Statement of research interests

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Research area and approach

My research interests lie in string theory and its geometrical description. If string theory is a valid framework for fundamental processes, its low energy predictions have to be consistent with the established results from particle physics. The derivation of the Standard Model, or supersymmetric extensions thereof, is one of the main goals of model building. My research is devoted to this issue.

Toric geometry allows a systematic analysis of a large class of string compactification processes. The study of compact Calabi-Yau (CY) manifolds plays a prominent role in string phenomenology. In the last years, combinatorial methods have been worked out that permit the classification and analysis of a large number of CY varieties in terms of reflexive polyhedra [1]. Kreuzer and Skarke have developed an algorithm that makes such a classification possible in principle for arbitrary dimensions [2]. Furthermore, the calculation of relevant topological data can efficiently be carried out by computer programs. My expertise lies in the **application of toric geometry to model building** in type IIB orientifold and F-theory compactifications.

Completed projects

Complex geometries like CYs can have numerous parameters that, via Kaluza-Klein reduction, give rise to massless scalar fields in the effective low-energy theory in four dimensions. Setting up realistic models is a difficult task, and depends significantly on the control of these moduli. One of the main issues of type IIB compactifications is the realization of strategies to overcome the appearance of unwanted scalar fields at low energy regimes. Most of these mechanisms necessitate the introduction of scalar potentials aimed at stabilizing the undesired fields. The **large volume scenario** (LVS) is a very efficient strategy to control Kähler moduli [5]. In collaboration with Andrés Collinucci, Maximilian Kreuzer and Christoph Mayrhofer, we presented new, compact, four-modulus 'Swiss cheese' CY threefolds [6] that accommodate the LVS. In this type of compact spaces, the overall volume is driven by a single four-cycle, whereas the other cycles contribute negatively to it. Each of these CYs were constructed starting from a hypersurface embedded in a toric fourfold. We attempted to realize MSSM-like configurations on magnetized D7-branes within the LVS. We paid special attention to the chirality problem pointed out by the authors in [7]. We extended their analysis by properly taking into account the Freed-Witten anomaly on non-spin cycles. These constraints turned out to be very restrictive on our models. Nevertheless, we were able to present setups in which these conditions were satisfied and up to three moduli stabilized.

Current research

My current research is concerned with model building in F-theory. I am interested in the realization of **global F-theory GUTs**. In a recent collaboration with Johanna Knapp, Maximilian Kreuzer and Christoph Mayrhofer, I focused on the construction of a large number of compact CY fourfolds that accommodate GUT models [8]. The fourfolds were obtained as elliptic fibrations over non-CY base manifolds. We constructed the latter as hypersurfaces in four-dimensional ambient toric varieties. With the help of toric techniques, one can search for divisors capable of supporting F-theory GUTs. In particular, one can check whether the base space is regular and contains del Pezzo divisors. We further tested the existence of mathematical and physical decoupling limits for each model. In the end, we were left with about 4 000 fourfold geometries. We constructed $SU(5)$ and $SU(10)$ GUT models on every del Pezzo divisor. Carrying out this procedure, we obtained more than 30 000 models. We worked out several examples with del Pezzo 8 and 7 surfaces in more detail. My major contributions to this project were the development of the algorithm for the systematic construction of the base manifolds in terms of non-CY hypersurfaces embedded in toric fourfolds, and the computer assisted check of divisors against necessary conditions for del Pezzo surfaces. The complete database of models is available at [9] for further mining. So far, no examples have been discussed where it is possible to make contact between F-theory GUT models and the CY fourfolds which are encountered in the calculation of $N = 1$ superpotentials. One could search the database for fourfold geometries that are suited for establishing a connection between these two exciting topics. Another interesting direction of future research would be to include flux quantization and anomaly cancellation conditions into the analysis.

Partially motivated by this project, together with Maximilian Kreuzer and Andreas Braun, I worked on a **new version of PALP** [3, 4], a package for analyzing lattice polytopes. We developed *mori.x*, a program adding further functionalities to the package concerning CY threefold hypersurfaces. We designed the program with an eye for applications to string theory model building. In this context, our motivation was to implement the construction of *smooth* CY hypersurfaces embedded in toric varieties, using the construction of Batyrev [1]. Here, the starting point is a dual pair of reflexive polytopes which determines both the ambient toric variety and the CY hypersurface. The smoothness of the CY hypersurface is achieved by triangulating the reflexive polytope, i.e. appropriately resolving the ambient space. Using these triangulations, the program computes the Stanley-Reisner ideals and the intersection rings of the hypersurfaces, as well as the Mori cone of the ambient spaces. The program can also analyze arbitrary (i.e. non necessarily CY) three-dimensional hypersurfaces.

A second line of research I am interested in is the study of the so-called **string landscape** concerning the existence of a vast number of metastable four-dimensional vacua. One part of the landscape that is accessible by accurate analytical and numerical methods is the complex structure moduli space of type IIB flux compactifications. Ashok and Douglas proved [10] that infinite sequences of type IIB vacua with imaginary self-dual flux can only occur in special degenerate points of the complex structure moduli space, the D-limits. In a recent project [11] Magdalena Larfors, Andreas Braun, Niklas Johansson and I refined the no-go result of Ashok and Douglas. We studied a class of one-parameter CYs and showed that there is no infinite sequence of vacua accumulating at their D-limits. Our result demonstrates analytically that the series of vacua related by monodromy transformations, recently discovered by Ahlqvist et al. [12], and seemingly accumulating to the large complex structure point, are finite. We corroborated the result with a numerical study of the sequences. In this project, we studied a small class of CY varieties. A future line of research would be to develop similar techniques for more general CY manifolds, and to better understand the role of warping corrections. Finally, it would be interesting to formulate more transparent conditions on the singularity required for infinite sequences of vacua.

In a third and more recent line of research, I am focusing on aspects of type IIA superstring model building. In particular, I consider processes of supersymmetry breaking in setups with intersecting D-branes, in which the breaking is due to small deformations of the intersecting angles with respect to the supersymmetric configuration. This tilting induces masses that can be explicitly determined via the computation of appropriate string two-point functions in the open string channel. In a collaboration with Pascal Anastasopoulos, I aim at extending the analysis of [13].

Summary

Taken together, my research directions are firmly based on the Viennese expertise in toric geometry methods and their application to string theory. These are very efficient techniques to treat global model building issues in IIB flux compactifications, F-theory and also heterotic string theory. Certainly, I am eager to learn about and work on new ideas.

References

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