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Faculty Supervisor: John McGreevy

Project Title: String Theoretic Approaches to the Black Hole Information Paradox

This summer, my UROP will be in the research group of John McGreevy in the physics department at MIT. I will study and extend existing models of microstates of black holes using the techniques of string theory with the long-term goal of better understanding the thermodynamics and information-theoretic properties of black holes. These questions are of great interest, since our current understanding of quantum black holes apparently violates a central axiom of physics – that the state of a system at one time determines its state at all future times. In the semiclassical approximation, black holes emit radiation as if they were in thermal equilibrium; hence, information about anything that falls into the black hole seems to be destroyed. Thus, a new description of black holes that does not rely on this approximation (but reduces to it in the regime where the approximation is valid) is required to properly resolve the paradox. Such a new theory, however, has eluded physicists since Hawking proved in 1975 that black holes radiate. Over the last ten years, the physics community has obtained new leads in resolving this problem via the tools of string theory. By transforming problems of gravity (which are often intractable and difficult to approach, as this example illustrates) into problems of quantum field theory (which are better understood), string theory provides a natural setting for studying this problem.

The specific means by which I will approach this problem is by studying non-perturbative corrections to timelike Lorentzian correlators in certain conformal field theories. More precisely, by the AdS/CFT correspondence, black holes in anti de Sitter space correspond to conformal field theories in a thermal ensemble; it is these dual field theories which interest us. Correlators in these theories, therefore, provide some quantitative description of the information theoretic properties of black holes that live in the dual geometry. Hence, although these black holes live in a geometry different from that of our universe, their dual description provides crucial insight into their statistical mechanics. Since the physics and mathematics of this project are quite sophisticated, tackling this project will require me to expand my knowledge on the foundations of the underlying theories; this entails significant reading in general relativity, quantum field theory, and string theory.

By the end of the summer, I will not only obtain a solid understanding of the central ideas that underlie the information theory of black holes, but also explore the behavior of some possible string-theoretic resolutions of associated problems. Previous work by Maldacena has shown that the semiclassical description of black holes in anti de Sitter space give correlators which vanish as the time between the events being correlated becomes large. This is precisely the signature of information loss. To remedy this, we consider the effects of additional objects that are missing from the semi-classical description. One such object that seems like a promising starting point (and will indeed be the starting point of my project) is called a D-instanton. Including a D-instanton that winds around the black hole horizon, it can be shown, in certain idealized conditions and to leading order, that it contributes to the correlator a small contribution that does not vanish at large time separations. Precisely characterizing what this time dependence looks like, after more completely accounting for finite instanton tension and other effects, is therefore an interesting question. Its answer could give clues to what might be missing from Hawking's original argument.

My project, however, may not only draw from the techniques of field theory, but also contribute back to our understanding of it. Although Hawking radiation presents the information paradox in the first place, its thermal nature is often used to describe the thermodynamics of strongly coupled gauge theories, again via the AdS/CFT correspondence. These connections have already been applied to the quark-gluon plasma created at RHIC, so exploring how string-theoretic models of black holes impact our understanding of other areas of high-energy physics is a question of great interest that I hope to tackle this summer. These ideas, however, are only starting points. Since the fundamental theory is still in its infancy, and many basic open questions in this field remain unanswered, the long-term goals of the project could shift and change as discoveries in the field shape our understanding. This project lies at the frontier of our knowledge, so it is difficult to predict exactly how it will unfold.

My motivation for undertaking this project is threefold. First, I want to explore fields of physics which are new and exciting to me. At the conclusion of the spring semester, I will have completed 8.323 and 8.962, MIT's courses in general relativity and quantum field theory, respectively. By studying the black hole information paradox, I will learn to apply my new knowledge and hopefully see an example where these two fields may be understood in a unified way. Second, since all my previous research projects in high school and at MIT were fundamentally experimental, I want to get significant experience in a purely theoretical project. My physics education is at a level where tackling open theoretical questions is now possible, and so I would like to dive in and experience a new side of physics research. Finally, I want to understand the cutting edge of physics today. By discovering a piece of the underlying physics on my own, I hope to bring myself to the forefront of this exciting frontier.