THE COMING REVOLUTIONS IN FUNDAMENTAL PHYSICS

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Hannibal

By Thomas Harris

(Sequel to *The Silence of the Lambs)*

LATE IN THE NOVEL:

> *" Lecter sits in his armchair with a big pad of butcher paper doing calculations. The pages are filled with the symbols both of astrophysics and particle physics. There are repeated efforts with the symbols of* ***string theory****.*
> *The few mathematicians who could follow him might say his equations begin brilliantly and then decline, doomed by wishful thinking."*

OUTLINE

THE TEN TOP QUESTIONS

THREE POSSIBLE

CONCEPTUAL REVOLUTIONS

CAN WE CONSTRUCT A
THEORY OF EVERYTHING?

THE TOP TEN QUESTIONS

Chosen at STRINGS 2000 by

M. Duff, E. Witten and D. Gross

EXCLUDED QUESTIONS:

- Important, Fundamental Questions in other Fields of Physics: Condensed Matter, Astrophysics, Biophysics
- Personal Questions:
  - How does one get tenure?

THE TOP TEN QUESTIONS

1) Are all the (measurable) dimensionless parameters that characterize the physical universe calculable in principle or are some merely determined by historical or quantum mechanical accident and uncalculable ?

2) How can quantum gravity help explain the origin of the universe ?

3) What is the lifetime of the proton and how do we understand it ?

4) Is Nature supersymmetric, and if so, how is supersymmetry broken ?

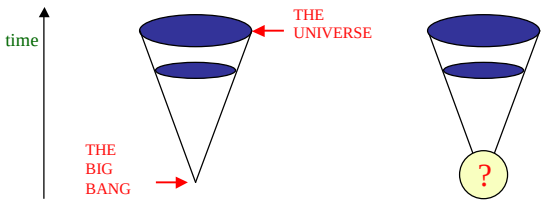
5) Why does the universe appear to have one time and three space dimensions ?

THE INITIAL CONDITIONS OF THE UNIVERSE

Traditional Physics States: Given the state of the system at t=0, **Initial Conditions, &** the **Laws of Physics** we can predict the state of the system at later times.

But as Space-Time (or whatever replaces it) is dynamical, the origin of the universe is a scientific issue.

STRING THEORY MIGHT ALLOW US, INDEED REQUIRE US, TO UNDERSTAND THE PRINCIPLE THAT FIXES THE INITIAL CONDITIONS OF THE UNIVERSE, AND THUS PREDICT ITS FATE.



THE TOP TEN QUESTIONS

3) What is the lifetime of the proton and how do we understand it ?

PROTONS SHOULD DECAY

Diamonds are not for ever

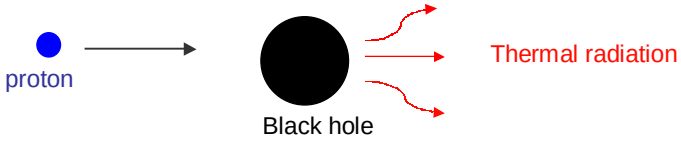
1. IN A UNIFIED THEORY WE EXPECT PROTON DECAY

Lifetime ~ $1/ M^4_{planck} \sim 10^{34\text{-}40}$ years

2. IF WE ARE TO UNDERSTAND THE BARYON ASYMMETRY OF THE UNIVERSE------> PROTONS MUST DECAY

3. IN THE STANDARD MODEL INSTANTONS PRODUCE PROTON DECAY

4. THERE ARE NO GLOBAL CONSERVATION LAWS IN ANY THEORY CONTAINING (QUANTUM) GRAVITY.



THE TOP TEN QUESTIONS

4) Is Nature supersymmetric, and if so, how is supersymmetry broken?

SUPERSYMMETRY is a natural and unique extension of relativistic and general relativistic symmetries of nature

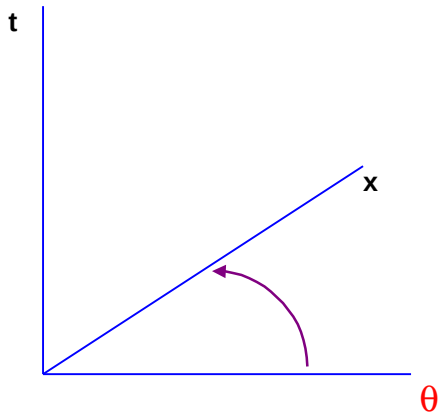
SUPERSYMMETRY unifies:

FERMIONS ---- The constituents of MATTER

BOSONS ---- The quanta of FORCE

The discovery of SUPERSYMMETRY is tantamount to the discovery of quantum dimensions of space-time

SUPERSPACE

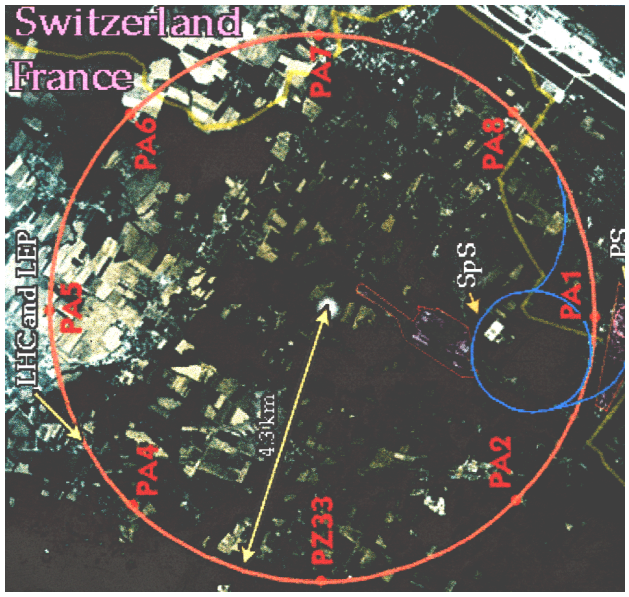


$$\theta_1 \theta_2 = -\theta_2 \theta_1$$

In Supersymmetric Theories for every Particle there exists A Super-Partner

Quark ---- Squark
Electron---Slectron
Photon ---Photino
Graviton---Gravitino

CERN Site of LEP $e^+ e^-$ and LHC p p Colliders



14 TEV

5 MILES

What Can We Expect From Experiment?

COMPLETION OF THE STANDARD MODEL

The HIGGS, CP Violation, Neutrino Masses

THE DISCOVERY OF SUPERSYMMETRY

A vast new world of particles

? String Effects

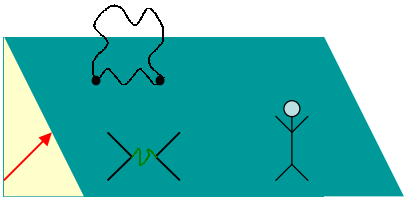
5) WHY DOES THE UNIVERSE APPEAR TO HAVE ONE TIME AND THREE SPACE DIMENSIONS?

In any theory containing gravity the global structure of Space-time is a dynamical question.

In String theory there are 9 or 10 spatial dimensions:

But 6 are compactified

Or-- we live on a BRANE



WHY is there only 1 time?

6) Why does the cosmological constant have the value that it has, and is it zero?

7) What are the fundamental degrees of freedom of M-theory and does the theory describe nature?

8) What is the resolution of the black hole information paradox?

9) What physics explains the enormous disparity between the gravitational scale and the typical mass scale of the elementary particles?

10) Can we understand quark and gluon confinement in Quantum Chromodynamics and the existence of a mass gap? (Worth $1,000,000)

THE COSMOLOGICAL CONSTANT

$\Lambda g_{\mu\nu}$ Vacuum Energy Density

Receives contributions from 0-point fluctuations of all fields

Might expect that $\Lambda \sim M^4_{planck} \sim 10^{120}$ ev^4

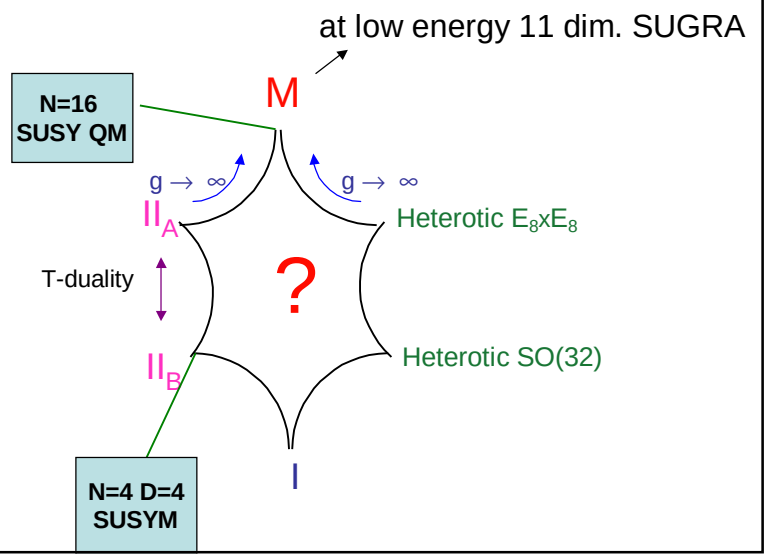
SUSY helps---but is broken ----> $\Lambda \sim M^4_{susy} \sim 10^{48}$ ev^4

EXPERIMENT: $\Omega_\Lambda \sim \Omega_c \sim 10^{-8}$ ev^4

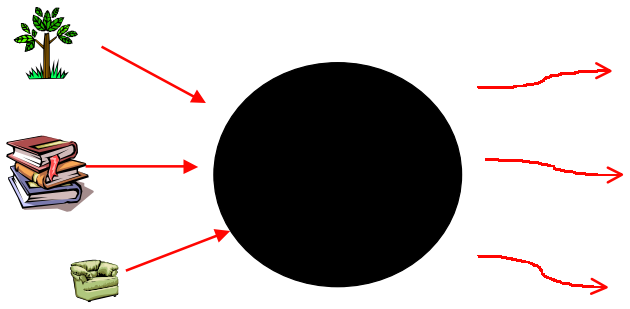
STRING THEORY HAS PROBLEMS WITH $\Lambda > 0$

? Finite number of degrees of freedom ?

7) What are the fundamental degrees of freedom of M-theory and does the theory describe nature?



8) What is the resolution of the black hole Information paradox?



Ordered stuff falls in Disordered radiation is emitted

INFORMATION APPEARS TO BE LOST
THE LAWS OF QUANTUM MECHANICS ARE VIOLATED

9) What physics explains the enormous disparity between the gravitational scale and the typical mass scale of the elementary particles?

The traditional answer is SUSY M_{susy} ~Tev

Converts the hierarchy of 10^{19} to $\log(10^{19}) \sim 1/g^2(M_{susy})$

BUT in BRANE WORLD SCENARIOS

$M_{planck} \sim M_{unif} \sim M_{string} \sim$ 1-10 Tev

10) Can we understand quark and gluon confinement in Quantum Chromodynamics?

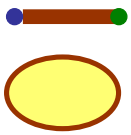
(Worth $1,000,000 from the Clay Institute)

BEST STRATEGY: Solve for QCD in the large N_{color} limit

N= # of colors(3) $\rightarrow \infty$ Ng^2 fixed

- Spectrum of non-interacting hadrons, coupling ~1/N

≡ HADRONIC STRING THEORY



Mesons

Glueballs

This Question can benefit from and contribute to our understanding of string theory.

THE ACHIEVEMENTS OF THE 21st CENTURY

3 (possible) CONCEPTUAL REVOLUTIONS

The Nature of Space-Time

The Initial Conditions of The Universe

The Unity of Kinematics and Dynamics

THE NATURE OF SPACE - TIME

"Space and time may be doomed." *E. Witten*

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

"The notion of space-time is clearly something we're going to have to give up." *A. Strominger*

"If you ask questions about what happened at very early times, and you compute the answer, the answer is: Time doesn't mean anything." *S. Coleman*

"The real change that's around the corner is in the way we think about space and time. We haven't come to grips with what Einstein taught us. But that's coming. And that will make the world around us stranger than any of us can imagine." *D. Gross*

WHY IS SPACE-TIME DOOMED ?

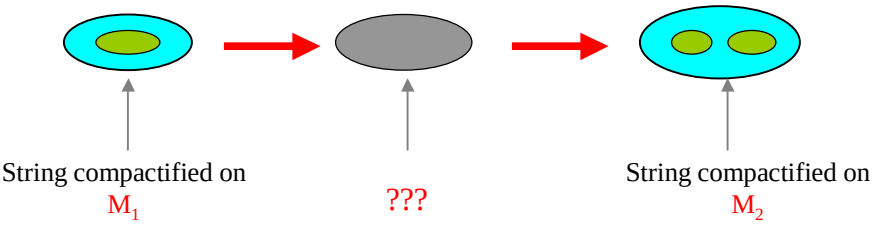
IN STRING THEORY WE CAN

- CHANGE THE NUMBER OF SPATIAL DIMENSIONS

II_A Theory in 10-d → M-theory in 11-d

$\lambda << 1$ $\lambda >> 1$

- CONTINUOUSLY TEAR THE FABRIC OF SPACE



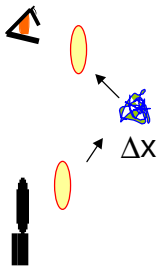
IN STRING THEORY WE CANNOT

- Probe arbitrarily small distances

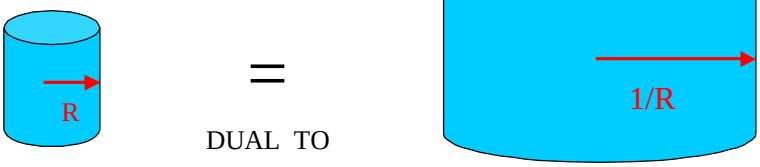
The String Uncertainty Principle

$$\Delta x = \frac{hc}{E} + \frac{GE}{c^4}$$

Strings expand at high energy



- Squeeze spatial volumes to zero size

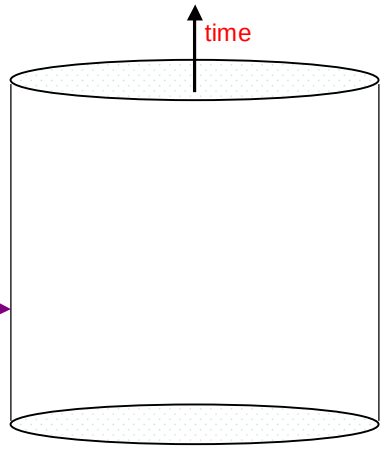


HOLOGRAPHY

The fundamental degrees of freedom of a consistent theory of gravity reside on the boundary of space time

T'Hooft

Susskind



N =4 Susy Gauge Theory On M_4

II_B String Theory on AdS_5

Maldacena

WE HAVE HINTS THAT SPACE-TIME CAN BE

REPLACED

Space (& time?) are emergent concepts

HOLOGRAPICALLY REPRESENTED

The fundamental degrees of freedom of a consistent theory of gravity reside on the boundary of space time

We are convinced that

By convention there is color,

" by convention there is space,

by convention sweetness,

by convention there is time,

by convention bitterness,

but in reality there are atoms and space.

but in reality there is …."

Democritus (400 B.C.)

THE UNIFICATION OF KINEMATICS AND DYNAMICS

Traditional physics distinguishes between

KINEMATICS	&	DYNAMICS
The framework for physics and its interpretation		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.

CAN WE GO ON FOREVER?

WE MAY BE TOO DUMB TO PROCEED

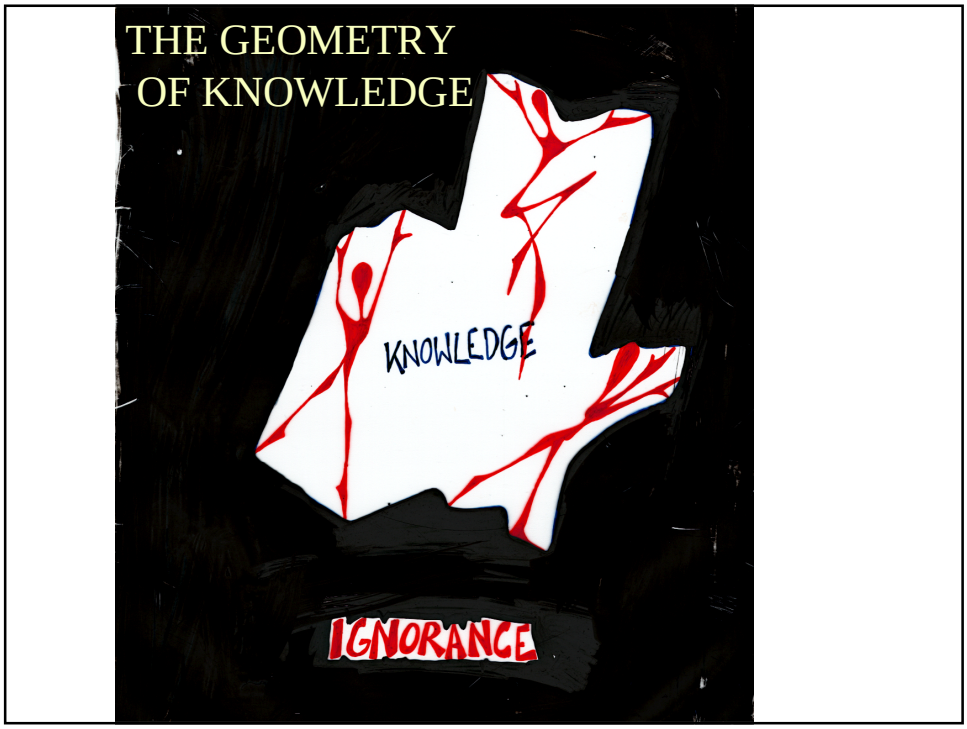
NO

WE MAY CONSTRUCT A FINAL THEORY

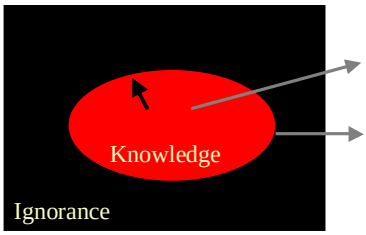
MAYBE

WOULD THIS BE THE END OF PHYSICS?

NO



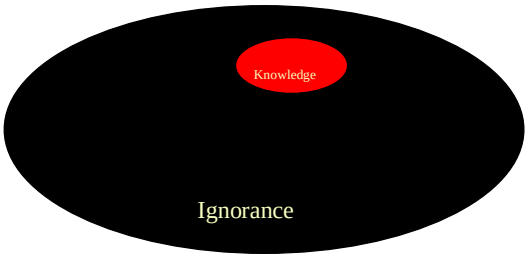
Knowledge, Ignorance and Wisdom



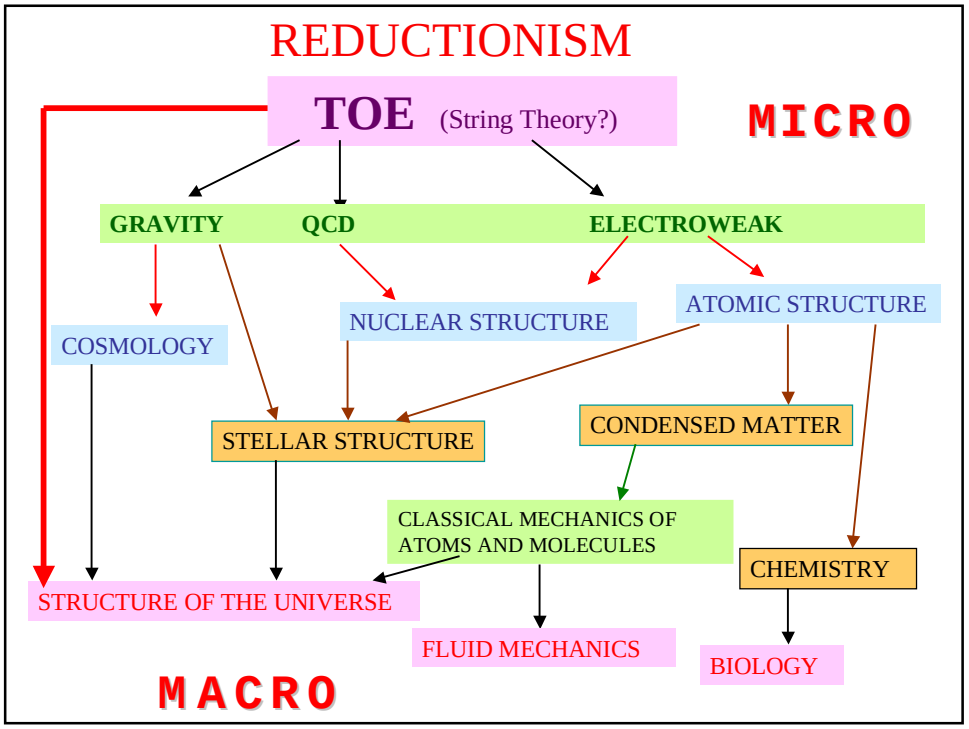
Knowledge ~ Volume

Ignorance ~ Surface

Wisdom ~ **Knowledge** / **Ignorance** ~ **Volume** / **Surface**



IS THE SEA OF IGNORANCE COMPACT?


REDUCTIONISM
TOE (String Theory?)
MICRO
GRAVITY
QCD
ELECTROWEAK
COSMOLOGY
NUCLEAR STRUCTURE
ATOMIC STRUCTURE
STELLAR STRUCTURE
CONDENSED MATTER
CLASSICAL MECHANICS OF ATOMS AND MOLECULES
CHEMISTRY
STRUCTURE OF THE UNIVERSE
FLUID MECHANICS
BIOLOGY
MACRO


THE
END