Research Interests & Scientific Activities

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5th of November, 2015
My background & research interests in short

Background:

- PhD in 2011 from universität bonn.
- Postdoc 2011-2014 at Penn.
- Fellow at CERN since September 2014.

Research field:

- String Phenomenology broadly defined.
- Development of techniques to determine effective physics of String Theory.
- Work at interface between physics/mathematics.
Obtaining the effective physics of string theory

UV theory | IR theories
---|---
String Theory in 10/11 dimensions | Effective theories in 4 (6) dimensions

**Goal:** obtain all data of effective theories from data of UV theory for

- **String Phenomenology:** particle physics, cosmology…. (focus of my talk)
- study of dynamics of strongly coupled QFTs with new tools.

**Problems:**

1. **Many solutions**, so called **vacua**, of string theory.
2. **solutions** rich & very complicated.

Need **formulation of String Theory** that allows to construct large set of string vacua & provides powerful tools to extract physics.
F-theory: all string vacua & duality techniques

F-theory is paradigm framework:
1. describes many vacua of String Theory
   ✤ evidence that it realizes all known effective theories of String Theory,
   ✤ ingredients to produce promising particle physics models & cosmology
2. provides duality techniques to control complicated physics
   ✤ Strong/weak duality (S-duality): \( g_s \rightarrow 1/g_s \)
   ✤ Geometrisation = translation between Effective theories \[\leftrightarrow\] Physics \[\leftrightarrow\] Geometry \[\rightarrow\] Calabi-Yau (CY) geometry
control physics by powerful tools in geometry.
F-theory: string coupling & branes to geometry

F-theory = Duality + Geometrisation in Type IIB String Theory.

- Type IIB has S-duality acting on complexified string coupling \( \tau = i g_S^{-1} + C_0 \) as

  \[ \tau \mapsto \frac{a \tau + b}{c \tau + d} \quad \text{with} \quad \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in \text{SL}(2, \mathbb{Z}) \]

- Natural object to consider is not \( \tau \): find \( \text{SL}(2, \mathbb{Z}) \)-“gauge-invariant” object

  \[ T^2 : \]

  \[ T^2(\tau) \]

- Two-torus \( T^2(\tau) \) is invariant under S-duality action on \( \tau \)

  \[ \text{S-duality invariant description requires replacing } \tau \text{ by geometry } T^2(\tau) \]
F-theory: string coupling & branes to geometry

**Important:** \( \tau = ig_s^{-1} + C_0 \) is dynamical field in String Theory

- Non-trivial field profile of \( \tau \) \( \Rightarrow T^2(\tau) \) varies over space-time.
- Sources of \( \tau \) are 7-branes at which \( |\tau| \to \infty \)

\( \Rightarrow \) singular \( T^2(\tau) \) signals 7-brane

\( \Rightarrow \) change of perspective: \( X \) defines manifold

\( \Rightarrow \) 7-branes replaced by geometry: singularities in \( X \)

- Interesting vacua of string theory constructed if \( X \) is Calabi-Yau manifold
Effective physics from geometry

Physics of 7-branes in IR: interesting effective theories in 4D (6D)

geometry of Calabi-Yau manifold X

1. Gauge group
2. Matter sector
3. Coupling functions

My research: geometric techniques for physics/geometry dictionary
Effective physics from geometry

<table>
<thead>
<tr>
<th>Effective Theory</th>
<th>Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gauge group</td>
<td>Sufficient in X: classified ✓</td>
</tr>
<tr>
<td>✷ non-Abelian part ✓</td>
<td></td>
</tr>
<tr>
<td>✷ U(1) factors &amp; discrete quotients</td>
<td></td>
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<tr>
<td>✷ discrete gauge group</td>
<td></td>
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<tr>
<td>✷ Large gauge transformations</td>
<td></td>
</tr>
<tr>
<td>2. Matter sector</td>
<td>Tate/Weierstrass models for X ✓</td>
</tr>
<tr>
<td>✷ simple representations ✓</td>
<td></td>
</tr>
<tr>
<td>✷ higher tensor representations</td>
<td></td>
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<tr>
<td>✷ generation of chiral spectrum ✓</td>
<td></td>
</tr>
<tr>
<td>✷ selection rules for Yukawas ✓</td>
<td></td>
</tr>
<tr>
<td>✷ Mordell-Weil group of elliptic fibrations</td>
<td></td>
</tr>
<tr>
<td>✷ Tate-Shafarevich group of genus-1 fibrations.</td>
<td></td>
</tr>
<tr>
<td>✷ (new) arithmetic structures on ellip. fibrations</td>
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number theory


arXiv:1408.4808


arXiv:1303.6970,
### Effective physics from geometry

<table>
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<tr>
<th>Effective Theory</th>
<th>Geometry</th>
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<tbody>
<tr>
<td>3. Computing coupling functions</td>
<td>* warping in F-theory encodes $\alpha'$-corrections to</td>
</tr>
<tr>
<td>✤ gauge coupling function</td>
<td>gauge coupling</td>
</tr>
<tr>
<td>✤ superpotential for moduli fields</td>
<td>* fourfold periods computed using differential eq.:</td>
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<td></td>
<td>determine F-theory flux superpotential.</td>
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**Application:** construction of MSSM, Pati-Salam & trinification models

Open questions & future research directions

1. Geometry/Physics:
   - **Classify** all possible gauge symmetries and matter reps in F-theory
   - **Construct** set of F-theory all vacua: moduli space of quantum gravity theory
   - Computation of all N=1 coupling functions of chiral 4D F-theory compactifications:
     a) matter couplings unknown.
     b) moduli stabilization & cosmology.
   - Engineer & study 6D SCFTs.

2. Conceptual questions:
   - **Defining data of F-theory**: CY $X$, $G_4$-flux, Hitchin system on discriminant locus of Calabi-Yau $X$, T-branes/gluing branes, matrix factorization, generalization of categories…?
   - **Microscopics** of F-theory: D3-branes, M2-branes, (p,q)-webs…?