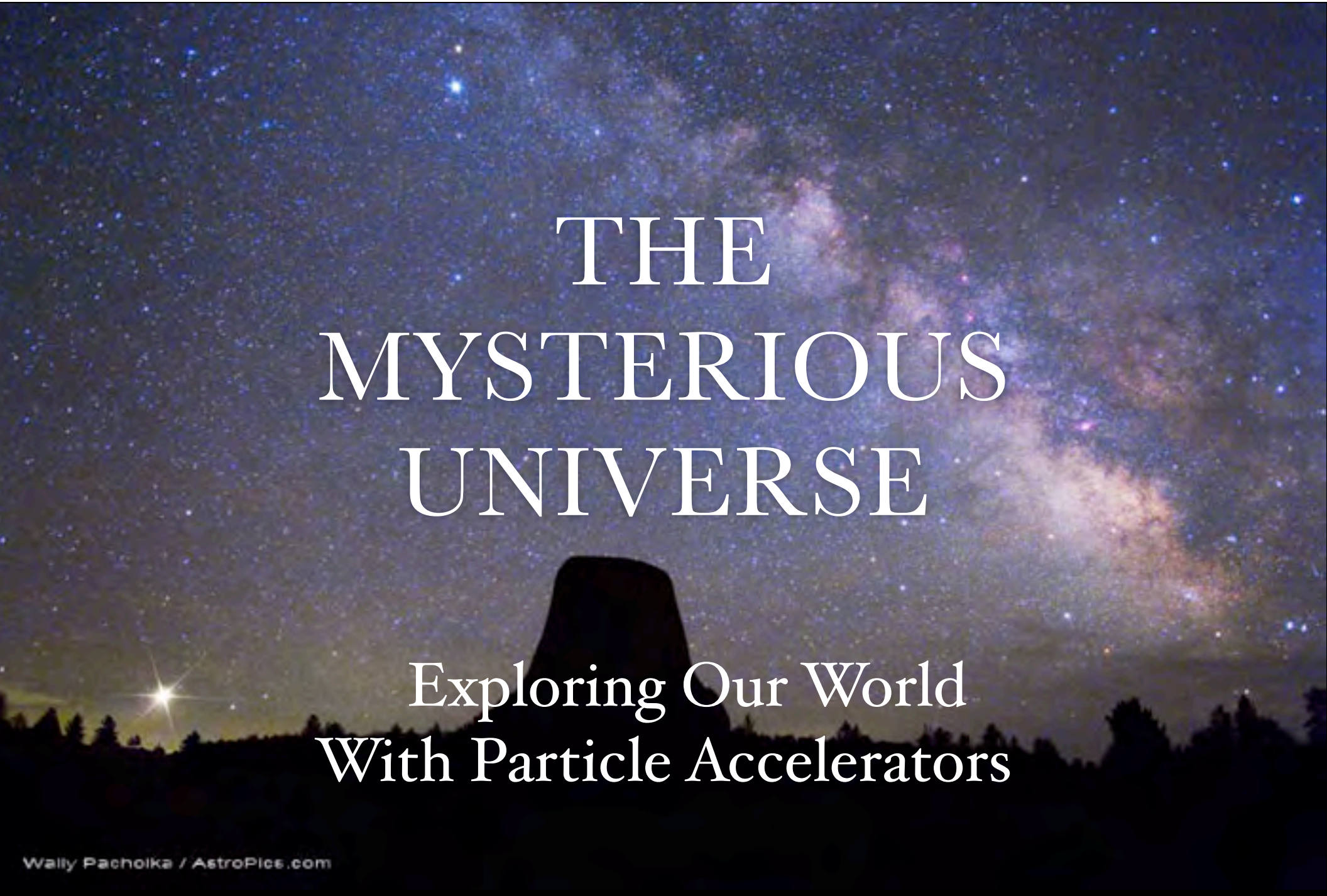

THE MYSTERIOUS UNIVERSE

Exploring Our World With Particle Accelerators

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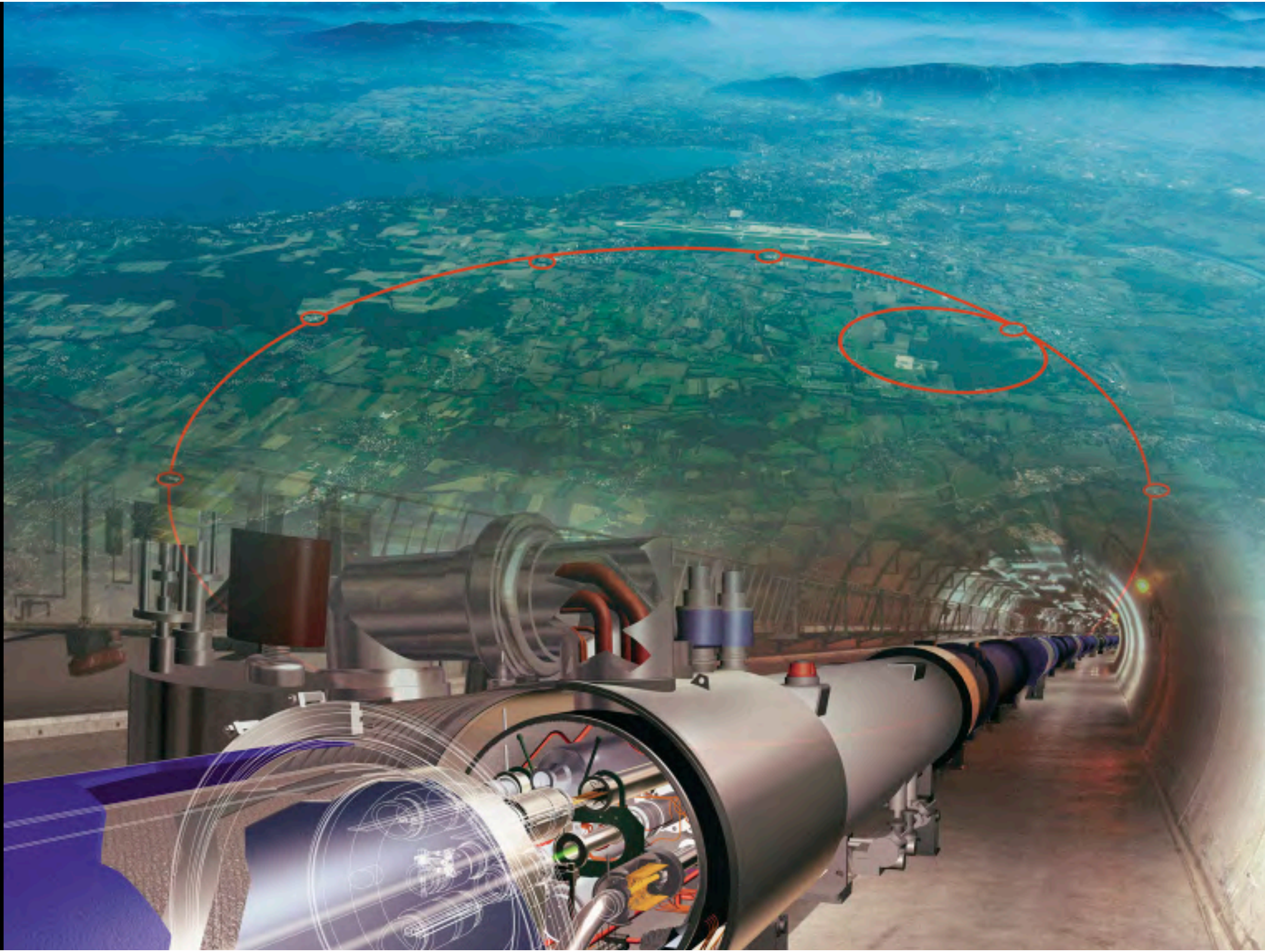
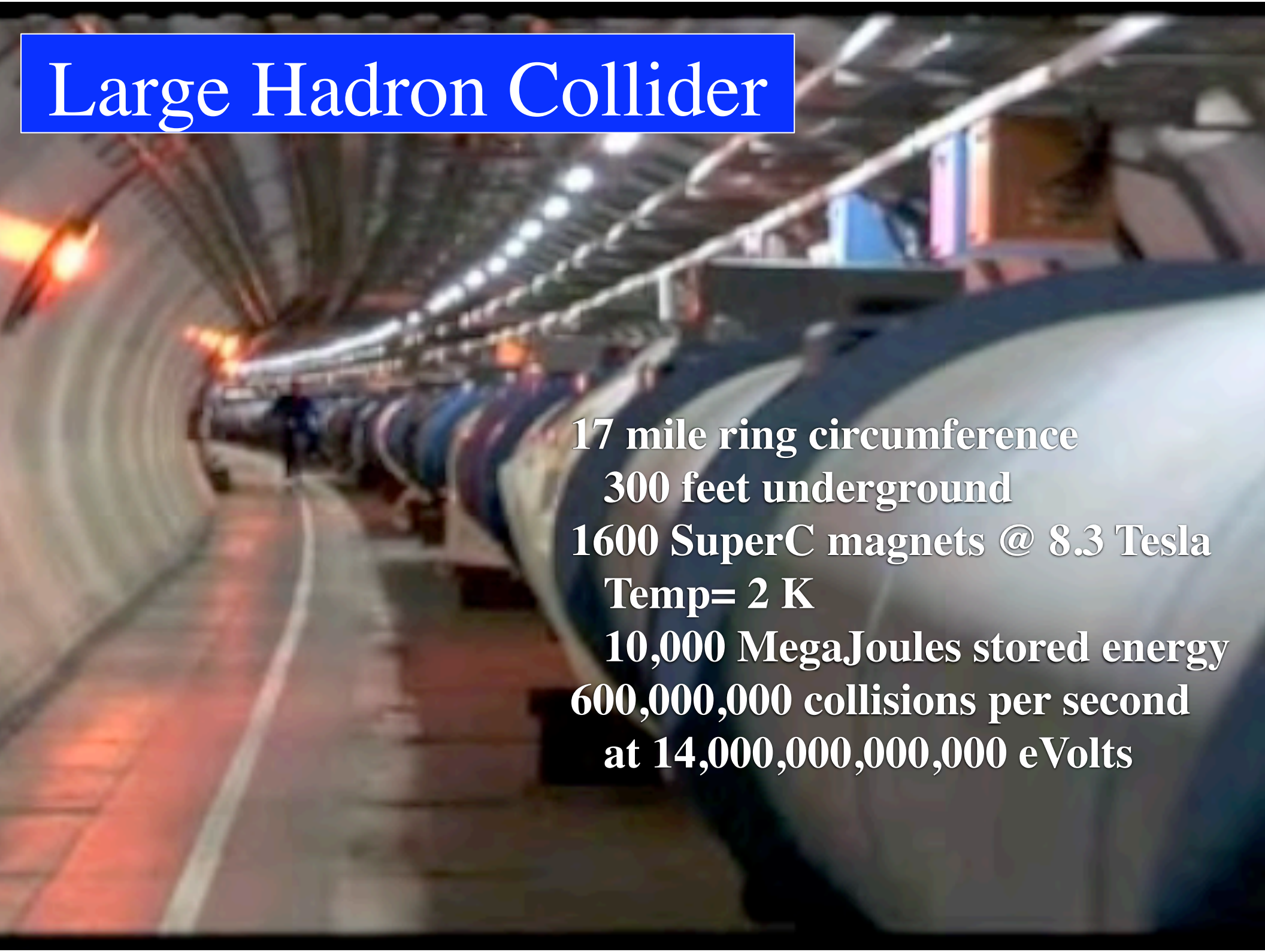


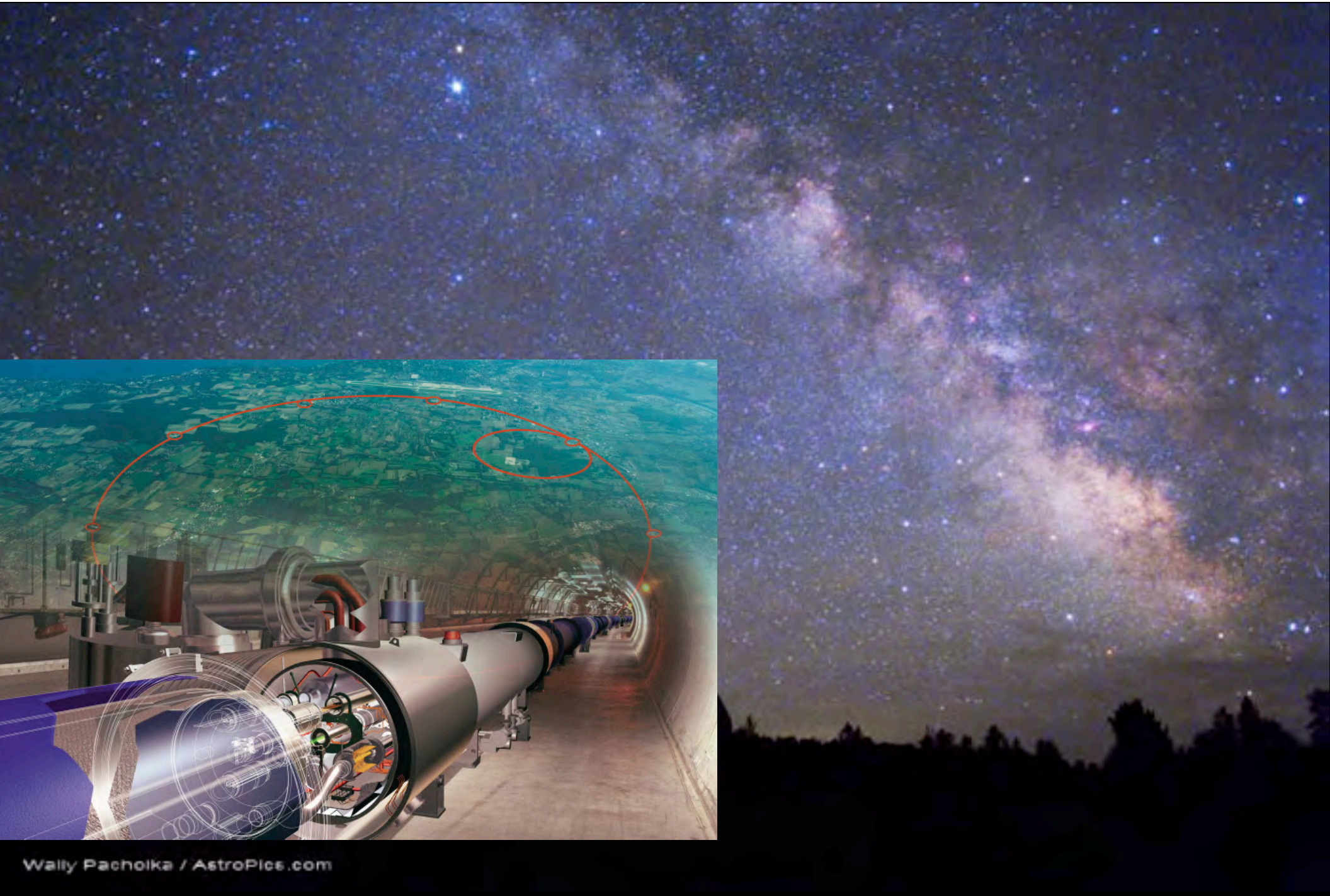
Large Hadron Collider



17 mile ring circumference
300 feet underground
1600 SuperC magnets @ 8.3 Tesla
Temp= 2 K
10,000 MegaJoules stored energy
600,000,000 collisions per second
at 14,000,000,000,000 eVolts

Large Hadron Collider

Proton beam stores 700 MegaJoules
equiv. to 747 energy on take-off
enough to melt 1/2 ton copper



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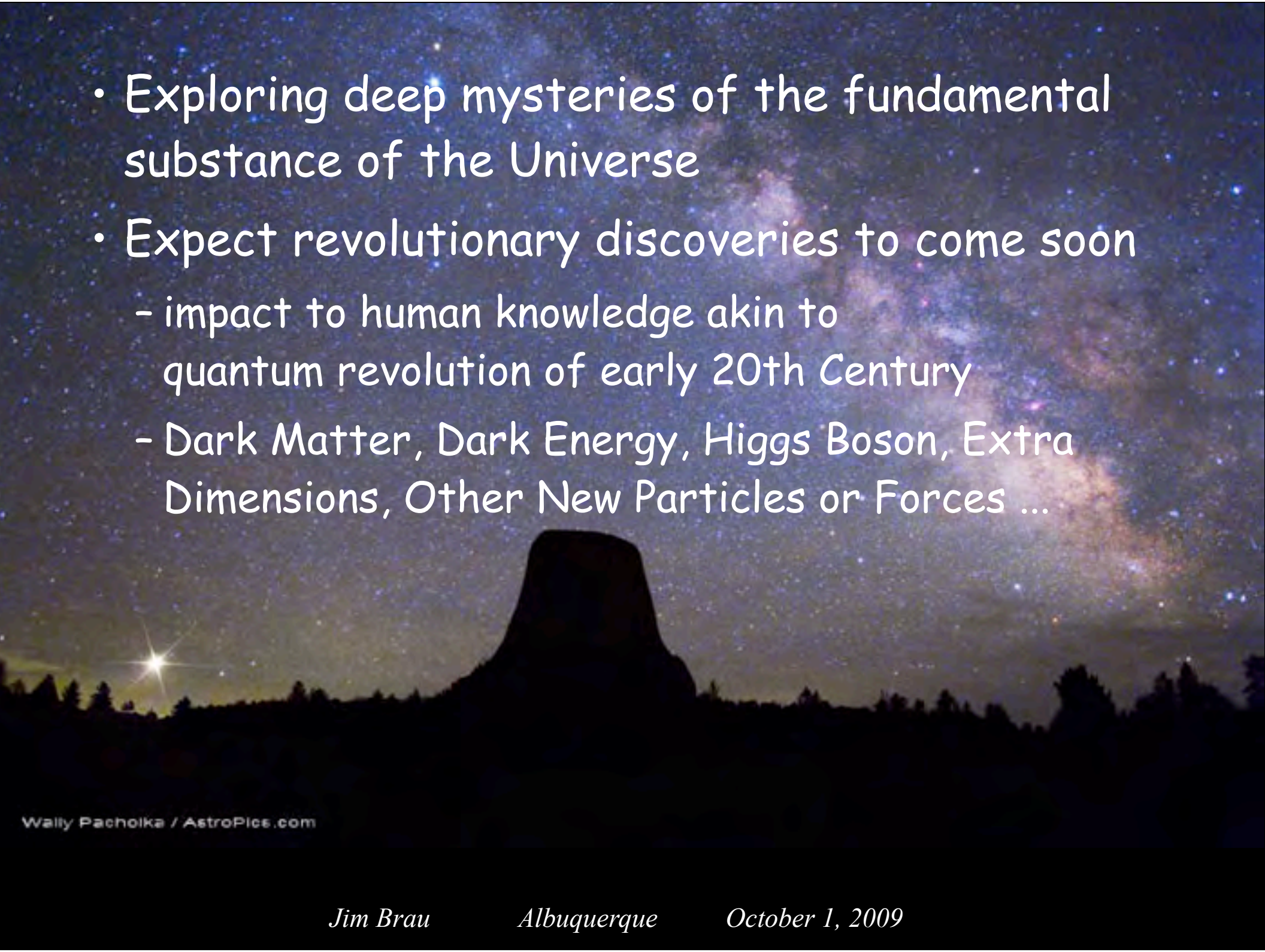
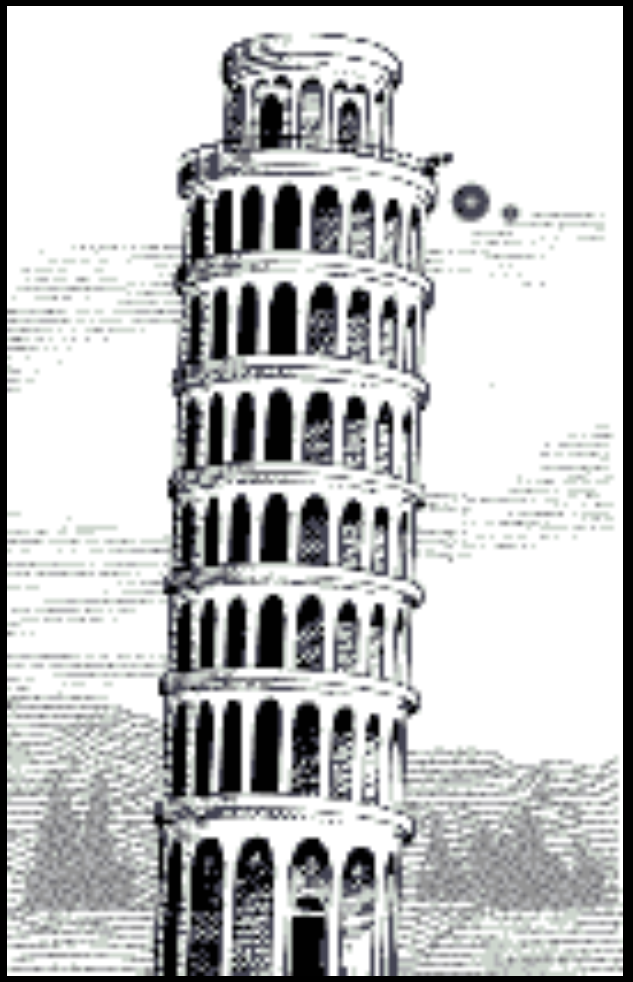


- Exploring deep mysteries of the fundamental substance of the Universe
- Expect revolutionary discoveries to come soon
  - impact to human knowledge akin to quantum revolution of early 20th Century
  - Dark Matter, Dark Energy, Higgs Boson, Extra Dimensions, Other New Particles or Forces ...

Galileo Galilei

image from Science 16 January 2009



http://physics-animations.com

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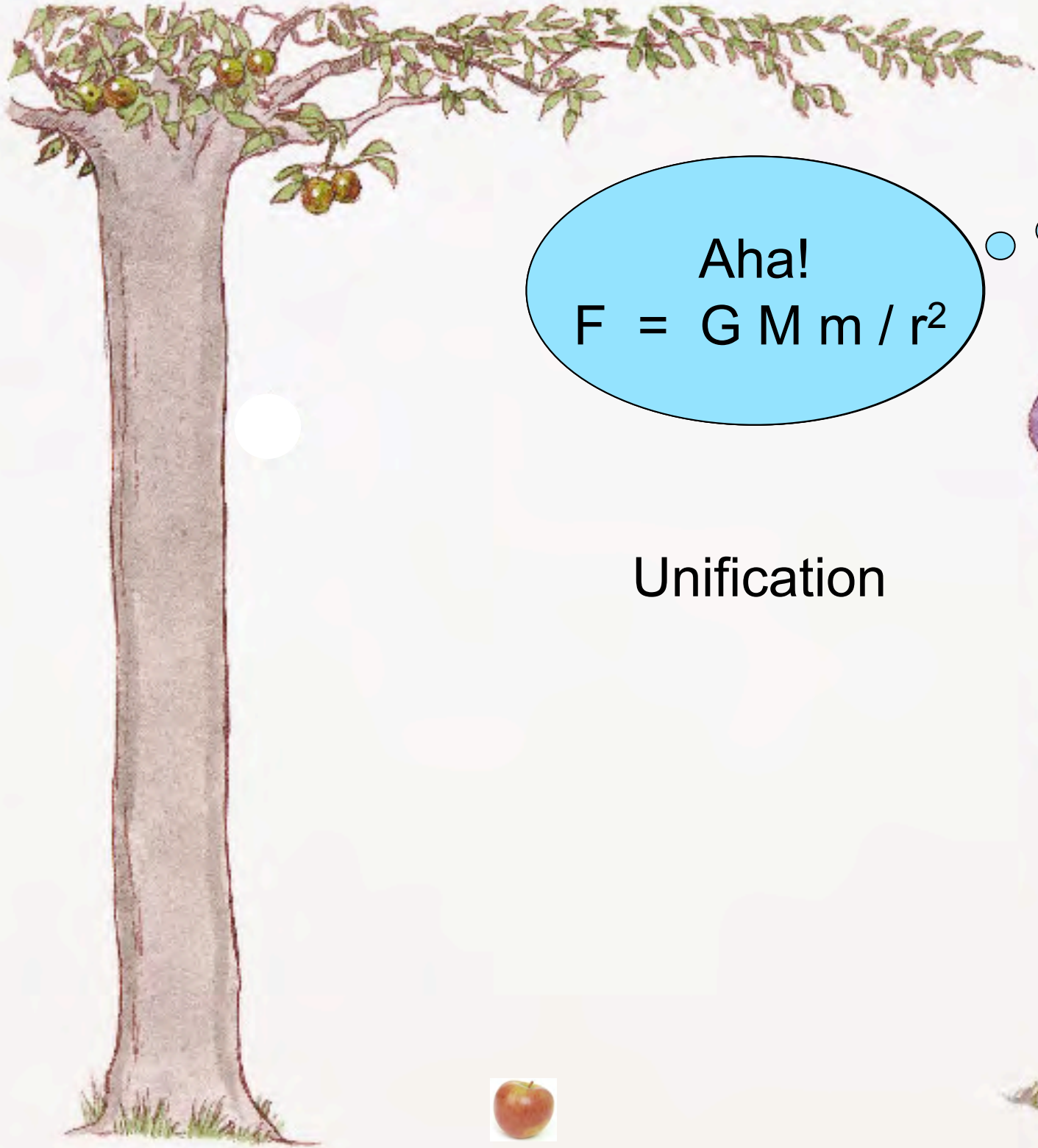
Jim Brau *Albuquerque* *October 1, 2009*



Aha!
$F = G M m / r^2$

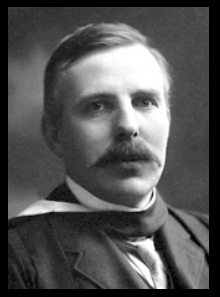
Unification


What is the Sun’s source of energy

Solar Energy

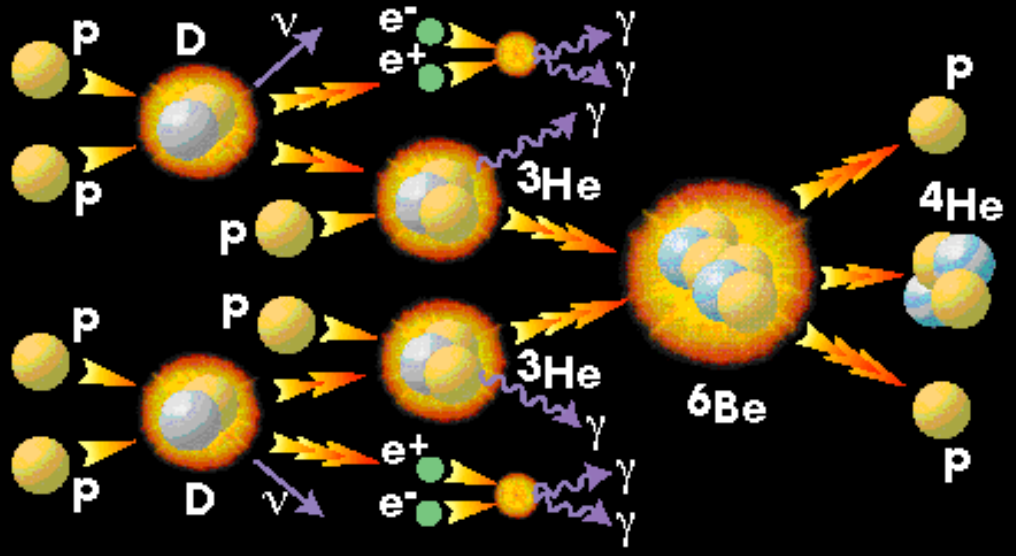
- What is the Sun's source of energy?
  - 19th Century - Chemical reactions? (burning)
    - Predicted solar lifetime too short - only 20,000 years
    - Evidence on Earth for much longer duration

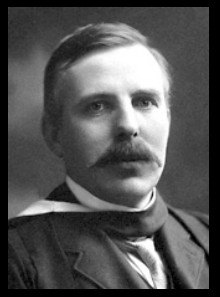
- 20th Century
  - Einstein's relativity $E=mc^2$
  - discovery of atomic nucleus and nuclear reactions



Solar Energy

- What is the Sun's source of energy?



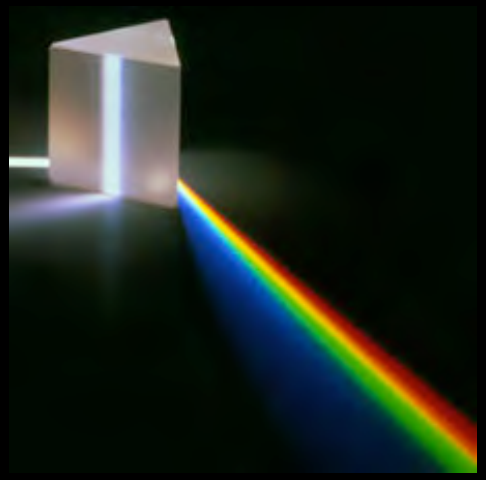


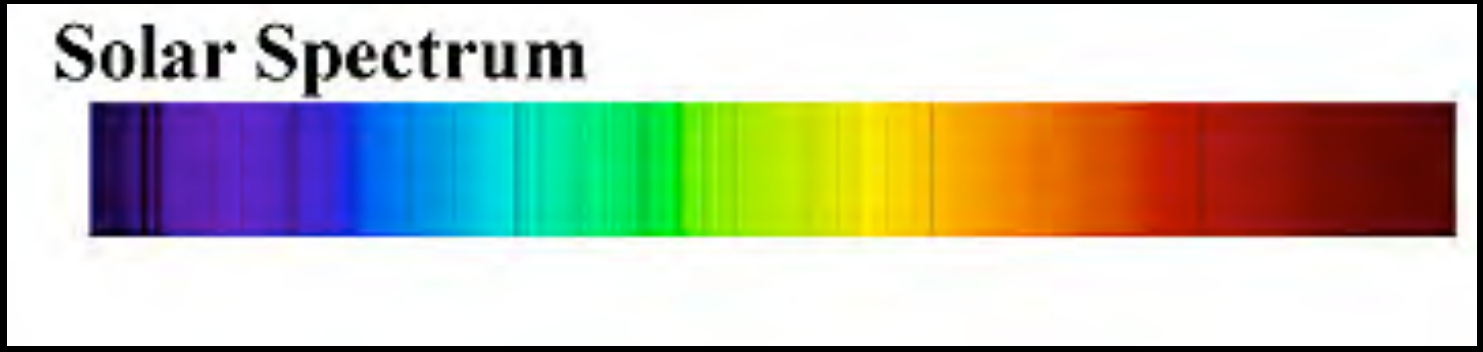
Enough energy
for the Sun to shine
for ten billion years

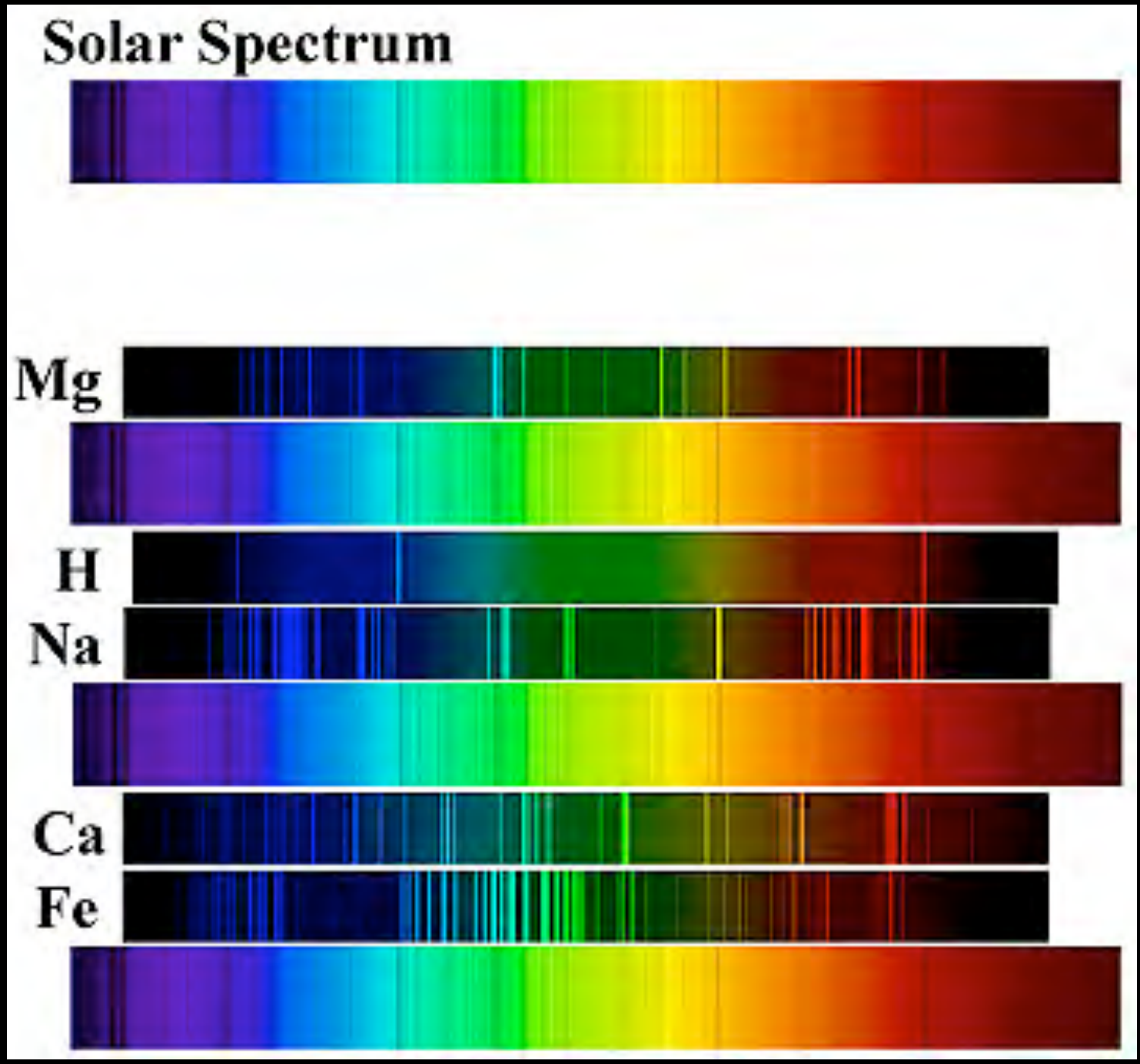
Relativity

- When a man sits with a pretty girl for an hour, it seems like a minute.
- But let him sit on a hot stove for a minute—and it's longer than any hour.
- That's relativity.

A. Einstein




Solar Spectrum



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Quasi-stellar Radio Sources (Quasars)

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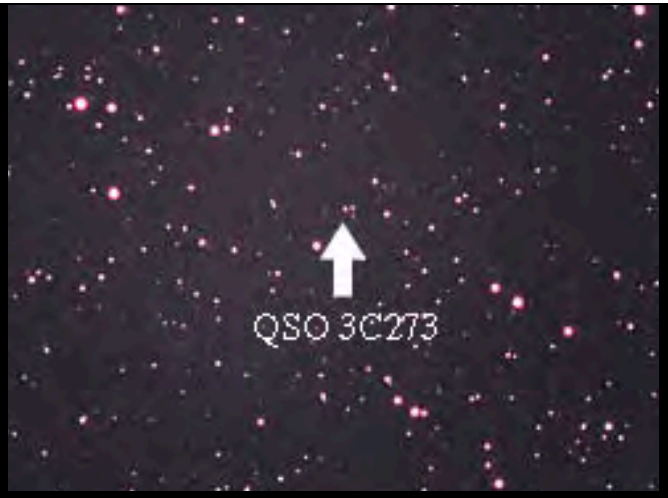
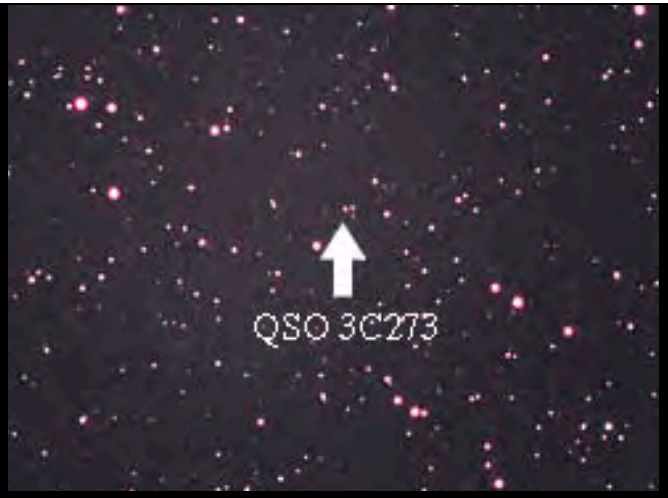
Quasars

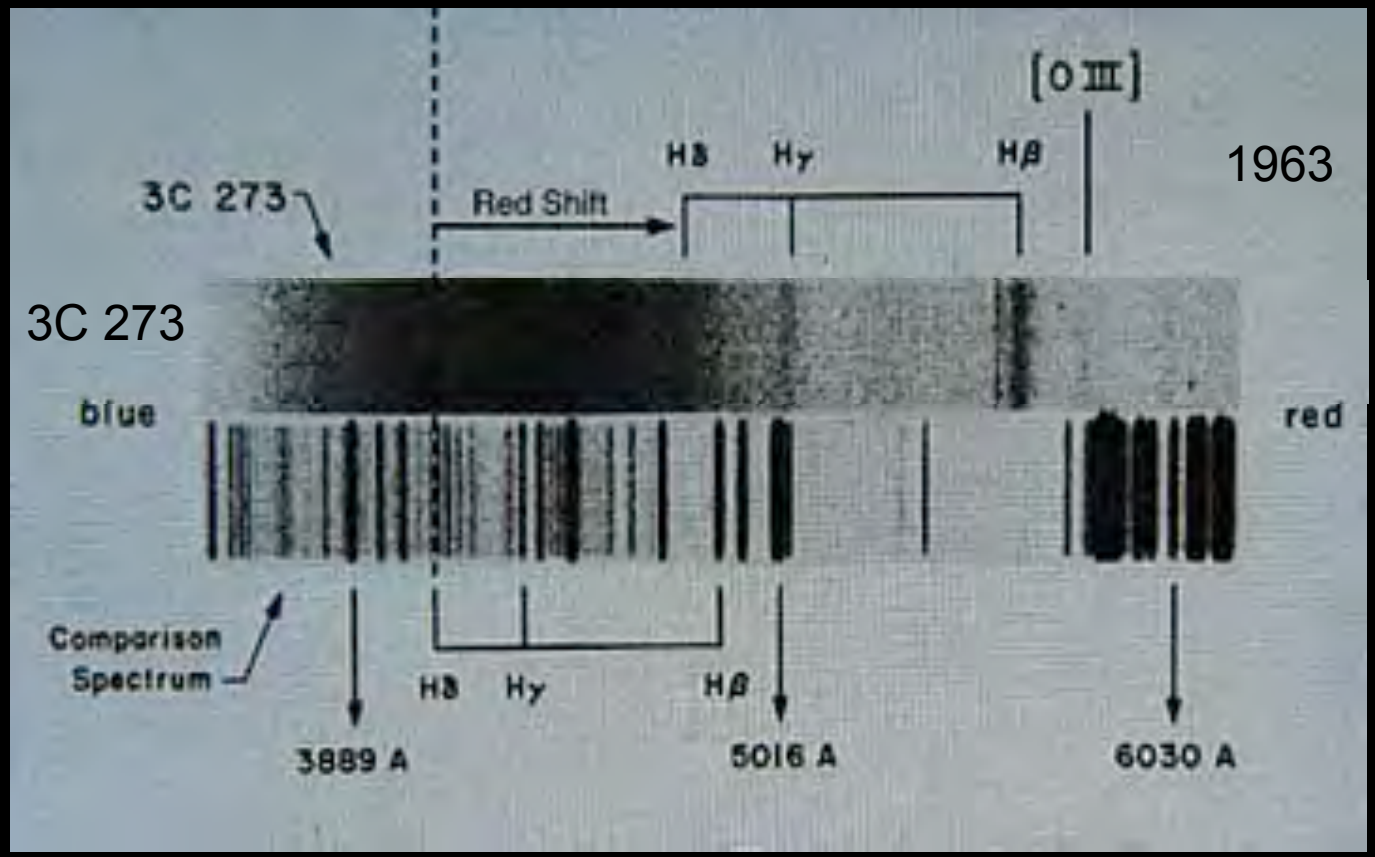


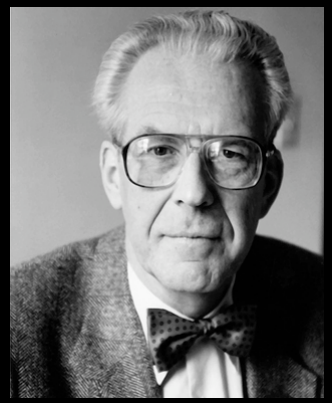
Quasars

Brightest Objects in the Universe



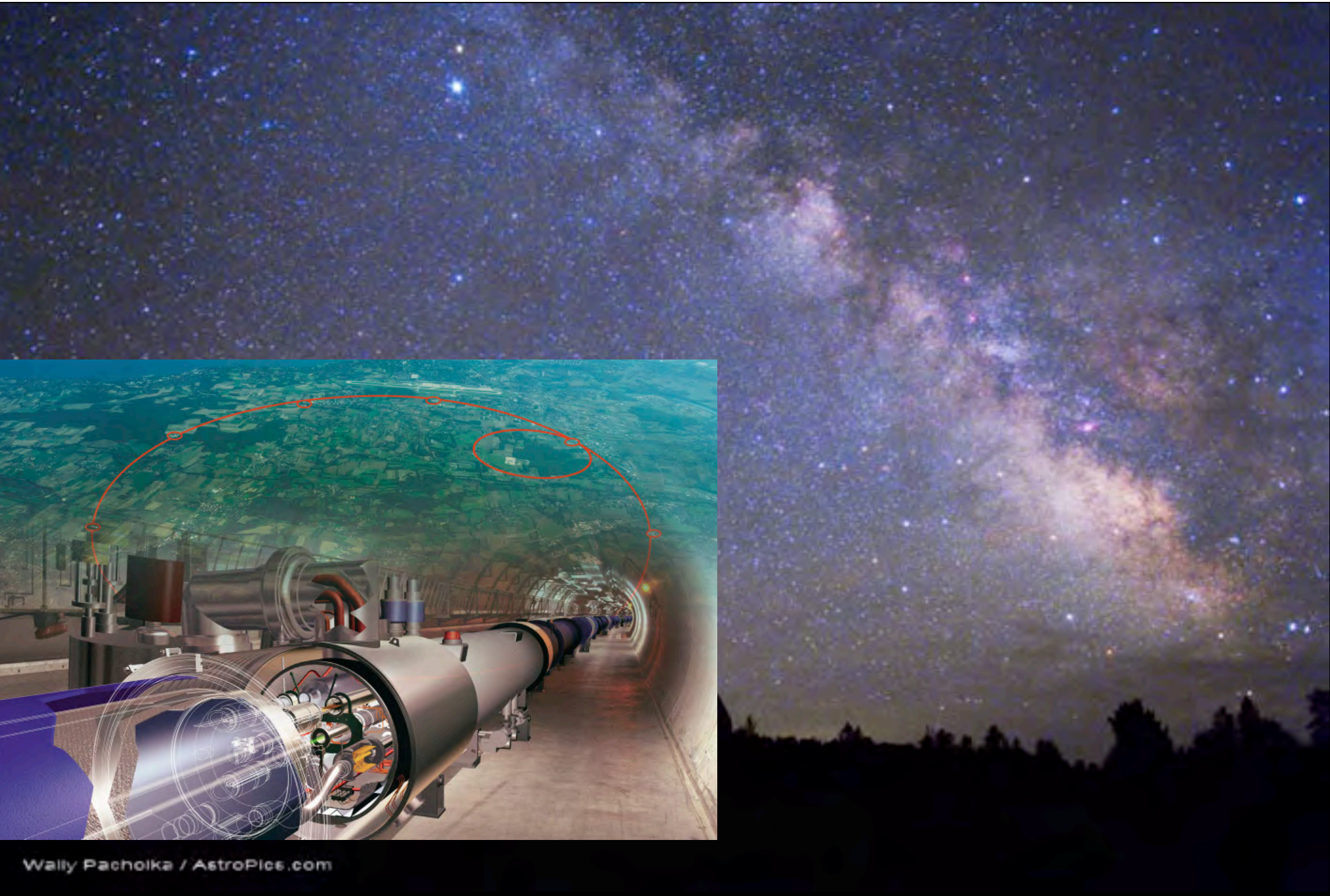
- Distant, Active Young Galaxies





Speed of recession
44,000 km/sec
15% speed of light!

Distance
2.4 billion light yrs



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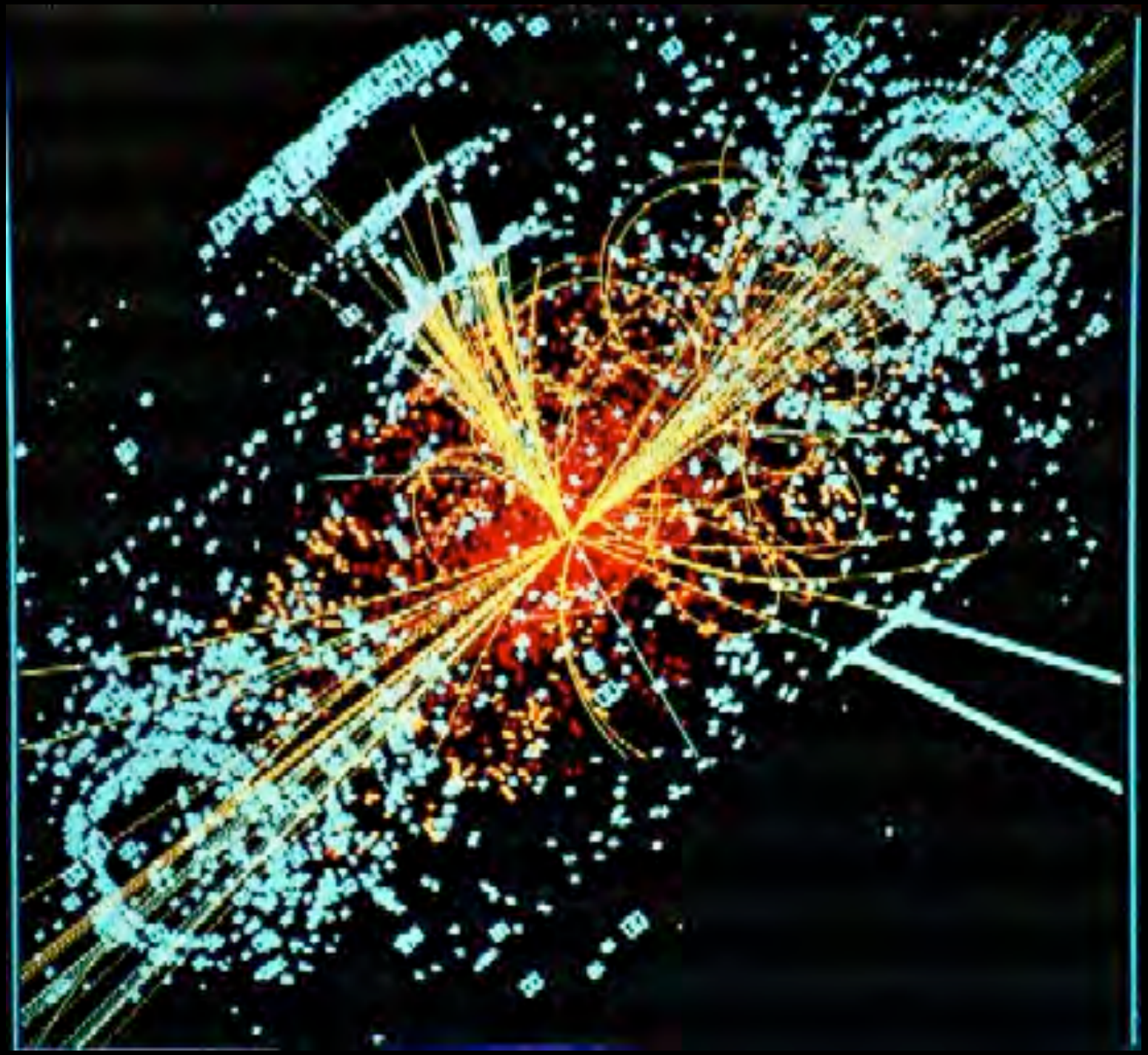

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1929 - Hubble Discovered Universe is Expanding

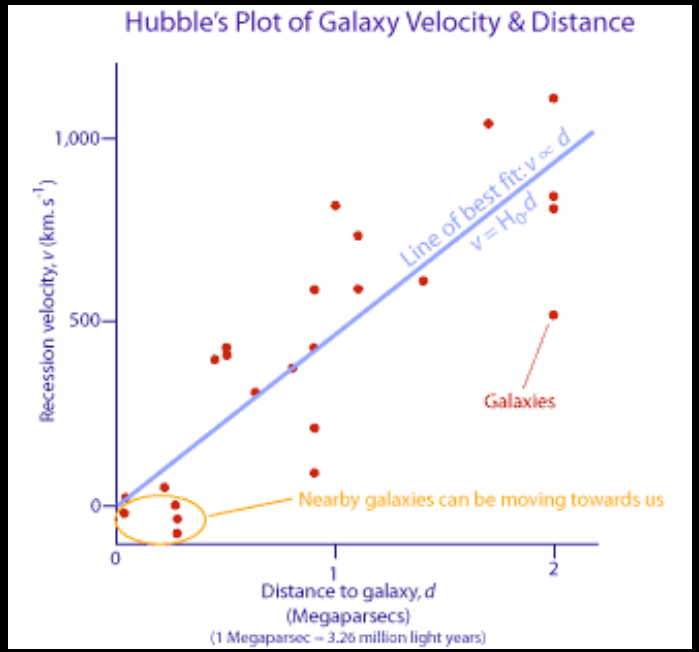
Edwin Powell Hubble
(1889-1953)

1929

1929 - Hubble Discovered Universe is Expanding

First evidence that Universe began with a Big Bang

Edwin Powell Hubble
(1889-1953)



1929

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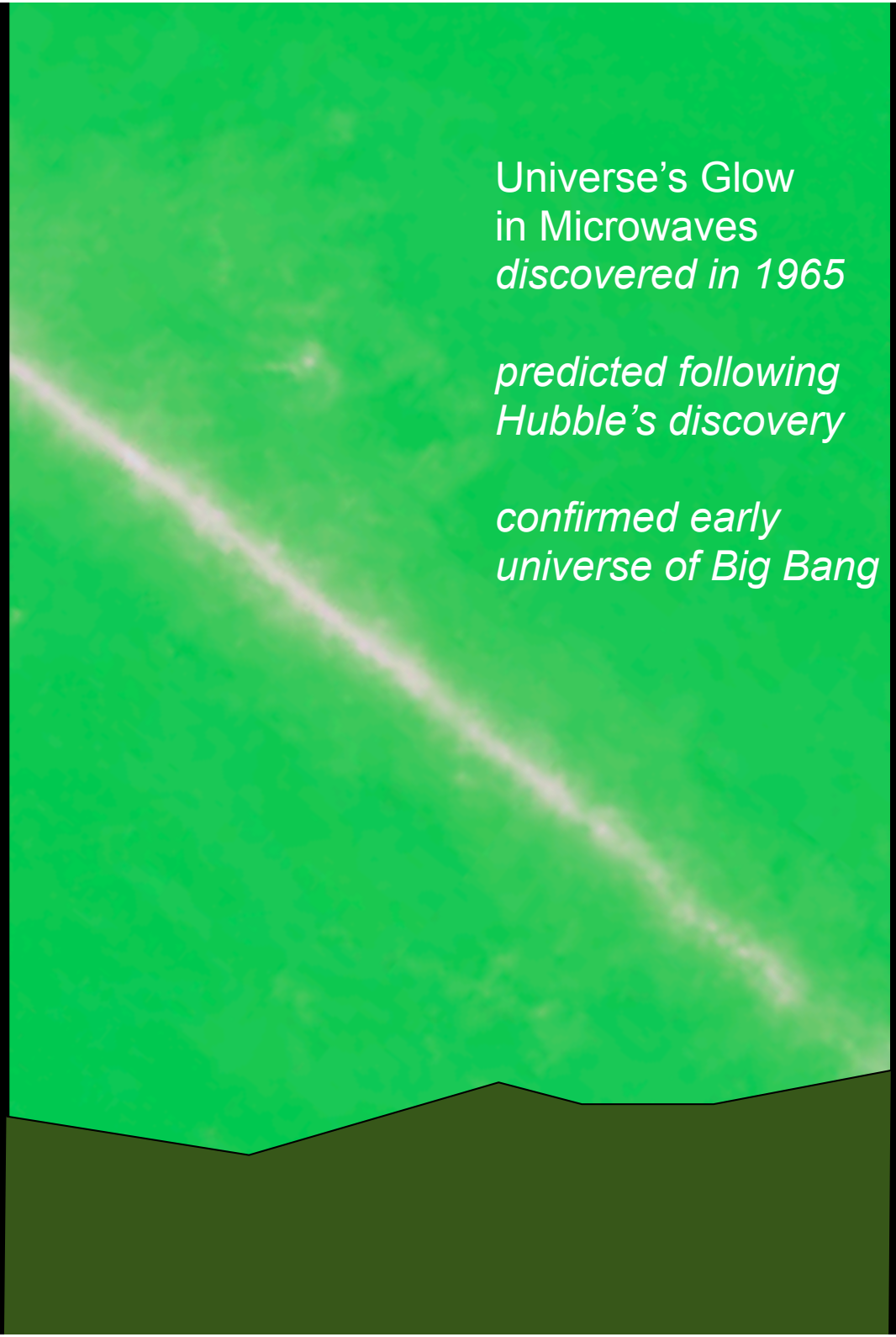
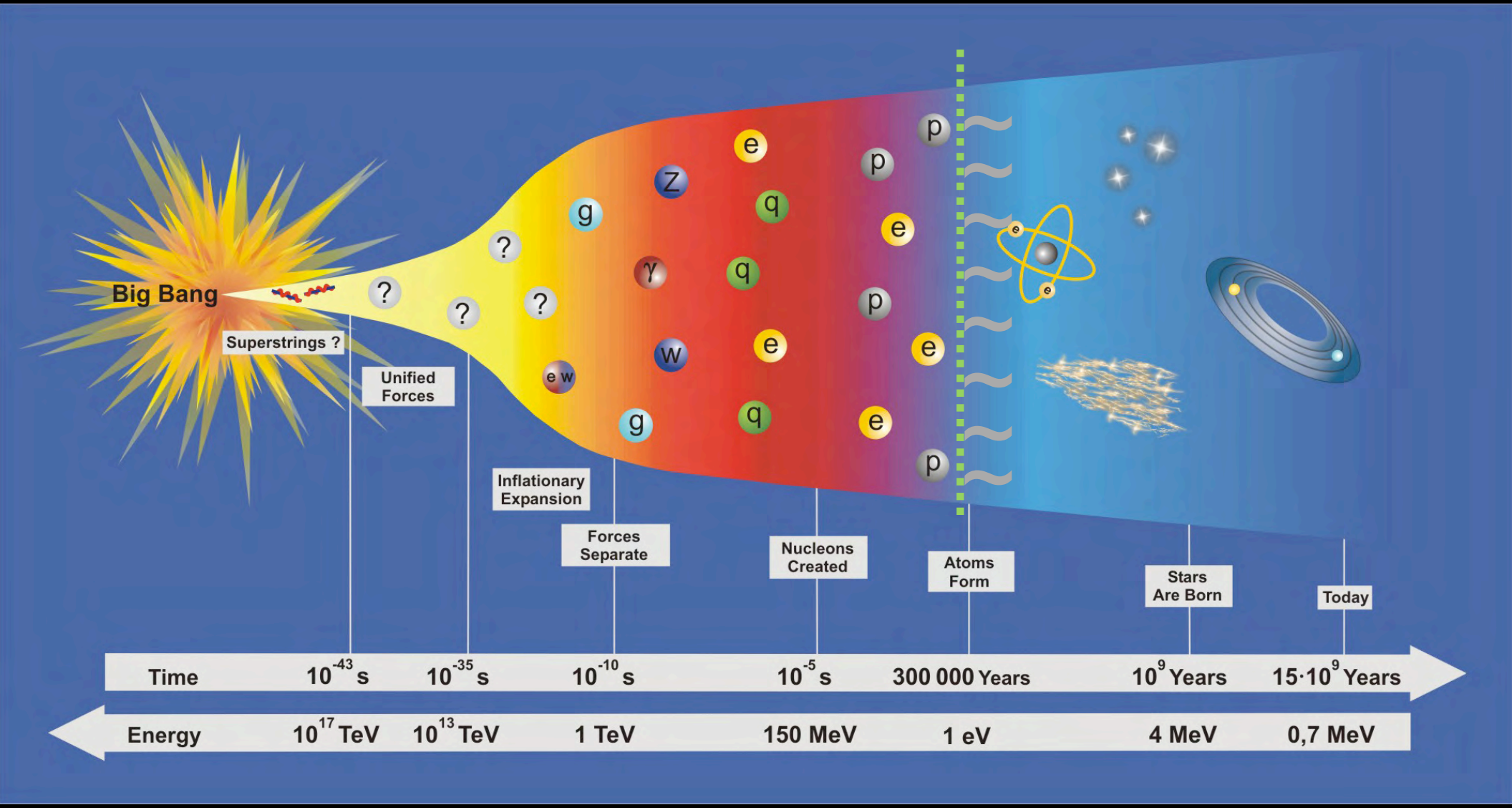
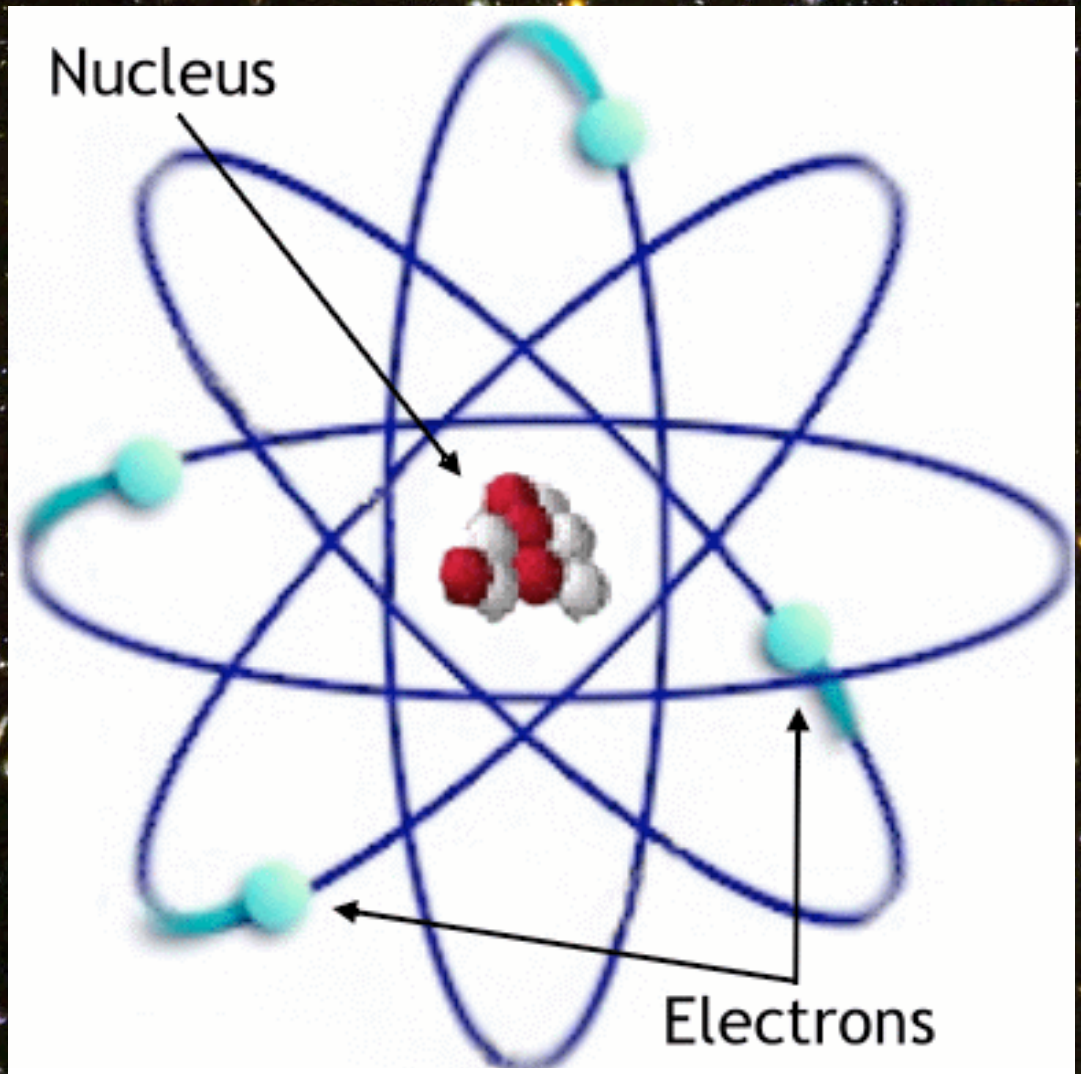

Universe's Glow
in Microwaves
discovered in 1965
*predicted following
Hubble's discovery*
*confirmed early
universe of Big Bang*

Big Bang


Big Bang
Superstrings ?
Unified Forces
Inflationary Expansion
Forces Separate
Nucleons Created
Atoms Form
Stars Are Born
Today
Time
10^-43 s
10^-35 s
10^-10 s
10^-5 s
300 000 Years
10^9 Years
15·10^9 Years
Energy
10^17 TeV
10^13 TeV
1 TeV
150 MeV
1 eV
4 MeV
0,7 MeV

The Universe is Made of Particles



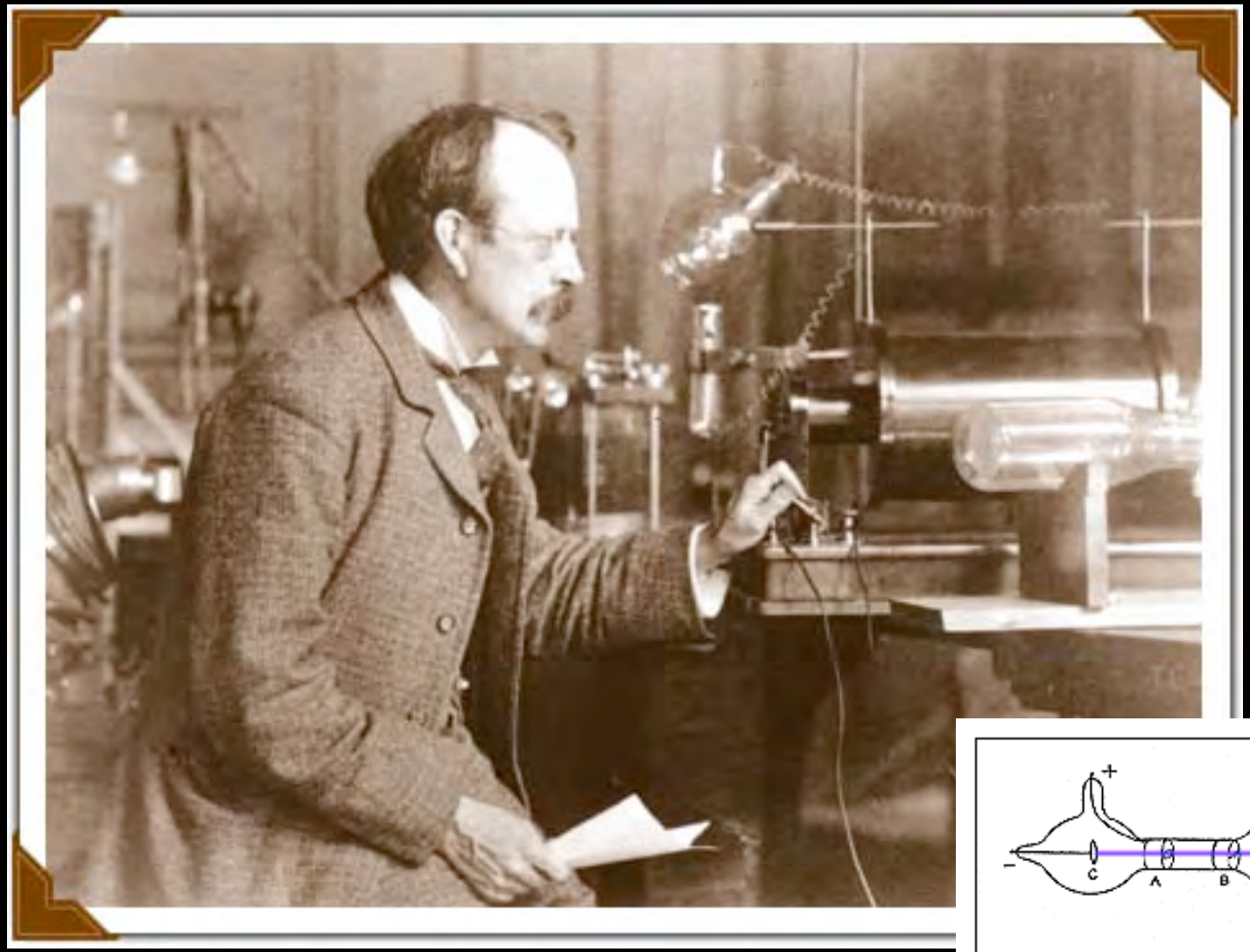
THE ATOM

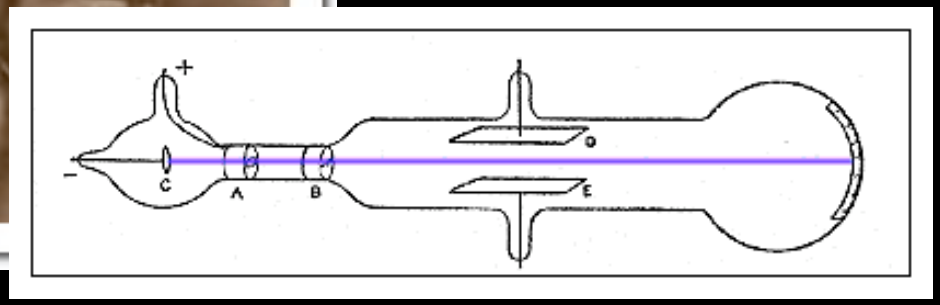
- Investigating the particles reveals the fundamental structure of the Universe and matter within it

The Universe is Made of Particles

- Investigating the particles reveals the fundamental structure of the Universe and matter within it

1897 - J.J. Thomson Electron





Credit: American Institute of Physics

J.J. Thomson, On 1897 Discovery

Speaking in 1934

Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen? -- which itself is so small that a crowd of these atoms equal in number to the population of the whole world would be too small to have been detected by any means then known to science.

Credit: American Institute of Physics

20th Century Particle Physics Laboratories

electron linear accelerator at Stanford (SLAC)

proton synchrotron at Fermilab (near Chicago)

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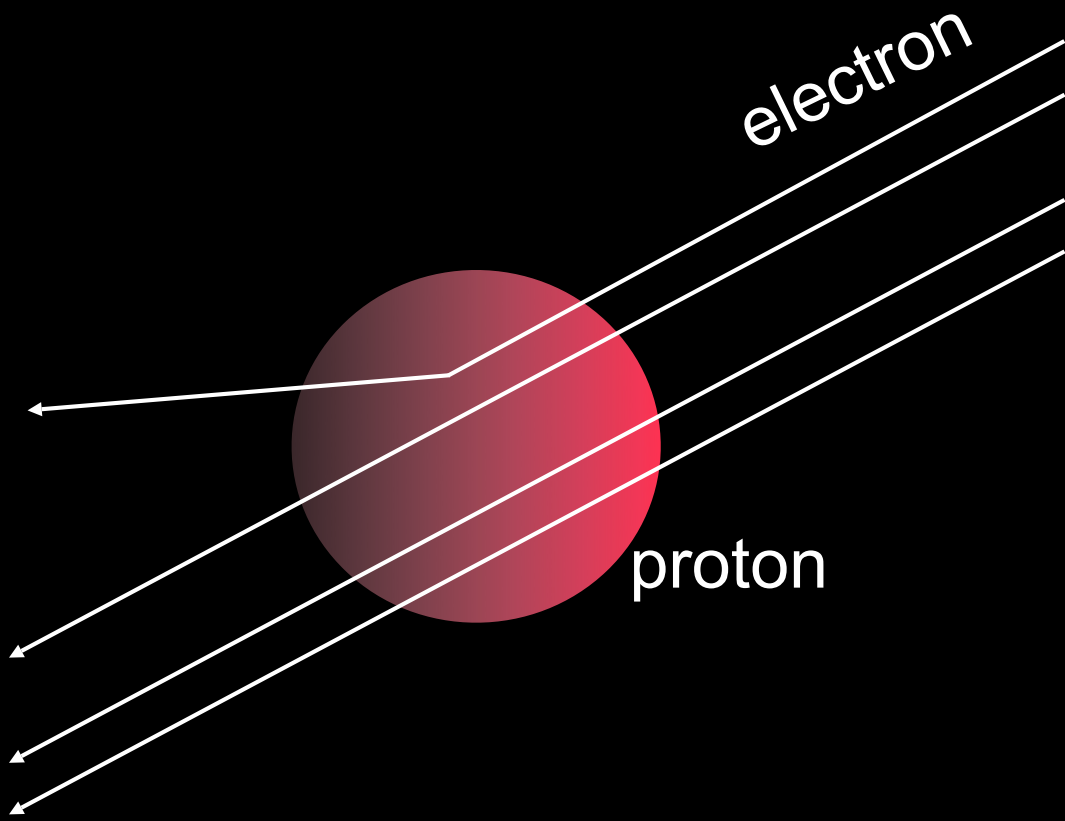
1969 - Quarks discovered (inside atomic nucleus) Stanford



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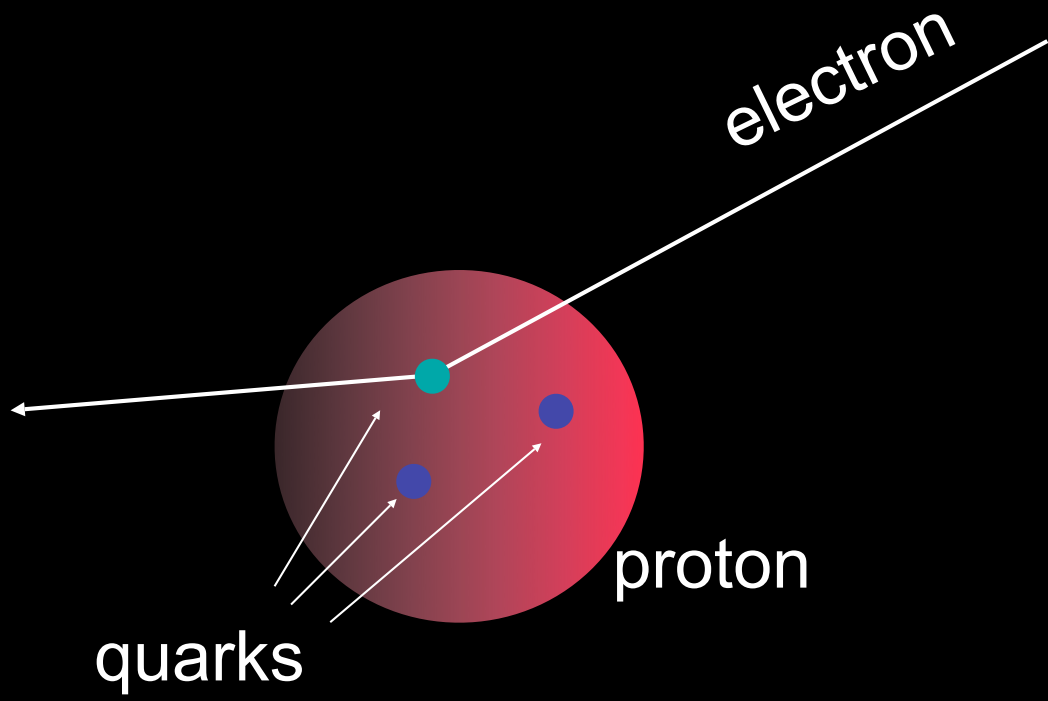
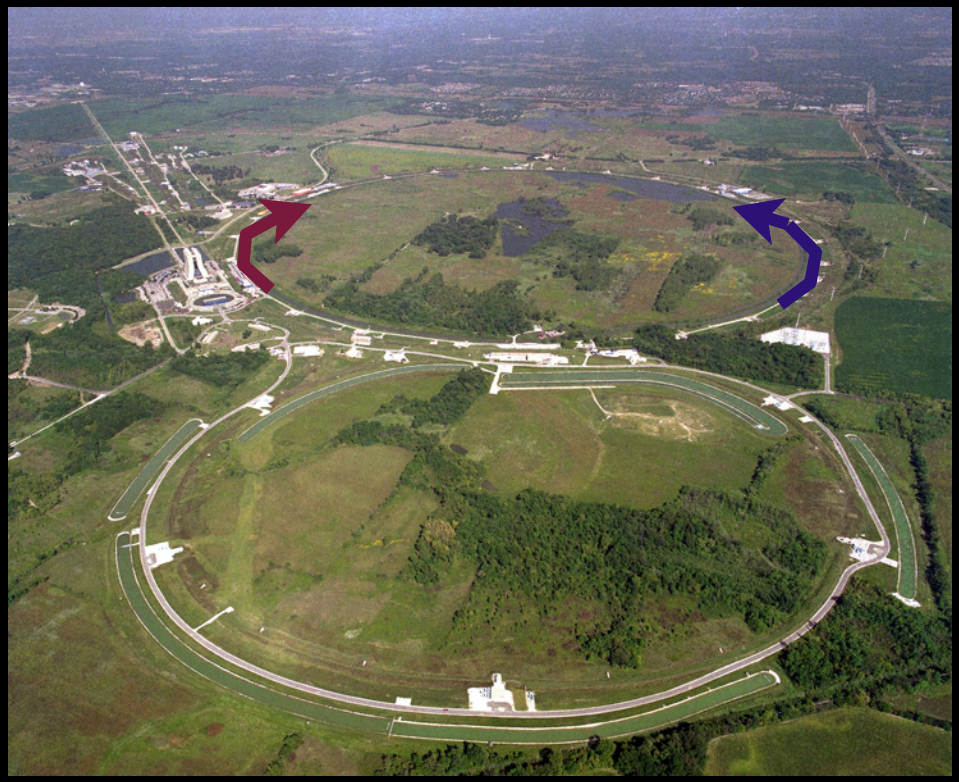
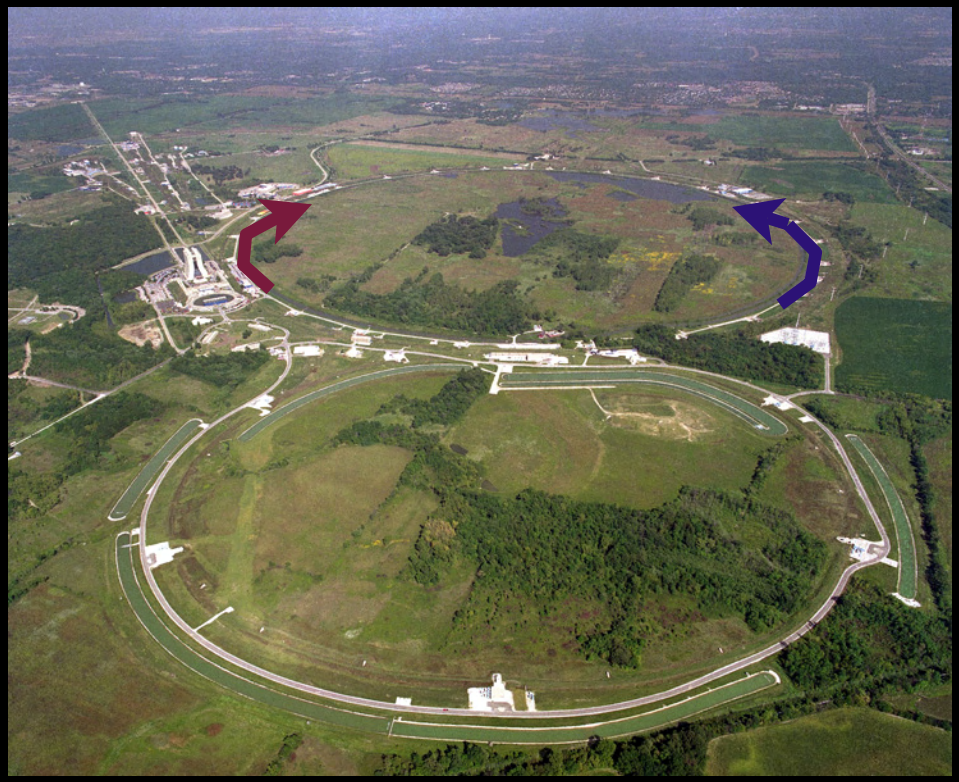


1995 - Top Quark Discovered at Fermilab



1995 - Top Quark Discovered at Fermilab



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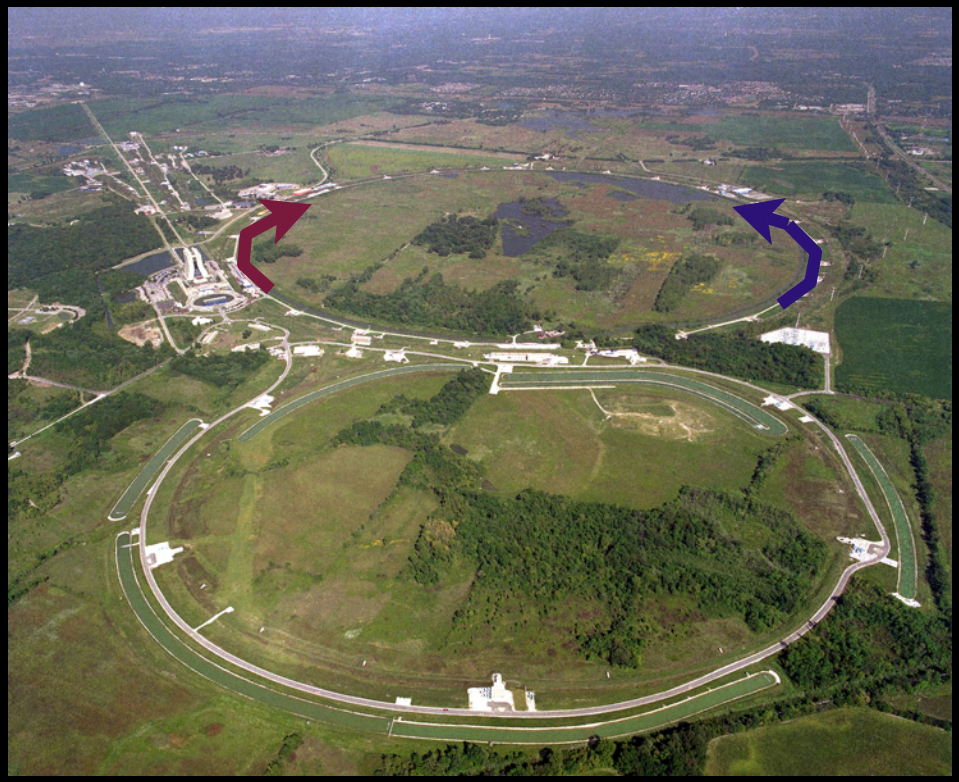
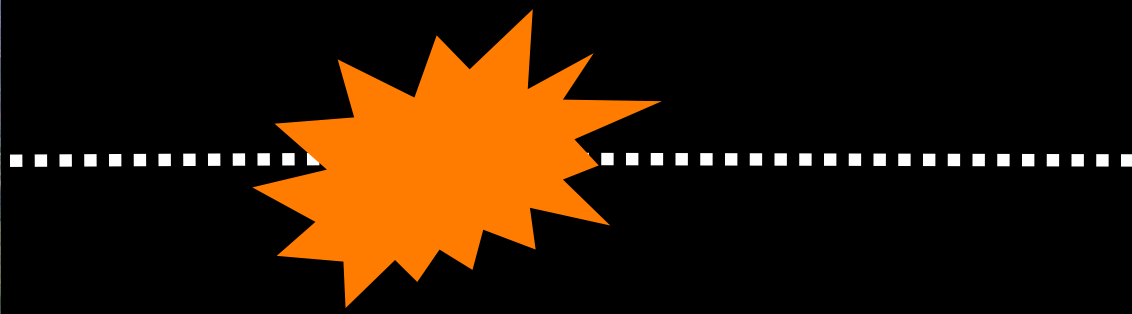
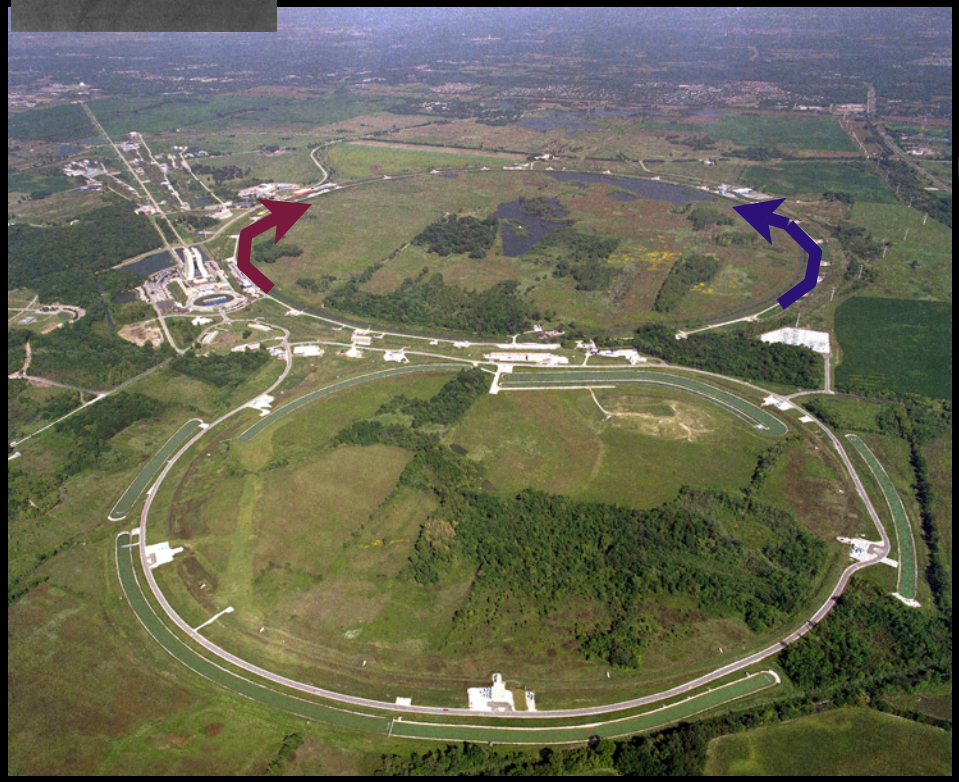
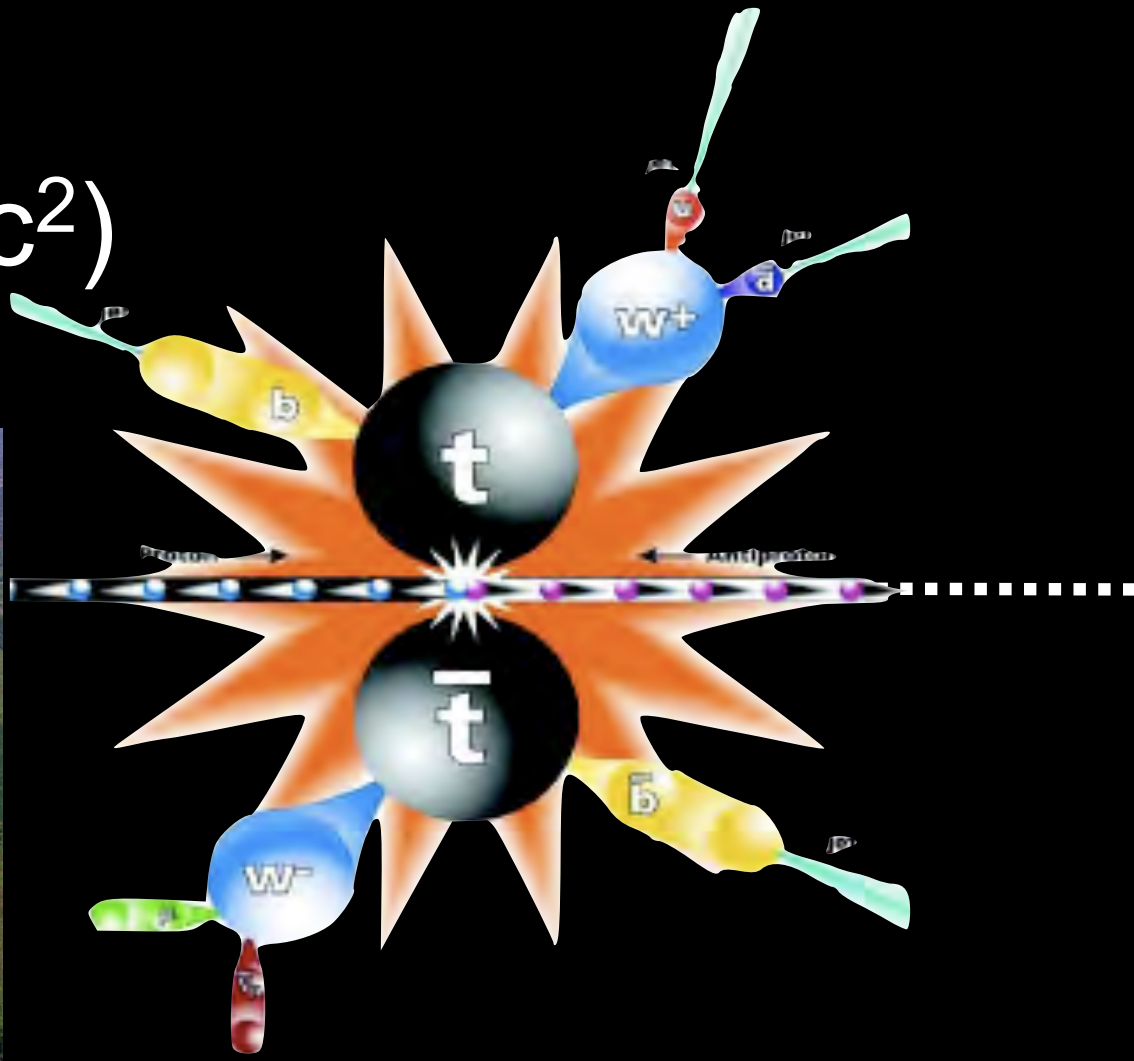




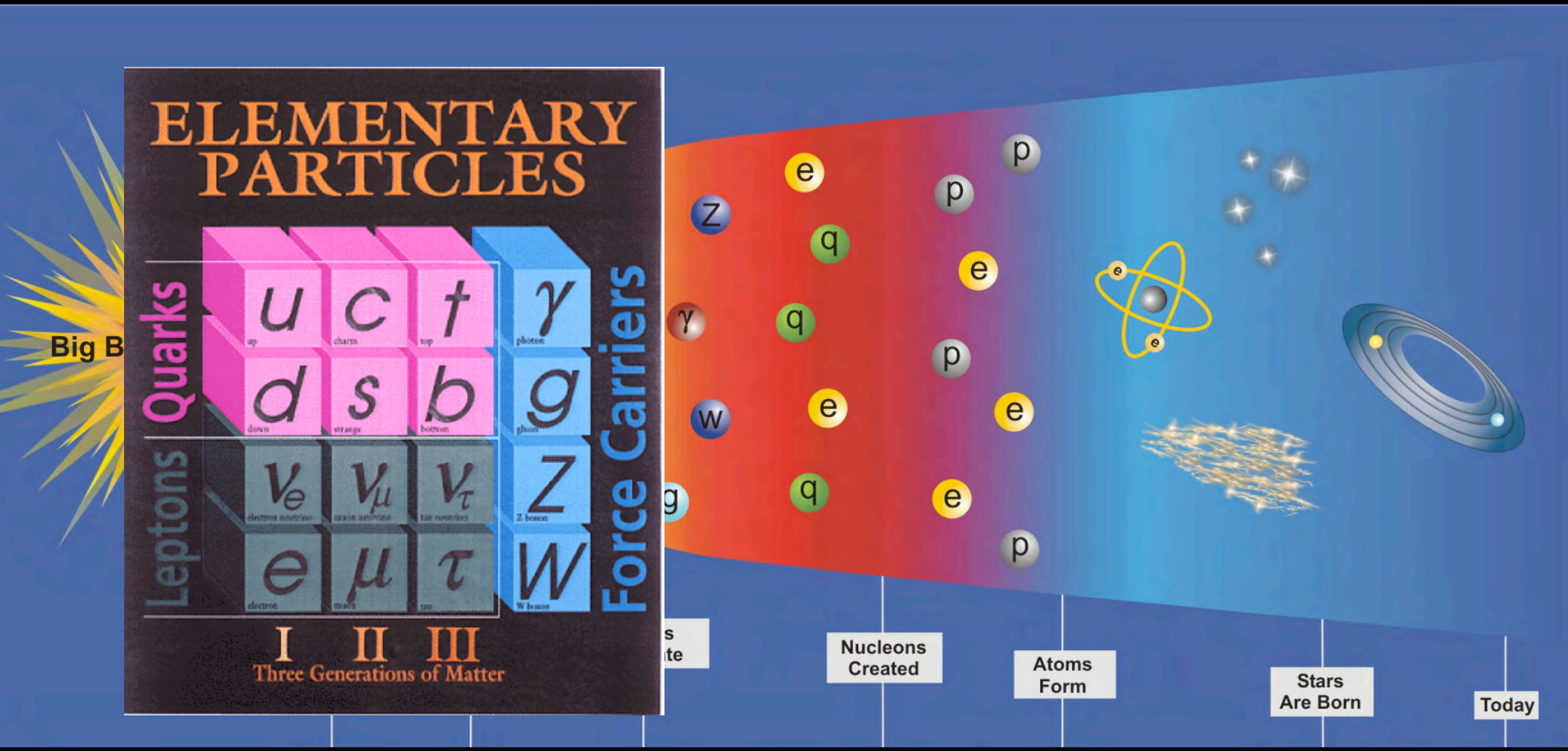
1995 - Top Quark Discovered at Fermilab

Creation of massive matter ($E=mc^2$)



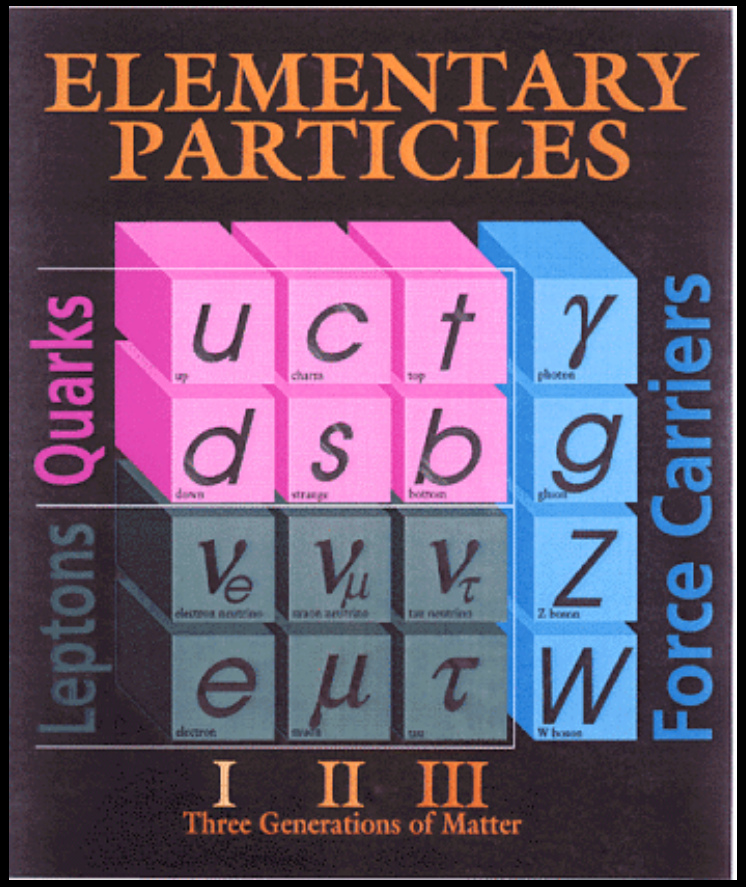


Particles


ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u c t γ
d s b g
νe νμ ντ Z
e μ τ W
I II III
Three Generations of Matter
Big B
Nucleons Created
Atoms Form
Stars Are Born
Today

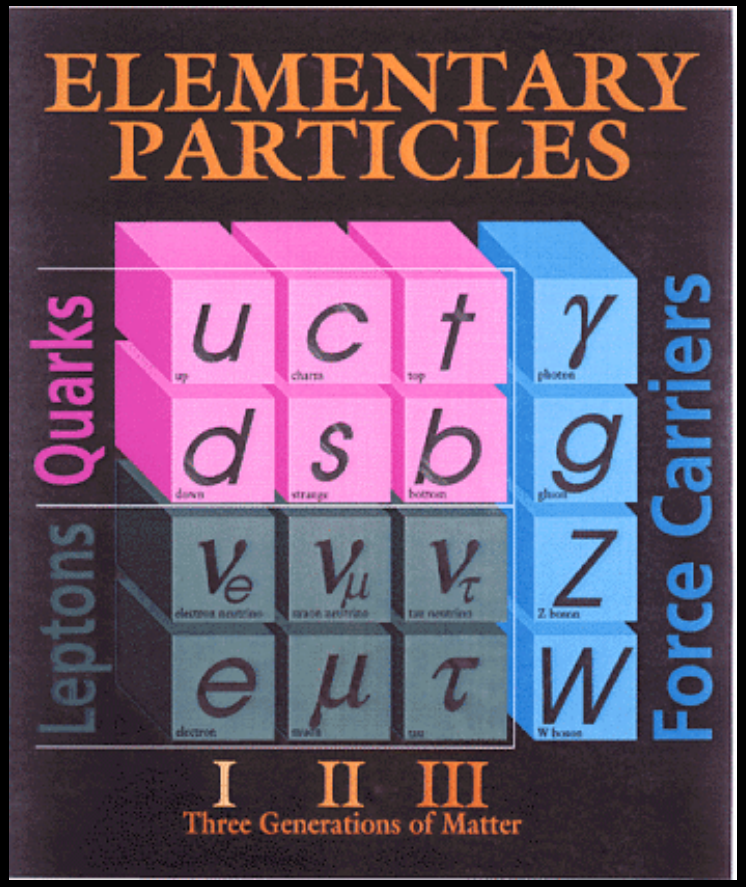
Particles and Forces

"interactions"



Particles and Forces

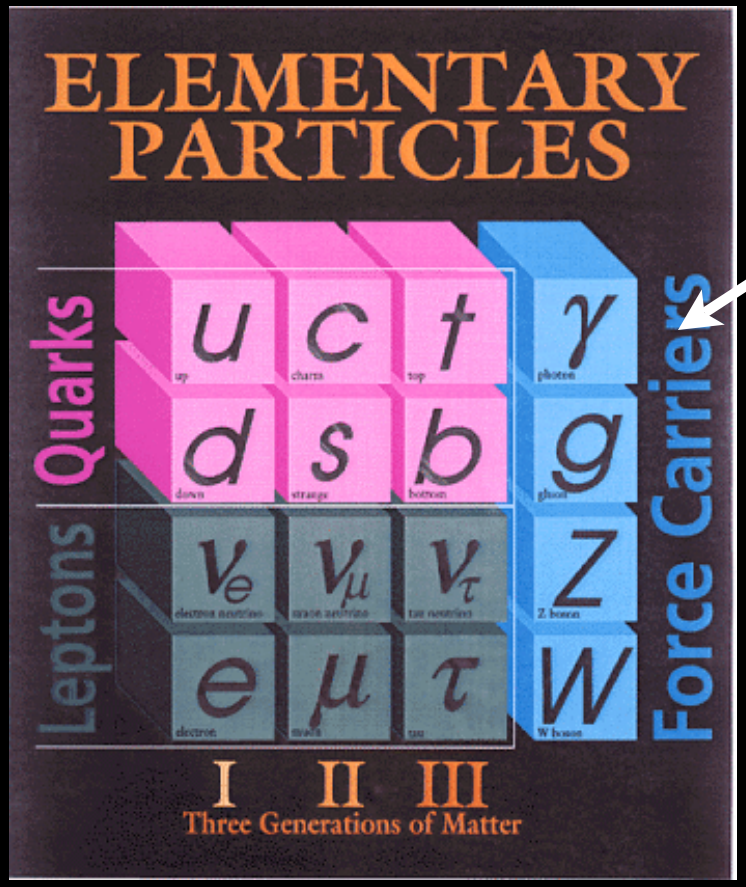
"interactions"



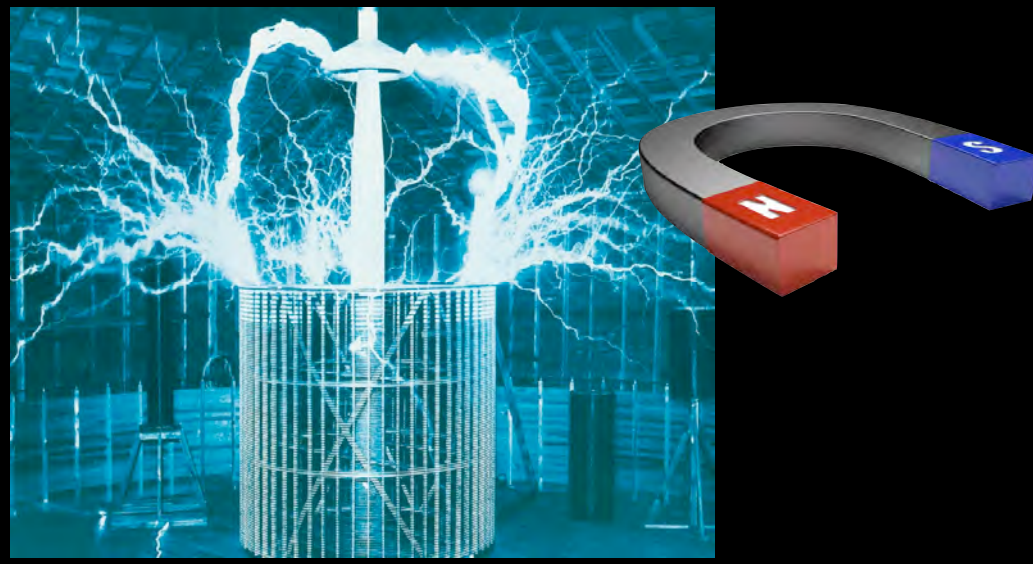
- Gravity - weakest

Particles and Forces

"interactions"

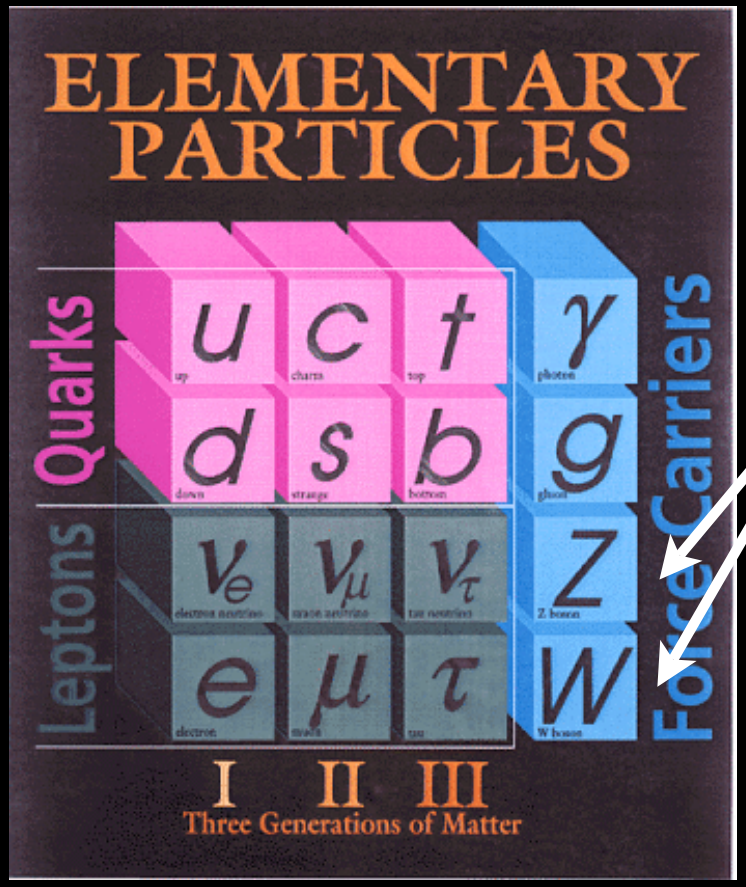


- Gravity - weakest
- Electromagnetism



Particles and Forces

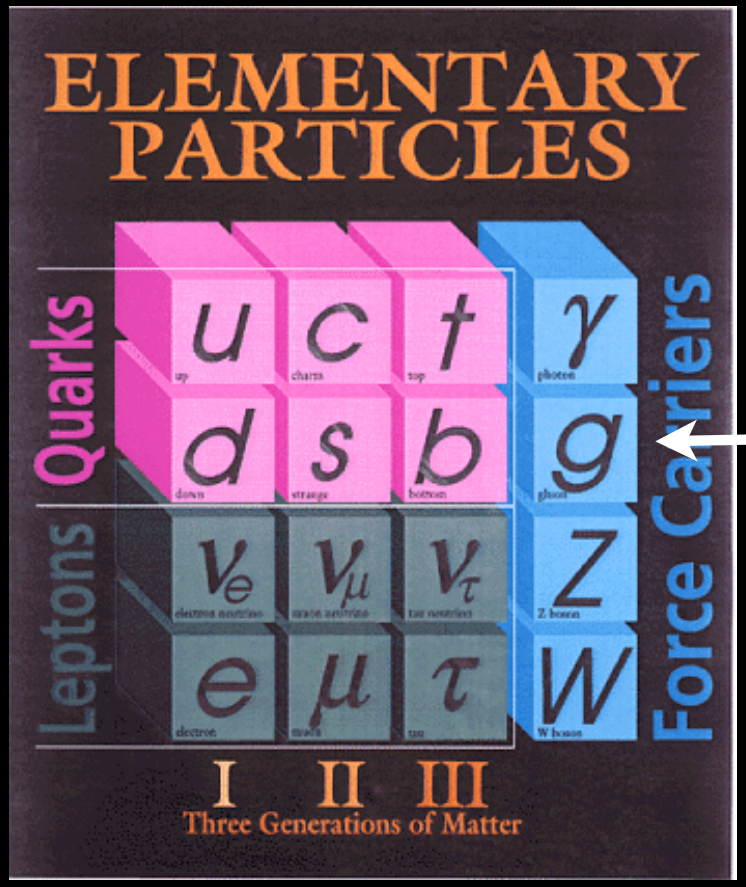
"interactions"



- Gravity - weakest
- Electromagnetism
- Weak Nuclear

Particles and Forces

"interactions"



- Gravity - weakest
- Electromagnetism
- Weak Nuclear
- Strong Nuclear

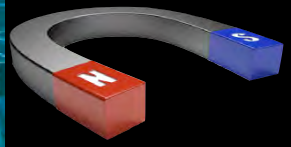
Forces

"interactions"

Are Forces Related?

1850

- Gravity
- Electricity
- Magnetism



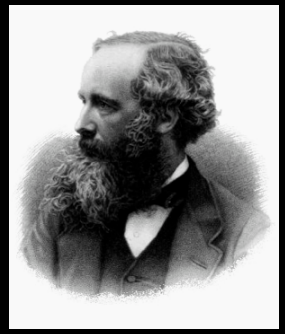
Forces

"interactions"

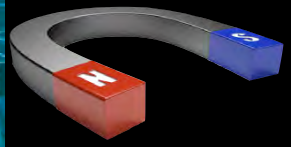
Are Forces Related?

1864

Unified theory
- Electromagnetism
- Light (photons)



- Gravity
- Electricity
- Magnetism



Forces

"interactions"

Are Forces Related?

2000

- Gravity
- Electromagnetism
- Weak Nuclear
- Strong Nuclear

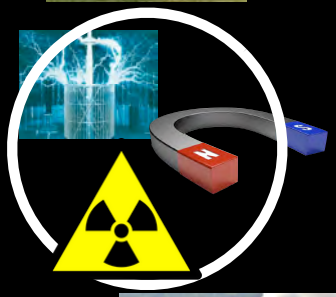
Forces

"interactions"

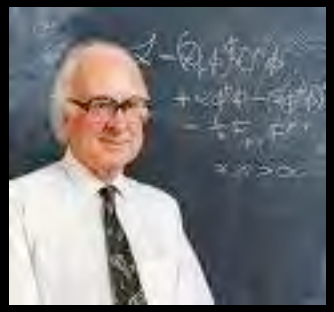
Are Forces Related?

2000

- Gravity
- Electroweak
- Strong Nuclear



Next Advance Expected
- discovery of
  the Higgs Boson
  at accelerators



Forces

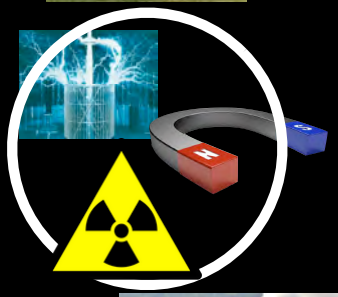
"interactions"

Are Forces Related?

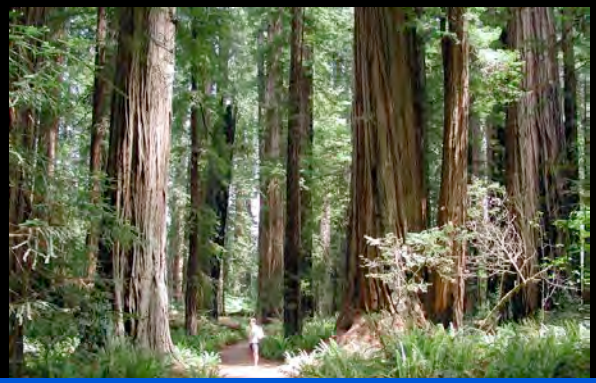
2000

- Gravity
- Electroweak
- Strong Nuclear

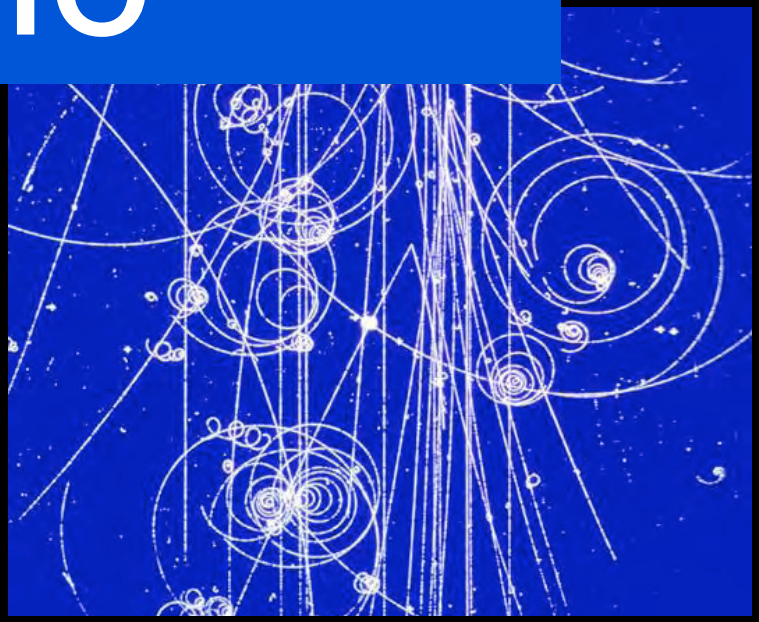
Are all forces related?
New particles would be involved in any unification



What is Matter?



all Atomic



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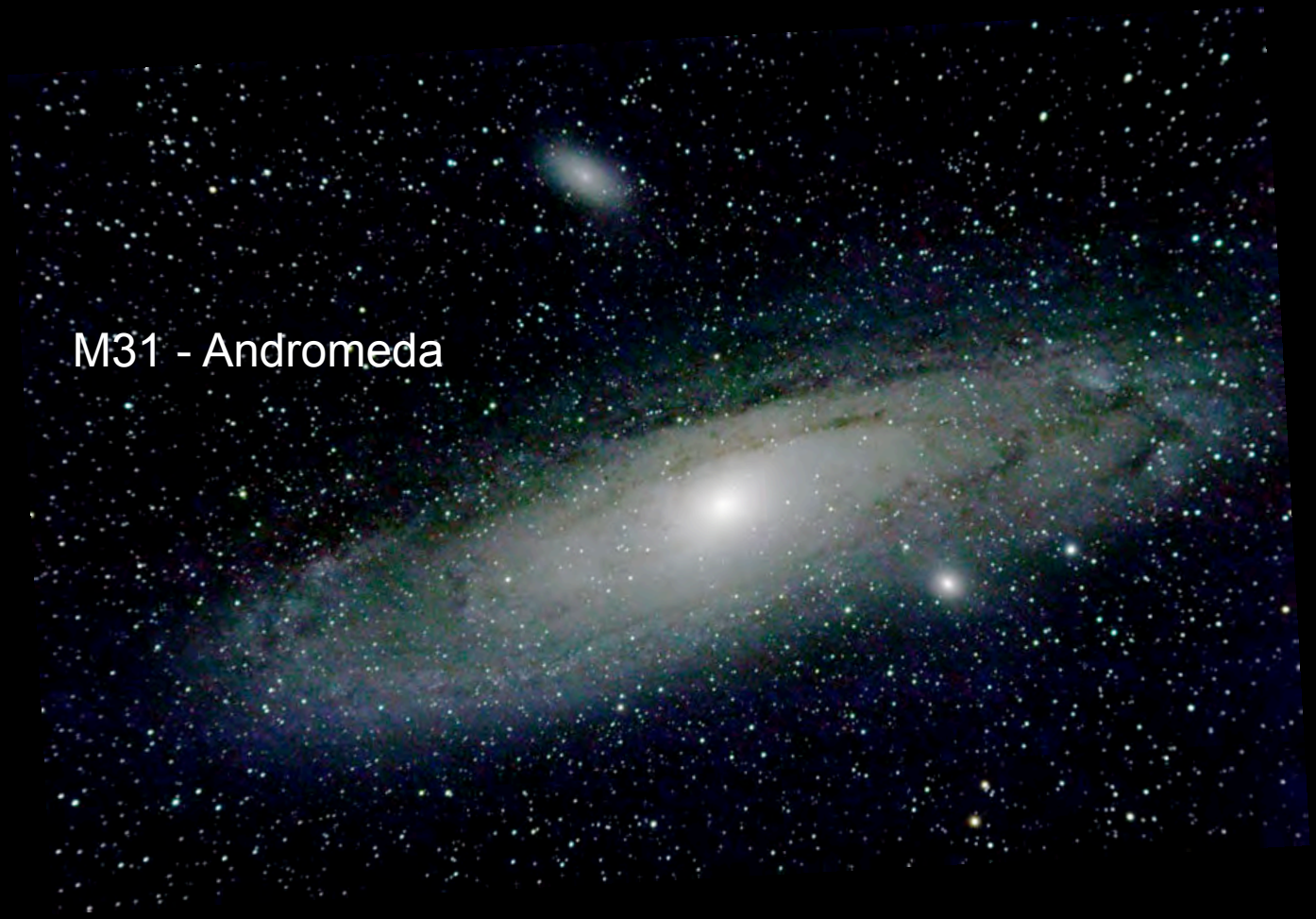
Halo of Dark Matter



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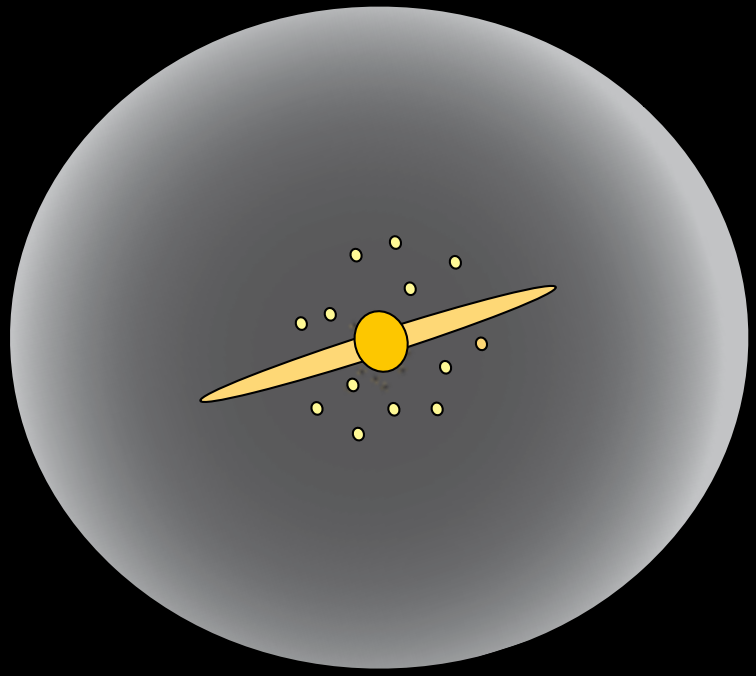
Halo of Dark Matter



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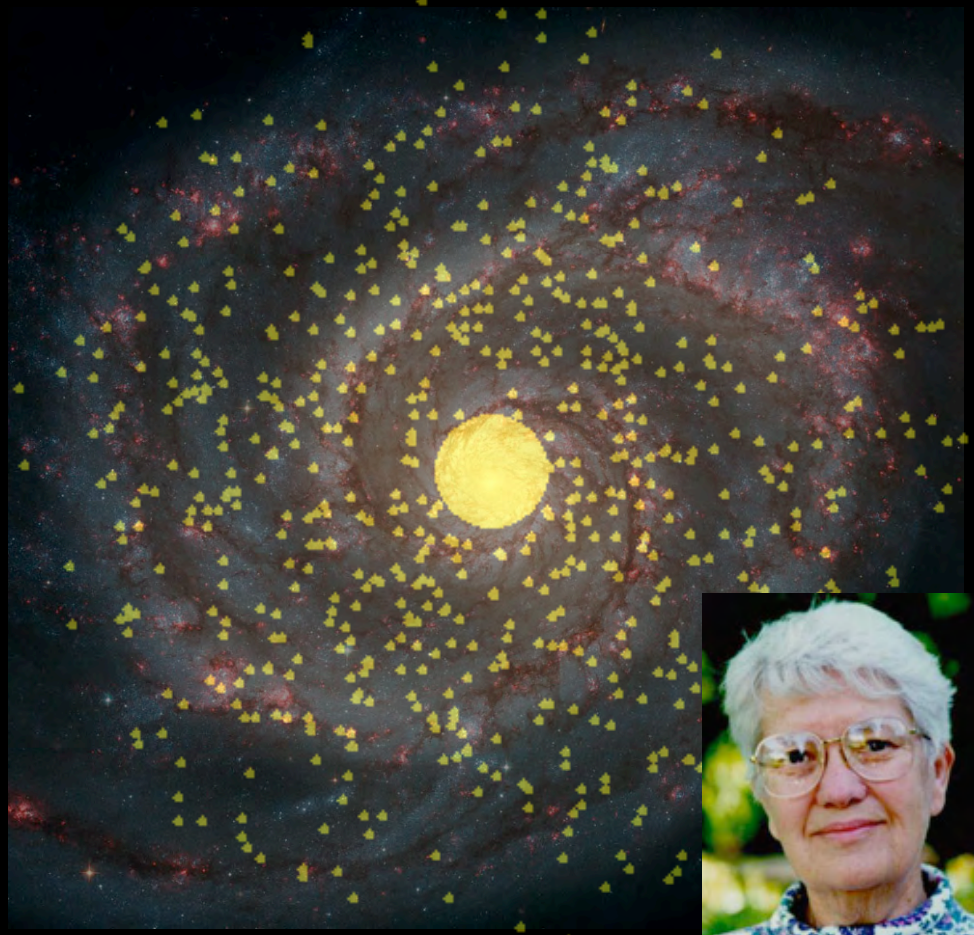
How we know dark halos surround galaxies?

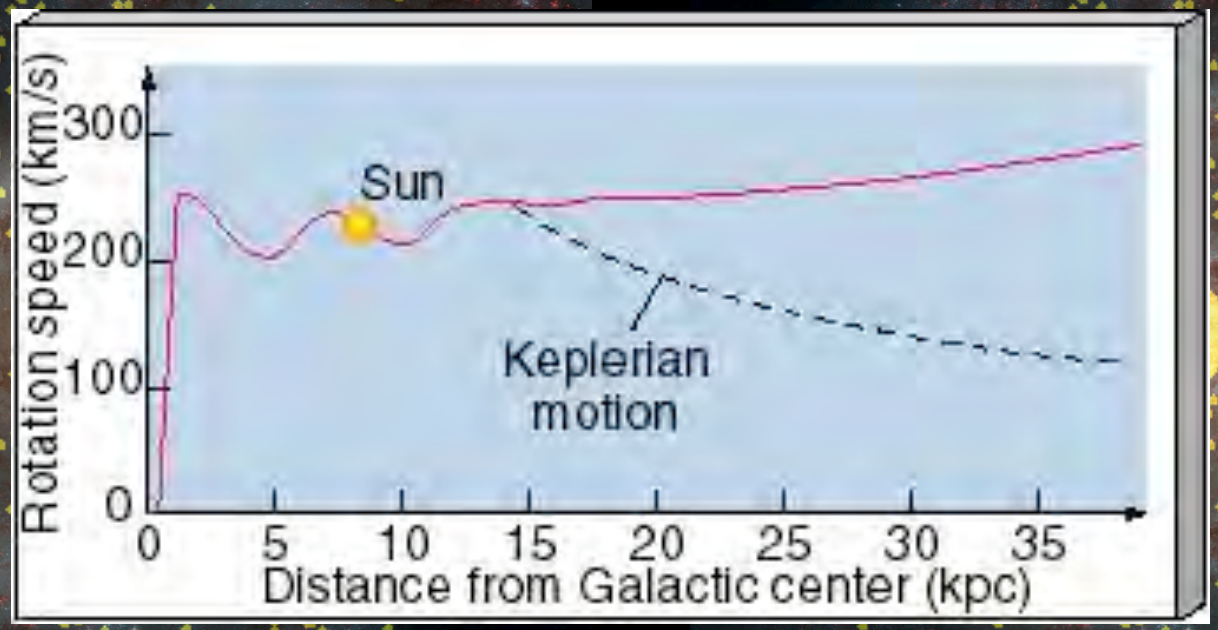


Vera Rubin
1950s

Expected-
based on stellar mass

Observed-
reveals invisible ("dark") mass

How we know dark halos surround galaxies?



Vera Rubin
1950s

Expected-
based on stellar mass

Observed-
reveals invisible ("dark") mass

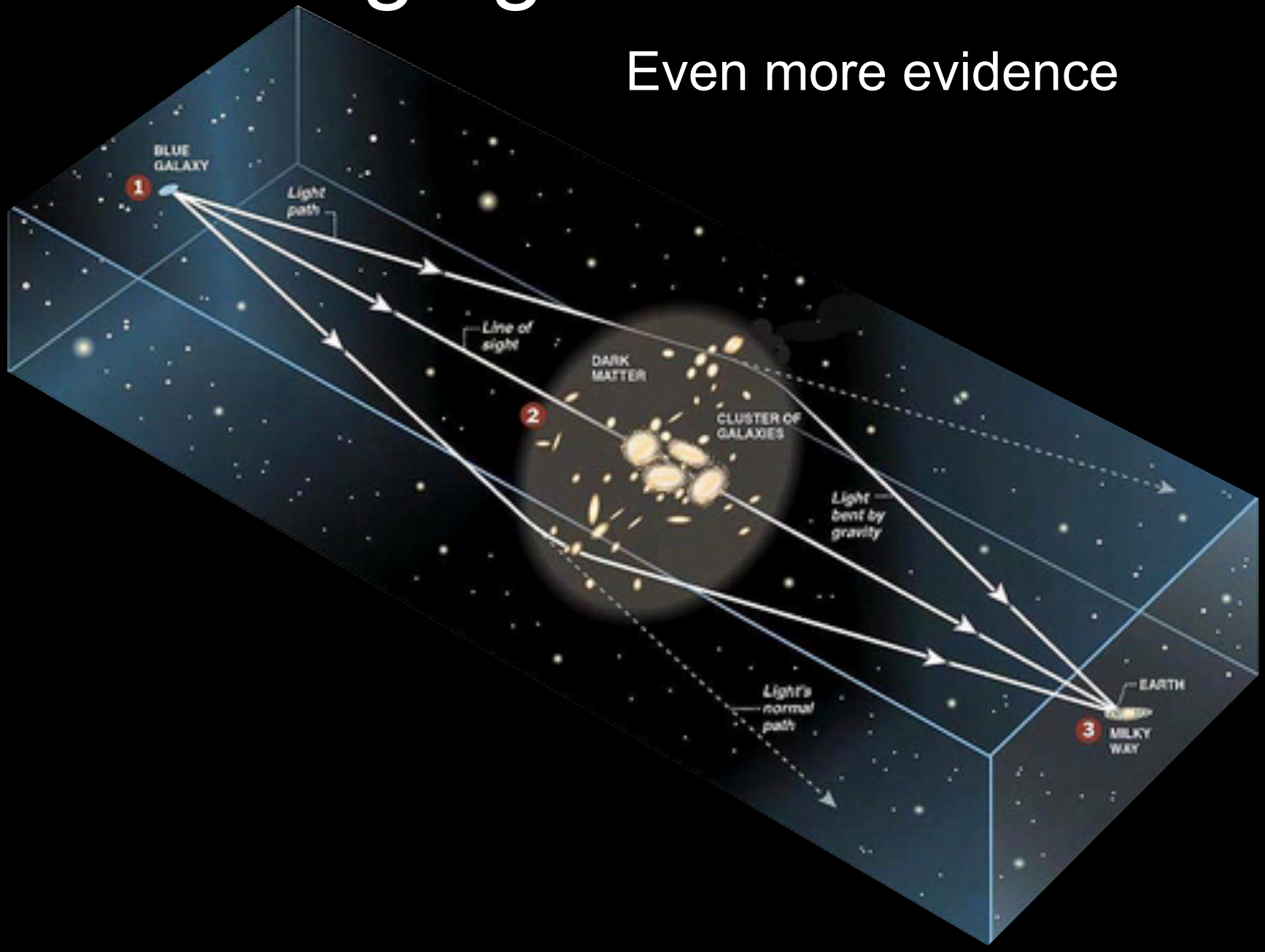
Early Dark Matter Evidence

- 1930s motions of clusters of galaxies cannot be understood – Fritz Zwicky

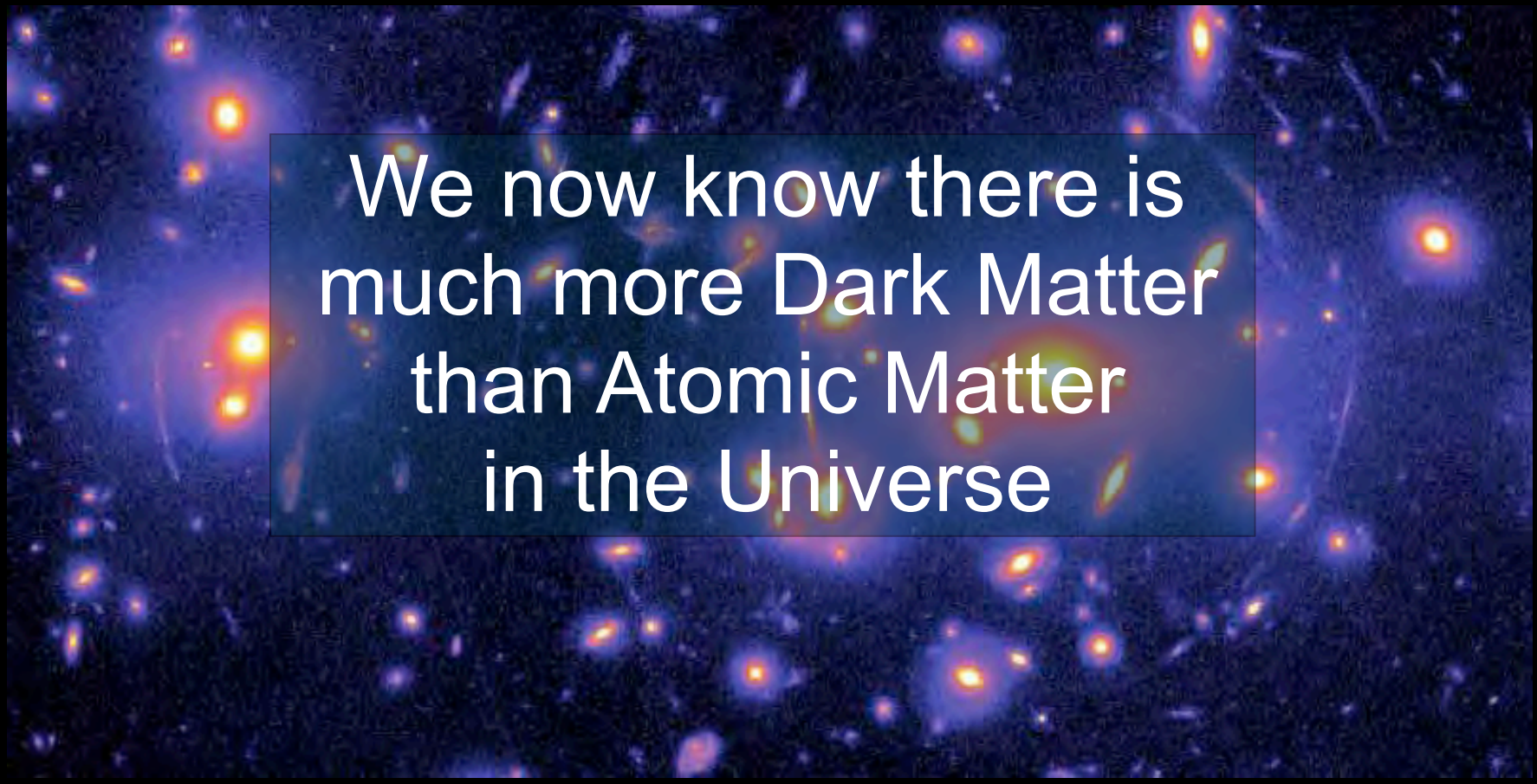
Coma Cluster

Imaging Dark Matter

Even more evidence



Imaging Dark Matter



Einstein Rings

Hubble Data analyzed by Yale astrophysicists

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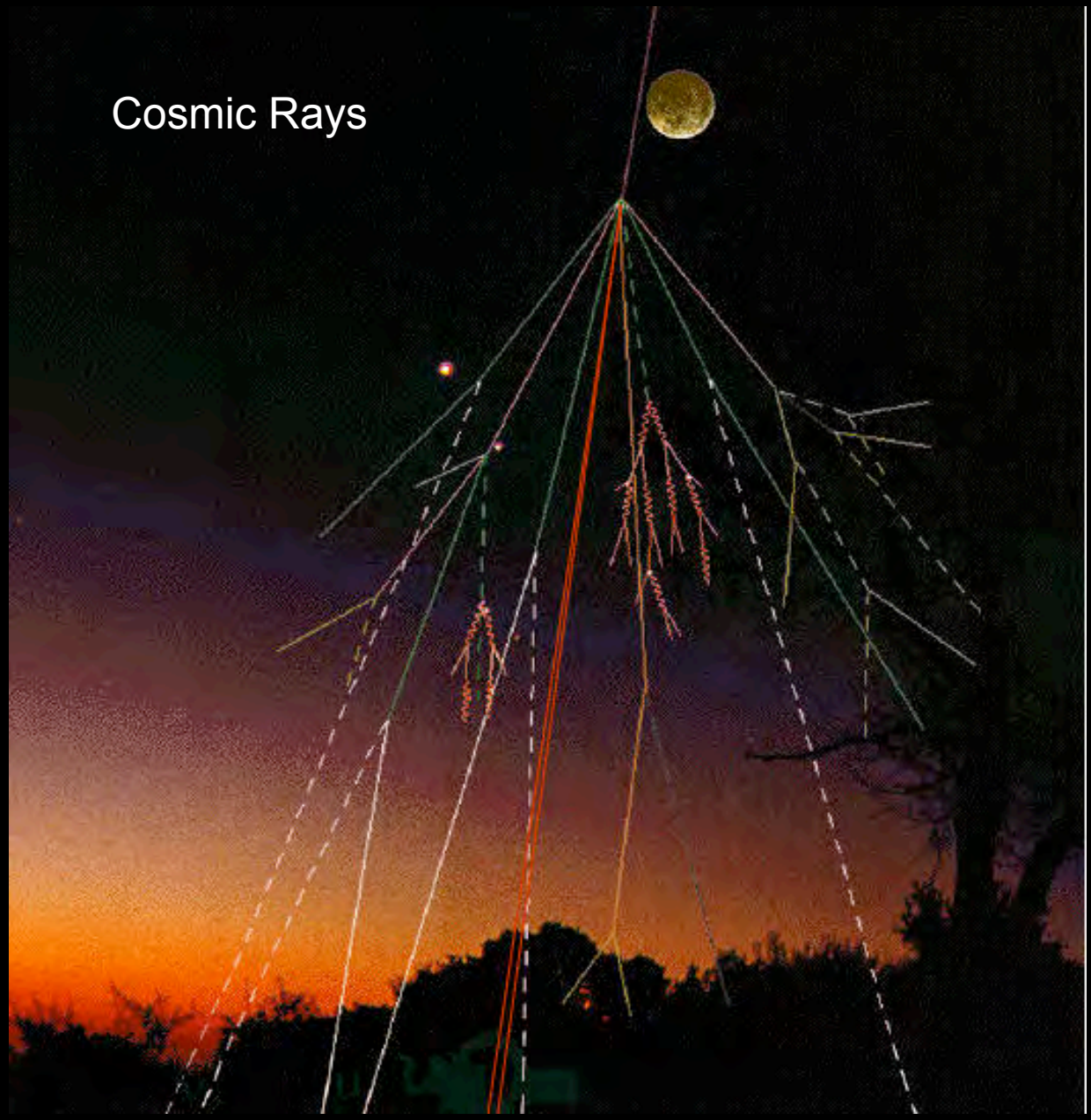
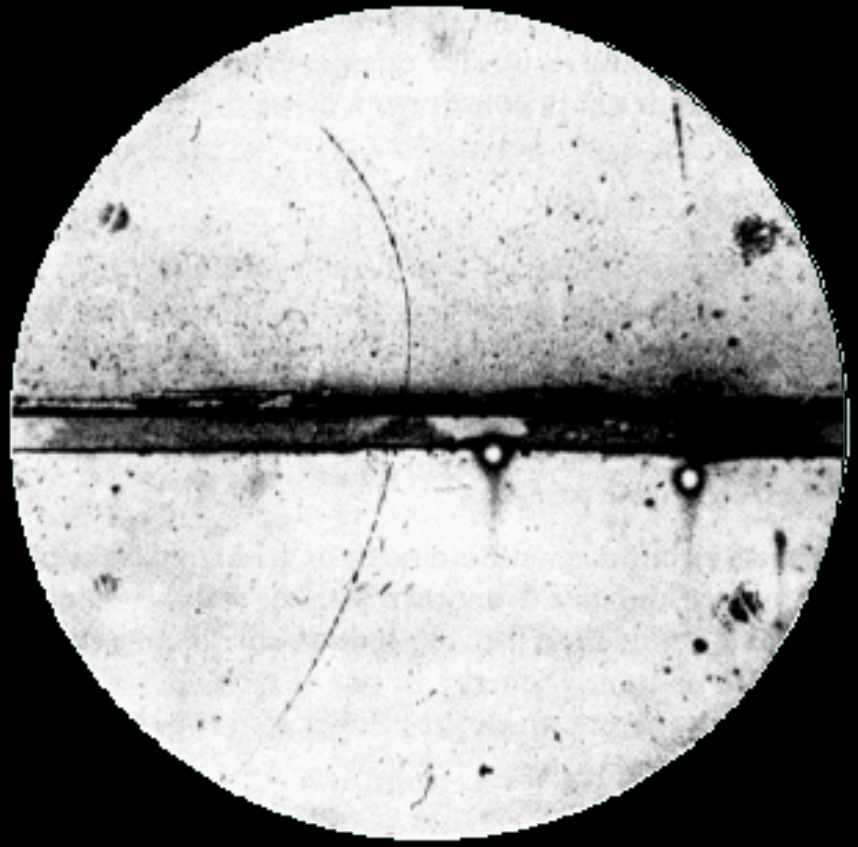
What is Dark Matter ?

- Perhaps a new form of elementary particle?
- Can we learn from history of physics?

1932

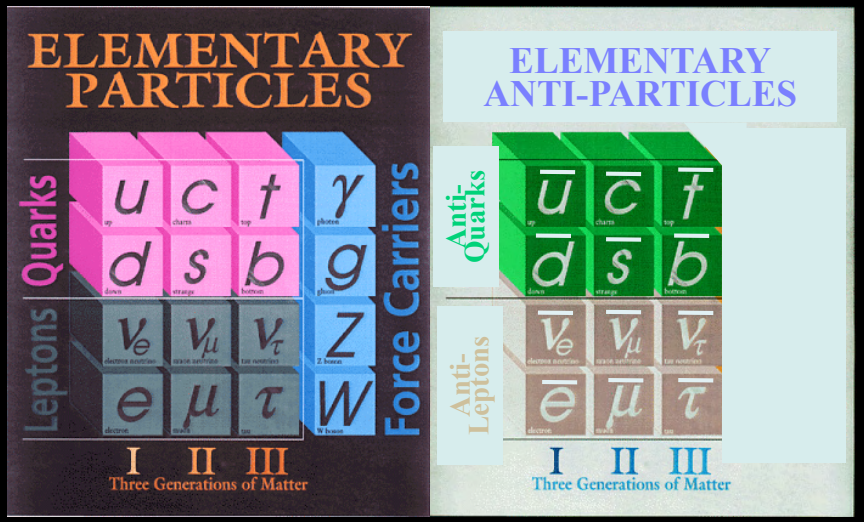


1932 - Discovery of Anti-Matter



1932 - Discovery of Anti-Matter

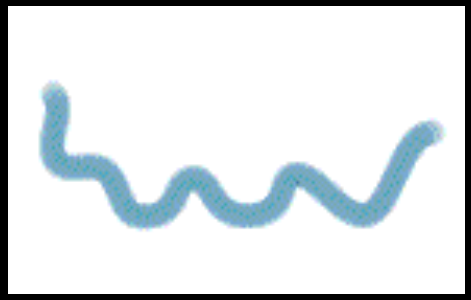
Anti-particle for every known particle

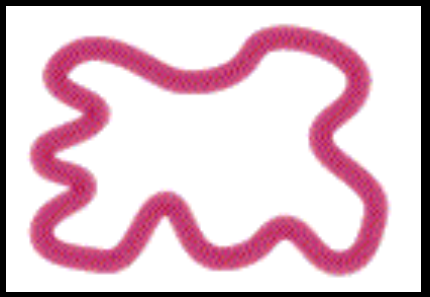


Candidate Theory Explains Dark Matter

SuperString Theory

- Unifies all particles and all forces
  - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string

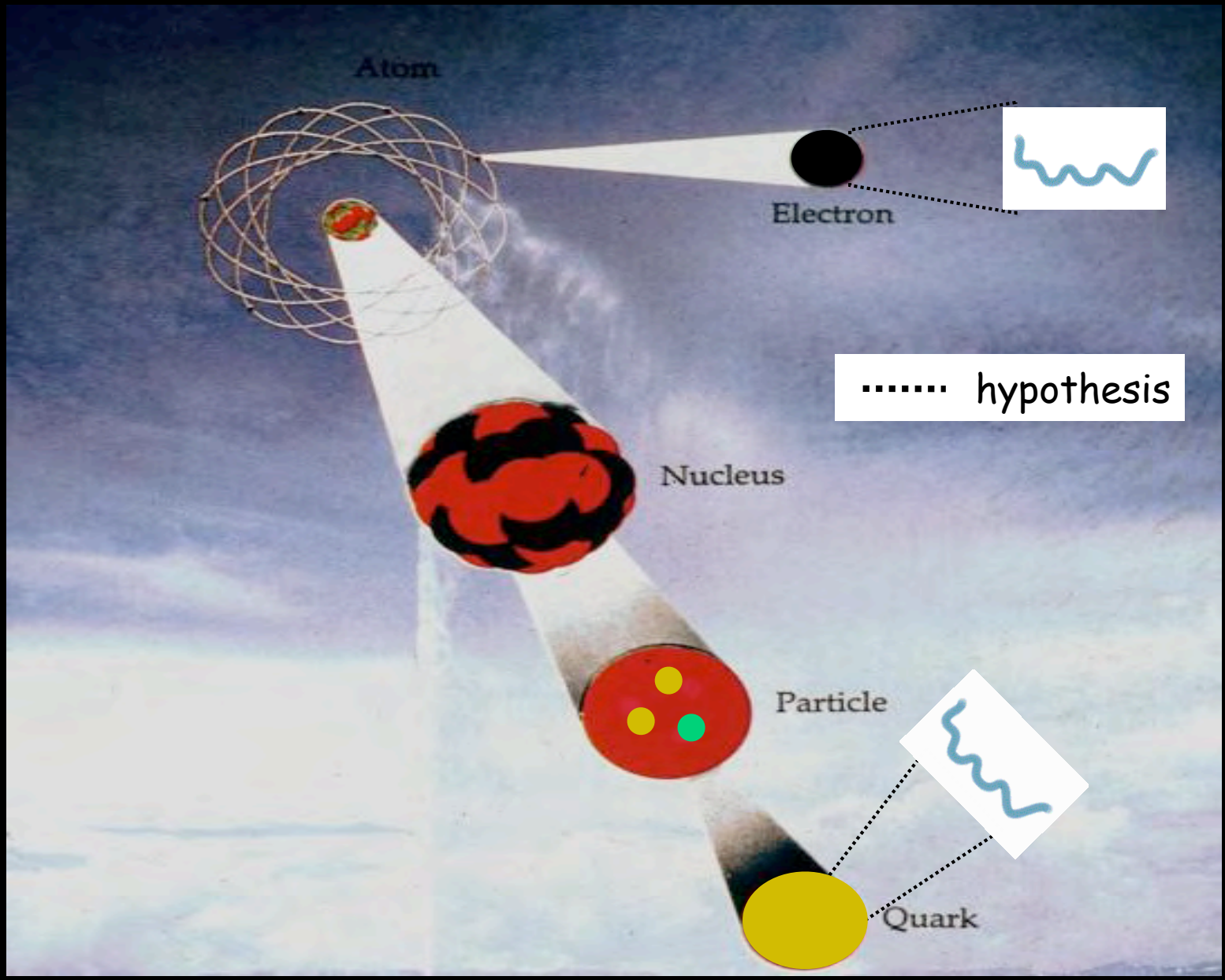




- Strings are miniscule
  - Atom is 10,000,000,000,000,000,000,000,000 x bigger

    Dimension of String $=10^{-25}$ atomic size $= 10^{-35}$ meters
- Requires another set of matching particles
  - the super-partners of ordinary particles

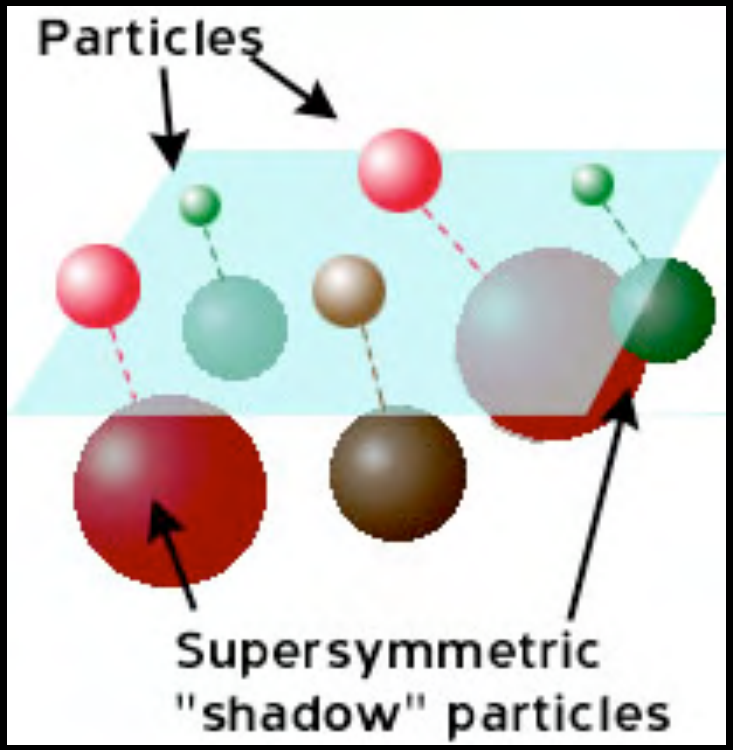
The Structure of Matter

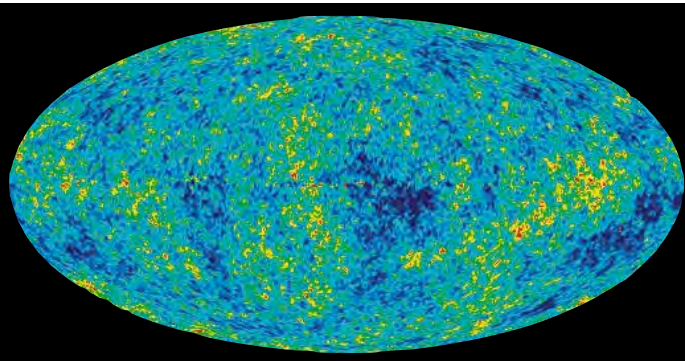


Supersymmetry, Strings, and Dark Matter

- History repeats?
- Just as with anti-matter, New particles are predicted

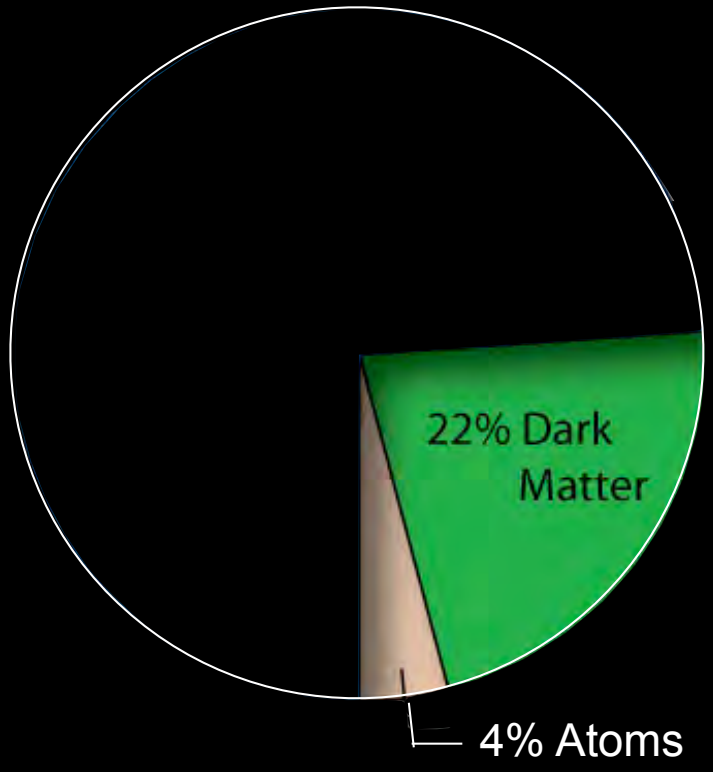
- The supersymmetric particles have just the properties expected of Dark Matter





The Matter Crisis

- not enough matter (atomic or dark matter) to "make-up" known stuff of the Universe



Measuring Expansion of Universe

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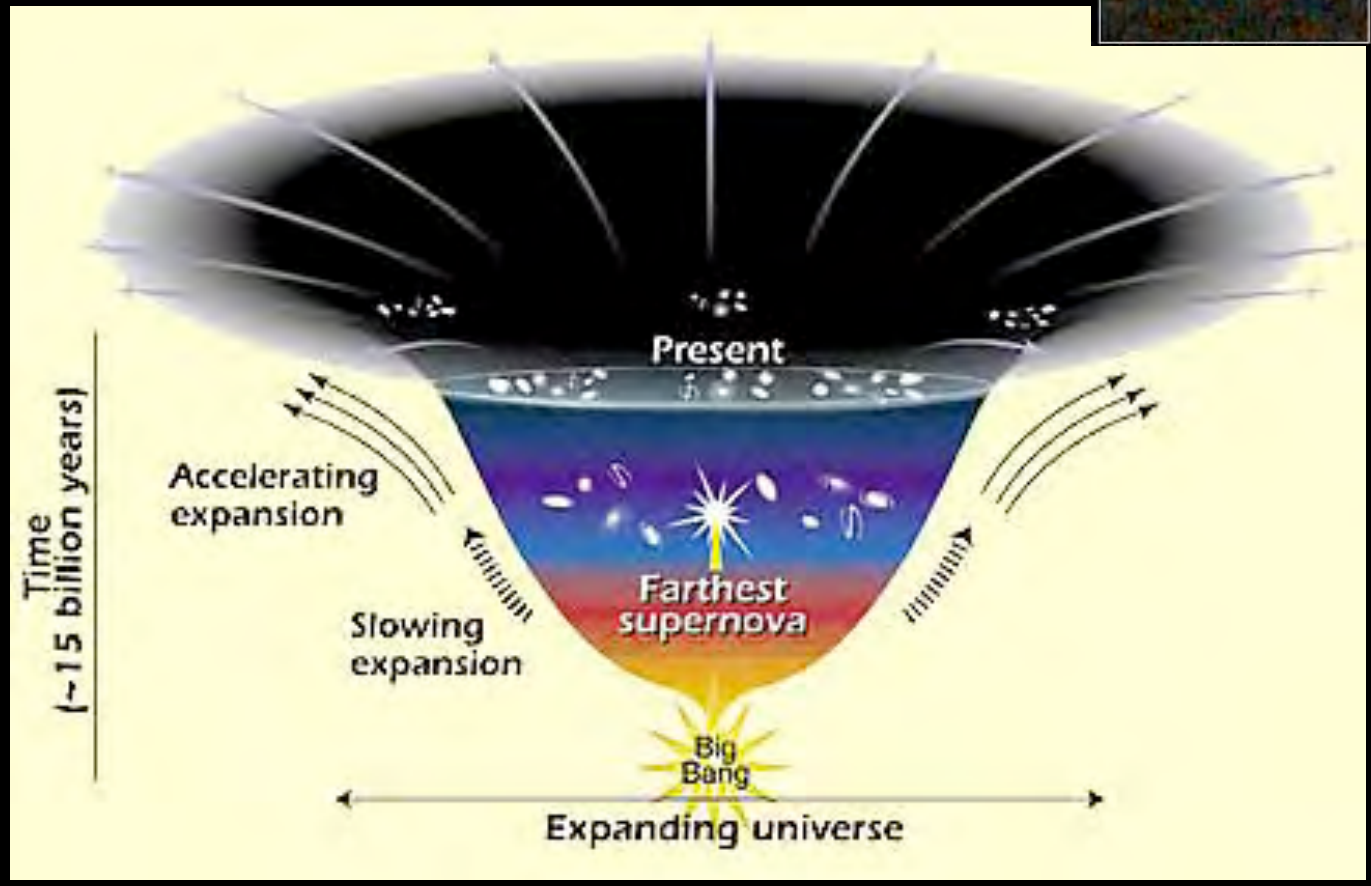
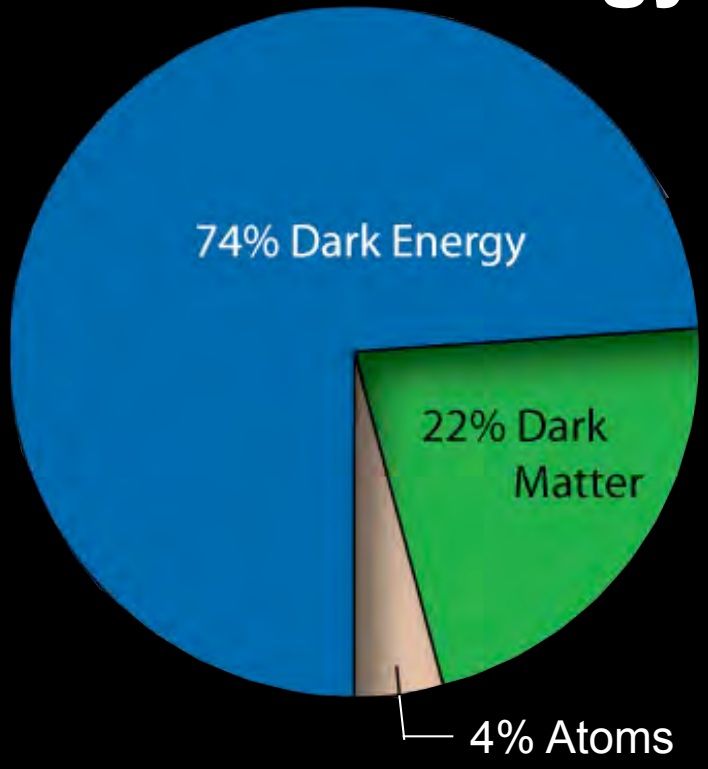


Expansion of the Universe is Accelerating

Driven by <u>Dark Energy</u>

Acceleration Component called “Dark Energy”

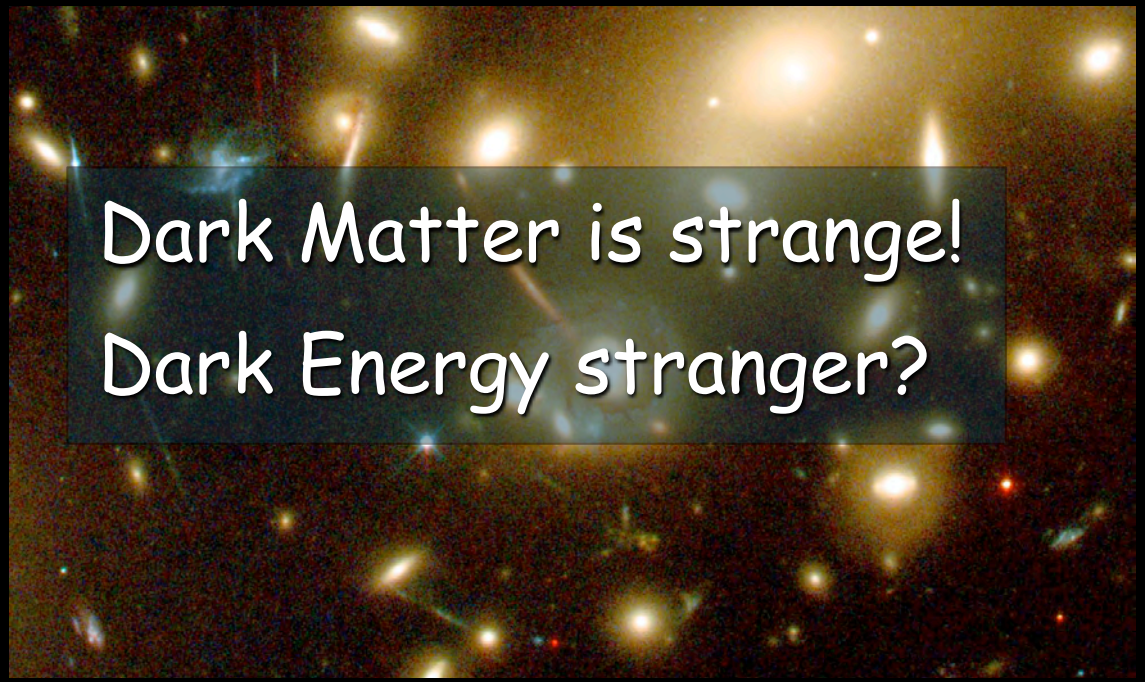
- Solves “Matter” Crisis
- The dominant “stuff” of the universe is **dark matter** and **dark energy**



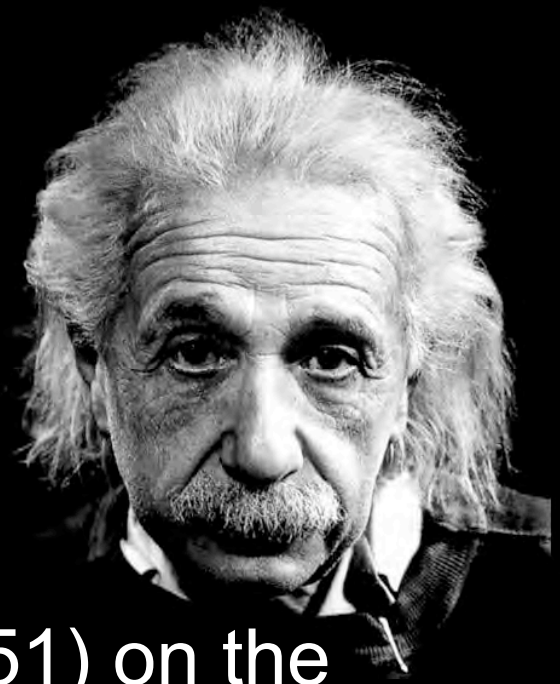
The Dark Side Controls the Universe

Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY



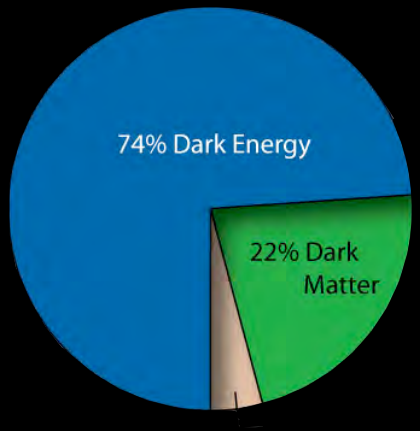
What is Dark Energy?



- No one knows yet
  - but we have some hints

- Cautioned by Einstein's comment (1951) on the understanding of the photon:

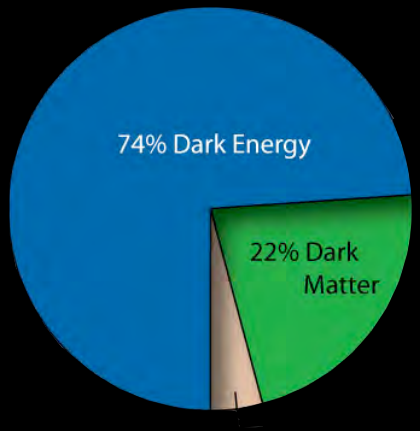
  All these fifty years of conscious brooding have brought me no nearer to the answer to the question "what is the light quanta."
  Nowadays every rascal thinks he knows, but he is mistaken.



Quantum Nature of Nothing is Something

Empty Space

"Vacuum"



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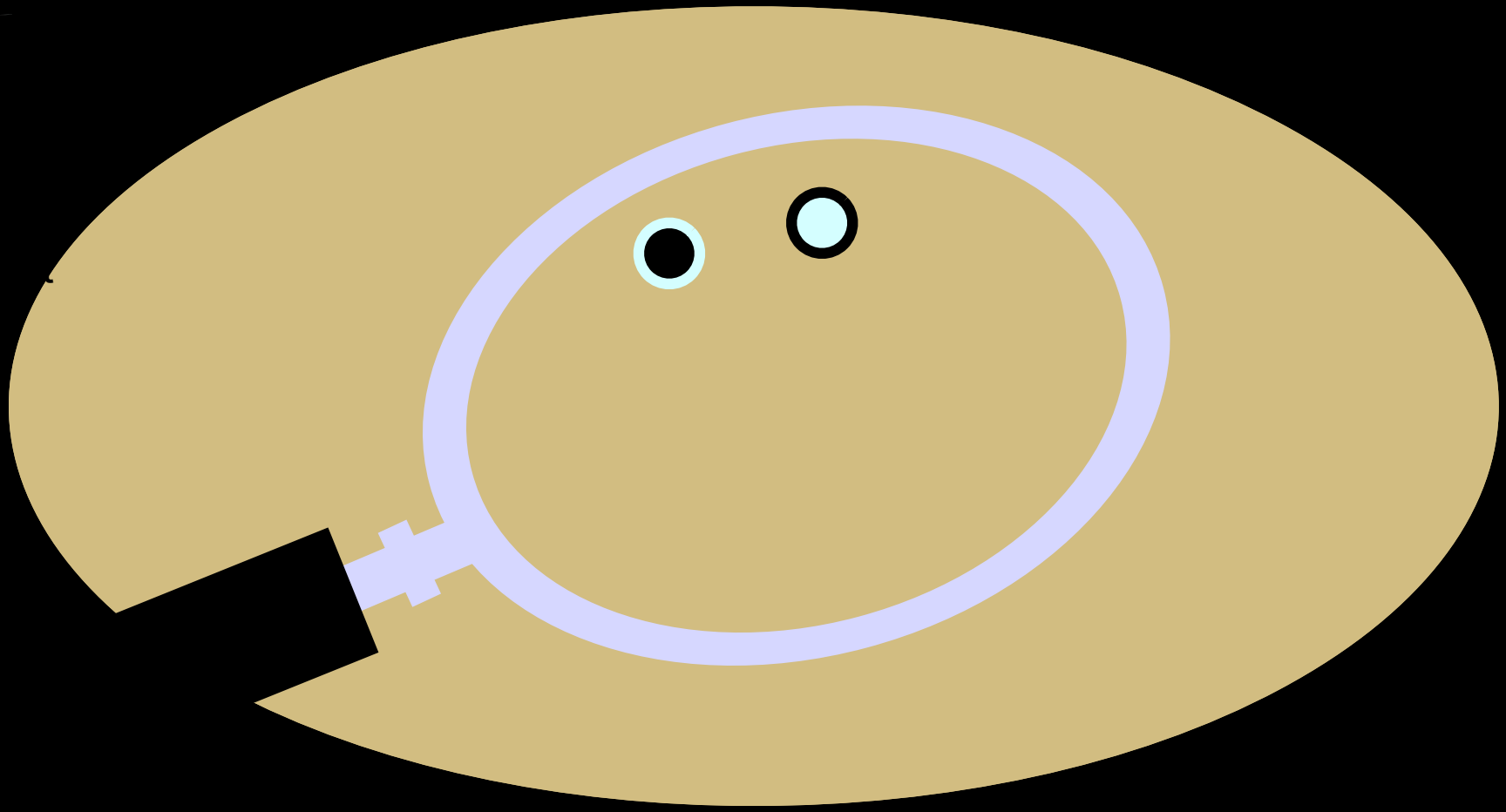
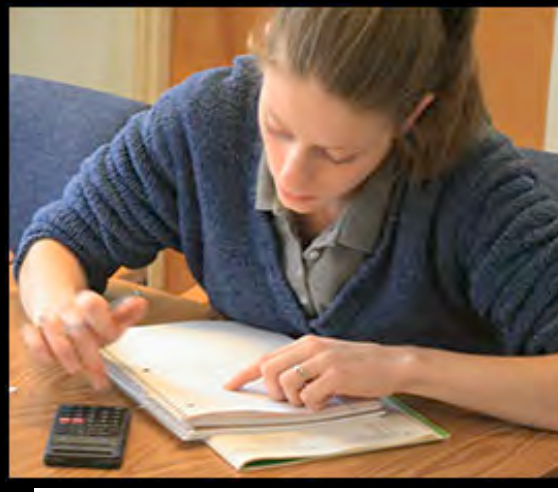


Calculating Dark Energy

- Solid Quantum Mechanical Foundation
  - effect of particles in the vacuum



$$E_o = \frac{1}{4\pi}\hbar\omega$$

cuum energy is the sum of all the simple harm

$$E_o = \sum_j \frac{1}{4\pi}\hbar\omega_j$$

λ) for the scalar field. This sum may be evalu
go to infinity. The periodic boundary conditi
eger values of n. There are then $Ldk/2\pi$ discre
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$$E_o = \frac{1}{4\pi}\hbar L^3 \int \frac{\omega}{(2\pi)^3} d^3k$$

pose a cutoff at a maximum wavevector k_{max}

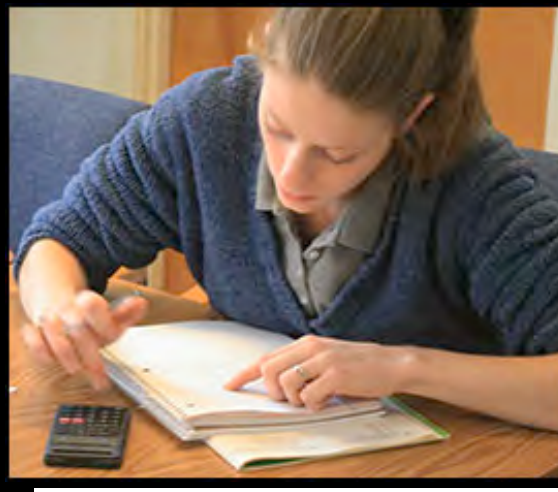
$$\rho_{vac} \equiv \lim_{L\to\infty} \frac{E_o}{L^3} = \frac{\hbar k_{max}^4}{32\pi^3}$$

Calculating Dark Energy

- Solid Quantum Mechanical Foundation
  - effect of particles in the vacuum
- Does the calculation agree with measurement?

NO! 1,000,000,000,000,000,000,000,
000,000,000,000,000,000,000,
000,000,000,000,000,000,000,
000,000,000,000,000,000,000,
000,000,000,000,000,000,000,
000,000,000,000,000 $=10^{120}$

times too big



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Large Hadron Collider (LHC)
Geneva, Switzerland

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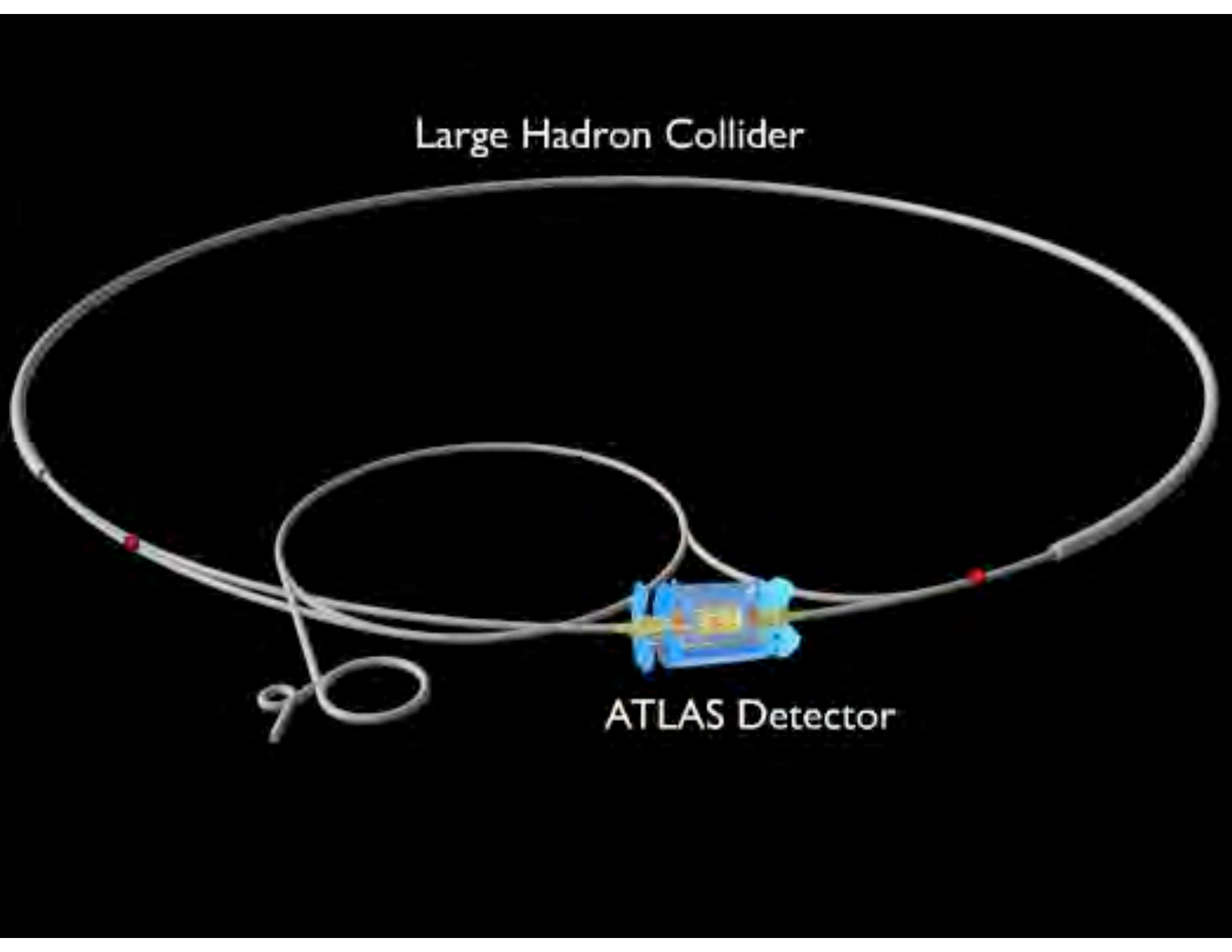
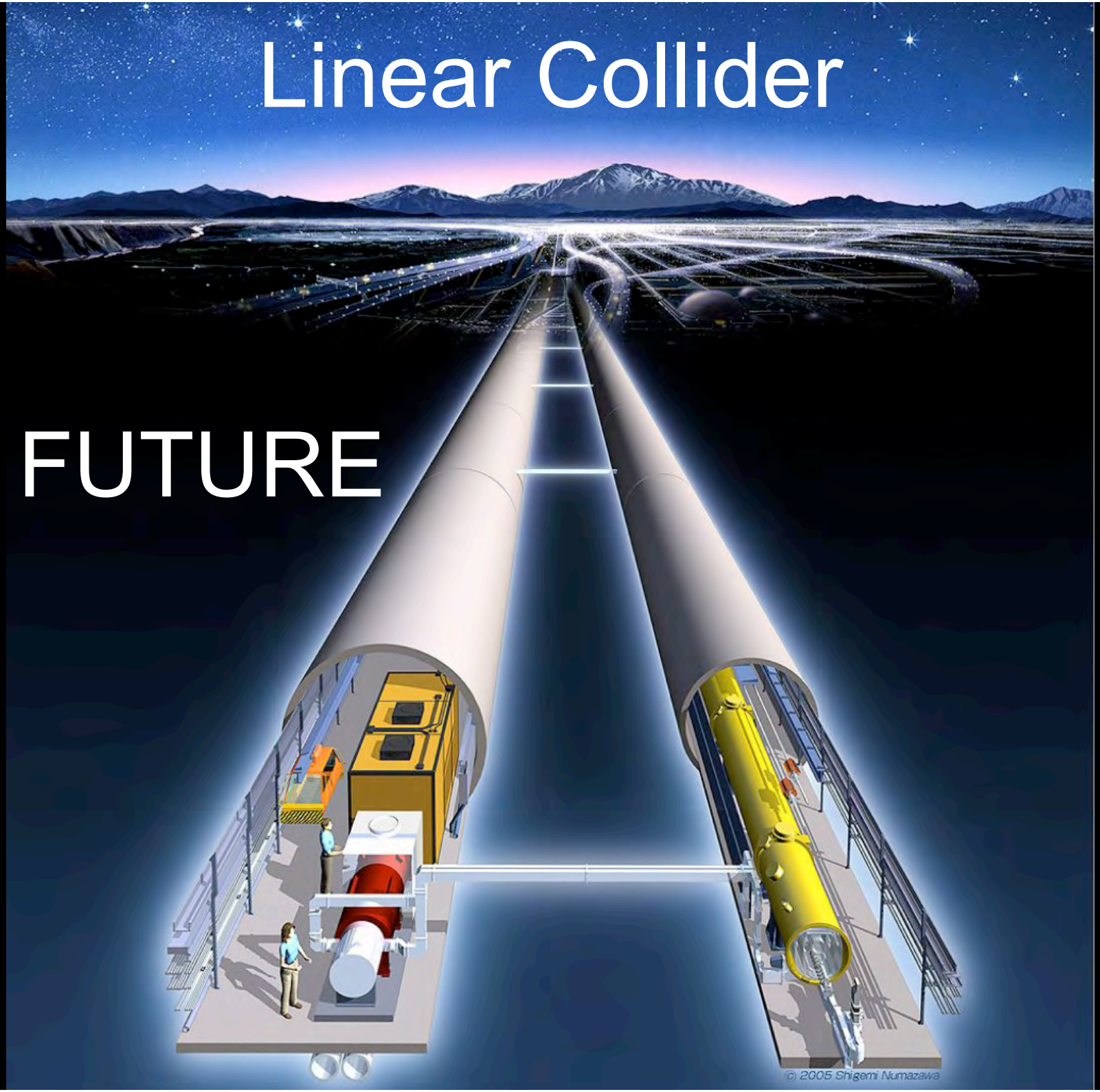

Large Hadron Collider
ATLAS Detector

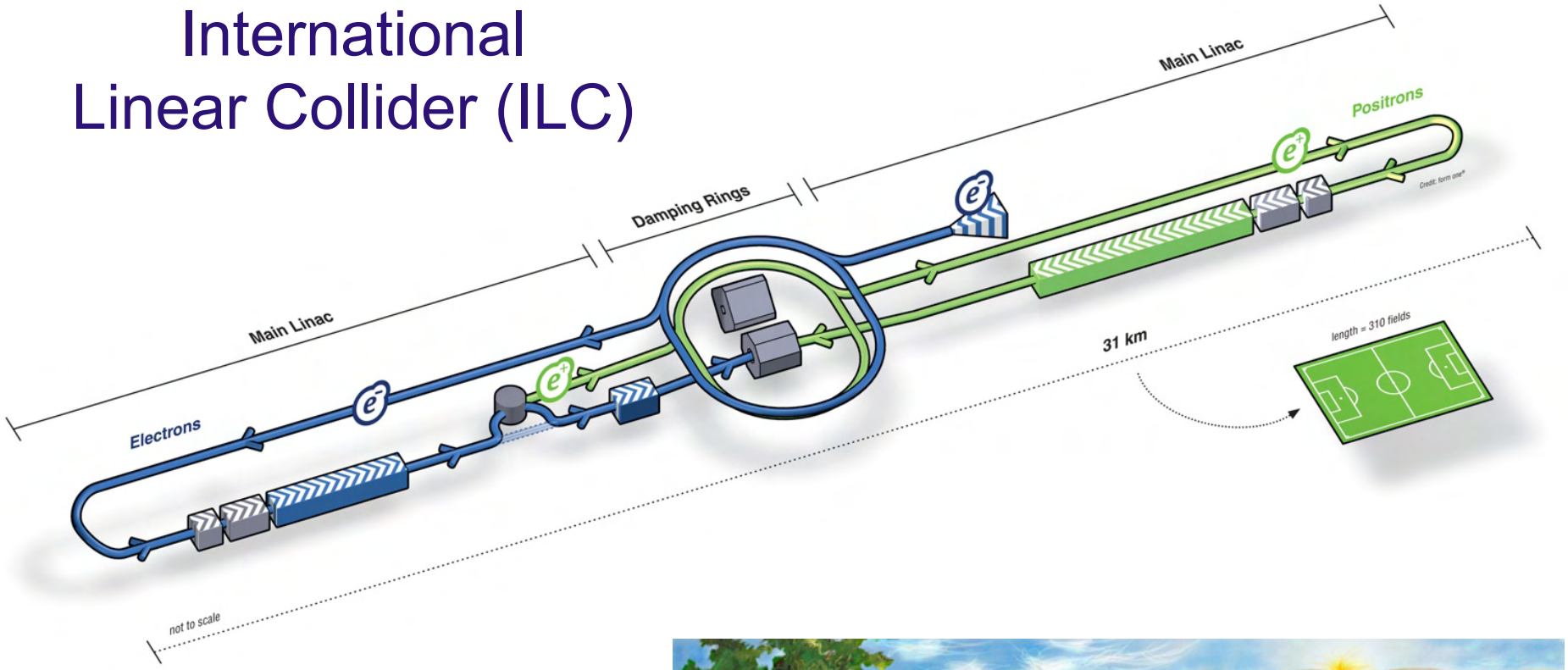
Large Hadron Collider (LHC)
Geneva, Switzerland

Begins operation
this year

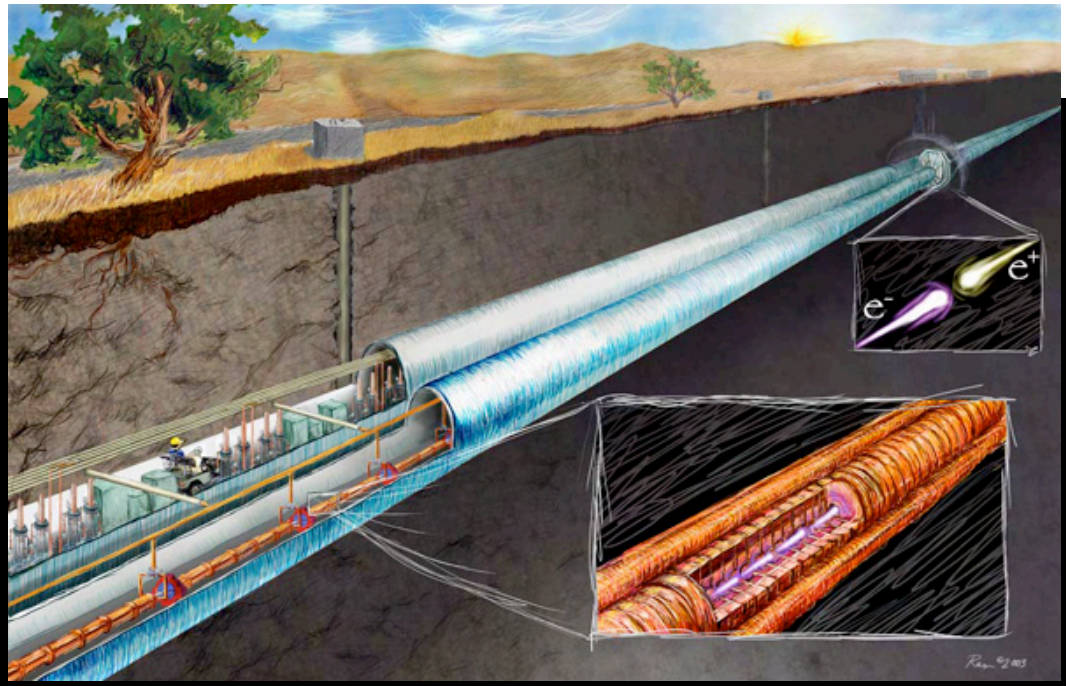
Will search
for Dark Matter,
Higgs Bosons,
other New Particles
and Forces


Linear Collider
FUTURE
© 2005 Shigemi Numazawa

International Linear Collider (ILC)



FUTURE



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Scientific Goals of the LHC and the ILC

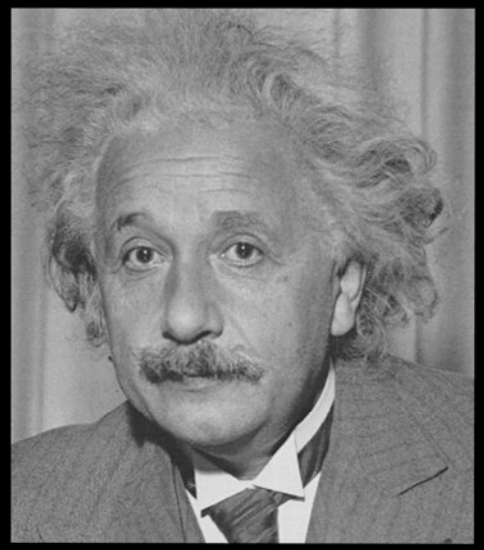
- Dark Matter particles
- Higgs Boson
  - responsible for mass of fundamental particles
  - responsible for weak nuclear and electromagnetic force differences
- Hidden extra dimensions of space
- New forces
- New fundamental particles

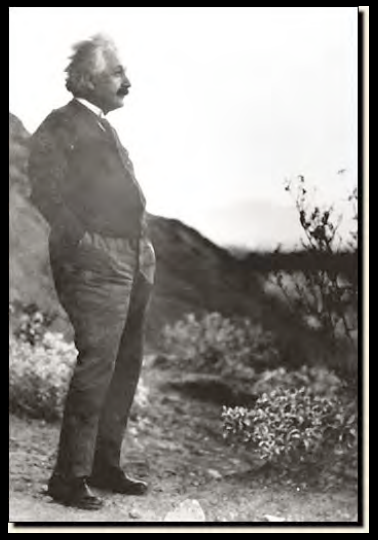
Particle Accelerators and the Universe

- Big Bang occurred 13.7 billion years ago
  - expanding Universe, cosmic fireball, other observables
- Universe expanded and cooled; fundamental particles condensed into structures
- Accelerators have revealed fundamental particles and their interactions
- Dark Matter dominates mass of the Universe
  - controlled early evolution, continues impact today
- Dark Matter discovery could come from next accelerator experiments
  - Large Hadron Collider (LHC), International Linear Collider (ILC)

One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike

—and yet it is the most precious thing we have.





The most beautiful experience we can have is the mysterious.

It is the fundamental emotion which stands at the cradle of true art and true science.

Jim Brau *Albuquerque* *October 1, 2009*

Acknowledgements

RESEARCH SUPPORTED BY

Department of Energy

OFFICE OF SCIENCE

NATIONAL SCIENCE FOUNDATION

Philip H. Knight