Research statement

Consistent quantisation of gravity is the outstanding problem of contemporary theoretical high energy physics. My present research focuses on two fairly distinct aspects of quantum gravity: three-dimensional gravity and flux compactifications in string theory. My main achievement in the former area is establishing a holographic correspondence between higher curvature gravities and logarithmic conformal field theories, and in the latter the discovery and analysis of long series of connected vacua related by monodromy transformations of the internal manifold.

Achievements so far

The main reason to study three-dimensional gravity is to try to find models where gravity can be quantised without invoking the full machinery of string theory. A natural candidate is Einstein gravity with negative cosmological constant: it is simple enough to lack propagating degrees of freedom, but complicated enough to contain black holes. Considerable effort and ingenuity has been devoted to quantising this theory, but the results are unsatisfactory. (See, e.g., [1, 2].)

During the last few years I have been exploring alternative pure gravity theories in three dimensions. One proposal is to include a gravitational Chern–Simons term, which yields topologically massive gravity (TMG). As described by Deser, Jackiw and Templeton [3], this adds gravitons to the spectrum. Their energy has opposite sign to that of the black holes, making the theory unstable. However, Li, Song and Strominger [4] argued that for a certain "chiral tuning" of the coupling, the gravitons disappear, removing the instability.

This claim raised quite some debate, for which I am partly responsible. In [5] with Daniel Grumiller, we demonstrate the existence of gravitons at the chiral tuning, and show that they furnish a non-unitary representation of the isometry generators of AdS — exactly like in logarithmic conformal field theory (LCFT). This analysis was generalised and complemented by a nonperturbative study by D. Grumiller, Roman Jackiw and myself [6]. We perform a canonical analysis and are thus able to count the dimension of the physical phase space. We find one single degree of freedom per point — the logarithmic graviton.

Based on these findings, we conjectured that TMG at the critical point is dual to an LCFT. Representing a novel kind of holographic duality, this conjecture resulted in a lot of subsequent activity. In these analyses, the LCFT conjecture has passed all tests it has been put to. For reviews and extensive lists of references, see, e.g, [7] and [8]. My own contribution in the wake of this conjecture is the formulation of a consistent set of logarithmic boundary conditions [9] (with D. Grumiller), analyses of other logarithmic gravity theories three dimensions [8] (with D. Grumiller and Thomas Zojer) and a numerical study of the stationary and axi-symmetric solution space of TMG [10] (with Sabine Ertl and D. Grumiller).

More recently, together with Hamid Afshar, Branislav Cvetković, S. Ertl and D. Grumiller, I have turned my focus toward conformal Chern–Simons gravity, a theory whose action consists solely of the gravitational Chern–Simons term. In [11] we perform a holographic description of this theory, unravelling several interesting features, for instance how the Weyl gauge symmetry of the bulk theory gives rise to an extended global symmetry algebra at the boundary.

My other main field of study is the physics of string theory compactifications. Here, the effective four-dimensional physics depends crucially on the geometry of the internal space. Two examples I have studied are D3-brane black holes[1] and flux compactifications. Let us focus here on the latter.

In two papers, the first with Ulf Danielsson and Magdalena Larfors [14] and the second with Diego Chialva, U. Danielsson, M. Larfors, and Marcel Vonk [15], we perform detailed analytical and numerical studies of the scalar potential in type IIB flux compactifications. In [14] we find long series of connected minima related by monodromy transformations. This provides a natural setting for embedding chain inflation [16] in string theory, and allows for the description of flux-changing domain walls not consisting of D5 branes. The follow-up paper [15] generalizes the monodromy transformations to include geometric transitions.

These ideas were taken up recently by Ahlqvist *et al.* [17] and they find, among other things, long series of vacua seemingly converging to the large complex structure point in complex structure moduli space. This is suggestive, since this point is precisely a locus where infinite sequences are allowed by the no-go result of Ashok and Douglas [18]. However, in a collaboration with Andreas Braun, M. Larfors and Nils-Ole Walliser [19] we extend the no-go theorem to include also these loci, demonstrating that the sequences actually terminate.

Prior to my graduate studies I worked on theoretical and topological aspects of non-relativistic quantum mechanics. Together with Erik Sjöqvist I developed a topological test for detection of degeneracies of real Hamiltonians [20, 21].

Future plans

My future plans are to continue exploring quantum gravity from the two points of view described above. From the 3D gravity perspective there are several interesting avenues to pursue. First, it was recently realised [22] that there are critical tunings also of higher curvature theories in higher dimensions. In these critical theories the logarithmic story from three dimensions is repeated almost word by word. This opens up the possibility study logarithmic holography in higher dimensions.

It would also be of considerable interest to use the AdS/LCFT correspondence to study strongly coupled condensed matter systems. LCFTs appear in systems exhibiting quenched random disorder, i.e., systems with some kind of impurities which are time independent and homogeneous at macroscopic distances. Prominent examples include spin glasses, quenched random magnets, self-avoiding polymers and percolation.

Furthermore, several questions remain unanswered about the logarithmic structures in TMG. Much points toward that it is possible to eliminate the logarithmic modes, and

[1] See [12, 13] for some results on black holes.

thereby define a potentially unitary theory, by enforcing stronger boundary condition on the gravitational fluctuations. Proving consistency of this procedure would require a thorough understanding of the quantization of a theory with an asymptotic boundary. For instance, computing the one-loop partition function by standard methods yields the result that the logarithmic gravitons do contribute. However, it is not straightforward to implement arbitrary boundary conditions in the heat kernel methods used to compute the partition function. Developing such techniques, i.e., restricting the functional space over which the Hilbert space trace is taken, would be very interesting.

Related to this is the story developed by Castro, Hartman and Maloney [23] (see also [24] with Gaberdiel and Volpato). They take quantum aspects of the bulk theory into account, with the result that singular vectors in the dual CFT can be detected. It would be very interesting to continue along these lines, in particular to develop Fadeev–Popov like techniques to deal with zero norm states.

Another aim is to extend the analysis of conformal Chern–Simons gravity to the topologically gauged theories constructed by Chu and Nilsson [25]. These theories couple the ABJM theories to superconformal gravity. The gravity part of the corresponding action is conformal Chern–Simons gravity, and when these models are higgsed, an Einstein–Hilbert term and a cosmological constant are generated. The relative coefficients put the effective theory exactly at the chiral point! This raises several interesting questions: Are there logarithmic excitations in this theory? Is the theory unitary? If not, can the unhiggsed model be seen as a unitary completion?

Regarding the type IIB landscape it would be interesting to extend our recent finiteness results to more general singularities, and in particular to models with complex structure moduli space of general dimension. Analysing the same questions in the presence of warping would also be of great interest.

Naturally, I am also excited about engaging in new fields of study. Higher spin theories in three dimensions and four-dimensional conformal gravity have for instance both caught my attention lately. Finally, one should not be afraid of addressing problems also outside physics. Sometimes, all it takes is a new angle on the right question. And a little bit of luck.

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