Research Statement

Broad overview

My current research is in the area of string theory [1] and its low-energy limit supergravity. More in particular, I am working on compactifications of supergravity from ten dimensions to the four non-compact dimensions of our world in the presence of fluxes, which are non-zero expectation values for the form fields of supergravity. Furthermore, I am studying in full generality how to embed D-branes [2] into these supergravity solutions without completely breaking the supersymmetry. Such D-branes are important for phenomenology as one way to realize the Standard Model within string theory is through intersecting D-branes [3]. The research on D-branes builds on the expertise that I acquired during the work on my PhD thesis (papers [(rsh)1–6] and thesis [(rsh)7])[1].

The importance of fluxes lies in the fact that they provide a simple mechanism for lifting unobserved massless scalars out of the low-energy 4D spectrum, which would otherwise plague compactifications of string theory. For this reason compactifications with fluxes have been intensively studied (for a recent review see e.g. [4]). One way to obtain a vacuum solution, which is easier than explicitly solving for the equations of motion, is solving for the supersymmetry conditions instead. Indeed, several papers [5], among which my own paper [(rsh)11], have shown integrability theorems stating that the supersymmetry conditions together with the Bianchi identities for the form fields imply all the other equations of motion of supergravity as integrability conditions.

The most intensively studied and best understood solution of these supersymmetry conditions is a compactification of type IIB string theory, where the internal geometry is a Calabi-Yau manifold just like it would be in the fluxless case [6]. In this case, however, not all the moduli are stabilized at the perturbative level, and non-perturbative effects like instantons or gaugino condensation have to be taken into account [7]. In some models on the type IIA side on the other hand, it is possible to stabilize all moduli already at the classical level, which allows for better control of the solution. Generically the internal manifold is then not a Calabi-Yau geometry anymore.

The goals of my research into flux compactifications, and the branes that can be embedded in them, are two-fold. First, I would like to find general properties that hold for broad classes of these flux vacua [(rsh)8, 10–13]). A lot of research so far has gone into the study of the very specific set-up of type IIB on a warped Calabi-Yau manifold. I think it is important, though, to get an understanding of the complete landscape of string theory and not just some special corner. I also study in general the embedding of sources like D-branes and O-planes [(rsh)8, 10, 13] and how they backreact on the geometry [(rsh)11].

Secondly, I work on constructing specific non-trivial, but still tractable flux compact-

[1] References indicated with (rsh) refer to the list of original research articles in my publication list, included in this application, and (proc) to the list of proceedings articles and lectures. Other references can be found in the bibliography of this research statement.

ifications, which ideally should be representative for the generic properties. One such class is formed by compactifications on group and coset manifolds [(rsh)14–16, 18–20]. They are relatively simple since many problems normally involving differential equations can be reduced to algebraic equations. Further important topics are the construction of non-supersymmetric solutions [(rsh)18] and, more specifically, solutions which have a space-time part with positive cosmological constant [(rsh)16, 19, 20]. The goal of this latter research is to investigate what the minimal and simplest ingredients are to construct such a de Sitter space-time. This in contrast with other approaches (e.g. [7]) which typically involve non-perturbative effects and complicated uplifting terms of which the backreaction is not fully under control (see e.g. [8]).

Apart from compactifications where the 4D space-time of our world is directly modeled, flux solutions of supergravity also have a crucial application in the AdS/CFT correspondence. They serve then as the geometric dual of 4D Yang-Mills theory, describing the strong force, or, in a more recent development, a three-dimensional Yang-Mills or Chern-Simons-matter theory, which can serve as a model for certain condensed matter phenomena.

In studying flux compactifications, I have made extensive use of and contributed to the formalism of Generalized Complex Geometry. Indeed, in [9] it was found that the supersymmetry conditions for supergravity compactifications in their most general form can be naturally described in this formalism, only very recently introduced in the mathematics literature in [10]. In fact, this domain of research is an excellent example of parallel development in both physics and mathematics. Generalized Complex Geometry builds on the G-structure formalism, but manages to describe both the geometry and the B-field of supergravity in a uniform way. Generalized Complex Geometry also provides the framework to very naturally extend the mathematical notion of calibrations, describing submanifolds of minimal volume, to generalized calibrations, describing D-branes with minimal energy taking into account both the world-volume flux on the D-brane and the background fluxes [(rsh)8],[11]. I recently wrote a review on both G-structures and Generalized Complex Geometry, and their applications to flux compactifications [(proc)6].

Concrete lines of research

The field of theoretical high energy physics is highly dynamic. On the one hand there are lines of research which stay on the foreground for many years. On the other hand highly interesting topics can appear in a matter of months spurred by a small number of seminal papers. In such an environment it is crucial to keep one's finger on the pulse of the recent developments, stay open for new avenues of research and be prepared to readjust research plans. Nevertheless, I will shortly present here a number of concrete lines of research.

- A first interesting development is the construction of flux compactifications with a dS space-time. A space-time with positive cosmological constant is a necessary ingredient for the description of an early phase of inflation as well as the current state of the universe. Such a compactification, which in particular breaks supersymmetry, is notoriously difficult to embed in string theory or supergravity. As a matter of fact several no-go theorems have been proposed. The key for unlocking no-go theorems, however, lies in their assumptions and it turns out to circumvent them by a subtle choice of geometric fluxes, orientifold source terms, and possibly more exotic ingredients. The goal of this research [(rsh)16, 19, 20] is to find the minimal ingredients allowing to construct the simplest and most tractable solutions, without the need of non-perturbative effects or additional uplifting terms. In particular, [(rsh)19, 20] show that G-structure techniques can be used also in this non-supersymmetric case to study the internal manifold of the compactifications.

- The class of group and quotient manifolds turned out to be a simple yet fruitful source for concrete examples of flux compactifications [(rsh)14, 15, 18, 19]. Another promising class could be toric varieties, for which there exists a whole technology, namely toric geometry. In string theory, toric geometry has so far mostly been used to produce examples of Calabi-Yau manifolds (although there are no compact toric Calabi-Yau manifolds, they can be constructed for instance as submanifolds of toric varieties). A first attempt to instead use three-dimensional toric varieties directly as the internal space in flux compactifications was made in [12] and this certainly deserves further study.

- An active field of research is the construction of the 4D effective theory corresponding to a compactification, which turns out to be a gauged supergravity. One of the goals is to entangle the connection between the gaugings in the 4D theory and the fluxes of the 10D theory (for a review see e.g. [14]). It turns out that such a description puts RR-fluxes, geometric fluxes and even non-geometric fluxes on the same footing, which hints at a connection with Exceptional Generalized Geometry. I personally started working on this topic in [(rsh)12] where I applied the techniques of Generalized Complex Geometry.

- The applications of G-structures and Generalized Complex Geometry are not restricted to compactifications with fluxes. They can also play an important role in finding new supersymmetric backgrounds that have a CFT dual (see e.g. [15]). As a particular example, the coset models of [(rsh)14] include as a special case $\text{AdS}_4 \times \mathbb{CP}^3$, which, since [16], got a lot of attention as the dual geometry to a three-dimensional Chern-Simons-matter theory describing multiple M2-branes. In fact, the CFT-duals for the whole family of massive solutions on one of the coset models of [(rsh)14] has been proposed in [17]. Moreover, the construction of further CFTs in that paper with more supersymmetries ($N = 2, 3$) spurred the search for new AdS_4 vacua, which lie beyond the coset ansatz and have genuine $\text{SU}(3)\times\text{SU}(3)$-structure [18, 19]. In this way, the $\text{AdS}_4/\text{CFT}_3$-correspondence can lead to the discovery of new AdS-vacua as well as new CFT duals. I started working on this topic in [(rsh)17], where I showed that there are indeed no AdS_4 flux vacua with *ordinary* SU(3)-structure and enhanced supersymmetry and the required global symmetry, in agreement with [17, 18]. Furthermore I constructed examples of coisotropic D-branes on the homogeneous family of vacua with Sp(2)-symmetry.

  Another interesting development to which the techniques of G-structures and Generalized Complex Geometry could be applied is the construction of backgrounds with Lifshitz or Schrödinger symmetry groups, which are dual to field theories where time and space scale in a different way under dilatation. These model certain condensed matter phenomena near a critical point [20, 21]. For a review see [22]. Originally, such configurations were constructed as solutions of an effective gravity theory, not necessarily derived from the compactification of 10D (or 11D) supergravity or string theory. For the consistency of the duality it is important to find such an embedding in a fundamental theory (see e.g. [23, 24] for examples). Recently, I have also been looking into applying the technique of consistent reduction for constructing such solutions. I have been looking so far at reductions on tri-Sasakian manifolds, which have the nice property that the low-energy effective theory includes a non-abelian gauge field.

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