Instituto de Física Teórica UAM-CSIC

Unification of particles and forces

String Theory and Particle Physics

UAM CSIC Consejo Superior de Investigaciones Científicas

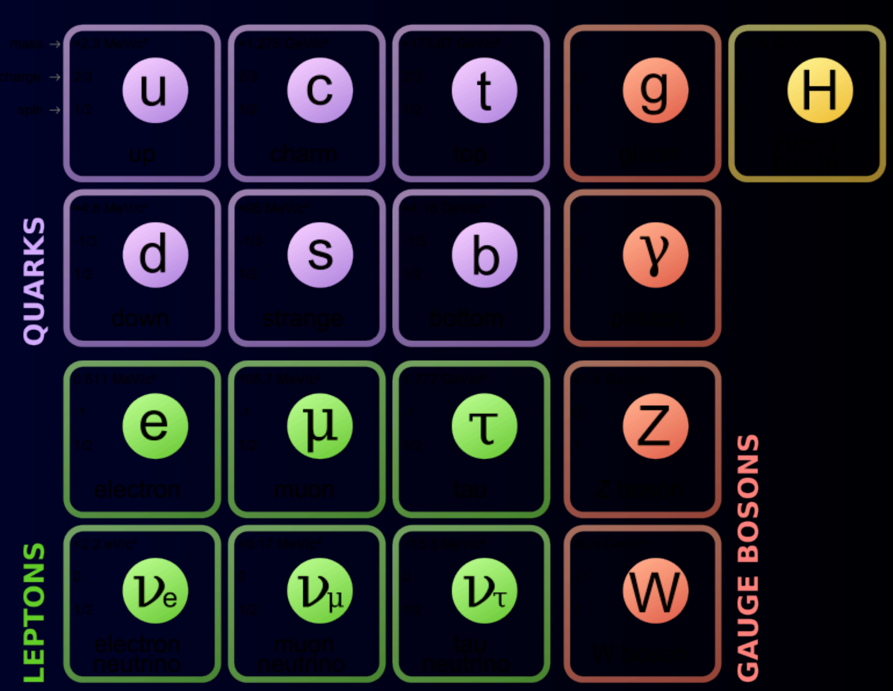
The Standard Model of Elementary Particles

What are we made of?

Everything around us is made up of elementary particles, for instance the quarks within protons and neutrons in atomic nuclei, and the leptons, like the electrons which orbit around nuclei. Together they form the atoms which are constituents of matter.

What holds particles together?

Elementary particles are subject to forces associated to four fundamental interactions: electromagnetism, the strong force, the weak interaction, and gravity.
Each one of these interactions is associated with one or several force particles, the gauge bosons: the photon, the Z y W bosons, the gluons and the (still hypothetical) graviton.

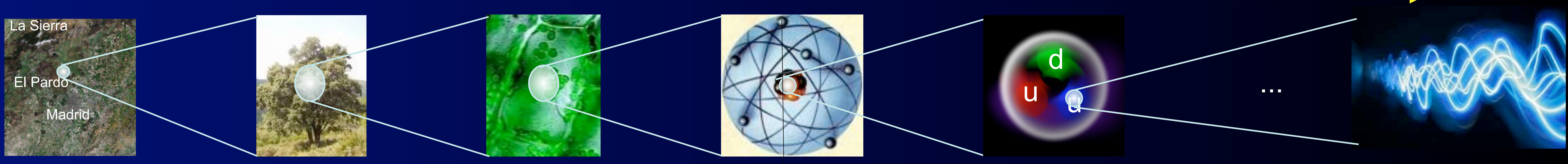


The Higgs boson

The mass of elementary particles arises from their interaction with the Higgs field, which permeates all of space and time, and whose interactions with particles contributes to their internal energy, i.e. their mass. The fluctuations of the Higgs field itself correspond to a new kind of particle, the Higgs boson, discovered in 2012 in the Large Hadron Collider LHC at CERN in Geneva.

From particles to strings

One more step...



10^5 m = 100 Km
Satellite image of the Madrid area, centered on the El Pardo forest

1m
A holm oak tree in the El Pardo forest

10^{-5} m = 10 μm
Plant cell

10^{-10} m = 0.1nm
Carbon atom

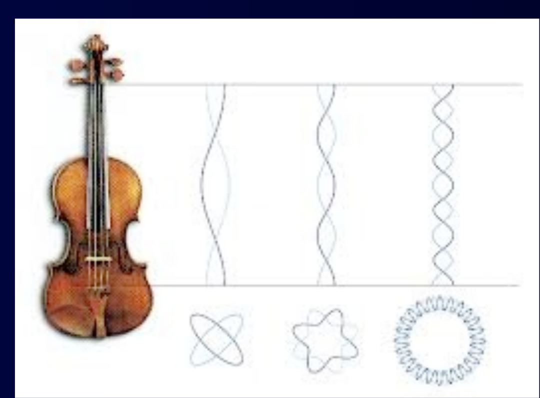
10^{-15} m
Internal structure of the proton

10^{-33} m
Planck scale?

In string theory, elementary particles are not point-like objects, but rather extended objects, tiny vibrating strings.

Unification of particles and forces

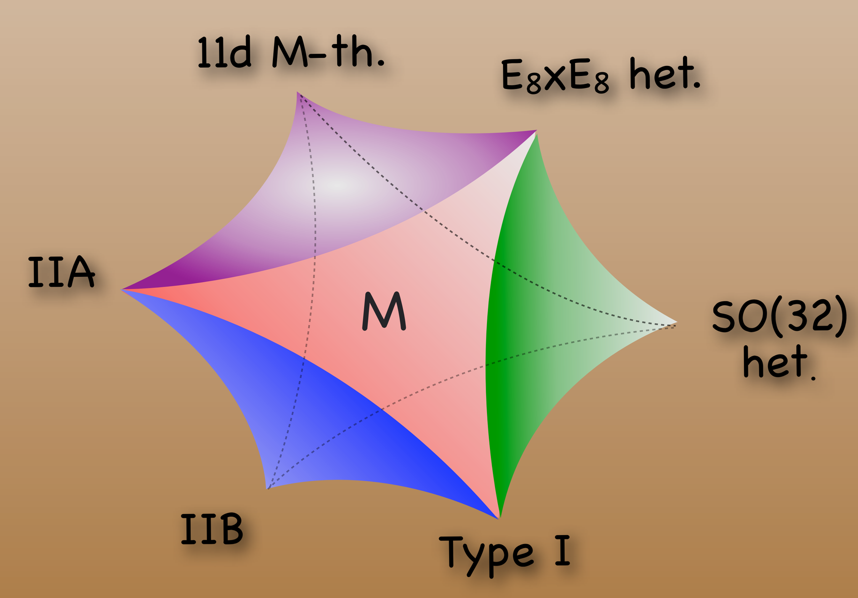
In string theory, the different kinds of particles we see (quarks, leptons, interaction particles and the Higgs boson) would correspond to different vibration modes of a unique kind of underlying string, like the different notes in a violin string. It thus implies a unification of matter particles and interaction particles.



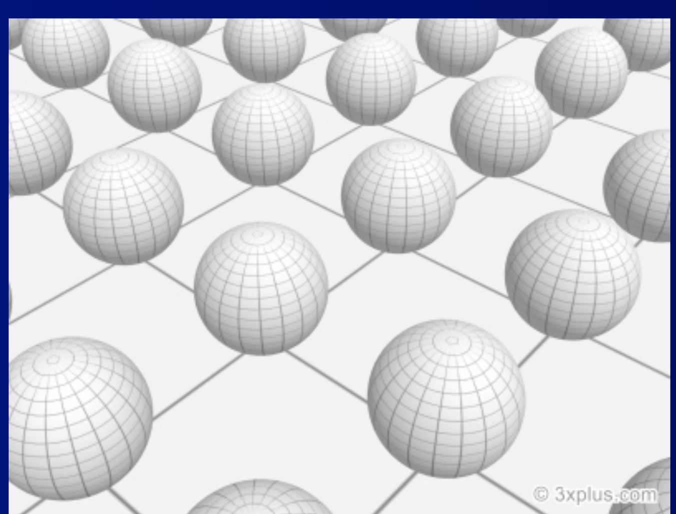
Five theories and a Mystery

There exist in principle five mathematically consistent string theories. They are known as type IIA and IIB, type I, SO(32) heterotic and E8 x E8 heterotic.
They are all formulated in 10 dimensions and with a high degree of supersymmetry.

However, the behavior of these theories at strong coupling reveals they are actually different manifestation of a unique underlying theory, which also encompasses the so-called M-theory, which lives in 11 dimensions and whose formulation remains mysterious.

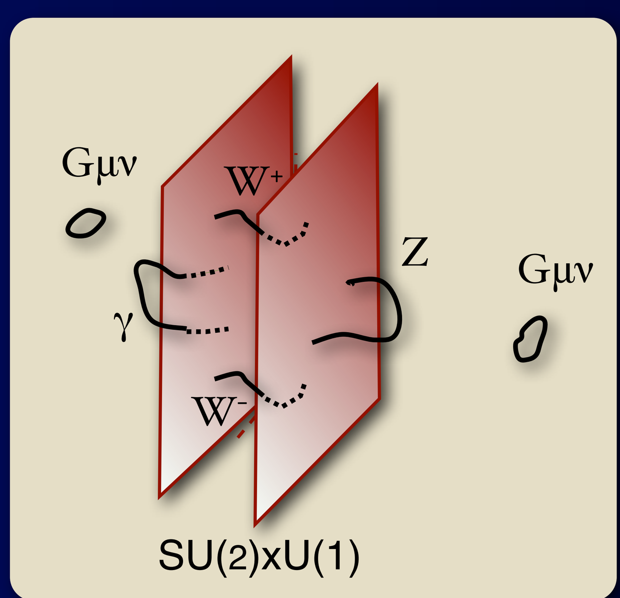


Extra dimensions, compactification...

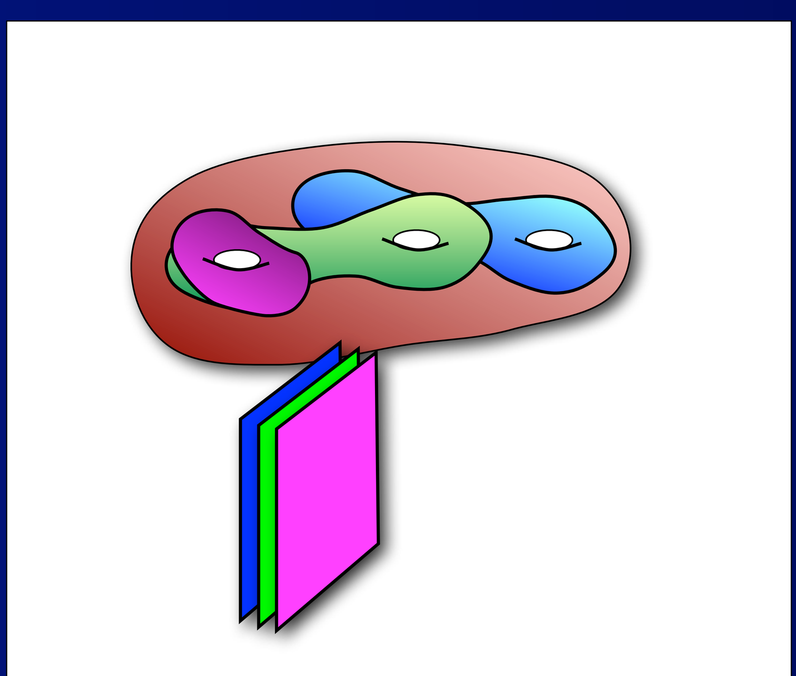


To produce theories with four dimensions (three spatial, plus time), six of the ten dimensions of string theory must be "curled up", compactified, defining a space of very small size.
Although they are not directly observable, the extra dimensions are enormously important, since their geometry and properties determine the resulting content of particles and forces in four dimensions.

... and D-branes

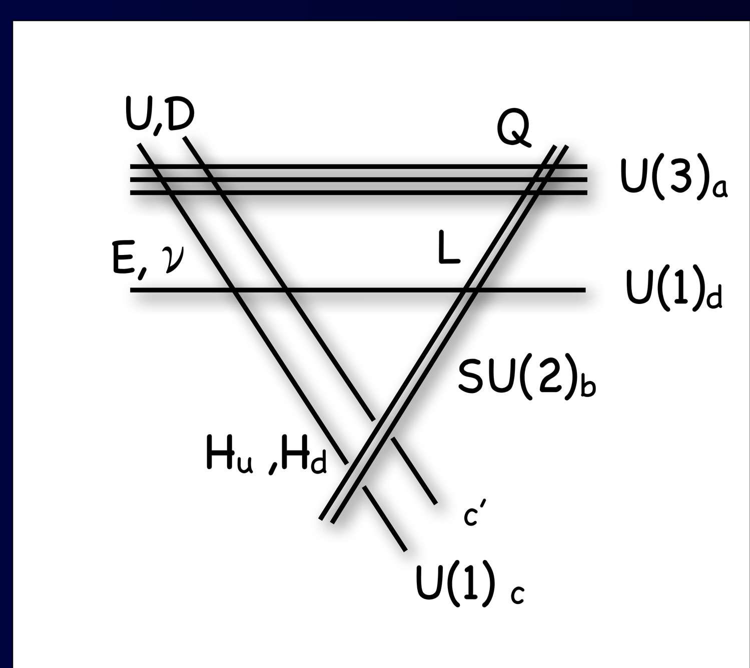


In string theory, the graviton arises as the lightest vibration mode of the closed string. In many models, matter and interaction particles and the Higgs boson can arise from vibration modes of open strings.
Open strings have the property that their endpoints are fixed on D-branes, certain subspaces of 10-dimensional space-time. The geometry of D-branes in the extra dimensions determined the content of particles and forces in the model.



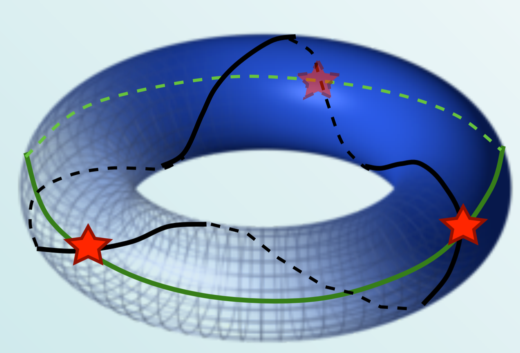
Intersecting D-branes

In the simplest particle physics string models, the Standard Model particles arise as open string with their endpoints on stacks of D-branes wrapped in the extra dimensions in different ways.
Gauge bosons are open strings among overlapping D-branes, whereas quarks, leptons and the Higgs boson arise from open strings located at the intersections of D-brane stacks.



The origin of the 3 families

In models of intersecting D-branes, the replication of matter particles is due to the fact that the D-brane stacks can intersect at several points in the extra dimensions.

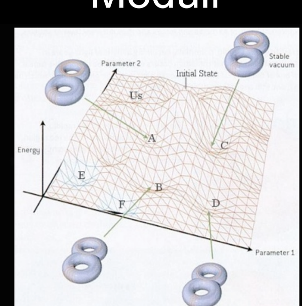


Open puzzles

String scale

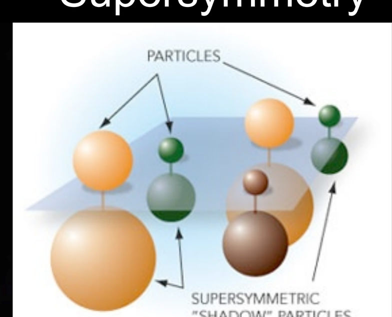
The energy required to observe the extended nature of strings could be the enormous Planck scale ~10^{19} GeV. However, its actual value is still unknown and might be much closer to experimentally accessible energies.

Moduli



Many string theory models in four dimensions lead to a multitude of moduli, scalar particles with no mass which are in fact not observed in Nature. Mechanisms to remove there unwanted guests are under active study.

Supersymmetry



The simplest string theory construction produce supersymmetric models. The breaking of supersymmetry at a scale close to the electroweak scale would led to supersymmetric particles within the reach of the LHC.

Masses

In the Standard Model there are three families of ever increasing masses. String theory can explain the existence of multiple families, but neither explains why there are precisely three, nor allows to predict the value of their masses.

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