String theory, sheaf cohomology and the *homalg* package

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Outline

1. Brief introduction to string theory

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2. Sheaf cohomology in string theory and the homalg package

Section 1

Brief introduction to string theory

Getting started with string theory

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Why string theory?

- Current understanding of phsyics:

$$\textit{General relativity} + \textit{Quantum field theory}$$

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⇒ String theory is a good candidate theory

Getting started with string theory

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General relativity + *Quantum field theory*

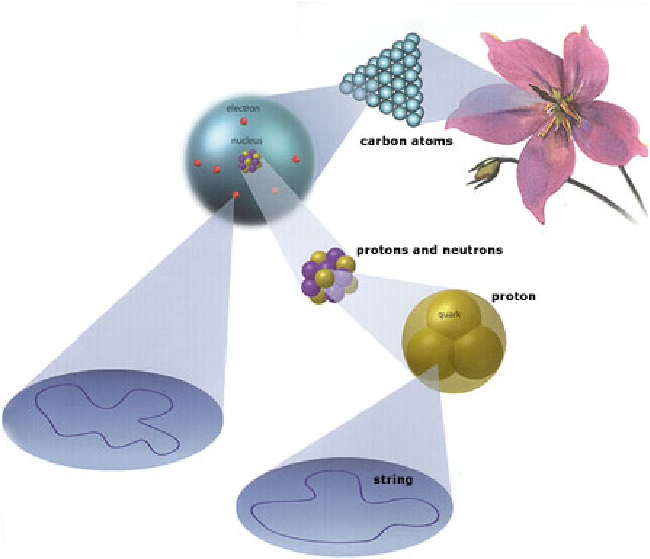
- Is there a single description of everything?

$\Rightarrow$ String theory is a good candidate theory

Starting point of string theory:

Replace point particles by 1-dimensional objects.

Replacing point particles by strings from 'a Layman's guide to string theory'



Minor change with big consequences

Spacetime

- We are living in a 10d Riemannian manifold $\mathcal{S}$
- Compactification means $\mathcal{S} = \mathbb{R}^{1,3} \times_w \mathcal{M}_6$ and $\mathcal{M}_6$ **compact**

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- Vibrations of string $\widehat{=}$ elementary particles.

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- Vibrations of string $\widehat{=}$ elementary particles.
- Every (closed) string gives rise to $|\mathbb{N}|$ elementary particles $|n\rangle$ with masses

$$M^2\left(|n\rangle\right) = \frac{4}{\alpha'}\left(n-1\right)$$

where $\alpha' \ll 1$ is the *Regge slope*.

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$\Rightarrow$ Eventually focus on the massless particles

Further consequence - D-branes appear in string theory

Rough picture

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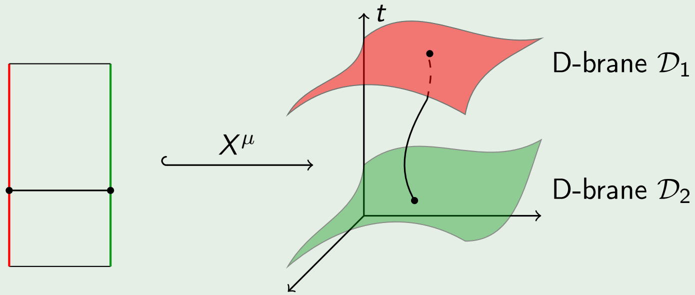
Picture of open strings and D-branes



worldsheet (Σ, h) 10-dim. spacetime $(\mathcal{S}, g)$

Search for our world

String landscape

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- Each solution corresponds to the physics of an entire universe

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- A number of solutions come quite close to our universe. However, no perfect match found yet! hep-th/0502005 and many others

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$\Rightarrow$ An enormous search!

The search in the string landscape

Section 2

Sheaf cohomology in string theory and the homalg package

Special solutions to string theory: the B-model hep-th/9112056

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The B-model ...

is the region of the string landscape described by hep-th/0403166

- $\mathcal{S} = \mathbb{R}^{1,3} \times \mathcal{M}_6$ where $\mathcal{M}_6$ is a CY 3-fold
- use $\mathcal{N} = (2,2)$ supersymmetric theory on $\mathcal{M}_6$
- string coupling $g_s \to 0$
- focus on topological sector
- ...

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Dictionary in B-model hep-th/0208104

Physics	Mathematics
D-brane $\mathcal{D}$ on $\mathcal{M}_6$	$\mathcal{D} \in D^b(\mathfrak{Coh}(\mathcal{M}_6))$
Massless string excitation s between D-branes $\mathcal{F}_\bullet, \mathcal{G}_\bullet$	$s \in \mathrm{Ext}^q(\mathcal{F}_\bullet, \mathcal{G}_\bullet)$

Special solutions to string theory: F-theory GUT model

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Step 1: Model base and GUT

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Example

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1. Smooth, compact toric variety X_Σ, $\dim X_\Sigma = 4$

Example

1. $X_\Sigma = \mathbb{CP}^3 \times \mathbb{CP}^1$, $S = \mathbb{C}[x_0, \ldots, x_3, y_0, y_1]$

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2. $B_3 \subset X_\Sigma$, $\dim B_3 = 3$

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1. Smooth, compact toric variety X_Σ, $\dim X_\Sigma = 4$
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3. $S_{\mathrm{GUT}} \subset B_3$ with $\dim S_{\mathrm{GUT}} = 2$

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1. $X_\Sigma = \mathbb{CP}^3 \times \mathbb{CP}^1$, $S = \mathbb{C}\left[x_0, \ldots, x_3, y_0, y_1\right]$
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- For $i \in \{1, 2, 3, 4, 6\}$ pick $a_i \in H^0\left(X_\Sigma, \mathcal{O}_{X_\Sigma}\left(i\overline{K}_{B_3}\right)\right)$.

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- For $[x, y, z] \in \mathbb{CP}_{2,3,1}$, $p \in B_3$ set

$$\mathcal{C}_p := \{[x, y, z] \in \mathbb{CP}_{2,3,1}\ ,\ Q\left(x, y, z, p\right) = 0\}$$

$$Q\left(x, y, z, p\right) := x^2 - y^2 + xyza_1\left(p\right) + x^2z^2a_2\left(p\right) + yz^3a_3\left(p\right) + xz^4a_4\left(p\right) + z^6a_6\left(p\right)$$

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- $Y_4 := \bigcup_{p \in B_3} C_p$ with $\pi\colon Y_4 \to B_3$ s.t. $\pi^{-1}(p) = \mathcal{C}_p$

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Step 2b: Elliptic fibration over B_3 - Our example

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Step 3: Build A $SU(5) \times U(1)_X$ Model Over S_{GUT}

Require that $a_2 = a_{2,1} w$, $a_3 = a_{3,2} w^2$, $a_4 = a_{4,3} w^3$, $a_6 \equiv 0$ s.t.

- $a_{j,k} \in H^0\left[X_\Sigma, \mathcal{O}_{X_\Sigma}\left(j \cdot \overline{K}_{B_3} - k \cdot D_{\text{GUT}}\right)\right]$
- $a_1, a_{j,k}$ not divisable by w in S

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- $C_{10} := \{p \in X_\Sigma \ , \ s_{B_3} = w = a_1 = 0\}$
- $C_{\overline{5}m} := \{p \in X_\Sigma \ , \ s_{B_3} = w = a_{3,2} = 0\}$
- $C_{5H} := \{p \in X_\Sigma \ , \ s_{B_3} = w = a_{3,2} \cdot a_{2,1} - a_{4,3} \cdot a_1 = 0\}$

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- Pick $\mathcal{F} \in \text{Pic}(X_\Sigma)$ and $\mathcal{H} \in \text{Pic}(S_{\text{GUT}}) - \iota^* \text{Pic}(B_3)$.

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$\Rightarrow$ The actual search is then a scan over admissable fluxes $(\mathcal{F}, \mathcal{H})$.

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Further improvements needed:

As much performance as possible - there is a big search ahead.

Thank you for your attention! Questions?