

On the Origin of the Physical Laws



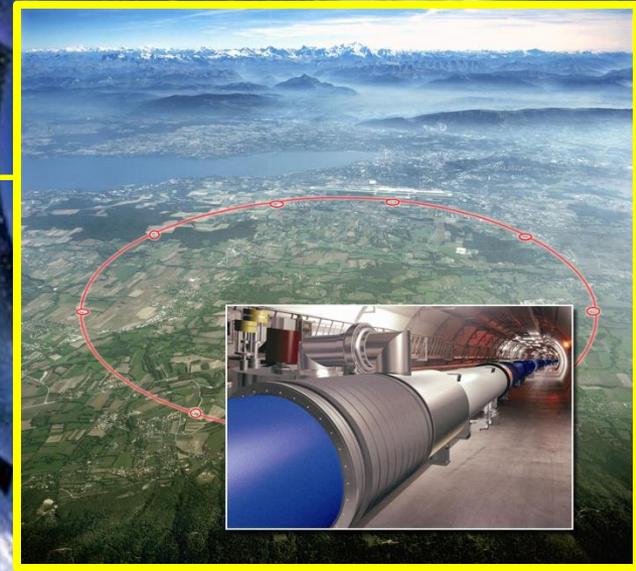
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Texas A&M University

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Academy of Athens

Multiverse and the LHC

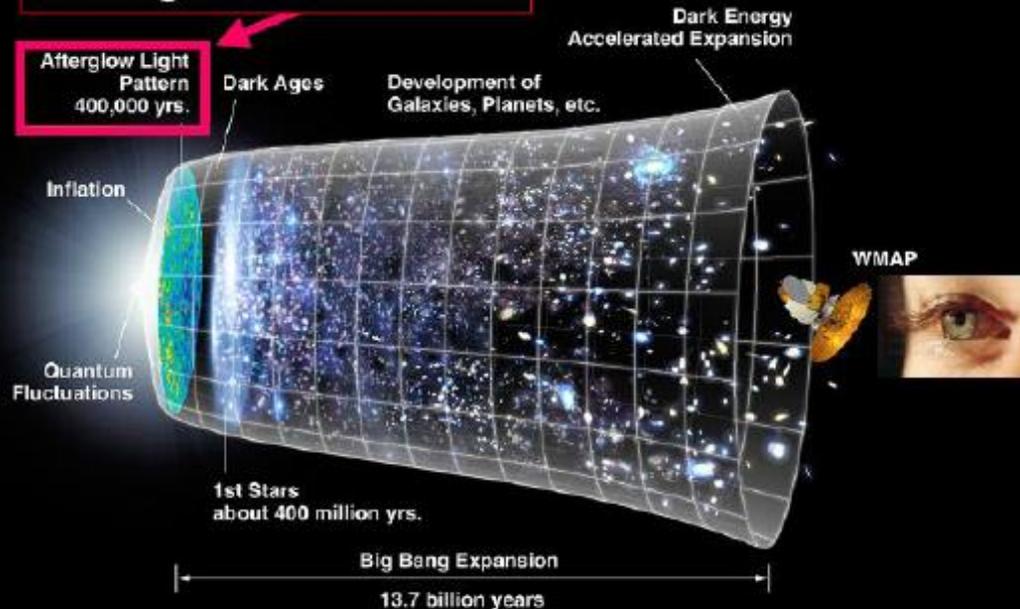


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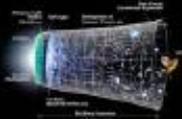
Research in collaboration with:
Tianjun Li, James A. Maxin, Joel W. Walker

The Most Distant Light

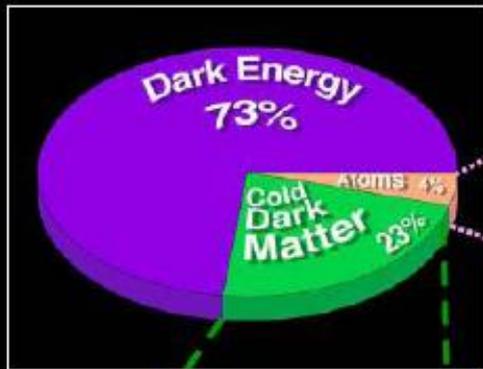
Message from the Universe



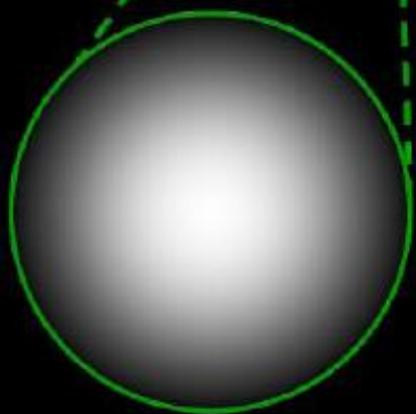
Cosmic Microwave Background (CMB) was emitted when the Universe was only **380,000 years old**.



Contents of the Universe



4%



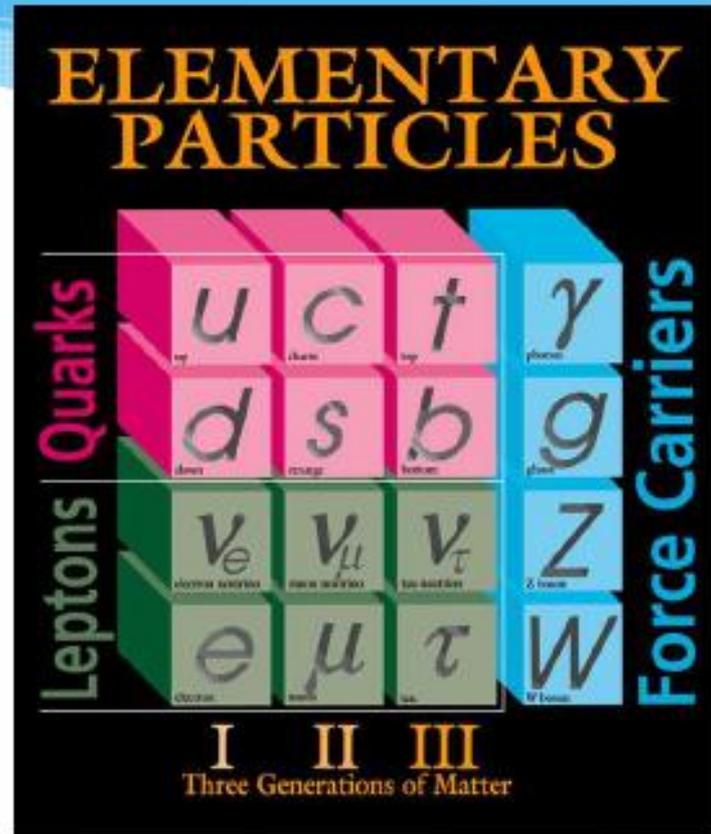
The 23% is still unobserved in the laboratory.

(This new matter can not be seen visually!)

We call this Cold Dark Matter.

The Standard Model

- ❑ **Quarks** and **leptons** are the most fundamental particles of nature that we know about.
- ❑ **Up** & **down quarks** and **electrons** are the constituents of ordinary matter.
- ❑ The other quarks and leptons can be produced in **cosmic ray showers** or in **high energy particle accelerators**.
- ❑ Each particle has a corresponding antiparticle.



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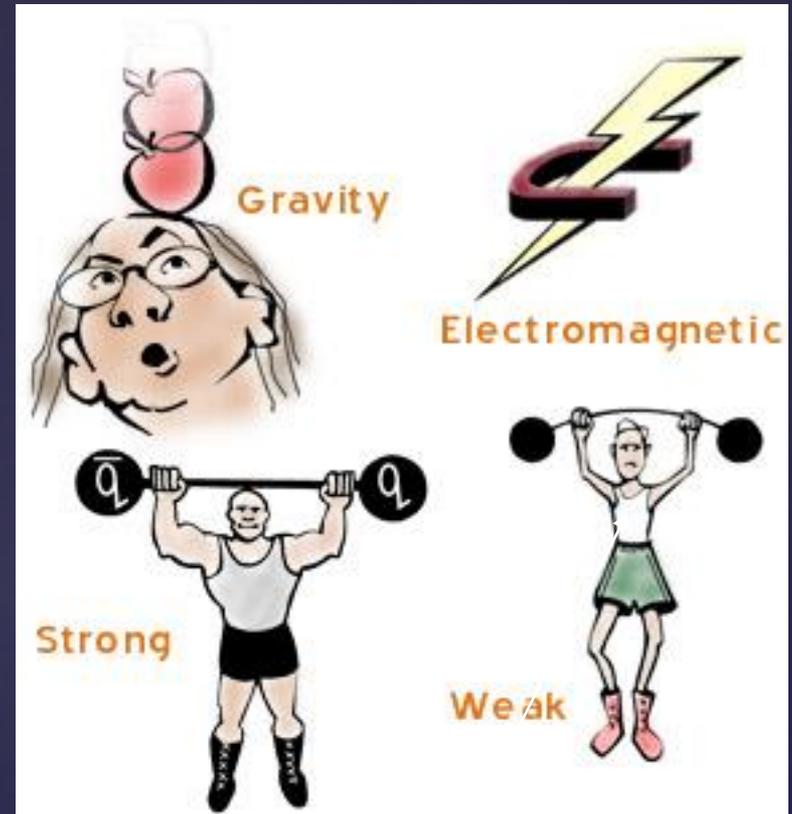
The Four Fundamental Forces

1. Gravity

2. Weak Force

3. Electromagnetic force

4. Strong Force



Doesn't that look like George W. ?

All other forces you know about can be attributed to one of these!

Gravity

Gravity is the weakest of the 4 forces. The gravitational force between two objects of masses m_1 and m_2 , separated by a distance d is:

$$F = Gm_1m_2/d^2$$

G = gravitational constant = 6.7×10^{-11} [N]
 d = distance from center-to-center

The units of each are:

[Force] = [Newton] = [N]

[mass] = [kg]

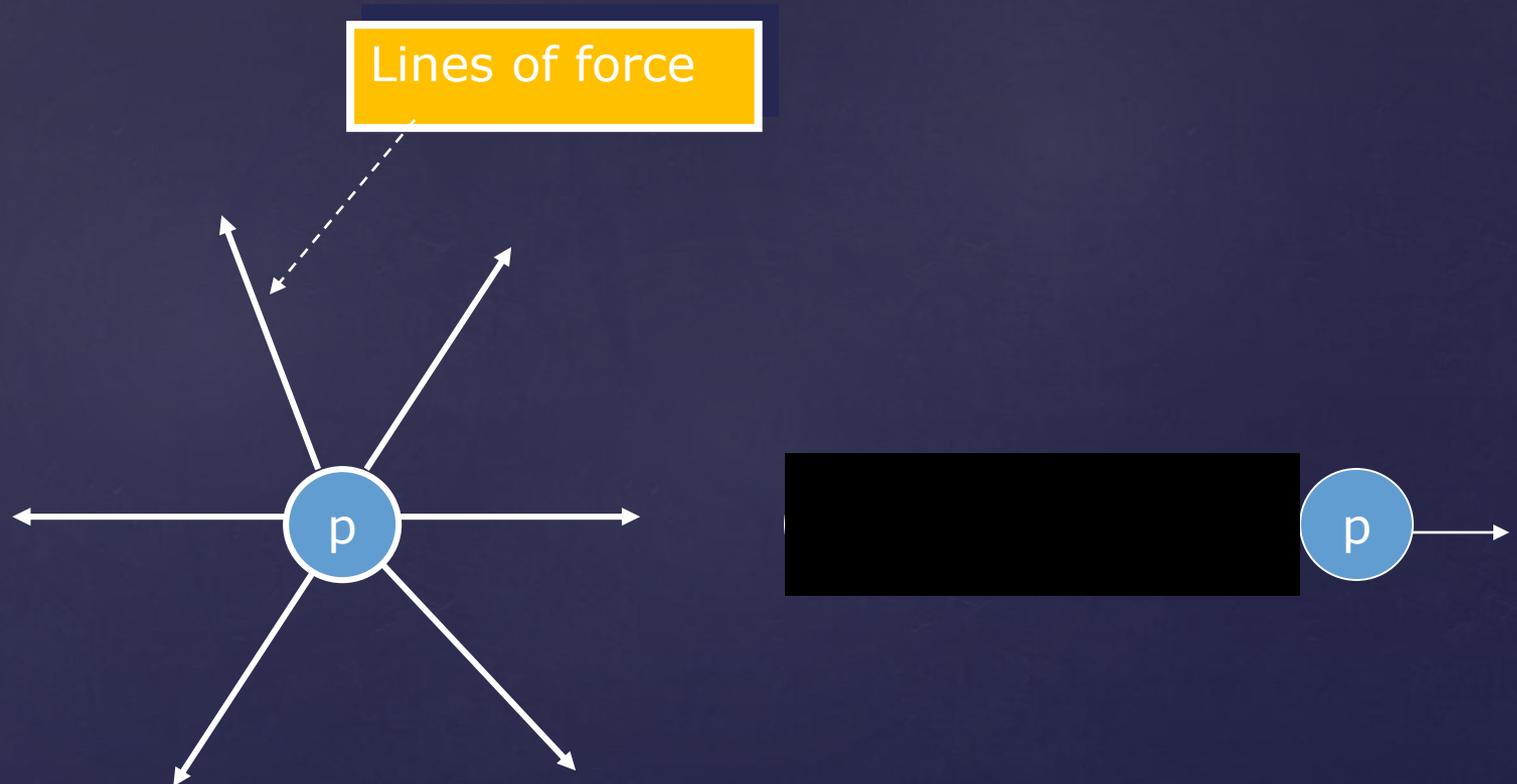
[distance] = [meters]

Gravity is only an attractive force



The Electric Force

In the old days, we believed that "force" was transmitted more or less instantaneously by a "field of force".

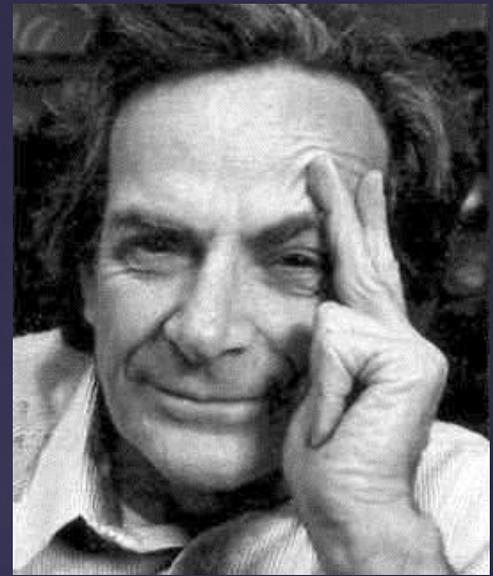


The proton to the right is repelled by the "electric field" created by the one on the left (electrical repulsion).

The New Concept of Force

In the 1950's, a new theory of interactions was developed.

At the heart of it is the concept that:



Richard Feynman, 1918-1988
1965 Nobel Prize in Physics

Forces are the result of the exchange of "force carriers" between the two particles involved in the interaction.

The force carrier of the electromagnetic force is the photon (γ)

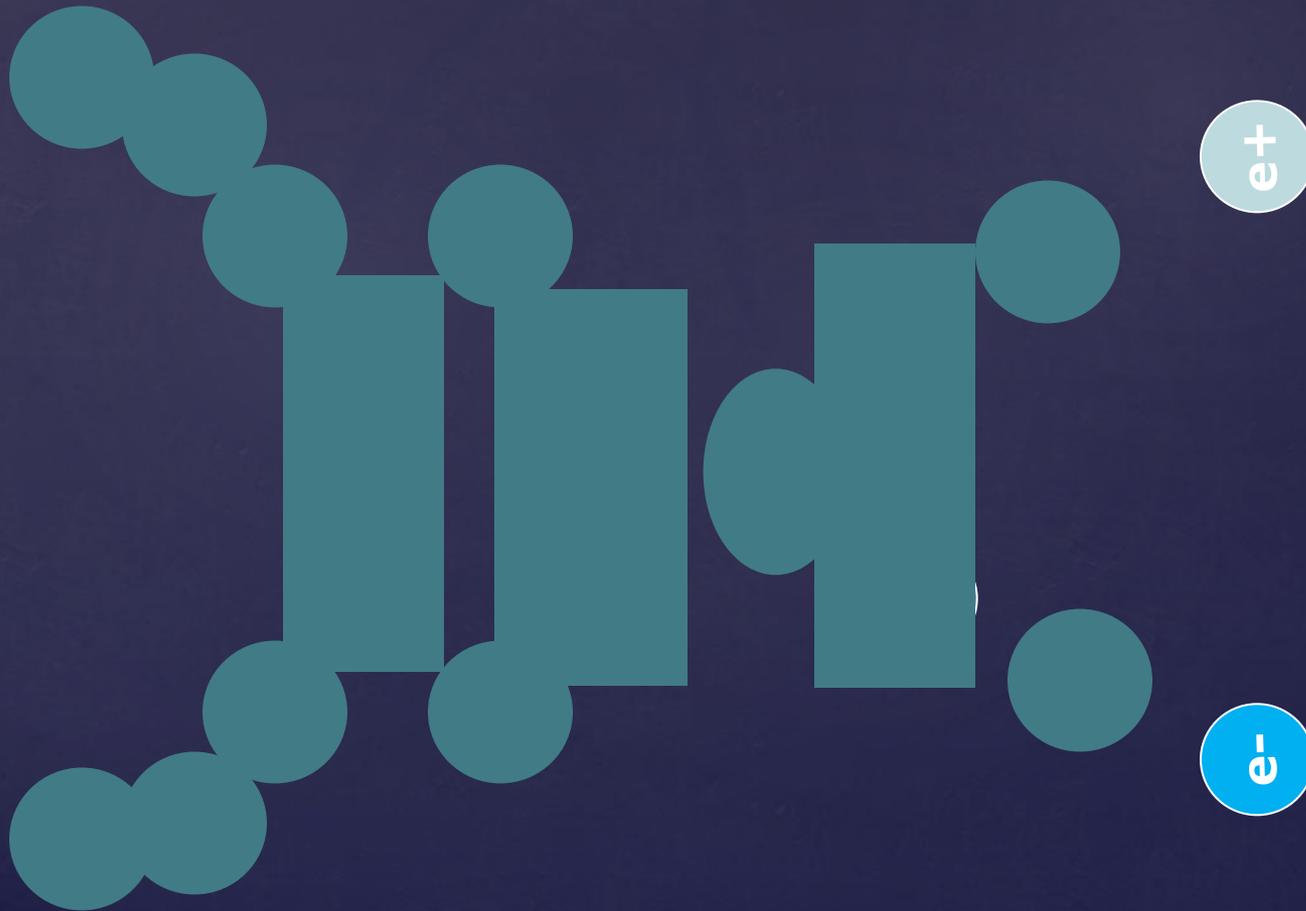
The Photon (γ)

Property	Value
Mass	0
Charge	0

The photon is the “mediator” of the electromagnetic interaction

The photon can only interact with objects which have electric charge !!!!!

Electron-Positron Scattering



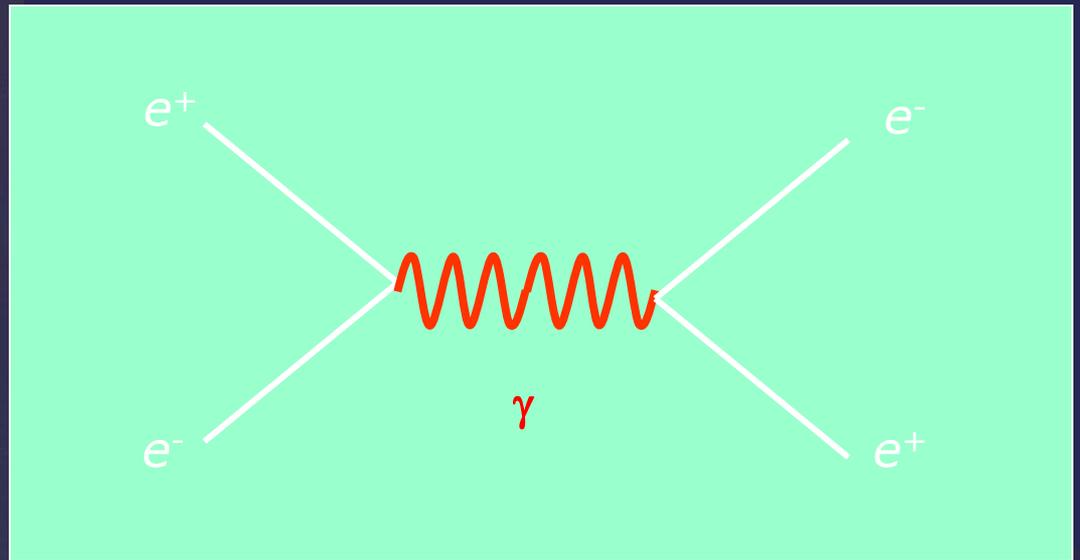
□ A great simplification which allows us to represent these physical processes are facilitated by **Feynman Diagrams**.

□ It turns out, they can also be used to calculate the probability for the process to occur (Beyond the scope of this module though).

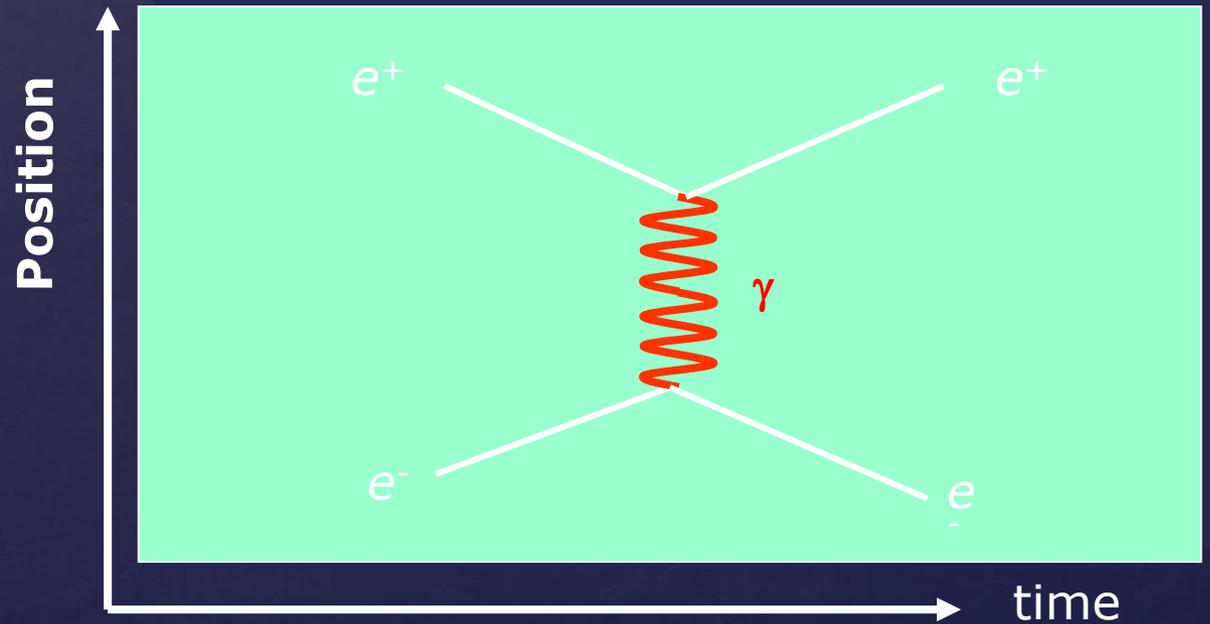
□ We will use them more in a qualitative sense to visualize various processes.

Feynman Diagrams

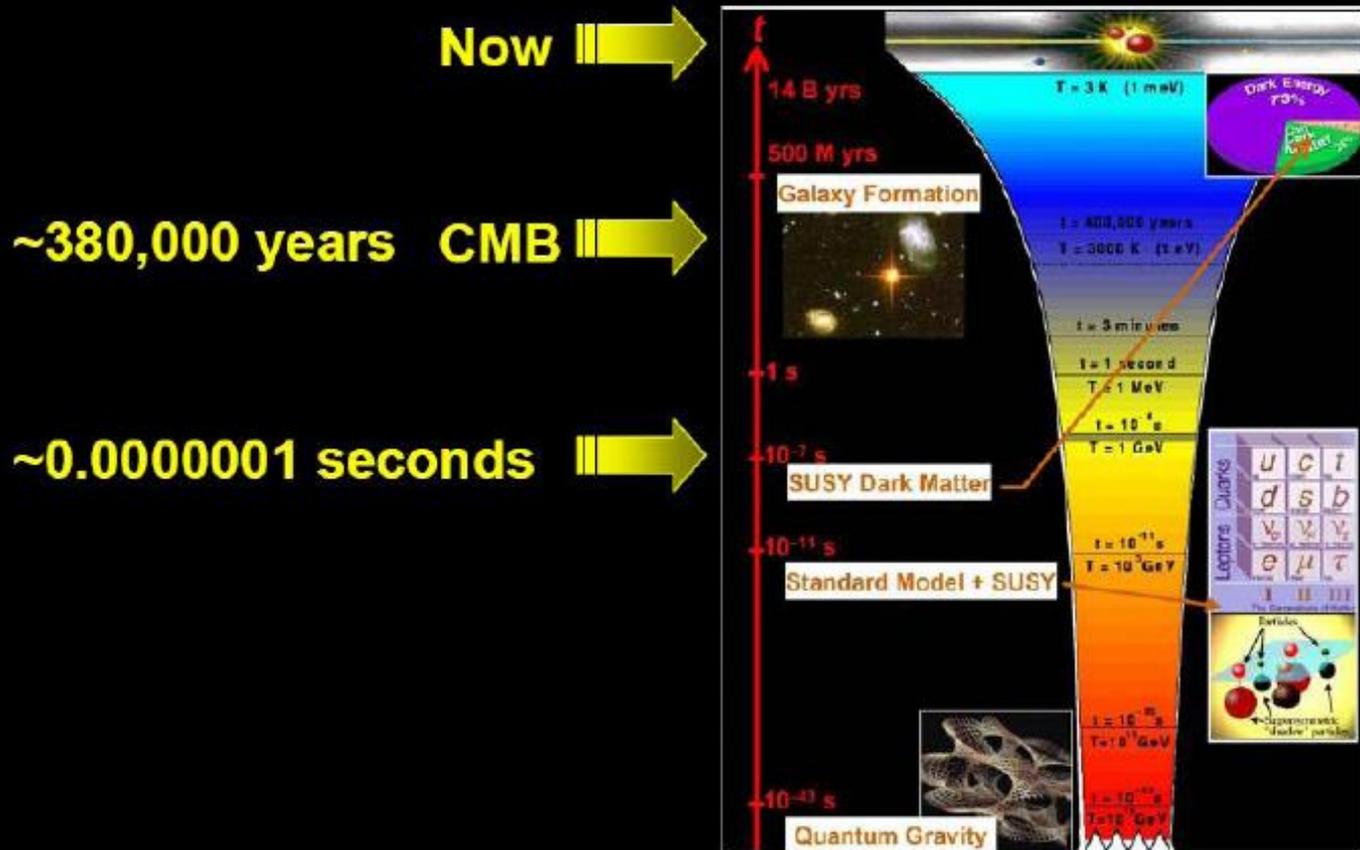
Electron-Positron
Annihilation



Electron-Positron
Scattering



When Were the Dark Matter Particles Created?



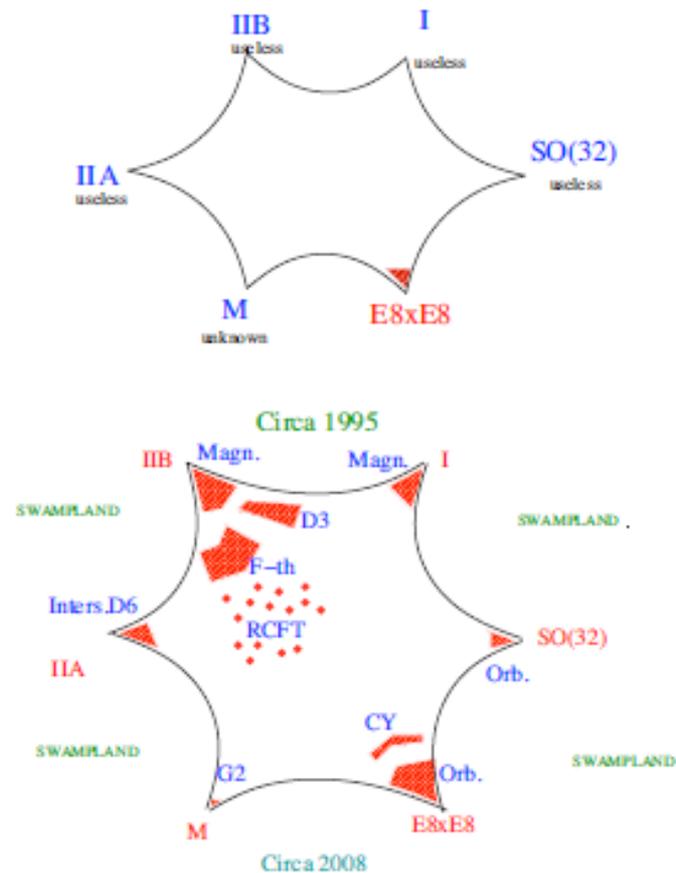
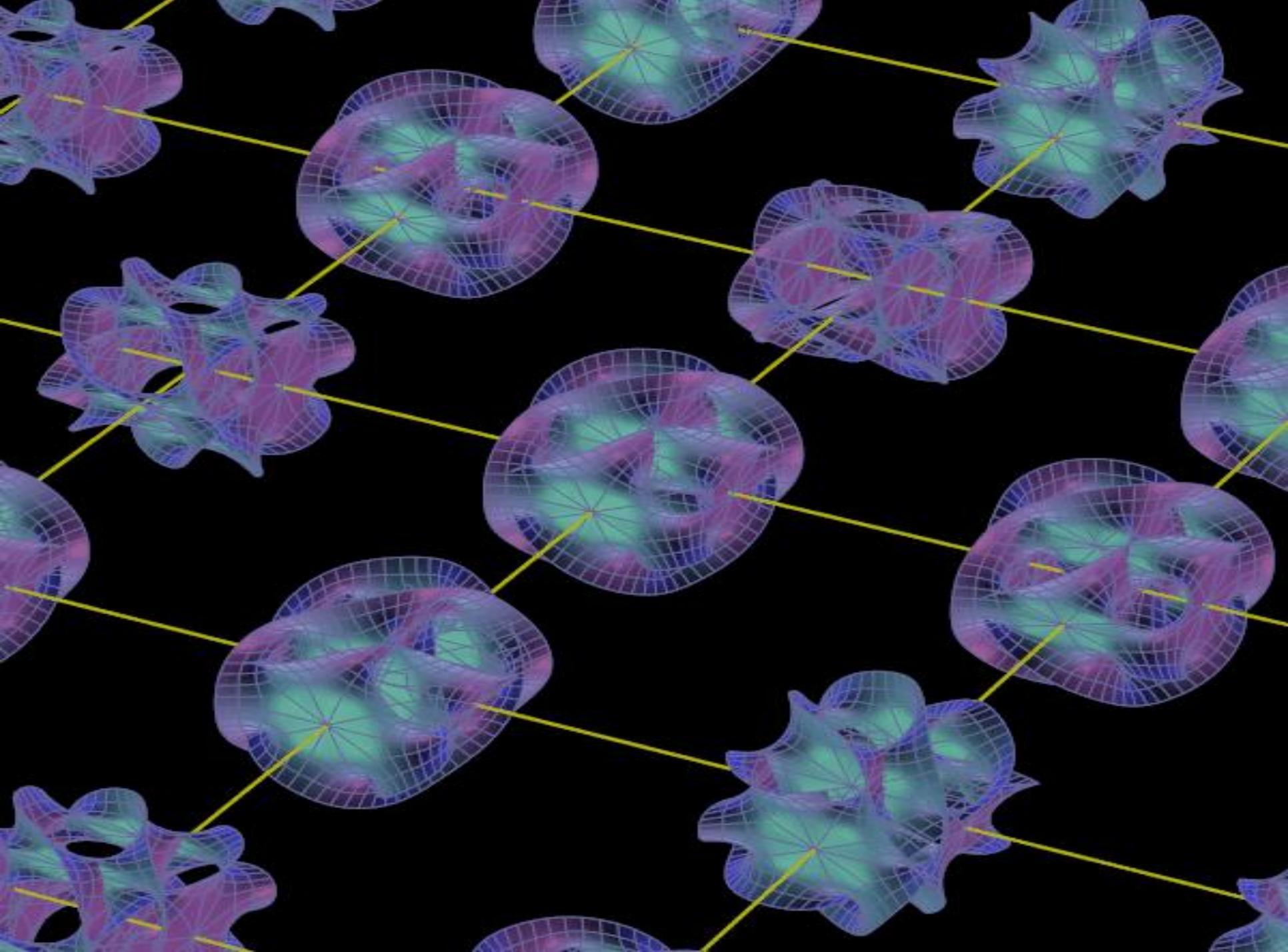
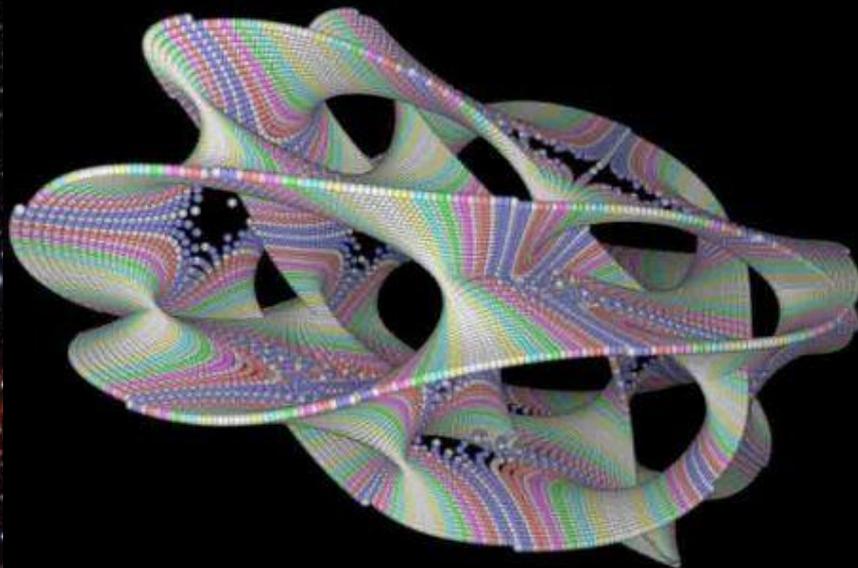
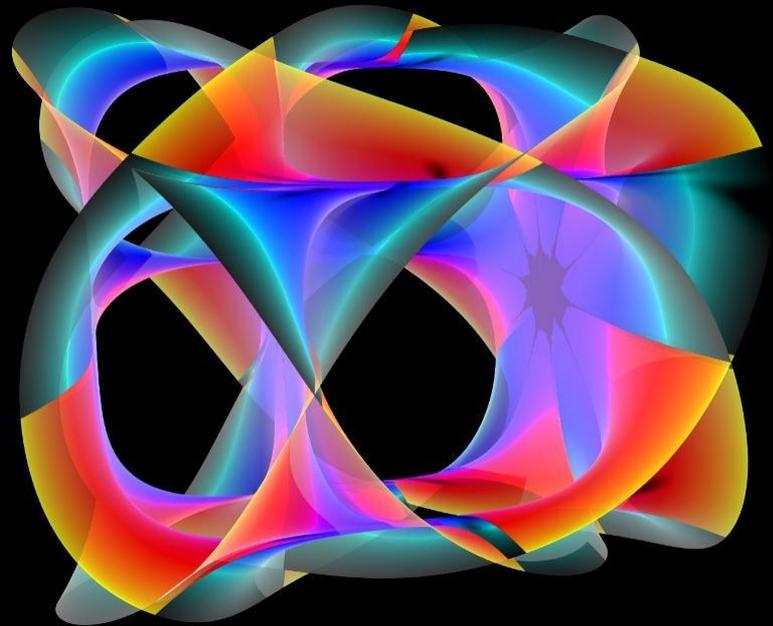
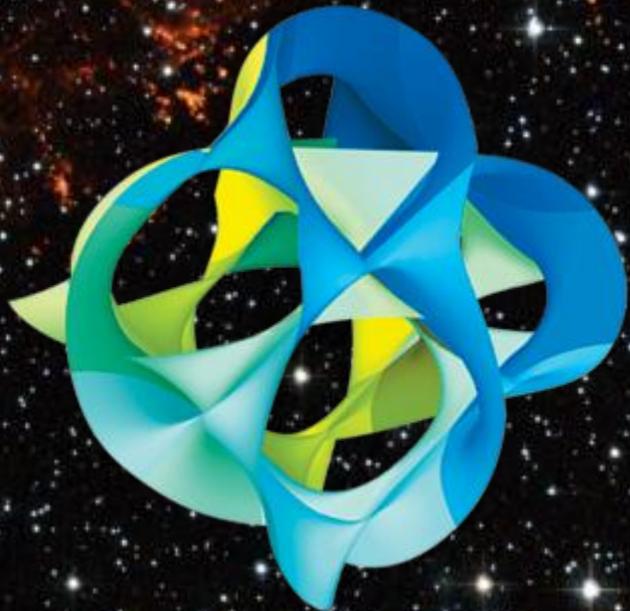
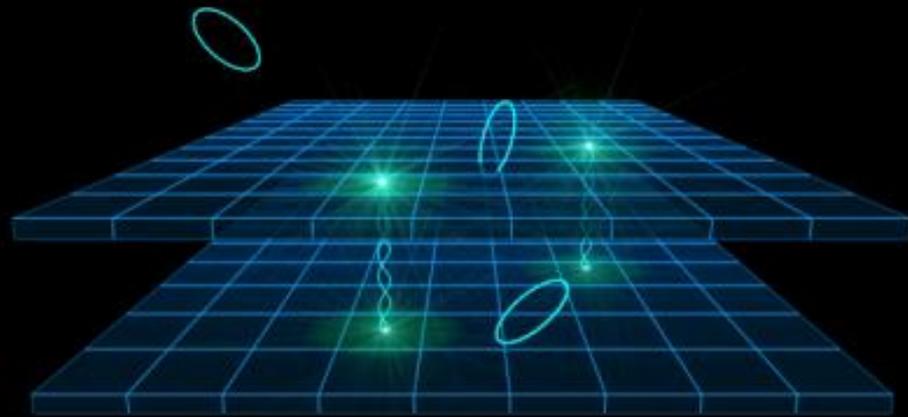
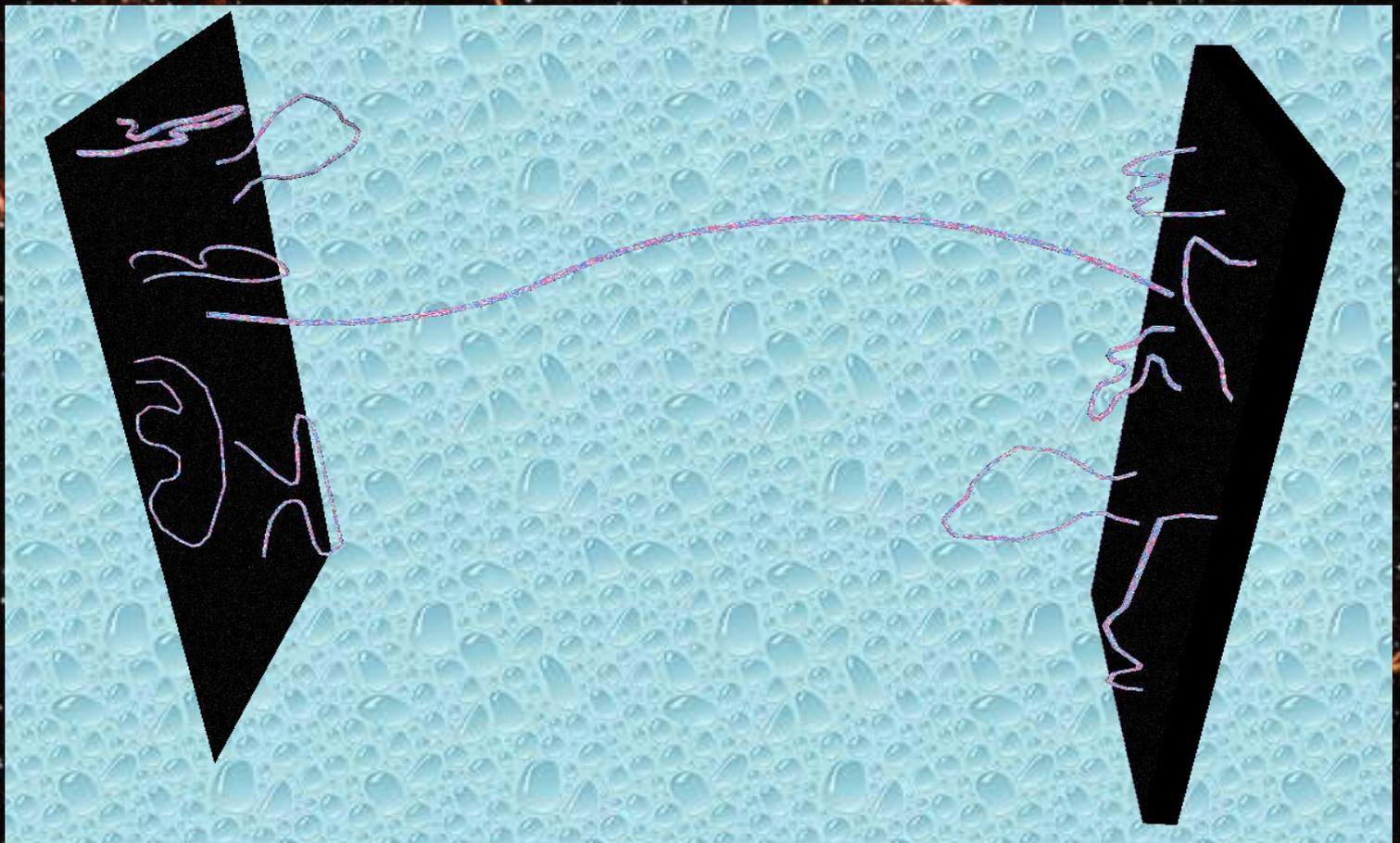


Fig. 1. The diagram shows the current (quite limited) understanding of the M-theory (interior of polygon graphs) unifying all known string theories, which appear as its low-energy limits. The left diagram shows the understanding we had in the mid 90s and is placed here for comparison of the progress made. The characterisation *useless* in the 1995 situation (upper panel) indicates the ability of the corresponding string theory to include the standard model group. The red-shaded interior regions lead to a partial understanding of M-theory issues, either through F-theory (termed F-th) considerations or rational conformal field theory (RCFT) analysis. The discovery (in 1996) of solitonic states in string theory, termed D(irichlet) branes changed the picture. Many of the previously thought as useless string theories can incorporate standard model groups in non-trivial ways, involving intersecting brane situations (termed Inters. on the lower panel) and compactification to magnetised manifolds (termed Magn. in the right picture), orbifold (termed Orb.) or Calabi-Yau spaces (CY) etc. The M low-energy theory on the lower right corner of the super-unification graphs is identified now with the 11-dimensional supergravity (Pictures taken from Ref. ².)







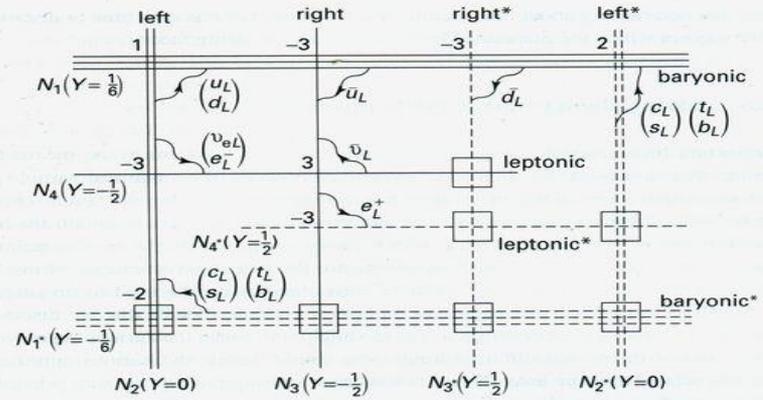
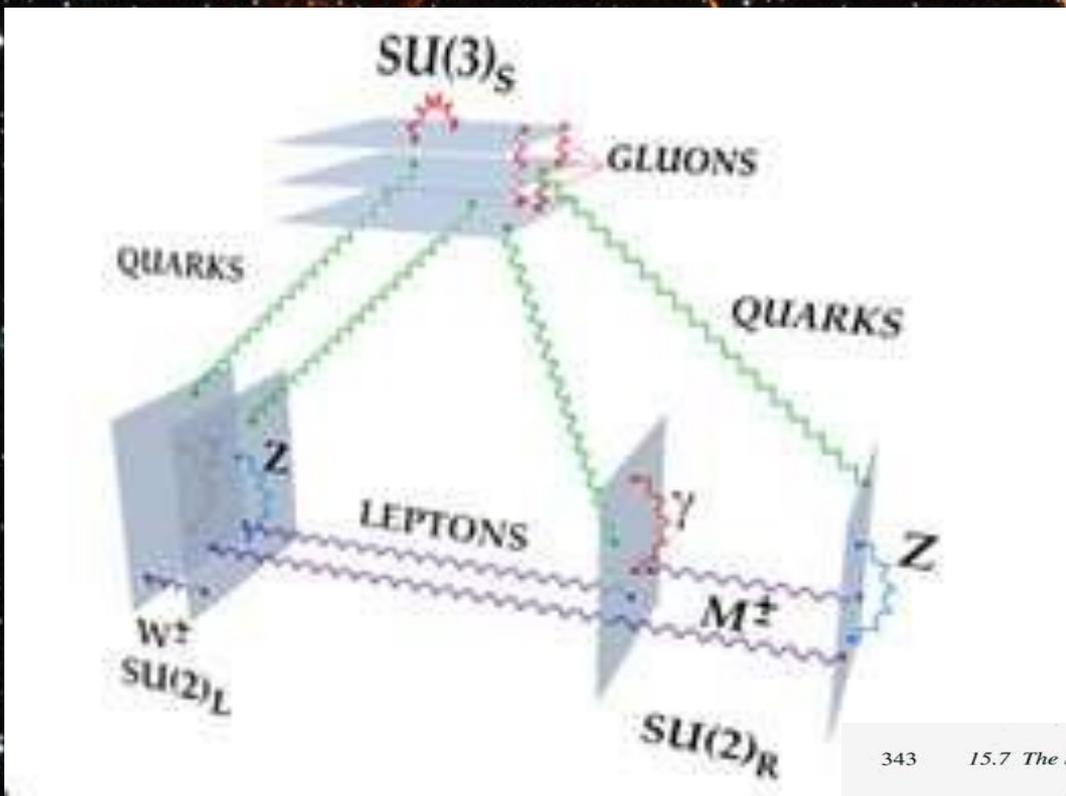


Figure 15.8 The brane configuration that leads to a Standard Model gauge group and matter content. There are $N_1 = 3$ baryonic branes, $N_2 = 2$ left branes, $N_3 = 1$ right branes and $N_4 = 1$ leptonic branes. The image D-branes created by the orientifolds are shown in dashed lines. Intersections framed by a square are mirrors of previously accounted intersections and do not give new particles.

No Scale SUGRA: A Case Study in Reductionism

There is a function called the Kähler potential which must be specified by the model builder in order to fix the metric of superspace, and determine the scalar potential. It is not fixed by the symmetries of the theory. There is however a particularly natural choice.

$$K = -3 \ln (T + T^* - \sum \phi_i^* \phi_i)$$



$$V_{SUGRA} = 0$$

The scalar potential is flat and vanishing. Supersymmetry is **BROKEN**, and there is no cosmological constant. This is all desirable at the *Tree Level*.

CONSTRAINT: $m_0 = 0, \quad A = 0, \quad B = 0 \quad m_{1/2} \neq 0$ for SUSY breaking

The gaugino mass $m_{1/2}$ remains undetermined at the classical level.

All soft-terms though, are dynamically evolved in terms of only the single parameter ($m_{1/2}$), which may itself be determined by radiative corrections to the potential !

- E. Cremmer, S. Ferrara, C. Kounnas and D. V. Nanopoulos, Phys. Lett. B 133, 61 (1983)
- J. R. Ellis, A. B. Lahanas, D. V. Nanopoulos and K. Tamvakis, Phys. Lett. B 134, 429 (1984)
- J. R. Ellis, C. Kounnas and D. V. Nanopoulos, Nucl. Phys. B 241, 406 (1984)
- A. B. Lahanas and D. V. Nanopoulos, Phys. Rept. 145, 1 (1987)

Relation to String Theory

The no-scale structure emerges naturally as the infrared limit of string theory.

In particular,

- Heterotic M-theory compactifications
- Type IIB flux compactifications – **Flipped SU(5)**
- F-theory compactifications (non-perturbative limit of Type IIB)

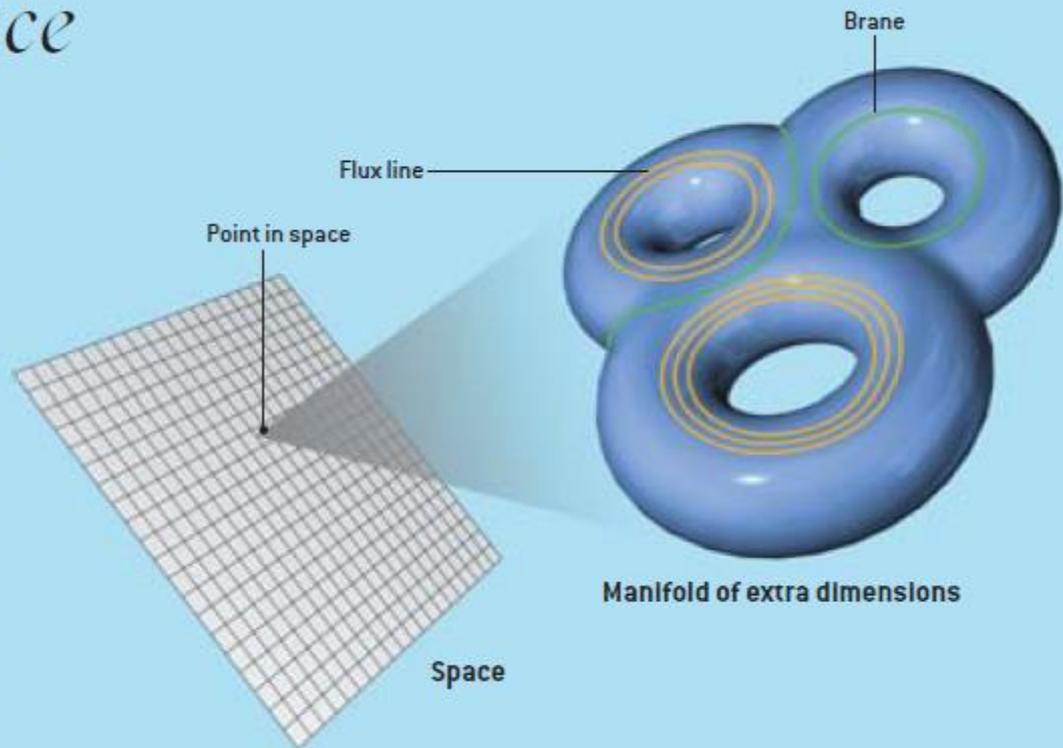


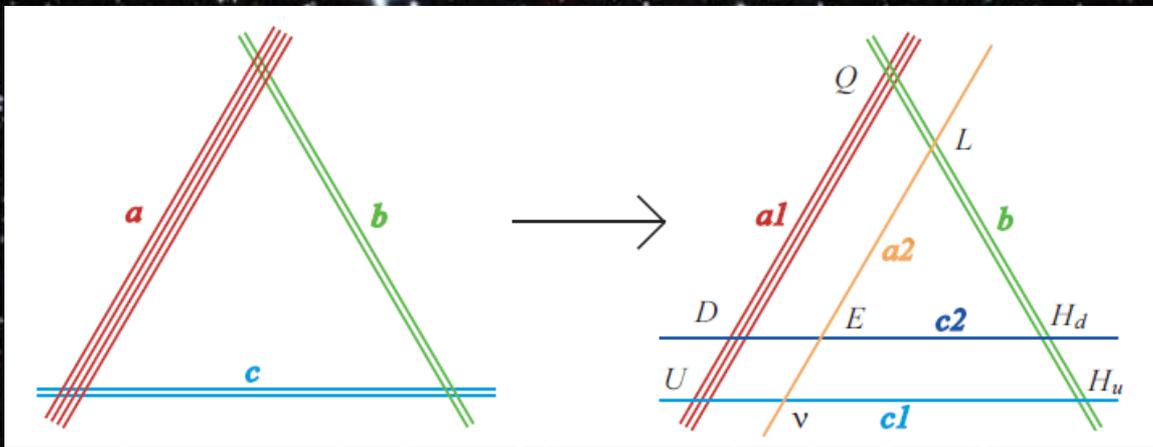
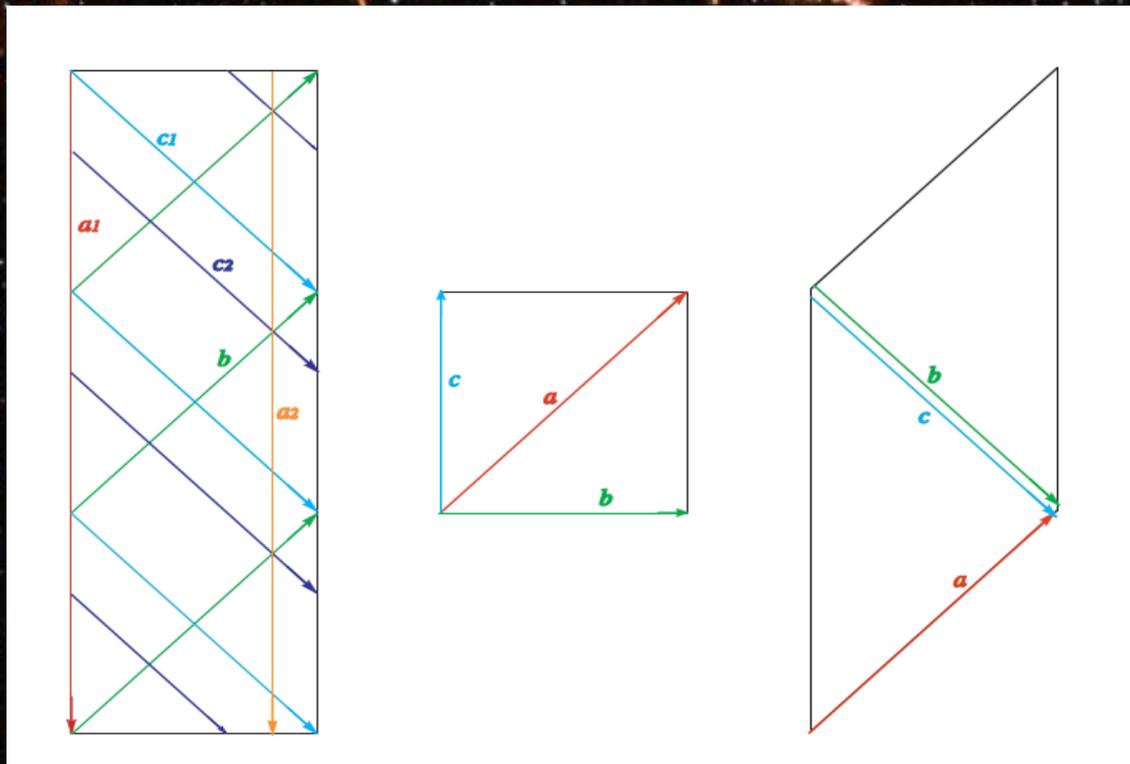
MULTIVERSE vs MUNIVERSE

VACUUM STATE

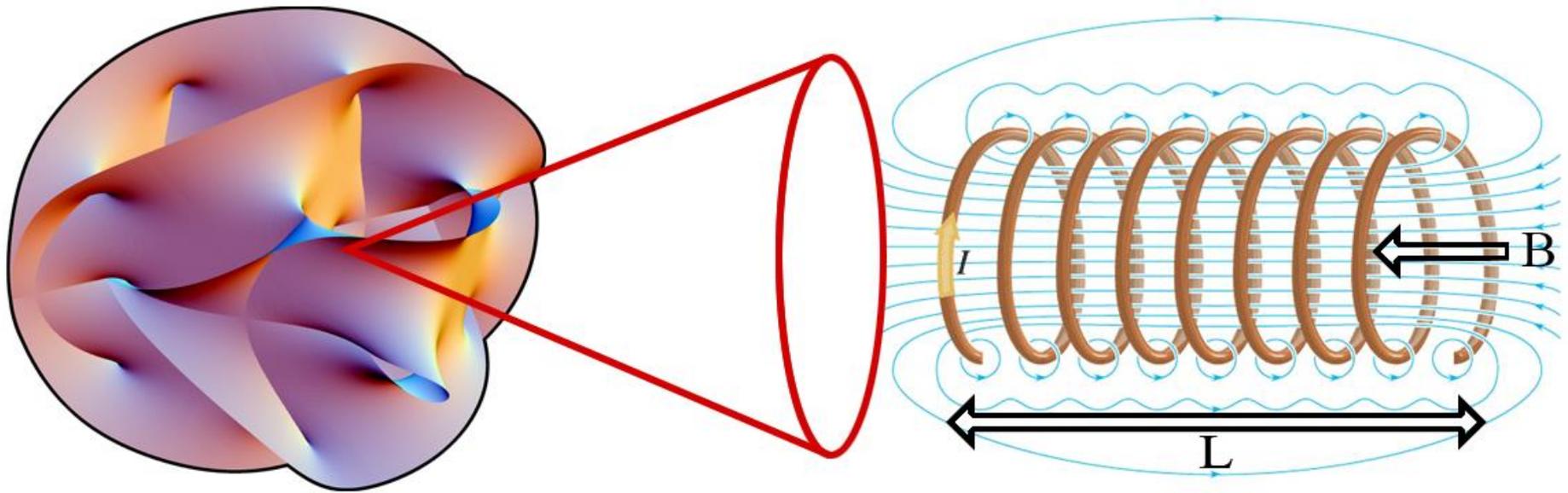
The Hidden Space

Any given solution to the equations of string theory represents a specific configuration of space and time. In particular, it specifies the arrangement of the small dimensions, along with their associated branes (*green*) and lines of force known as flux lines (*orange*). Our world has six extra dimensions, so every point of our familiar three-dimensional space hides an associated tiny six-dimensional space, or manifold—a six-dimensional analogue of the circle in the top illustration on page 81. The physics that is observed in the three large dimensions depends on the size and the structure of the manifold: how many doughnutlike “handles” it has, the length and circumference of each handle, the number and locations of its branes, and the number of flux lines wrapped around each doughnut.





“Towards Realistic SUSY Spectra and Yukawa Textures from Intersecting Branes”,
 Phys.Rev.D77:125023,2008, C-M Chen, T Li, V.E.Mayers,D.V.Nanopoulos



A Calabi-Yau Six Dimensional Compact Space

Three Dimensional Compact Space

“Like” a Solenoid

where $B \equiv$ Magnetic Field

$$B = N \times \left(\frac{I}{L} \right)$$

$$N = 1, 2, \dots$$

Quantized in units of (I/L)

$I \equiv$ Current

$L \equiv$ Solenoid Length

$N \equiv$ Number of Turns

$$\Phi \equiv \text{Flux} = \int \vec{B} \cdot \vec{ds} = N \times \left\{ S \left(\frac{I}{L} \right) \right\} ; N = 1, 2, \dots$$

Quantized!

No-Scale Supergravity provides an indispensable mechanism for the dynamic determination of the T_i “Moduli”, *i.e.* the Size and Shape of the Six-Dimensional Compactified Space, thus stabilizing the 6D Geometry of our Universe !!!

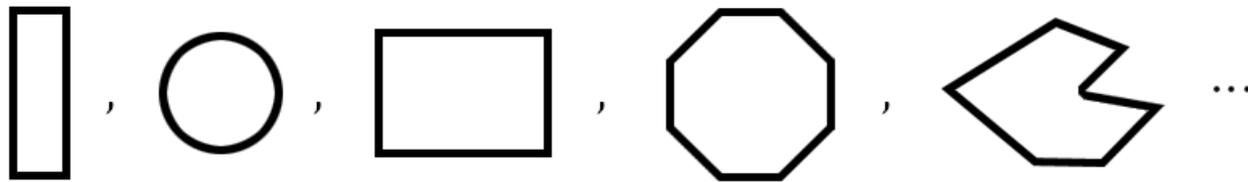
$$\frac{dV_{Universe}}{dT_i} = 0 \quad ; \quad i = 1, 2, \dots$$

For Example, $M_{1/2}$, The Supersymmetry Breaking Scale (which determines the masses of Supersymmetric Particles at the LHC), is Dynamically Determined through its explicit dependence on the Modulus “T” that fixes the Overall Size of the Six-Dimensional Compactified Space.

∴ LHC May Well “Measure” the Overall Size of the the Compactified Part of our Universe, as Stabilized by the No-Scale Mechanism, By Detecting and Studying in Detail Supersymmetric Particles ...

$$N = 1, 2, \dots \text{ (Fluxes)} \leq N_{\text{Cut}} \approx \mathcal{O}(10)$$

$$d = 3 \text{ Compact Spaces} \approx \mathcal{O}(500)$$



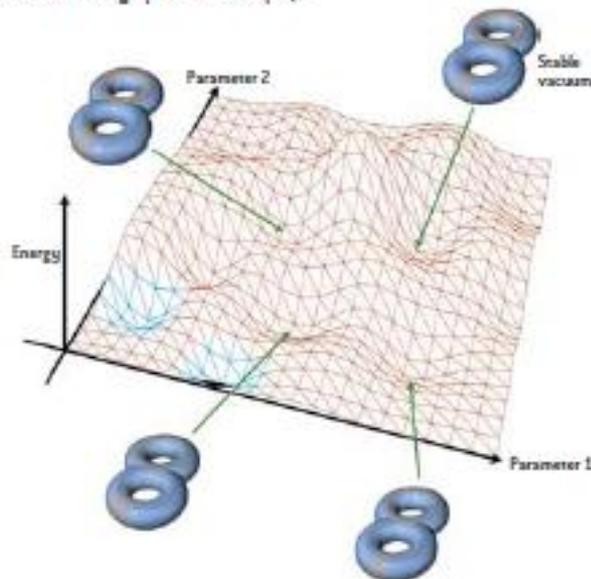
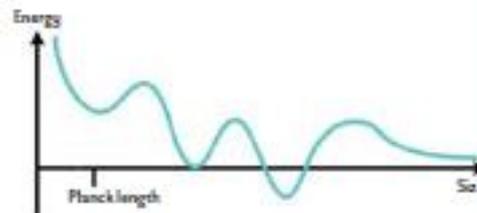
$$\therefore 10^{500} \text{ Universes } \dots$$

Possibility of transitions between Universes:

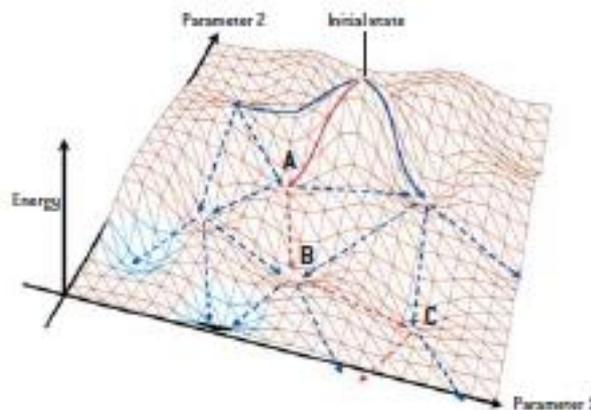
$$U^{N=8} \Rightarrow U^{N=6} \dots$$

Topography of Energy

A landscape emerges when the energy of each possible string solution is plotted as a function of the parameters that define the six-dimensional manifold associated with that solution. If only one parameter is varied—say, the overall size of that manifold—the landscape forms a simple line graph. Here three particular sizes (all close to the Planck scale) have energies in the troughs, or minima, of the curve. The manifold will naturally tend to adjust its size to end up at one of the three minima, like a ball rolling around on the slope (it might also “roll off” to infinity at the right-hand end of the graph in this example).



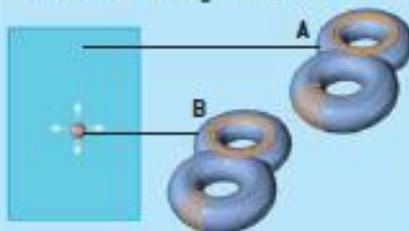
The true string theory landscape reflects all parameters and thus would form a topography with a vast number of dimensions. We represent it by a landscape showing the variation of the energy contained in empty space when only two features change. The manifold of extra dimensions tends to end up at the bottom of a valley, which is a stable string solution, or a stable vacuum—that is, a manifold in a valley tends to stay in that state for a long while. Blue regions are below zero energy.



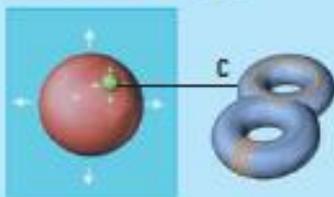
Quantum effects, however, allow a manifold to change state abruptly at some point—to tunnel through the intervening ridge to a nearby lower valley. The red arrows show how one region of the universe might evolve: starting out at a high mountaintop, rolling down into a nearby valley (vacuum A), eventually tunneling through to another, lower valley (vacuum B), and so on. Different regions of the universe will randomly follow different paths. The effect is like an infinite number of explorers traversing the landscape, passing through all possible valleys (blue arrows).

Bubbles of Reality

The possibility of decay from one stable vacuum to another suggests a radical new picture of our universe at the largest scales.



Tunneling from one stable vacuum to another would not occur everywhere in the universe at once. Instead it would occur at one random location, producing an expanding bubble of space (arrows) having the new vacuum. In this example, the blue region of space has vacuum A, whose manifold of small extra dimensions consists of a two-handled doughnut with groups of two and four flux lines wrapped around the handles. The red region, which has vacuum B, emerges when one of the four flux lines decays. Corresponding to their different manifolds, the two regions will have different kinds of particles and forces and thus different laws of physics.



The red region grows rapidly, potentially becoming billions of light-years in diameter. Eventually another transition occurs within the red region, this time a decay of one of the two flux lines. This decay generates the green region, which has vacuum C and still another set of particles and forces.

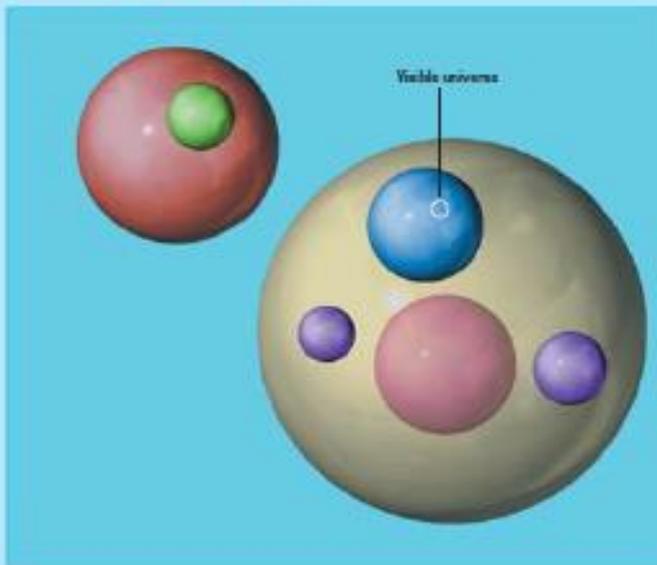


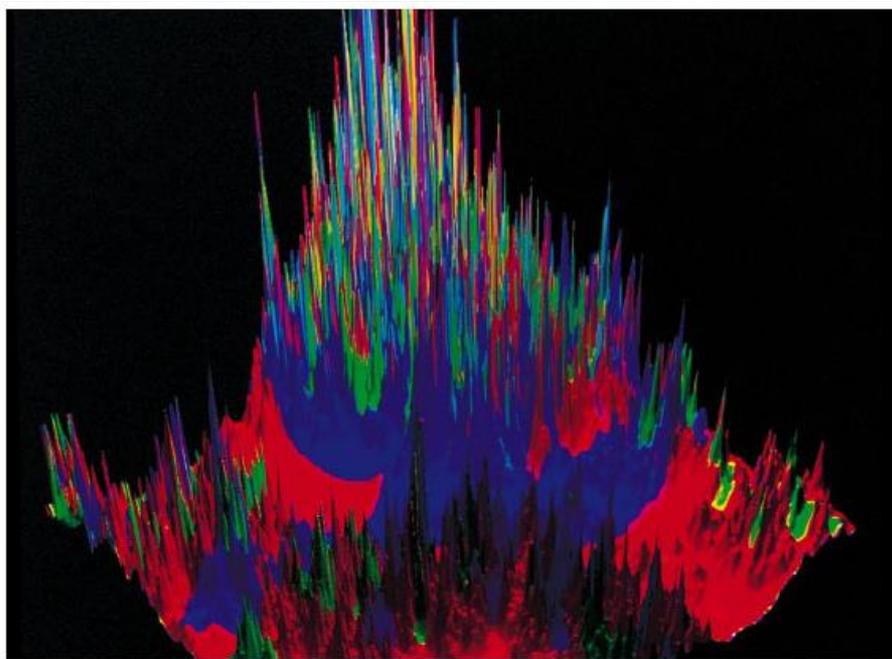
The green region also grows rapidly, but it never catches up with the red region. Similarly, the red region never completely replaces the original blue vacuum.

Because the quantum tunneling is a random process, widely separated locations in the universe will decay through different sequences of vacua.

In this way, the entire landscape is explored; every stable vacuum occurs in many different places in the universe.

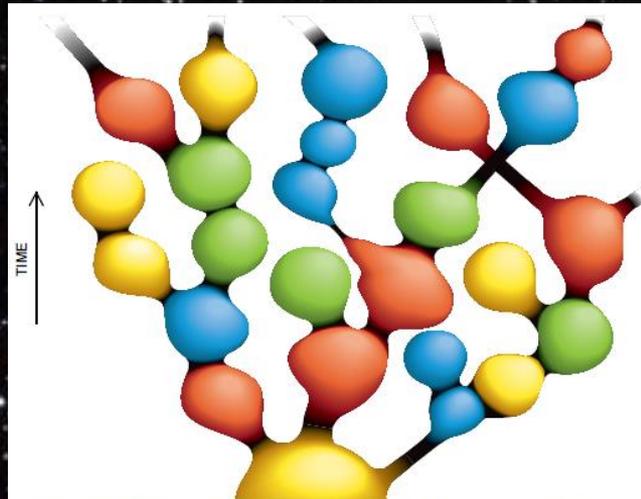
The whole universe is therefore a foam of expanding bubbles within bubbles, each with its own laws of physics. Extremely few of the bubbles are suitable for the formation of complex structures such as galaxies and life. Our entire visible universe (more than 20 billion light-years in diameter) is a relatively small region within one of these bubbles.





SELF-REPRODUCING UNIVERSE: in a computer simulation consists of exponentially large domains, each of which has different laws of physics (represented by colors). Sharp peaks are new "big bangs"; their heights correspond to the energy den-

sity of the universe there. At the top of the peaks, the colors rapidly fluctuate, indicating that the laws of physics there are not yet settled. They become fixed only in the valleys, one of which corresponds to the kind of universe we live in now.



SELF-REPRODUCING COSMOS appears as an extended branching of inflationary bubbles. Changes in color represent "mutations" in the laws of physics from parent universes. The properties of space in each bubble do not depend on the time when the bubble formed. In this sense, the universe as a whole may be stationary, even though the interior of each bubble is described by the big bang theory.

κόσμον τόνδε, τὸν αὐτὸν ἀπάντων, οὔτε τις θεῶν οὔτε ἀνθρώπων ἐποίησεν,
ἀλλ' ἦν ἀεὶ καὶ ἔστιν καὶ ἔσται πῦρ ἀείζωνον, ἀπτόμενον μέτρα καὶ
ἀποσβεννύμενον μέτρα.

Heraclitus *Fragments* 30

This world, the same for all, neither any of the gods nor any man has made,
but it always was, and is, and shall be, an ever living fire, kindled in due
measure, and in due measure extinguished¹.

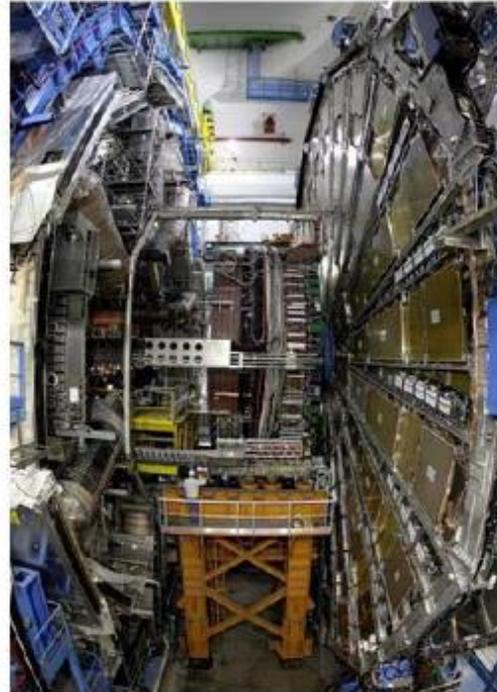
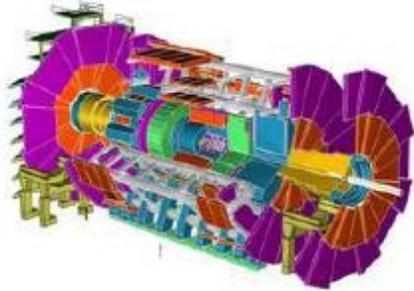
¹ παραδίδεται από τον Πλούταρχο, *Περὶ τῆς ἐν Τιμαίῳ ψυχογονίας*, 5 p. 1014 A. Trans. G. W. T. Patrick, see <http://fxylib.znufe.edu.cn/wgfljd/%B9%C5%B5%E4%D0%DE%B4%C7%D1%A7/pw/heraclitus/herpatu.htm>, 20.

LARGE HADRON COLLIDER (LHC)

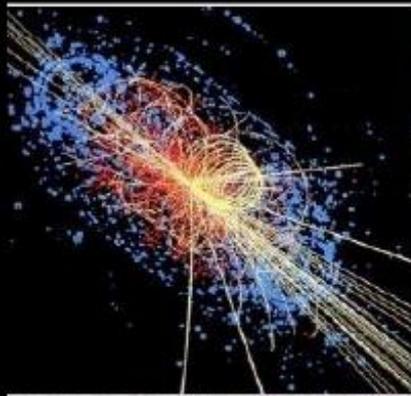
The LHC at CERN will provide the first proton-proton (pp) collisions in 2009.
Two beams will collide head-on with a center of mass energy of 14 TeV.



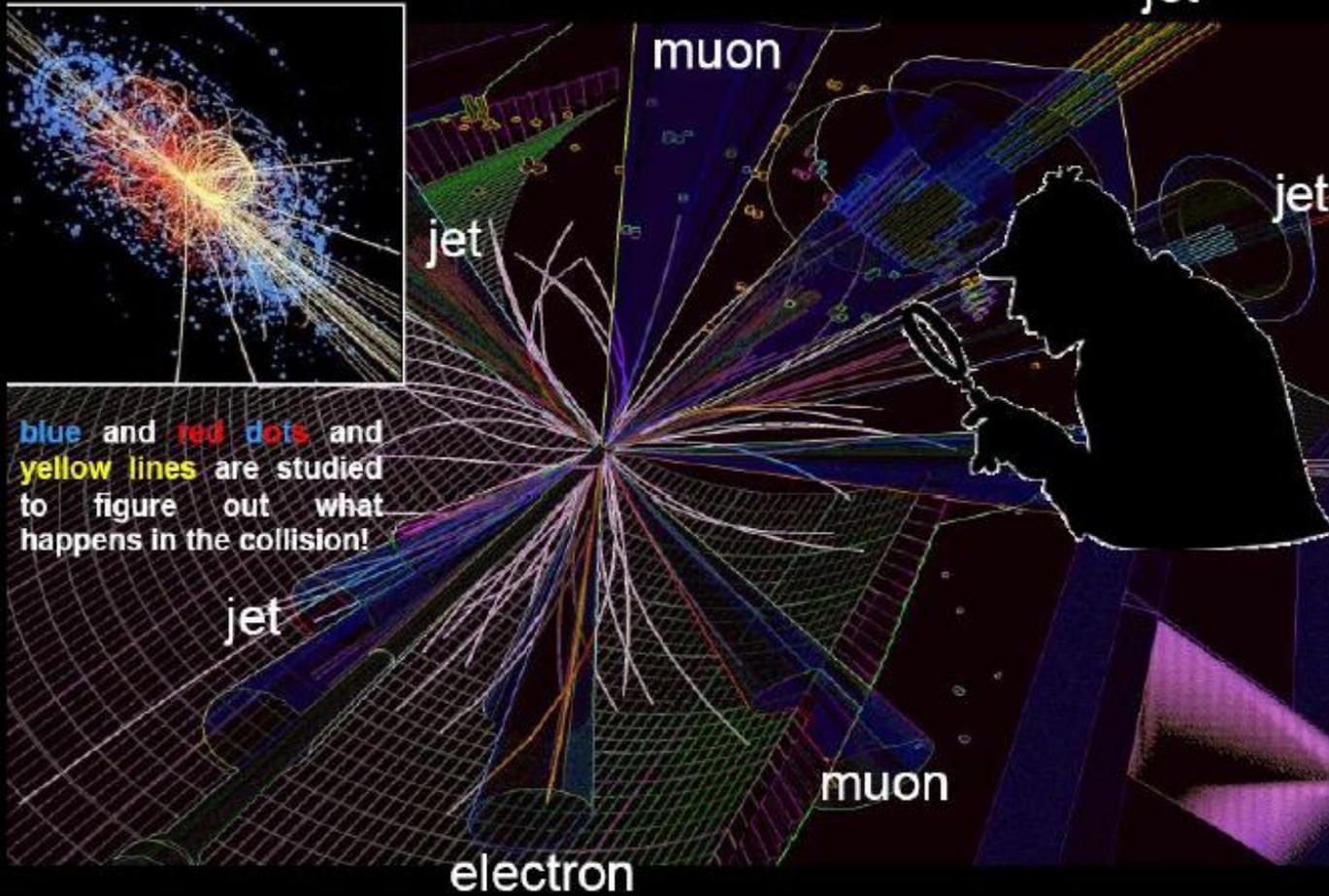
Inside Atlas



pp Collision



blue and red dots and yellow lines are studied to figure out what happens in the collision!



Blueprints of the No-Scale Multiverse at the LHC

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We present a contemporary perspective on the String Landscape and the Multiverse of plausible string, M- and F-theory vacua. In contrast to traditional statistical classifications and explication to the anthropic principle, we seek only to demonstrate the existence of a non-zero probability for a universe matching our own observed physics within the solution ensemble. We argue for the importance of No-Scale Supergravity as an essential common underpinning for the spontaneous emergence of a cosmologically flat universe from the quantum “nothingness”. Concretely, we continue to probe the phenomenology of a specific model which is testable at the LHC and Tevatron. Dubbed No-Scale $F\text{-}SU(5)$, it represents the intersection of the Flipped $SU(5)$ Grand Unified Theory (GUT) with extra TeV-Scale vector-like multiplets derived out of F-theory, and the dynamics of No-Scale Supergravity, which in turn imply a very restricted set of high energy boundary conditions. By secondarily minimizing the minimum of the scalar Higgs potential, we dynamically determine the ratio $\tan\beta \simeq 15 - 20$ of up- to down-type Higgs vacuum expectation values (VEVs), the universal gaugino boundary mass $M_{1/2} \simeq 450$ GeV, and consequently also the total magnitude of the GUT-scale Higgs VEVs, while constraining the low energy Standard Model gauge couplings. In particular, this local minimum minimum lies within the previously described “golden strip”, satisfying all current experimental constraints. We emphasize, however, that the overarching goal is not to establish why our own particular universe possesses any number of specific characteristics, but rather to tease out what generic principles might govern the superset of all possible universes.

PACS numbers: 11.10.Kk, 11.25.Mj, 11.25.-w, 12.60.Jv

INTRODUCTION

The number of consistent, meta-stable vacua of string, M- or (predominantly) F-theory flux compactifications which exhibit broadly plausible phenomenology, including moduli stabilization and broken supersymmetry [1], is popularly estimated [2, 3] to be of order 10^{500} . It is moreover currently in vogue to suggest that degeneracy of common features across these many “universes” might statistically isolate the physically realistic universe from the vast “landscape”, much as the entropy function coaxes the singular order of macroscopic thermodynamics from the chaotic duplicity of the entangled quantum microstate. We argue here though the counter point that we are not obliged a priori to live in the likeliest of all universes, but only in one which is possible. The existence merely of a non-zero probability for our existence is sufficient.

We indulge for this effort the fanciful imagination that the “Multiverse” of string vacua might exhibit some literal realization beyond our own physical sphere. A single electron may be said to wander all histories through interfering apertures, though its arrival is ultimately registered at a localized point on the target. The journey to that destination is steered by the full dynamics of the theory, although the isolated spontaneous solution re-

flects only faintly the richness of the solution ensemble. Whether the Multiverse be veridical or reality, the conceptual superset of our own physics which it embodies must certainly represent the interference of all navigable universal histories.

Surely many times aforesaid has mankind’s notion of the heavens expanded - the Earth dispatched from its central pedestal in our solar system and the Sun rendered one among some hundred billion stars of the Milky Way, itself reduced to one among some hundred billion galaxies. Finally perhaps, we come to the completion of our Odyssey, by realizing that our Universe is one of at least 10^{500} so possible, thus rendering the anthropic view of our position in the Universe (environmental coincidences explained away by the availability of $10^{11} \times 10^{11}$ solar systems) functionally equivalent to the anthropic view of the origin of the Universe (coincidences in the form and content of physical laws explained away by the availability, through dynamical phase transitions, of 10^{500} universes). Nature’s bounty has anyway invariably trumped our wildest anticipations, and though frugal and equanimous in law, she has spared no extravagance or whimsy in its manifestation.

Our perspective should not be misconstrued, however, as complacent retreat into the tautology of the weak anthropic principle. It is indeed unassailable truism that an

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Part II of The Golden Point Saga, as Featured in arXiv: 1007.5100

Also Starring: Tianjun Li, James A. Maxin & Joel W. Walker

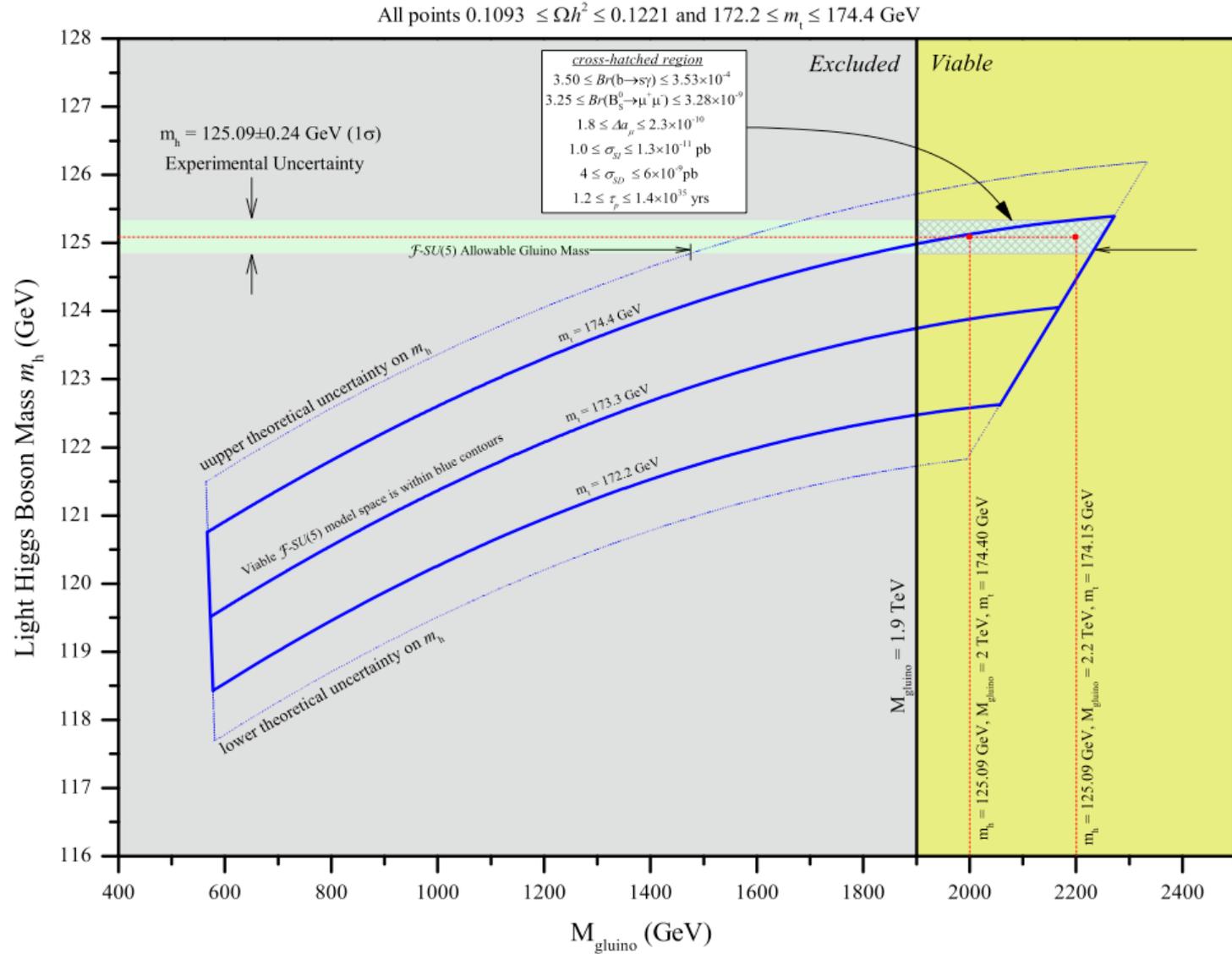
DYNANODPOULOS

THE GOLDEN STRIP

*of Correlated Top Quark, Gaugino,
and Vectorlike Mass In No-Scale, No Parameter*

F -SU(5)

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**THANK YOU
VERY MUCH**

