ERC Consolidator Grant 2013

Research proposal [Part B2)][[1]](#footnote-2)

*(not evaluated in Step 1)*

**Part B2: *The scientific proposal* (max. 15 pages, excluding Ethical Issues Table and Annex)**

***(see Guide for Applicants for the Consolidator Grant 2013 Call – instructions for completing 'Part B' of the proposal)***

**Section a. State-of-the-art and objectives**

**Section b. Methodology**

**Section c. Resources (incl. project costs) [[2]](#footnote-3)**

(Note: To facilitate the assessment of resources by the panels, the use of the following costing table is strongly suggested.)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Cost Category** | **Month 1-18** | **Month 19-36** | **Month 37-54** | **Month 55-60** | **Total  (M1-60)** |
|  |  |  |  |  |  |  |
| **Direct Costs:** | *Personnel:* |  |  |  |  |  |
| PI[[3]](#footnote-4) |  |  |  |  |  |
| Senior Staff |  |  |  |  |  |
| Post docs |  |  |  |  |  |
| Students |  |  |  |  |  |
| Other |  |  |  |  |  |
| Total Personnel: |  |  |  |  |  |
|  |  |  |  |  |  |
| *Other Direct Costs:* |  |  |  |  |  |
| Equipment |  |  |  |  |  |
| Consumables |  |  |  |  |  |
| Travel |  |  |  |  |  |
| Publications, etc |  |  |  |  |  |
| Other |  |  |  |  |  |
| Total Other Direct Costs: |  |  |  |  |  |
|  |  |  |  |  |  |
| Total Direct Costs: |  |  |  |  |  |
| **Indirect Costs (overheads):** | Max 20% of Direct Costs |  |  |  |  |  |
| **Subcontracting Costs:** | (No overheads) |  |  |  |  |  |
| **Total Costs of project:** | (by reporting period and total) |  |  |  |  |  |
| **Requested Grant[[4]](#footnote-5):** | (by reporting period and total) |  |  |  |  |  |

The project cost estimation should be as accurate as possible. The evaluation panels assess the estimated costs carefully; unjustified budgets will be consequently reduced.

There is no minimum contribution per reporting period; the requested contribution should be in proportion to the actual needs to fulfil the objectives of the project.

|  |  |
| --- | --- |
| **For the above cost table, please indicate the % of working time the PI dedicates to the project over the period of the grant:** | **%** |

Specify briefly your commitment to the project and how much time you are willing to devote to the proposed project in the resources section.

Please note that you are expected to devote at least 50% of your total working time to the ERC-funded project and spend at least 50% of your total working time in an EU Member State or Associated Country (see Ideas Work Programme 2013).

ERC Consolidator Grant 2013

Research proposal [Part B2]

**“A computational approach to quantum black holes”**

**QuantumBlackHoles**

PI: Toby Wiseman

Institution: Imperial College London, UK

Duration: 60 months

Section 2 a. **State of the art and objectives**

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 and background**

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.

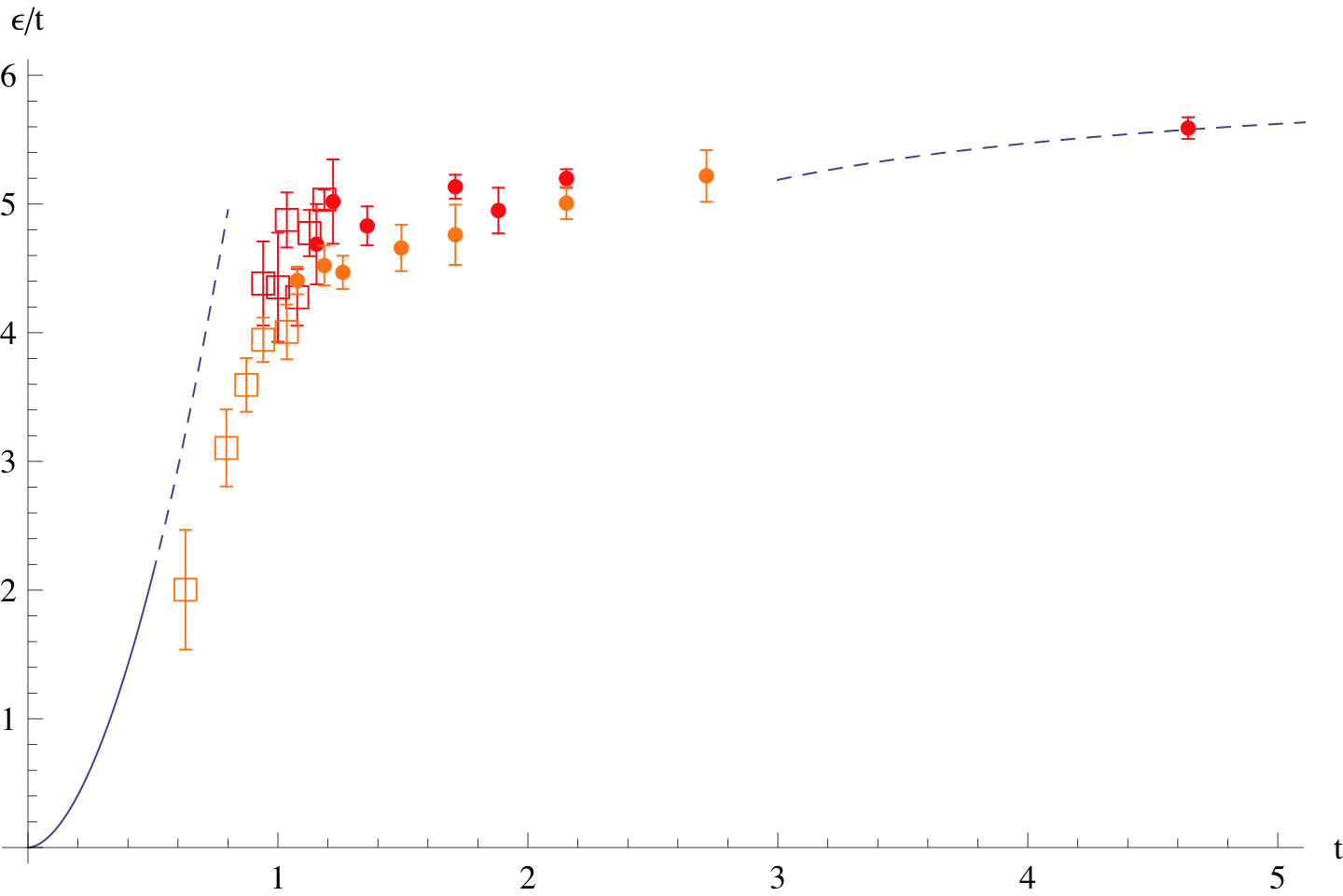
In a special case **indirect** information about this plasma has been attained by pen-and-paper techniques. When the dual gauge theory is 1+1 dimensional and is conformally invariant one may compute the number of microstates (and hence entropy) of the dual black holes. Strominger and Vafa [1] famously 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.

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].



*Left*: figure adapted from [10] showing expectation value of energy divided by temperature plotted against temperature in dimensionless units. Data points are from Monte Carlo simulation of gauged quantum mechanics. (the BFSS model) for N=??. The holographic correspondence claims the low temperature physics is dual to that of classical black holes. The blue curve on the left starting at the origin is the prediction at low temperature from semiclassical black holes in the gravity side of the correspondence. We see nice consistency with quantum simulation precisely in the low temperature regime t<1 where we should expect it. It should be noted that the low temperature behaviour of the same gauge theory, but with no fermions (and no gravity dual) has a quite different behaviour, with the function plotted increasing rather than decreasing with decreasing temperature.

**Objectives and state of the art:**

**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 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 geometry (breaking SO(9) rotational invariance down to SO(3)\*SO(6), as discussed in [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 [9]. 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 [10]) 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, such as treating the natural ‘slow’ and ‘fast’ degrees of freedom separately.

*State of the art:*

Following my work [??] and that of the Japanese group lead by Nishmura [??] there has been more work on the quantum mechanical version of the theory at large N, again by myself and Nishmura’s group []. This is the current state of the art. So far, whilst I pointed out in [??] that it is crucial to add a mass term to obtain a well defined thermal theory, the Japanese group has so far worked without a mass term, and I only introduced it in [??] but it was not the supersymmetric mass term, so the theory with mass did not have a dual gravity description. The theory with mass term has been simulated for small N, so not in a regime approximating gravity, and also not at finite temperature [??]. Thus working with the correct theory (including the crucial mass term), at large N and finite temperature has so far not been attempted, although it is clear that it can be done using the techniques I have previously employed. Furthermore, the use of improved algorithms to simulate the theory, such as using the decomposition into slow and fast degrees of freedom, has so far not been attempted.

**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 [12]. 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.

*State of the art:*

The only work studying a higher dimensional theory on a torus at finite temperature is mine with Catterall and Joesph [??]. These simulations were somewhat crude, and I am confident they can be very significantly improved, to give much more precise results about the dual quantum black holes. In terms of understanding the physics of the thermal phase transitions, the state of the art remains my work with Aharony and Minwalla [??]. Recently there have been simulations of maximally supersymmetric gauge theory in 1+1 [??], 1 + 2 [??] and 1+3 [??], but these have not been looking at the relevant limit for quantum black holes, so finite temperature and large N. However, the work in 1+3 [??] is very encouraging that with sufficient resources, we can realistically make significant progress over the next 5 years, certainly in the case of 1+1 and 1+2, and possibly 1+3, at large N and finite temperature.

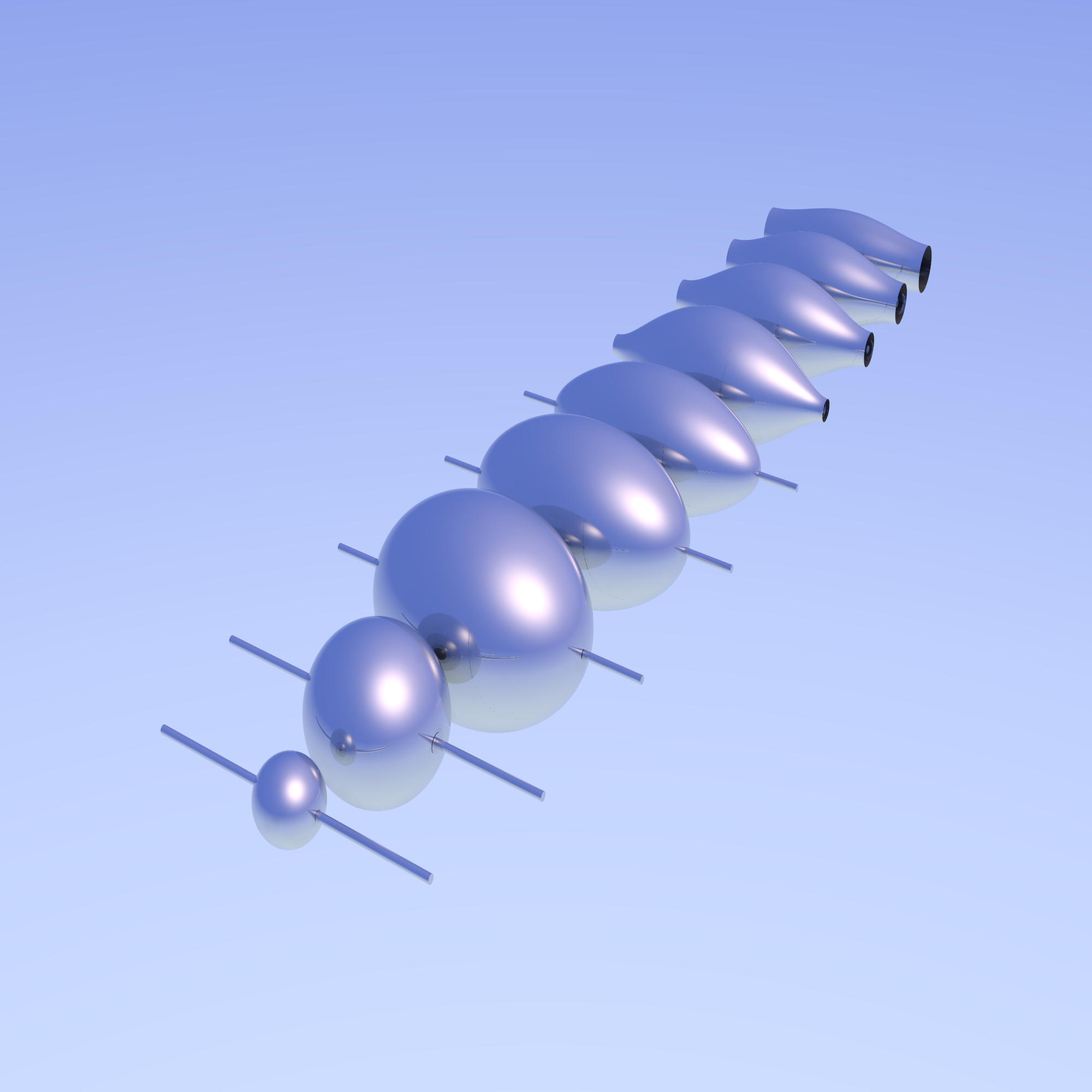
**Objective 3: Classical black holes and the holographic correspondence**

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 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 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 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.

*State of the art:*

**State of the art:** In my earliest work I introduced the use of numerical calculation to find solutions of black holes in higher dimensional theories of gravity where typically they cannot be analytically found. Over the last decade I (together with collaborators Headrick, Lucietti, Figueras and my PhD students) have progressed that field forward to the point where now we have a framework of numerical techniques designed to elegantly solve the problem. Furthermore we have demonstrated that the application of the methods can yield interesting and important physical results. In [??] I showed that the solutions that are required in the small mass limit are related black holes in Kaluza-Klein theory in 1+9 dimensions with one spatial dimension compact. The state of the art is that such solutions have been found in 1+4 dimensions, but the relevant solutions in 1+9 have not been found. I have recently contributed a review with G. Horowitz of the 1+4 black hole solutions in the first text book on the subject of `Higher dimensional black holes’ [??]. When a mass term is turned on the asymptotics of the solution change. In the vacuum these asymptotics are known [??], but there have been no studies to date exploring black holes in these asymptotics.



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

Figure depicting actual numerical solutions for black holes in the Kaluza-Klein theory (adapted from [17])

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. 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.

*State of the art:*

Limited work has been performed in the past [15] for gauged quantum mechanics, 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. Interesting past work [??] has explored Hamiltonian methods to examine vacuum correlation functions for 1+1 dimensional gauge theories. However, this work did not focus on the spectrum describing dual black holes, and used a different light cone approach., and was considerably complicated by studying the 1+1 gauge theory, rather than the 1+0 case. In fact despite the fact it focused on the harder 1+1 case, the work was very impressive in solving many states in the theory, and again is very promising in terms of the application I am interested in here – namely studying the quantum mechanical version, and the states representing black holes.

Whilst not directly related there has been interesting related work discussing the time dependence of the holographic quantum mechanics we are interested in here. In particular Polchinski [??] has studied toy models of this theory, where analytic information may be extracted. This work cannot give precise asnwers as we wish to do here, but will certainly inform our work, in terms of the expected structure of the states we will see. Berenstein also has very interesting work where the time dependent quantum theory we are interested in (without mass) is simulated in the high temperature limit (using semiclassical methods). Whilst this high temperature regime is not one where the physics is related to black holes, it remains very interesting work, and certainly we should be able to use it to study the states relevant to that high temperature regime

***Future impact:***

My previous results [??] and those of the Japanese group have already had considerable impact. 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 and Lawrence Yaffe 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.

Thus the numerical approach to direct computation in holographic theories of quantum gravity has already demonstrated significant international impact. The resources requested in this proposal would enable me to pursue the above objective, and hone these numerical approaches so that we can precisely formulate and answer questions by direct computation in these holographic duals to quantum black holes. The impact among the string theory and quantum gravity community would be very significant, as these precision tests of holography would be the most non-trivial direct tests to date. In the unlikely event that holography was seen to fail, meaning that the semiclassical gravity predictions did not agree with the gauge theory direct calculation, this would of course overturn a huge body of work, and have massive international significance. However, I believe this is unlikely. In the more likely event that the correspondence is seen to hold, it will still by highly significant, and I expect it would open up a large research field internationally where many lattice field theoriests would begin to study quantum gravity using the numerical methods discussed in this proposal. Refined questions beyond thermodynamics could be formulated and asked, and I would expect a new branch of research would be born. String and quantum gravity theorists would use the tools that we develop, or at least collaborate with lattice theorists, including myself and the postdocs involved in this proposal, to give quantitative answers to develop our understanding of quantum black holes. Once the tools are available, there are a multitude of refined questions that many people in the field of quantum gravity would like to answer.

I should stress that in particular for objective 4 any progress at all on the issue of information loss would be of huge significance. This paradox has existed for decades and no approach to quantum gravity has yet made any quantitative statements regarding it. For these methods to enable holography to make any statements – even if they do not completely resolve the issues – would be deeply significant for the string theory and quantum gravity fields, and would likely have great international impact.

Section 2 b. **Methodology**

**Resources**

Two of the postdocs I have requested will work on this topic. The first 3 year postdoc will be hired at the start of the grant. The second will be hired in year 3 allowing an overlapping period where accumulated knowledge can be effectively transferred. I expect these postdocs will have a background in lattice field theory, and also knowledge of string theory and holography. An example of such a person is Anosh Joseph who recently completed his PhD with Catterall in Syracuse. I will work closely with these postdocs on the research directions I will now outline. The cluster I am requesting (200 cores) will be critical in providing the necessary computational resources for myself and my postdocs to carry out the research in this topic.

**Methodology for objectives 1 and 2: Solving quantum black holes by thermal simulation of quantum mechanical and higher dimensional holographic gauge theories**

*Studying the quantum mechanical holographic correspondence*

Using the supersymmetric lattice methods so far developed, and the new methods to be discussed below, the aim is to study the large N quantum mechanical gauge theory, and to gain precision understanding of it. The thermal properties of the theory will be determined using large scale simulations run on the dedicated cluster I have requested. In the large N limit the behaviour of the thermodynamics should reproduce the predictions from classical black hole thermodynamics on the gravitational side of the holographic correspondence. My previous results with Catterall and those of Nishimura’s group have seen consistency with this [3,4] but my aim will be to obtain high precision data to allow a strong test that the holographic correspondence works as conjectured. Beyond confirming black hole behaviour is seen at large N, the next step is to deduce the quantum corrections to this black hole physics. In some sense this is easier, as it is moving to finite N that `turns on’ these corrections. However, the challenge is to quantify what such corrections look like, and then measuring them. It is well known in Euclidean semiclassical quantum gravity how to compute semiclassical corrections to black holes using 1-loop path integral techniques. Doing this (in principle) straightforward calculation for the black holes on the gravity side of the correspondence and then comparing the answer quantitively with the lattice simulation finite N corrections to the large N limit would give a fascinating window into quantum gravity. Finding agreement with these semiclassical gravity expectations would provide a highly non-trivial confirmation of these old Euclidean gravity methods - which incidentally are employed in all manner of places, such as cosmology to make predictions about the quantum origin of the universe, even though there are no actual tests of the voracity of these semiclassical methods. Going to small N would allow one to access the truly quantum regime. From the point of view of the lattice simulations this is the easiest regime to tackle since, of course, N and so the number of degrees of freedom, is small. The challenge here is to identify the most meaningful quantities to measure. Since this is so far from the regimes where we have understood gravity, not much is known concretely here. Of course this means there is huge potential for discovery and opening up new research possibilities.

As one raises the temperature in this theory one can see a transition from physics that is described by quantum gravity and that where the full string theoretic nature of the equivalent theory is revealed. At high temperatures the system corresponds to a hot gas of strings (as well as the `D-branes’). The transition between these two behaviours is a fascinating subject. From our previous studies we have seen that the transition appears to be quite smooth, but we were unable to test whether there is a weak first order phase transition or a second or higher order transition. Determining this would be an important goal for the research project. This is a particularly interesting question as I expect it is a universal feature of quantum theories of gravity, and may not be tied to the particular version of the holographic theory that one studies, or indeed possibly the theory of quantum gravity one takes. In the context of the production of black holes at LHC this transition from black holes to a hot gas of strings is of critical importance. Whether the transition is smooth or there is a phase transition may have significant impact on what is observed, particularly if only low mass black holes are formed which are near to the transition temperature and quickly cool to it.

*Quantum field theory correspondences*

Moving beyond simulation of the quantum mechanics introduces spatial dimensions and the problem is that of gauge field theory. This clearly makes moving to large N more challenging, since to maintain resolution on the lattice more degrees of freedom are needed. In addition, the approach to the correct supersymmetric continuum theory is increasingly subtle in higher dimensions, and full supersymmetric lattice formulations of the theory must be employed. However we have already demonstrated this can be done, even at moderate N [5] in the case of the theory with one compact spatial dimension. The advantage to higher dimensions is that the range of physical phenomena that can occur is even richer. In particular as one varies the temperature and the size of spatial dimensions then phase transitions can occur in the large N limit. This was first understood in my papers [2,6] where such phase transitions were related to phase transitions between different types of black hole in the gravity side of the correspondence. Our recent simulation [5] saw evidence of an expected large N phase transition, but to properly confirm this, to determine its order and properties we require much more study of the theory. One of the most interesting features of this is that the quantitative behaviour of the classical black holes on the gravity side is actually not known as they are of an exotic variety. This is a key element of **Objective** **3** where these solutions will be determined by numerical classical gravity methods.

*Detailed Methodology*

My work with Catterall to date involved a modest ~ 20,000 processor hours (performed on the LQCD cluster at Fermilab; approx 40 days with 20 processor cores running in parallel). They showed the feasibility of seeing and studying black hole behaviour in the lattice simulations. However these first simulations where too crude to accurately test the black hole behaviour, and far too crude to extract novel quantum physics of black holes. The goal now is to significantly improve the simulations. One approach is simply to move to larger scale parallelization, and proceed in a brute force manner with increasing computational resources. With the computational resources I am requesting in this proposal this is a direction I will employ. However based on experience with different numerical problems I believe that one should always also try to develop the algorithmic approach to a problem, one that builds in as much physical insight as possible. An improved algorithm typically will always beat brute force scaling up of resources, certainly in the long term. Furthermore we have not exploited key physical aspects of the problem.

There are two physical aspects to our problem that are novel and do not arise in usual (eg. QCD) lattice simulations. Firstly we are interested in the large N limit. Since the theory is strongly coupled this is not a trivial semiclassical limit, but nonetheless quantum fluctuations while important in determining the configurations that dominate the path integral, become relatively suppressed about those configurations. This appears to lead to a significant simplification in the behaviour of the theory, but one that is not taken advantage of in the numerical approach. Secondly due to the supersymmetry enjoyed by our theories they may have a moduli space even at the quantum level, or at least some anomalously light degrees of freedom. The physical degrees of freedom in the theory can then be thought of as the `fast’ ones, the usual strongly coupled ones in gauge theory, together with these `slow’ ones.

In order to address the first issue I will explore whether there is an improved representation of the theory to work with. In particular I expect the collective field representation may provide such a radically new approach to these problems [7]. Such representations have the advantage that certain simplifications can be explicitly seen at large N. Related methods were utilized a few years ago by Leigh et al [8] to claim an exact *analytic* calculation of the vacuum wavefunction of large N pure gauge theory in 3 dimensions. In fact it did not give the precise answer, but follow up lattice work showed it did give a surprisingly accurate one. I believe by working with such representations we will be able to develop an algorithm where the simplification evident in the semiclassical large N limit can be directly implemented. The main drawback of collective field methods is their non-locality, but dynamical fermions introduce such non-locality anyway, so in our context this does not pose such an obstacle. The strategy will be to test collective field methods in the quenched theory first. This is straightforward to simulate accurately using conventional methods even at large N. Assuming these collective field method give significant improvement, we would then implement them for the full supersymmetric theory.

The second issue, that of light degrees of freedom, has a simple physical origin, namely the slow modes describe the dynamics and shape of the black hole, and the fast modes describe its constituent degrees of freedom. I propose to use the BMN mass term in the quantum mechanical theory to ameliorate this issue. The resulting quantum mechanics is refered to the `BMN plane wave matrix theory’ [9]. The big advantage of this regulation, as first discussed in [10], is that even with the regulator the equivalent gravity theory still exists and is known. Thus this mass isn’t a regulator to be worked with and then removed. It is intrinsically interesting even for non-zero values, representing a new parameter by which to deform, test and probe the holographic correspondence. An important point is that the classical black hole solutions are not yet known on the gravitational side of the correspondence deformed by this BMN mass term, and it is an important direction addressed later in **Objective 3** that these will be found.

While this mass term will control the light modes, by lifting the quantum moduli space, it cannot remove the separation of scale between light and heavy modes. Real progress may be made by separating the light and heavy degrees of freedom at the level of the path integral, and then simulating the two with different timescales. A good guess (in an appropriate gauge which can be fixed in the quantum mechanics) for the light degrees of freedom is to take them to be the diagonal components of the various matrices of the gauge and matter fields. In principle one can directly split the path integral up into first an integral over the off-diagonal components of the fields, and then these diagonal components. This is likely to be far more efficient if the lattice equilibration time for the off-diagonal modes is considerably quicker when the light degrees of freedom are fixed. These effects can be studied to some extent already in the quenched theories. I propose to study this separation of degrees of freedom and determine the viability of the method. It is possible that improved guesses for splitting the degrees of freedom may be required, and this is something that would also be studied, using physical input and insight gained from simulation. It is also worth noting that the split between dynamics/shape degrees of freedom and internal constituent degrees of freedom is fascinating from the perspective of the corresponding black hole physics and insight gained will also have impact in the theoretical understanding of the holographic correspondence.

For the gauge theory with a compact space circle one of the black holes in the gravity side of the correspondence (the `localized’ one) has a profile depending on the spatial circle direction in a specific way. On the lattice the physics will not naively reflect this localization as all possible positions of the black hole are summed over. However, if one can successfully separate the light and heavy degrees of freedom in the theory as discussed above, it should be possible to ‘freeze’ the one degree of freedom corresponding to the centre of mass of the gauge theory plasma on the circle. In this case, computing one point functions of the stress tensor may allow a very explicit comparison of the profile of this plasma with the corresponding gravity black hole prediction and open up new research possibilities into understanding the relation between locality in the field theory and the dual gravity theory.

Another important issue that affects Monte Carlo simulation for these theories is the `sign problem’, namely the Euclidean action used to perform the Monte Carlo simulation is not necessarily real. Our work and that of the Japanese group employs the method of `reweighting’ to tackle this sign problem. In our recent work [10] we have carefully computed the complex phase of this action and indeed its fluctuations away from zero are on average small, justifying this reweighting approach. However, we have little understanding why this phase appears to play little dynamical role, where in other theories with fermions (such as QCD) it can be a major obstacle to Monte Carlo methods. I intend to investigate whether we can gain analytic understanding for this phase by thinking about its origin in the gravitational side of the correspondence. Furthermore, I intend to see whether the isolation of the slow degrees of freedom from the fast ones can be used to control this phase.

**Methodology for objective 4: Calculation of the spectrum of quantum gravity and black holes**

Thermal lattice formulations are well suited to studying the finite temperature behaviour of these field theories in the large N limit. However, another important area that we would like to learn about in quantum gravity is the spectrum of states in the theory, and in particular the nature of the spectrum in the energy range where the states account for the microphysics of black holes. There are various conjectures for the behaviour of the energy levels of these type, and it is an important challenge to confirm whether these hold.

In principle knowing the spectrum (both the Hamiltonian eigenvalues and eigenfunctions) gives one the detailed quantum dynamics of the theory, not just its thermal equilibrium behaviour. Whilst realistically I would not expect to be able to extract the complete spectrum, determining some features of it would allow us to probe the dynamics. The key driving questions would be whether one can use this to understand *black hole evaporation* and *information loss*. These are incredibly profound questions originating in Hawking’s work in the 1970’s that sadly so far have received little input from holography even though it represents the first controlled theory of quantum gravity. Any progress in these directions would be huge breakthroughs in the string theory and quantum gravity fields.

I will pursue a numerical Hamiltonian approach to solving the gauge theories of interest. Whilst it is well known how to describe gauge theories in a Hamiltonian setting, certainly the simplest example of this is the quantum mechanical case, where the Hamiltonian is well understood and various formal mathematical properties of it have even been studied in the 1990’s in the context of M-theory (for example, it is known to have a continuous spectrum). A few years ago there has was numerical work (using only desktop computing) looking at the low lying spectrum of this theory with N=2 [11]. Being at such small N and in a model withg reduced supersymmetry these do not tell us about quantum gravity. In the different setting of the light-cone formulation impressive numerical work with a Hamiltonian formulation has been employed using much greater computing resources [12]. However this was a two dimensional theory where the Hamiltonian methods were used in the context of Discrete Lightcone Quantisation (which is formally only approximate as it ignores certain zero modes) which is a rather complicated setting. No information about quantum gravity and black hole physics was extracted, although an impressive check of holography was performed by studying vacuum correlators. This work is encouraging in that Hamiltonian methods in related theories to ours have been seen to work, and I believe it is now a case of using them to ask the physically interesting questions for quantum gravity. Another very attractive feature of the Hamiltonian approach is that the `sign problem’ of the thermal lattice methods do not arise.

Once the eigenvalues and eigenfunctions of the Hamiltonian are found, then detailed questions regarding the time dependent dynamics of quantum black holes can be asked. A key observable that has been discussed at length using analytical approximations is time dependent correlation functions, the idea being that the thermal nature of a quantum black hole implies that time correlations are very quickly lost, with the black hole `scrambling’ information that falls into it very rapidly (a so called `fast-scrambler’) [??]. Using the numerical spectral information we will be able to build various time dependent correlators and study the behaviour at unequal times. Showing explicitly that such scambling behaviour is seen in the full quantum theory would be of trememdous significance in the quantum gravity and string communities, as there has been a large literature of discussion on this subject, but as I have emphasized already, there has been no way to directly calculate properties of such correlators expect to use toy models or gross approximation. It is worth noting that in the work [??] the spatial correlation functions were built precisely from the spectrum with good accuracy, and this strongly suggests that the time dependent correlators I aim to compute are indeed accessible.

*Detailed Methodology*

In the modern setting of holography the aim would be to focus on the quantum mechanical version of the holographic equivalence and expand the wavefunction in an appropriate finite basis. A sensible canidate is to use a truncated Fock basis formed by taking fermionic operators and polynomials of bosonic opeerators to act on the vacuum. The basis is truncated by restricting the number of bosonic quantum to be less than a cutoff. The Hamiltonian operator would then be diagonalized using standard numerical methods (for example the Arnoldi methods).

Systematically increasing the size of the basis then allows the true Hamiltonian spectrum to be constructed. I believe that if one can appropriately take into account the global symmetries in the theory, which simply relate various states, then given the progress made in [11] and the scale of the numerical problem tackled in [12] I think it is realistic to assume significant progress can be made into determining the spectrum of the quantum mechanical theory at large N where it will be possible to see black holes physics. A key technical point is that in the quantum mechanical theory without mass term, the spectrum is known to be continuous, with the continuum extending to zero energy. Such a situation would be very difficult to work with, as the basis states chosen would not represent these continuum states well. However, introducing the supersymmetric mass term, will yield a discrete spectrum and remove the numerical problems associated to a continuum.

**Methodology for objective 3: Classical black holes and the holographic correspondence**

In order to test the idea of holography, we need to know the properties of the black holes which describe the thermal behaviour of the gauge theories that we hope to compute using ab initio methods of **Objective 1** and **2**. As discussed above the gauge theories that are most likely to be cleanly numerically solved to high precision first are the gauged quantum mechanics with supersymmetric ‘BMN’ mass deformation and the gauge field theory on a spatial circle. It is sobering to think that in neither example are the classical black hole solutions on the gravitational side of the holographic correspondence known, as these black holes lack the symmetry to allow analytic or simple numerical (by which I mean solving o.d.e.s) construction. Once I have added matter fields to my numerical approach, the tools will then be in place to tackle the problem of the black holes corresponding to the thermal physics of these theories. Computing this thermal physics directly in the gauge theory in the large N limit using the numerical lattice methods of **objective A.1** will allow me to directly compare with the classical black hole predictions, to give highly non-trivial tests of the conjectured holographic correspondence. Assuming it holds true, these will be among the most non-trivial tests of holography to date. Of course in the unlikely event I see deviations that suggest the correspondence does not hold, this would be a huge discovery with tremendous impact in the string theory community.

*Detailed Methodology*

Finding equilibrium or time independent solutions in gravity, known as *stationary* solutions, as in electromagnetism should be an elliptic partial differential equation (p.d.e.) problem, where equations with the character of the Laplace equation should be solved as a boundary value problem. Understanding how to implement this generally in gravity is always complicated by the coordinate invariance (or gauge symmetry) of the theory. However, the state of the art is that developed in [13,14,15] where I have a method to phrase the stationary gravitational problem as an elegant and geometric elliptic problem, and furthermore have algorithms to solve this.

It should be emphasized that this formulation as an elliptic problem is absolutely critical so that standard numerical apparatus developed to solve elliptic p.d.e.s can be employed. In fact one does not solve the Einstein equations themselves, but actually must modify the equations to massage them into elliptic character. A key point is understanding that whilst one solves modified equations, the solutions one finds are those to the original problem. This turns out to be a very interesting geometric problem, related to the existence of Ricci solitons (studied extensively by mathematicians in geometry), and we recently made much progress in analytically proving that in many cases of interest, solving the modified equations implies a solutions of the actual gravity ones we are interested in [16]. In the same textbook as I reviewed the Kaluza-Klein solutions, I have also written a review of the numerical methods required to find the solutions of interest here, and this represents the current state of the art [??].

I am very confident that this objective can be achieved, certainly within the first and a half of the proposal.

Section 2 c. **Resources**

The main aim of this proposal is to build an effective group at Imperial College dedicated to development of the numerical approaches to tackling black holes in holographic theories. For the initial exploratory development of these methods it has been sufficient for me to work with my collaborators Ofer Aharony (Weizmann, Isreal), Shiraz Minwalla (TIFR, India) and Simon Catterall (Syracuse, US) and his student (Anosh Joseph). However now to develop the numerical program past this exploratory phase into a mature field that is capable of realizing the results that it clearly has the potential to do, it is necessary for me to build a dynamic group locally at Imperial College dedicated to these research directions. Whilst I have a clear picture of where the research must go over the next 5 years, I would be incapable of implementing a fraction of it without the support of such a dedicated research team, and crucially, sufficient computational resources for them. The resources I am requesting are aimed to build a well supported group of an appropriate size.

I expect to spend at least 70% of my time on this project, and therefore request that fraction of my salary. To build the group I request funds to support 4 postdoc positions (each of 3 years). Two will begin in year 1 of the proposal, and two will begin in year 3. In addition to the salaries for these posts and part salary for myself, I am requesting travel expenses for myself and my group, to enable visits to my current collaborators in the US, India and Israel, and to allow new collaborations to be built, particularly with the group at KEK, Japan, lead by Nishimura, and also with Berenstein in UCSB, US. This money will also allow travel to high profile international meetings (such as the various string theory and gravity conferences held each year). I am also requesting funds for equipment to buy myself and the postdocs the necessary high specification desktop computers and associated hardware (such as external discs and backup systems) needed for numerical work, and also laptops to enable effective work while traveling.

In the past I have run simulations on the LQCD cluster in Fermilab which I had a (relatively modest) time allocation on for collaboration with Catterall. However, for the proposed group at Imperial that I will build to function well, and in particular to be able to develop code and access the much greater resources required now in this phase of the research, it is essential to have dedicated time on a cluster. I will achieve this by buying a 200 core cluster dedicated to my group. These will be administered by the Imperial High Performance Computing (HPC) center, although I emphasize my team would have sole access to these processors. This would be installed early in year 1, and I am also requesting money to upgrade and add processors in year 3.

An important aspect of the program is to organize 3 workshops during the 5 year period, each lasting one week. The aim of these is to bring the relevant international researchers in numerical techniques, but also in string theory and black hole physics, to London in order to foster collaboration. This will allow effective dissemination of our results, and also keep us abreast of numerical developments in other groups, such as UCSB and KEK, and string and black hole theory developments. In addition it will allow the postdocs an opportunity to build their profile and connections internationally, which is important for their future career progression. I propose to have meetings in years 1, 3 and 5. I have previously organized 2 such successful events, finding that ~30-40 international participants is a good number to allow invitation of the key leaders in relevant research fields, and also the most promising junior researchers, while still having a group that is small enough to have genuinely interactive discussion and close participation. These workshops can be organized for approximately £15,000 each at Imperial, including travel expenses for speakers, hotel accommodation, room booking and conference fee expenses. I therefore am requesting £45,000 to fund the 3 proposed meetings.

Another aspect of the program is to train PhD students and junior postdocs working in the field, and also to give them a grounding in the relevant string and gravity theory. To this end I will organize two Summer schools, each of two weeks duration to be held in years 1 and 3. The aim would be to invite around 15 PhD students and junior postdocs from the UK and elsewhere in Europe, US, Japan and Israel, for the two week period, and then have 5 senior scientists (including Nishimura, Catterall, Minwalla, Berenstein) visit for short periods to give a series of pedagogical lectures at the school. I am requesting £15,000 for each school to cover the cost of travel and accommodation for the participants, and also for the visiting lecturers. Obviously my own postdocs would benefit greatly from these events, and would also be expected to deliver some lectures.

Finally in order to build existing and new collaborations I am requesting money to support a visitor program. I am requesting funds to support approximately 1.5 months of stay in London per year, which may be taken by a single visit, or up to 6 one week visits (potentially overlapping). I have estimated this will require £5,000 per year to cover international travel and accommodation. Amongst the visitors I will invite are Catterall, Nishimura, Berenstein, Minwalla, Aharony, Hanada, and some of these would visit more than one time.

**Summary of the requested resources for the 5 year duration of the grant;**

**PI (Wiseman):** 70% salary, £4,000 travel/year, £16,000 equipment (spent as £8,000 initially, £1,000 in year 2, £5,000 in year 3 to update equipment, and £1,000 in years 4 and 5)

**4 postdocs (3 year positions):** They are expected to have completed their PhD and one previous postdoc. Two start in year 1, and the remaining two in year 3. In addition to salary, each would receive £3,000 travel/year and £4,000 to purchase equipment when they start.

**Cluster Computing:** £50,000 to purchase 200 cores dedicated to my group in year 1. A further £20,000 to upgrade and extend this cluster in year 3. To be administered by the Imperial High Performance Computing Center. Current cost; ~£12,000 per 48 cores (for Intel Xeon 6 core processors with 4Gb RAM).

**3 workshops**: £45,000. The workshops will be one week long and have ~30-40 international and UK invited participants. Each is estimated from previous experience to cost £15,000. These will be held in years 1, 3 and 5.

**2 Summer schools**: £30,000. These schools will be two weeks in duration and have ~15 PhD students and starting postdocs from Europe, US, Japan and elsewhere. I will invite 5 senior scientists to lecture at each. To be held in years 1 and 3.

**Visitor program:** £25,000. This will fund visits of senior international scientists for 6 weeks/year, probably divided between several visitors. The estimated cost is £5,000 per year, including accommodation and travel.

**Section** **d. Ethical and security-sensitive issues**

**ETHICS ISSUES TABLE**

|  |
| --- |
| **Areas Excluded From Funding Under FP7 *(Art. 6)***  (i) Research activity aiming at human cloning for reproductive purposes;  (ii) Research activity intended to modify the genetic heritage of human beings which could make such changes heritable (Research relating to cancer treatment of the gonads can be financed);  (iii) Research activities intended to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer; |

All FP7 funded research shall comply with the relevant national, EU and international ethics-related rules and professional codes of conduct. Where necessary, the beneficiary(ies) shall provide the responsible Commission services with a written confirmation that it has received (a) favourable opinion(s) of the relevant ethics committee(s) and, if applicable, the regulatory approval(s) of the competent national or local authority(ies) in the country in which the research is to be carried out, before beginning any Commission approved research requiring such opinions or approvals. The copy of the official approval from the relevant national or local ethics committees must also be provided to the responsible Commission services.

***Guidance notes on informed consent, dual use, animal welfare, data protection and cooperation with non-EU countries are available at:*** [***http://cordis.europa.eu/fp7/ethics\_en.html#ethics\_sd***](http://cordis.europa.eu/fp7/ethics_en.html#ethics_sd)

***For real time updated information on Animal welfare also see:*** [***http://ec.europa.eu/environment/chemicals/lab\_animals/home\_en.htm***](http://ec.europa.eu/environment/chemicals/lab_animals/home_en.htm)

***For real time updated information on Data Protection also see:*** [***http://ec.europa.eu/justice/data-protection/index\_en.htm***](http://ec.europa.eu/justice/data-protection/index_en.htm)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Research on Human Embryo/ Foetus** | **YES** | **Page[[5]](#footnote-6)** |
|  | Does the proposed research involve human Embryos? |  |  |
|  | Does the proposed research involve human Foetal Tissues/ Cells? |  |  |
|  | Does the proposed research involve human Embryonic Stem Cells (hESCs)? |  |  |
|  | Does the proposed research on human Embryonic Stem Cells involve cells in culture? |  |  |
|  | Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos? |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

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| --- | --- | --- | --- |
|  | **Research on Humans** | **YES** | **Page** |
|  | Does the proposed research involve children? |  |  |
|  | Does the proposed research involve patients? |  |  |
|  | Does the proposed research involve persons not able to give consent? |  |  |
|  | Does the proposed research involve adult healthy volunteers? |  |  |
|  | Does the proposed research involve Human genetic material? |  |  |
|  | Does the proposed research involve Human biological samples? |  |  |
|  | Does the proposed research involve Human data collection? |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

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| --- | --- | --- | --- |
|  | **Privacy** | **YES** | **Page** |
|  | Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)? |  |  |
|  | Does the proposed research involve tracking the location or observation of people? |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Research on Animals** | **YES** | **Page** |
|  | Does the proposed research involve research on animals? |  |  |
|  | Are those animals transgenic small laboratory animals? |  |  |
|  | Are those animals transgenic farm animals? |  |  |
|  | Are those animals non-human primates? |  |  |
|  | Are those animals cloned farm animals? |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Research Involving non-EU Countries (ICPC Countries[[6]](#footnote-7))** | **YES** | **Page** |
|  | Is the proposed research (or parts of it) going to take place in one or more of the ICPC Countries? |  |  |
|  | Is any material used in the research (e.g. personal data, animal and/or human tissue samples, genetic material, live animals, etc) :  a) Collected and processed in any of the ICPC countries? |  |  |
|  | b) Exported to any other country (including ICPC and EU Member States)? |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Dual Use** | **YES** | **Page** |
|  | Research having direct military use |  |  |
|  | Research having the potential for terrorist abuse |  |  |
|  | I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL |  |  |

**If any of the above issues apply to your proposal, you are required to complete and upload the 'B2\_Ethical Issues Annex' (template provided).**

**Without this Annex, your application cannot be properly evaluated and even if successful the granting process will not proceed.**

Please see the Guide for Applicants for the Consolidator Grant 2013 Call for further details and CORDIS <http://cordis.europa.eu/fp7/ethics_en.html> for further information on how to deal with Ethical Issues in your proposal.

1. Instructions for completing Part B2 can be found in the Guide for Applicants for the Consolidator Grant 2013 call. For specific information about financial issues, please consult the Guide for ERC Grant Holders on the ERC website. [↑](#footnote-ref-2)
2. Adapt to actual project duration. [↑](#footnote-ref-3)
3. Please take into account the percentage of your dedicated working time (minimum 50% of your total working time) to run the ERC-funded activity when calculating the salary. [↑](#footnote-ref-4)
4. Please make sure that the sums by reporting period and cost category match. [↑](#footnote-ref-5)
5. Please indicate here the page number of Part B2 of your proposal on which the ethical issue in question arises. [↑](#footnote-ref-6)
6. In accordance with Article 12(1) of the Rules for Participation in FP7, ‘International Cooperation Partner Country (ICPC) means a third country which the Commission classifies as a low-income (L), lower-middle-income (LM) or upper-middle-income (UM) country. Countries associated to the Seventh EC Framework Programme do not qualify as ICP Countries and therefore do not appear in this list. [↑](#footnote-ref-7)