Why strings?

String theory has a bizarre intellectual history. It originated in the late 60's, as an attempt to understand the properties of certain strongly-interacting particles ('mesons'). It was observed experimentally that mesons could be grouped into families. Members of the same family had similar properties, aside from ever-increasing masses and spins. To a good approximation there was a linear relationship between the observed (squared) masses m^2 and spins J,

$$J = \alpha_0 + \alpha' m^2 \,. \tag{1}$$

String theory originated as an attempt to explain this relationship. The picture was that a meson consisted of two particles ('quarks') tied together by a piece of 'string' – think of two golf balls connected by an elastic band. If the system spins around the quarks will want to fly apart. This stretches the string out a bit, which increases the mass exactly according to the above formula.

Although it had some of the right properties, ultimately string theory failed as a theory of strong interactions. It was replaced with a theory known as QCD (for 'quantum chromodynamics'). QCD is a gauge theory, closely analogous to ordinary electromagnetism. In QCD one regards a meson as made up of two quarks which interact via a type of electric field. In QCD, unlike ordinary electromagnetism, electric flux lines attract each other, and tend to bunch together. These bunched-together flux lines act a bit like a piece of string. So QCD also gives the correct relation (1) between meson masses and spins, as well as accounting for many other observed properties of strong interactions.

Although it didn't properly describe strong interactions, in studying string theory physicists stumbled upon an amazing mathematical structure. No one has really been able to make sense of strings moving in four dimensions. But it turns out that theories of strings moving in ten dimensions (with lots of 'supersymmetry') have all sorts of remarkable properties. In particular, there is a state of the string that has zero mass and spin 2. According to Einstein's theory of gravity, the gravitational force is carried by a massless particle with spin 2. So string theory in ten dimensions is, among many other things, a theory of gravity! Indeed today ten dimensional string theory has become the best candidate for unifying gravity with all the other particles and forces observed in nature.

So was it just an accident that string theory and QCD had some properties in common, such as the mass–spin relationship (1)? The answer, it turns out, is no. Recently very strong arguments have been put forward that a certain ten dimensional string theory is completely equivalent to a *four* dimensional gauge theory! The gauge theory in question is not QCD, although it's closely related. For example, the force between two quarks can be calculated in the gauge theory, by studying the behavior of the electric field in four dimensions. The force can also be calculated in the string theory, by studying a string which connects the two quarks. Remarkably, even though the string moves around in all ten dimensions, while the electric field only spreads out in four dimensions, the two forces exactly agree.

This sort of relation, between string theory and gauge theory, has been the focus of my research over the past few years. There are many puzzles to be sorted out. The problem is that at first sight the gauge theory doesn't have anything to do with gravity – gravity is encoded in the gauge theory in a very subtle way. I've worked on understanding how ten dimensional 'causal structure' (the property that objects always travel slower than the speed of light) emerges from the gauge theory [1]. I've also worked on understanding properties of ten dimensional black holes from the gauge theory point of view [2]. The main obstacle to making further progress along these lines is that the gauge theory is quite difficult to solve mathematically. I've been developing a set of approximations to help in studying the gauge theory [3]; using these approximations we've been able to count the states of a ten dimensional black hole by performing a gauge theory calculation [4].

Selected publications:

[1] *Gauge theory origins of supergravity causal structure*
Daniel Kabat and Gilad Lifschytz, `hep-th/9902073`

[2] *Tachyons and black hole horizons in gauge theory*
Daniel Kabat and Gilad Lifschytz, `hep-th/9806214`

[3] *Approximations for strongly-coupled supersymmetric quantum mechanics*
Daniel Kabat and Gilad Lifschytz, `hep-th/9910001`

[4] *Black hole thermodynamics from calculations in strongly-coupled gauge theory*
Daniel Kabat, Gilad Lifschytz and David Lowe, `hep-th/0007051`