String Theory

QMAP: Center for Quantum Mathematics & Physics

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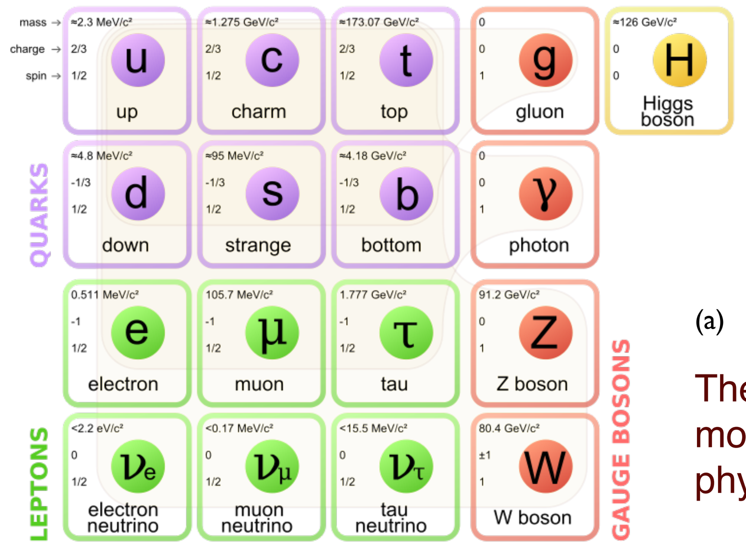
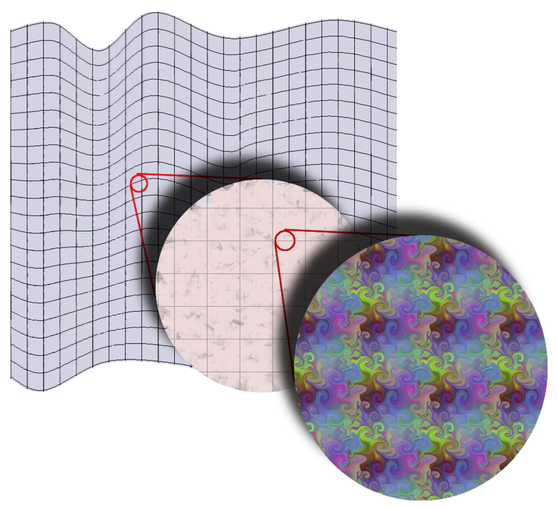
Why String Theory?

Quantum mechanics of elementary particles forms the basis of our understanding of the fundamental interactions in the universe.



(a)
The standard model of particle physics.

The Standard Model of particle physics probes physics only down to a scale of 10^{-19}m. Gravity has a natural scale of 10^{-35}m, which is far smaller.

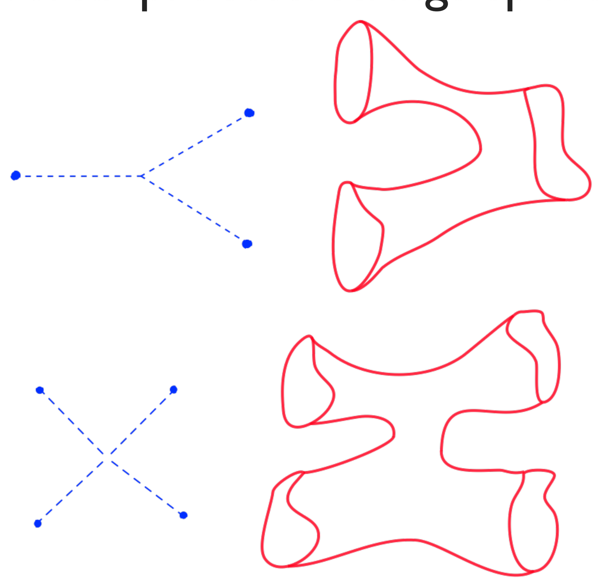


Physics organized by length scales. The deeper we probe, the stronger gravity gets.

String theory attempts to answer the age-old question: what comes beyond. Instead of turtles all the way down, at the very microscopic scale we have string-like one-dimensional objects.

Strings as microscopic constituents of nature.

Fundamental strings vibrate and different lead to different particle species. Furthermore, the interactions between particles is governed by a universal process: strings split and join.



Universal string interactions.

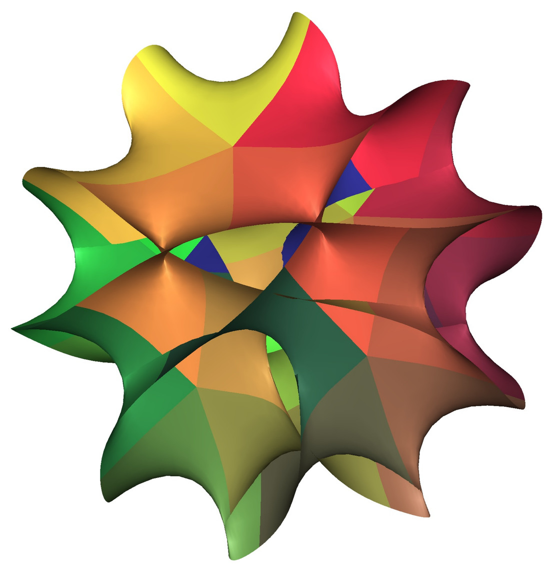
Strings and Gravity

The most interesting aspect of string theory is that it naturally incorporates gravity in a fashion consistent with quantum mechanics.

Closed string vibrations lead to gravitational interactions, giving rise to Einstein's equations:

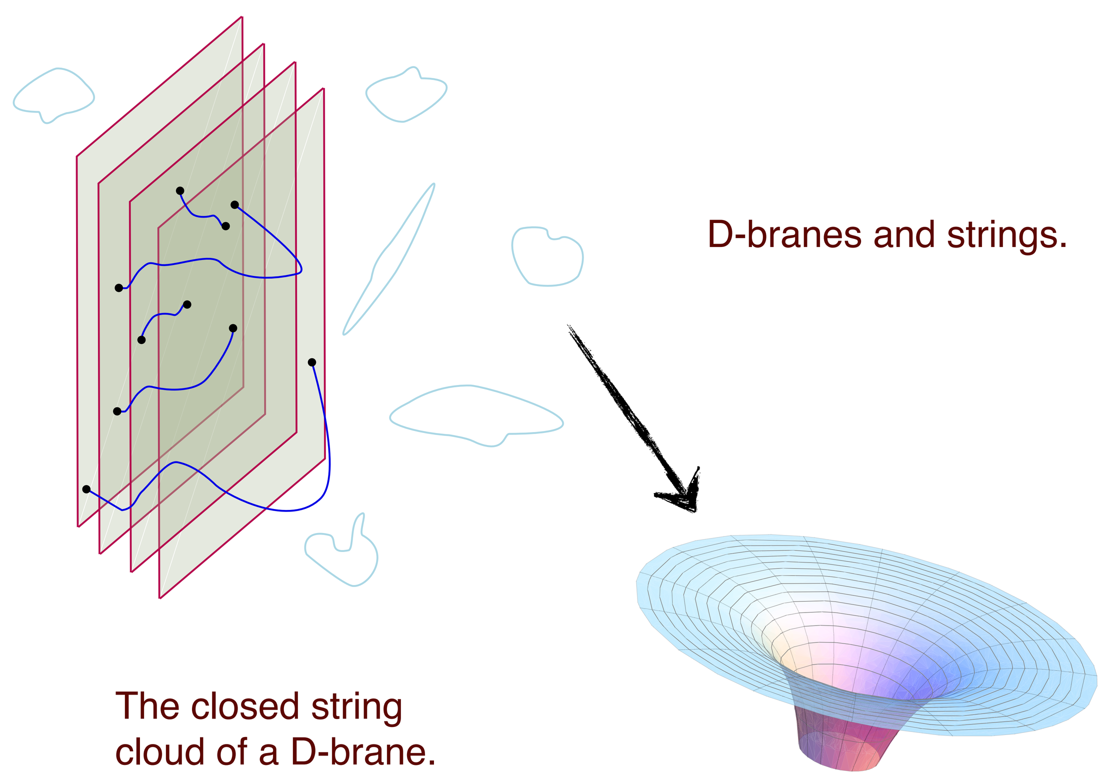
$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = 8\pi\, G_N\, T_{\mu\nu}$$

For consistency, string theory requires 10 dimensions. We see 4 macroscopic spacetime dimensions as the other directions are compact.



(b)
A two dimensional slice of a compact six dimensional Calabi-Yau manifold.

Open strings on the other hand have end-points, which lie on dynamical surfaces, called D-branes.



D-branes and strings.

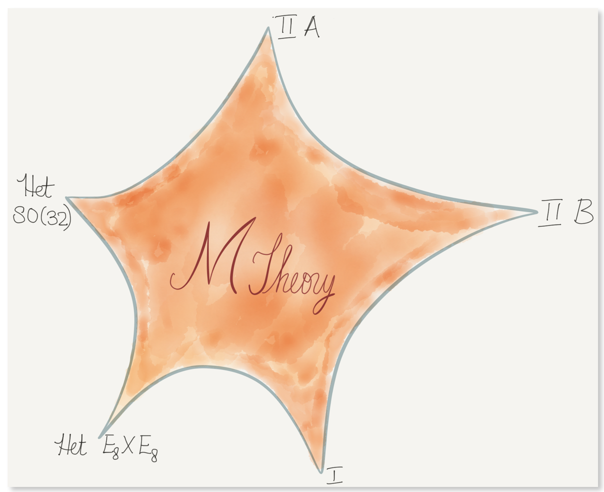
The closed string cloud of a D-brane.

D-branes and open strings can equivalently be replaced by their gravitational cloud, changing the stage on which closed string live.

In fact, gravitational clouds of D-branes naturally connect string theory to black holes.

Dualities

Dualities refers to the fact that one can have two very different presentations of the same physics. eg: electromagnetic duality where we swap the role of electricity and magnetism.

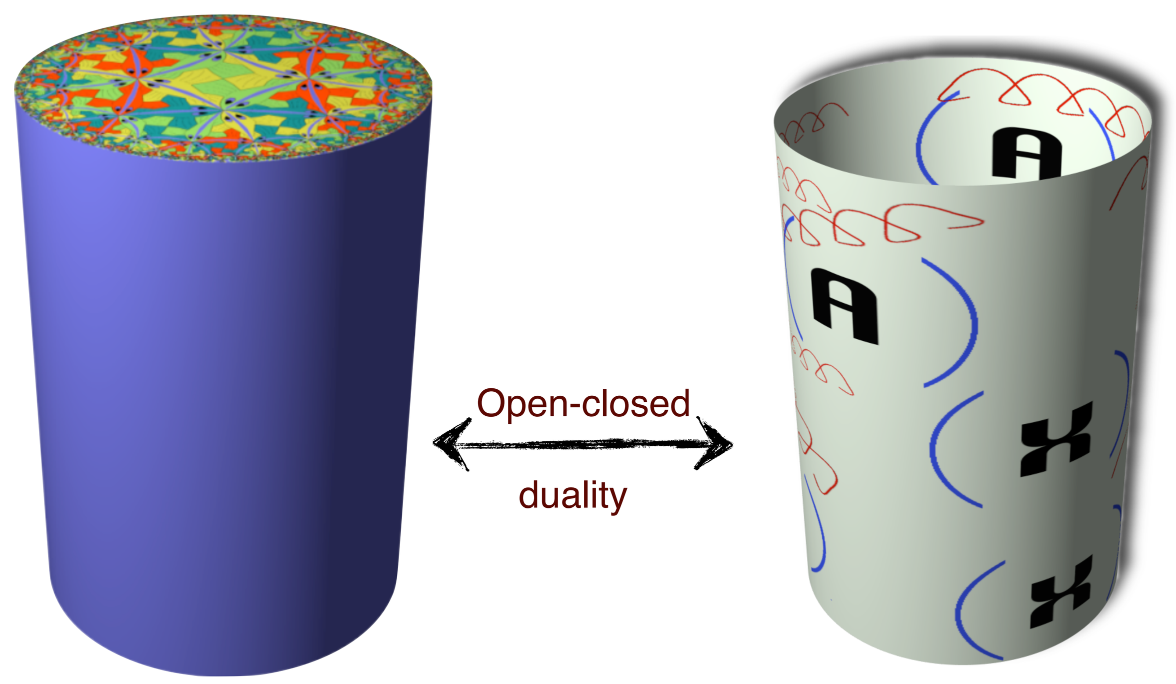


A caricature of the complex web of string dualities.

All known formulations of string theory are dual to M-theory, which can be thought of as a eleven dimensional theory.

Dualities can however make it difficult to make precise what the number of spacetime dimensions is!

A remarkable example is the AdS/CFT correspondence: in certain 10 dimensional backgrounds strings are dual to a close cousin of the standard model in 4 spacetime dimensions.



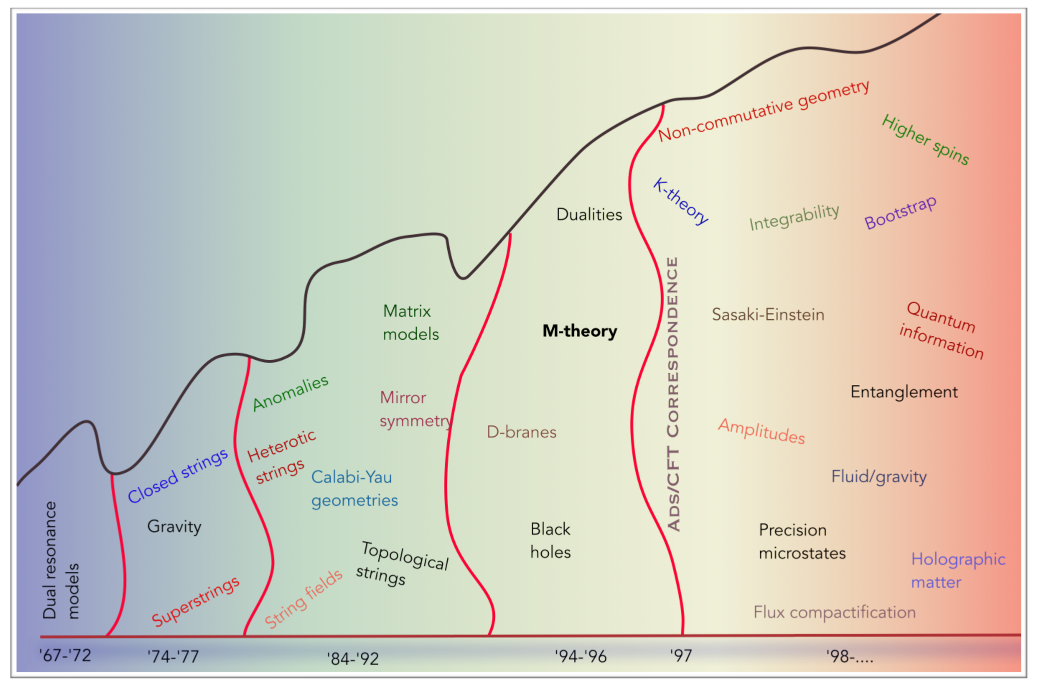
Open-closed duality

This correspondence is *holographic*. The particles are a hologram for the strings.

This is the most promising framework to study Quantum Gravity as we can relate it to well understood models of particle physics.

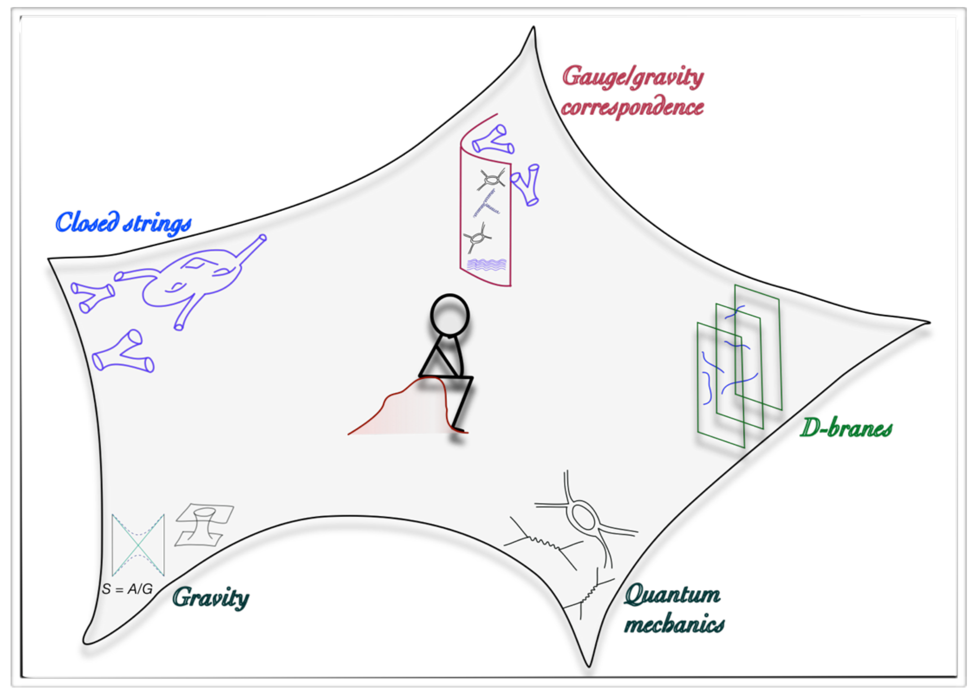
The web of strings

Over the past 4 decades string theory had played an important role in allowing us to connect between a-priori different areas of physics and mathematics.



Topics of current research include:

- ✦ What role does quantum information play in formulating quantum field theories and how does it elucidate the duality between particles and strings?
- ✦ What is the simplest quantum field theory?
- ✦ How does one derive universal features of low energy physics seen in diverse systems from these fundamental formulations?
- ✦ What is the appropriate mathematical language describing the dynamics of quantum fields?



These and other questions are actively explored at QMAP.

Images courtesy:
a) Standard Model, Wikimedia commons
b) Calabi-Yau quintic, Andrew Hanson, Indiana University