 585 (2018).

Non-linear evolution of the ergoregion instability in boson stars

Nils Siemonsen, William E. East (Perimeter Institute)

Rotating horizonless ultra-compact objects can exhibit an ergoregion; a region of spacetime in which all observers are forced to co-rotate. In these ergoregions, an asymptotically timelike Killing field turns spacelike, indicating that energies, measured by an observer at infinity, can be negative. Consequently, the energy of massless testfields is no longer bounded from below and a cascade into lower and lower energy states ensues - the ergoregion instability emerges. We study the non-linear development of the instability in highly compact scalar boson stars by evolving the coupled system of Einstein-Klein-Gordon equations numerically assuming axisymmetry. We characterize the linear instability phase, the final saturated state of the system, and radiated gravitational and scalar waves.

Applications of Heun Functions and Regge Theory in Gravitational Wave Astrophysics

Aditya Tamar

The observations in different domains of strong field gravity by current and future deployments of LIGO as well as the Event Horizon Telescope has provided significant motivation to instrumentation, data analysis as well mathematical research to extract parameters of interest from observation. In this regard, mathematical astrophysics, utilising novel mathematical techniques to study and/or extract

astrophysical data is expected to play a crucial role. The talk shall discuss two related areas of work and their impact on the broad field of gravitational wave astrophysics. Firstly, I shall discuss the astrophysical motivations and the utility to black hole perturbation theory of the recently formulated unconditionally convergent solutions of the class of Heun functions using the technique of path-sums, arising out of work with Pierre-Louis Giscard. The resultant formulation provides solutions in terms of a single elementary integral series representations of Heun functions, that is convergent from the black hole horizon upto spatial infinity. This significantly reduces the mathematical complexity in comparison to the well known Mano-Suzuki-Takesugi method that uses matched asymptotic expansions using parameters that don't exist in the Teukolsky equation and requires different functions for different spin of the black hole.
In addition, I shall also discuss the utility of complex angular momentum and Regge theory techniques to studying astrophysical observables of Kerr black holes. This is part of ongoing work with Antoine Folacci wherein in a recent paper by Folacci and I, by using the Green's function for Teukolsky equation, Regge theory has been shown to be remarkably effective in producing quasinormal mode frequencies for almost entire parameter range relevant for gravitational wave physics. I shall also describe the utility of Heun functions to Regge theory as well.
For other astrophysical applications of the Teukolsky equation such as computing gravitational wave fluxes, I shall discuss how a uniformly convergent Heun function can resolve mathematical bottlenecks arising from divergent series summations of spin weighted spheroidal harmonics and long range potentials (the latter being currently addressed using the Saski-Nakamura transform) and discuss the prospects of a unified formalism for black hole perturbation theory based solely on the Heun functions.

The ground state of nonlinear field theories

Vincenzo Vitagliano (U. Hull)

Substantial changes in the structure of the quantum vacuum occur in simple nonlinear quantum field theories even for the simplest choice of boundary conditions. Not only this leads to nontrivial modulation of the Casimir force as a function of external conditions (e.g., couplings or temperature), but it also regulates the behaviour at small vs large scales.

ABSTRACTS OF POSTER CONTRIBUTIONS

Hubble's Constant with Signals from GW170817 Standard Siren and GW190814 Dark Siren

Rajesh Kumar Dubey (Lovely Professional University), Shankar Dayal Pathak

The local universe expansion rate is one of the most fundamental and essential cosmological parameters. This value which is known by the name of Hubble's Constant is scientifically measured by electromagnetic sources called distance ladder. Surprisingly, using Gravitational Wave (GW) analysis this value can be measured making GW sources another significant method to act as standard sirens with their electromagnetic counterparts from their host galaxy. The gravitational wave event GW170817 was the outcome of the merger of two different neutron stars. The electromagnetic event was recorded from the host galaxy NGC4993. The GW170817 has been a considerable success in this direction measuring the value of universe acceleration $H_0 = 70.0^{+12.0}_{-8.0}\,\mathrm{kms}^{-1}\ \mathrm{Mpc}^{-1}$. The results obtained from this GW event is analysed and compared with the other observations done with traditional methods of CMB and Cosmic Distance Ladder. Another event in this series GW190817 is Compact Binary Coalescence involving a 22.2 - 24.3 Solar Masses Blackhole and a compact object with a mass of 2.50 - 2.67 Solar Masses. The EM counterpart of this event is unknown so far and hence the event is named Dark Siren. The detection of gravitational waves from merger event GW190814 reveals a different picture. The Hubble's value observed with this event is close to $H_0 = 75^{+59}_{-13}\,\mathrm{km\ s}^{-1}\mathrm{Mpc}^{-1}$. The source GW190814 which involves a massive black hole and the other compact object as the lightest black hole or the heaviest neutron star was localized to 18.5 deg^2 at a distance of Mpc. The diversity of the two events can be used to measure the expansion rate of the universe. This can also be used to verify this rate in different directions of the universe. The results obtained from the two different types of Gravitational waves, originating from two different types of mergers gives two different results for a single cosmological parameter. This in addition to giving answer to the value of Hubble's constant, also gives rise to Hubble's tension.

When Painlevé-Gullstrand coordinates fail

V. Faraoni, G. Vachon (Bishop's U.)

Painlevé-Gullstrand coordinates, a very useful tool in spherical horizon thermodynamics, fail in anti-de Sitter space and in the inner region of Reissner–Nordström. PG observers, who are in radial free fall with zero initial velocity, are stopped because of repulsive gravity, and we predict this breakdown of PG coordinates to occur in any region containing negative Misner–Sharp–Hernandez quasilocal mass. PG coordinates break down also in the static Einstein universe for completely different reasons. The more general Martel-Poisson family of charts, which normally has PG coordinates as a limit, is reported for static cosmologies (de Sitter, anti-de Sitter and the static Einstein universe). [Based on V. Faraoni & G. Vachon, Eur. Phys. J. C 80, 771 (2020)]

Strong cosmic censorship theorem in Bakry-Emery spacetimes

Makoto Narita (NIT/Okinawa College)

A class of naked strong curvature singularities is ruled out in Bakry-Emery spacetimes by using techniques of differential topology in Lorentzian manifolds. These spacetimes adimit a Bakry-Emery-Ricci tensor which is a generalization of the Ricci tensor. This result supports to validity of Penrose's strong cosmic censorship conjecture in scalar-tensor gravitational theories, which include dilaton gravity and Brans-Dicke theory.

Freely-falling bodies in standing wave spacetime

Sebastian J. Szybka, Syed U. Naqvi (Jagiellonian U.)

The phenomena of standing waves is well known in mechanical and electromagnetic setting where the wave has the maximum and minimum amplitude at the antinodes and nodes, respectively. In context of exact solution to Einstein Field equations, we analyze a spacetime which represents standing gravitational waves in an expanding Universe. The study the motion of free masses subject to the influence of standing gravitational waves in the polarized Gowdy cosmology with a three-torus topology. We show that antinodes attract freely falling particles and we trace the velocity memory effect.