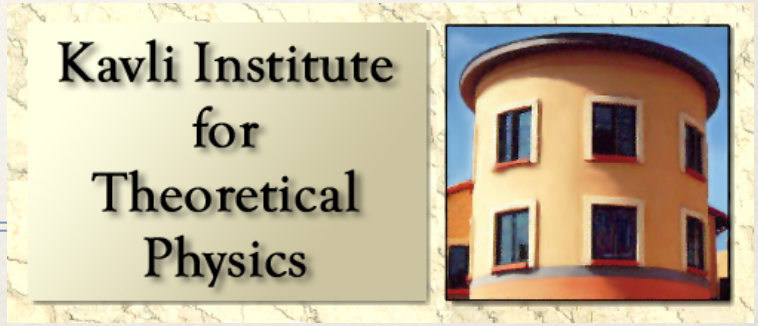
THE ROLE OF THEORY IN SCIENCE

THE INAUGURATION OF THE ICTS

Bangalore, December 28, 2009

DAVID GROSS



Prof. Nash, you have been awarded the Memorial Nobel Prize for Economic Science.

Is Economics a science?

He replied:

“No, any discipline that needs to add Science to its name isn’t ”.

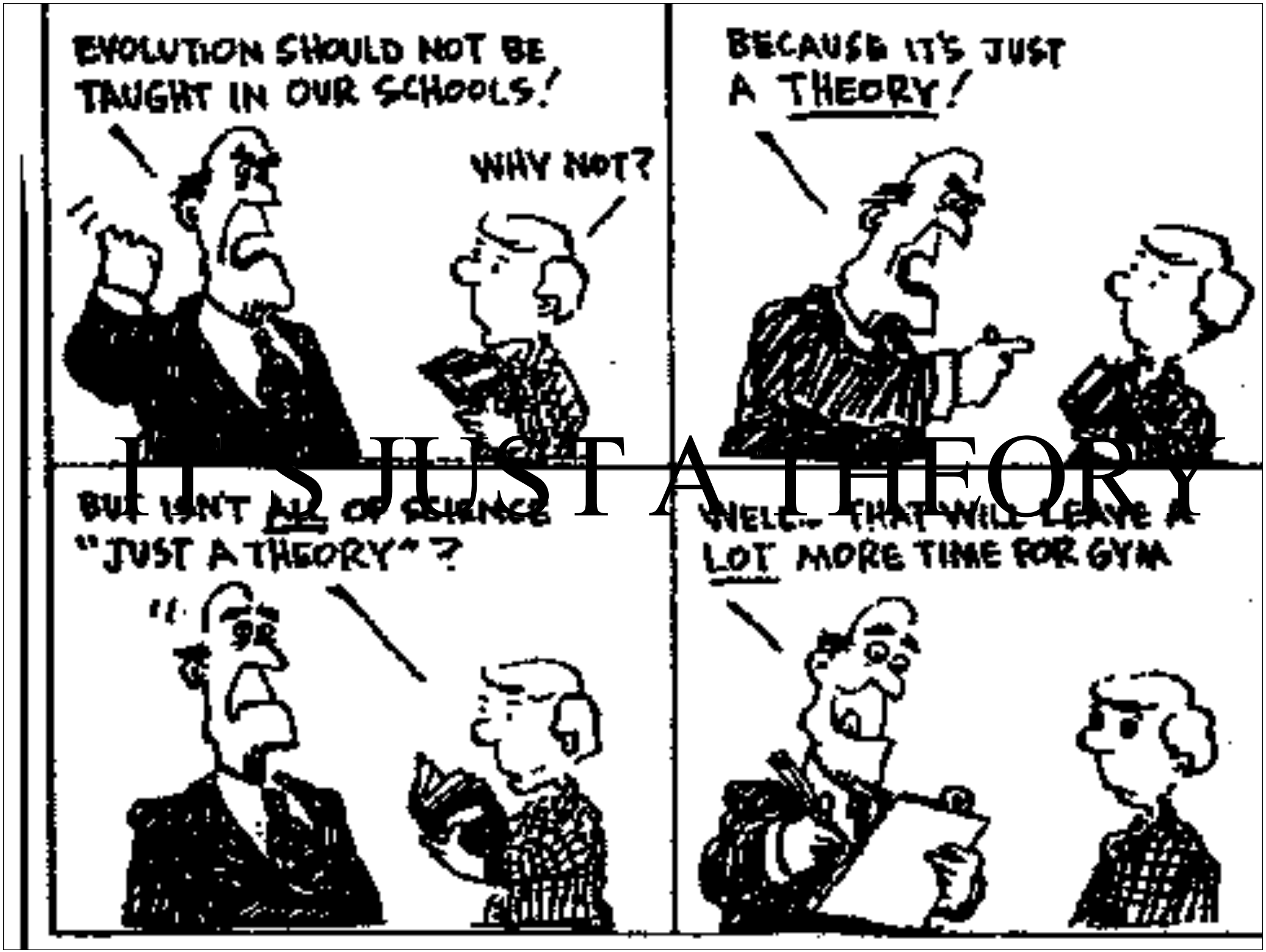
THE ROLE OF THEORY IN SCIENCE

THE ROLE OF THEORY INSTITUTES

OUR MINDS HAVE BEEN SHAPED BY NATURAL EVOLUTION TO CONSTRUCT MODELS (theories) OF THE WORLD IN ORDER TO SURVIVE AND PROSPER

Aristotle

Kanada



IT'S JUST A THEORY

The scientific method is based on the thesis that the final authority as to scientific truth is observation and experiment.

No theory or mathematical argument, no matter how compelling and beautiful, can be maintained in face of contradiction with observation or with experiment.

ARISTOTLE:

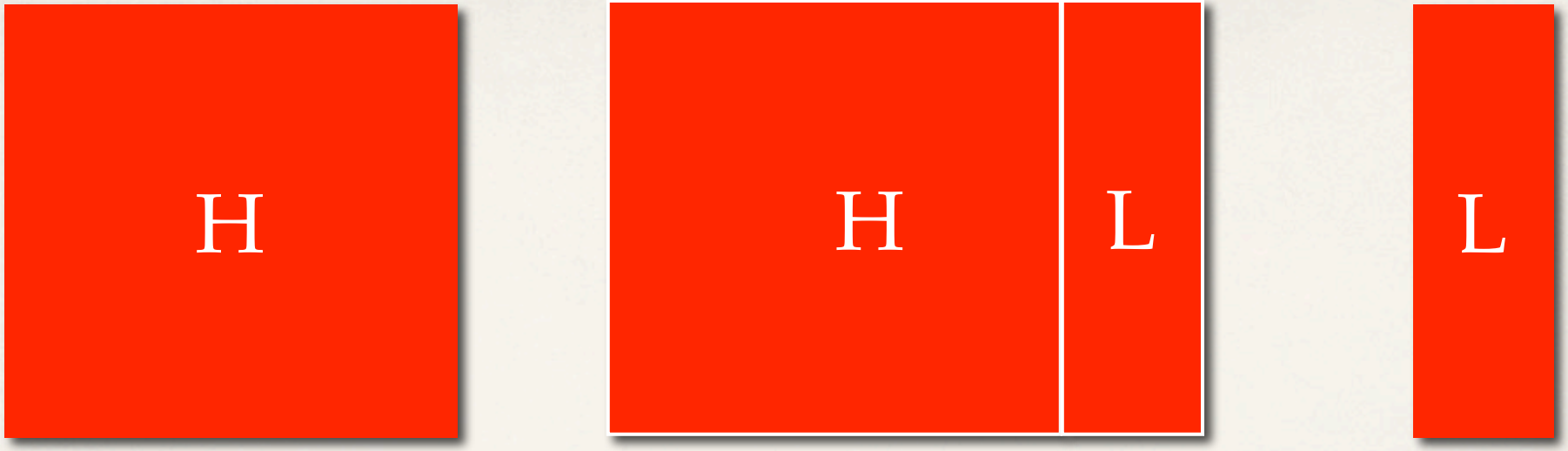
HEAVIER BODIES

FALL FASTER

GALILEO DISCOVERED THAT

ALL BODIES FALL WITH

THE SAME ACCELERATION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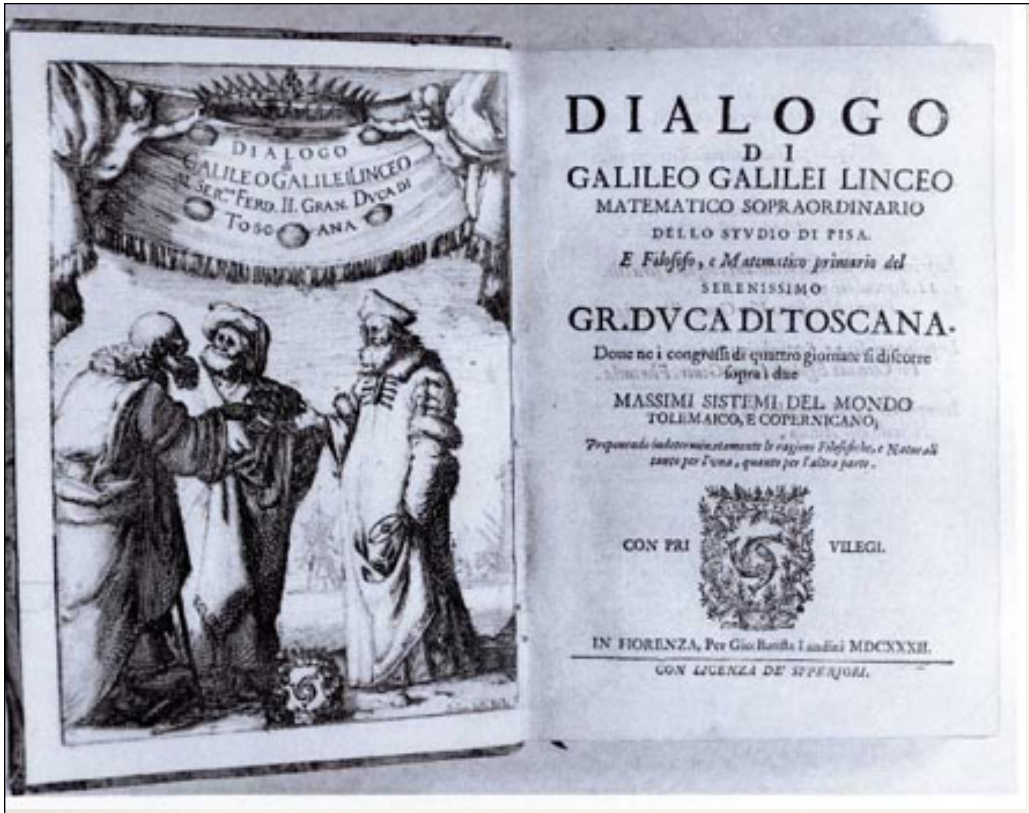


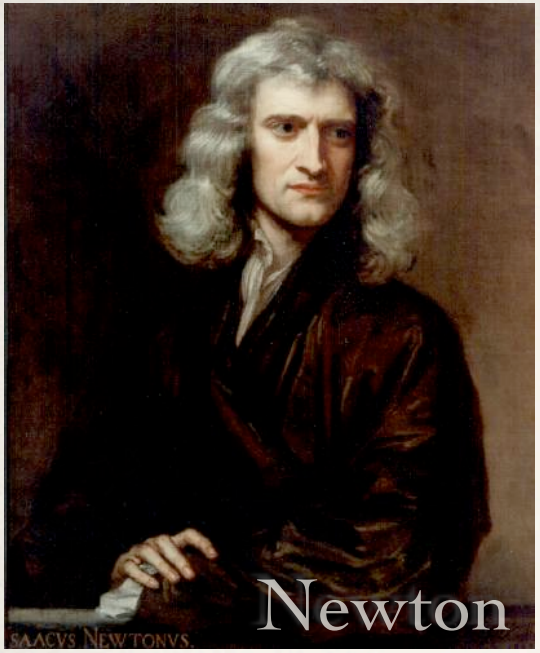
In the *Dialogue on the Great Two Systems of the World*

SIMPLICIO :

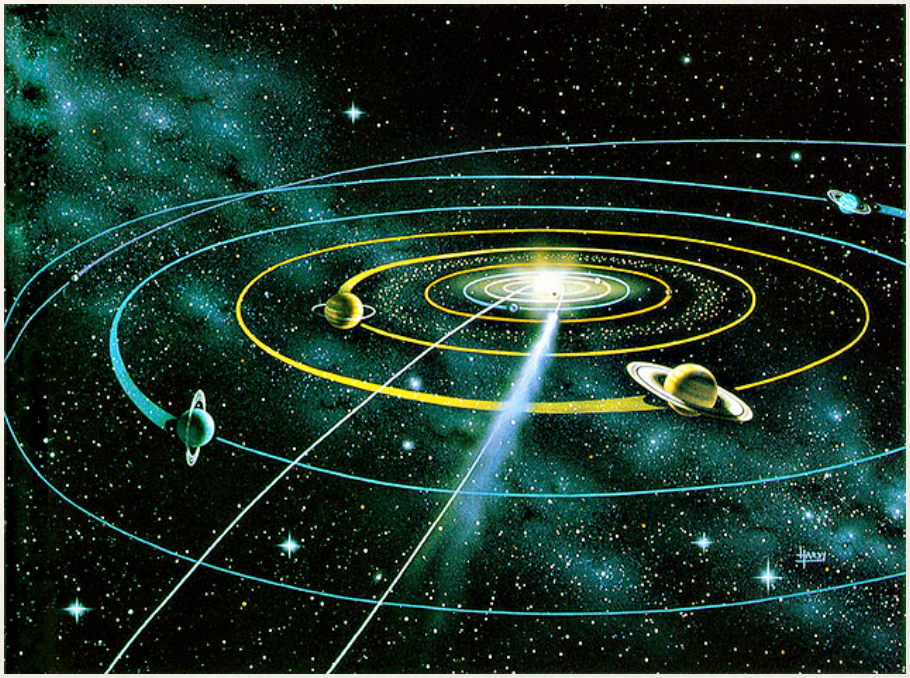
Did you actually do the experiment ?

GALILEO :

No, and I do not need it, as without any experience I can affirm that it is so, because it cannot be otherwise.



NEWTON



His theory of Mechanics and of Gravity set the standard for theoretical physics for centuries---

A concise mathematical framework

that unified disparate phenomena,

and had the power to make extremely precise predictions by means of which the theory could be tested and perhaps disproved.

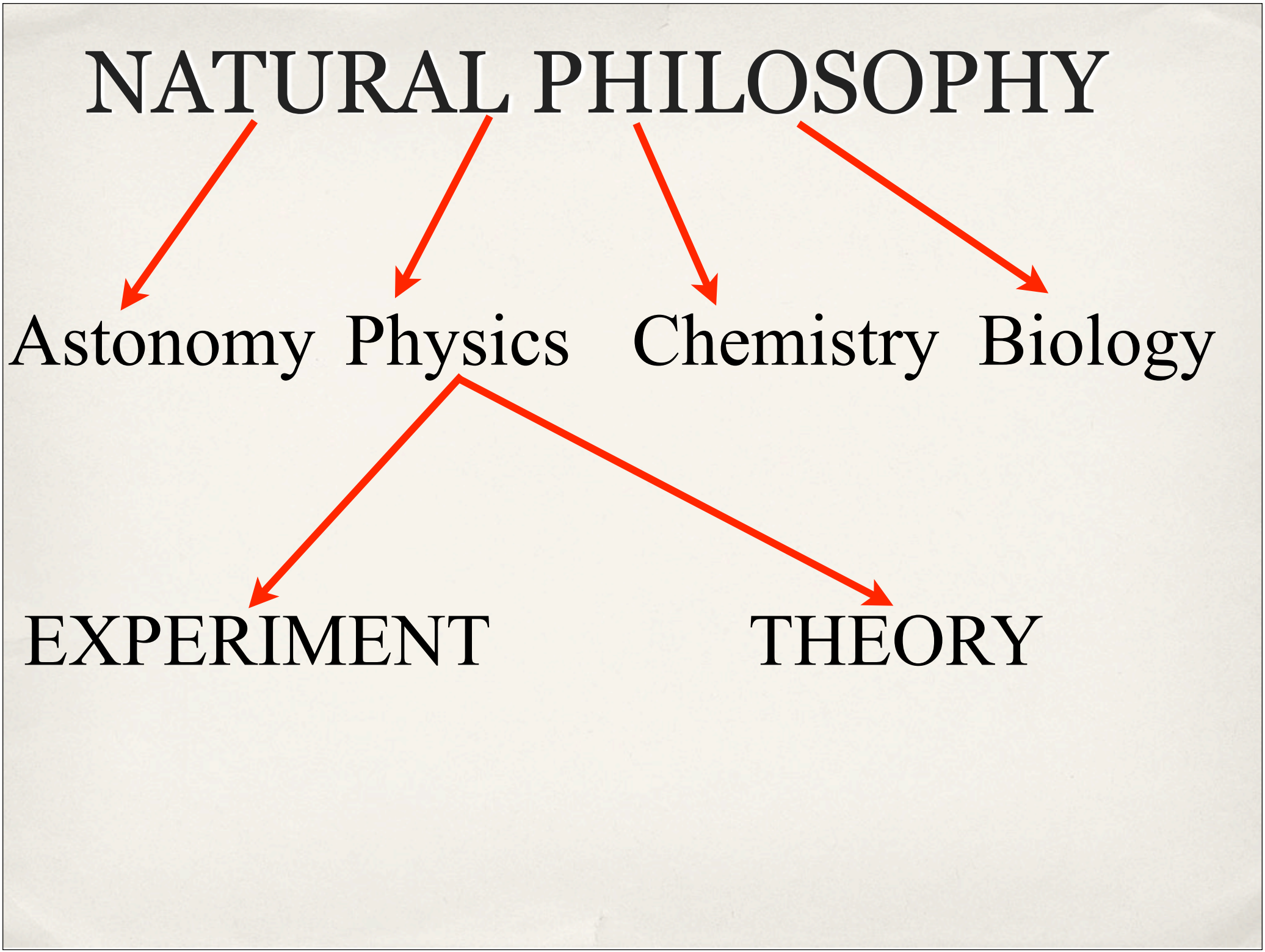
The language of nature is mathematics.

"Nature loves the integers."

Galileo

"The unreasonable effectiveness of mathematics in physics."

Wigner


NATURAL PHILOSOPHY
Astonomy
Physics
Chemistry
Biology
EXPERIMENT
THEORY

EXPERIMENT	THEORY
Discoveries are usually evidently real	We must wait for experimental confirmation
Expensive	Cheap

The ultimate product of science is the understanding of nature- a successful THEORY

Theorists write the textbooks

Theory plays many different roles in physics:

1. Quantifying and modeling observations.

   Fitting data with existing theories or new models.

   Discovering new patterns and regularities in the data.

HIGH ENERGY e-p SCATTERING

Discovered that the proton looked as if it were made of freely moving quarks.

1968 SLAC

1988

J. Friedman
H.Kendall
R. Taylor

POINTLIKE BEHAVIOR

THE PARTON MODEL

One could model the data by assuming that the proton was made of pointlike particles (partons).

2. Suggesting new experiments or observations, and specifying the required necessary precision to test these ideas.

SUM RULES

One could derive sum rules that tested the nature of the partons (quarks?).

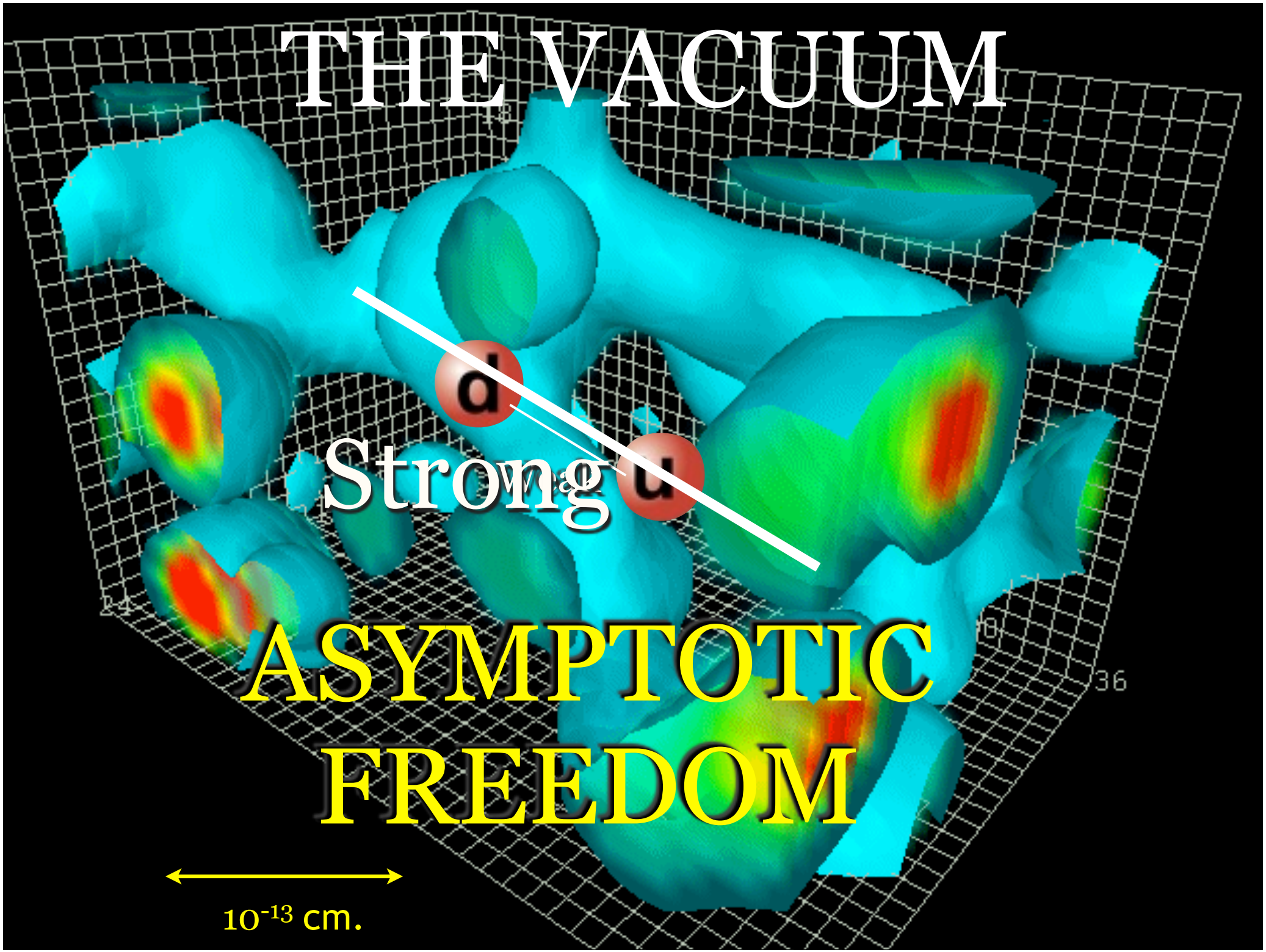
3. Predicting new phenomena or the precise results of experiments that can be used to falsify general principles or specific theories.

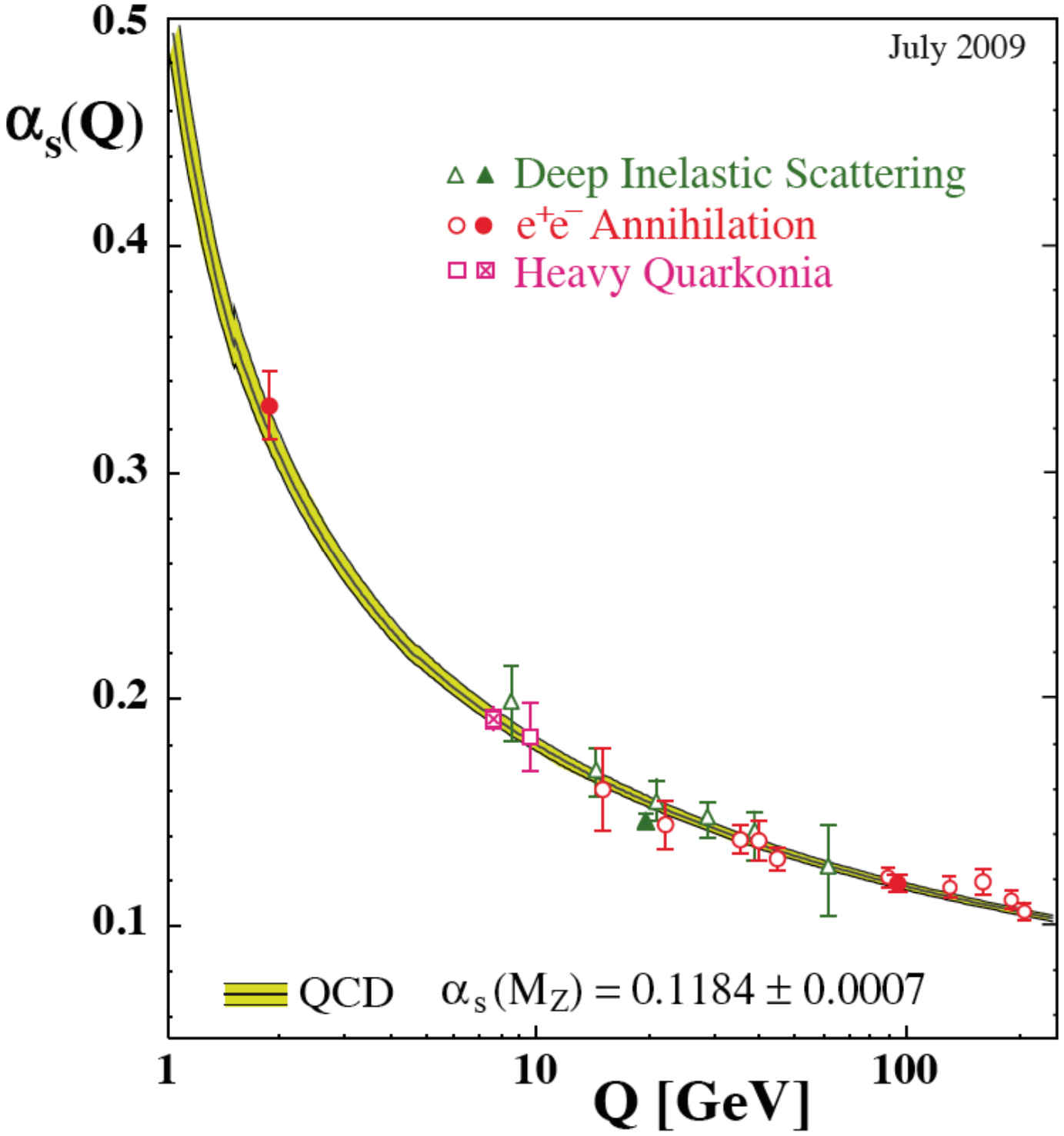
The experiments & the sum rules convinced me that:

1. Hadrons were made of point like constituents.

2. The charged constituents were quarks. Quarks are real.

BUT QUARKS MUST INTERACT STRONGLY, SO HOW COULD ONE EXPLAIN POINT LIKE BEHAVIOR?


THE VACUUM
d
Strong
u
ASYMPTOTIC
FREEDOM
10^{-13} cm.


July 2009
$\alpha_s(Q)$
0.5
0.4
0.3
0.2
0.1
Deep Inelastic Scattering
e^+e^- Annihilation
Heavy Quarkonia
QCD
$\alpha_s(M_Z) = 0.1184 \pm 0.0007$
1
10
100
Q [GeV]

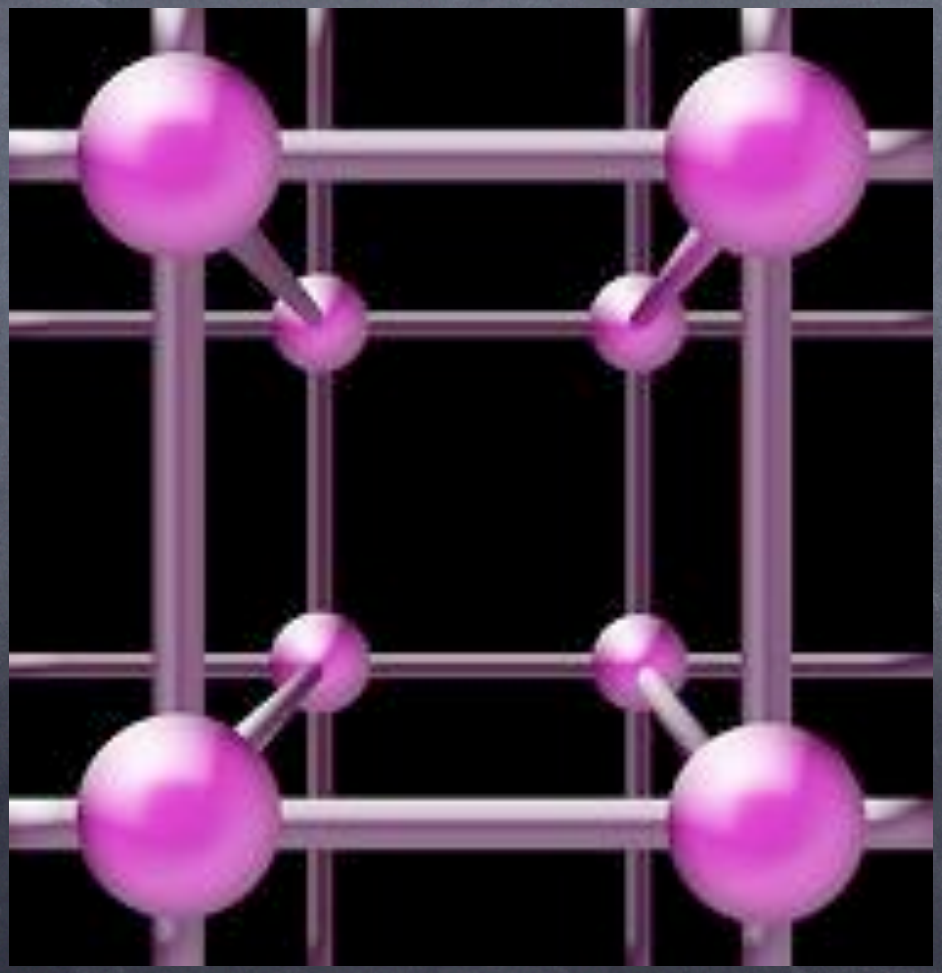
4. Finally, the ultimate reductionist goal of science,
that of unifying disparate phenomena
and reducing complex phenomena to
simple constituents and basic laws of dynamics.

ASYMPTOTIC FREEDOM

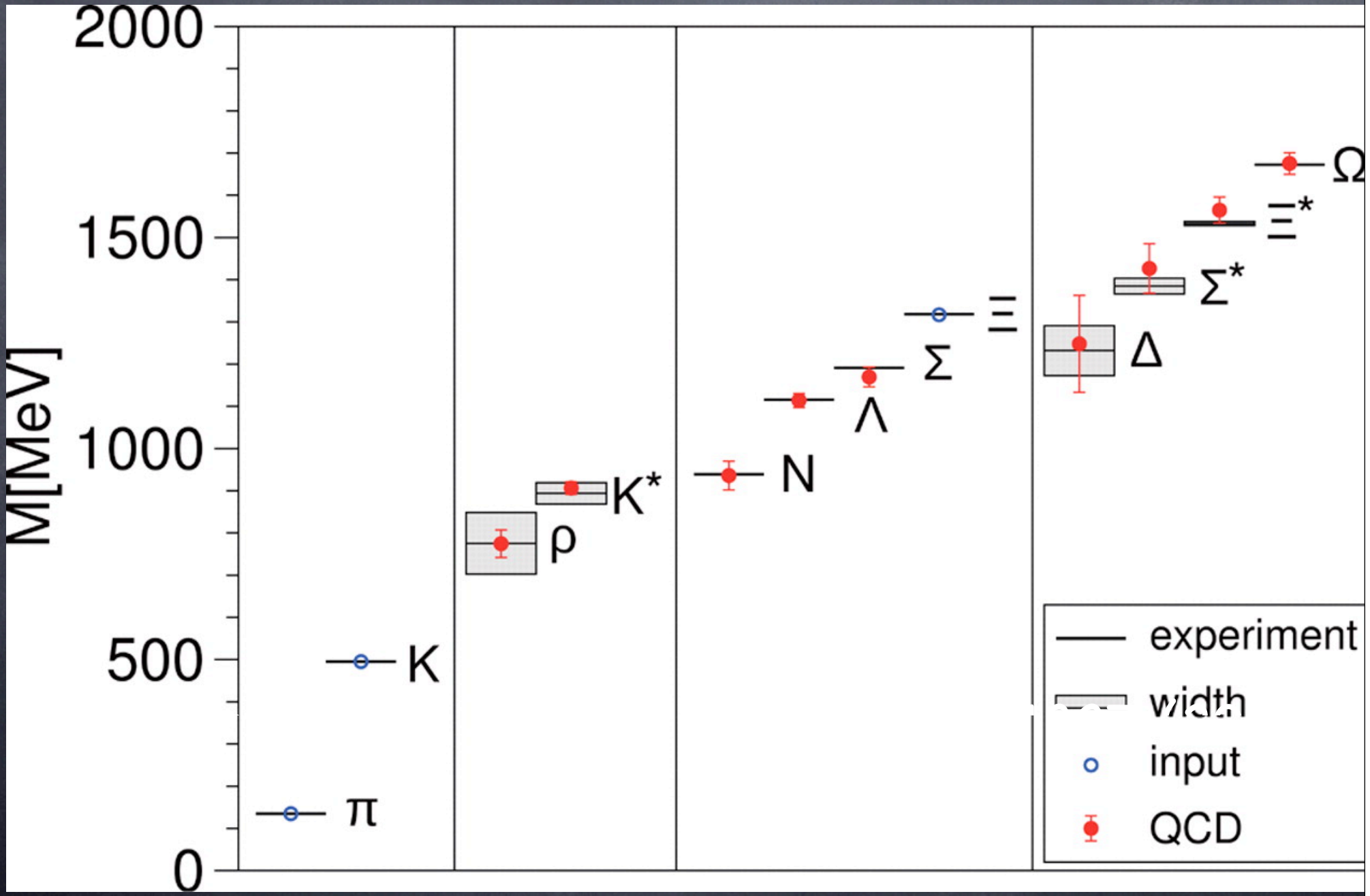
QCD

Quantum Chromodynamics

LATTICE QCD



The Light Hadron Spectrum Of QCD



5. Modeling and calculating the expected background to new experiments so that experimenters can discover new phenomena and distinguish the signals from the noise.

THEORETICAL BIOLOGY

Is there a theory of biology?

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

Is new mathematics required?

THE ROLE OF THEORY INSTITUTES

THE MISSION OF THE KITP

- **Programs that Transform Research Areas**
- **Interdisciplinary Outreach — Explore New Directions— Nurture New Frontiers for Physics**
- **A Window to the World**

  Foreign Visitors : 38% of Visitors are from outside the U.S.
  Web Services
- **Development of Young Scientists**

  Postdoctoral Program, KITP Graduate Fellows, Affiliates
- **Respond to Challenges Facing Physics in the US**

  e.g. KITP Scholars, High School Education, Theorists at Undergraduate Institutions, Journalist in Residence, Outreach...

THE FUTURE OF THEORY

Three threats to the future of theory

1. Google.

2. We are limited in our capabilities.

3. A final theory, a theory of everything.

“The End of Theory” by Chris Anderson.

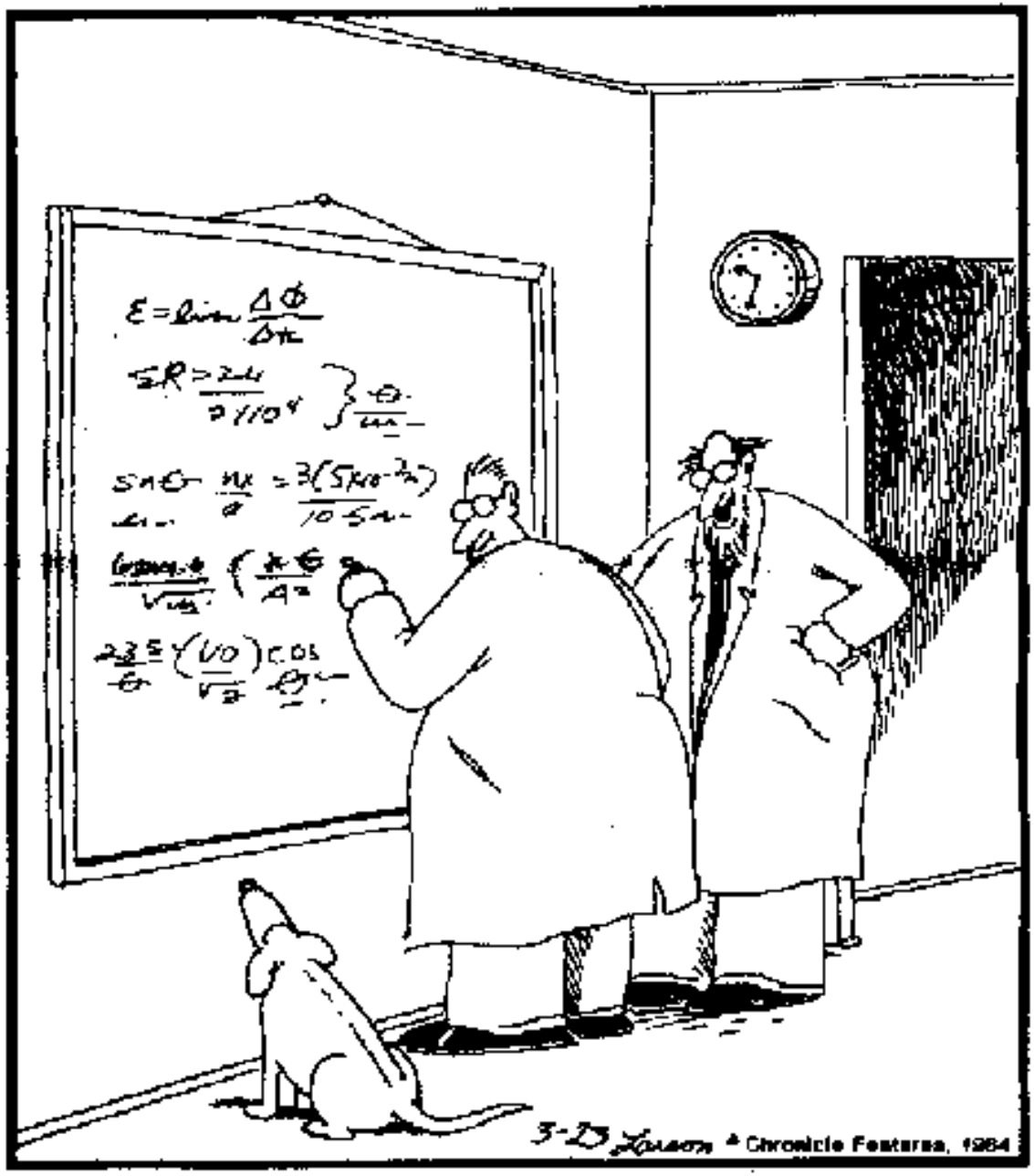
Makes the case that the deluge of data and the ability, exemplified by Google, of finding correlations in data without understanding or modeling the data, will, in the Pentabyte age, replace theory.

Google succeeded without having to revolutionize AI.

Google’s research director states :

“All models are wrong and increasingly you can succeed without them.”

THE FAR SIDE By GARY LARSON



"Ohhhhhhh . . . Look at that, Schuster . . .
Dogs are so cute when they try to comprehend
quantum mechanics."

MAYBE NOT

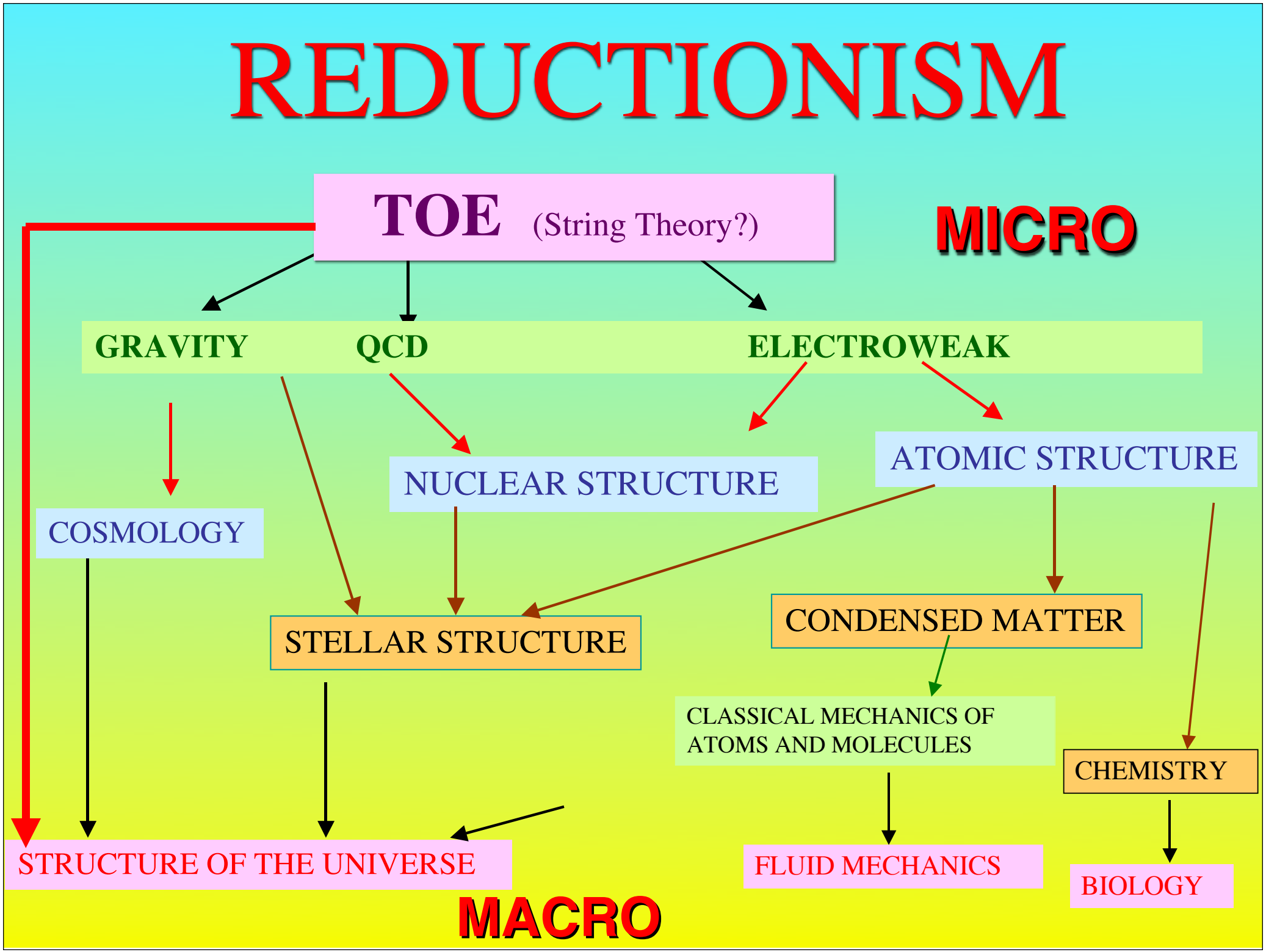
1. Language & Mathematics

   have infinite capacity

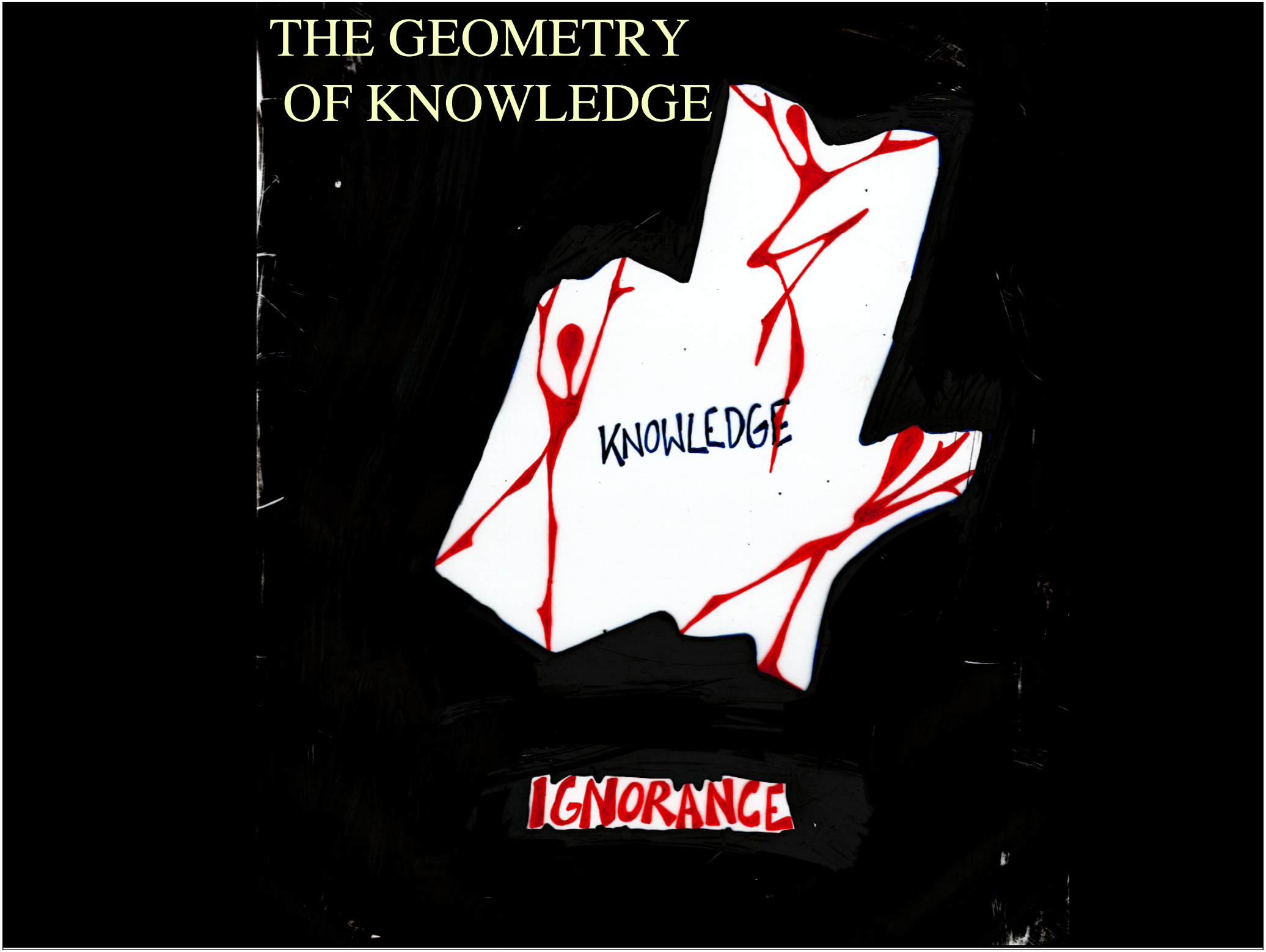
2. If we are too dumb we can modify genome to become smarter.

3. Experimental Observation:

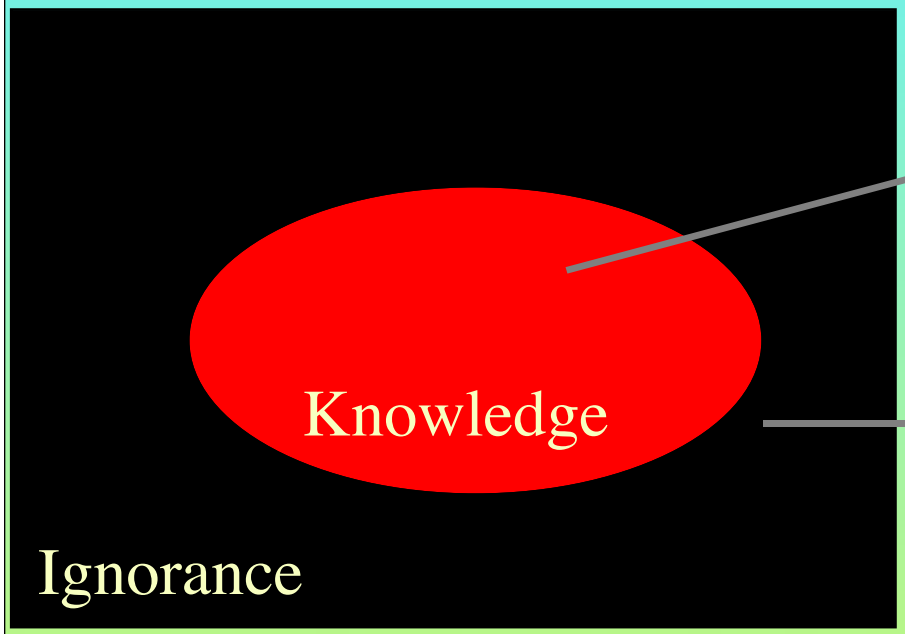
Brilliant young theorists are able to explore the frontiers of knowledge as early as ever.


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 GEOMETRY OF KNOWLEDGE



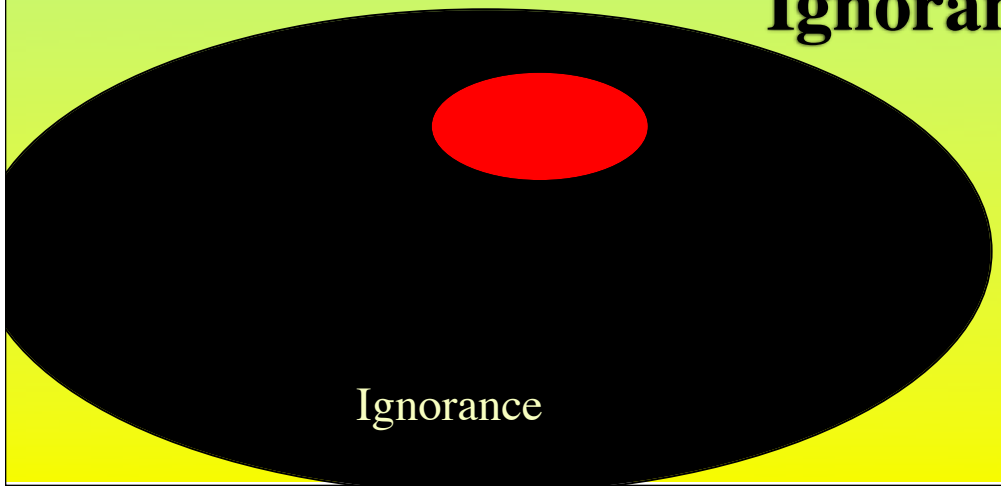
Knowledge, Ignorance and Wisdom



Knowledge ~ Volume

Ignorance ~ Surface

Wisdom ~ Knowledge ~ Volume
Ignorance Surface



IS THE SEA OF IGNORANCE COMPACT?

So,

lots of time for theory institutes,

such as the ICTS,

to prosper.

THANKS

THE END