European Research Council

ERC Consolidator Grant 2013

Research proposal [Part B1]

A computational approach to quantum black holes

QuantumBlackHoles

PI: Toby Wiseman

Institution: Imperial College London, UK

Duration: 60 months

Summary:

The challenge of combining gravity and quantum mechanics has driven theoretical physics for over half a century. A key goal is to understand how the most fundamental object in gravity, the black hole, behaves. Semiclassical arguments show that black holes not only acquire a temperature and associated entropy, but also evaporate when quantum mechanics is taken into account. Understanding this physics in a full quantum theory of gravity is the aim of this proposal.

For many years there was no precise formulation of a quantum theory of gravity. However, fifteen years ago string theory conjectured a precise definition through `holographic duality’. This states that certain quantum gravities are exactly equivalent or ‘dual’ to specific quantum theories of matter, without gravity and living in fewer dimensions (hence the term ‘holographic’). Such theories are precisely defined, and hence this dual formulation provides a definite framework for computation.

In principle we understand how to compute in the ‘dual’ matter theories. However the calculations are extremely challenging as these theories are similar in form to quantum chromodynamics, the theory of the strong interactions, and are strongly coupled systems. In special cases indirect information has been attained by pen-and-paper techniques, but despite valiant efforts, direct calculations to solve these theories when they describe quantum black hole physics have been unsuccessful.

We propose a new approach, namely numerical methods, to solve these strongly coupled theories of matter and hence directly simulate quantum black holes. The PI has previously performed the first simulations of this type, and the aim of this proposal is to develop these techniques so that for the first time we may extract precise information about quantum black hole physics in order to understand their thermodynamics, constitution, quantum corrections to their semiclassical behaviour, and the physics of their evaporation.

Section 1a. **Extended Synopsis of the Scientific Proposal**

The challenge of making gravity quantum mechanical has driven theoretical physics for half a century. The goal is to understand how space and time emerge from a quantum theory of gravity, and how the fundamental object in gravity, the black hole, behaves. About 15 years ago string theory conjectured a precise definition of quantum gravity through the `holographic correspondence’. This definition is simple in form but computing its implications is an enormous challenge. Analytic methods seem incapable of revealing the remarkable gravitational physics it describes. An analogy is the Schrödinger equation for electrons, which in principle determines all of chemistry – in practice only computers have made it possible to solve chemical problems ab initio. I recently pioneered the use of numerical methods to tackle these new theories of quantum gravity. My aim is to develop this numerical approach to quantum gravityto directly solve these theories and unravel the physics of quantum black holes. This is a new rapidly developing research area that is highly interdisciplinary between lattice field theory, string theory and quantum gravity.

**Motivation**

For many decades up until the late 1990’s the combination of quantum mechanics and classical gravity into a theory of quantum gravity had been the `holy grail’ of fundamental physics. Ideally this theory would be the quantum gravity of our world, but in the absence of that, any consistent theory of quantum gravity would be a tremendous breakthrough. The problem of quantum gravity is one where genuinely new physical ideas concerning the nature of space and time are required, in an analogous manner to the revolution in thinking that ushered in quantum mechanics in the 1920’s. A decade and a half ago modern string theory provided the first ever candidate for a well defined fully quantum description of certain theories that contain gravity. Before that point there simply was no precisely defined theory, and so there was no way to perform calculations to answer questions about how quantum gravity behaved. The new string theory definition of quantum gravity was finally a precise model in which one could perform calculations. While not phenomenologically viable for our universe, this represented a stunning breakthrough. The remarkable conjecture states that certain string theories, which reduce to quantum gravity in particular limits of their parameters, are completely equivalent – or `*dual’* - to specific quantum field theories (theories of quantum matter) but without gravity. These are of the `*gauge theory*’ type, which is a class that includes QCD, the theory of the Strong nuclear force, and most importantly they are precisely defined theories. This equivalence is called the `*holographic correspondence’,* referring to the fact that the gauge theory lives in at least one dimension less than the equivalent quantum gravity theory.

The idea then is that if one wishes to ask a question about quantum gravity, one simply must formulate the problem in the dual gauge theory and calculate the answer there. In principle we understand how to compute in the dual gauge theories. However, in practice, the calculations are extremely challenging as, like QCD, these theories are strongly coupled field theories, and hence perturbation methods cannot be used.

In recent years much progress has been made in understanding how the geometry of space and time is seen in the dual gauge theory, and in particular small fluctuations in this geometry which represent the graviton degrees of freedom. Certain holographic gauge theories are `integrable’ which allows powerful pen and paper methods to solve their small fluctuations about the vacuum and explicitly confirm that they reproduce the dual gravity theory. However these methods, remarkable as they are, cannot go beyond small fluctuations.

Other than these small fluctuations about the vacuum – the graviton – the fundamental object in gravity is the black hole. Many, if not all the mysterious of quantum gravity can be thought of in terms of the behavior of black holes quantum mechanically. Hawking and others in the 1970’s famously used semiclassical quantum methods to understand that black holes had a temperature and an associated thermodynamics. However, such semiclassical methods are restricted to the near classical limit, and give little information about the full quantum nature of black holes. For example, with no quantum theory of gravity it had been unclear what microscopic degrees of freedom would underlie this thermodynamics. This culminated in Bekenstein and Hawking’s ‘information loss paradox’, which describes the tension between our semiclassical and full quantum understanding of black holes, and specifically concerns how the information in the quantum degrees of freedom is released as a black hole in empty space evaporates by ‘Hawking radiation’. To this day it remains the key unresolved question in quantum gravity.

It was immediately realized that the holographic correspondence provided a concrete framework to address all questions regarding the quantum nature of black holes, since it provided a definite theory of quantum gravity in which to perform computations. The black hole on the gravitational side of the correspondence hole is viewed as thermal plasma in the gauge theory side, and its microscopic degrees of freedom are simply those of hot gauge theory plasma. *In principle*, using this holographic correspondence we now understand quantum black holes precisely in terms of gauge theory plasma. *In practice*, despite valiant work by many theorists, like QCD these gauge theories and their thermal plasma are strongly coupled systems and appear to be analytically intractable.

In a special case **indirect** information about this plasma has been attained by pen-and-paper techniques. When the dual gauge theory is 1+1 dimensional and is conformally invariant one may compute the number of microstates (and hence entropy) of the dual black holes. Strominger and Vafa [1] famously showed that if one deforms the theory away from the limit where it describes quantum black holes, one could calculate a quantity (a so-called `index’) which is independent of this deformation and counts the number of microstates. It can be evaluated in the suitably deformed theory by Cardy’s conformal field theory methods, and since it is independent of the deformation, the answer also gives the number of microstates in the strongly coupled regime which is dual to black hole physics. This was a huge breakthrough, and they showed that the entropy associated to these microstates precisely matched the semiclassical expectation from gravity. However it must be emphasized that this calculation is **indirect**. The dual gauge theory is not solved in the regime where it describes gravity, but rather must be deformed to a regime where it does not, and only very special quantities that are independent of this deformation can ever be accessible by this method. Direct calculations to solve these theories when they describe quantum black hole physics have been unsuccessful. For example there has been no successful direct evaluation of the entropy of the black holes in gauge theories in any other cases than this 1+1 conformally invariant one. And even in this case, it is only the entropy that can be computed. No other information, such as the spectrum of states, or other observables can be computed.

It is precisely the aim of this proposal to develop the necessary numerical methods to **directly** solve the gauge theories with holographic quantum gravity duals, in order that we can perform a wide variety of quantum black hole calculations. This will allow us to test the validity of the holographic correspondence, and to extract precise information about quantum black hole physics.

**Background and state of the art**

The gauge theories conjectured to be holographically equivalent to quantum gravitational theories (or more precisely string theories which contain quantum gravitational limits) are in various cases very explicitly known. The simplest examples are those derived from certain objects in string theory called ‘D-branes’. In these holographic equivalences the gauge theories are maximally Supersymmetric Yang-Mills (**SYM**) theories. For semiclassical quantum gravity to be described we should work at large N, where N is the number of ‘colours’ in the gauge theory - for QCD, which is a non-supersymmetric gauge theory, N = 3. It is this large number of local degrees of freedom that enables these gauge theories to describe gravitational physics in more dimensions – in analogy with a photographic hologram that encodes higher dimensions using the extra degrees of freedom associated to phase information.

In order to describe equilibrium black holes we should work at finite temperature, and study the gauge theory thermal plasma. The original discovery of holography by Juan Maldacena [2] linked the 1+3 dimensional SYM which is a conformal field theory (CFT) to a quantum string theory which includes within it quantum gravity in spacetimes that are asymptotically Anti-DeSitter (AdS). This is the very famous `AdS-CFT’ correspondence, which is derived from D3-branes. However, shortly after that Maldacena and collaborators [3] found lower dimensional examples of exactly the same holographic phenomena by considering D0, D1 and D2 branes. They found maximally supersymmetric 1+0, 1+1 and 1+2 dimensional Yang-Mills theories were dual to quantum string/gravity theories, where the semiclassical quantum gravity limit involves taking the large N ‘t Hooft limit. It is these large N SYM theories that will mainly interest us here. In particular for the 1+0 dimensional correspondence the gauge theory is simply a gauged quantum mechanical model. This is known as the BFSS quantum mechanics, and arose in discussions of M-theory in the mid 1990’s [4]. For numerical calculation it is by far the simplest starting point, and it is worth emphasizing that it contains all the same dual quantum gravitational physics as the higher dimensional examples, such as the classic 1+3 dimensional AdS-CFT example. Lacking conformal invariance it is less attractive for analytic approaches which is why it has received relatively little attention compared to the 1+3 AdS-CFT case, but lacking dimensions it is very attractive for numerical approaches.

I pioneered finite temperature numerical studies of such large N gauged quantum mechanics theories. Using numerical lattice field theory methods I performed the first studies of the quenched version (ie. ignoring fermions) of this theory in the large N limit [5]. In later work with lattice field theorist Simon Catterall (Syracuse), himself a world leader in supersymmetric lattice methods, I employed state of the art lattice field theory techniques using the `Rational Hybrid Monte Carlo’ (RHMC) method together with supersymmetric lattice formulations to perform the first simulations of the large N theory including the necessary fermions [6]. For the first time we showed that the thermal plasma behaviour of the gauge theory from direct computation was consistent with the predictions from semiclassical black hole thermodynamics. This was an important test of holography, and opened up the new research area of directly studying quantum black holes using these methods. Our studies were the first of their kind, with independent, concurrent and consistent results produced by a group at KEK in Japan lead by Jun Nishimura [7]. Having shown direct simulations of black holes are possible, and are consistent with predictions from gravity, these results attracted considerable interest from the international string theory and field theory communities. After only a few years these initial papers already have > 65 citations even though the number of people working in this numerical field is very small - essentially myself, Catterall and the Japanese group.

Evidence of international impact is that myself, Nishimura together with David Berenstein (UC Santa Barbara) and Lawrence Yaffe (U. Washington, US) in 2012 organized an 8 week program at the prestigious KITP(Kavli Institute for Theoretical Physics) in UC Santa Barbara (US) on novel numerical methods in quantum gravity and string theory. Such programs must pass a stringent refereeing process and be deemed of sufficient international interest and impact to warrant funding. Our application was strongly supported and was a very successful meeting, bringing together over 80 leading researchers from string theory, gravity and lattice field theory.

**Objectives and methodology**

**Objective 1: Solving quantum black holes by thermal simulation of BMN quantum mechanics**

By using Euclidean thermal lattice field theory and `non-lattice’ methods I will simulate gauge theories that in the large N ‘t Hooft regime describe black holes via holography. I will use brute force methods, and in addition refined algorithms to achieve this, tackling the large N quantum mechanical case of SYM gauge theory (the BMN quantum mechanics) which includes a supersymmetric mass term that regulates the IR behaviour of the theory. The goal will be to directly test the holographic conjecture, and perform precision studies of the thermal behaviour of quantum black holes.

I will study the large N `t Hooft limit of quantum mechanical models derived from D0-branes with a supersymmetric mass term (ie. the BFFS model with mass term, also known as the BMN quantum mechanics [8]) to regulate the subtle low energy behavior. This theory is maximally supersymmetric, and the dual string theory is well known, with the mass term deforming the asymptotics of the dual geometry [9]. Finite temperature lattice simulation will be performed using the Euclidean time method, with appropriate anti-periodic boundary conditions for fermions. So far, our studies and those of the Japanese group have neglected the mass term which is crucial to correctly define the canonical partition function as pointed out in my work [10]. The aim will be to study the theory at large enough N to confirm and test with precision that the black hole physics predicted from the semiclassical gravity side of the correspondence is indeed seen in these holographic gauge theories. Furthermore, I will examine how the effects of quantum gravity behave as one moves away from the semiclassical large N limit. In fact reaching very large N is hard due to the rapidly increasing number of degrees of freedom with increasing N which scale as N2. However, working at finite N to see these quantum corrections to the semiclassical limit should in principle be much easier, and no such studies have been performed so far. Semiclassical gravity methods (such as those recently discussed by Sen [11]) will be used to compute these corrections, which will then be checked by comparison to the full simulation. The transition in behaviour moving to finite modest N, the fully quantum regime, will also be studied, and we will explore which observables are expected to capture the physics of fully quantum geometry and black holes.

In order to take this field well beyond the current state of the art I will utilize the computing resources we are requesting to perform much larger scale simulations, coupled with the use of improved algorithms for these large N gauge theories. In particular I will improve the basic approach using two key areas of physical input. Firstly the theories naturally have ‘slow’ and ‘fast’ degrees of freedom. The slow degrees of freedom are those field configurations that are classical vacuum solutions. Current simulation techniques do not account for this, and thus the simulation time is governed by the slow degrees of freedom. By identifying these different degrees of freedom and treating them separately in the path integral I expect an enormous improvement can be made. Secondly I believe new representations of the gauge theory can be used to improve the exploration of the large N limit. The so called ‘collective field’ representation of gauge theory has allowed progress to be made in analytic work as various simplifications can be explicitly seen at large N [12]. This representation has not been used in Monte-Carlo simulation and I believe this innovative approach has tremendous potential. Thirdly I will make use of the ‘non-lattice’ methods introduced by the group of Nishimura. These exploit the fact that for a 1+0 dimensional gauge theory, the gauge may be non-perturbatively fixed, and hence one does not have to use the standard lattice discretization. In particular the use of Fourier Series to represent the field on the thermal time circle appears to give considerably more accurate results than using a lattice. Application of these ideas to the quantum mechanical holographic model with mass term, which has never been calculated at large N, should allow huge progress to be made on studying black hole physics directly in these gauge theories.

**Objective 2: Solving quantum black holes in thermal higher dimensional holographic theories**

Directly solving thermal gauge theories with holographic gravity duals in higher dimensions than the quantum mechanical case, so in 1+1, 1+2 and 1+3 dimensions, allows richer black hole physics to be studied in the gauge theory. I will study the thermal behaviour of these gauge theories in the large N `t Hooft limit on a spatial torus and compare it to the expected semiclassical thermodynamic black hole behaviour. In addition I will study thermal phase transitions, which correspond on the gravity side of the correspondence to transitions between different varieties of black holes that dominate the partition function (‘Gregory-Laflamme’ transitions).

Moving beyond the quantum mechanics, one must work considerably harder to maintain supersymmetry on the lattice. The only viable option is to use the recently developed supersymmetric lattice formulations to directly study the 1+1, 1+2 and 1+3 dimensional versions of holographic gauge theories derived from D1, D2 and D3 branes [13]. I will study these thermal supersymmetric lattice formulations at large N using Monte-Carlo methods, and again I aim to improve previous treatments by efficiently separating slow and fast degrees of freedom. I will test that the expected semiclassical thermodynamic behavior of the dual black holes is indeed seen in the gauge theory in each higher dimensional case, thereby providing highly non-trivial tests of the holographic correspondence. The extra spatial dimensions will be compactified on a torus. This is necessary to give a finite volume system that can be simulated on the lattice. However an interesting benefit is that the dual black hole phenomena is far richer than in the quantum mechanical case once the SYM has compact spatial directions. Then there is not just one type of black hole, but there may be several varieties, and in the semiclassical gravity we understand there may be ‘Gregory-Laflamme’ phase transitions between these – this is a subject I have worked extensively on in the gravity context over the last 10 years. As I showed in [5] this gravity phase transition actually manifests itself as thermal phase transitions at large N in the gauge theory. Such phase transitions are relatively easy to see in the lattice simulations. In [14] Catterall and I performed the first simulations of large N thermal 1+1 SYM on a circle, and we did indeed see evidence for a phase transition related to the ‘Gregory-Laflamme’ phase transition expected from the semiclassical gravity analysis. However much more work is needed to accurately confirm this, and also to study the higher dimensional examples, and this is the aim of this objective.

**Objective 3: Classical black holes and the holographic correspondence**

While some black holes in the gravity dual to the gauge theories to be studied in objectives 1 and 2 are known analytically, others are not. I will use classical gravity numerical methods to find the unknown black holes solutions; those dual to the thermal BMN quantum mechanics theory with mass term, and various solutions dual to thermal phases of the 1+1, 1+2 and 1+3 gauge theories on spatial tori.

The black hole dual to the quantum mechanical gauge theory I will study in objective 1 is known when there is no mass term (the BFSS case). However, including a mass term is crucial to eliminate problems in the IR dynamics of the model. In this case the dual black hole solutions are not known, and furthermore are too hard to find using analytic methods as the solutions have too little symmetry. The mass term has the effect of reducing the symmetries in the dual gravity such that the solutions are not described by tractable ordinary differential equations, but by 2 dimensional partial differential equations (PDEs). Another area of my past research has focused on developing numerical methods in classical gravity to find black hole solutions in settings with little symmetry. I will apply these methods to find the relevant black holes, which when the problem is phrased correctly, amounts to a coupled elliptic two dimensional PDE problem. Finding these solutions will allow the semiclassical gravity predictions for the thermodynamics to be precisely computed, and therefore detailed comparison with the gauge theory thermal behavior with mass term computed in Objective 1 to be made. This will allow tests of the holographic conjecture to be made for different values of the mass, rather than only in the zero mass limit which strictly speaking is not well defined. Furthermore, in the case of the higher dimensional gauge theories on tori, only some black hole solutions are known. As I showed in [5] this problem is related to the problem of black holes in Kaluza-Klein theory that I have worked extensively on in the past. I have recently contributed a review of these Kaluza-Klein black hole solutions in the first text book on the subject of `Higher dimensional black holes’ [15]. I will use the methods I have previously employed to find the relevant ‘localized’ and ‘inhomogeneous’ black hole solutions on the torus directions, allowing detailed comparison of their thermodynamic behaviour, and also thermal phase transitions between the different types of black hole.

**Objective 4: Calculation of the spectrum of quantum gravity and black holes**

I will numerically compute the spectrum and eigenstates in the large N BMN quantum mechanics which holographically describes quantum gravity. I will focus on the quantum states that are thought to compose black holes. I will address questions of time dependence of fully quantum black holes, Hawking radiation and if possible, gain insight into Hawking’s `information loss paradox’.

Thermal Euclidean lattice methods are ideally suited to studying equilibrium black hole physics using dual large N gauge theories. However to understand the real time dynamics of quantum gravity a Hamiltonian approach is most appropriate. I will examine the use of numerical methods (such as the Arnoldi method) to directly diagonalise the Hamiltonian for these large N gauge theories, focusing on the quantum mechanical case with mass term (the BMN model derived from D0 branes) where such an approach is very natural. This bears much similarity to the case of quantum chemistry - a finite basis must be used to represent the wavefunction, and then the Hamitonian is diagonalized in this basis. Limited work has been performed in the past [16], but not in the maximally supersymmetric theories required, not at large N, and not with mass term. However, this strongly indicates that there is much potential for progress to be made.

This approach will enable the spectrum of these theories (not just the low lying spectrum, but the parts of the spectrum required to describe black holes) to be deduced for the first time. This allows the fascinating prospect that information on the real time dynamics will be obtained from the Hamiltonian eigenfunctions, and will shed light on Hawking’s famous long standing black hole `information loss paradox’. In particular I will use the computed Hamiltonian eigenfunctions to calculate real time correlators in the theory, and explore the loss of correlation over time that is expected to be very rapid, reflecting how information is effectively lost even though the time evolution is unitary.

**Track record of PI**

I introduced the use of numerical lattice methods to tackle the holographic large N gauge theories, and performed the first calculations of the thermal properties of quantum black holes [5,6,10,14]. I also pioneered the use of numerical methods to find black hole solutions in classical gravity in the context of higher dimensions and string theory. Both of these numerical directions are integral to this proposal. I have demonstrated scientific leadership to develop these two research directions and gained international recognition of these novel numerical approaches in scientific communities that traditionally were not familiar with numerical techniques.

**Resources and timeline**

To address the objectives of this proposal I must build a group at Imperial College dedicated to these research directions. I am requesting four 3-year postdoctoral positions, two starting in year one and two beginning in year three. It is critical I am able to devote the majority of my time to this research, hence I am requesting 70% of my salary. I will purchase cluster computing hardware (200 cores) to ensure my group is well resourced for large scale numerical computations. I will also run a visitor program at Imperial, and organize 3 one-week workshops in years 1, 3 and 5, together with a Summer school for starting postdocs and PhD students in years 1 and 3.

I envisage the division of labour to be that one of the postdocs starting in year one works on objectives 1 and 2, and the other starting in year 1 works on objectives 3 and 4. I intend to work closely on all these objectives with the postdocs. I expect objective 3 to be complete by the beginning of year 3, and so when the second pair of postdocs start in year 3, they will both work on objectives 1, 2 and 4. In particular I expect that significant progress will have been made on objectives 1 and 2 within the first 3-4 years, and in the last two years I expect objective 4 to be the priority.

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16. M. Campostrini and J. and Wosiek, Nucl.Phys.B703 (2004) 454

Section 1b. **Curriculum vitae**

**Toby Wiseman**

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**Academic history**

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| Oct 2010- present | **Senior lecturer** in theoretical physics, Imperial College. |
| Oct 2006-Oct 2010 | **Lecturer** in theoretical physics, Imperial College. |
| Oct 2006-Oct 2011 | **STFC advanced fellow** – a prestigious fellowship, with only ~10 per year being awarded in the UK across the fields of cosmology, astrophysics and high energy physics, both theoretical and experimental. |
| Sep 2003-Sep 2006 | **Postdoctoral** researcher at Harvard in particle theory group of Prof Nima  Arkani-Hamed and Prof Lisa Randall |
| Mar 2002-Aug 2003 | **Postdoctoral** researcher in Relativity and High Energy Physics groups at  DAMTP, Cambridge; funded by JRF at Pembroke College |
| Oct 1998-Feb 2002 | **PhD** in high energy physics group at DAMTP, Cambridge  Adviser: Prof Neil Turok, Title: Non-linear gravity on branes |
| Oct 1997-Jul 1998 | Distinction in Part III Maths (1 year advanced mathematics) at Cambridge, UK  (**top result** in applied Part III course, out of ~ 80 candidates) |
| Oct 1994-Jul 1997 | First class undergraduate degree in physics (Natural Sciences) at Cambridge, UK  (**top result** in my final year out of ~120 candidates) |

**Selected academic awards**

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| 2006 | STFC Halliday award – prestigious prize for top STFC advanced fellow in year |
| 2001 | Best participant award at Eriche ‘Subnuclear Physics’ Summer School |
| 1998 | Cambridge University Mayhew Prize for top result in applied Part III Maths |
| 1997 | Cambridge University Hartree and Clerk-Maxwell Prizes for top undergraduate physics result |

**PhD students**

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| Oct 2012 – present  Oct 2009 – present | Supervisor for **Andrew Hickling** (Theory group, IC) STFC funded  *Expected to graduate 2016*  Supervisor for **Alex Adam** (Theory group, IC) STFC funded  *Expected to graduate 2013* |
| Oct 2007 - Jul 2011 | Supervisor for **Sam Kitchen** (Theory group, IC) STFC funded  *Graduated 2011- currently working in IT consulting for Deloitte, London, UK* |
| Oct 2006 - Oct 2010 | Supervisor for **Ben Withers** (Theory group, IC) STFC funded  *Graduated 2010 - currently a postdoc in Mathematical Sciences, Durham, UK* |

**Selected Teaching**

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| 2011 - present | 26 lecture course on ‘General Relativity’ as part of the Imperial physics undergraduate program. |
| 2006 - present | 30 lecture course on ‘Diﬀerential Geometry’ as part of the Imperial Theory group QFFF MSc program. |
| 2008 - present | Supervise MSc dissertations for 1-2 students/year as part of Theory group  QFFF MSc program. |
| 2008 - present | Personal tutor for 10 physics undergraduates at Imperial. |

**Conference Organization**

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| Jan-Mar 2012 | Organizer (with Nishimura, Berenstein, Yaffe) for theKavli Institute for Theoretical Physics (KITP) University of California, Santa Barbara, of 8 week program “Novel numerical methods for strongly coupled quantum field theory and quantum gravity”. |
| Sep 2010 | Main organizer for ‘Higher dimensional black holes’ conference at Imperial |
| Oct 2009 | Main organizer for ‘Numerical approaches to AdS/CFT, large N and gravity’ conference, held at Imperial |
| April 2009 | Joint organizer for ‘Supersymmetry, Branes and M-theory’ meeting at Imperial |
| April 2008 | Joint organizer for ‘Gravity, Supersymmetry and Branes’ meeting at Imperial |
| July 2007 | On organizing committee, PASCOS ’07 conference at Imperial |

**Seminar Organization**

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| Jul 2011- present | Imperial Physics department colloquium organizer |
| Sep 2006-Jan 2009 | Arranged Imperial Theory group seminars |
| Sep 2004-Jan 2006 | Arranged Joint Theory seminars between Harvard, MIT and Boston University |
| Sep 2004-Jan 2006 | Arranged weekly Harvard phenomenology seminars |
| Oct 2002-Jul 2003 | Arranged weekly DAMTP high energy physics/gravity seminars |

**Other academic responsibilties**

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| 2010- present | In charge of Imperial Theoretical physics group PhD admissions ; typically we have >100 candidates for 4 funded places. |
| 2002- present | I referee for a variety of leading journals in my field:  JHEP, Phy. Rev. Lett., Phy. Rev. D, Class. Quant. Grav., Nucl. Phys. B |
| 2008- present | I have been a PhD examiner at Cambridge, Durham, Kings and Imperial. |

**Media**

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| March 2008 | My research was featured in **New Scientist** article *“Has ‘dark ﬂuid’ saved Earth from oblivion?”* |
| Oct 2006 | STFC Frontiers magazine personal interview on Halliday award; “Strings,  black holes and plasma balls” |

**Funding ID**

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| Oct 2011-Oct 2014 | Co-investigator (1 of 12) for STFC consolidated grant “M-theory, Cosmology and Quantum Field Theory” at Imperial; total value £1,514,000 |

Section 1c. **Early Achievements Track-Record**

**Summary of publications;** 34 publications in refereed journals, 2 published book chapters

Total citations (SPIRES database) 1570, h-index = 22

**10 Highlighted refereed journal publications**

*Please note that it is conventional in high energy theory for author lists to be* ***ALPHABETICAL.***

*All are without my PhD advisor (N. Turok)*

1. M. Bhaseen, J. Gauntlett, B. Simons, J. Sonner and T. Wiseman, ``Holographic superfluids and the dynamics of symmetry breaking,'' **Physical Review Letters** 110 (2013) 015301 **; Citations: 5**

In publication 1 I used numerical gravity methods to study time dependent phenomena in AdS-CFT relevant to describe out-of-equilibrium quenches in strongly coupled superconductors. This is the first work studying time dependent holographic superconductors, and very interesting links were made to the quench physics of BCS theory.

1. P. Figueras and T. Wiseman, “Gravity and large black holes in Randall-Sundrum II braneworlds,”

**Physical Review Letters** 107 (2011) 081101 ; **Citations: 15**

In publication 2 I used the numerical methods I have developed to numerically find black holes to solve a longstanding phenomenological question. It had been conjectured that black holes in a certain very popular model of extra dimensions (the RSII model) behaved radically differently to those in normal gravity in that they very quickly lose energy by classical radiation. This placed strong constraints on the RSII model, and there were > 100 papers discussing the phenomenology of this. In this letter Figueras and I showed the conjecture is incorrect as it ignores an important subtlety, and moreover numerically found the black holes and deduced that they have similar properties to those in usual Einstein gravity.

1. J. P. Gauntlett, J. Sonner and T.Wiseman, ``Quantum criticality and holographic superconductors in M-theory,'' **Journal of High Energy Physics** 1002 (2010) 060 ; **Citations: 89**
2. J. P. Gauntlett, J. Sonner and T.Wiseman, ``Holographic superconductivity in M-Theory,''

**Physical Review Letters** 103 (2009) 151601 ; **Citations: 142**

In publications 3 and 4, Gauntlett, Sonner and myself showed how to explicitly embed superconducting holographic gauge theories into string theory. There has been huge interest in using holography to study superconductivity, but this had not been rigorously derived from string theory, but rather only toy models had been studied. Our work and that of the Gubser et al provided the first rigorous embeddings.

1. S. Catterall and T. Wiseman, ``Black hole thermodynamics from simulations of lattice Yang-Mills theory,'' **Physical Review D** 78 (2008) 041502 ; **Citations: 64**

In publication 5 Catterall and myself performed thermal simulations of the fully supersymmetric BFSS quantum mechanics, which underlies much of this proposal. Together with concurrent work by the group of Nishmura, these were the first calculations of holographic gauge theories where direct calculation showed that black hole thermodynamics was correctly reproduced in the gauge theory.

1. O. Aharony, S. Minwalla and T. Wiseman, ``Plasma-balls in large N gauge theories and localized black holes,'' **Classical and Quantum Gravity** 23 (2006) 2171 ; **Citations: 69**

Publication 6 discovered a new class of hot metastable objects (`plasmaballs’) in certain large N gauge theory. When there is a gravity dual, these plasmaballs are dual to slowly evaporating black holes of an entirely new variety.

1. H. Kudoh and T. Wiseman, ``Connecting black holes and black strings,''

**Physical Review Letters** 94 (2005) 161102 ; **Citations: 75**

Publication 7 for the first time elucidated the beautiful structure of the various static black hole solutions in Kaluza-Klein theory.

1. O. Aharony, J. Marsano, S. Minwalla and T. Wiseman, `` Black hole-black string phase transitions in thermal 1+1 dimensional supersymmetric Yang-Mills theory on a circle,’’

**Classical and Quantum Gravity** 21, 5169 (2004) ; **Citations: 97**

Publications 8 elucidated the relation between the `Gregory-Laflamme’ gravity phase transition and thermal phase transitions of 1+1 dimensional SYM on a circle. As part of this I performed the first large N lattice simulations of the BFSS quantum mechanics in the quenched limit.

9) T. Wiseman, ``Static axisymmetric vacuum solutions and nonuniform black strings,’’

**Classical and Quantum Gravity** 20, 1137 (2003) ; **Citations: 147**

1. T. Wiseman, ``Relativistic stars and Randall-Sundrum gravity,’’

**Physical Review D65**, 124007 (2002) ; **Citations: 95**

Publications 9 and 10 introduced for the first time the use of numerical methods to find classical static black holes solutions in higher dimensions.

(Citation data taken from SPIRES database)

**Invited contributed chapters in textbooks**

G. Horowitz and T. Wiseman, “General black holes in Kaluza-Klein theory”, Chapter 4 and T. Wiseman, “[Numerical construction of static and stationary black holes](http://inspirebeta.net/record/920553)”, Chapter 10 of “Higher dimensional black holes”, editor G. Horowitz, Cambridge University Press, (2012), ISBN-13: 9781107013452

This is the first textbook on the subject of black holes in higher dimensions. It is edited by G. Horowitz (UCSB) and has chapters by various famous researchers (eg. Maldacena, Myers, Horowitz, Gregory). I was asked to contribute 2 chapters.

**Conference Organization**

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| Jan-Mar 2012 | Organizer (with Nishimura, Berenstein, Yaffe) for the Kavli Institute for Theoretical Physics (KITP) University of California, Santa Barbara, of a 2 month program “Novel numerical methods for strongly coupled quantum field theory and quantum gravity”. Programs must pass a stringent refereeing process and be deemed of sufficient international interest and impact to warrant funding. Our application was strongly supported and was a very successful meeting. |
| Sep 2010 | Main organizer for ‘Higher dimensional black holes’ conference at Imperial – funded by Halliday award, 5 days, ∼ 40 high proﬁle international delegates |
| Oct 2009 | Main organizer for ‘Numerical approaches to AdS/CFT, large N and gravity’ conference, held at Imperial, funded by Halliday award, 5 days, ~ 30 high proﬁle international delegates |

**A selection of invited presentations to international conferences and workshops**

*(all listed meetings are international involving at > 40 participants, and I was a plenary or main speaker)*

2012 Perimeter Institute *“Exploring AdS/CFT dualities in dynamical settings”* ; KITP, UC Santa Barbara “*Novel numerical methods for strongly coupled quantum field theory and quantum gravity*”

2011 Madeira *“Numerical Relativity & High Energy Physics”* ; Benasque, Spain; *“Gravity and strings”* ;

Edinburgh, UK; *“Numerical relativity beyond astrophysics”*

2010 Tokyo, Japan; *“Yukawa Institute for Theoretical Physics Summer Workshop”*

2009 Benasque, Spain; *“New perspectives from strings and higher dimensions”*

2008 TIFR, Mumbai; *“Monsoon Workshop on String Theory”* ; Valencia, Spain; *“Quantum black holes, braneworlds and holography”* ; Niels Bohr, Denmark; *“Mathematical aspects of General Relativity”*

2007 Newton Institute, Cambridge; *“Strong Fields, Integrability and Strings”* ; KCL, UK, *“Fundamental Physics Conference”* ; Hebrew University, Israel; *“Higher Dimensional GR”* ; FQXi, Iceland; *“FQXi - Inaugural conference”*

2006 KITP, Santa Barbara; *“GR beyond 4 dimensions” ;* Berlin*, “11th Marcel Grossmann GR meeting”*

2004 Perimeter Institute, Canada; *“GR beyond 4d”* ; Denver, US; *“Spring APS meeting”*

2003 Ambleside, UK; *“COSMO ’03”* ; 2002 Imperial College, UK; *“Brane world gravity”*

**Awards**

*Halliday award, 2006:*  The STFC is the research council in the UK that funds all of theoretical and experimental high energy physics, astrophysics and cosmology. They award a number of advanced 5 year fellowships each year across all of these areas. These advances fellowships are prestigious positions, given to the top young researchers. However, one Halliday award is then given to the best of all these advanced fellows in the year. This is a prestigious award and also carries £50000 extra funding.