Singularities for Cosmology in String Theory

Ander Retolaza

Tuesday, 29th November 2016

About myself

About myself

- PhD at Institute for Theoretical Physics, Madrid, with *Angel Uranga*.
- Thesis title:

  Applications of **Toric Calabi-Yau Singularities** to **Cosmological model building in String Theory**

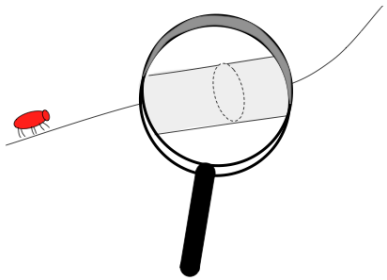
- I am interested in Inflation in general, other aspects of String Phenomenology and other String Theory related topics which do not necessarily have a phenomenological application.

Basics of String Theory (ST) - I

- In ST particles are claimed to be very small extended objects.
- 5 different types of consistent ST's exist. All of them have a vibrating mode of the string corresponding to a Graviton. Quantum Gravity
- For the theory to be consistent at the quantum level one finds $D = 9 + 1$ **!!!**

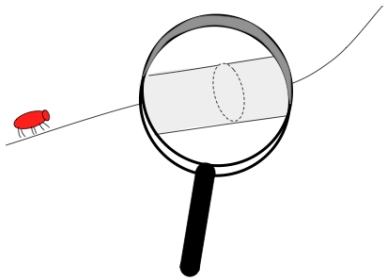
Basics of String Theory (ST) - I

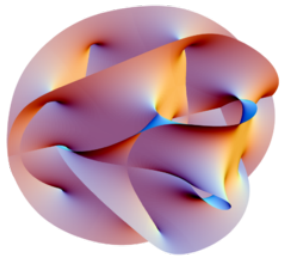
- In ST particles are claimed to be very small extended objects.
- 5 different types of consistent ST's exist. All of them have a vibrating mode of the string corresponding to a Graviton. Quantum Gravity
- For the theory to be consistent at the quantum level one finds $D = 9 + 1$ **!!!** But we only observe 3+1 dimensions
- Solution: compactify



Basics of String Theory (ST) - I

- In ST particles are claimed to be very small extended objects.
- 5 different types of consistent ST's exist. All of them have a vibrating mode of the string corresponding to a Graviton. Quantum Gravity
- For the theory to be consistent at the quantum level one finds $D = 9 + 1$ **!!!** But we only observe 3+1 dimensions
- Solution: compactify





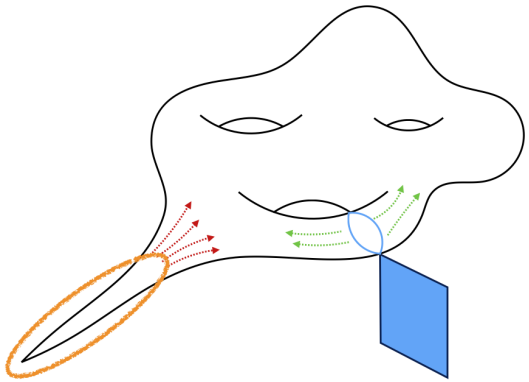
- Actually we need to compactify 6 dimensions

Basics of String Theory (ST) - II

- In ST particles are claimed to be very small extended objects.
- But usually we study its low energy limit, where the string looks point-like: a QFT. The QFT is 10D SUpersymmetric theory including GRAvity.

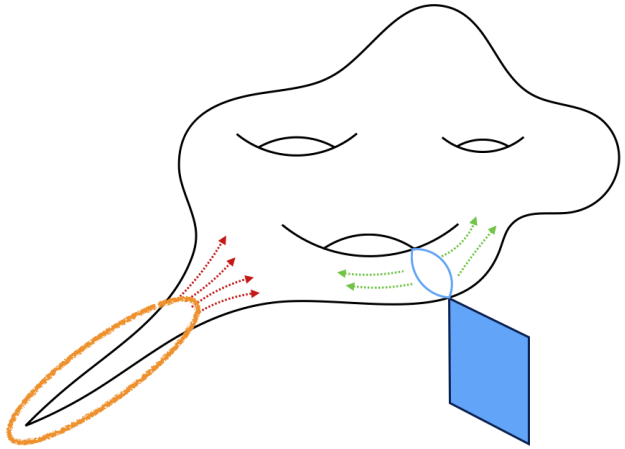
Basics of String Theory (ST) - II

- In ST particles are claimed to be very small extended objects.
- But usually we study its low energy limit, where the string looks point-like: a QFT. The QFT is 10D SUpersymmetric theory including GRAvity.
- So, for model building, we usually study 10D SUGRA compactified to 4D.
- 4D effective field theory depends on: 10D fields, non-perturbative objects (e.g. Dp-branes), and geometry of compact space.



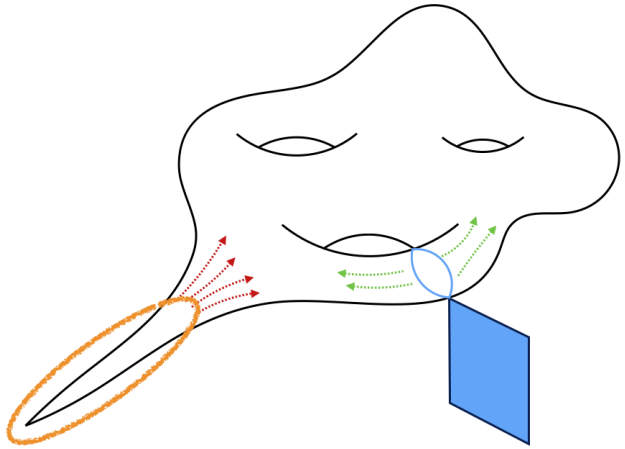
Toric Calabi-Yau Singularities - Generalities I

- They are some special cone-like (non-compact) geometries



Toric Calabi-Yau Singularities - Generalities I

- They are some special cone-like (non-compact) geometries



- With appropriate fluxes (generalized electromagnetic flux) they give rise to warp factors that enable a ST generalization of the *Randall-Sundrum* idea: warping used for creating hierarchies in 4D theory. These geometries are *warped throats*.

$$ds^2 = e^{2A(r)}\eta_{\mu\nu}dx^\mu dx^\nu + e^{-2A(r)}\left(dr^2 + r^2 d\Omega^2_{X_5}\right) \quad \text{with}$$

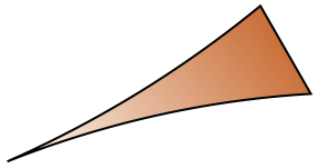
$$F_5 = 4e^{4A(r)}\frac{dA}{dr}(1+\star_{10})dr \wedge dx^0 \wedge dx^1 \wedge dx^2 \wedge dx^3$$

Toric Calabi-Yau Singularities - Generalities II

Why **toric** CY singularities?

- We describe them using a Gauged Linear Sigma Model (GLSM) giving the toric action. The GLSM easily encoded into toric/web diagrams, which are very useful to **decode certain topological properties** of the cone.
- They allow for a holographic dual Gauge Theory description (AdS/CFT-like).
- Unlike for more general singularities, the mirror and **gauge dual are known explicitly**. Gauge theory can be easily described in terms of *dimer diagrams*, allowing for a systematic description of the several phenomena one may find on the gauge theory.

Toric Calabi-Yau Singularities - The conifold example



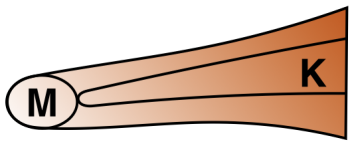
The typical example: Klebanov-Strassler throat

- Based on the conifold: a cone over $X_5 \sim S^2 \times S^3$.
- Without fluxes holographic dual is a $\mathcal{N} = 1$ SCFT

$$SU(N) \times SU(N) \quad \text{with} \quad A_1, A_2 \ \textit{in} \ (\square, \overline{\square}) \ \& \ B_1, B_2 \ \textit{in} \ (\overline{\square}, \square)$$

$$W = A_1 B_1 A_2 B_2 - A_1 B_2 A_2 B_1$$

- With fluxes: finite-size S^3 on the bottom and



$$\int_{S^3} F_3 \sim M \quad ; \quad \int_{S^2 \times \mathbb{R}^+} H_3 \sim K(r) \quad ; \quad N(r) \sim \int_{X_5} F_5 \sim M^2 \log(r/\varepsilon)$$

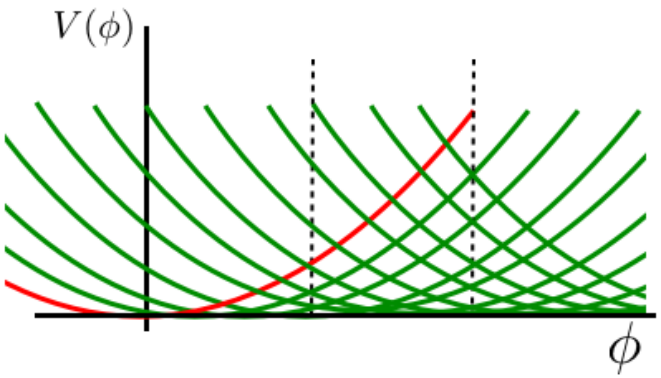
$$e^{-4A(r)} \sim \alpha'^2 g_s^2 M^2 \frac{4\log(r/\varepsilon) + 1}{r^4}$$

- Gauge dual is no longer conformal. Gauge theory phenomena related to geometry: duality cascades, confinement...
- Other singularities $\Rightarrow$ Other gauge duals.

Cosmological model building in ST - Generalities

ST intends to be a theory of everything: it should be able to describe our Universe. In particular, it should be able to embed *Inflation* and *positive CC*.
These issues have turned out not to be very simple, we are still working on them!

- Inflation: large field inflation ($\Delta\phi \geq M_p$) requires control over corrections to EFT describing inflation. This requires embedding the EFT on a UV theory including gravity: ST best theory.
- For slow roll inflation, best inflaton candidates: *axions* ($\phi \sim \phi + f_\phi$).
- But in QG, $f_\phi < M_p$, so extra structure required: Monodromy



Cosmological model building in ST - Inflation on warped throats

The inflaton (axion) potential comes from Non-Perturbative effects. First proposals: 5-brane axion monodromy. Then F-term axion monodromy...

Cosmological model building in ST - Inflation on warped throats

The inflaton (axion) potential comes from Non-Perturbative effects. First proposals: 5-brane axion monodromy. Then F-term axion monodromy...

My contribution

- We developed geometries (warped throats) using toric geometry tools to embed inflation both in the 5-brane and F-term axion monodromy scenarios.

Cosmological model building in ST - $\Lambda > 0$

More trouble: $\Lambda > 0$ is rather non-natural in ST compactifications.

- Among many ideas, KKLT is the scenario that most people like: an anti-D3-brane on the bottom of a warped throat (small Λ). There was a long discussion of the validity of the EFT description of this setup.
- Recent developments about the nilpotent goldstino allow for a better description of this kind of setup.
- ST embedding of nilpotent goldstino requires anti-D3-branes on a orientifold.

Cosmological model building in ST - $\Lambda > 0$

More trouble: $\Lambda > 0$ is rather non-natural in ST compactifications.

- Among many ideas, KKLT is the scenario that most people like: an anti-D3-brane on the bottom of a warped throat (small Λ). There was a long discussion of the validity of the EFT description of this setup.
- Recent developments about the nilpotent goldstino allow for a better description of this kind of setup.
- ST embedding of nilpotent goldstino requires anti-D3-branes on a orientifold.

My contribution

- Finding criteria that tell which toric singularities are compatible with orientifolds and how the effect of the orientifold is on the gauge theory side.
- Using the above ideas to provide a new scenario with $\Lambda > 0$. De Sitter with Dynamical SUSY Breaking.

Cosmological model building in ST - $\Lambda > 0$

More trouble: $\Lambda > 0$ is rather non-natural in ST compactifications.

- Among many ideas, KKLT is the scenario that most people like: an anti-D3-brane on the bottom of a warped throat (small Λ). There was a long discussion of the validity of the EFT description of this setup.
- Recent developments about the nilpotent goldstino allow for a better description of this kind of setup.
- ST embedding of nilpotent goldstino requires anti-D3-branes on a orientifold.

My contribution

- Finding criteria that tell which toric singularities are compatible with orientifolds and how the effect of the orientifold is on the gauge theory side.
- Using the above ideas to provide a new scenario with $\Lambda > 0$. De Sitter with Dynamical SUSY Breaking.
- Building up throats with instanton contributions involving flavour branes.

Current work...

- Trying to provide a ST embedding for a new type of mechanism giving rise to inflation.
- Learning more on orientifolds of toric singularities and their applications to cosmology, mostly focusing on the conifold.

Current work...

- Trying to provide a ST embedding for a new type of mechanism giving rise to inflation.
- Learning more on orientifolds of toric singularities and their applications to cosmology, mostly focusing on the conifold.

Thank you :)