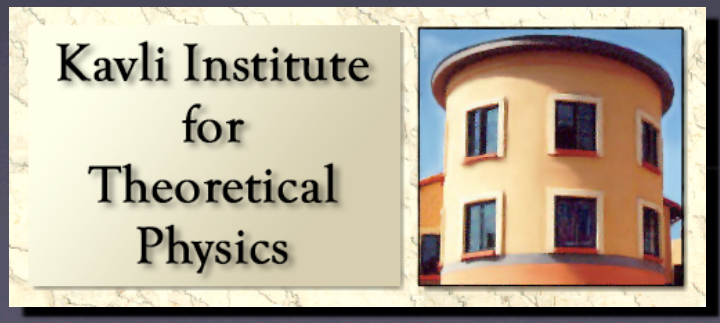
PERSPECTIVES ON THE STATE OF STRING THEORY

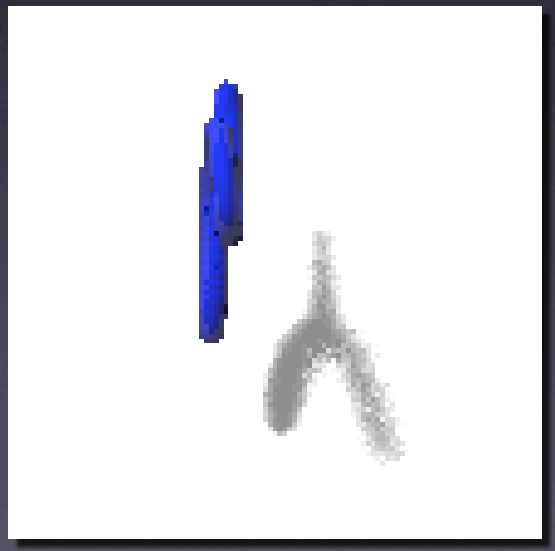
International Conference on the Frontiers of Science--KITPC

DAVID GROSS



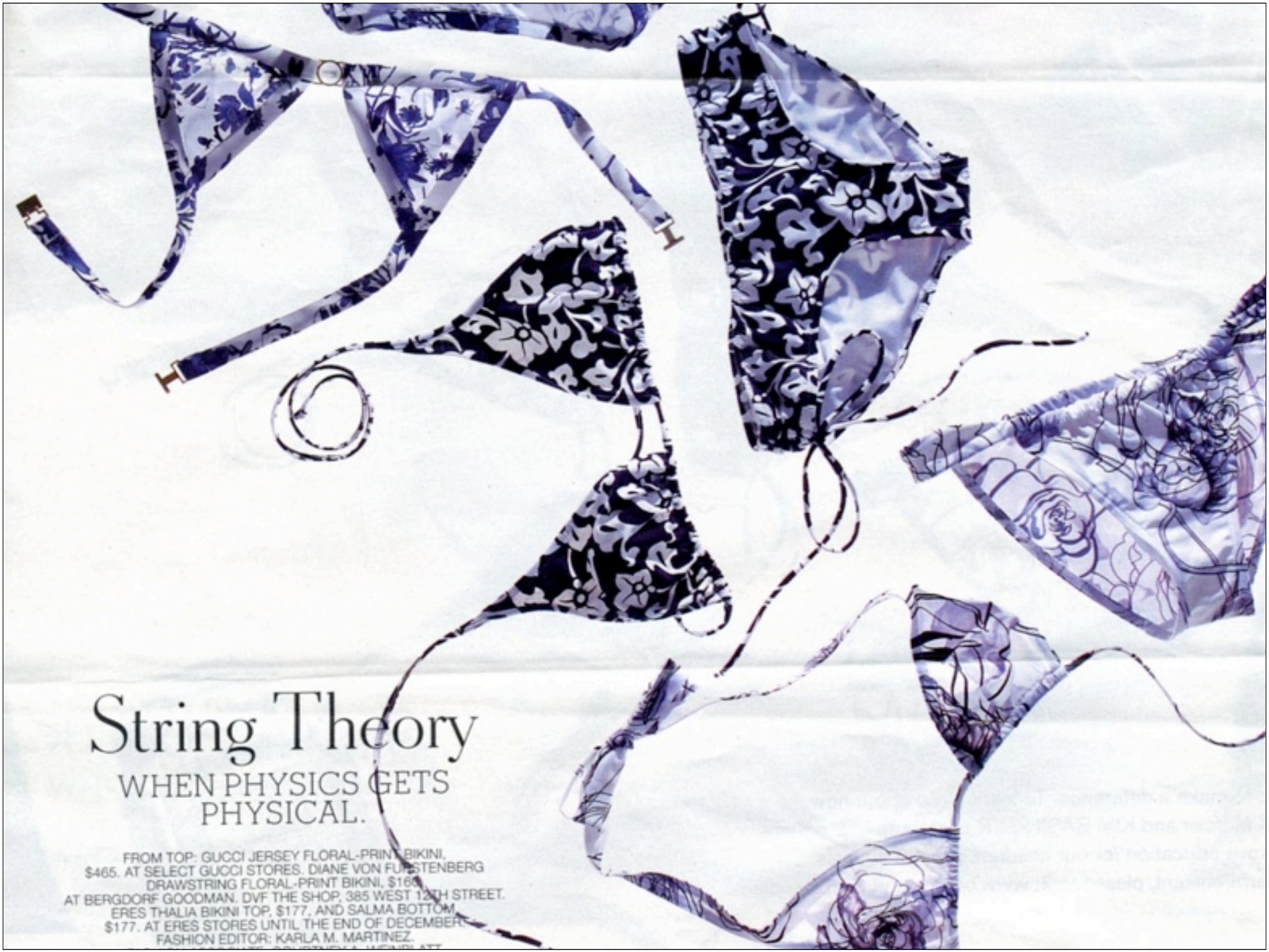
STRING THEORY

Where do we stand?



"It's all string theory to me."


HARVEY'S
PLACE
TONITE 5-8
IS STRING
THEORY
BULLSHIT?



String Theory

WHEN PHYSICS GETS PHYSICAL.

FROM TOP: GUCCI JERSEY FLORAL-PRINT BIKINI, $465. AT SELECT GUCCI STORES. DIANE VON FURSTENBERG DRAWSTRING FLORAL-PRINT BIKINI, $160. AT BERGDORF GOODMAN. DVF THE SHOP, 385 WEST 12TH STREET. ERES THALIA BIKINI TOP, $177, AND SALMA BOTTOM, $177. AT ERES STORES UNTIL THE END OF DECEMBER. FASHION EDITOR: KARLA M. MARTINEZ.

THE ACHIEVEMENTS OF STRING THEORY

- A Consistent, Logical Extension of the Conceptual Framework of Physics

REVOLUTIONS IN PHYSICS

Relativity	c	Velocity of light
Quantum Mechanics	h	Quantum of action
String Theory ?	G	Planck length

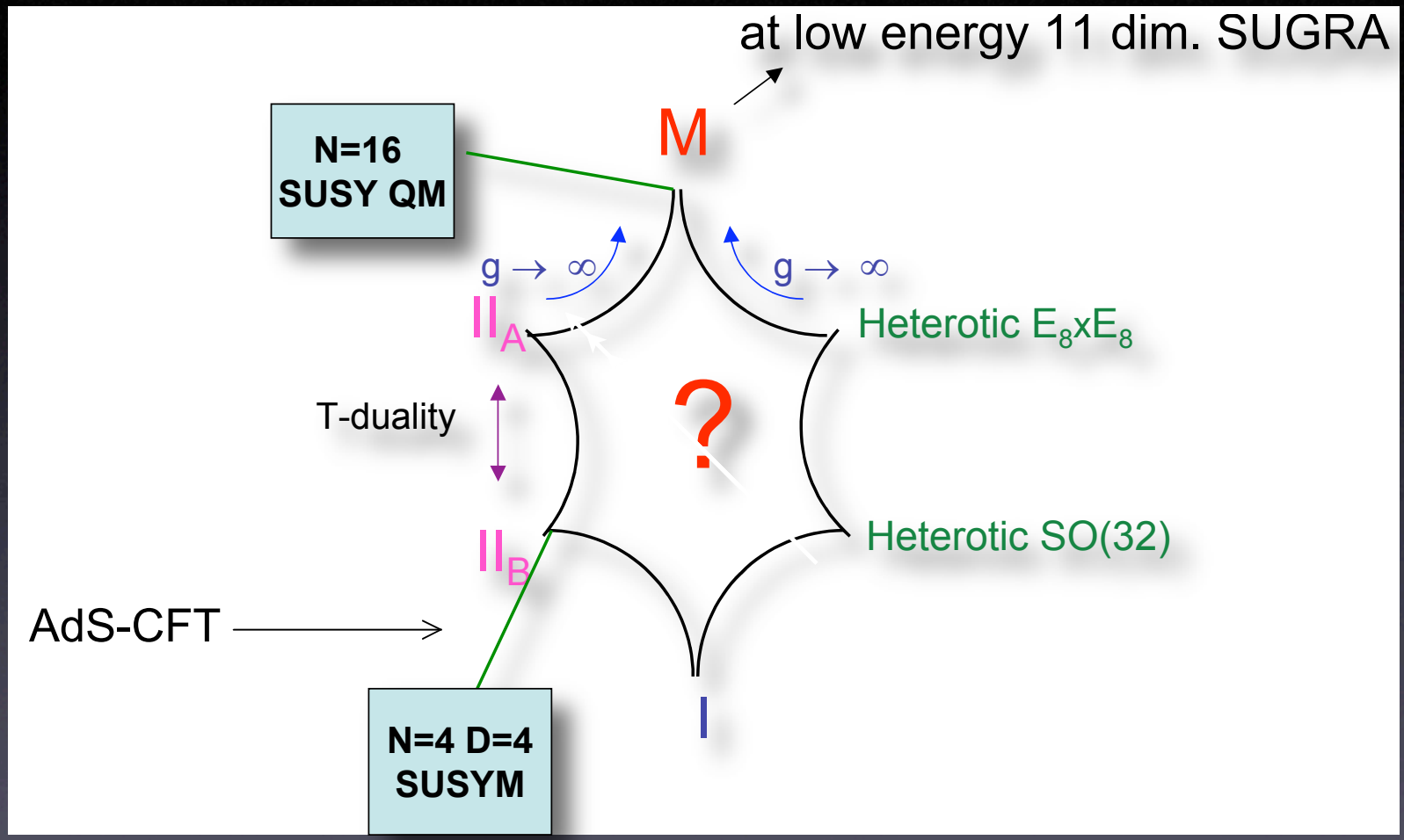
- A Consistent and Finite Quantum Theory of Gravity
- A Rich Structure That Could Yield a Unique and Comprehensive Description of the Real World (a T.O.E)

THE FAILURES OF STRING THEORY

- We still do not understand what string theory is.

We do not have a formulation of the dynamical principle behind ST. All we have is a vast array of dual formulations, most of which are defined by methods for constructing consistent semiclassical (perturbative) expansions about a given background (classical solution).

The Many Faces of String Theory



IS STRING THEORY REALLY DIFFERENT FROM FIELD THEORY ?

WHAT IS MISSING ?

- Perhaps "String theory" is like quantum field theory - a framework and not a definitive theory.
- Perhaps we are missing a fundamentally new principle of symmetry, of dynamics, of consistency, ... that leads to a unique solution --- not a "vacuum" but a space-time, a cosmology.

WHAT ARE THE NEW RULES?

SPACETIME IS EMERGENT

We have many examples
(e.g. AdS/CFT, Matrix theory)
in which some or all of space
is not fundamental– and only emerges
as a large distance, classical
approximation.

We have no idea what it might mean
to formulate physics without time.

STRING THEORY HAS MANY HOPES FOR THE FUTURE

UNIFIED THEORY OF ALL THE FORCES

NEW CONCEPTS OF SPACE-TIME

RESOLUTION OF THE PUZZLES OF QUANTUM GRAVITY AND COSMOLOGY

BUT MEANWHILE

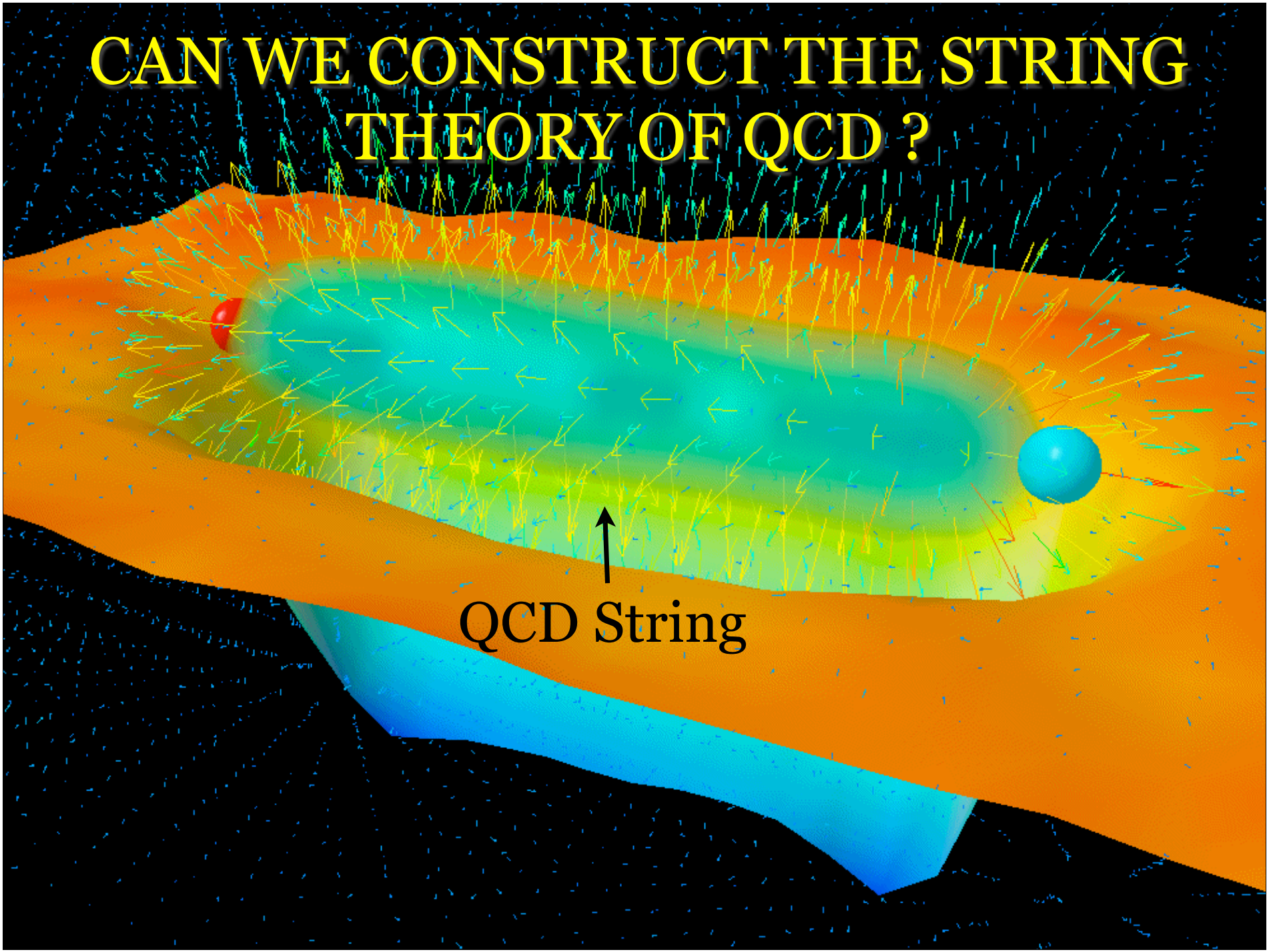
NEW INSIGHTS INTO GAUGE THEORY

& into mathematics

NEW PHENOMENOLOGICAL SCENARIOS

STRING THEORY OF QCD

CAN WE CONSTRUCT THE STRING THEORY OF QCD ?

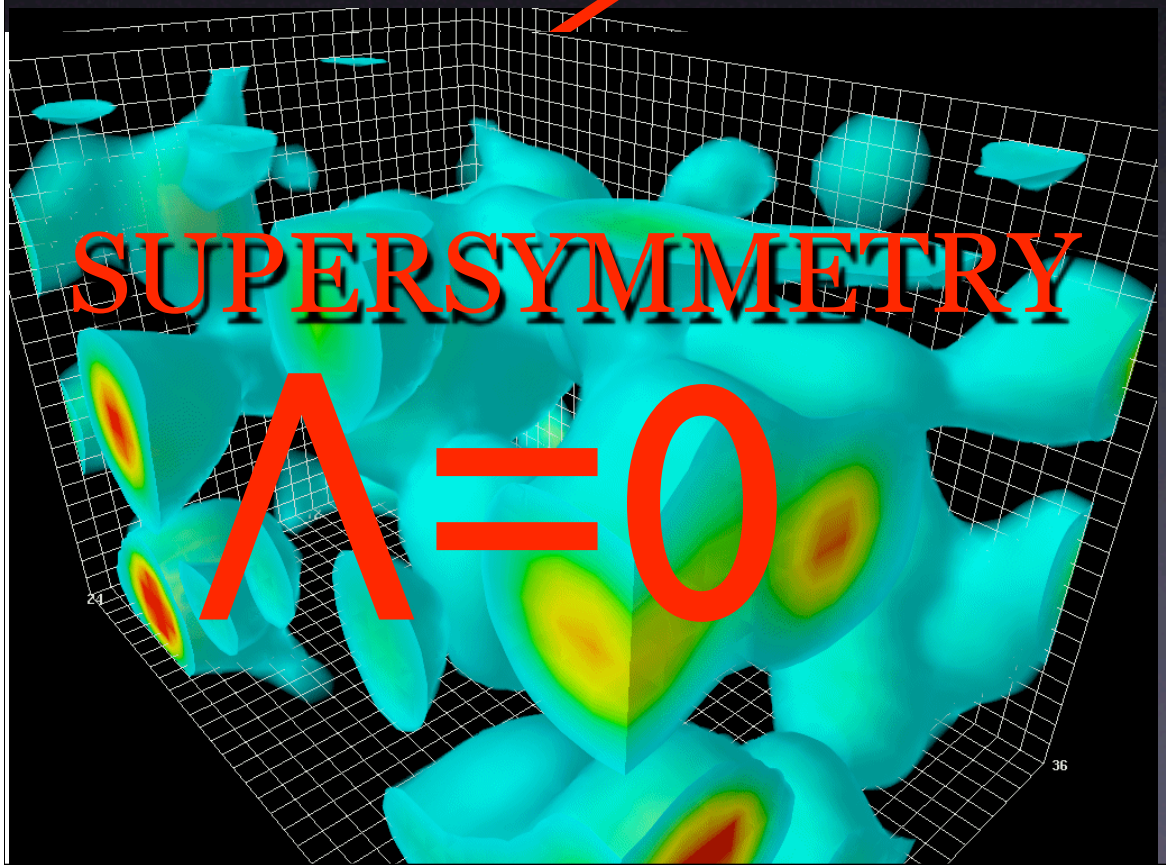


GAUGE THEORY

STRING THEORY

THE COSMOLOGICAL CONSTANT

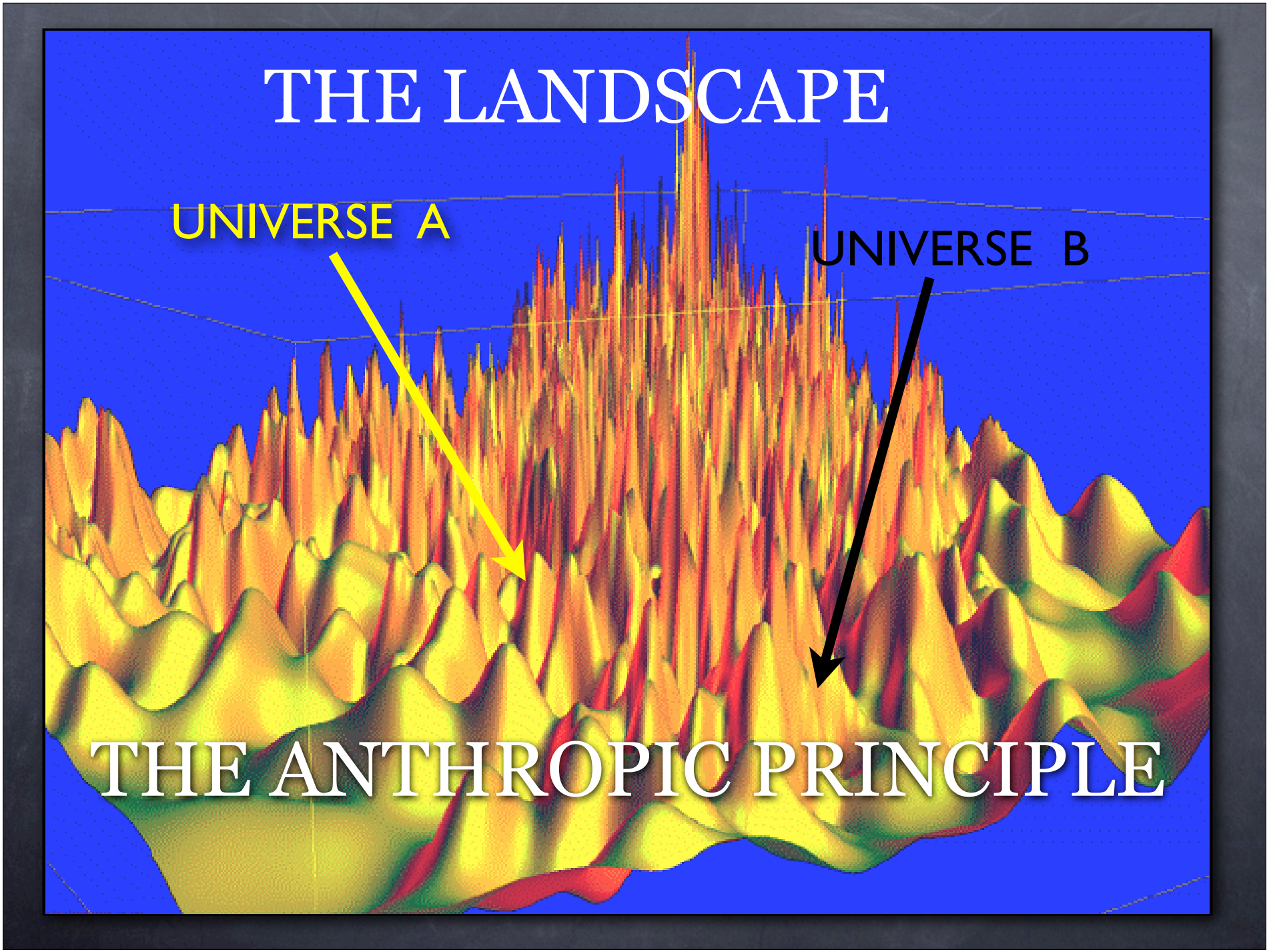
THE FLUCTUATIONS IN THE VACUUM GIVE RISE TO AN ENERGY:



$\Lambda \sim 10^{120}\ ev^4$

$\Lambda \sim 10^{60}\ ev^4$

$\Lambda_{obs} \sim 10^{-4}\ ev^4$

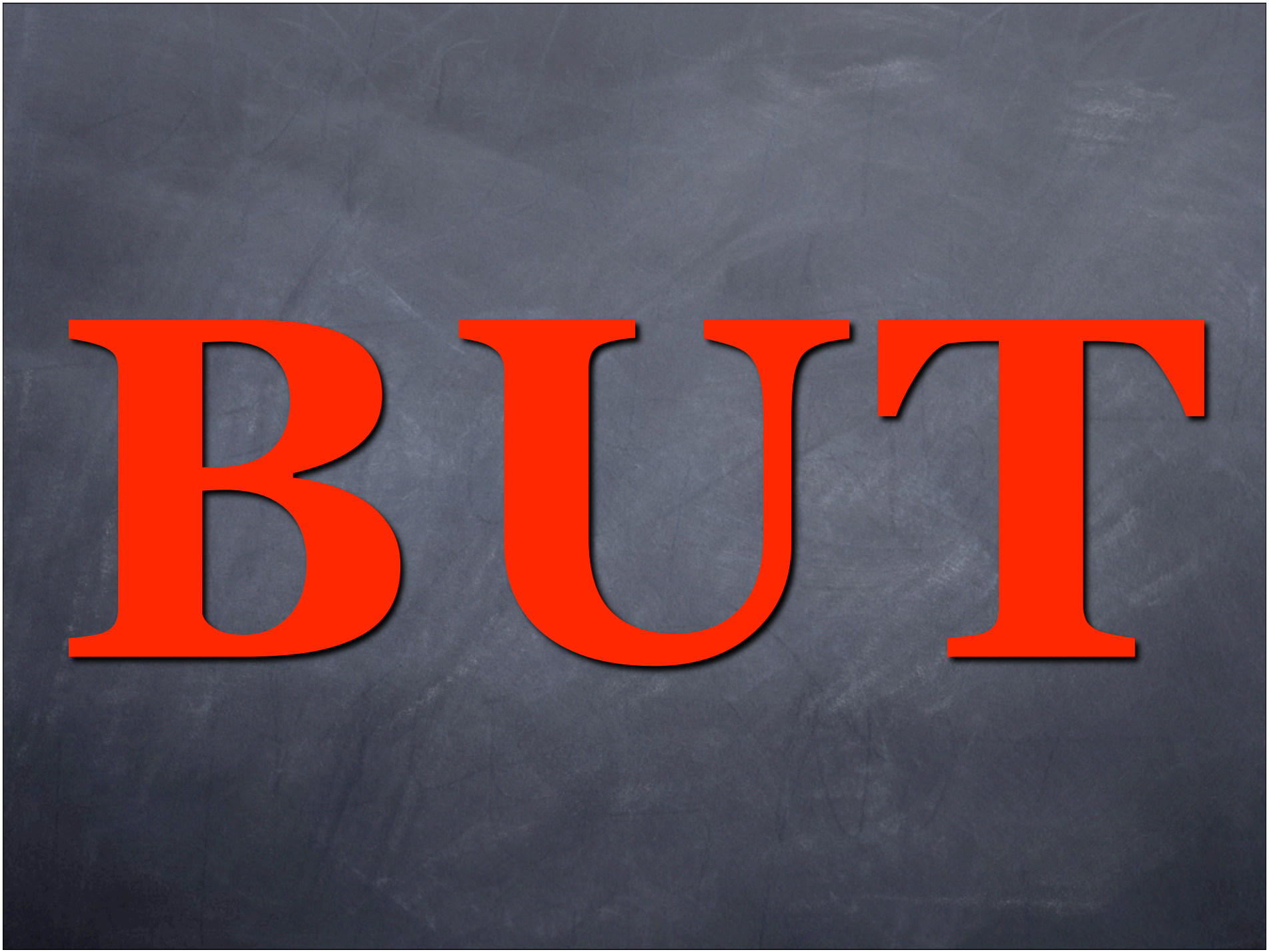

THE LANDSCAPE
UNIVERSE A
UNIVERSE B
THE ANTHROPIC PRINCIPLE

There exist a large number of "universes" within which many (most?) of the fundamental parameters (laws, ..?) vary and the parameters that govern our universe and are necessary for life are rare.

Many String "vacua" (10^{500}, ∞) with varying Λ,...

There exists a dynamical mechanism that populates the ensemble of "universes".

Eternal Inflation


BUT

The “vacua” of string theory are all meta-stable, most are uncontrollable and none constitute a consistent cosmology.

The mechanism of eternal inflation is technically and conceptually shaky.

CAN WE EXPLAIN

$$\Lambda_{\text{observed}} \sim 10^{-4}\text{ev}^4$$

or

$$\frac{\Lambda_{\text{observed}}}{\Lambda_{\text{susy}}} \sim 10^{-64}$$

or

$$\left(\frac{\Lambda_{\text{observed}}}{\Lambda_{\text{susy}}}\right)^{1/4} \sim 10^{-16}$$

DIRAC (1937)
The Large Number Problem

$$\frac{M_{\rm proton}}{M_{\rm planck}} \sim 10^{-19}$$

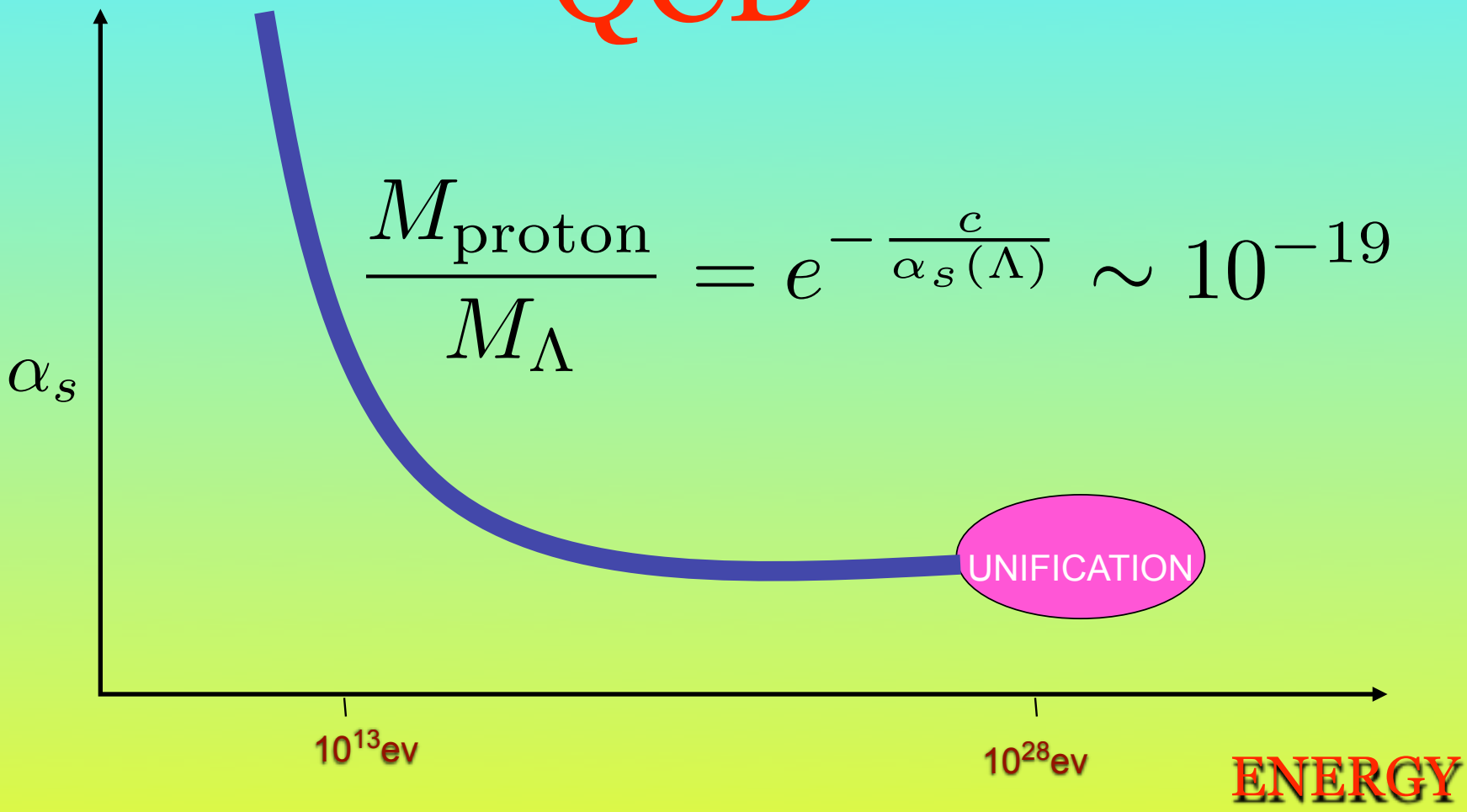
Dirac did not invoke anthropic arguments.

He suggested that this ratio was related to the size of the universe in atomic units

-----> prediction that $\dot{G}_N \, , \, \dot{\alpha} \neq 0$

QCD

$$\frac{M_{\text{proton}}}{M_\Lambda} = e^{-\frac{c}{\alpha_s(\Lambda)}} \sim 10^{-19}$$



The Hierarchy

$$\frac{M_{\rm ew}}{M_{\rm Gut}} \sim 10^{-16}$$

Supersymmetry
+ Logarithms

Neutrino Masses

Seesaw
Mechanism

$$M_\nu \sim 1eV \sim \frac{M_{\rm Dirac}}{M^2_{Majorana}}$$

The problem is not that

$$\left(\frac{\Lambda_{\text{obs.}}}{\Lambda_{\text{est.}}}\right)^{\frac{1}{4}} \sim 10^{-16}$$ is so small .

The problem is that we do not understand any mechanism that could determine Λ .

THE DANGERS OF THE ANTHROPIC PRINCIPLE

Hard (impossible) to falsify, often tautological.

Goes against history.

The entire normal observable world is, in principle, explainable in terms of the standard model of physics, with very few parameters without resorting to AP. Indeed the understanding of atomic physics, and thus the properties of ordinary matter, atomic physics, chemistry & life, require only the principles of QM, the existence of nuclei, the theory of electromagnetism and one undetermined number that measures the strength of the electric force.

Easy way out. Thrives on ignorance.

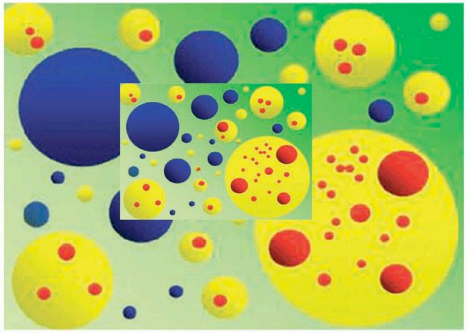
The message in a nutshell

•Origin of life is a chicken and egg problem: in order for biological evolution to take off, efficient systems for replication and translation are required, but these systems themselves appear to be products of extensive selection

•The standard solution is an ***RNA World*** without proteins in which replication is catalyzed by ribozymes and from which the translation system somehow emerges. However, the feasibility of the RNA world is dubious at best, and the path to translation is obscure

•The ***Many Worlds in One*** version of the cosmological model of eternal inflation (Vilenkin-Garriga) might offer a viable alternative
-all macroscopic histories permitted by conservation laws are repeated an ***infinite number of times in the infinite universe***
-this dramatically expands the range of possibilities for the transition from chance to biological evolution in the history of life

"Bubbles with different properties nucleate and expand in the inflating high-energy background. We live in one of the bubbles and can observe only a tiny part of it." Alex Vilenkin, *Science* 26 May 2006



•complex systems ***inevitably*** emerge by chance

•biological evolution ***could*** start with a coupled system of replication and translation, hence ***NO*** bona fide RNA world (albeit key role of RNA in the origin of life)

•However improbable (***rare*** – in the infinite universe) the emergence of such a complex system by chance might be, its occurrence in our universe could be made inevitable by ***anthropic selection***

So, since:

We are not sure what the final theory is and what the rules of the game are.

We suspect that space and time are emergent concepts. In view of this our understanding of the foundations are pretty shaky and we cannot claim to know the selection mechanism for the universe.

And finally, just because we cannot produce the solution is not evidence that it does not exist.

We Should Not Give Up!

THE STRATEGY

CALCULATE

CALCULATE

CALCULATE

& OBSERVE

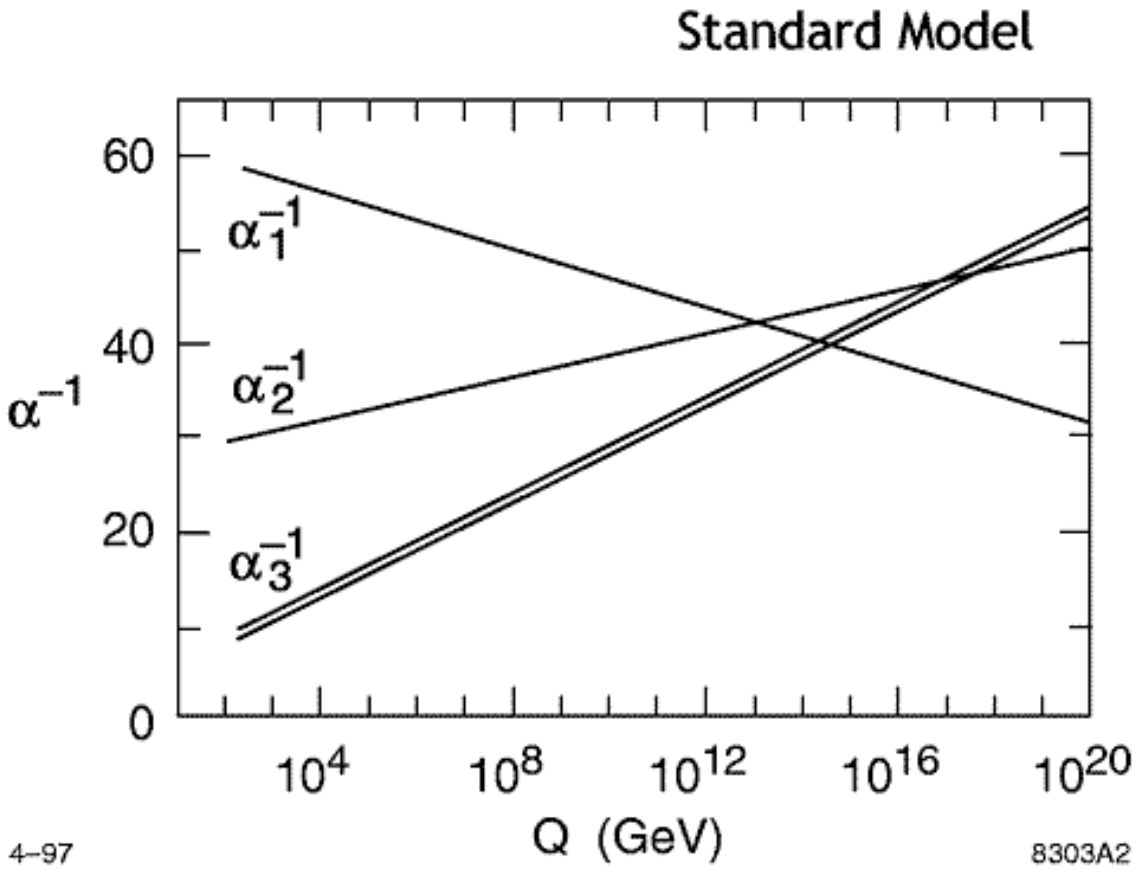
SUPERSYMMETRY

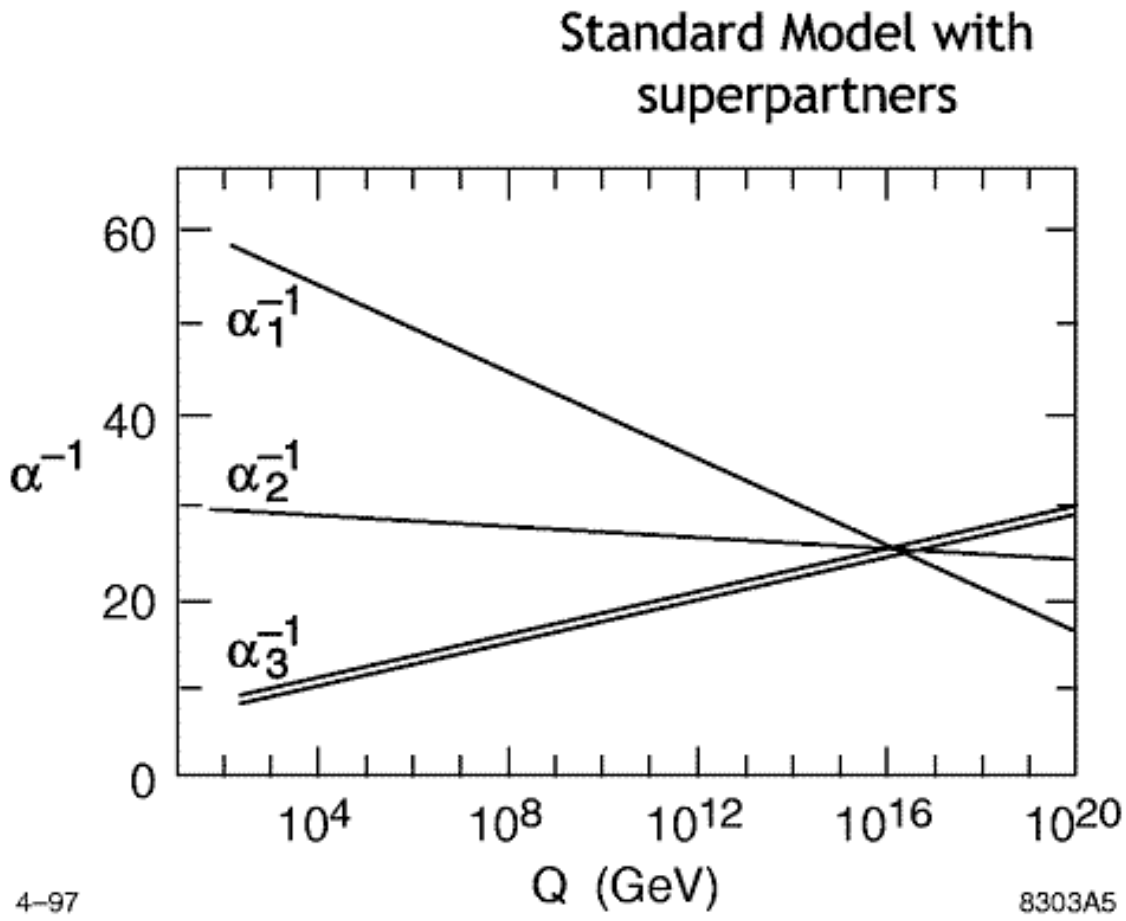
STRING THEORY

The Hierarchy Problem → TeV

Dark Matter → TeV

Coupling Constant Unification → TeV


Standard Model
60
40
20
0
α^{-1}
α_1^{-1}
α_2^{-1}
α_3^{-1}
10^4
10^8
10^{12}
10^{16}
10^{20}
Q (GeV)
4–97
8303A2


Standard Model with
superpartners
60
40
20
0
α^{-1}
α_1^{-1}
α_2^{-1}
α_3^{-1}
10^4
10^8
10^{12}
10^{16}
10^{20}
Q (GeV)
4–97
8303A5


The LARGE HADRON COLLIDER
could discover the SUPER WORLD.

We wish all the best for

THE KITPC