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Research Statement

My research interests include relativity, cosmology, quantum field theory and string theory. In particular, I have worked extensively on holographic dualities. Holography, if correct, would change the paradigm for physical reality. This idea arose from black hole physics and concrete examples were found in the context of the AdS/CFT duality.

In order to promote this far-reaching idea into a physical theory one needs to understand in detail the "holographic dictionary", i.e. how quantum field theory data are encoded in bulk solutions and vice versa how spacetime is reconstructed from QFT data. A significant part of my work has been devoted to developing and extending the holographic dictionary. In particular, I have developed the method of holographic renormalization, which is the gravitational counterpart of renormalization in QFT. The method is essential for obtaining well-defined rules for computations in gravity/gauge theory duality and moreover it explicitly shows how spacetime is reconstructed from gauge theory data. Ultimately, this line of research should lead to a manifestly holographic reformulation of physics, thus completing the shift of paradigm.

This research program has had strong interface with current research on hyperbolic manifolds in mathematics and led to new results both in mathematics and in General Relativity. In particular, I have obtained new results about the asymptotic structure of Asymptotically locally AdS spacetimes refining and extending earlier results of Fefferman and Graham, and gave a rigorous first principles derivation of conserved charges for these spacetimes using Noether's theorem and covariant phase space techniques.

My current research includes black holes and extending the holographic methods to cosmology.

Central questions in theoretical physics are the puzzles associated with black hole physics, such as the question about the statistical explanation of black hole entropy and the information loss paradox. Holography provides a new paradigm where one can hope to address these questions at the quantitative level. Part of my recent work has been devoted to using holographic techniques with this aim. A particularly interesting idea that emerged in recent years is the fuzzball proposal, according to which associated with any black hole microstate there should be horizon-free non-singular solution of the underlying theory. This proposal has the potential to resolve the black hole puzzles and as such it should be pursued. In our works we analyzed the relation of this proposal to gravity/gauge theory duality and used precision holography to perform highly non-trivial checks, finding a rather impressive supporting evidence.

Striking new observations over the last two decades have transformed cosmology from a qualitative to a quantitative science and forthcoming experiments (e.g. the Planck satellite) promise a wealth of new precision data. This represents a unique window into Planck scale physics and a challenge for fundamental theory. In recent work I have put forward a holographic framework for inflationary cosmology. The holographic description correctly reproduces standard inflationary predictions in their regime of applicability. Perhaps more importantly, however, this framework gives rise to new models for the very early Universe that are best described holographically, i.e. via a perturbative three dimensional QFT (with no gravity!). These models provide a holographic alternative to standard inflationary scenarios, present a new and simple mechanism for the generation of a nearly scale-invariant spectrum of primordial cosmological perturbations and have smoking-gun type predictions which near-future observations will test. Custom-fitting of the WMAP and other astronomical data reveals that these models, despite exhibiting a phenomenology distinct from standard slow-roll inflation, are competitive to ΛCDM! This is an exciting period, where experimental data will tell us within the next few years whether these ideas are correct or not. It may well be that future observations confirm the predictions of these holographic models, thus providing the first observational evidence for the holographic nature of our Universe.

Holography represents a potential shift of paradigm for physical reality that we are only beginning to comprehend. The increased number of applications to such disparate fields as mathematics, particle physics phenomenology, condensed matter physics and cosmology, represents in my view only the seeds for a more drastic reformulation of physics, akin to that caused by quantum mechanics and general relativity a hundred years ago. I intend to work at the forefront of this exciting endeavor in the years to come.