

The background is a solid blue color. It is covered with a dense pattern of orange and yellow string-like loops, which are three-dimensional and have a metallic sheen. These loops are of various sizes and orientations. Interspersed among the loops are small, light-colored letters and symbols, including 'A', 'B', 'C', 'D', 'E', 'F', 'G', 'H', 'I', 'J', 'K', 'L', 'M', 'N', 'O', 'P', 'Q', 'R', 'S', 'T', 'U', 'V', 'W', 'X', 'Y', 'Z', and some mathematical symbols like ' $\Delta$ ' and ' $\gamma$ '.

# String Theory

## A Brief Report

# Plan

- What is string theory?
- Unification ideology.
- What is duality in physics?
- Open-Closed string duality, the bridge between string theory and quantum field theory.
- String theory as a tool: RHIC, LHC, condensed matter, mathematics.
- M-theory and a return to ideology.

# String Theory

- Basic idea is that the fundamental constituents of nature have extension.
- The different forces and particles we see are associated to the strings internal degrees of freedom being different
- Unifying idea
- All matter and forces including gravity are strings.

# String Theory

Some points to note:

- We need supersymmetry
- We need ten dimensions

We have observed so far:

- We don't have supersymmetry
- We have four dimensions



# String theory

Ideological Attitude:

There must be extra dimensions and there must be supersymmetry.

We don't know what determines the shape or scale of these extra dimensions.

# String theory

- The extra dimensions are hidden a la Kaluza, Klein theory (1921)
- Supersymmetry is there but broken (somehow)
- If only our experiments were better then susy and extra dimensions would be observed (ideological statement)

# String theory

- Key success:

## GRAVITY

- Einstein's equation's emerge and are automatically quantised with no problems.
- String theory is still the only true theory of quantum gravity
- Given that we have gravity and we have quantum mechanics this is a good ideological reason to believe in strings

# String theory

We have open strings and closed strings

Closed strings are responsible for gravity  
and open strings for gauge theories

How different really is an open to a closed string? They are still strings after all.



# Duality in Physics

Duality in physics is when two seemingly different physical systems have a dictionary that allows one to map all the physical properties of one system on to the other and vice versa.

# Duality in Physics

- There are two sides to a coin, we only see one side at a time but every point on one side of the coin implies something on the opposite side:



# Duality in Physics

In various cases we have been able to construct dictionaries between distinct systems that can map the physics of one system to another or the physics of the same system to one with different parameters eg swap electric and magnetic fields and invert the charge.

# Duality in Physics

- Having the the right duality *frame* can often make calculation easier.
- Like picking the right coordinates for a system with symmetries

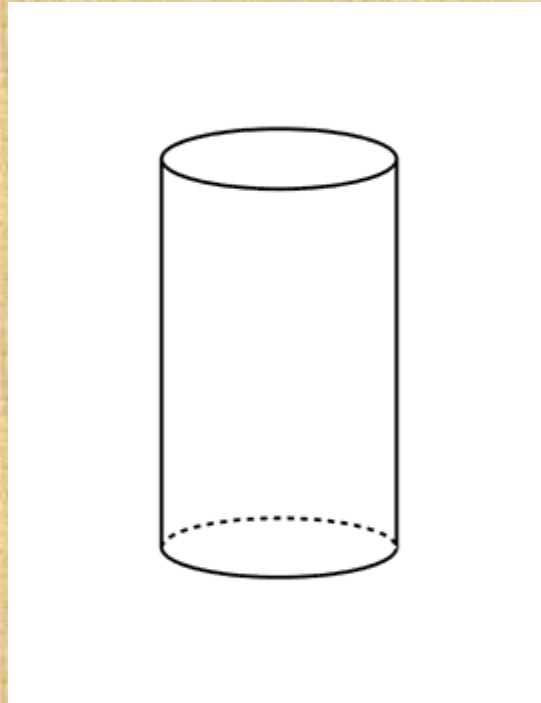


# Duality in Physics

- Having the duality map is like seeing the two sides of the coin. What one would like though is to see the coin and realise why the map exists.
- String theory often provides this.

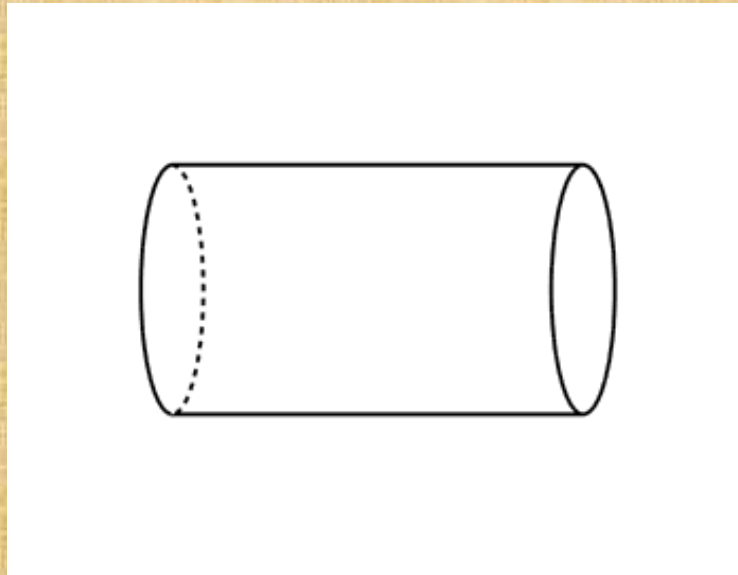
# Duality in String theory

- Back to open and closed strings
- The world sheet of a closed string is a cylinder:



# Duality in String theory

- The world sheet of an open string at one loop is also a cylinder:



# Duality in String theory

The cylinder is the like the coin, whether it is an open string at one loop or a simple closed string is a matter of choice depending on which side we view.

This means there is a complex duality between open and closed strings.



# Duality in string theory

- Since closed strings relate to gravity and open strings to gauge theory, this duality relates a gravitational system to open in gauge theory.
- In 1997 Maldacena made this duality very concrete and began the construction of the dictionary between gravity and gauge theories.

# String theory as a tool

- The relation to gauge theory now provides us with tools away from our ideological bias.
- Gauge theories are real in fact every force of nature is a gauge theory. Understand gauge theory interactions and you understand particle physics.

# String theory as a tool

- This connection and the detailed dictionary has allowed calculations to be done using the dual picture that could not be done otherwise.
- The best example and the first case of a string theory paper being cited by a proper experimental group is RHIC.

# String theory as a tool

- RHIC is a heavy ion collider that smashes gold ion together at enormous energies.
- More energy than cern but flithy dirty because of the large objects in the collision.
- A quark gluon plasma/liquid.gas is produced.
- How do we model such a thing?



# String theory as a tool

- What dominates the dynamics is the strong nuclear force.
- Computers are almost useless (but people try) and there are no analytical QCD techniques possible since we are at strong coupling and there is no possibility of perturbation theory.

# String theory as a tool

- Using string theory, gauge theory thermodynamics (at strong coupling) are somewhat amazingly dual to a particular sort of black hole.
- The thermodynamics and other properties map to properties of the plasma
- This provides the best theoretical fit so far for RHIC experiments!

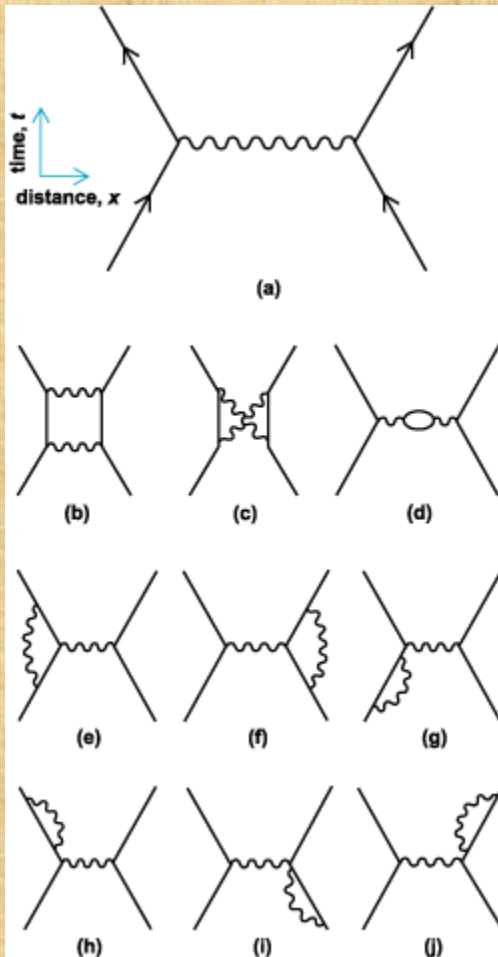
# String theory as a tool

- LHC

What about scattering in gauge theories.

Using the connection between open strings and gauge theories gives use a way calculate scattering amplitudes in QCD without the use of huge numbers of feynman diagrams.

# String theory as a tool



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Simple thing from string theory



# String theory as a tool

- At QM: Bill Spence, Gab Travaglini and Andi Brandhuber have been at the forefront of developing these scattering calculation tools.
- Now complex scattering amplitudes such as the 6 gluon one loop which is thousands of diagrams can be done directly using string inspired techniques.

# String theory as a tool

- Most recent application has been to condensed matter where again the map between gravity and field theory has been exploited.
- This has given a new effective theory of superconductors using the dual gravitational description.
- Hydrodynamics has also been tackled this way to give new bounds on viscosity of fluids.

# String theory as mathematics

Mirror symmetry makes predictions for possible 6 dimensional surfaces.

Most recently string theory was used to prove the geometric Langlands conjecture which deals with a map between objects in number theory and objects in geometry. The way it did this was yet again using gauge theory and duality.

# String theory as mathematics

- Ricci flow from quantising gravity
- The construction of topological invariants from the string partition function
- The incorporation of noncommutative geometry
- Almost every area of mathematics is connected to string theory



# Back to Ideology

- Key problem:

No LHC predictions other than SUSY and extra dimensions. No clear smoking gun.

Too many possibilities are allowed by string theory

# Back to ideology

- Key success:
- Black hole entropy explained with detailed microstate counting and in some cases the information paradox has been resolved.

This is essentially because of our success with gravity.

# Ideological Problems

- String theory is formulated as perturbation theory
- Its like you get given the Feynmann diagrams but not the path integral that they approximate.
- That is good enough at weak coupling for most things but even then not entirely eg. Tunneling is nonperturbative.
- String theory is not unique (there are five of them).

# Ideological problems

- Need to formulate the theory away from weak coupling and do so nonperturbatively.
- This is M-theory
- Strings are no longer present only membranes and fivebranes



# M-theory

- M-theory is unique
- It has no dimensionless parameters at all
- It reduces to the different string theories in various perturbative limits
- It is truly nonperturbative and has been used to solve quantum field theories exactly at low energies. That is:  
all loops and all instantons

# Spacetime vs worldsheet

- Another ideological problem is that string theory is formulated as a world sheet theory. This is actually akin to quantum mechanics.
- Want to have a spacetime field theoretic description where strings can be created or destroyed. This is known as string field theory.

# Spacetime vs worldsheet

- This has several problems the most important is:

Difficult for closed strings

# Hopes

- Given a true nonperturbative (M-theory) description along with a string field theoretic description we could then hope to tackle our tool box limitations of producing the standard model etc. Until then should we really be surprised that we aren't describing experimental particle physics.