Nobel symposium on LHC results

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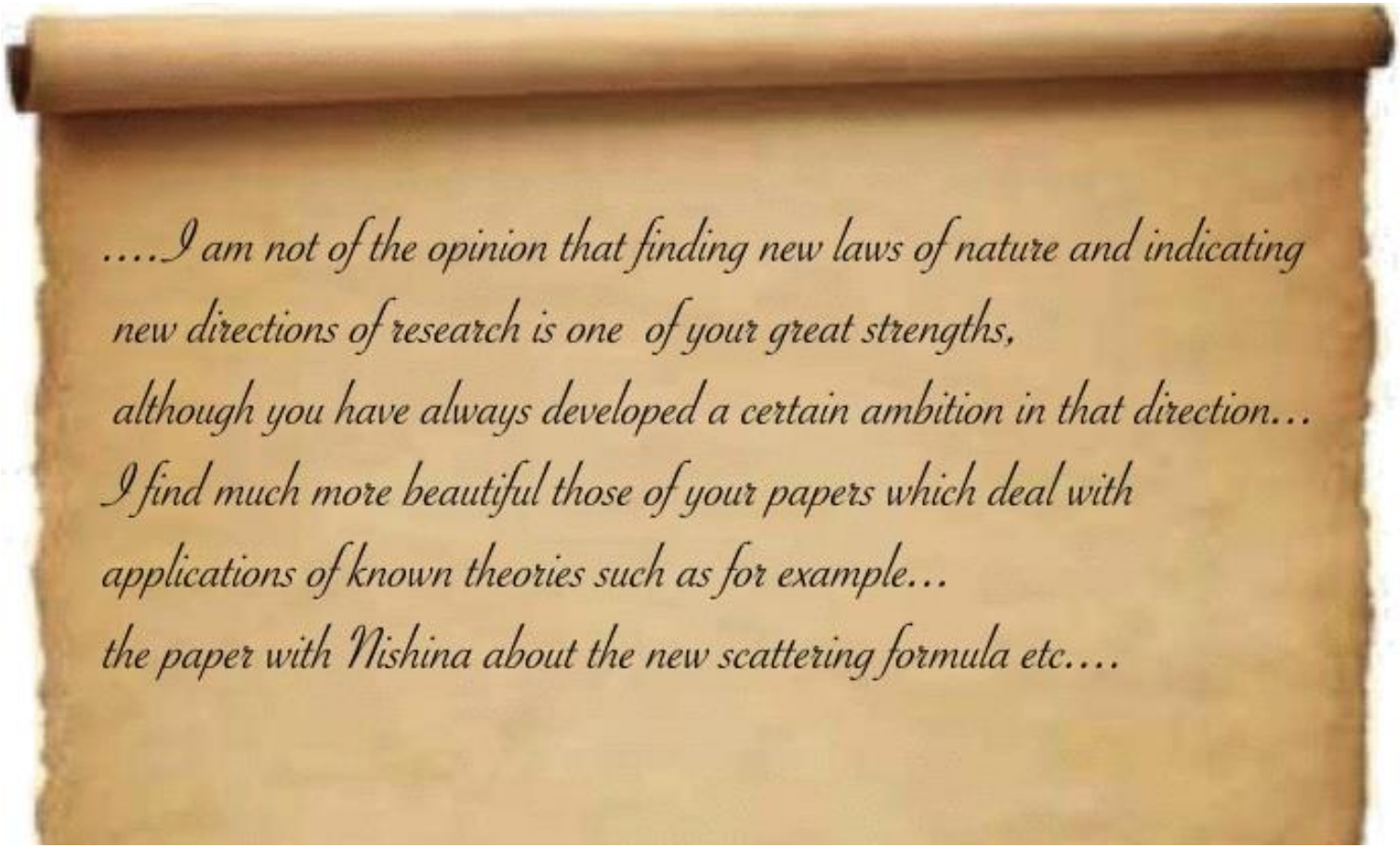
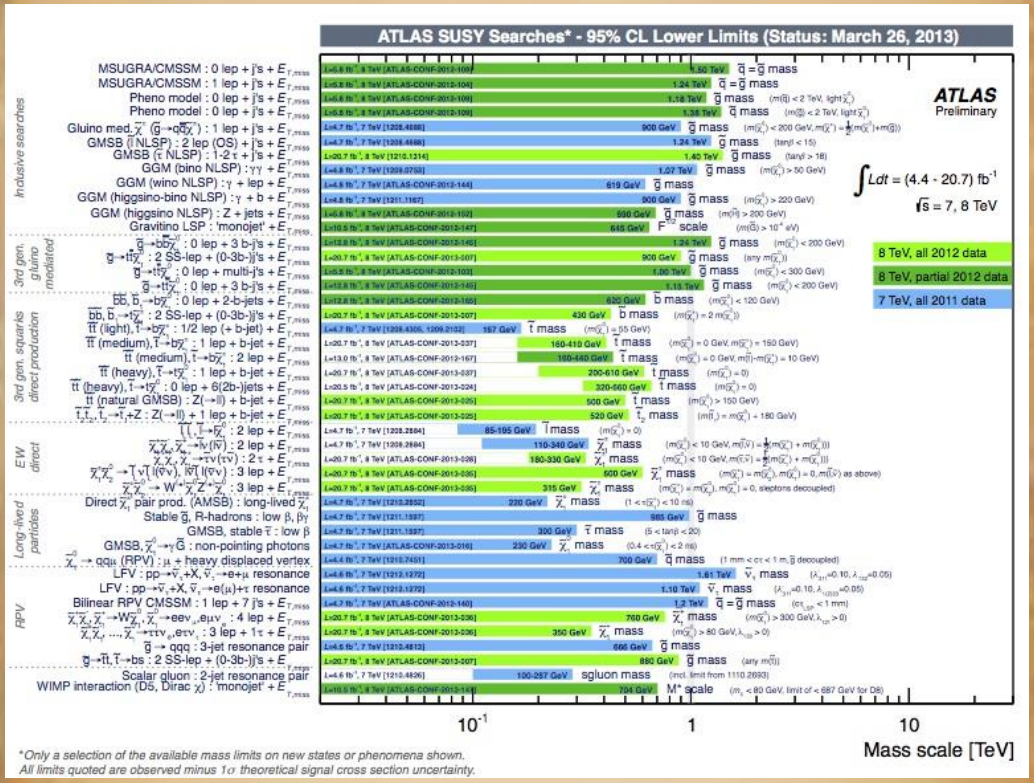
String Theory: Results, Magic and Doubts
16 May 2013

Shortly Before arriving in Stockholm, Klein received a letter from his good friend Pauli which reads in part:

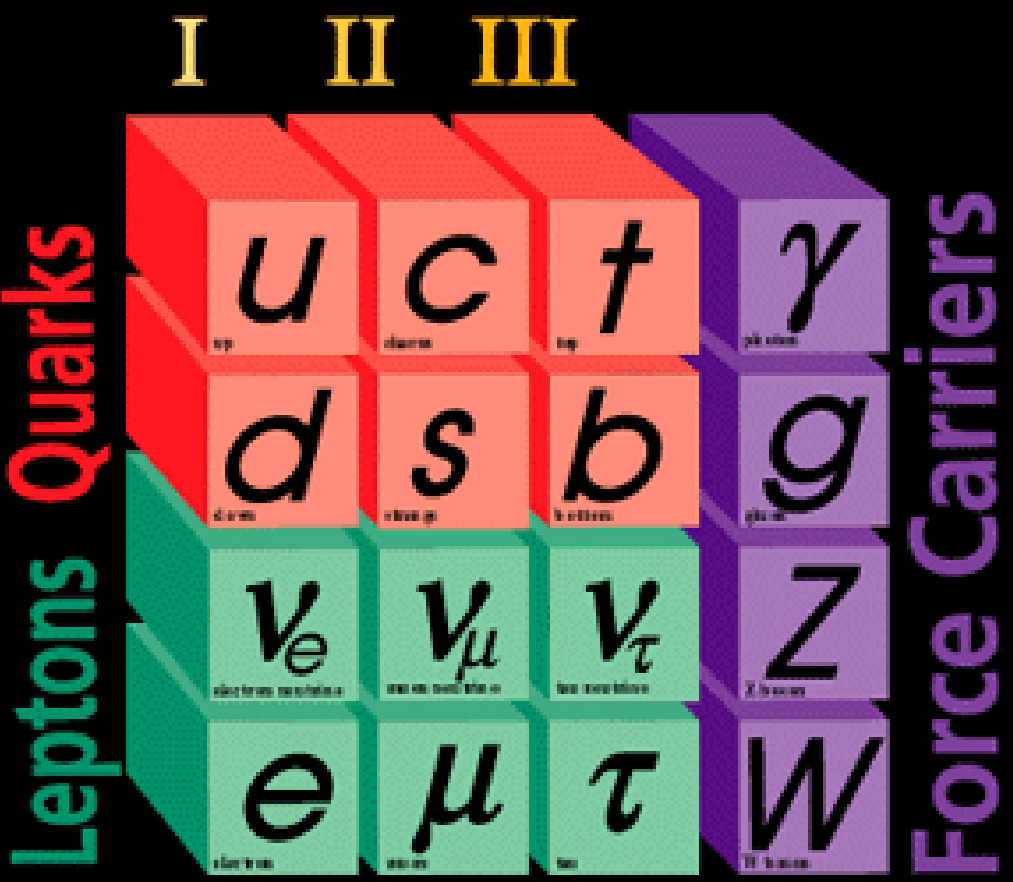


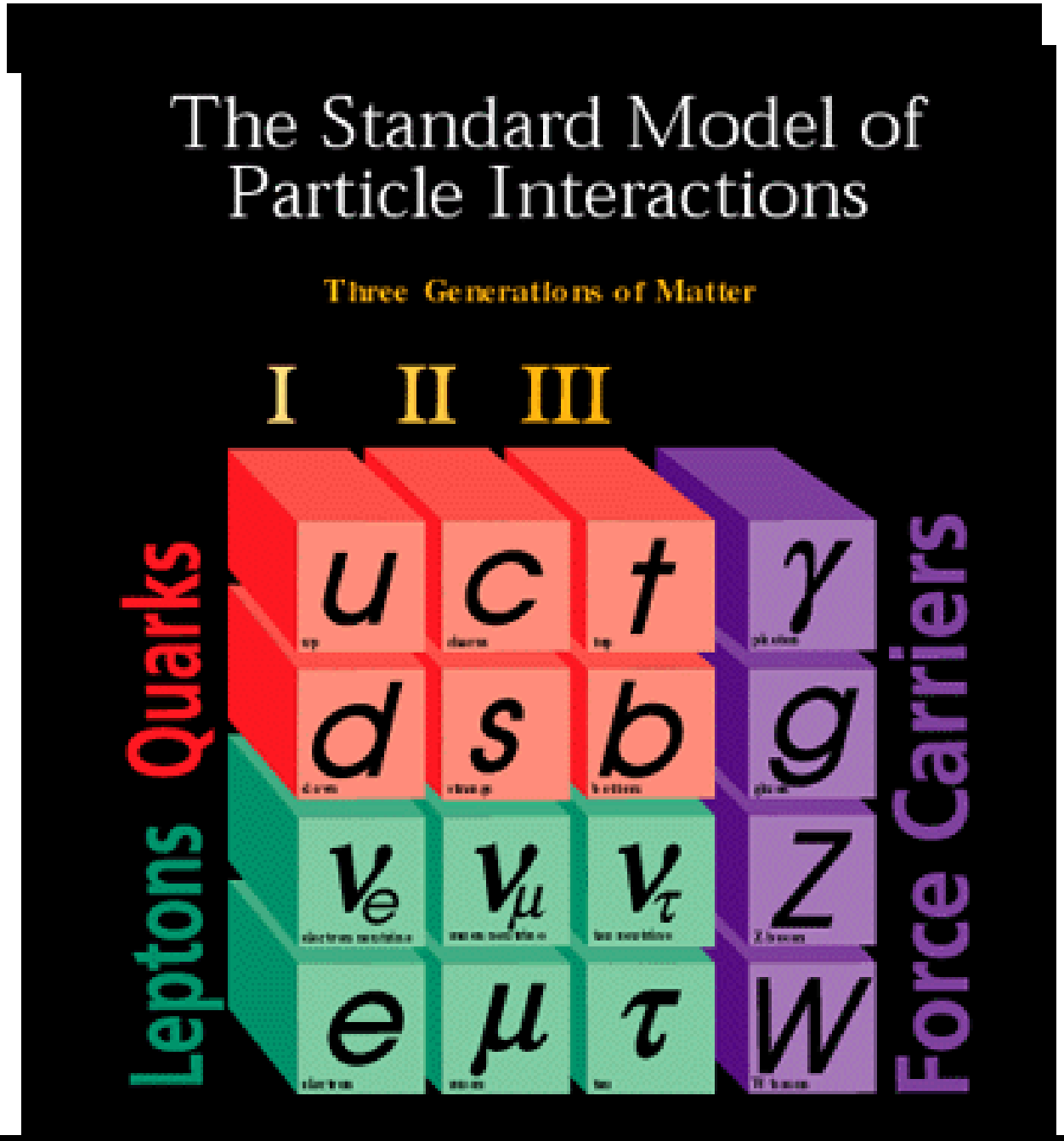
From Nature to the LHC



The Standard Model of Particle Interactions

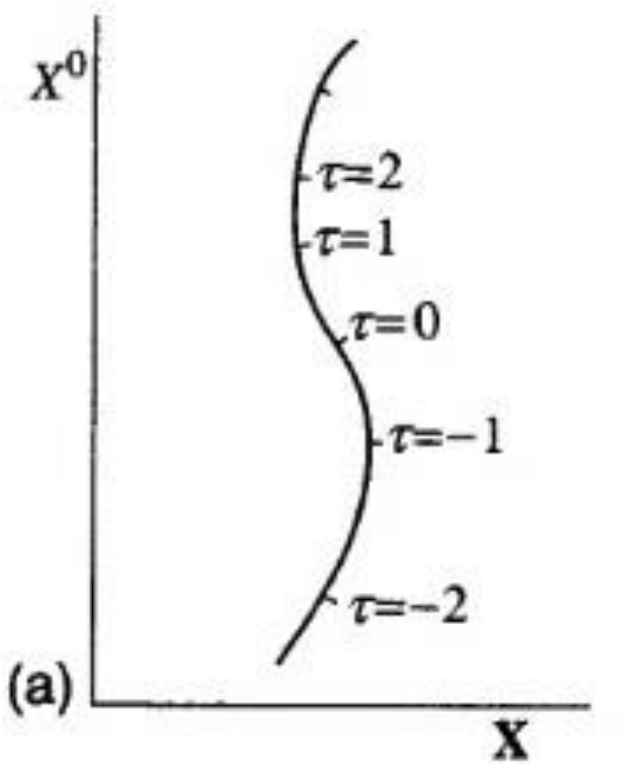
Three Generations of Matter




The Standard Model of Particle Interactions
Three Generations of Matter
I
II
III
Quarks
Leptons
Force Carriers
u
c
t
γ
d
s
b
g
ν_e
ν_μ
ν_τ
Z
e
μ
τ
W

H

Worldline



$$\mathscr{L}'_0 = \bar{\psi} i\gamma^\mu (\partial_\mu + ieA_\mu)\psi - m\bar{\psi}\psi .$$

$$\mathscr{L} = (D_\mu \phi)^\dagger (D^\mu \phi) + \mu^2 \phi^\dagger \phi - \lambda(\phi^\dagger \phi)^2 - \tfrac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

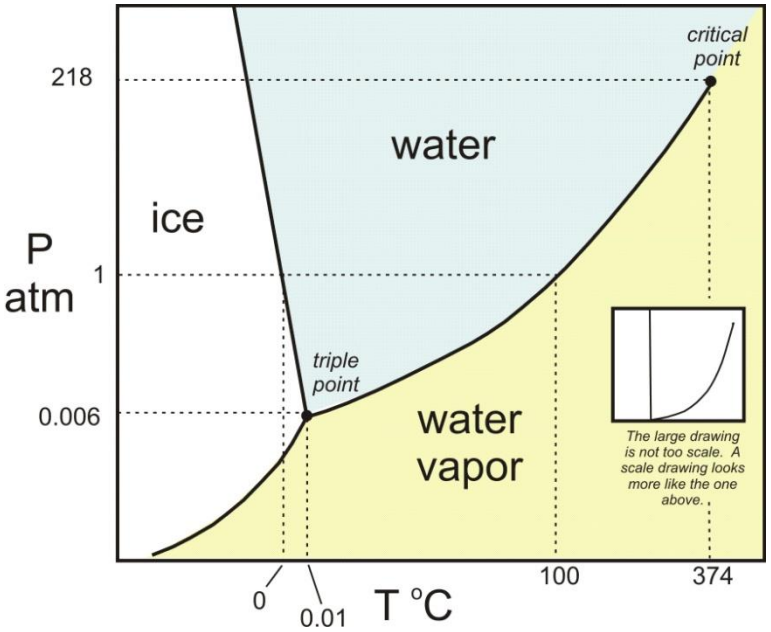
The Level of Professionalism

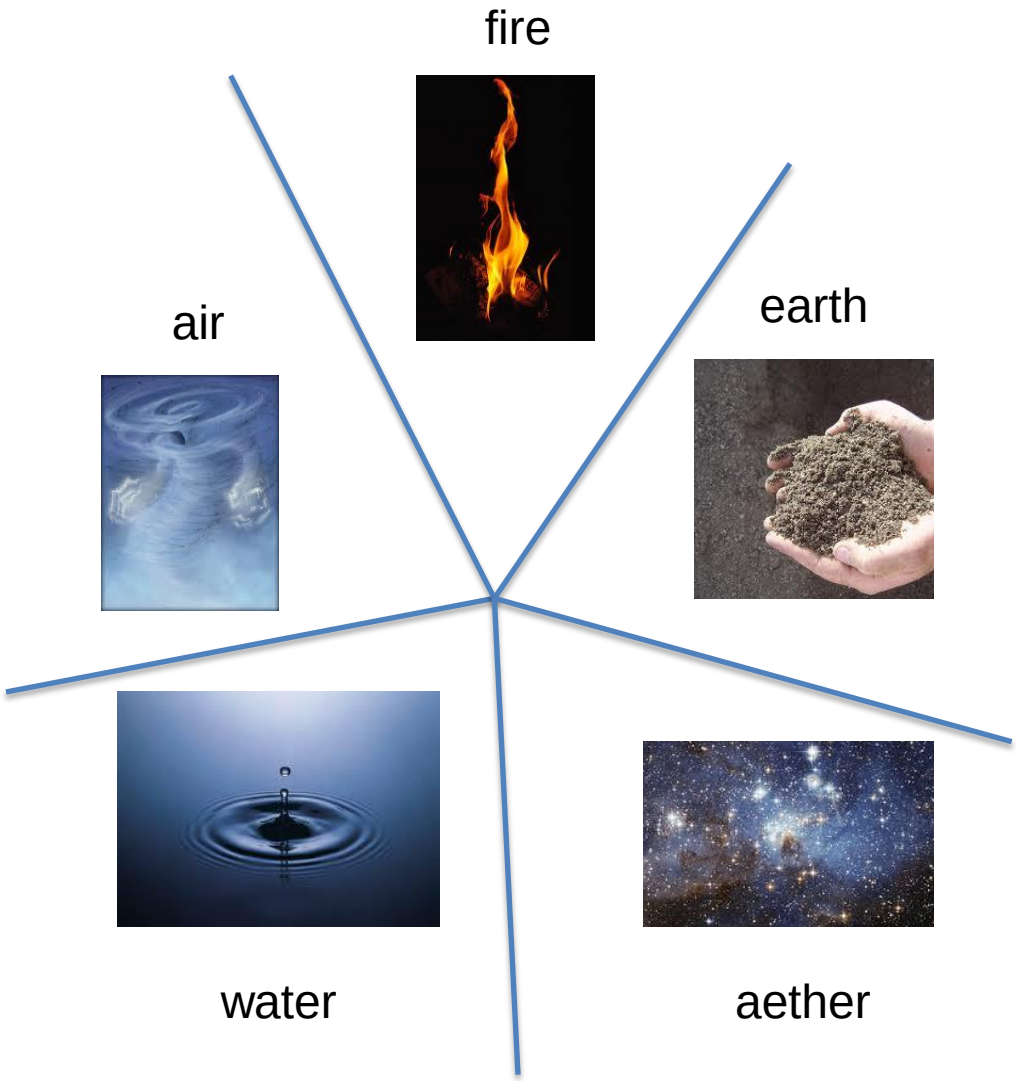
1. In calculations involving the electromagnetic force – 0.00115965218.

2. In calculations involving the weak force - 0.1%

3. In calculations involving the color force - 1%

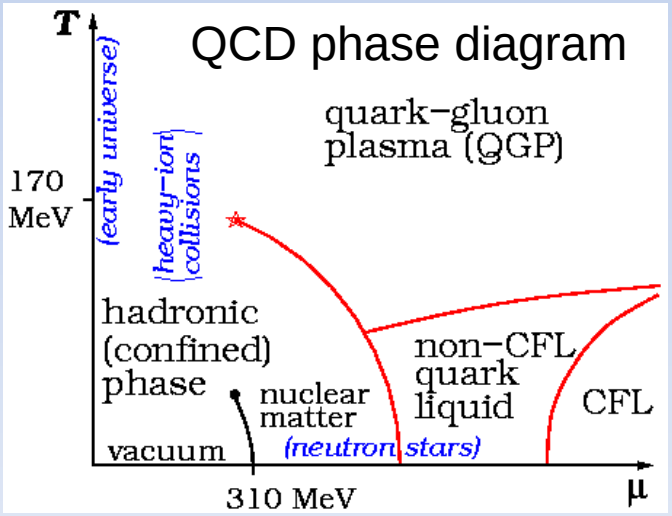
Phase structure





Gauge theories phases

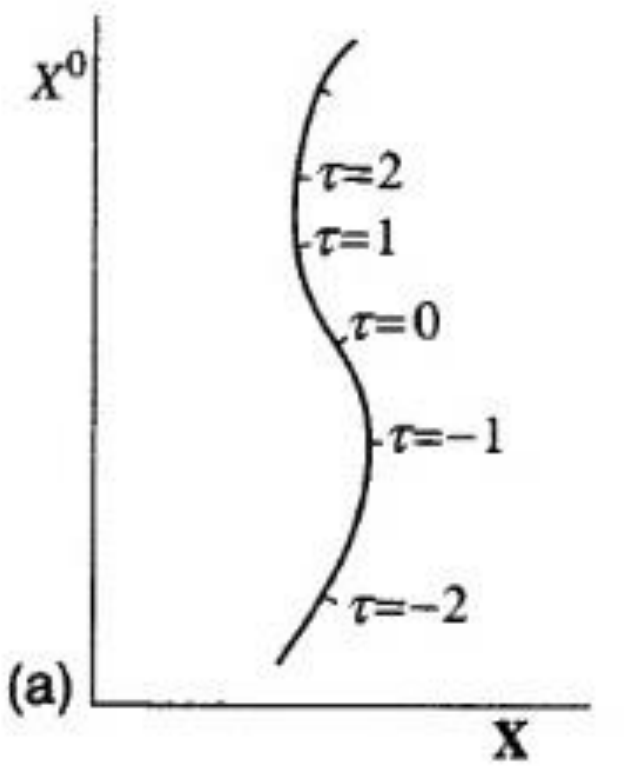
- Weak interactions, Brout–Englert–Higgs phase
- QCD, confinement, B.E.H. for monopoles
- Electromagnetism, Coulomb phase
- Oblique confinement, B.E.H. for dyons, quantum Hall effect ?
- Conformal phase

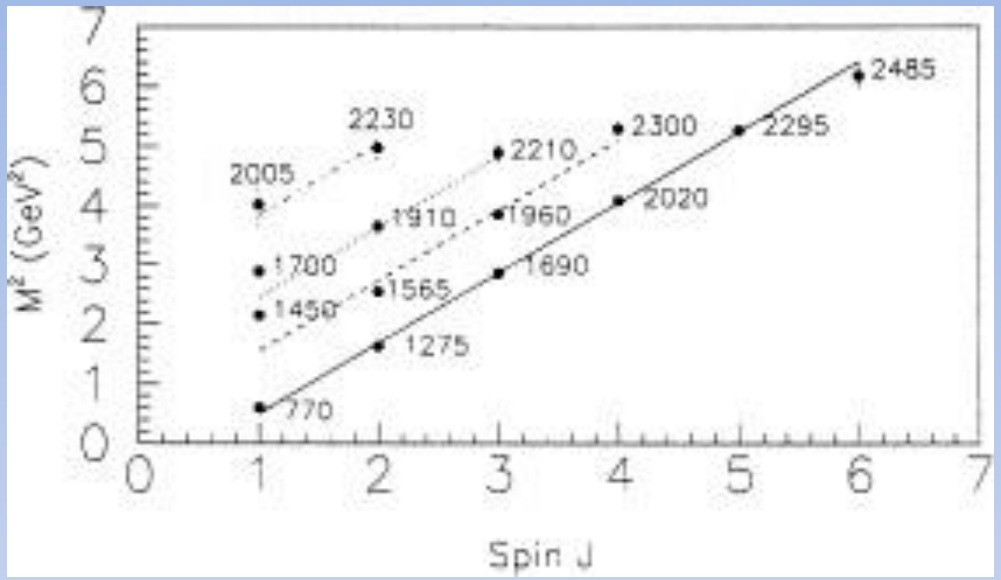


Questions:

Can humans give up Heisenberg's dictum?

Worldline





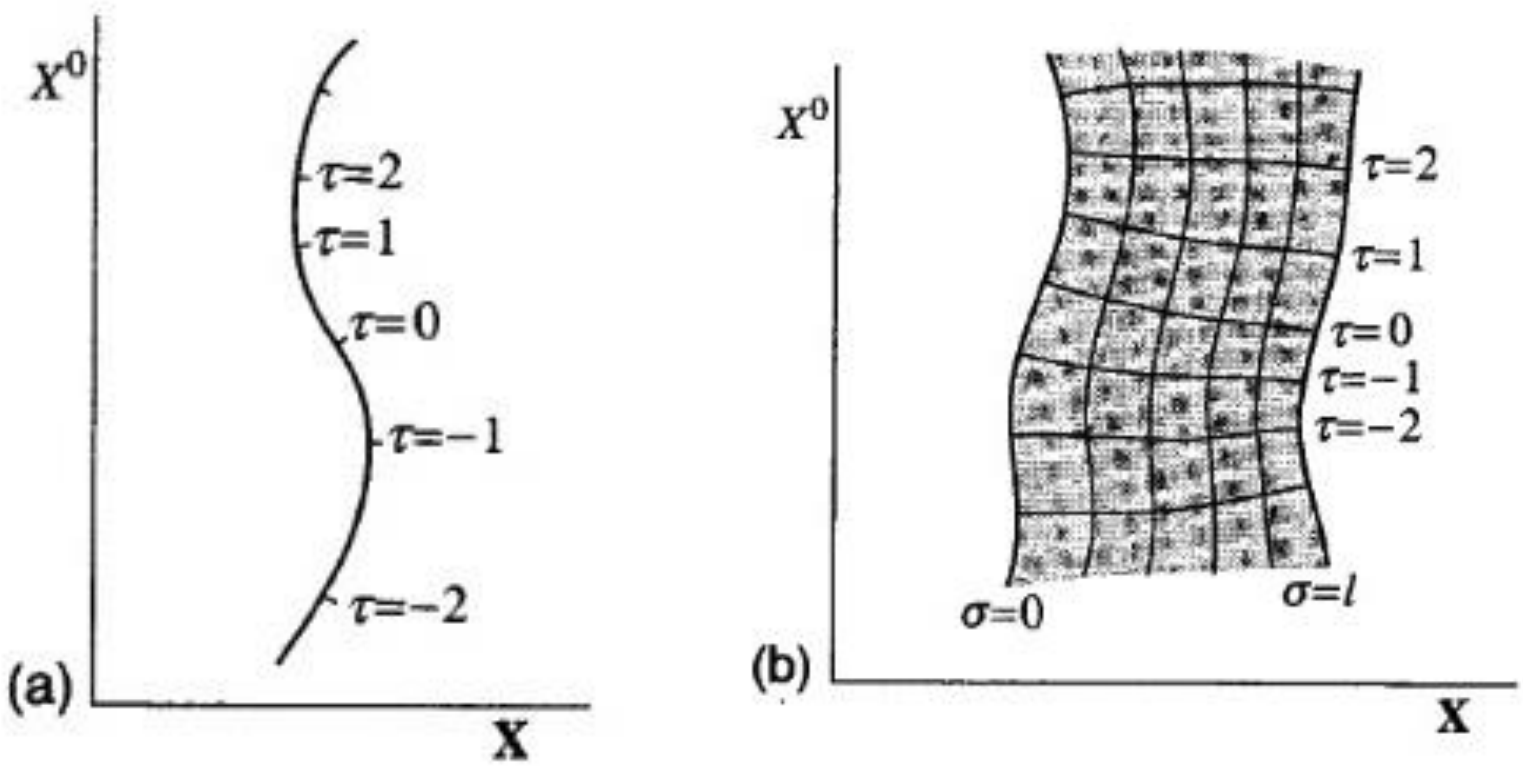
Regge trajectories, what one gets if the meson is made by two quarks attached by a long, spinning string

String Theory first appeared to describe strong interactions

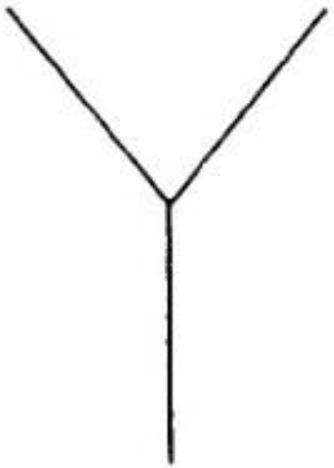
Only later it was realized that the correct theory of quark and hadrons is QCD…

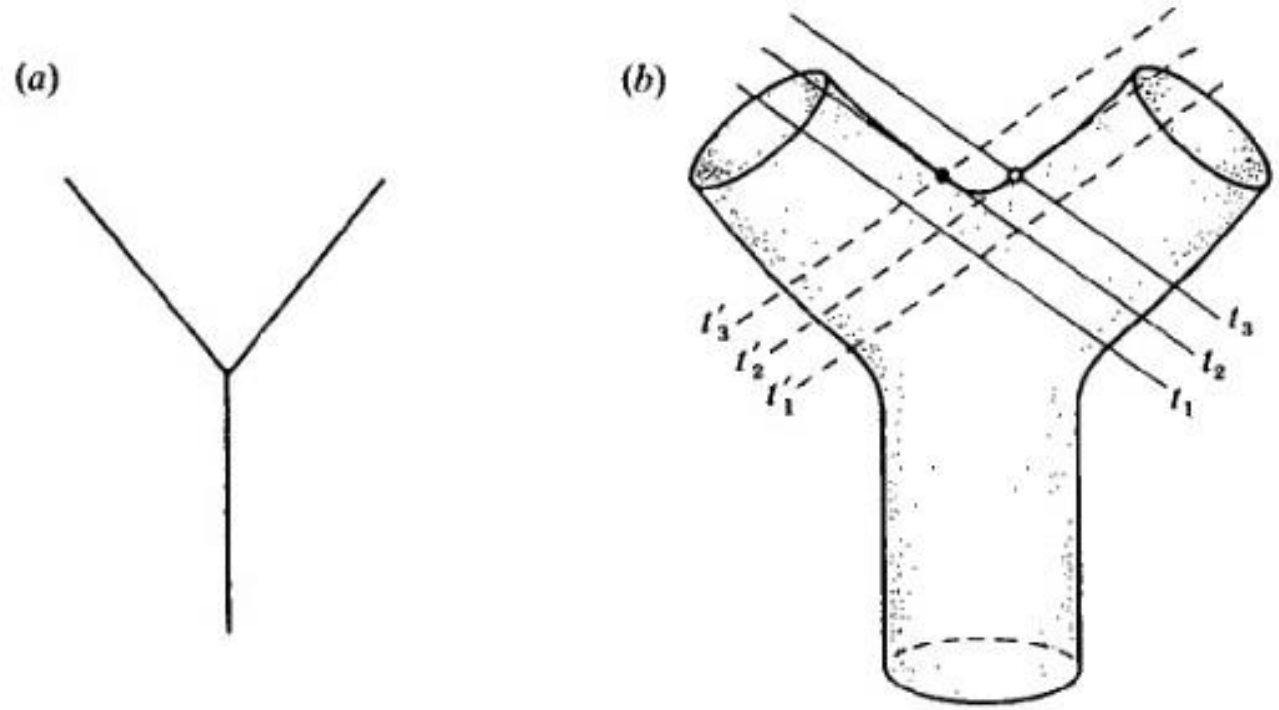
… and that String theory is a theory of Quantum Gravity !!

Worldline vs Worldsheet



(*a*)




(a)
(b)
t_3'
t_2'
t_1'
t_3
t_2
t_1

Bohr correspondence principle

Open string

$$\int -\frac{1}{4}\mathrm{Tr}F_{\mu\nu}^2\, d^4x$$

Bohr correspondence principle

Open string

$$\int -\frac{1}{4}\mathrm{Tr}F_{\mu\nu}^2\, d^4x$$

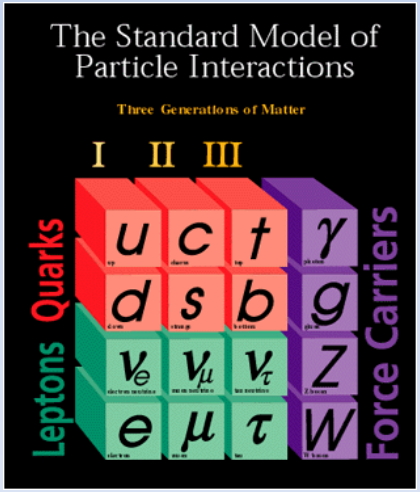
Closed string

$$\int R\sqrt{-g}\, d^4x$$

The Significance of a Scientific Research is measured not only by the quality of its results but also by the quality of the questions it raises.

Why? Why? Why.?

“Old” Why Questions.



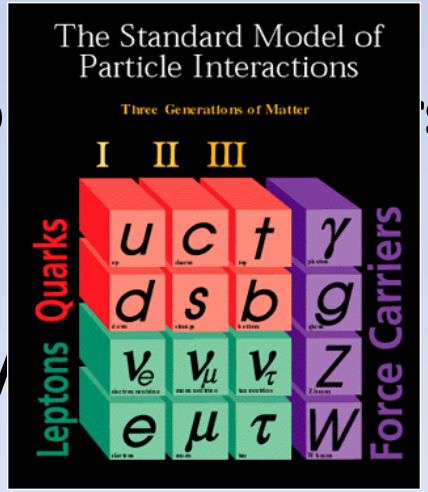
Why? Why? Why?

"Old" Why Questions

Why does a Universe have four dimensions ?

Why is there o se ?

Why is there M



String Theory as an Innovator

- What must be the “dimension” becomes a scientific question : Central charge=26,15 sometimes means dimensions= 26 or =10 (condensed matter systems classified) N.K.K was already there but the number of dimensions are obtained bottom up by the known interactions
- To obtain stability Super Symmetry (world sheet) was invented.

  SUSY (or approximate) needed for stability.

String Theory as an Innovator

- Transient Hagedorn ($S=\beta E$) exponential density of states.
- The many heavy massive states make a theory containing gravity finite (lots of fine details).
- Klein showed that the number of particles is not fixed in an interacting relativistic quantum field theory. In some string cases Topologies must mix.

Magic of String Theory

No concept in Math remains unambiguous

Magic of String Theory

Metric

With extended objects

Large=Small

$$R \to \frac{1}{R}$$

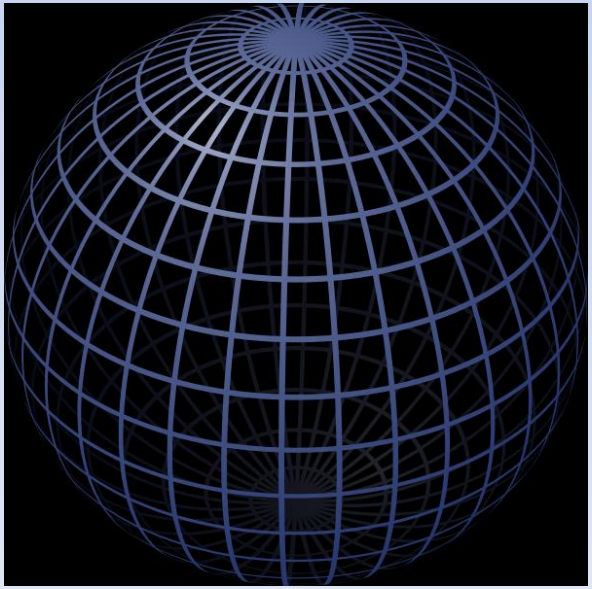
T is a residual gauge symmetry following B.E.H. mechanism

$$SU(2) \times SU(2) \to U(1) \times U(1)$$

Magic of String Theory

Topology

With extended objects
Surface of a Sphere=Torus



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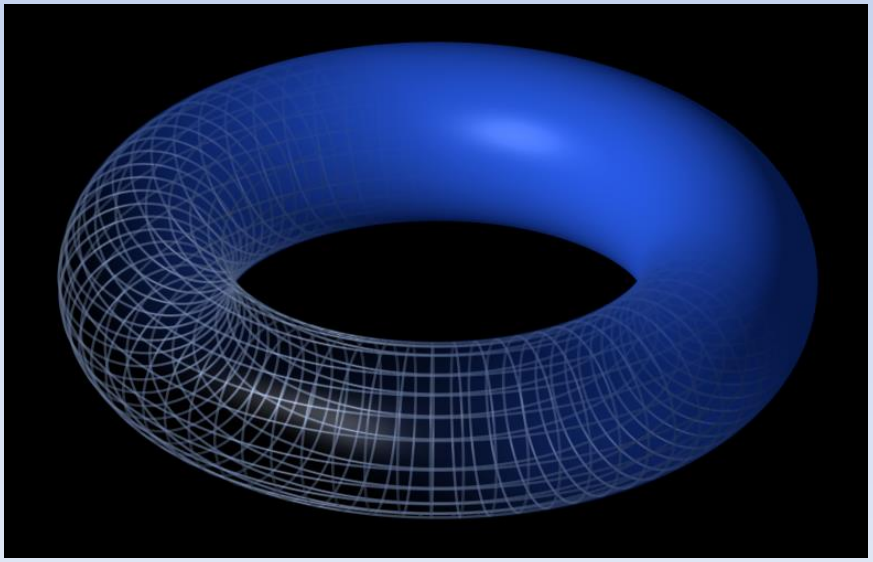


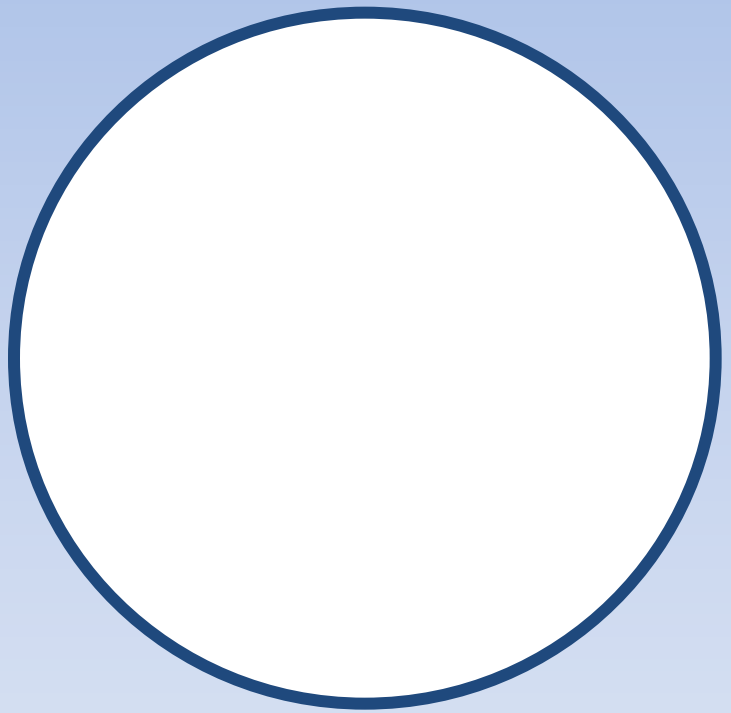
Magic of String Theory

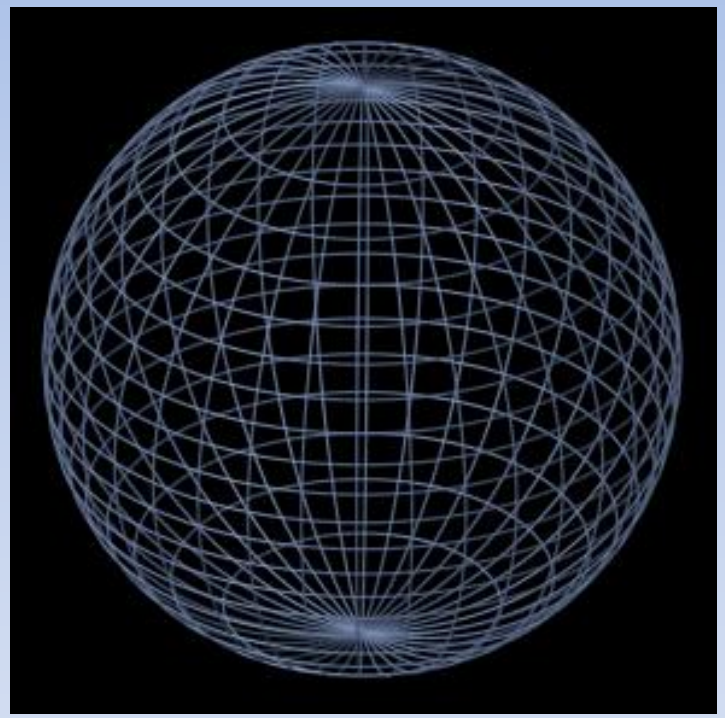
Dimension

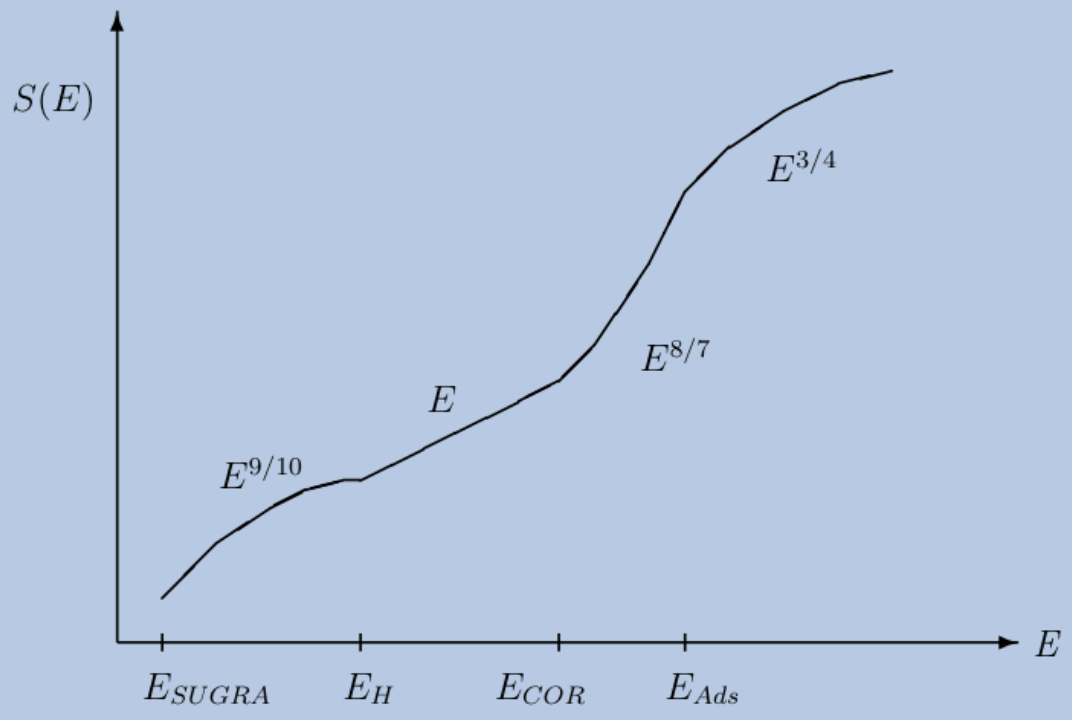
With extended objects

1=3 , 4=10

SU(2) dim=3, rank=1



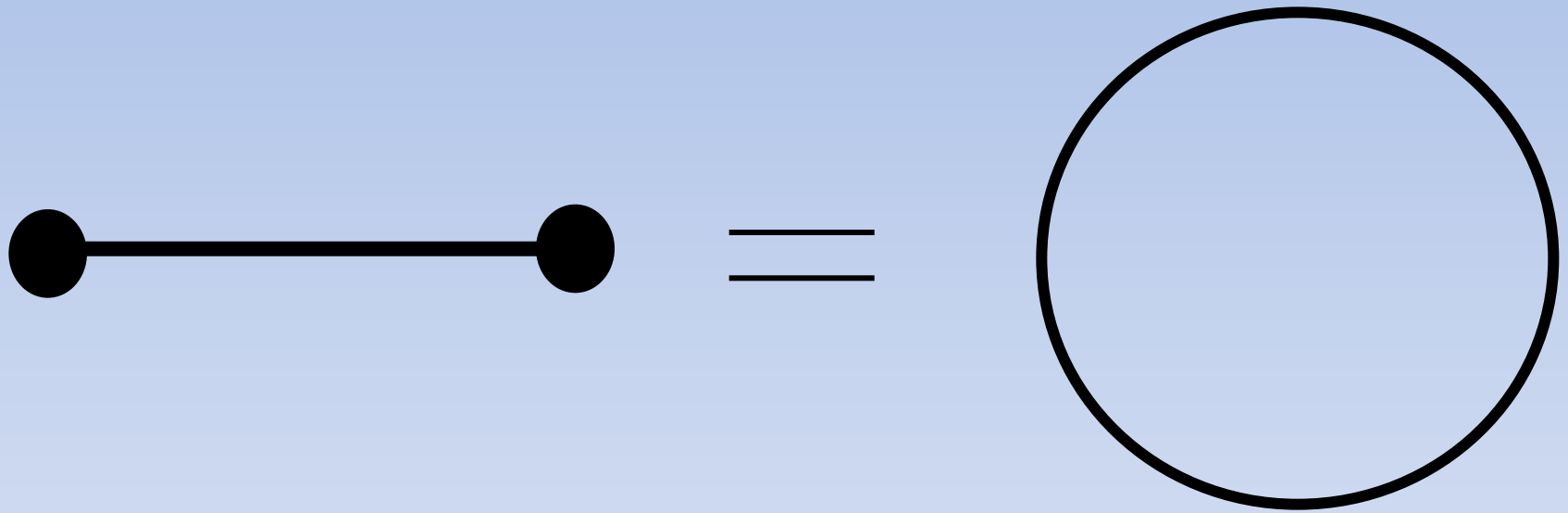



$S(E)$
$E^{3/4}$
$E^{8/7}$
E
$E^{9/10}$
E
E_{SUGRA}
E_H
E_{COR}
E_{Ads}

Magic of String Theory

Singularities

With extended objects



Magic of String Theory

commutativity

With extended objects

$[x,y]=0$ =

Dualities

- Geometry
- Topology
- Number of dimensions, small and large
- (non-)Commutativity
- Singularity structure
- Associativity

=

Amplitude Magic

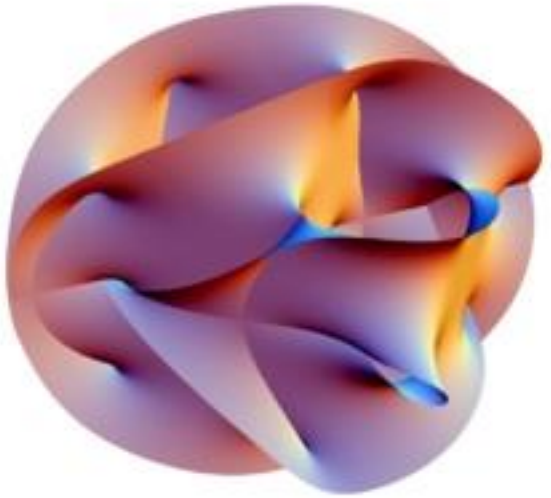
- Many complicated become one simple.

- A flavor of unexpected finiteness ?

String theory as Math , CDM and more.

- Interesting encoding in topological theories.

In general many Math applications.

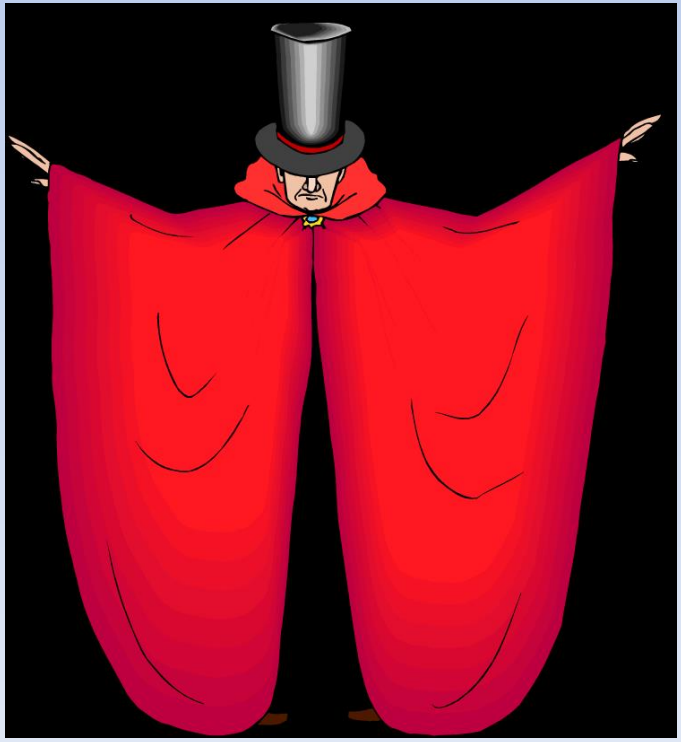


CDM-Hydrodynamics…..

Magic of String Theory

Singularities are a reflection of a breakdown of an approximation.

Gravity has magic cloaks to hide its secrets

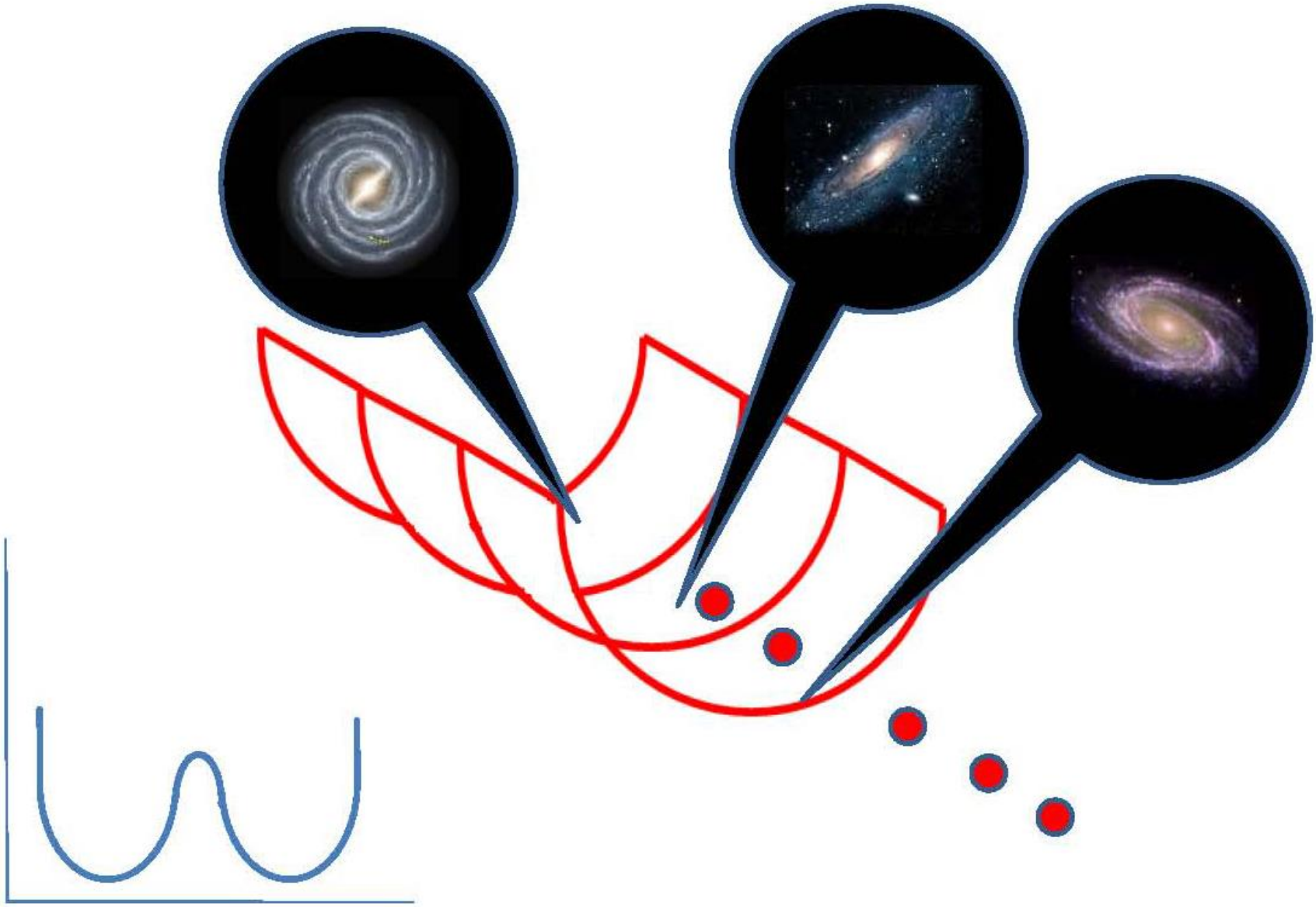


HORIZONS

String theory as an Emulator

- Features Extra dimensions in a consistent way, Experimental bound shifted by many orders of magnitude. LHC pushes up the limit on possible large extra dimension to around 5 Tev? Submicron corrections?
- Symmetries like S-duality, strong-weak coupling, N=4 d=4 SUSY Yang-Mills
- Important role of solitons (dyons-branes)

The theory has amazing properties : The ground states of the potentials are infinitely degenerate and are situated along a flat direction



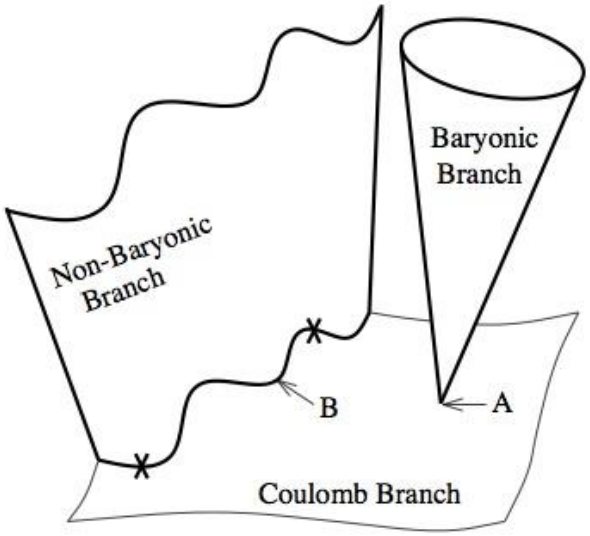
Wanted:

Inflaton
Dark matter candidates
Hidden sector particles
Many openings

Generically many unemployed particles in string theory

String theory as an Emulator

- Rich moduli, lots of extra particles



Needed for inflation, dilaton, dark matter?

String theory as a “Vindicator"

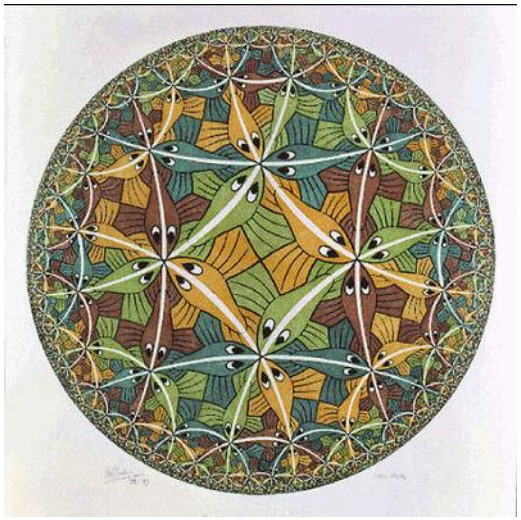
- No global symmetries in a theory with gravity.

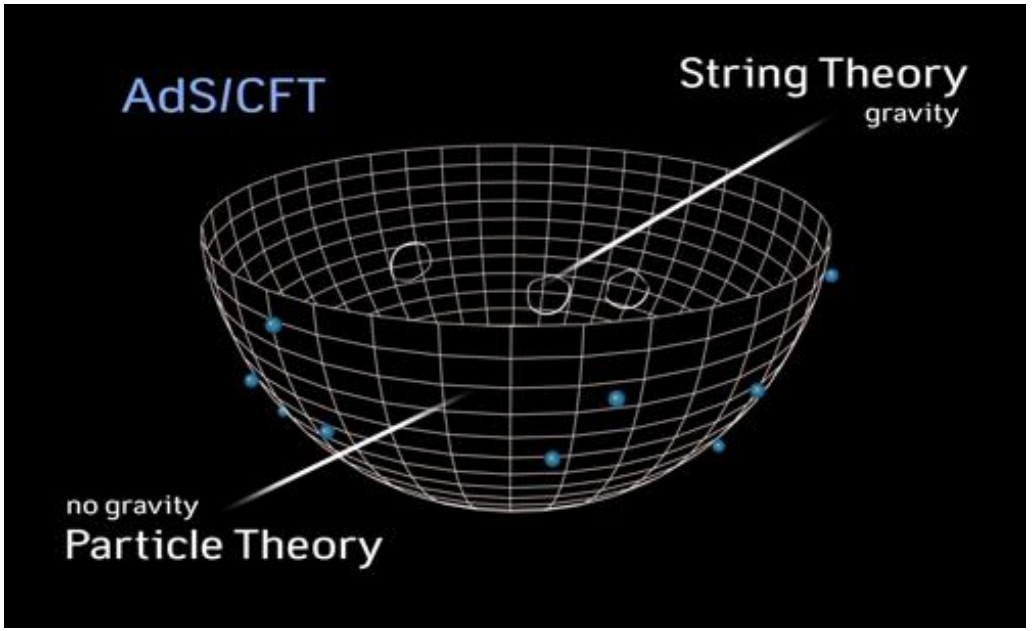
String inspired Phenomenology ?

String theory as a “Vindicator"

- The idea of Holography vindicated by AdS/CFT

N=4 d=4 large N SUSY YM SU(N) like string theory on $\mathrm{AdS}_5 \times S^5$ with RR Flux

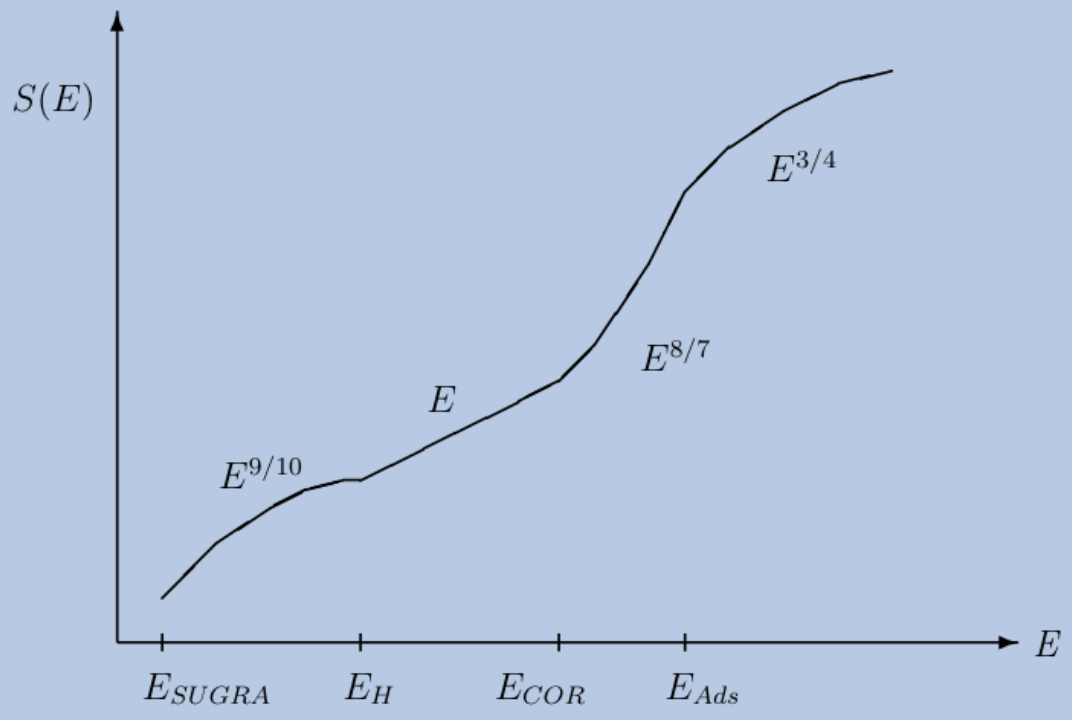




Field Theory has it all?

- Particles, Strings, Black holes of all kinds are all characters in one story.

- The non-locality of Gravity moved to locality in a different representation.


$S(E)$
$E^{3/4}$
$E^{8/7}$
E
$E^{9/10}$
E
E_{SUGRA}
E_H
E_{COR}
E_{Ads}

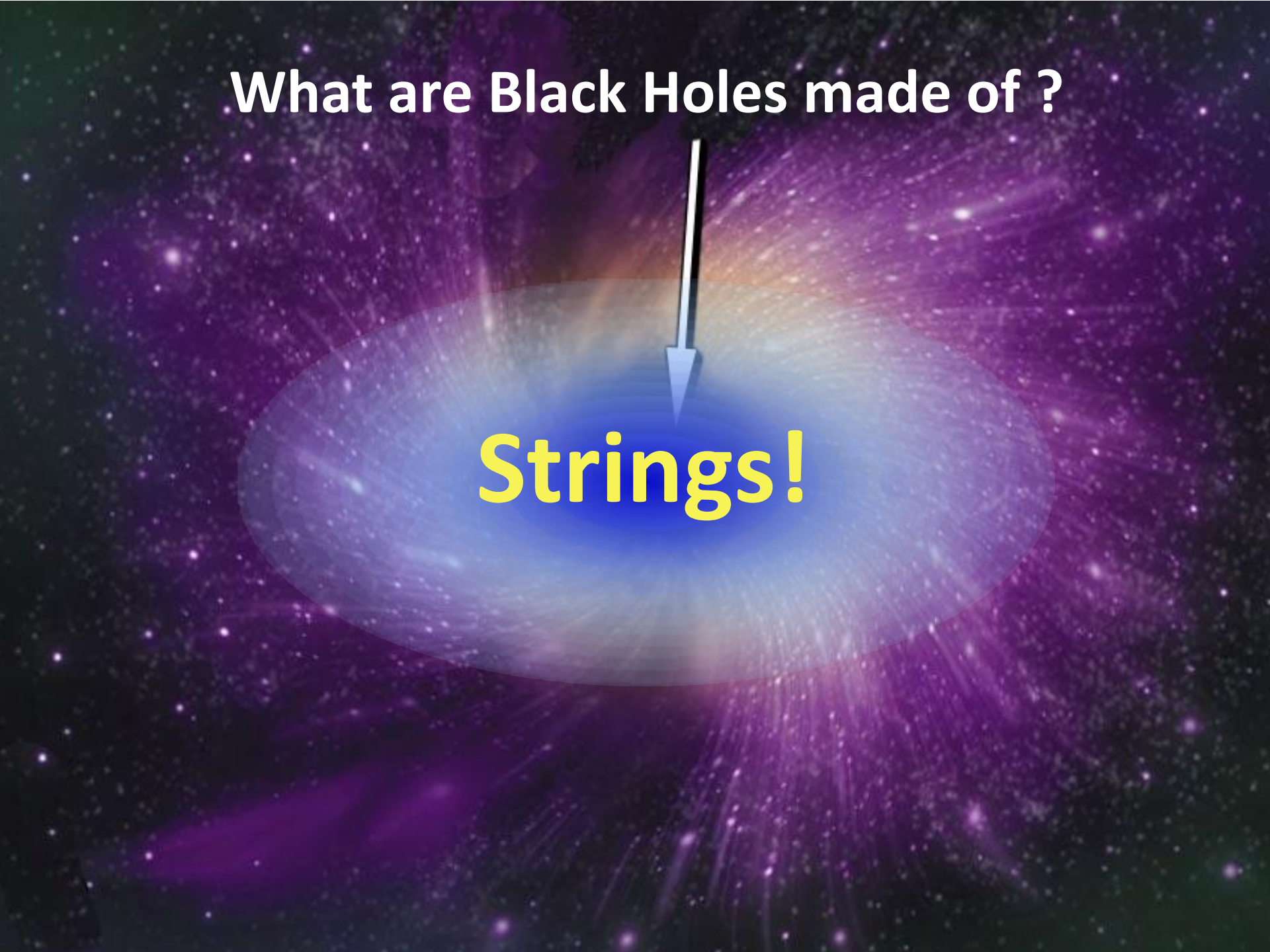
$$S = \frac{c^3 A}{4G\hbar}$$

This requires drastic changes in intuition

The entropy of the black hole is not proportional to its volume as we are used to at low energies but only to the area of its horizon.

Moreover the information of the black hole maybe encoded on its horizon → HOLOGRAPHY

What are Black Holes made of ?



$$S = \frac{c^3 A}{4G\hbar}$$

String theory as a “Vindicator"

- Taking the sting out of the BH information paradox.

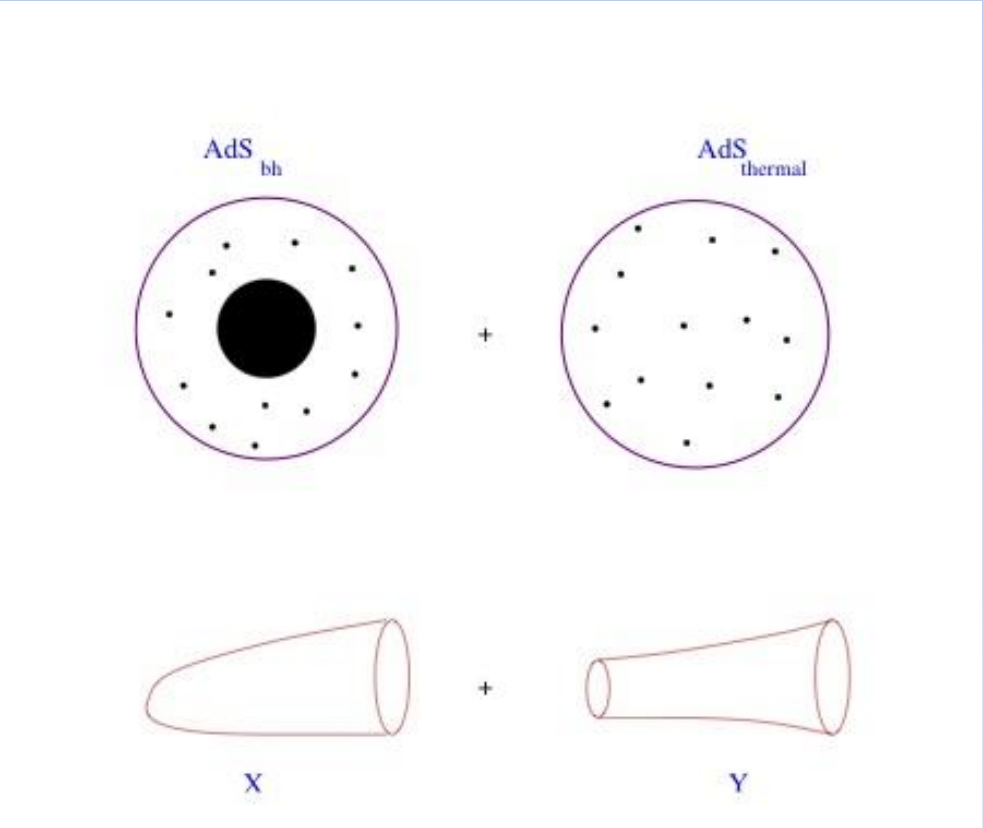
- One can live with singularities

Basic Point: one needs to mix topologies

Klein: The number of particles is not fixed in an interacting relativistic theory.

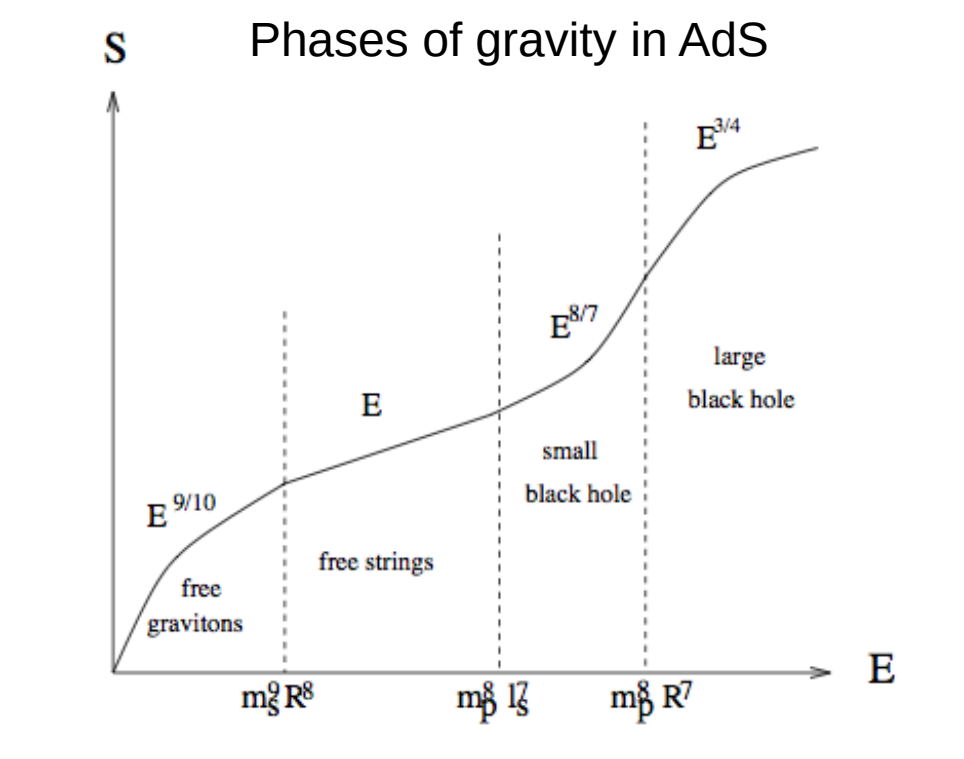
Does one need to mix topologies?

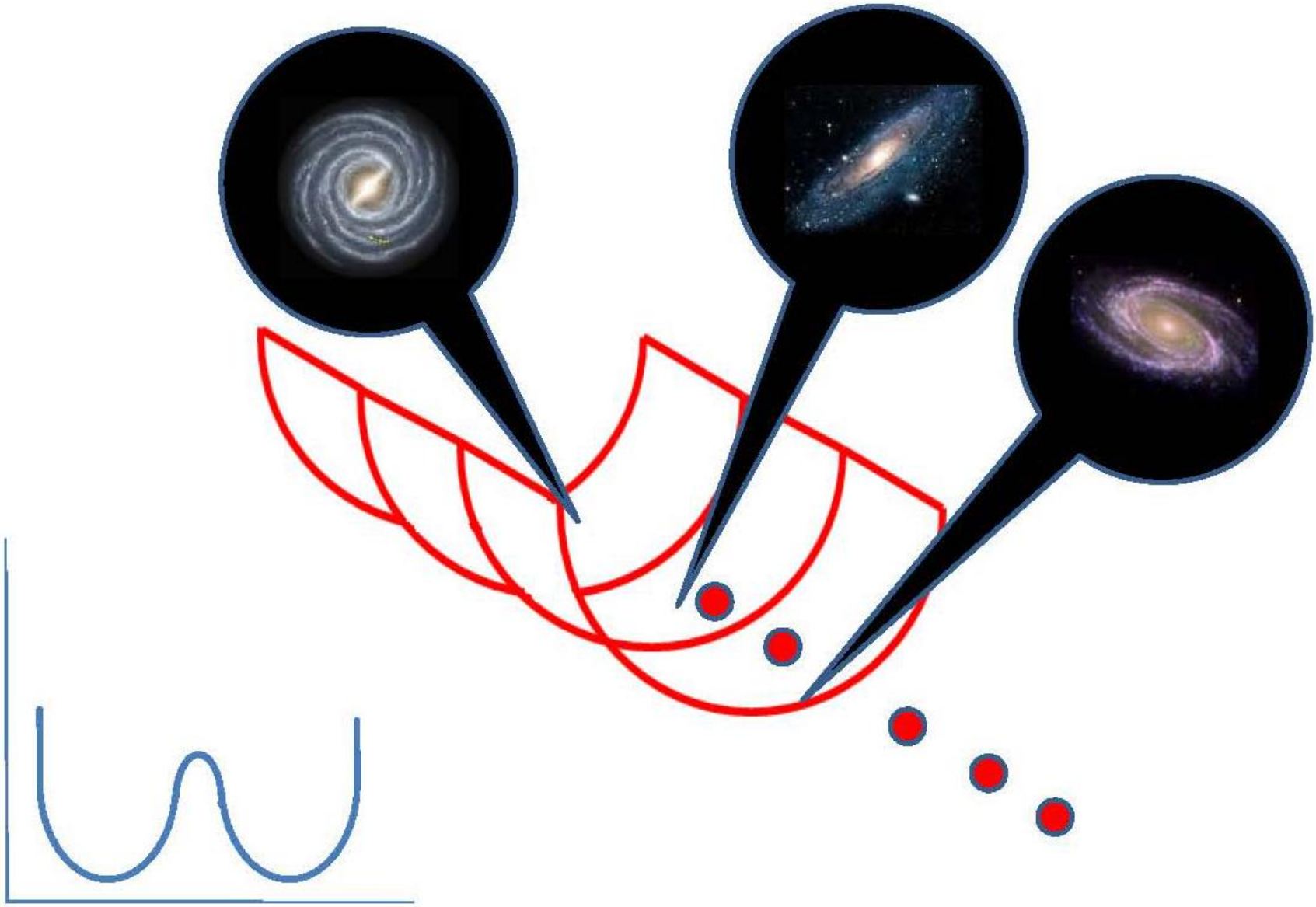
For Holography to work, YES.



Phases of Gravity

- Topological
- Matrices
- Particles
- Strings
- Black holes
- Aether

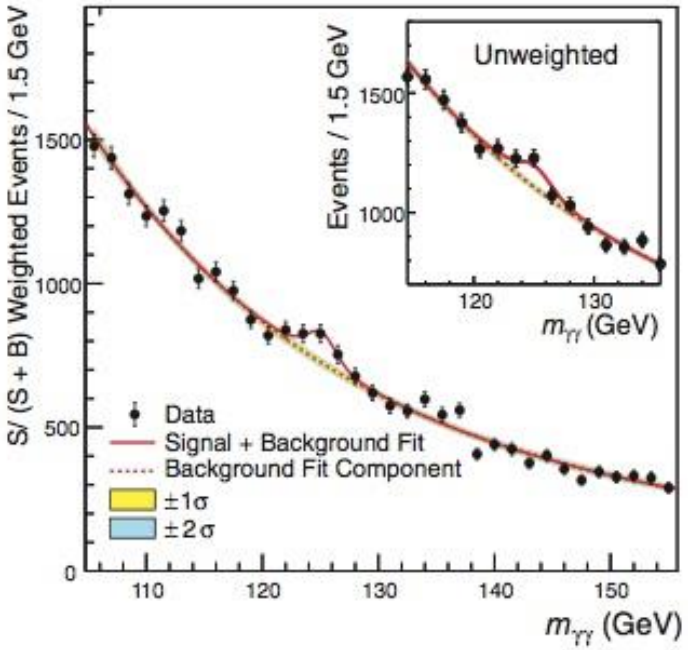


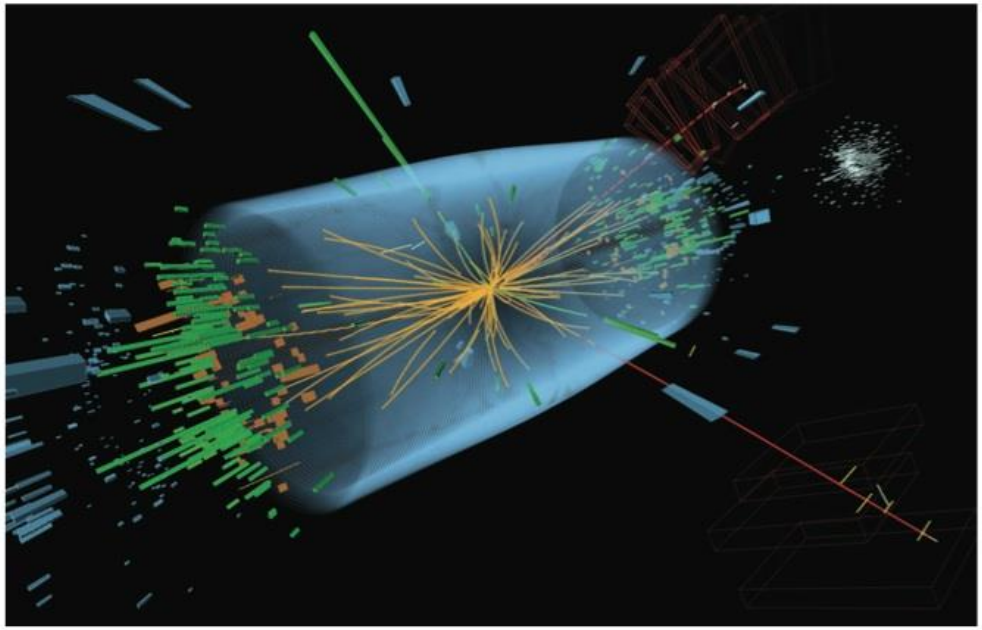


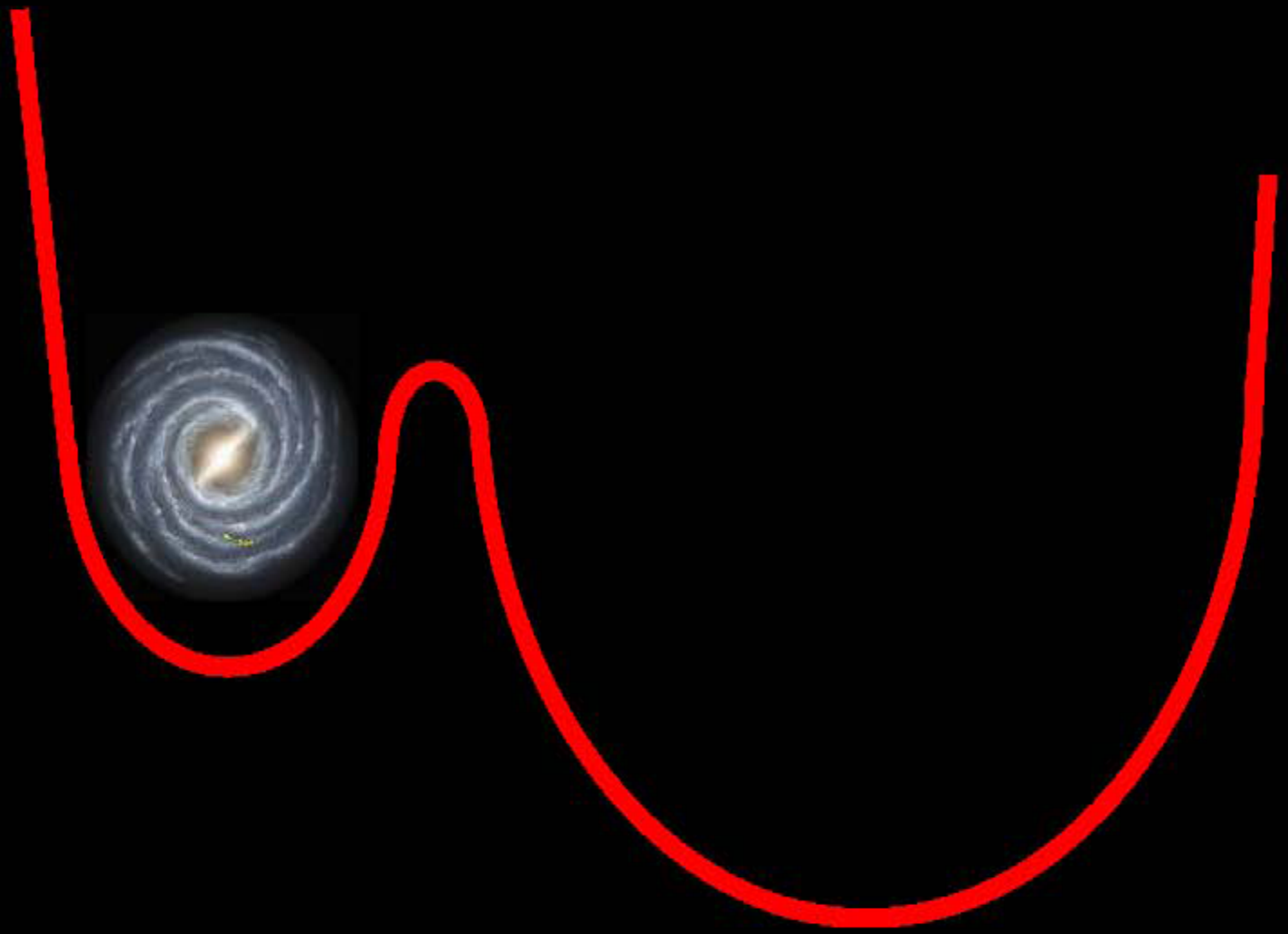
The Number of Universes

A Scientific Question ?

Finally at LHC what seems a fundamental scalar is found



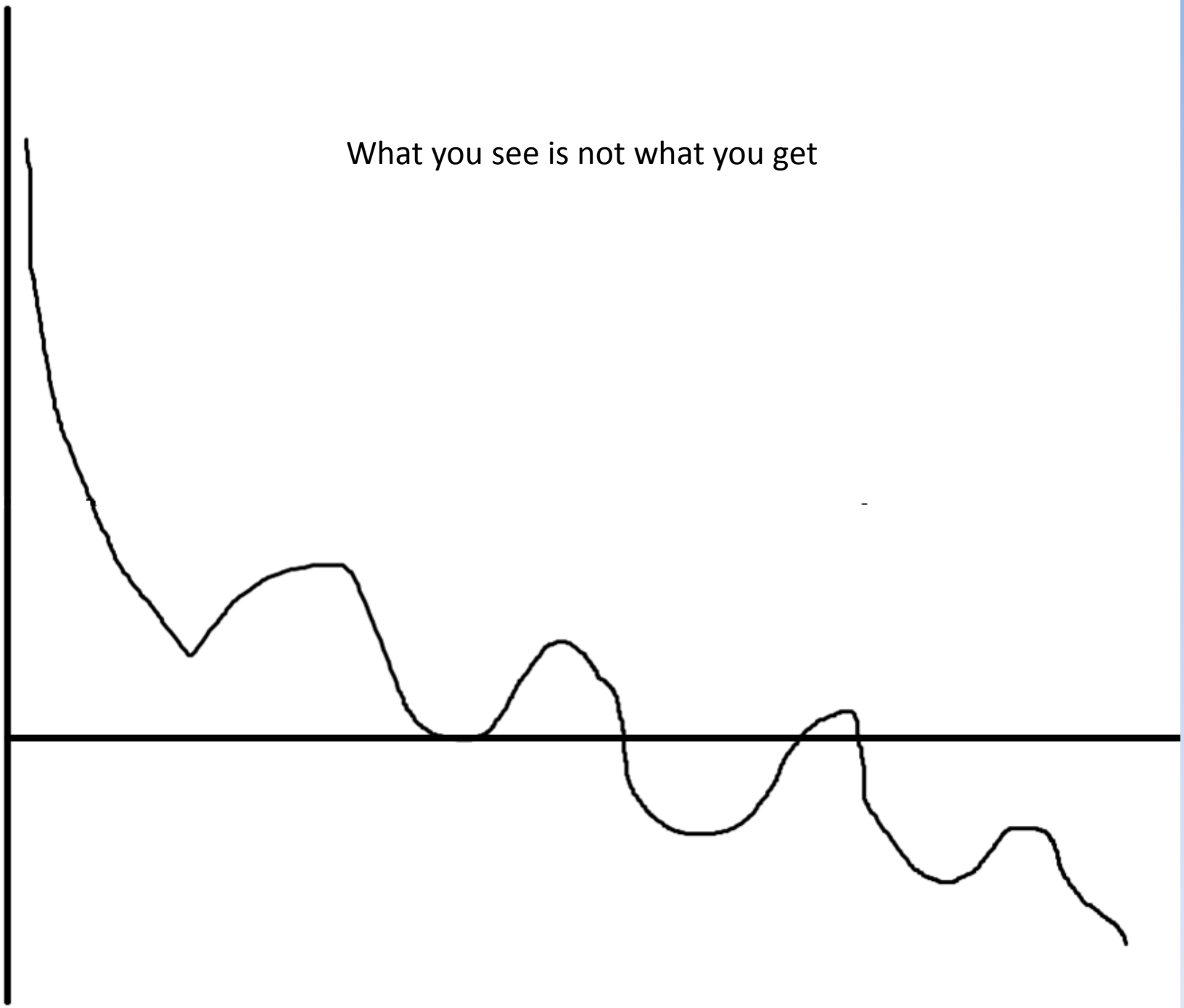




Photograph by Jim Brandenburg

National Geographic 100 Best Pictures
Collector's Edition Vol. 1

What you see is not what you get




$\mathcal{L}_{\text{susy}} = W_\alpha^A W^{A\alpha}|_{\theta 2} + \bar{W}_{\dot{\alpha}}^A \bar{W}^{A\dot{\alpha}}|_{\bar{\theta}2} + \Phi^{i\dagger} e^{gV} \Phi^i|_{\theta 2 \bar{\theta} 2}$
$+ W(\Phi^i)|_{\theta 2} + W^*(\Phi^{i\dagger})|_{\bar{\theta}2}$

One Ring to rule them all, One Ring to find them, One Ring to bring them all and in the darkness bind them.

Beauty

One Ring to Rule Them All

One Ring to Bring Them All
and in the Darkness bind them

Concentrated Power

One Equation?

Infinite number of solutions!!

The more we strive for more
understanding and more unification
the more we find our "positioning"
in the universe less central.

and then at the end we wonder why we
have been privileged to realize this.

Open issues

- Get rid of the constraints of the ambient space and the world sheet, (A unified descriptions of all phases of "Gravity”)
- Emergence of interactions?
- The role of α’ and scale/conformal invariance
- A realistic model.
- More on time dependent backgrounds.
- New higher dimensional non Lagrangian(?) QFT(?) in d=4 , 5

Questions:

- Can humans give up Heisenberg's dictum?
- How to find the wisdom not to be too attached to human problems(perturbation, natural(ness))?
- Will one evolves beyond QFT and String theory to a unified(?) picture?
- Will bounds shift again and an actual discovery occur?
- Is the universe stable?

Algebra, matrices and representations to replace geometry ?