Research Statement

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My primary research interests are in field theory and gravity. I specifically work with defects in space time, large extra dimensions (brane worlds), strongly coupled gauge theories and AdS/CFT. I have worked on a variety of diverse topics during my PhD and postdoctoral research. My experience has been useful in broadening my overall knowledge and has enabled me to gain a different perspective and insight into my work. I love to tackle complicated mathematical problems and enjoy the challenge of thinking up new ways of looking at them in order to find a solution. The fascination of working in high energy theory is that the solution will always have some deep underlying physical meaning.

My dissertation is in the area of brane worlds. In certain brane world scenarios we live on a four dimensional brane, embedded in a higher dimensional space. It is interesting to study a brane with a non zero cosmological constant. In the Karch Randall model an AdS_4 brane is embedded in AdS_5 space. The four dimensional metric is multiplied by an overall 'warp factor' which blows up far from the brane, so the geometry includes the boundary of AdS_5 and the bulk space has infinite volume. Surprisingly in this case four dimensional gravity is still reproduced, provided that the cosmological constant is small. This is due to the presence of an ultralight KK mode which plays the role of the graviton.

I investigated the case where there are two AdS_4 branes instead of just one. The presence of the second brane means that the extra dimensional space no longer has infinite volume and there are now two gravitons present – a massless mode and an ultralight mode. I studied the effects of changing the position of the second brane on the behaviour of these two modes. The most interesting and significant case is when the second brane approaches the turn around point in the warp factor. In this case the mass of the ultralight mode blows up and we are really only left with the massless graviton. This is extremely important – we may wonder what happens to the mysterious 'extra' mode when we try and mimic the flat case in this way (by cutting off the space), and it in fact decouples just in time so we match on to a theory with a single massless graviton.

I have also worked on deconstructing gravity. Whilst deconstructing gauge theories has been very successful, extending this idea to gravity has proved problematic. In works by Arkani- Hamed, Georgi and Schwartz a discrete gravitational extra dimension was studied in a flat background. It was found to be impossible to reproduce 5D gravity all the way up to the five dimensional Planck scale. These problems are caused by the scalar longitudinal component of the massive graviton.

In a work I did with Randall and Schwartz, the discretisation of warped AdS geometry was studied instead in order to see whether the situation is improved when the background is curved. Because RS has a holographic dual representation, we expected to find a self-consistent four dimensional discrete theory. We found that unlike the flat space theory, it is possible to take the large volume limit. However, although the low energy theory is valid above the scale of the local curvature at any site, we are still prevented by strong coupling from taking the continuum limit of the lattice theory. The theory behaves like flat space at energies between the warped AdS scale and the warped higher dimensional Planck scale. We have the associated strong coupling problems in this regime because the holographic description is no longer valid. Nevertheless, we have found that many features of the continuum theory are correctly reproduced. It is important to note that lattice theories are an extremely useful tool as they are easier to construct than exact solutions to GR.

I have also been working with SUSY Wilson loops.
Local operators preserving some SUSY have been well studied in N=4 SYM. However nonlocal operators may capture interesting properties of the gauge theory. The supersymmetric Wilson loop is one such

observable. The loop couples to the scalars as well as the gauge bosons of N=4 SYM. Introduced by Maldacena it has the remarkable property that boundary divergences of individual graphs seem to be either absent or cancelled by bulk divergences. If the SUSY Wilson loop is indeed perturbatively finite, we could have an infinite set of finite geometric probes of a 4 dimensional QFT.

On the string theory side according to AdS/CFT this SUSY Wilson loop W is described by an open string ending on the loop at the boundary of AdS_5. If the Wilson loop is exactly calculable it provides an invaluable test of the correspondence. Another unexpected duality was recently postulated for a new class of loops introduced by Drukker *et al.* When a loop with these particular couplings is restricted to S^2 it resembles ordinary Yang Mills on the 2-sphere. When restricting to the zero instanton sector the expectation value of W is given by the Hermitian matrix model. This idea of a relationship between two such different field theories is intriguing. The suggestion is that a class of loops in 4 dimensional N=4 SYM might be exactly solvable and linked to loops in a lower dimensional non supersymmetric theory!

In order to validate the conjecture, various tests have been performed to order g^4. Further checks are needed with various contours and at higher perturbative order.

In a work with Bassetto et al I investigated the correlator of 2 Wilson loops in order to try and substantiate the correspondence. Firstly we looked at the pure Yang Mills theory. It is conjectured that the correlator of many loops is given by the multi-matrix model. At order g^6 we found agreement with perturbative results on the decompactified sphere, obtained from Feynman graph calculations.

We then turned to the N=4 SYM theory, considering the connected correlator of 2 latitude loops on the 2 sphere (using the measure put forward by Drukker *et al*). At order g^4 the expressions were seen to agree perfectly with the computation in YM_2. At order g^6 we considered the limit where one of the loops shrinks to a point. When W is small compared to distances separating it from other loops or operators, it can be approximated by an expansion in local operators of increasing scaling dimension. We can find the anomalous dimensions of the unprotected operators as they always appear in the expansion together with powers of log R, where R is the radius of the shrunk loop. The absence of such terms strongly supported the matrix model conjecture. We then concluded our investigation at order g^6 by using both analytic and numerical methods to perform a complete calculation of the correlator (without shrinking the radius of either loop) and eventually found agreement with the QCD_2 calculation.

In a work with Bassetto, I also looked at the role of instantons, especially in the light of recent work using S-duality in N=4 SYM to suggest that the Wilson loop is dual to a t'Hooft loop operator. It has been proposed that the circular t'Hooft operator is described by the non zero instanton sector of 2D Yang Mills and we studied this conjecture for non trivial dual groups and different representations.

I have most recently been working on spacetime foam models. Together with Schreck and Sorba I investigated the consequences of having a foam punctured with many time dependent point-like defects, looking for violations of Lorentz Invariance in the photon dispersion relation. In the particular model studied – with a dense, homogeneous and isotropic defect distribution – we found no such violation, showing that it is possible to preserve Lorentz invariance even in the presence of small spacetime structure.

I have many ideas for future research, both in field theory and gravity.
I would like to study different models of defects, seeing the effects they have on the dispersion relations of different types of particles, and scattering. I want to investigate the topology of defects, eventually relating the constraints from experiment to their size and properties.

A line of enquiry I would like to pursue is to see to what extent the correspondence between the 4D supersymmetric theory and QCD_2 is due to the peculiar couplings of the loop to the scalars, and to what extent it is due to the circular contour used. An earlier result due to Plefka *et al* suggests there is something special about this measure in particular, and I would like to investigate other forms of scalar couplings which preserve a similar amount of SUSY to see whether they also correspond to some lower dimensional theory. A challenging and exciting possibility is to look at adding fermionic couplings to the SUSY Wilson loop. I would like to see how this affects the finiteness of the SUSY loop, and whether it alters the exact calculability of certain contours.

In order to link more closely to phenomenology, it is useful to study the AdS/QCD correspondence. It has been demonstrated that this duality fails for small t'Hooft coupling. I would like to investigate more fully the form of corrections needed to a possible dual that could improve the matching.

I am extremely interested in the wealth of recent work in two important areas - in investigating the duality seen between light-like Wilson loops and scattering amplitudes in N=4 SYM, and especially in looking at the possible UV finiteness of N=8 SUGRA. I would be very excited to join a group working in either of these subjects and be part of a project of such tremendous significance.

I would also like to continue with my research in the area of brane worlds, and extend it to cosmology. One of the most interesting questions we can ask in the area of brane world physics is what black holes on the brane will look like. I am intrigued by the idea of finding an exact solution to the geometry describing brane world black holes in 4+1 dimensions which has thus far proved elusive. I would like to explore whether new approaches can shed light on this problem. Although very challenging this would be an extremely important result. For instance, I will investigate different choices of quantum state and perform a careful analysis of their gravitational back reaction. In the attempt I will at the very least hope to gain useful insight into the problem. I want to investigate the physics near the horizon region, as this is where many of the important effects will be seen. I also think it would be interesting to investigate black holes on higher co-dimension branes. Finally I would like to relate my findings to the AdS-CFT correspondence and see whether they support a conjecture that the dual to the 5D classical black hole is a 4D quantum corrected black hole. There are also implications for cosmology. If a brane world black hole is formed in the early universe, the effects on its subsequent dynamics could be vastly different from a primordial Schwarzschild black hole in standard cosmology. For instance, they have a lower temperature and evaporate more slowly. I feel there are many exciting and challenging areas I would like to explore.