

THE FUTURE OF PHYSICS

DAVID GROSS

CERN

January 26, 2005

On October 7, 2004 the KITP celebrated:

25 years of the Institute for Theoretical Physics

The inauguration of the new wing of the KITP

The “ Future of Physics ” conference

&

The 2004 Nobel Prize in Physics





Kungliga
Svenska Vetenskapsakademien
har den 5 oktober 2004 beslutat
att med det

NOBELPRIS

som detta år tillerkännes den som inom
fysikens område gjort den viktigaste
upptäckten eller uppfinnningen
gemensamt belöna

David J Gross

∓ David Politzer och Frank Wilczek
för upptäckten av asymptotisk frihet
i teorin för den starka växelverkan

• STOCKHOLM DEN 10 DECEMBER 2004 •

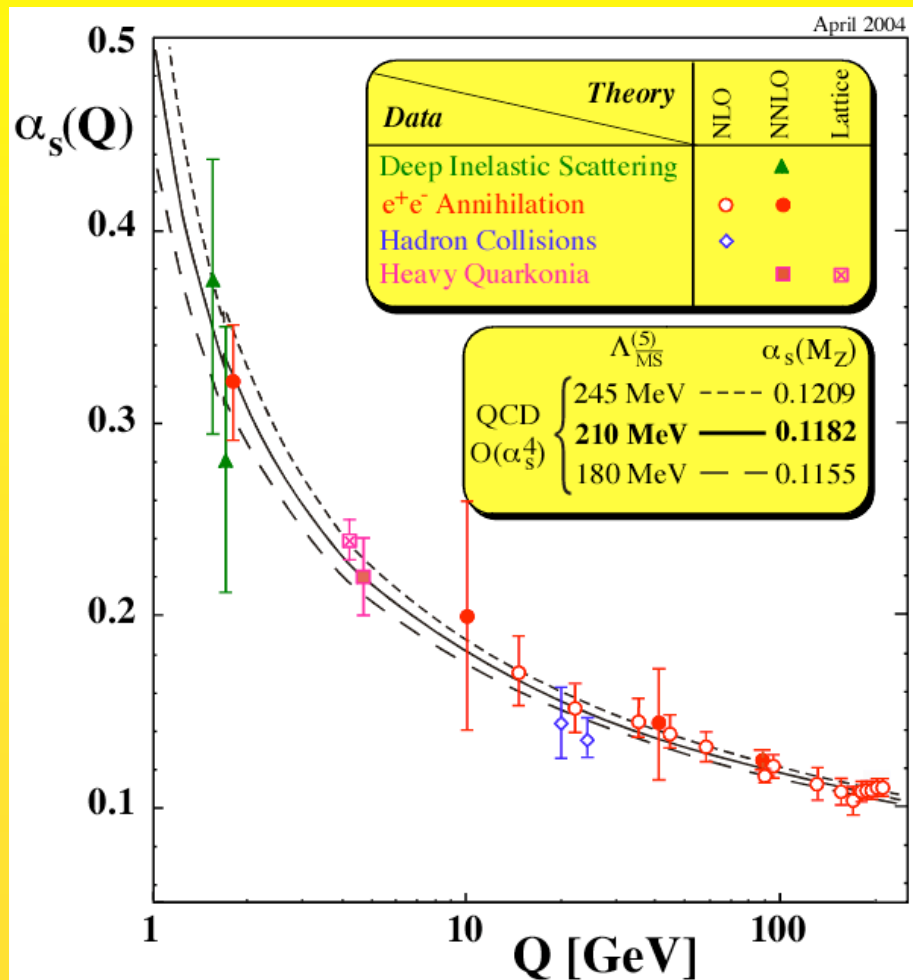
Jan Lindholm



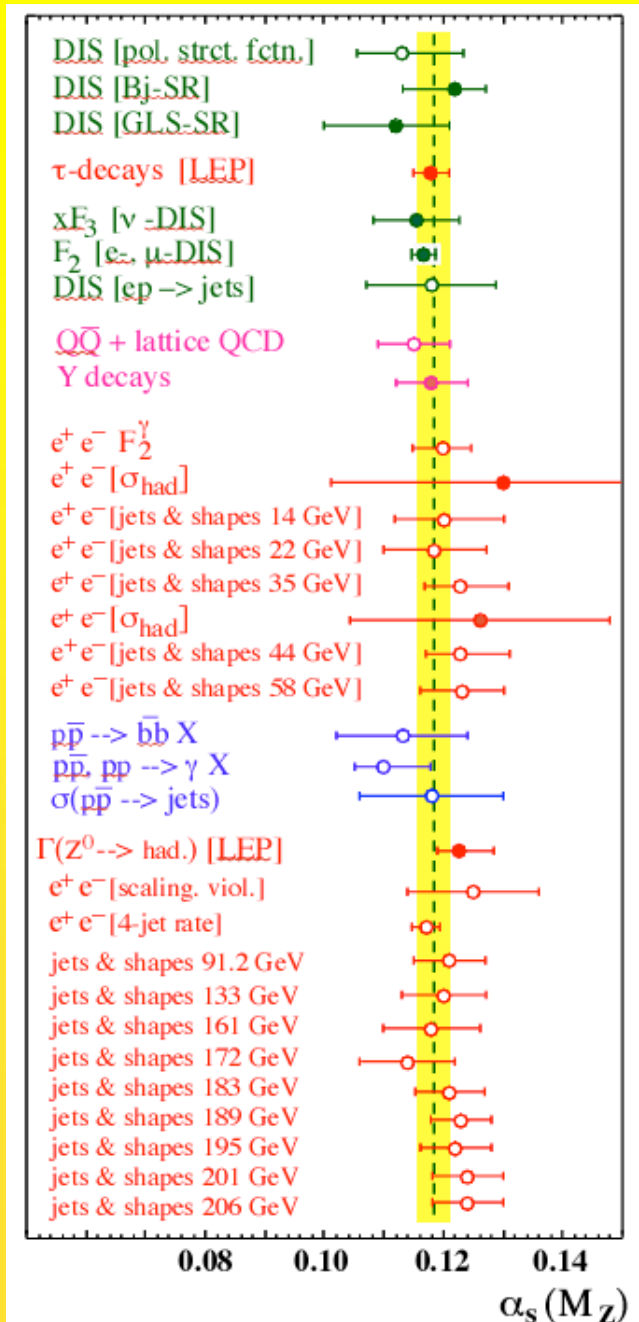
Arvid Carlsson

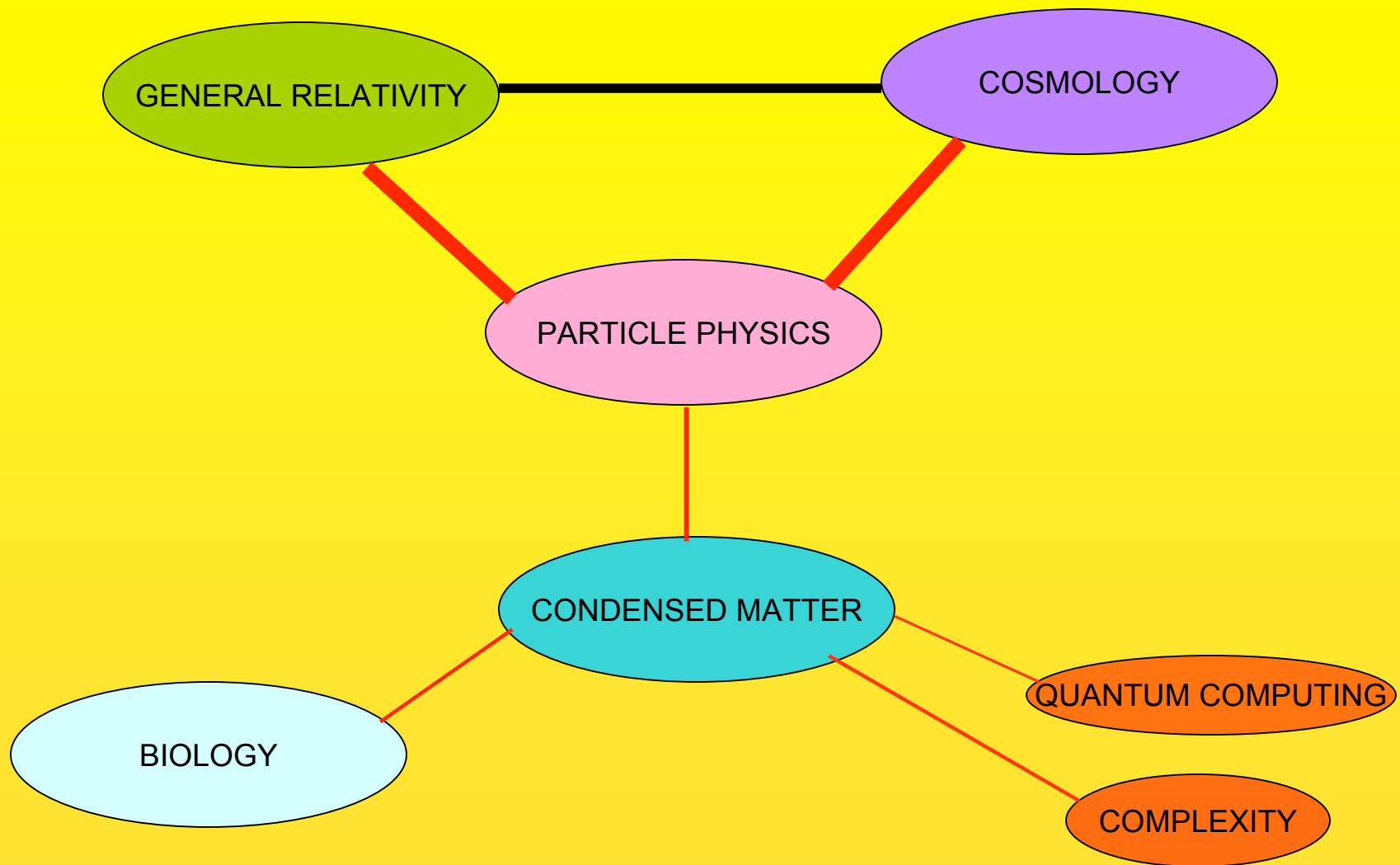
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THE DISCOVERY, EXPLORATION, VERIFICATION AND UNDERSTANDING OF QCD IS DUE TO THE REMARKABLE WORK OF MANY EXPERIMENTERS AND THEORISTS OVER 40 YEARS !

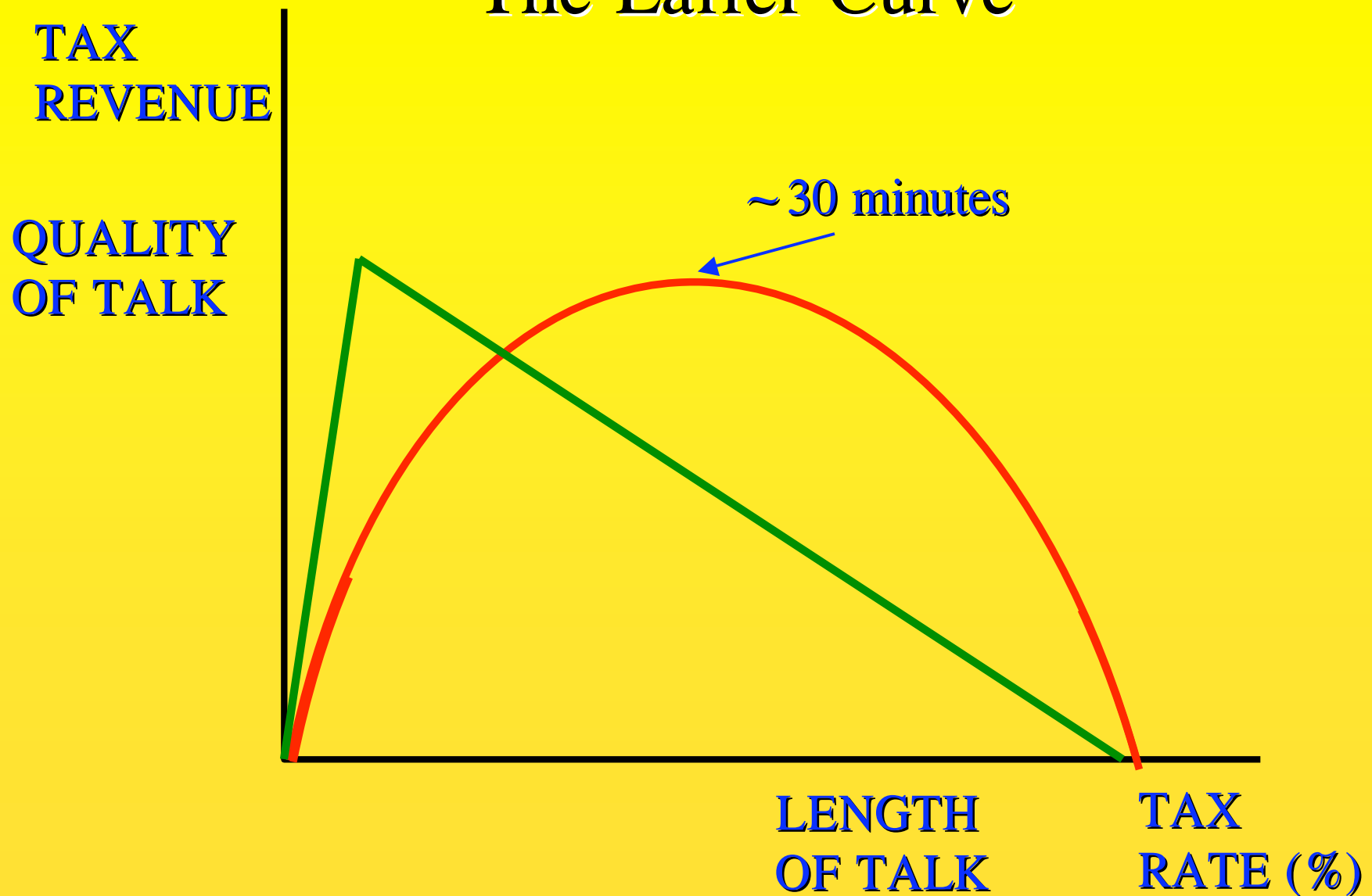


World summary of $\alpha_s(M_Z)$



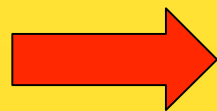


The KITP Curve The Laffer Curve



**WE HAVE LEARNED A LOT
IN THE LAST 25--35 YEARS**

**THE MOST IMPORTANT
PRODUCT OF KNOWLEDGE
IS IGNORANCE**



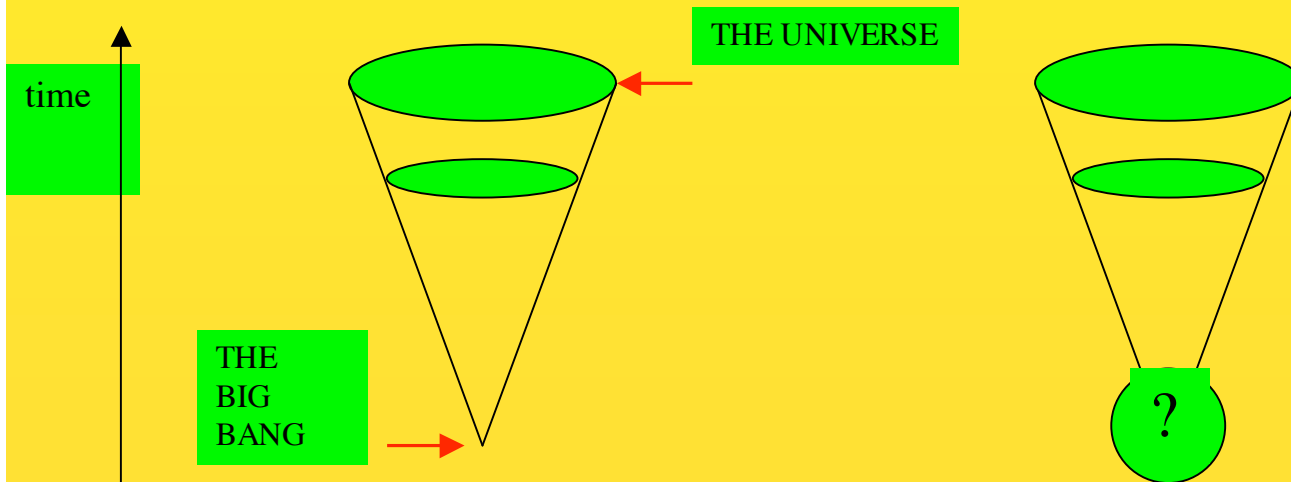
25 QUESTIONS

THE ORIGIN OF THE UNIVERSE

How Did the Universe Begin?

How far back can we probe?

Can we determine the initial conditions?
Time itself is an emergent concept?
Big crunch \rightarrow Big Bang or cyclic?



DARK MATTER

25%

What is the Nature of Dark Matter?

How does dark matter interact with ordinary baryonic matter ? Is it wimpy?

Can we detect it in the laboratory?

How is it Distributed in the Universe?

What does this tell us about structure formation?

DARK ENERGY

70%

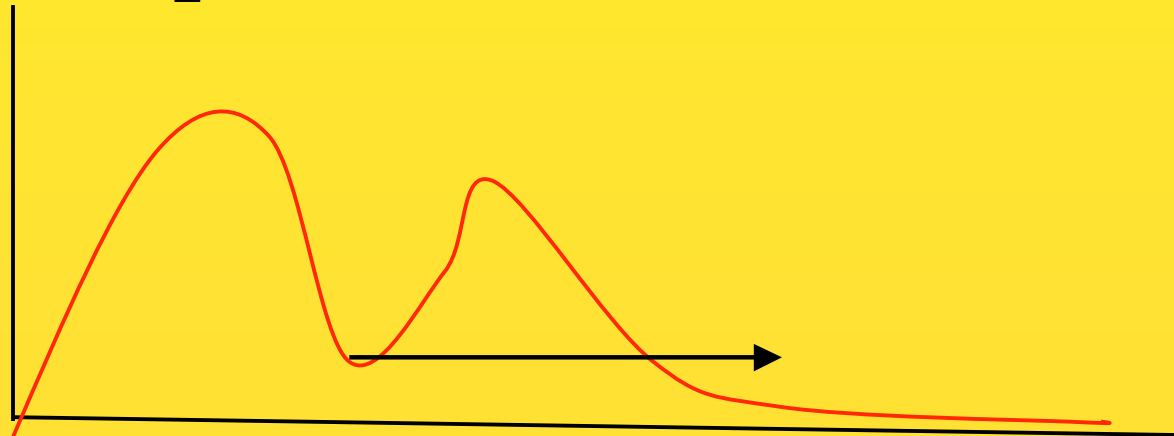
What is the Nature of the Dark Energy?

Is it just Λ ?

Is it constant?

Can we tell?

Is DeSitter Space Stable?



FORMATION

How Do Stars Form?

How do we understand the spectrum of masses, frequency of binaries, and cluster?

How Do Planets Form?

What is the frequency of habitable planets ?

GENERAL RELATIVITY

Is Our Current Understanding of General Relativity Correct at All Scales?

Will strong gravity survive observational tests via gravitational wave astronomy?

Can we use astrophysical observations to determine whether the Kerr metric correctly describes the geometry around black holes?

QUANTUM MECHANICS

Is quantum mechanics the ultimate description of nature?

Will it fail at very short distances
or in large complex systems
or in conscious systems
or as a description of the universe ?

MYSTERIES OF THE STANDARD MODEL

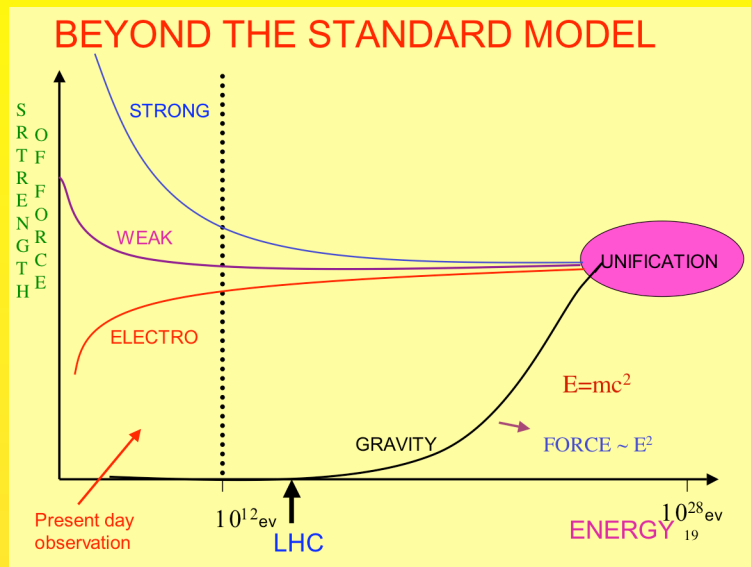
The masses and mixings of the quarks
and leptons

The origin of baryons & the proton
lifetime



SUPERSYMMETRY

IS THERE LOW ENERGY SUPERSYMMETRY?



HOW IS IT BROKEN?

ONCE WE KNOW THE SPECTRUM, CAN WE WORK THE OTHER WAY, TO FIND EVIDENCE FOR THE INTERACTIONS OR GEOMETRY THAT IS PRESENT AT THE GRAVITY SCALE?

Q C D

CAN WE SOLVE QCD?

CAN WE CONSTRUCT A USEFUL
DUAL STRING DESCRIPTION
OF HADRONS FOR LARGE N_C ?

WHAT IS STRING THEORY?

THE LESSONS OF DUALITY?

Threats to our notions of

ELEMENTARITY

&

LOCALITY

WHAT IS SPACE-TIME?

Is space-time doomed?

“Space and time may be doomed.” *E. Witten*

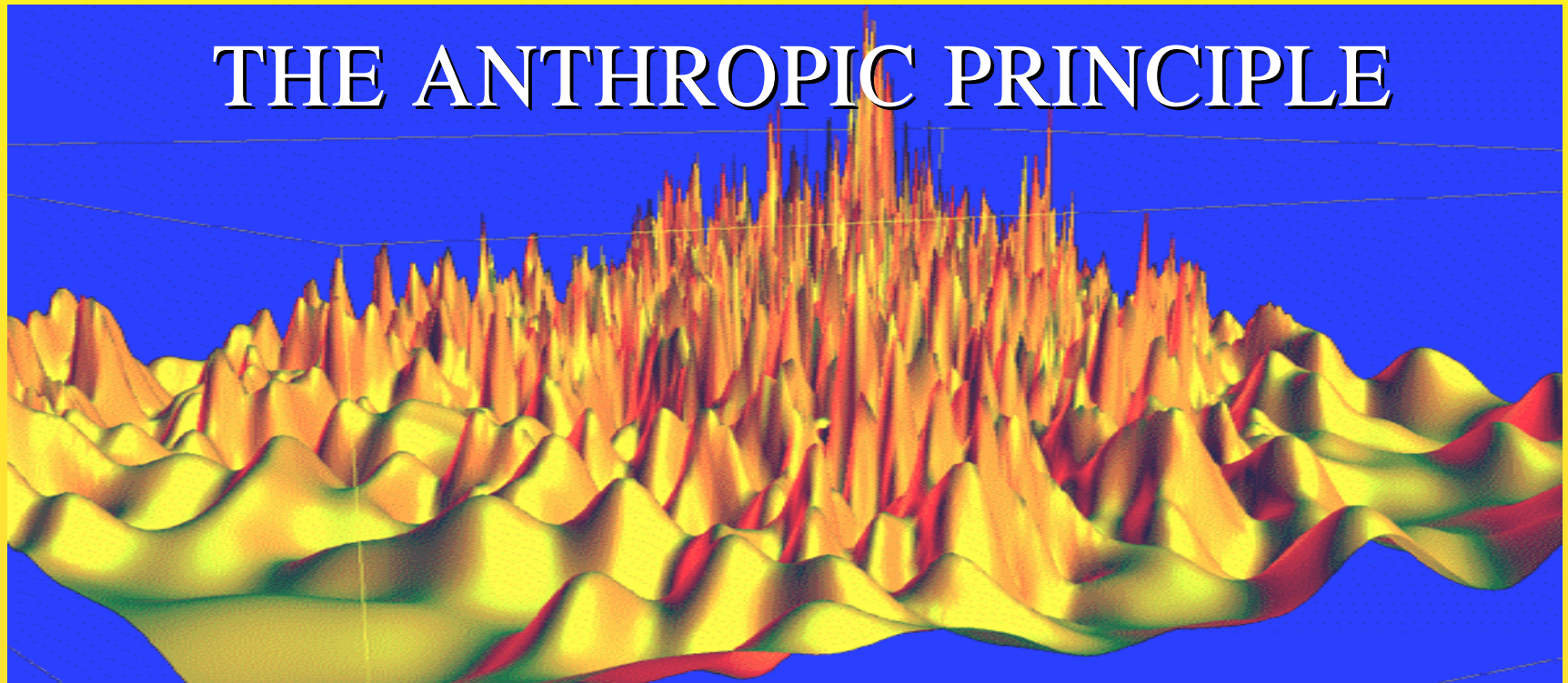
“I am almost certain that space and time are illusions.” *N. Seiberg*

CAN WE IMAGINE
THAT TIME IS EMERGENT?

Are All the Parameters and Laws That
Characterize the Physical Universe Calculable
(in Principle) or Are Some Determined By
Historical or Quantum Mechanical Accident ?

“NATURE IS CONSTITUTED SO THAT IT IS

THE ANTHROPIC PRINCIPLE



Kinematics, Dynamics and Initial Conditions

Traditional physics distinguishes between

KINEMATICS

The framework for
physics and its
interpretation

&

DYNAMICS

The specific laws of
nature and the forms
of matter

Quantum Field Theory

The Standard Model

I suspect that, as we learn to understand string theory and explore the nature of space-time, the distinction between Kinematics and Dynamics will be blurred.

Quantum Mechanics may emerge as more inevitable and perhaps less mysterious.

NEW STATES OF MATTER

Are there generic non-Fermi liquid behaviors of interacting condensed matter systems which are, in principle, accessible experimentally in a routine manner (e.g. topological quantum matter)?

COMPLEXITY

What is the theory of very large complex dynamical systems. As our computers become more and more powerful, we are trying to use them to make predictions about the earth's climate, chemical processes in biological cells, and ultimately the human brain.

We know that intrinsic limits of predictability must exist because these systems generally have chaotic features; however, we usually have lots of trouble identifying those features and separating them from less interesting behaviors.

So what do we do??

QUANTUM COMPUTERS

WILL QUANTUM COMPUTERS BE QUIET OR DEAF?

The key obstacle is decoherence: outside perturbations that reduce the quantum computer to a merely classical one. Two almost opposite strategies to combat this problem are to reduce as much as possible this offending noise by isolating the quantum bits far from any “environment”, or instead to construct “topological” quantum bits that are delocalized and subtly expressed so that they are decoupled from the noise all around them.

CAN WE CONSTRUCT A REAL QUANTUM COMPUTER? (> 10,000 QUBITS)

APPLICATIONS

Can we understand how to make a material that is superconducting at room temperature and beyond?

Can we understand how to make a room temperature ferromagnet out of engineerable electronic (semiconducting) materials?

THEORETICAL BIOLOGY

Is there a theory of biology?
Can theoretical physics help?
Is new mathematics required?

How do we think about, analyze and model systems, like many in biology, that exhibit dynamics over many, wide-ranging time scales?

GENOMICS

Can the theory of evolution be quantitative and predictive?

Can one tell the shape of an organism by looking at its genome?

CONSCIOUSNESS

What are the principles that underlie the self-organization responsible for memory and consciousness?

Can one measure the onset of consciousness in an infant?

Can one make a machine with free will, with teleonomic behavior?

COMPUTATIONAL PHYSICS

Will computers replace analytic techniques?

If so how should we modify the training of physicists?

When will computers become creative theoretical physicists?

How will we train them?

BALKANIZATION

Given the diversity of physics---from string theory to wet biology could physics splinter into identifiable subgroups offering separate graduate education?

Will the balkanization of physics continue, so that we will become a bunch of specialized sub-fields and important centers of excellence, **such as the KITP**, will no longer be relevant?

REDUCTIONISM

We tend to take it for granted that because big things are made of little things, the behavior of the big things must be entirely determined, at least in principle, by that of the little things.

Is this any more "obviously" true than (was) the idea that nature cannot tell the difference between her left hand and her right hand??

THE ROLE OF THEORY

What is the proper role of theory in the physics and in science more generally? Is theory a handmaiden of experiment, so that it is to be judged primarily on its ability to predict the outcome of actual experiments? Or, is the goal rather to achieve a "higher" level of understanding, which might focus on the solution of well-defined mathematical models, consistent with general physical principles, regardless of whether such models are realizable in practice in the world?

How much value do we assign to simplicity and mathematical elegance, versus ability to describe complicated systems with all their details?

DANGERS

One can see traditional "big" physics (including astrophysics) projects becoming unrealizable over the next 25 years. The questions are still likely to be there. What new approaches should be considered now and what should be the role of theorists in doing this?

**WILL PHYSICS CONTINUE
TO BE IMPORTANT?**

**WILL THE KITP CONTINUE
TO BE IMPORTANT?**

YES?

Thank You

THE END

