Black Holes VI
Abstracts

Invited Talks

Jacob D. Bekenstein

Racah Institute of Physics, Hebrew University of Jerusalem

Black Holes in the TeVeS Theory of Gravity

TeVeS is an alternative gravity theory designed to provide a relativistic basis for the MOND paradigm of extragalactic astrophysics (modify gravity but use no dark matter). I will discuss some properties of black holes in TeVeS. I start with a review of Giannios' black hole solution to TeVeS, the analogue of Schwarzschild black holes. Charged black holes are more challenging because the scalar in the theory has charge as its source. I describe how this hurdle is overcome to obtain a close analogue of Reissner-Nordstrom black holes. The question of uniqueness of all these solutions is left pending. I show that, despite the difference in the theories, TeVeS black hole thermodynamics is very similar to the GR one. In connection with this I consider whether the breaking of Lorentz invariance in TeVeS leads to violations of the generalized second law, as would be argued by Dubovsky and Sibiryakov.

Martin Bojowald

Center for Gravitational Physics and Geometry, The Pennsylvania State University

Aspects of Black Holes in Loop Quantum Gravity

Loop quantum gravity provides a framework in which gravity can be quantized in a background independent manner. Key features of the resulting quantum nature of space and time can be studied in models of black holes, with implications for the global structure and our understanding of physical processes. Applications include the horizon area spectrum, black hole entropy, evaporation and the fate of the classical singularity in quantum gravity.

Ivan Booth

Department of Mathematics and Statistics, Memorial University

Isolated, Slowly Evolving and Dynamical Trapping Horizons

It is well known that the standard definition of a black hole as a region of spacetime that does not lie in the casual past of future null infinity is teleological and highly nonlocal. Such a definition sets black holes strongly apart from the regular objects studied by physics. Thus, it is not surprising that there is a growing interest in alternative quasilocal characterizations of black holes and their boundaries. These include trapping, isolated, and dynamical horizons and they have found applications in classical, quantum, and numerical relativity. In this talk I will review some of the recent work in this area.

Patrick Brady

Department of Physics, University of Wisconsin - Madison

Learning about Black Holes Through Gravitational-wave Observations

A great deal has been learned about black holes by observing their effects on nearby matter. As gravitational-wave detectors begin to probe the Universe with unprecedented sensitivity, astronomers can look forward to a more direct method of observing black holes. After I review gravitational-wave generation by black holes, I will discuss the possibilities for learning about black holes, stellar evolution, and fundamental physics through the observation of these waves.

Steve Carlip

Physics Department, University of California, Davis

Black Hole Thermodynamics from Euclidean Horizon Constraints

To explain black hole thermodynamics in quantum gravity, one must introduce constraints to ensure that a black hole is actually present. I show that for a large class of black holes, the presence of such "horizon constraints" allows us to use conformal field theory techniques to compute the density of states, reproducing the Bekenstein-Hawking entropy in a nearly model-independent manner. I argue that the relevant degrees of freedom may be understood as Goldstone-boson-like excitations that arise from the weak breaking of symmetry by a conformal anomaly induced by the horizon constraints.

Marc Henneaux

Physique Théorique et Mathématique, Université Libre de Bruxelles

Spacelike Singularities and Infinite-Dimensional Algebras in Gravitation Theory

We review recent work on the conjectured existence of Lorentzian Kac-Moody symmetries in gravitation theory, starting from the BKL analysis of spacelike singularities.

Veronika Hubeny

Department of Mathematical Sciences, Durham University

Emergent Spacetime and Looking Beyond Horizons via Gauge/gravity Correspondence

I will present an overview of some of the recent advances in extracting bulk gravity information from the dual gauge theory "data", using the AdS/CFT correspondence. In particular, I will focus on deciding bulk metric from CFT correlators, and discuss the signatures of beyond-the-horizon physics.

Stefanie Komossa

Max-Planck-Inst. für Extraterr. Physik

Massive Black Holes in the Nearby and Distant Universe - the High-Energy View

Black holes with their extreme gravitational fields are ideal 'laboratories' to search for effects of, and test predictions of, strong-field gravity. High-energy X-ray emission is a powerful probe of the physical conditions in the immediate vicinity of black holes. This review concentrates on supermassive black holes (SMBHs) with masses up to ten billion times the mass of our sun. Such black holes are believed to be the prime movers of quasars, the most luminous long-lived objects in the universe. The SMBHs' presence is revealed by characteristic relativistic distortions of emission lines in X-ray spectra of some of these sources. There is also growing evidence that SMBHs reside at the centers of most or all 'normal' galaxies, and that they play a major role in the formation and evolution of galaxies. In the high-energy regime, such SMBHs show up by tidal disruption of stars, causing giant flares of electromagnetic radiation. In some cases, SMBHs come in pairs and the final merging of the two will be a strong source of gravitational wave emission. This talk provides a review of recent exciting new results in black hole research, focussing on X-ray observations of nearby single and binary SMBHs, and very distant ones in the early universe.

Jutta Kunz

Institut für Physik, University of Oldenburg

Rotating Black Holes in Higher Dimensions

In $D = 4$ dimensions the Kerr-Newman solutions present the unique family of stationary asymptotically flat black holes of Einstein-Maxwell (EM) theory. The corresponding $D > 4$ charged rotating black holes of EM theory have not yet been obtained in closed form. We have constructed charged rotating EM black holes numerically in $D = 2N + 1$ dimensions, $D \geq 5$, focussing on black holes with equal-magnitude angular momenta. In this case, the angular dependence can be treated explicitly, leading to a system of 5 D-dependent ordinary differential equations.

When a Chern-Simons term is added, the stationary black hole solutions possess surprising properties. Considering the Chern-Simons coefficient as a parameter, critical values of this parameter exist. At a first critical value, the theory corresponds to the bosonic sector of minimal $D = 5$ supergravity. The black hole solutions are then known analytically, and black holes with vanishing horizon angular velocity, but finite angular momentum arise. As the Chern-Simons coefficient is increased, counterrotating black holes appear, whose horizon rotates in the opposite sense to the angular momemtum. At a second critical value rotating black holes with vanishinh angular momentum emerge, and black holes may possess a negative horizon mass, while their total mass is positive. Charged rotating black holes with vanishing gyromagnetic ratio appear, and black holes are no longer uniquely characterized by their global charges.

Furthermore, rotating black holes in Einstein-Maxwell theory with negative cosmological constant are discussed. These charged black holes also possess equal-magnitude angular momenta, and approach asymptotically the Anti-de Sitter spacetime background.

Finally, rotating black strings with equal magnitude angular momenta are addressed. Exploring the Gregory-Laflamme instability of these rotating black strings via linearized perturbation theory, we find that the Gregory-Laflamme instability persists up to extremality for all even dimensions between six and fourteen. Then the properties of rotating non-uniform black strings with equal-magnitude angular momenta in six dimensions are discussed. Our numerical results yield a first indication for the occurrence of a topology changing transition, associated with such rotating nonuniform black strings.

Samir Mathur

Department of Physics, The Ohio State University

How Fuzzballs Resolve the Black Hole Information Paradox

The information paradox arises if we assume that quantum gravity effects are confined to within the planck length. From string theory we find that when we make a bound state on N quanta, the size of the state is a power of N times the planck length, and for black holes this scale reaches upto the horizon. The state information is thus distributed in a very quantum 'fuzzball' filling the interior of the horizon.

Sharon Morsink

Department of Physics, University of Alberta

General Relativity and the Properties of Neutron Stars

Neutron stars are interesting relativistic systems since they have strong gravitational fields and they can potentially rotate at relativistic speeds. In the case of the accreting X-ray pulsars, the observed light is most likely emitted from the surface of the star meaning that observations of X-rays can probe the strong gravitational field near the neutron star's surface. I will talk about the use of relativistic raytracing to infer the macroscopic properties (mass and radius) of rapidly rotating neutron stars. I will review some of the recent X-ray observations and discuss what we have learned about neutron stars in the process.

Frans Pretorius

Department of Physics, Princeton University

Black Hole Collisions

The collision of two black holes is thought to be one of the most energetic events in the universe, emitting in gravitational waves as much as 5-10% of the rest mass energy of the system. An international effort is currently underway to detect gravitational waves from black hole collisions and other cataclysmic events in the universe. The early success of the detectors will rely on the matched filtering technique to extract what are, by the time the waves reach earth, very weak distortions in the local geometry of space and time. In the case of black hole mergers numerical simulations are needed to obtain predictions of waveforms during the final stages of coalescence. 2005 was a watershed year for numerical simulations of black holes, and we are now beginning to explore the fascinating landscape of black hole collisions in the fully non-linear regime of Einstein's theory. In this talk I will give an overview of the recent successes and what we have learned about the merger process, for both astrophysically relevant binaries and more esoteric configurations. The latter include hyperbolic encounters fine-tuned to an approximate threshold of merger, exhibiting behavior similar to zoom-whirl geodesics in a black hole background. These types of orbits may have some relevance to speculative black hole formation by parton collisions at the LHC in large extra dimension scenarios.

Kristin Schleich

Department of Physics and Astronomy, University of British Columbia

Topology and Dimensionally Reduced Spacetimes

The study of spacetimes with continuous symmetries through the use of dimensional reduction to a lower dimensional spacetime is common in both classical gravity and string theory. Surprisingly, when dimensional reduction of a higher dimensional spacetime leads to a 3- dimensional asymptotically flat or asymptotically anti-de Sitter spacetime, either the reduced spacetime has at most one black hole or else must exhibit pathological geometry. These results use only the topological censorship theorems and topological methods so they do not depend on the details of either the theory or geometric properties of the reduction. I will discuss these results for the 3- dimensional case and comment on their extension to higher dimensions.

Lee Smolin

Perimeter Institute

Chiral Matter as Excitations of Quantum Geometry

Recent work has shown that some versions of loop quantum gravity and spin foam models are not just theories of quantum gravity, they have emergent chiral matter-like degrees of freedom. These propagate through the quantum geometry and in some cases interact with each other. In one version the simplest such excitations correspond to the fermions in the first generation of the standard model. I describe recent results and work in progress on the properties of these excitations in different models of dynamical quantum geometry.

Work by and with Sundance Bilson-Thompson, Jonathan Hackett, Fotini Markopoulou and Yidun Wan.

Rafael Sorkin

Department of Physics, Syracuse University

Topological Quantization of NUTty Angular Velocity

The "Kerr-bolt" line-element for a rotating black hole with NUT charge is characterized by three real parameters, a radius, a spin rate, and the NUT charge itself. After analytic continuation to Euclidean signature, one might have expected the exclusion of conical singularities to fix a periodicity, while leaving free two continuous parameters interpretable thermodynamically as a temperature and an angular velocity. However, the twisted topology gives rise to further conditions, leaving behind only a disconnected family of (generically one-dimensional) solution-manifolds. In particular the angular velocity divided by the temperature must be a rational multiple of 2π. This quantization of angular velocity prevents the free variations presupposed by an equation like $TdS = dM + \Omega dJ$, perhaps explaining why customary thermodynamical relationships tend to break down in the presence of NUT-charge. (Work with Robert Mann and Masoud Ghezelbash.)

W. G. Unruh

Department of Physics and Astronomy, University of British Columbia

Radiation Reaction Force on Accelerated Particles

I will use a technique based on the Penrose Kirkoff integral to evalute the radiation reaction for an accelerated "charged" particle.

Jorge Zanelli

Centro de Estudios Científicos de Santiago

The Universe as a Topological Defect

It is shown that a topological invariant in six dimensions integrated over a manifold with a four dimensional topological defect yields an effective Einstein-Hilbert action on the defect.

Contributed Talks

Ramin Daghigh

Natural Sciences Department, Metropolitan State University

The Mystery of the Asymptotic Quasinormal Modes of Gauss-Bonnet Black Holes

We analyze the quasinormal modes of D-dimensional Schwarzschild black holes with the Gauss-Bonnet correction in the large damping limit and show that standard analytic techniques cannot be applied in a straightforward manner to the case of infinite damping. However, by using a combination of analytic and numeric techniques, which can only be applied to vector perturbations, we are able to calculate the quasinormal mode frequencies of vector perturbations for a range where the damping is large but finite. We show that in this "intermediate" damping region the famous ln(3) appears in the real part of the quasinormal mode frequency. In our calculations, the Gauss-Bonnet coupling, α, is taken to be much smaller than the parameter μ, which is related to the black hole mass. Even though our calculations are done for the simplest case of five spacetime dimensions, it is shown that the results hold in every dimension greater than four by substituting an approximate expression for the metric in the calculations, which is valid in the intermediate damping region for small α.

Saurya Das

Department of Physics, University of Lethbridge

Where are the Black Hole Entropy Degrees of Freedom?

Understanding the area-proportionality of black hole entropy (the 'Area Law') from an underlying fundamental theory has been one of the goals of all models of quantum gravity. A key question that one asks is: where are the degrees of freedom giving rise to black hole entropy located? Taking the point of view that entanglement between field degrees of freedom inside and outside the horizon can be a source of this entropy, we show that when the field is in its ground state, the degrees of freedom near the horizon contribute most to the entropy, and the area law is obeyed. However, when it is in an excited state, degrees of freedom far from the horizon contribute more significantly, and deviations from the area law are observed. In other words, we demonstrate that horizon degrees of freedom are responsible for the area law.

Henrique De Oliveira

Universidade do Estado do Rio de Janeiro

Black Hole Bremsstrahlung

We examine the decay of a black hole in motion acted on by nonlinear gravitational perturbations that correspond to decelerate it. In the full dynamics of General Relativity a radiative transfer process is set up by which the black hole loses kinetic energy by the emission of gravitational waves. The final configuration is that of a black hole in uniform motion with smaller rest mass and velocity. We obtain the mass loss function of the process and the angular and time patterns of the gravitational radiation emitted. The angular pattern is typical of bremsstrahlung and the temporal wave form is that of a initial pulse with an exponential tail. The process corresponds to a high power output in the initial dominant pulse.

Valerio Faraoni

Physics Department, Bishop's University

New Solutions for Black Holes in a Cosmological Background

Does the horizon of a black hole embedded in a cosmological background resist the cosmic expansion or does it follow it? The Schwarzschild-de Sitter black hole does not expand, while the recent Sultana-Dyer solution is comoving. New exact solutions describing dynamical black holes perfectly comoving with the cosmic substratum will be presented.

Valeri Frolov

Department of Physics, University of Alberta

A Toy Model for Topology Change Transitions

I consider a test brane interacting with a black hole and demonstrate that this system provides one with a toy model for study of the topology change transitions.

Masoud Ghezelbash

Department of Physics, University of Waterloo

Bianchi Type IX Supergravity

We present new M2 and M5 brane solutions in M-theory based on transverse self-dual Bianchi type IX space. All the other recently M2 and M5 branes constructed on transverse self-dual Taub-NUT, Egughi-Hanson and Atiyah-Hitchin spaces are special cases of this solution. The solution provides a smooth transition from Eguchi-Hanson type I based M

branes to corresponding branes based on Eguchi-Hanson type II space. All the solutions can be reduced down to ten dimensional fully localized intersecting brane configurations.

Rituparno Goswami

Department of Physics, University of Alberta

On Trapped Surface Formation in Gravitational Collapse

A class of perfect fluid collapse models is constructed to examine the final fate of a continual gravitational collapse. While the pressure could be negative in the interior of the cloud, at some later epoch, the weak energy condition is satisfied. The collapsing star radiates away its matter as the process of gravitational collapse evolves, so as to avoid the formation of trapped surfaces. The collapsing interior is matched to an exterior which is a generalized Vaidya spacetime to complete the model. Also I discuss the implications of such a result towards the resolution of singularity issue and various black hole paradoxes at classical and quantum levels.

Stepan Grinyok

University of Alberta

Effect of Polarization in Colliding Impulsive Gravitational Waves

The effect of polarization in colliding impulsive plane gravitational waves is considered on the example of the Nutku-Halil solution, which describes cross-polarized waves. We study motion of a test particle in (u, v) plane and discuss the corresponding geodesics equations and their integrability. The numerical results show that the equations are non-integrable. We also show that the proper life-time of a particle trapped in between colliding gravitational waves increases with the angle of relative polarization. The essential difference between the behavior of the geodesics in Khan-Penrose (zero polarization angle) and Nutku - Halil (non-zero polarization) is observed. This fact indicates the repulsive nature of the polarization. We discuss possible applications of the results to graviton spin-spin interaction problem.

Ryan Kerner

Department of Physics, University of Waterloo

Tunnelling From Gödel Black Holes

I consider the spacetime structure of Kerr-Gödel black holes, analyzing their parameter space in detail. I claim that it is not possible to have the closed timelike curve (CTC) horizon in between the two black hole horizons. I apply the tunnelling method to these black holes to compute their temperature and compare the results to previous calculations obtained via other methods.

Pavel Krtous

Institute of Theoretical Physics, Charles University in Prague

Geodesic Motion and Test Fields in the Background of Higher-dimensional Black Holes

In a series of three papers, we recently investigated properties of geodesic motion and of a test scalar field in the background of the generic rotating higher-dimensional black hole. In this talk we briefly discuss the integrability of the geodesic motion, the relation between different constants of motion, and the relation to the separability of the Hamilton-Jacobi equation. We also present a class of algebraically special test electromagnetic fields which generalize the electromagnetic field of a charged black hole in four dimensions. It will be shown that in higher dimensions the gravitational back reaction of such fields cannot be easily solved.

David Kubiznak

Department of Physics, University of Alberta

Hidden Symmetries of Higher Dimensional Rotating Black Holes

We demonstrate that the rotating black holes in an arbitrary number of spacetime dimensions and without any restriction on their parameters possess the hidden symmetries associated with the Killing-Yano and Killing tensors. Together with the spacetime symmetries generated by the Killing vectors these tensors form a structure which makes the geodesic motion completely integrable, enables to separate the Hamilton-Jacobi and Klein-Gordon equations and opens the question about the possibility to decouple and separate the field equations with spin in these spacetimes.

Hari Kunduri

Particle Theory Group, University of Nottingham

Near Horizons and Anti de Sitter Black Holes

Supersymmetric black holes in anti de sitter spacetime should have an exact quantum description in terms of high energy BPS states of the dual gauge theory. However, such states are labelled by five parameters, whereas the most general known black holes have only four. It is therefore important to investigate whether other black hole solutions, such as black rings, could exist. In this talk I will describe work done with James Lucietti and Harvey Reall in which we determined the most general near horizon geometry of a supersymmetric AdS5 black hole, assuming only the existence of two rotational symmetries. The near horizon is topologically spherical. Although we found a near horizon corresponding to that of a black ring, it suffers from a conical singularity

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Gabor Kunstatter

Department of Physics, University of Winnipeg

Quantum Structure of Black Holes

We describe a midi-superspace quantization scheme for generic single horizon black holes in which only the spatial diffeomorphisms are fixed. The remaining Hamiltonian constraint yields an infinite set of decoupled eigenvalue equations: one at each spatial point. The corresponding operator at each point is the product of the outgoing and ingoing null convergences, and describes the scale invariant quantum mechanics of a particle moving in an attractive $1/X^2$ potential. The variable X that is analoguous to particle position is

the square root of the conformal mode of the metric. Physical quantum states can be constructed either in the Schrodinger representation or via Bohr quantization. The latter, by construction, turns the Hamiltonian constraint eigenvalue equation into a finite difference equation which gives rise to a discrete spatial topology exterior to the horizon. The spectrum approaches the continuum in the asymptotic region.

Hideki Maeda

Centro de Estudios Científicos (CECS)

Self-similar Black Holes in the Friedmann Universe with Dark Energy

We numerically find a one-parameter family of spherically symmetric self-similar black-hole solutions which are asymptotically Friedmann at large distances and contain a perfect fluid with equation of state $p = (\gamma - 1)\mu$. The expansion of the Friedmann universe is accelerated in this range of the parameter. For $\gamma = 1/3$, the ratio of the black hole event horizon to the cosmological event horizon is from 0 to 0.36. This suggests that small black holes in the universe with dark energy can grow as fast as the universe in contrast to the positive pressure case, in which there are no such black hole solutions.

Megan McClure

University of Cape Town

Non-isolated Dynamic Black Holes

Modifying the Kerr-Schild transformation used to generate black hole spacetimes, new dynamic black hole spacetimes are obtained using a time-dependent Kerr-Schild scalar field. Unlike the standard Schwarzschild solution, the time-dependence introduces a mass-energy distribution, so the singularity is non-isolated. Physical solutions are found for black holes that shrink with time and for white holes that expand with time. The $g_{tt} = g^{rr} = 0$ surface is dynamic, moving inward with time for the black holes and outward for the white holes, allowing null geodesics instantaneously held at fixed r to later escape or enter respectively, so this surface cannot act as the event horizon. By finding a surface that shrinks or expands at the same rate as the null geodesics move, and within which null geodesics move inward or outward faster than the surfaces shrink or expand respectively, it is verified that these spacetimes do in fact behave like black or white holes.

Mauricio Mendivelso

Observatorio Astronomico Nacional

Black Hole Entropy and Brickwall Model

On 1984 G. 't Hooft showed how the result $S_{BH} = \frac{1}{4}A$ (relating Bekenstein-Hawking entropy S_{BH} with event horizon area A to a black hole) can be reproduced if it is consider enclosed by a double reflectant wall with the inside one radius similar to the event horizon radius. However, how was showed by S. Mukohyama and W. Israel in 1998, this system allows to reproduce the result to a star-like object (with an unnecessary event horizon). To discuss what kind of object is described by 't Hooft brickwall model and the consequences of this result to Bekenstein-Hawking entropy understanding is the goal of this presentation.

Salvatore Mignemi

Dipartimento di Fisica, Università di Cagliari

Black Hole Asymptotics in Einstein-Gauss-Bonnet Gravity

We discuss the dynamical system associated to black hole solutions of Einstein-Gauss-Bonnet gravity and give a complete classification of the spherically symmetric solutions in terms of their asymptotic behavior.

Don Page

Department of Physics, University of Alberta

Constants of Motion for Higher Dimensional Black Holes

We explicitly exhibit $n-1$ constants of motion for geodesics in the general D-dimensional Kerr-NUT-AdS rotating black hole spacetime, arising from contractions of even powers of the 2-form obtained by contracting the geodesic velocity with the dual of the contraction of the velocity with the $(D-2)$-dimensional Killing-Yano tensor. These constants of motion are functionally independent of each other and of the $D-n+1$ constants of motion that arise from the metric and the $D-n=[(D+1)/2]$ Killing vectors, making a total of D independent constants of motion in all dimensions D. The Poisson brackets of all pairs of these D constants are zero, so geodesic motion in these spacetimes is completely integrable.

Eduardo Rodrigues

UERJ

Numerical Evolution of Radiative Robinson-Trautman Spacetimes

The evolution of a collapsing bounded source of matter emitting gravitational waves and a null radiation field is studied in the realm of radiative Robinson-Trautman spacetimes. The null radiation field is expected to take place in realistic gravitational collapse, and can either be an incoherent superposition of waves of electromagnetic, neutrino or massless scalar fields. By imposing that the radiation field is an decreasing function of the retarded time, the Schwarzschild solution is the asymptotic configuration after an intermediate Vaidya phase. We have analyzed the joint emission of gravitational waves and the null radiation field, in which one of the main consequences is the enhancement of the amplitude of the emitted gravitational waves. Another important issue we have touched is the mass extraction of the bounded configuration through the emission of both types of radiation.

Dinesh Singh

Department of Physics, University of Regina

An Analytic Perturbation Approach for Classical Spinning Particle Dynamics

We present a perturbation method to analytically describe the dynamics of a classical spinning particle, based on the Mathisson-Papapetrou-Dixon (MPD) equations of motion. By a power series expansion with respect to the particle's spin magnitude, we demonstrate how to obtain an analytic representation of the particle's kinematic and dynamical degrees of

freedom that is formally applicable to infinite order in the expansion. Within this formalism, it is possible to identify a classical analogue of radiative corrections to the particle's mass and spin due to spin-gravity interaction. We explicitly demonstrate the robustness of this approach with astrophysically relevant examples and consider potentially interesting future applications that may follow, based on the underlying principles presented here.

Andrey Shoom

Department of Physics, University of Alberta

Interior of Distorted Black Holes

We study the interior of distorted static axisymmetric spherical black holes. We obtain a general interior solution and study its asymptotics both near the horizon and singularity. As a special case, we apply the results obtained to the case of the so-called 'caged' black hole.

Todd Springer

Department of Physics, University of Minnesota

Cosmological Black Hole Formation and the QCD Phase Transition

We solve dynamical equations of motion to determine the conditions under which an overdense region in the early universe will lead to collapse to a black hole, starting from horizon crossing of the overdense region to the point of instability. We focus on the sensitivity of collapse to the QCD equation of state, including first and second order phase transitions from quarks and gluons to hadrons or just a rapid crossover. We then solve rate equations to determine the mass distribution of black holes in the present universe. A second order phase transition or rapid crossover would have significant consequences only if the index of primordial density fluctuations $n > 1.25$. However, a first order transition would lead to a black hole dominated universe for any realistic value of n including $n = 1$.

Sourav Sur

Department of Physics, University of Lethbridge

Entanglement as a Source of Black Hole Entropy: Corrections to the Area Law

We reexamine aspects of entanglement entropy of a scalar field found by tracing over it's degrees of freedom inside a sphere. As is well-known, the entropy is proportional to the area of the sphere when the field is in ground state, such entanglement entropy can be attributed to the source of black hole entropy, which is also proportional to the area of it's horizon. We estimate the amount of deviation from this area law by assuming the field to be in a superposition of ground state and excited state. We also identify location of the degrees of freedom that give rise to the above entropy and find the effects on the entropy when the scalar field is massive.

Hirotaka Yoshino

University of Alberta

Spin-spin Interaction of Two Gyratons and the Black Hole Formation

The gyraton describes a gravitational field of a lightlike object with finite energy and spin duration in time. In this talk, I explain our study on black hole formation in the head-on collision of two gyratons. Specifically, I highlight the importance of the spin-spin interaction in this process.

Andrei Zelnikov

Department of Physics, University of Alberta

Quasinormal Modes in 2D Black Holes

We study a nonminimal massive scalar field in a 2-dimensional black hole spacetime. We consider the black hole which is the solution of the 2d dilaton gravity derived from string-theoretical models. We found an explicit solution in a closed form for all modes and the Green function of the scalar field with an arbitrary mass and a nonminimal coupling to the curvature. Quasinormal modes, greybody factors, and the Hawking radiation are calculated explicitly for this exactly solvable model.
