Local organising committee

Christopher Berry, Miranda Bradshaw, Chris Collins, Joanne Cox, Carl-Johan Haster, Haixing Miao, Hannah Middleton, Simon Stevenson

Acknowledgements

The BritGrav 15 committee would like to thank the Institute of Physics and Classical & Quantum Gravity for sponsoring the event. We are also grateful to the University of Birmingham Engineering and Physical Sciences Marketing for help with advertising.
Posters

Posters will be displayed in the Physics West Library and can be viewed during tea and coffee breaks throughout the conference.

Tension between the power spectrum of density perturbations measured on large and small scales.
Tom Charnock
University of Nottingham

Maximising the detection probability of kilonovae associated with gravitational wave observations
Yiming Hu
University of Glasgow

How might black holes disappear?
Saeede Nafooshe
Nova Gorica University

Searching for Intermediate Mass Ratio Binaries Using Gravitational Waves
Gareth Thomas
University of Birmingham

An online version of this programme can be found at: www.sr.bham.ac.uk/britgrav15
All talks will be held in the Physics West Lecture Theatre W117

Monday 20th April

9:00am Registration

10:00am Session 1

Testing Gravity at The Micron Scale with a Superconducting Torsion Balance

Chris Collins  
Co-authors: Clive Speake, Michaela Nelson  
University of Birmingham

The best current measurements of gravity exclude deviations from the inverse square law of order one for scales down to about 60 microns. Some models of dark energy, such as Supersymmetric Large Extra Dimension models, predict large deviations at scales slightly below this. The Inverse Square Law Project at Birmingham aims to measure gravity at ranges of about 15 microns by developing a novel superconducting torsion balance to provide a unique platform for short-range weak force measurements.

Near-unstable Fabry-Perot cavities for future gravitational wave detectors

Haoyu Wang  
University of Birmingham

Using larger laser beam spot size on the cavity mirrors has been proposed to provide a reliably reduction in coating thermal noise. This could be theoretically achieved by pushing the cavity to the edge of geometric stability. However, in such cases, a tiny cavity length perturbation or mirror shape imperfectness would drive the cavity out of stability boundary and thus practical issues need to be addressed.

In this project, we would give a detailed study about the behaviour of a Fabry-Perot near-unstable cavity when gradually pushing it to near instability. The short term goal is to understand the performance and mitigate problems of near-unstable cavities as a core component in gravitational wave detectors. Theoretical analysis and experimental demonstrations would be given to understand how far away from stability the cavity could be practically built. The long term goal is to gain an insight for future gravitational wave detection projects that how big the beam size can be used and how to optimise their designs based on this work.

Design of a modal decomposition beam sensor

Joshua Freedman  
Co-authors: Andreas Freise  
University of Birmingham

Measuring the modal content/eigenmode of a laser beam is a challenging experimental task. This project aims to numerically demonstrate a novel sensor for such purposes. The diagnostic knowledge provided by this sensor, could lead to new feedback interferometry methods capable of improving upcoming experiments such as Advanced LIGO. In this talk, a brief introduction to the background of the modal sensor will be presented, preliminary work undertaken and diagnostic capabilities of the sensor will also be discussed.

Second Einstein Telescope BNS Mock Data & Science Challenge

Duncan Meacher  
ARTEMIS, OCA

We present the results on the second ET Mock Data and Science Challenge focused on the search for binary neutron stars. We show that using a newly developed low latency analysis pipeline we are able to analyse simulated mock ET data containing multiple overlapping GW signals within a noise dominant background down to low frequencies. We will report the results of this analysis as well as the results of parameter estimation on the detected signals. We will then discuss the implication of these results in terms of cosmological measurements.
Estimation of gravitational wave event statistical significance

Yiming Hu  
IGR, University of Glasgow

Co-authors: Collin Capano, Thomas Dent, Chad Hanna, Martin Hendry, Chris Messenger, John Veitch, Matthew Wes

We address a critical issue in finding the statistical significance of candidate transient gravitational-wave events a ground-based interferometer network. Given the presence of non-Gaussian noise artefacts in real data, the noise background must be estimated empirically from the data itself; however, the data also contains signals, thus the background estimate may be overstated due to contributions from signals. It has been proposed to mitigate this possible bias by removing single-detector data samples that pass a multi-detector consistency test (and thus form coincident events) from the background estimates. We conduct a high-statistics Mock Data Challenge to evaluate the effects of removing such samples, modeling a range of plausible detector noise distributions in combination with a range of plausible foreground astrophysical signal rates, allowing us to calculate the exact false alarm probabilities of candidate events in the chosen noise distributions. Three slightly different methods of calculating event significance are each deployed in two different modes: removal or non-removal of coincident samples. The three methods show good consistency with each other, however discrepancies arise between removal and non-removal for false alarm probabilities below $\sim 10^{-3}$. We suggest that for the first detection, we should use non-removal method to make the announcement solid.

Searching for Neutron Star Black Hole binaries with gravitational waves

Alex Nielsen  
Max Planck Hannover

Binary systems containing one neutron star and one black hole have a decent chance of being detected by upcoming ground based gravitational wave detectors. If realised these would be the first known detections of such binary systems. We give an overview of the status of current searches for these systems and discuss some of the science that can be done with observations including constraining formation models, heavy element abundances, black hole spin effects and the possibility that tidal disruption of the neutron star lead optical counterparts such as short gamma ray bursts or kilonovae.

Parameter estimation with Advanced LIGO

Christopher Berry  
University of Birmingham

Co-authors: Ilya Mandel, Hannah Middleton, Leo Singer, Alex Urban, Alberto Vecchio, Salvatore Vitale, Kipp Cannon, Ben Farr, Will Farr, Philip Graff, Chad Hanna, Carl-Johan Haster, Satya Mohapatra, Chris Pankow, Larry Price, Trevor Sidery and John Veitch

Advanced LIGO will begin operation later in 2015. Binary neutron stars are the most likely source of a gravitational-wave signal. I discuss what we could learn following detection of such a signal, and in particular how well we could locate the source on the sky to allow for follow up by electromagnetic observatories. The best measured parameter will be the chirp mass, even if some error is introduced by neglecting the neutron stars’ spins. Sky localisation is less precise, requiring hundreds of square degrees to be covered.
Dynamic temperature selection for parallel-tempering in Markov chain Monte Carlo simulations

Will Vousden  
University of Birmingham

Co-authors: Will Farr, Ilya Mandel

The emerging field of gravitational wave astronomy – and many other areas of physics – requires efficient methods for characterising complex, high-dimensional, and often multi-modal probability distributions. Most popular methods, such as Markov chain Monte Carlo sampling, perform poorly on strongly multi-modal distributions, being liable to settle on one mode without finding others. Parallel tempering addresses this problem by sampling simultaneously with separate Markov chains from tempered versions of the target distributions in such a way that the modes are flattened out, and therefore easier for the sampler to migrate between.

An open problem in the application of parallel tempering is the selection of the temperatures at which to sample from the target distribution. We propose an adaptive scheme that selects temperatures in order to optimise the communication between samplers of different temperatures, and therefore maximise the efficiency of the sampler. In our tests, scheme reduces the autocorrelation time of the sampler by a factor of 1.5 or more.

Using Gaussian process to improve waveform models for binary black holes

Christopher Moore  
Cambridge, Institute of Astronomy

Co-authors: J. Gair and C. Berry

Modelling binary black hole mergers is a major challenge in the advanced detector era. The penalty for getting it wrong is severe; namely a lower probability for detection, and systematic errors in the parameters of identified sources. Gaussian processes provide a convenient, non-parametric method for interpolating model waveforms across parameter space. This technique is used to construct a new likelihood function which can be used in detection and parameter estimation studies which addresses the aforementioned problems. I will discuss the method and present results of parameter estimation calculations on mock advanced LIGO data.

Determining the core-collapse supernova explosion mechanism with gravitational waves.

Jade Powell  
Glasgow University

A gravitational wave detection of a galactic core-collapse supernova signal could provide us with the opportunity to see through to the core of the collapsing star. The Supernova Model Evidence Extractor (SMEE) is a Bayesian algorithm, which will allow us to determine the core-collapse explosion mechanism of a supernova detection. We use principal component analysis of waveforms from axisymmetric simulations of core-collapse supernovae exploding via the neutrino and magnetorotational mechanisms to create signal models, which represent the main features of the two different mechanisms. Determination of the core-collapse explosion mechanism can then be achieved by model selection with a Nested Sampling algorithm. Using recoloured noise for advanced LIGO and Virgo we demonstrate that SMEE can be used to accurately distinguish the explosion mechanism of core-collapse supernovae throughout our galaxy.

Binary black hole spin-orbit resonances

Simon Stevenson  
University of Birmingham

Co-authors: Ilya Mandel, Christopher Berry, Ben Farr, Will Farr

There are many theoretical uncertainties in the binary evolution that leads to the formation of binary black holes, a potential source for ground based gravitational-wave detectors. Here we focus on the prediction of the orientation of black hole spins with respect to the orbital angular momentum. Black hole spins will not in general be aligned with the orbital angular momentum after the second supernova in these systems. Post-Newtonian evolution of these systems causes misaligned spins to precess around the total angular momentum. The spins can freely precess, or can...
be attracted to spin-orbit resonances where they precess in a common plane with the orbital angular momentum. Depending on the initial conditions after the second supernova, binary black holes may cluster into different regions of parameter space by the time they enter the Advanced LIGO frequency band. It is suggested that gravitational-wave measurements of spin-orbit misalignments in coalescing binary black holes can be used to distinguish between these regions of parameter space, and thus inform us about the formation channels of compact binary systems.

**Astrophysical constraints on massive black holes from pulsar timing array observations.**

**Hannah Middleton**  
PhD student, University of Birmingham

Co-authors: Alberto Vecchio, Will Farr, Alberto Sesana.

Results from pulsar timing arrays can be used to constrain the gravitational wave background produced by the mergers of many supermassive black hole (SMBH) binaries found at the centre of merging galaxies. As yet, the sensitivity required to measure the gravitational wave background has not been reached, however it is possible to constrain the level to an upper limit. Using these results and assuming a simple merger rate model described by physical parameters, we are investigating the implications of an upper limit, or future detection, for the properties of the merging population of SMBHs.

1:00pm Lunch

2:00pm Session 3  
Chair: Hannah Middleton

**Giant and empty: black-hole occupation fraction in brightest cluster galaxies**

**Davide Gerosa**  
University of Cambridge (DAMTP)

Co-authors: Alberto Sesana

We investigate the consequences of superkicks on the population of supermassive black holes (SMBHs) in the Universe residing in brightest cluster galaxies (BCGs). There is strong observational evidence that BCGs grew prominently at late times (up to a factor 2-4 in mass from $z=1$), mainly through mergers with satellite galaxies from the cluster, and they are known to host the most massive SMBHs ever observed. Those SMBHs are also expected to grow hierarchically, experiencing a series of mergers with other SMBHs brought in by merging satellites. Because of the net linear momentum taken away from the asymmetric gravitational wave emission, the remnant SMBH experiences a kick in the opposite direction. Kicks may be as large as 5000 Km/s (“superkicks”), pushing the SMBHs out in the cluster outskirts for a time comparable to galaxy-evolution timescales. We predict, under a number of plausible assumptions, that superkicks can efficiently eject SMBHs from BCGs, bringing their occupation fraction down to a likely range $0.9 < f < 0.99$ in the local Universe. Future thirty-meter-class telescopes like ELT and TMT will be capable of measuring SMBHs in hundreds of BCGs up to $z=0.2$, testing the occurrence of superkicks in nature and the strong-gravity regime of SMBH mergers.


**Hierarchical model of weak lensing mass - X-ray temperature scaling relation**

**Maggie Lieu**  
University of Birmingham

Galaxy clusters and groups are fundamental to probe cosmology from the mass function. For this we need accurate measurements of their total mass. Weak lensing mass measurements are only dependent on the gravitational potential however for low mass and low signal-to-noise systems, are difficult to obtain. In this talk I will present a hierarchical model to probe the lensing and X-ray properties of the underlying population.
Constructing N-body Simulations with General Relativistic Dynamics

Mateja Gosenca
Co-authors: Julian Adamek, Shaun Hotchkiss

N-body simulations normally use equations of Newtonian dynamics to evolve particles and fields forward in time. On galactic scales and at times late enough for velocities and gradients of fields to be small this turns out to be an extremely good approximation. However, in modified gravity models, at earlier times when neutrinos are relativistic, or on much larger scales, evolving relativistic sources become important. Therefore, nonlinear evolution of cosmic structure requires a more sophisticated modelling of dynamics. We model general relativity numerically with a weak-field approximation, but still allow for large gradients of the fields and relativistic velocities for the particles. This makes the system much more complicated. In this work, we therefore simplify the system by considering a one-dimensional, spherically symmetric setup. Apart from just reducing the complexity, this setup also allows us to model spherically symmetric fluctuations such as a void or a spherical halo.

Post-Newtonian Cosmological Models

Viraj Sanghai
Co-authors: Timothy Clifton

We construct a framework to probe the effect of non-linear structure formation on the large-scale expansion of the universe. We take a bottom-up approach to cosmological modelling by splitting up our universe into cells. The matter content within each cell is described by the post-Newtonian formalism. We assume that most of the cell is in the vicinity of weak gravitational fields, so that it can be described using a perturbed Minkowski metric. Our cells are patched together using the Israel junction conditions. We impose reflection symmetry across the boundary of these cells. This allows us to calculate the equation of motion for the boundary of the cell and, hence, the expansion rate of the universe. At Newtonian order, we recover the standard Friedmann-like equations. At post-Newtonian orders, we obtain a correction to the large-scale expansion of the universe. Our framework does not depend on the ambiguous process of averaging in cosmology.

Applying Bayesian data analysis to learn about periodic variability in pulsars

Gregory Ashton
Co-authors: D.I. Jones, R.Prix

The theoretical physics of pulsars often offers more than one interpretation for the observed phenomena. In particular an array of models have been posed to explain the low-frequency variations in timing residuals that are often termed ‘timing-noise’. Our understanding of these models is important for carrying out gravitational-wave searches since we must be able to build templates of the signals.

The timing-noise in some pulsars demonstrate periodicities which are compatible with the time-scales of precession. For pulsar B1828-11, the evidence was sufficiently strong that precession became the accepted model. However, recent work by Lyne et al. (2010) proposed an alternative model in which the pulsar undergoes periodic state-switching.

In this talk I will present our efforts to quantify how well both of these models explain our observations. We do this by using observational data and applying techniques from Bayesian data analysis.

Magnetic Field Evolution In Superconducting Neutron Stars

Vanessa Graber
Co-authors: Nils Andersson, Sam Lander, Kostas Glampedakis

Due to low temperatures and high densities, protons and neutrons in the outer core of a neutron star have the special ability to flow without experiencing any friction; the charged protons form a superconductor, whereas the neutrons are referred to as a superfluid and both states create vortices that interact with their surroundings. This behaviour
on microscopic length scales crucially influences the large scale dynamics of the star. We address the question of how the star’s magnetic field evolves in the presence of superconducting protons. In comparison to normal matter, the important difference in a superconductor is that the vortices carry the magnetic field. Its strength is then related to the total number of individual vortex lines. We are currently investigating which mechanisms acting on vortices on microscopic scales could impact the macroscopic evolution of the magnetic field.

**Fluid dynamics in neutron star oceans**

*Alice Harpole*  
*University of Southampton*  
*Co-authors: Ian Hawke*

Type I X-ray bursts are thermonuclear explosions which occur on the surface of accreting neutron stars. It is believed that the burning begins in a localised spot in the ocean of the star, before spreading across the entire surface. As neutron stars are compact objects, the effects of strong gravity must be taken into account when investigating the ocean physics. The speed of propagation of the burning front is much slower than that of the acoustic speed in the ocean, which also must be addressed when modelling these systems numerically. We shall discuss the relativistic fluid equations used to describe the burning front propagation, in particular looking at the relativistic extension to the low Mach number approximation.

**Magnetized superconducting neutron stars with entrainment**

*Konstantinos Palapanidis*  
*University of Southampton*  
*Co-authors: Nikolaos Stergioulas, Samuel Lander*

We construct equilibrium configurations of magnetized, two-fluid neutron stars using an iterative numerical method. We assume that the neutron star has two regions: the inner core, which is modelled as a two-component fluid consisting of type-II superconducting protons and superfluid neutrons, and the crust, a region composed of normal matter. We assume that the entrainment $\varepsilon_*$ is a function of proton and neutron densities and thus a force acts on neutrons too. We consider purely poloidal field cases. We emphasize the requirement of convergence of several quantities, before a numerical solution can be considered acceptable. Here, we introduce new quantities to specify the equilibrium since the old are shown to be ill conditioned. If the magnetic field is not too strong, we show that convergence is assisted by decoupling the magnetic field from fluid quantities, after the latter have already converged. In specific cases, we discuss the influence of the entrainment factor on the magnetic field configuration. We show that models with and without entrainment are similar having different magnetic field lines along the crust-core boundary.

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<th>3:40pm Tea and posters</th>
<th>Physics Library</th>
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<td>4:10pm Session 4</td>
<td>Chair: Maggie Lieu</td>
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**The Bianchi Asymmetry**

*Nigel Martin*

The contracted Bianchi identities restrict the evolution of the Einstein tensor, reflecting the way that Newton’s laws restrict the evolution of the stress energy tensor. Their action is well recognised. The uncontracted Bianchi identities contain a further constraint, tying the evolution of the Einstein tensor to the evolution of the Weyl tensor. This constraint can be expressed thus:

$$\nabla^{[abc} \nabla_d a = G_b [d;c] - \frac{1}{3} g_b [dG;c]$$

There is a general assumption that this equation can only be driven from the right hand side. This means that, working at a point, physics tells us the evolution of the Einstein tensor irrespective of the Weyl tensor. The evolution
of the Weyl tensor is then determined by the evolution of the Einstein tensor together with the current state of the Weyl tensor. Thus (for example) the Einstein tensor must be zero at a point if it is zero everywhere in the past light cone. I question that assumption.

**The Extended Constraint Equations in General Relativity**

**Jarrod Williams**  
QMUL

The reformulation of the Einstein field equations as a Cauchy problem, leading to a system of constraint equations and evolution equations, has proved a powerful tool in mathematical General Relativity. On the other hand, the conformal Einstein equations (CEFEs) offer a new approach to the study of asymptotic properties of isolated systems. In this talk I will describe how, under a 3+1 splitting of spacetime, the CEFEs give rise to the so-called Extended Constraint equations, and will conclude with a discussion of some of the recent developments in their analysis.

**Numerical derivations of trumpet initial data for single black hole spacetimes**

**Gernot Heißel**  
Cardiff University

Co-authors: Mark Hannam

Most current black hole binary simulations are based on the moving puncture method, and initially represent the black holes as wormholes, i.e. with slices that connect two asymptotically flat ends through a throat of finite areal radius. Stable simulations have been achieved with gauge conditions that cause the slices to quickly lose contact with the second asymptotically flat end, and approach a ‘trumpet’ topology. Thus one can argue that the ideal initial data for these codes is trumpet data, thereby reducing the initial, non-trivial, gauge dynamics. This has already been shown in the example of single black hole simulations.

In my talk, I would like to present the results on a numerical derivation of Schwarzschild trumpet initial data. After that I would like to elaborate on the extension of this approach to Kerr spacetime, which is currently work in progress.

**Higher Dimensional Gravitational Wave Extraction in Numerical Relativity**

**William Cook**  
University of Cambridge, DAMTP

We present work in progress on two methods for extracting gravitational wave signals from numerical simulations of black holes in higher dimensions. These methods provide us with higher dimensional counterparts to the perturbative Regge-Wheeler-Zerilli-Moncrief formalism and the Newman-Penrose formalism used in 4 dimensional simulations.

**Full Inspiral-Merger-Ringdown Binary Black Hole Gravitational Waveforms: The Phenomenological Approach**

**Sebastian Khan**  
Cardiff University

Co-authors: Mark Hannam, Sascha Husa, Frank Ohme and Michael Puerrer

With the advanced GW detectors taking their first science data in the summer of this year the need for accurate and reliable GW waveform models, crucial in searches and parameter estimation, are urgently needed.

Our new model has a high level of agreement with complementary waveform models (e.g., the SEOBNR family) in those regions of parameter space where numerical-relativity waveforms exist. The models disagree in regions where we are currently ignorant of the correct GR gravitational-wave signal, in particular high aligned spins.
Tuesday 21st April

9:00am Session 5  Chair: Chris Collins

Gauge invariant quantum gravitational decoherence

Teodora Oniga  University of Aberdeen
Co-authors: Charles Wang
Decoherence due to environmental gravitons is a prediction which has received increasing interest, with various approaches being used to explore their effects on quantum coherence, such as Ref. [1]. Recently, the theory of open quantum systems was proposed as a suitable formalism to study gravitational decoherence [2]. However, this was implemented using a gauge-fixed master equation and only for a scalar matter field. Here I present a more comprehensive approach, by constructing a gauge and Lorentz invariant master equation for a generic quantum system in a bath of gravitons using linearized gravity. In addition, quantum gravitational fluctuations and gravitational self-interactions are naturally incorporated. The resulting framework could enable the study of a wide variety of quantum systems subject to environmental gravitational fields, including zero point spacetime fluctuations. In particular, it would provide new tools to investigate novel quantum gravity effects ranging from the decoherence of starlight from deep space to the decoherence of matter such as cold atoms in the lab.


Towards understanding the ultraviolet behavior of quantum loops in infinite-derivative theories of gravity

Spyridon Talaganis  Lancaster University
Co-authors: Tirthabir Biswas, Anupam Mazumdar
In this talk I will consider quantum aspects of a non-local, infinite derivative scalar field theory - a toy model depiction of a covariant infinite derivative, non-local extension of Einstein's general relativity which has previously been shown to be free from ghosts around the Minkowski background. The graviton propagator in this theory gets an exponential suppression making it asymptotically free, thus providing strong prospects of resolving various classical and quantum divergences. In particular, I will find that at 1-loop, the 2-point function is still divergent, but once this amplitude is renormalized by adding appropriate counter terms, the ultraviolet (UV) behavior of all other 1-loop diagrams as well as the 2-loop, 2-point function remains well under control. I will go on to discuss how one may be able to generalize our computations and arguments to arbitrary loops.

Hartle Hawking wave function in Causal Set quantum gravity

Lisa Glaser  University of Nottingham
Co-authors: Sumati Surya
Causal Set theory is a proposal for a discrete theory of space-time that can quantize gravity. In this theory we have defined the Hartle-Hawking no-boundary wave function using discrete analogs of spacelike hypersurfaces. Our definition can then be used to examine this wave function in 2 dimensions using Markov Chain Monte Carlo methods. We find that for small universes non-manifold like geometries dominate the path integral. These geometries are characterized by a rapid spatial expansion and show signs of spatial homogeneity.
Removing Faddeev-Popov zero modes from Yang-Mills theory and perturbative gravity

Jos Gibbons

University of York

Co-authors: Atsushi Higuchi

Covariantly quantising Yang-Mills theory or perturbative gravity introduces Faddeev-Popov ghosts and antighosts. The propagator of these fields is infrared-divergent, due to so-called zero modes of the FP-fields. We contrast two prescriptions for remedying this. The first deletes an IR-divergent term from the propagator for massive FP-fields before obtaining an IR-limit effective propagator. The second proves the zero modes are cyclic in the Lagrangian formalism and hence can be rendered dynamically irrelevant. We have shown these prescriptions have the same effective action in perturbation theory, and discussed a number of advantages of the second prescription. Our treatment of the Yang-Mills case is at arxiv 1410.7830; our work on the gravity case is in preparation.

Quasi-Static Solutions for Compact Objects in Chameleon Models

Ilia Musco

LUTH, Observatoire de Paris (Meudon)

Co-authors: P. S. Corasaniti; P. Ferreira; D. Mota

It has been suggested that a scalar field ϕ non-minimally coupled to matter could be responsible for the observed accelerated expansion of the Universe. However, the fact that we are able to measure its effect only on cosmological scales but not on local ones, such as that of our solar system, might be the consequence of a screening mechanism. This is the essence of the Chameleon model. Understanding its viability requires solving the field equations in the transition regime where the scalar field transitions from a region of high density to the outer region where it plays the role of the Dark Energy. In this work we analyze quasi-static spherically symmetric solutions for objects such as standard stars and more compact objects like white dwarfs and neutron stars, by solving the Tolman-Oppenheimer-Volkoff equations coupled with the Klein-Gordon equation in a quasi static regime. We derive a solution that takes into account the background expansion without needing to introduce an artificial cosmic matter corresponding to a non-spatially flat metric. The interior of the star is characterized using a polytropic equation of state while outside we consider a dark matter halo with a Navarro-Frenk-White density profile until it matches onto the cosmic density of an expanding spatially flat background.

Horava gravity with mixed derivative terms

Mattia Colombo

School of Mathematical Sciences, University of Nottingham

Co-authors: A. Emir Gumrukcuoglu, Thomas P. Sotiriou

Horava gravity has been constructed so as to exhibit anisotropic scaling in the ultraviolet, as this renders the theory power-counting renormalizable. However, when coupled to matter, the theory has been shown to suffer from quadratic divergences. A way to cure these divergences is to add terms with both time and space derivatives. We consider this extended version of the theory in detail. We perform a perturbative analysis that includes all modes, determine the propagators and discuss how including mixed-derivative terms affects them. We also consider the Lifshitz scalar with mixed-derivative terms as a toy model for power counting arguments and discuss the influence of such terms on renormalizability.

Geodesic Completeness and Non-Local Theories of Gravity

Aindriú Conroy

Lancaster University

Co-authors: Anupam Mazumdar and Alexey S. Koshelev

By use of the Raychaudhuri Equation, a generalised non-local bouncing cosmology is examined at the bounce point t=0. The talk begins with an outline of the importance of the Raychaudhuri Equation regarding singularity theorems in General Relativity before moving onto a generalised non-local theory of gravity. The equations of motion of such an action are contracted with a congruence of null geodesics and studied at the bounce point t=0 in order to find
the required conditions for such a cosmology to avoid singularities. Further details will be illustrated by conformal diagrams.

With particular reference to http://arxiv.org/abs/1408.6205

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10:40am Coffee and posters

11:10am Session 6 Chair: Will Farr

A mathematical model for Penrose's CCC-scenario

Christian Luebbe Birkbeck College London

Penrose suggested that our universe is made up of aeons in which the far future of a past aeon has lead to the big bang of our current aeon - the CCC-scenario. In this talk I will discuss a mathematical model that uses conformally invariant scalar fields, potentially coupled to other matter, to achieve the desired features of the CCC-scenario.

Numerical Problems in Perturbed Coupled Quintessence

Alexander Leithes Queen Mary, University of London

Co-authors: Karim Malik, Nelson Nunes, David Mulryne

We investigate the evolution of perturbations in coupled Quintessence with multiple CDM fluids and scalar fields. This is performed numerically using Python with a focus on whether particular gauge choices give greater efficiency in the associated code. We also use more general equations than previous work in order that our tests may be conducted over many scales.

Newtonian perturbation theory from the Schroedinger-Poisson equations

Adam Christopherson University of Florida

Co-authors: Nilanjan Banik, Pierre Sikivie, Elisa Todarello

Dark matter is a crucial ingredient of the standard cosmological model, making up over 80% of the total matter in the Universe. Although observational evidence strongly favours the existence of dark matter, we are yet to physically detect a particle, despite many attempts to do so. In order to model the dynamics of structure formation with dark matter one uses Newtonian physics, where we are able to understand much in the linear regime. While this is reliable for WIMPs, it is not necessarily the case for other candidates. In particular, for the axion, one might expect that this description as a classical, pressureless fluid is incomplete, since the axion is really a quantum field. In this talk I will describe work done on the first step towards the goal of describing structure formation with axions. Namely, I will show that the wavefunction approach reproduces the usual evolution equation for the density perturbation, albeit with an additional term dubbed the 'quantum pressure' term. I will close with a discussion of limitations of the approach, and plans for future work.

Particle and Photon Orbits in McVittie Spacetimes

Brien Nolan Dublin City University

McVittie spacetimes represent an embedding of the Schwarzschild field in isotropic cosmological backgrounds. Depending on the scale factor of the background, the resulting spacetime may contain black and white hole horizons, as well as other interesting boundary features. In order to further clarify the nature of these spacetimes, we address this question: do there exist bound particle and photon orbits in McVittie spacetimes? Considering first circular photon orbits, we obtain an explicit characterization of all McVittie spacetimes for which such orbits exist. We show that McVittie spacetimes with background scale factor corresponding to a $\Lambda$-CDM cosmology do not admit
circular photon orbits. However, we prove that in two large classes of McVittie spacetimes, there are bound particle and photon orbits: future-complete non-radial timelike and null geodesics along which the areal radius $r$ has a finite upper bound. These geodesics are asymptotic at large times to circular orbits of a corresponding Schwarzschild or Schwarzschild-de Sitter spacetime. The existence of these geodesics lays the foundations for and shows the theoretical possibility of the formation of accretion disks in McVittie spacetimes. We also summarize and extend some previous results on the global structure of McVittie spacetimes. The results on bound orbits are established using centre manifold and invariant manifold techniques from the theory of dynamical systems.

**Slow rotating vacuum solutions with a cosmological constant.**

*Matthew Wright*  
University College London

Co-authors: Christian Boehmer

Hartle’s slow rotation formalism is developed in the presence of a cosmological constant. We find the generalisation of the Hartle-Thorne vacuum metric, the Hartle-Thorne-(anti)-de Sitter metric. Without a cosmological constant, the general slow rotating vacuum exterior is not asymptotically flat, and thus a slow rotating perfect fluid cannot in general be matched to an asymptotically flat exterior. However with a comological constant the exterior is always asymptotically (anti)-de Sitter and a general perfect fluid can be matched to this exterior. Thus we are able to find models describing an isolated rotating body, to second order in the angular velocity.

**Conformal properties of the extreme Schwarzschild de-Sitter spacetime**

*Edgar Gasperin Garcia*  
Queen Mary University of London

Co-authors: Juan Antonio Valiente Kroon

We analyse the extremal Schwarzschild de-Sitter (eSdS) spacetime through an asymptotic intial value problem. We make use of the extended conformal Einstein field equations (XCEFE) and conformal Gaussian system of coordinates to obtain an symmetric hyperbolic system evolution equations. We derive asymptotic initial data for the eSdS spacetime and use the conformal evolution equations to analyse the evolution of initial data off the initial hypersurface. In particular, we study the formation of singularities exploiting the structure of the conformal evolution equations.

**Killing spinors in electrovacuum spacetimes**

*Micahel Cole*  
Queen Mary University of London

It has been shown that the existence of a Killing spinor, along with asymptotic flatness and restrictions on the Petrov type, gives a characterisation of the Kerr spacetime. The existence of such a Killing spinor can be guaranteed by prescribing initial conditions on a Cauchy surface for the spacetime. I will discuss how these results can be extended to solutions of the Einstein-Maxwell equations, and the corresponding Kerr-Newman spacetime.

**Completion of metric reconstruction for a particle orbiting a Kerr black hole**

*Cesar Merlin Gonzalez*  
University of Southampton

In General Relativity the description of a compact object embedded in a strong gravitation field can be obtained using perturbation theory. Solving for the components metric perturbation is a highly non trivial task, since in general involves solving a set of ten coupled partial differential equations. By imposing the radiation gauge condition, a piece of the metric components can be recovered from curvature scalars obtained by solving a wave like equation (Teukolsky equation). This reconstructed metric requires to include extra homogeneous solutions that correspond to the non-radiative sector and are not recovered thought the reconstruction procedure. In this paper we devise a method to complete the solution in a ’Kerr gauge’ for general orbits of the Kerr spacetime. The amplitude of these solution is obtained by looking at the discontinuities of gauge invariant auxiliary variables of the reconstructed
solution, instead of analysing the components of the metric perturbation. We show the simplicity of our method by obtaining the amplitudes for the circular orbits around Schwarzschild and Kerr cases. We extend the procedure for eccentric equatorial orbits in Kerr.

12:50pm Lunch

1:50pm Session 7 Chair: Simon Stevenson

Bound States of Fermions in Kerr Black Hole Background

David Dempsey Sheffield University
Co-authors: Sam Dolan
We have investigated the Dirac equation in a Kerr Black Hole Background. Bound states can be calculated by imposing ingoing boundary conditions on the horizon and exponential decay at infinity. The Chandrasekhar-Page radial equations have been reduced to a three term matrix valued recurrence relation. This can then be solved via a matrix valued continued fraction to give the eigenvalues of the energy. The bound states have complex energies arising from the fact that these modes decay over time due to the absorption from the black hole. I present plots of the radial density, showing the effect of the spin of the black hole on these states.

Unruh-DeWitt Fermion detector in (1+1) Dimensions: Arbitrary Worldlines and Inequivalent Spin Structures

Vladimir Toussaint University of Nottingham
Co-authors: Jorma Louko
We examine an Unruh-DeWitt particle detector that is coupled linearly to the scalar density of a massless Dirac field in (1+1)-dimensional Minkowski spacetime and on its cylindrical quotient, allowing the detector’s motion to remain arbitrary and working to leading order in perturbation theory. In Minkowski, the detector’s response is identical to that of a detector coupled linearly to a massless scalar field in four-dimensional Minkowski space, and in the special case of uniform acceleration we recover the known Unruh effect results. On the cylinder we show that the detector’s response distinguishes the periodic and antiperiodic spin structures, and the zero mode that is present for periodic spinors contributes to the response by a state-dependent but well defined and controllable amount. Explicit analytic and numerical results are obtained for inertial and uniformly accelerated trajectories.

You shall not pass! Quantum effects at a Cauchy horizon

Benito A Juárez-Aubry University of Nottingham
Co-authors: Jorma Louko
We study the effects of quantum matter on an observer as it approaches a Cauchy horizon. As a prototype, we study the case of a geodesically infalling observer in the 1 + 1 Reissner-Nordström spacetime with a massless scalar field in the Hartle-Hawking-Israel state. Firstly, we compute the transition probability per unit time of an Unruh-DeWitt detector along the future-directed geodesic in the vicinity of the future inner horizon of Reissner-Nordström. Secondly, we calculate the stress-energy along the observer’s geodesic, with the aid of conformal techniques, as the future Cauchy horizon is approached. The rate of divergence can be found analytically in both cases, and we show that both the transition rate and worldline energy diverge proportionally to \( (\tau_h - \tau)^{-1} \) as \( \tau \to \tau_h \).
Renormalised vacuum polarisation of rotating black holes

Hugo Ferreira
University of Nottingham

Quantum field theory on rotating black hole spacetimes is plagued with technical difficulties. In this talk, I describe a general method to renormalise and compute the vacuum polarisation for rotating black holes, exemplifying with the warped AdS3 black hole. I will use a ‘quasi-Euclidean’ technique, which generalises the Euclidean techniques used for static spacetimes, and I will subtract the divergences by matching to a sum over mode solutions on Minkowski spacetime. This allows us, for the first time, to have a general method to compute the renormalised vacuum polarisation (and the stress-energy tensor), for a given quantum state, on a rotating black hole spacetime.

Einstein-Charged Scalar Field Theory: Black Hole Solutions and Their (In)stability

Supakchai Ponglertsakul
University of Sheffield

A charged scalar field can be used to extract energy from a charged black hole via superradiant scattering. A mirror-like or AdS boundary could lead the system to an instability. This is because the scalar fields are trapped outside the black hole and repeatedly amplified, therefore ultimately the back-reaction on the black hole background will become non-negligible. In fact the charged scalar field on the Reissner-Nordstrom background with mirror had been shown to possess superradiant instability [1]. However the possible end-point of this super-radiant instability remains unanswered. In this talk, I will consider a fully coupled system between gravity, an electric field and a charged scalar field. By solving the Einstein equations, numerical solutions representing solitons and black holes are obtained. Then I will comment on the stability of these solutions.


Wave regularity in singular spacetimes

Yafet Sanchez Sanchez
University of Southampton

Einstein’s theory revolutionised physics by describing gravity as the geometry of spacetime. In certain extreme circumstances, like the Big Bang or black holes, the curvature is so extreme that the geometric description of space and time stops making sense and a tear called a singularity is formed. The way we detect these kind of situations is by considering incomplete geodesics in spacetime. This characterization is only useful if the regularity of the metric is at least $C^{1,1}$ to have a well defined notion of geodesic. In order to go beyond this regularity we propose to see singularities as obstructions to wave equations rather than geodesics. In the talk I will show how some to pose wave equations in spacetimes with low regularity and show some applications to conical spacetimes and shell-crossing singularities.

Instability of Enclosed Horizons

Bernard Kay
Department of Mathematics, University of York

We argue that, both classically and quantum-mechanically, stationary black holes enclosed by boxes have unstable horizons. The instability is due to small perturbations reflecting off the box and piling up on the horizon leading to a blow-up in the stress energy tensor at the horizon. We verify the existence of such a blow-up explicitly for a simple analogue system consisting of the massless wave equation in 1+1 Minkowski space to the left of an eternally accelerated mirror with Dirichlet boundary conditions on the mirror. Stronger results are obtained if there is also an eternally decelerating image mirror in the opposite Rindler wedge.

We further argue that, as a result of this instability, the full (Kruskal) maximal extension of the Schwarzschild
spacetime is not relevant for the quantum gravity of a black hole in a box, and, instead that our results lend support to ’t Hooft’s 1985 “brick-wall” model according to which, to the extent that one can have a description in terms of a classical spacetime inside the box, that classical spacetime is something like the exterior Schwarzschild portion of Kruskal only (for radii less than the radius of the box) with a non-classically-describable region around the horizon itself.


Non-existence of stationary Hadamard states for a black-hole in a box and for the 1+1 massless wave equation to the left of an accelerated mirror

Umberto Lupo
Co-authors: Bernard S. Kay

We conjecture [1] that, on the subspacetime of Kruskal to the left of a constant Schwarzschild-radius surface (representing an enclosing box) and with Dirichlet boundary conditions at that surface, there is no stationary Hadamard state for the Klein-Gordon field. We also prove an analogue of this conjecture for the massless wave equation on the region of 1+1 Minkowski space to the left of an eternally accelerated mirror. Existence of a stationary Hadamard state is however conjectured/known to hold when there is also an image box/mirror in the left Schwarzschild/Rindler wedge.

This conjecture/result further strengthens the conclusion in [2] (see abstract to this conference by B.S. Kay) that the full (Kruskal) maximal extension of the Schwarzschild spacetime is not relevant for the quantum gravity of a black hole in a box, and, instead lends support to ’t Hooft’s 1985 “brick-wall” model according to which, to the extent that one can have a description in terms of a classical spacetime inside the box, that classical spacetime is something like the exterior Schwarzschild portion of Kruskal only (for radii less than the radius of the box) with a non-classically-describable region around the horizon itself.


3:30pm Tea and posters

4:00pm Session 8 Chair: Alberto Vecchio

IOP Thesis Prize

Timothy Clifton

Co-authors: Adrian Ottewill, Barry Wardell

The growing reality of gravitational wave astronomy is giving age-old problems a new lease of life; one such problem is that of the self-force. A charged or massive particle moving in a curved background space-time produces a field that affects its motion, pushing it off its expected geodesic. This self-field gives rise to a so-called self-force acting on the particle. In modelling this motion, the self-force approach uses a perturbative expansion in the mass ratio.

One of the most interesting sources of gravitational waves are extreme mass ratio inspirals - systems perfectly suited to self-force modelling. One of the key problems within the self-force model is the divergence of the field at the
particle. To resolve this, the field is split into a singular component and a smooth regular field. This regular-singular split, introduced by Detweiler and Whiting, is used in most modern self-force calculations. We derive high-order expansions of the Detweiler-Whiting singular field, and use these to push the boundaries on current precision limits of self-force calculations. Within the mode-sum scheme, we give over 14 previously unknown regularisation parameters, almost doubling the current regularisation parameter database. We also produce smooth effective sources to high order, and propose an application of the higher terms to improve accuracy in the m-mode scheme. We also examine non-geodesic motion and discuss the applications of this work.

Modelling precessing black hole binaries

Patricia Schmidt
California Institute of Technology

Co-authors: Mark Hannam, Sascha Husa, Frank Ohme

The coalescence of two stellar mass black holes is regarded as one of the most promising sources for the first gravitational-wave (GW) detection with ground-based detectors. The current detection strategies, however, rely on theoretical knowledge of the gravitational waveforms, and an accurate and complete description of the GW signal is key to success.

Spinning black hole binaries may have arbitrarily oriented spin angular momenta which causes the orbital plane and the spins to precess, leading to complex dynamics that leaves a direct imprint on the GW. Additionally, the intrinsic binary parameter space is seven-dimensional, which complicates efforts to obtain a simple, closed-form description of the waveform through inspiral, merger and ringdown.

I will present a conceptually intuitive framework that allows us to systematically model precessing waveforms by simply “twisting up” aligned-spin waveforms, and then explore the possibility of representing the seven-dimensional parameter space by a lower-dimensional subset.
Public Lecture
Gravitational waves – Advances towards detection

A public lecture on gravitational-wave science by Prof. Jim Hough.

Tuesday 21 April 2015 from 7:30pm to 9:00pm
Large Lecture Theatre, Poynting Physics Building

The detection of gravitational-wave signals is still one of the most challenging areas of experimental physics. And the reward for success will be considerable in that the information carried by these signals will give us new insight into the hearts of some of the most violent events in the Cosmos from the formation of black holes to aspects of the evolution of the Universe. A global network of gravitational-wave detectors is now reaching the final stages of construction, with first data expected in 2015. The nature of gravitational waves, how the detectors work, and what the data from the detectors can tell us about the Universe we inhabit, will be discussed.

Refreshments will be provided following the lecture, there will also be some hands-on demonstrations and the chance to chat with our researchers.

Professor James Hough OBE FRS FRSE FInstP FAPS FRAS is a Research Professor in Natural Philosophy and the emeritus holder of the Kelvin Chair of Natural Philosophy at the University of Glasgow. He is the Assistant Director of the Institute for Gravitational Research. He has had a long and distinguished career in the field of gravitational-wave detection, and we are delighted that he could speak here in Birmingham.

This event is run in conjunction with the 15th British Gravity (BritGrav) Meeting, organised by the Gravitational Physics Group of the University of Birmingham. We are running several activities with the hope of exciting the public (of all ages) about current research regarding gravity.

Tickets: http://britgrav15.eventbrite.com/
**BritGrav 15**

**Brief Timetable**

**Monday 20\textsuperscript{th} April**

- 09:00–10:00 **Registration**
- 10:00–11:00 **Talks: session 1**
- 11:15–11:45 **Coffee and posters**
- 11:45–13:00 **Talks: session 2**
- 13:00–14:00 **Lunch**
- 14:00–15:40 **Talks: session 3**
- 15:40–16:10 **Tea and posters**
- 16:10–17:10 **Talks: session 4**
- 17:30–19:00 **Drinks reception**
- 19:00–22:00 **Conference dinner**

**Tuesday 21\textsuperscript{st} April**

- 09:00–10:40 **Talks: session 5**
- 10:40–11:10 **Coffee and posters**
- 11:10–12:50 **Talks: session 6**
- 12:50–13:50 **Lunch**
- 13:50–15:30 **Talks: session 7**
- 15:30–16:00 **Tea and posters**
- 16:00–17:25 **Talks: session 8**
- 17:25–17:35 **Prize announcements**
- 19:30–21:00 **Public lecture: Gravitational waves–Advances towards detection (Prof. Jim Hough)**