String Theory, Geometry and String Model Building

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This scientific program brought together mathematicians and theoretical physicists working at the interface of geometry and string theory. The focus was on new developments in Calabi-Yau varieties and related supersymmetric backgrounds such as flux geometries and so-called non-geometries, as well as their applications to compactifications of string theory as models for particle physics and cosmology. There was a flexible schedule of focused talks, reflecting both mathematical and physical problems. It allowed ample time for discussion and more informal presentations. A number of new results and collaborations emerged from the meeting, several due to interactions that would not have been possible without the instigation of the scientific program. The scientific program focused on several broad topics following the framework of the original proposal while at the same time responding to ideas that emerged during the meeting:

(i) Hull–Strominger system and related non-Calabi–Yau flux compactifications: These are the most generic geometries describing compactifications of the heterotic string relevant to building models of particle physics. The presence of flux implies the background gives a natural non-Kähler generalization of CY geometry. A central point of discussion was the characterization of the moduli spaces of such backgrounds.

(ii) Generalized geometry and "non-geometric" CY manifolds: Generic supersymmetric string flux backgrounds have a natural description using generalized geometry, that is structures on an extended tangent space. More radically one can consider "non-geometric" analogues of CY manifolds which are consistent as string conformal field theories but have no global geometric descriptions. Understanding both topics, and in particular the moduli spaces of such backgrounds, was a topic that dominated the meeting.

(iii) Generalized CICYs: The classic constructions of CY spaces as complete intersections (CICYs) have recently been generalized by allowing line bundles which are not positive relative to the projective ambient spaces. This gives rise to a new classification problem and also requires non-trivial generalizations of standard methods, for example for the computation of bundle cohomology on these spaces. Aspects of these issues were discussed throughout the meeting.

(iv) String theory and machine learning: This is an emerging topic within the string community which generated significant interest and discussion. The basic idea is to tackle the problem of analyzing a large number of string vacua using advanced computational methods that include tools from data science and machine learning.

(v) F-theory and duality to heterotic backgrounds: F-theory characterizes non-perturbative string backgrounds in terms of elliptically fibered CY geometries and is a key approach to model building. Study of explicit constructions using CICYs, possible singularity structures, and the nature of the dualities to equivalent heterotic models were central points of discussion.

(vi) G_2-holonomy manifolds: M-theory compactified on a G_2 -manifold is a third source of effective theories relevant to model building. Several topics were covered, including instanton corrections and the construction of non-perturbative superpotentials and the role of limits of K3 metrics in the construction of G_2 geometries.

(vii) Arithmetic of Calabi–Yau manifolds and the attractor mechanism: An relation between the arithmetic properties of Calabi-Yau spaces defined over finite fields and the attractor properties of back-hole solutions in the four-dimensional theories associated to string compactifications on these Calabi-Yau spaces was presented. This relationship between number theory and properties of string vacua led stimulating discussions about its possible physical interpretation. Beyond these broad themes, important applications to understanding the space of string models within all possible theories (the so-called "swampland"), explicit supersymmetric models of particle physics and consistent truncations of supergravity models came up in several presentations.

A measure of the success of the scientific program was the number of new results and collaborations, in many cases as a direct result of the interdisciplinary nature of the meeting. A few of the key new results are the following. There was a lively discussion about the question of the moduli spaces of Hull–Strominger systems. This led to several new conjectures and synergies between a number of complimentary approaches. Talks by Antonella Grassi and Gil Calvalcanti both addressed singularities in Calabi–Yau manifolds. They were able to outline the equivalence of their two approaches (via complex and symplectic geometry). Tristan Hubsch, Andre Lukas and Andrei Constantin started a number of calculations on generalized CICYs, specifically aimed at understanding the new methods required to calculate bundle cohomology on those spaces. Philip Candelas and Sven Krippendorf discussed the possibility of applying machine learning to the Kreuzer-Skarke list of reflexive polytopes to acquire a better understanding of large classes of Calabi-Yau manifolds.

There was a number of new collaborations. Callum Brodie, Magdalena Lafors, Andre Lukas and Fabian Ruehle started a project on building SU(3)-structure geometries on

Calabi-Yau hyper-surfaces in toric four-folds. Emanuel Malek, Michela Petrini and Daniel Waldram started a new project on generic constructions of N=2 consistent truncations via generalised geometry. After discussion with Tristan Hubsch, Andrei Constantin and Andre Lukas started a new project to find analytic formulae for line bundle cohomology on surfaces, including del Pezzo surfaces. This project will likely lead to applications of machine learning, a direct result of the discussions on this topic at the meeting.

Overall, the scientific program was remarkably successful. The opportunity to bring together a wide range of experts from mathematics and physics, over a sustained period and with plenty of scope for informal discussion, led to an significant of new results and collaborations engendered by the meeting. The framework of an MITP scientific program was ideal, both in length and the number of participants. It led to a significant progress at the interface between string theory and geometry, and opened up a number of fascinating new directions. This suggests that there is significant potential for a follow-up meeting at MITP.