

A night sky photograph featuring the Milky Way galaxy stretching across the upper right portion of the frame. The sky is filled with numerous stars. In the lower center, the dark silhouette of a rock formation, likely a butte, is visible against the horizon. The overall scene is dark and atmospheric, with a mix of blue, purple, and white light from the stars and galaxy.

THE MYSTERIOUS UNIVERSE

Exploring Our World
With Particle Accelerators

Wally Pacholka / AstroPics.com

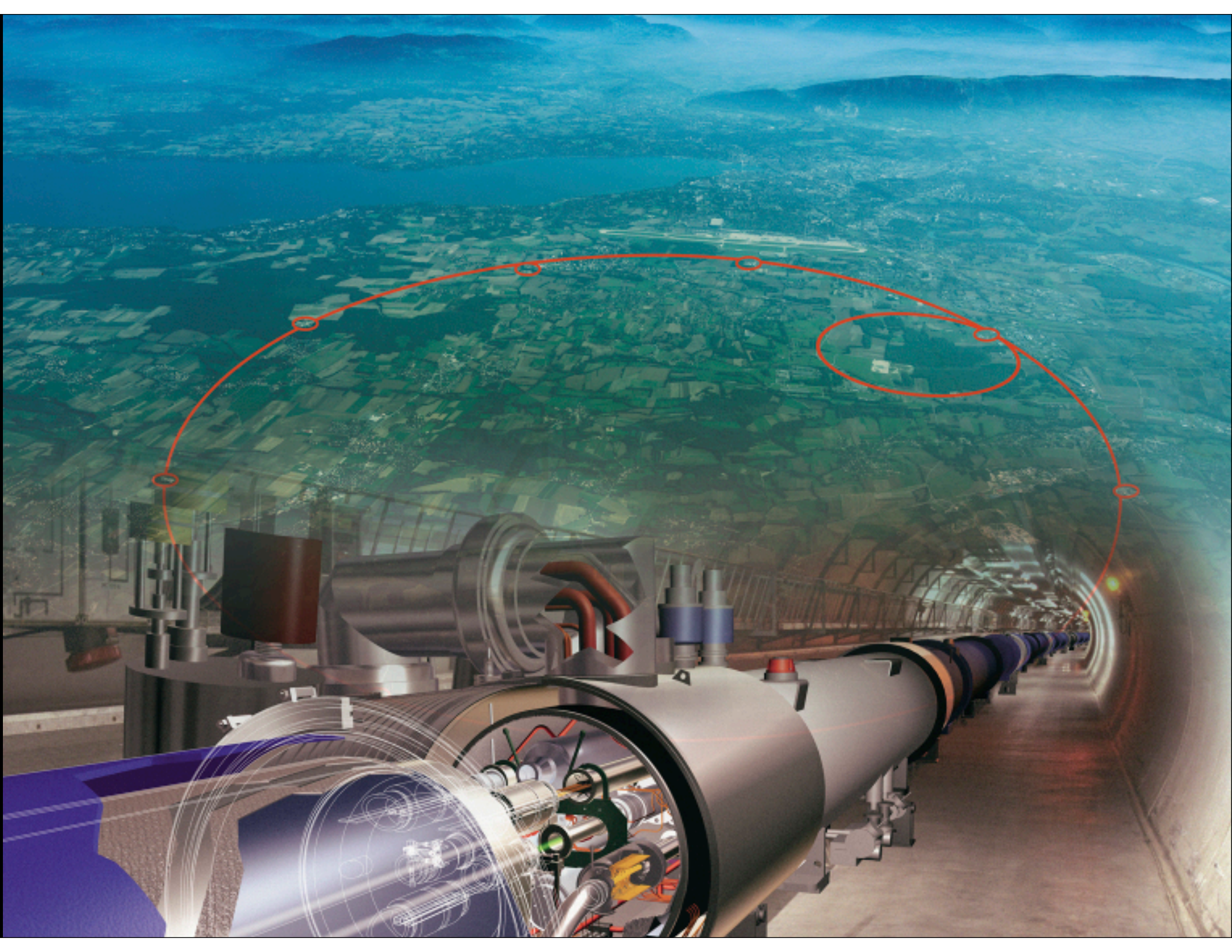


Jim Brau

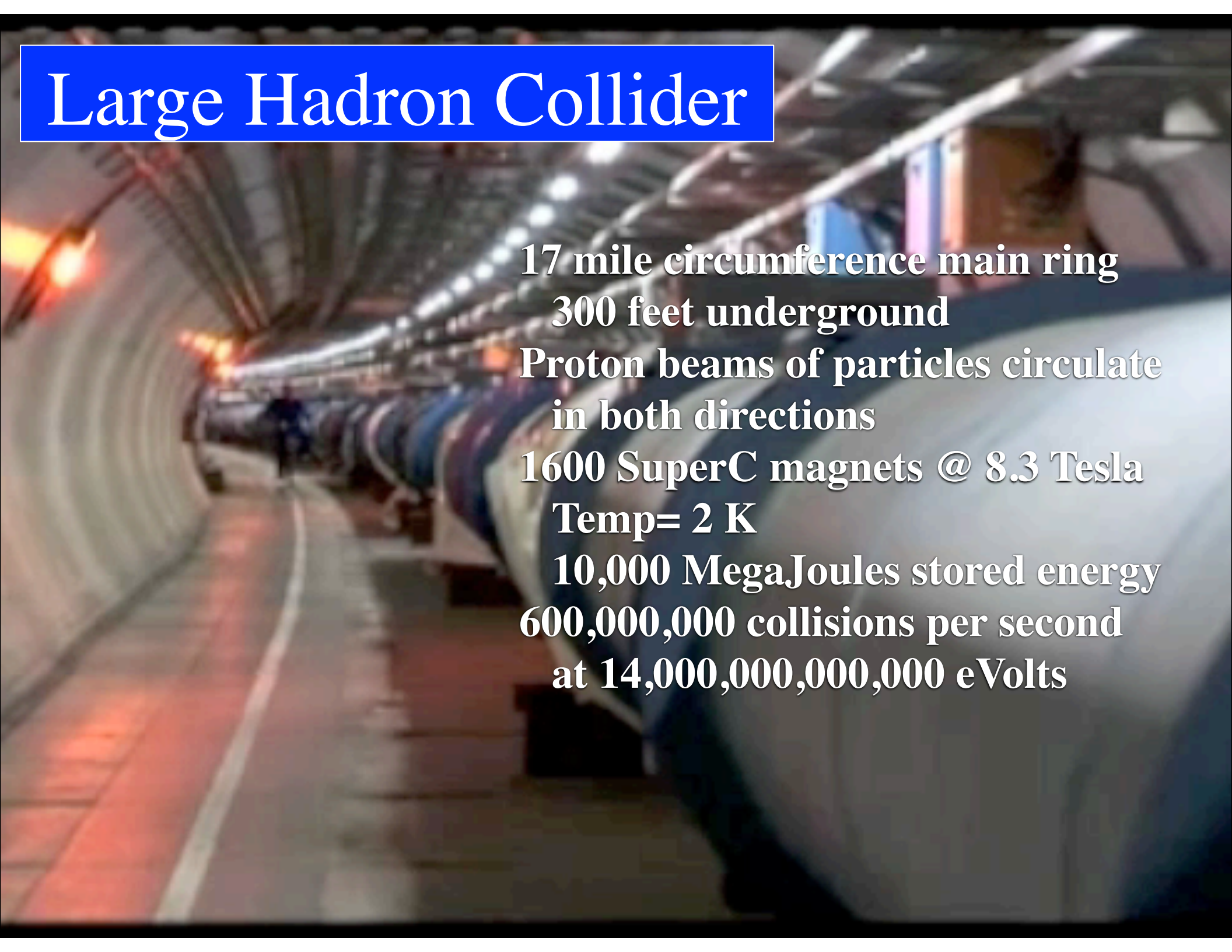
JLab Science Series

November 23, 2010





Large Hadron Collider

A photograph of the interior of the Large Hadron Collider tunnel. The image shows a long, curved tunnel with a red safety line on the floor. The walls are lined with various pipes and machinery, and the lighting is dim, with some bright spots from overhead lights.

17 mile circumference main ring
300 feet underground

Proton beams of particles circulate
in both directions

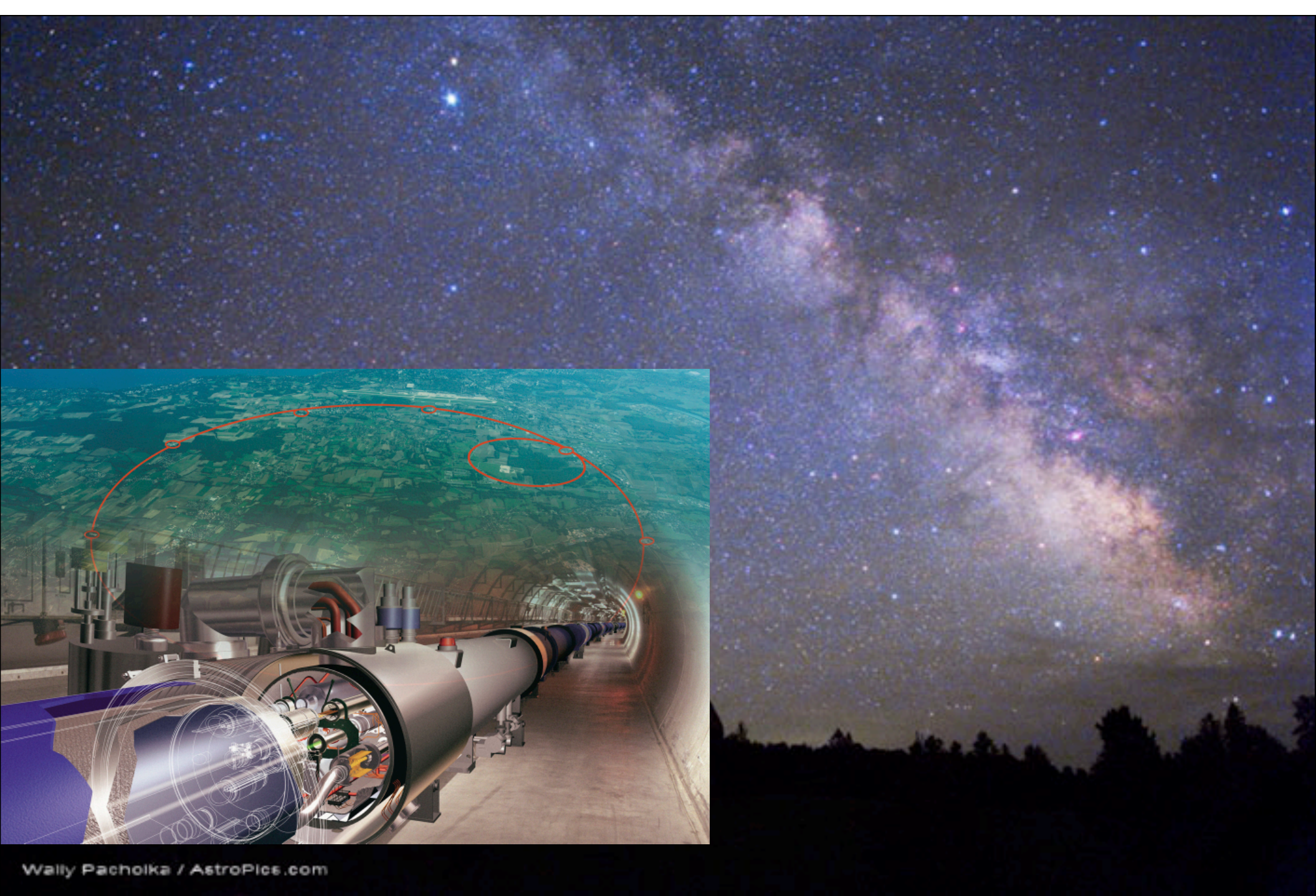
1600 SuperC magnets @ 8.3 Tesla
Temp= 2 K

10,000 MegaJoules stored energy
600,000,000 collisions per second
at 14,000,000,000,000 eVolts

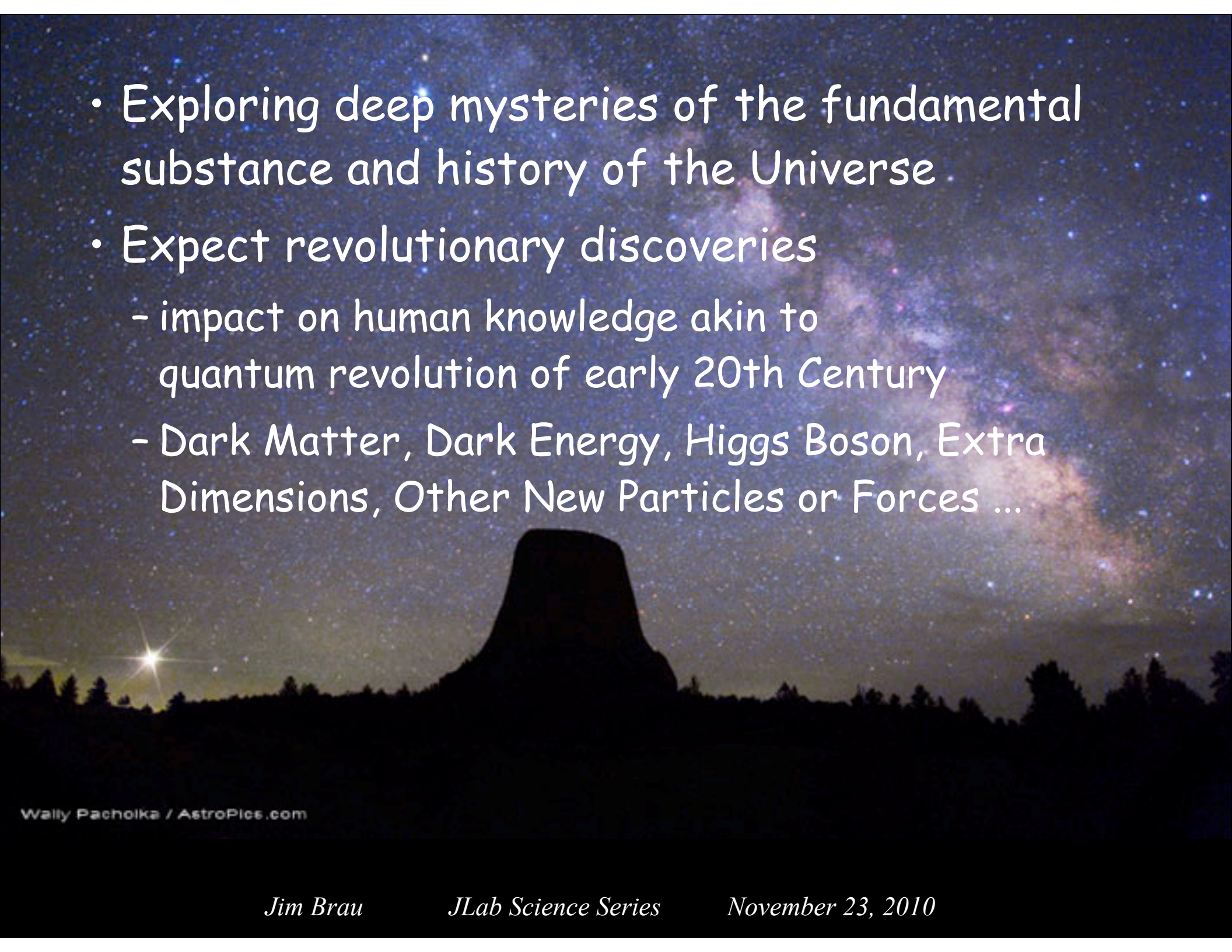
Large Hadron Collider



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



Wally Pacholka / AstroPics.com

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

Wally Pacholka / AstroPics.com

Galileo Galilei

1609



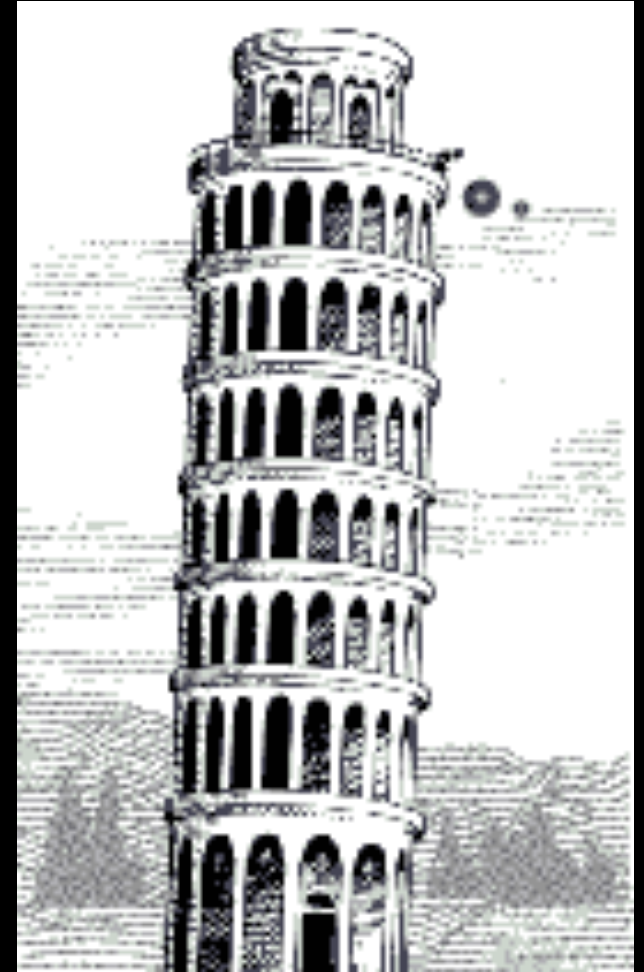
image from Science 16 January 2009

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Galileo Galilei



<http://physics-animations.com>

image from Science 16 January 2009

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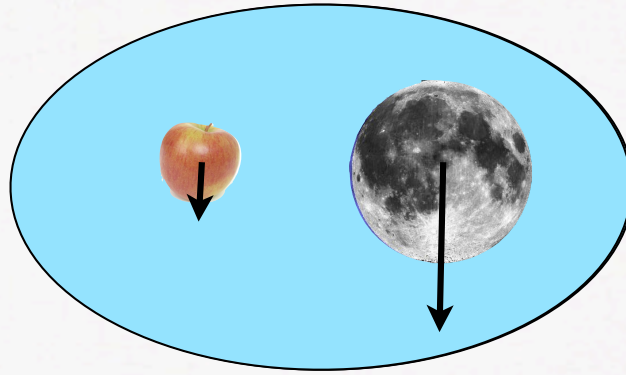
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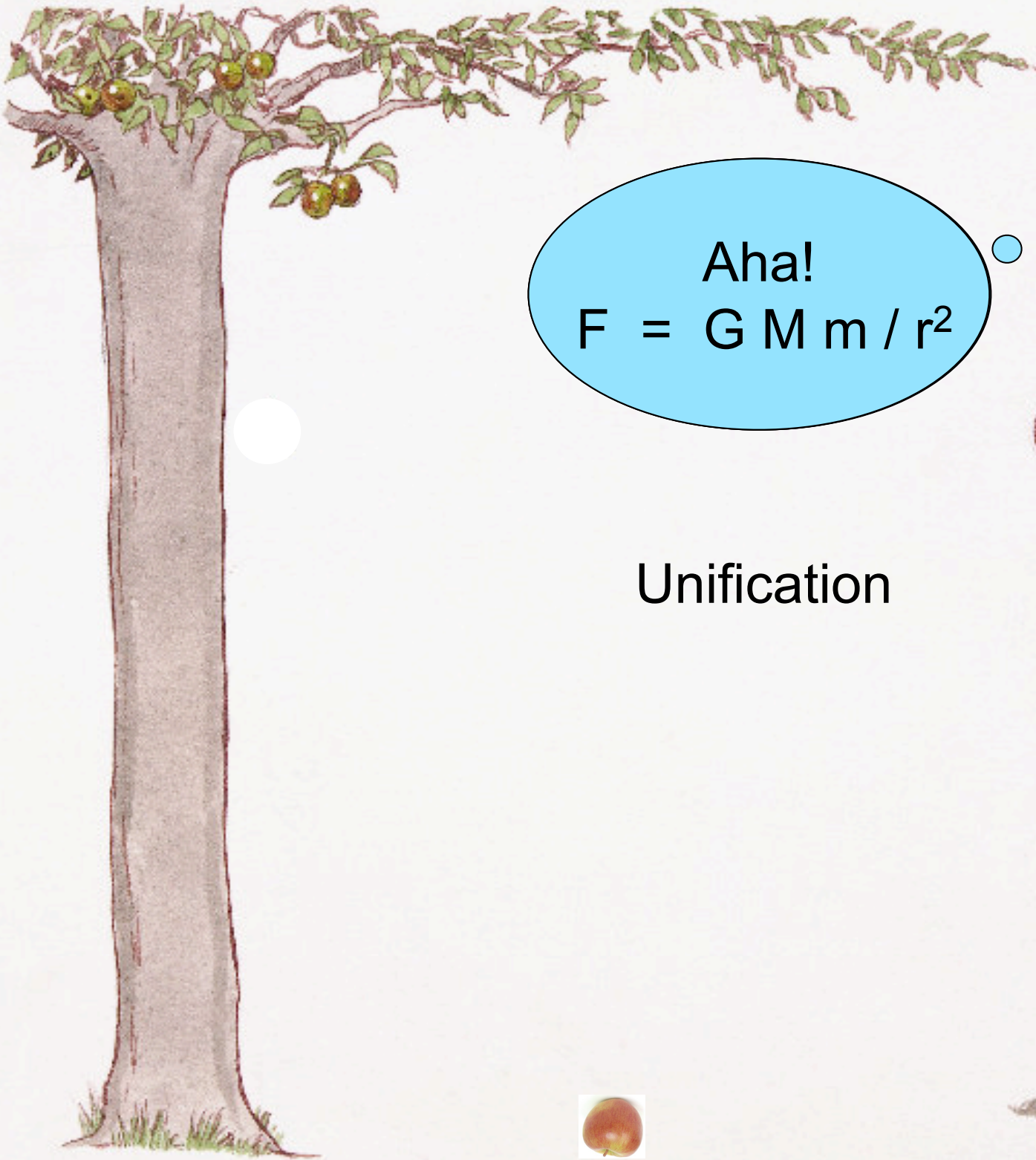
November 23, 2010

Sir Isaac Newton (1642-1727)









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



Unification



A photograph of a bright sun in a blue sky with scattered white clouds. The sun is located in the upper left quadrant, casting a strong glow. The clouds are fluffy and white, scattered across the sky. The overall scene is bright and clear.

What is the Sun's source of energy

Solar Energy

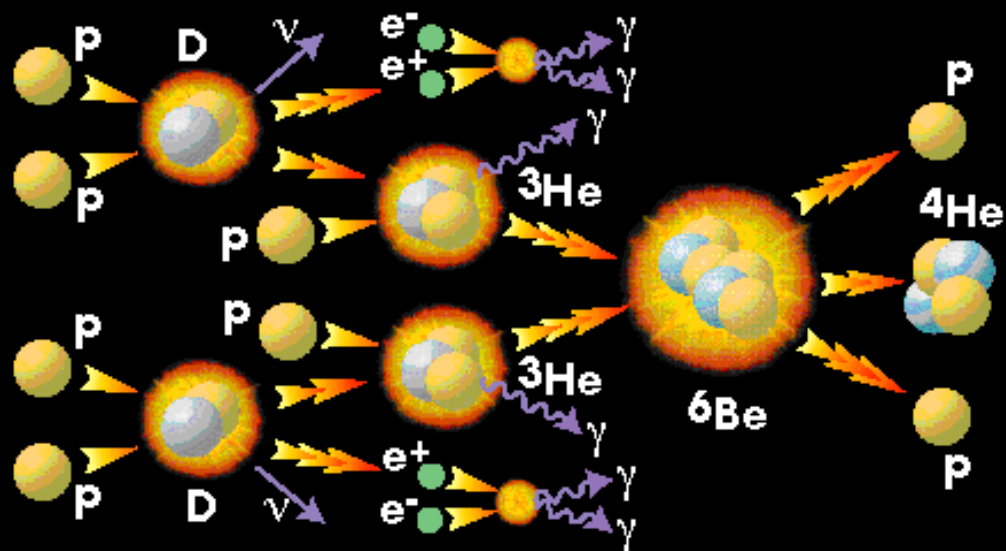


- What is the Sun's source of energy?
 - 19th Century - Chemical reactions? (burning)
 - Predicted solar lifetime too short - only 20,000 years
 - Evidence on Earth for much longer duration
 - 20th Century
 - Einstein's relativity $E=mc^2$
 - discovery of atomic nucleus and nuclear reactions



Solar Energy

- What is the Sun's source of energy?



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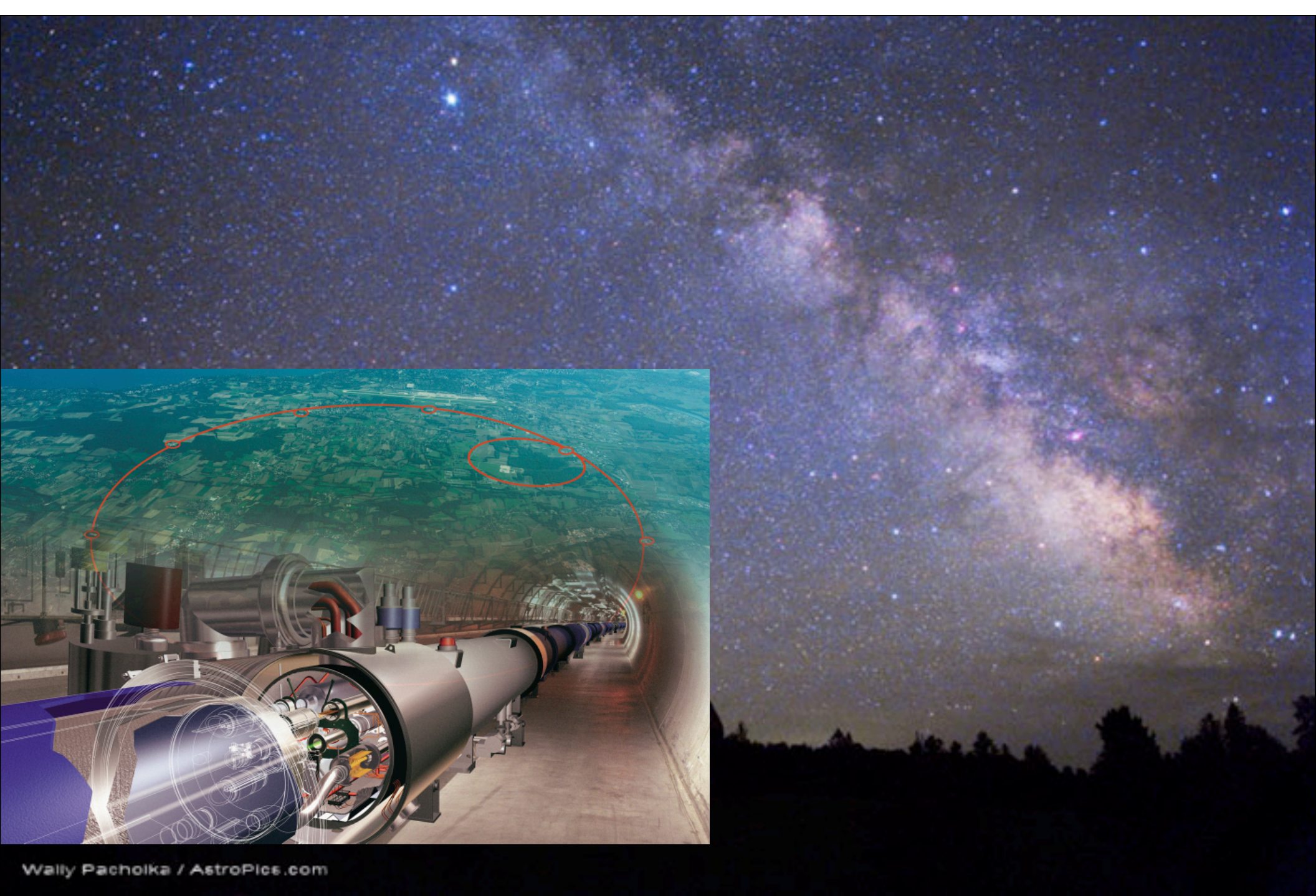
Enough energy
for the Sun to shine
for ten billion years

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





Wally Pacholka / AstroPics.com

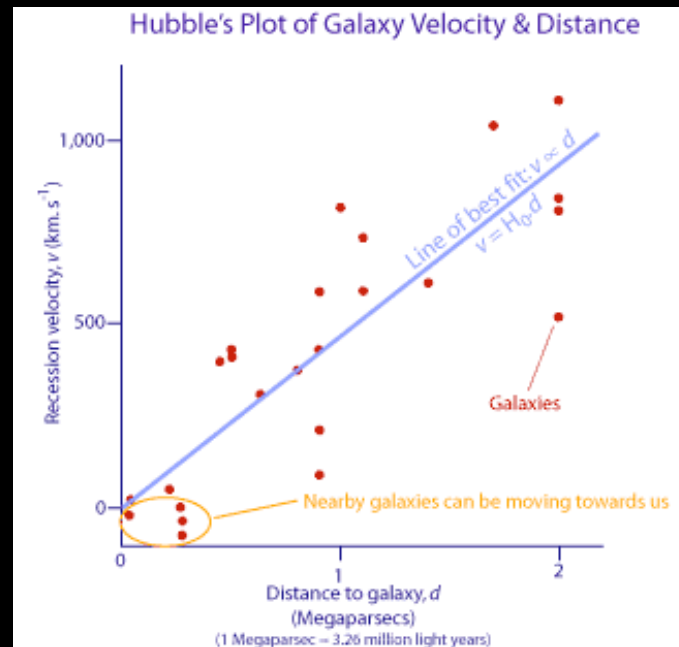
1929 - Hubble Discovered Universe is Expanding



First evidence that Universe began with a Big Bang



Edwin Powell Hubble
(1889-1953)



1929



Brau

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www.MrEclipse.com

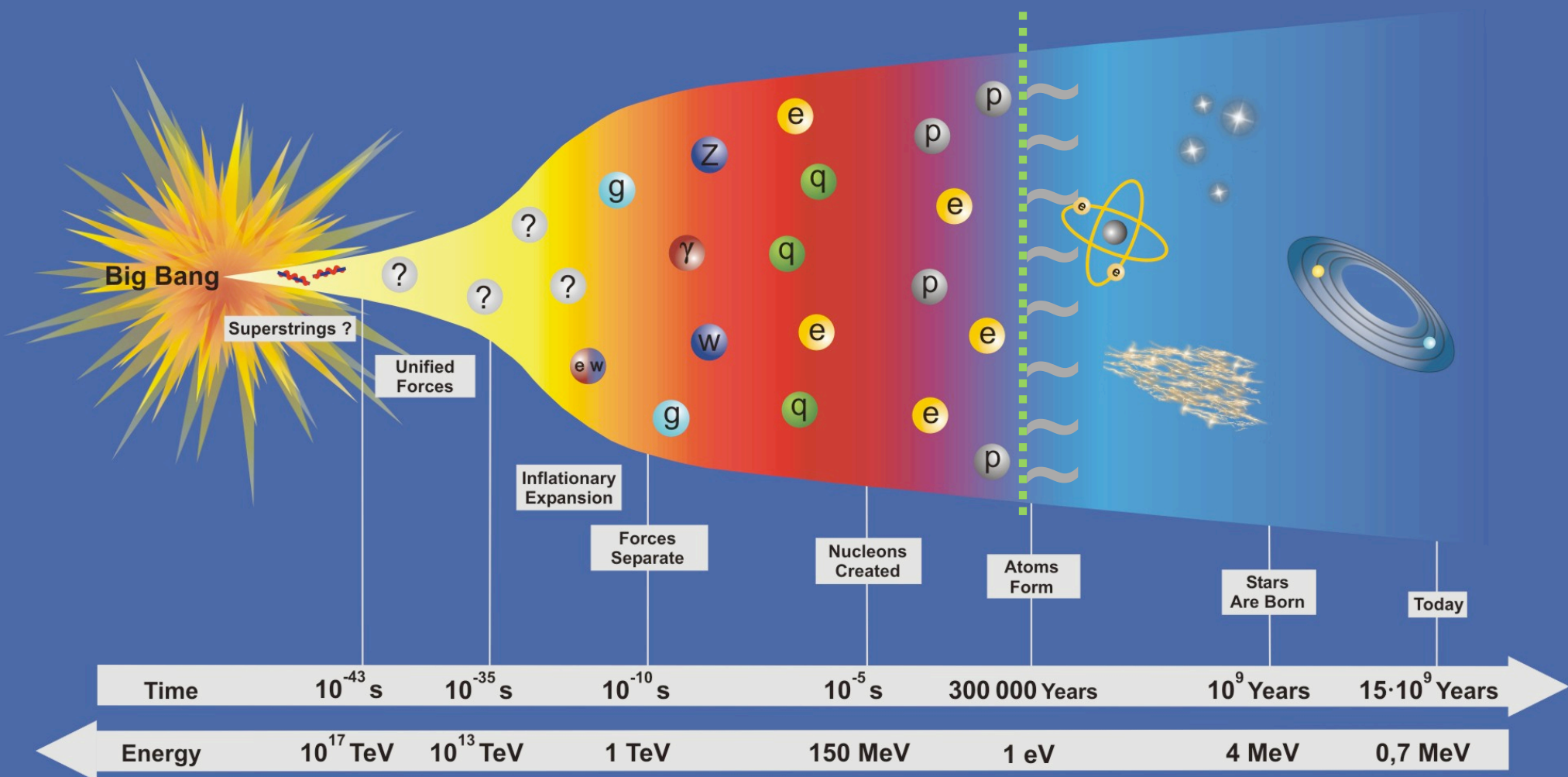


Universe's Glow
in Microwaves
discovered in 1965

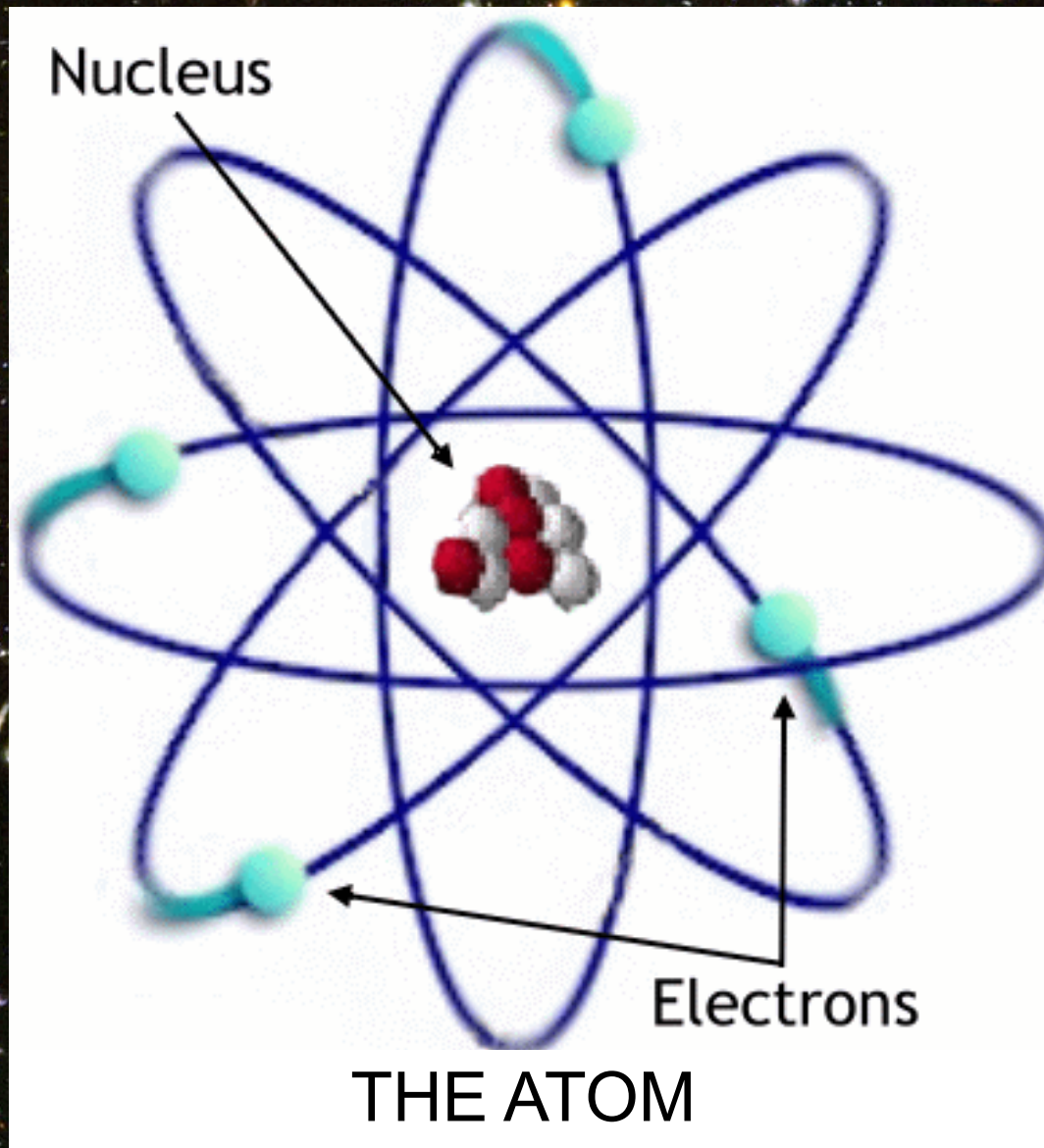
*predicted following
Hubble's discovery*

*confirmed early
universe of Big Bang*

Big Bang



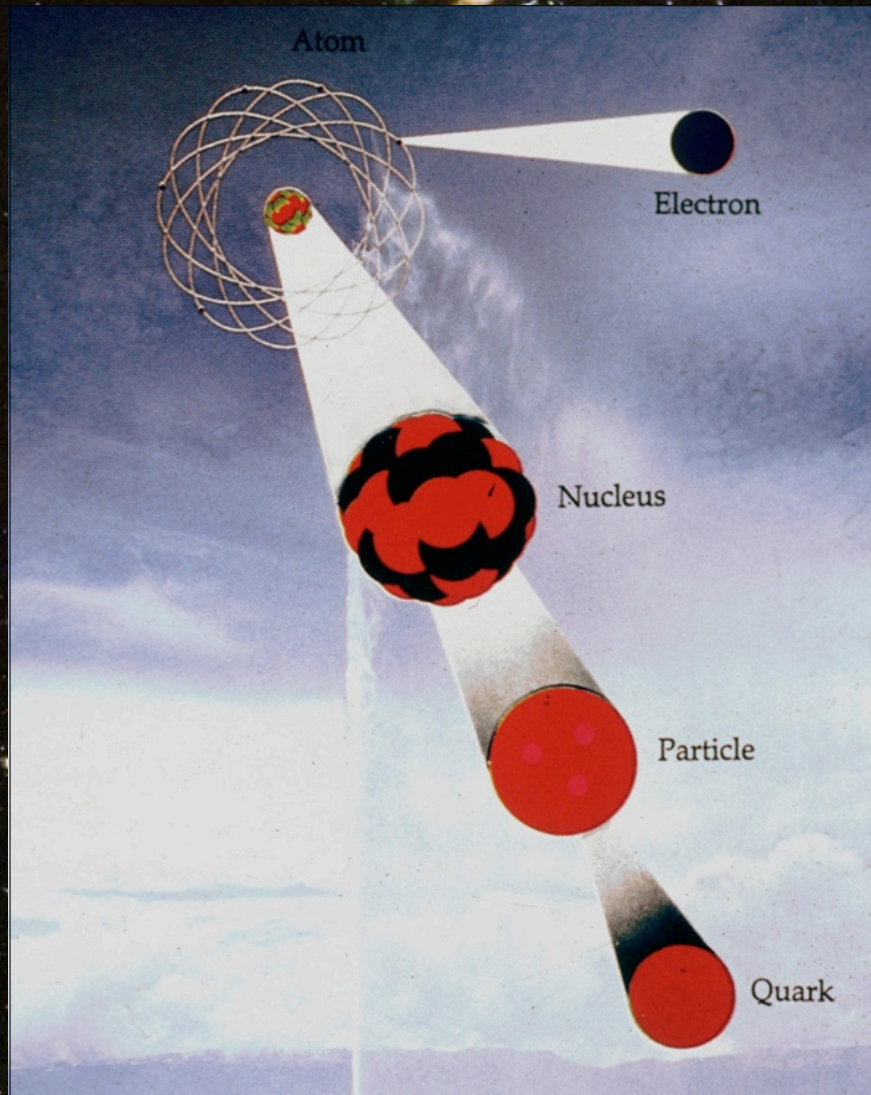
The Universe is Made of Particles



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

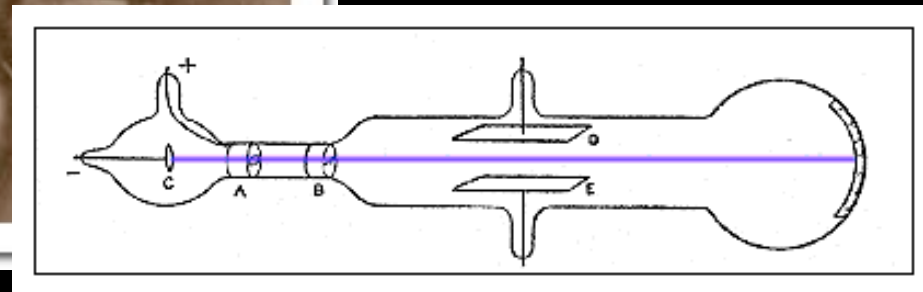
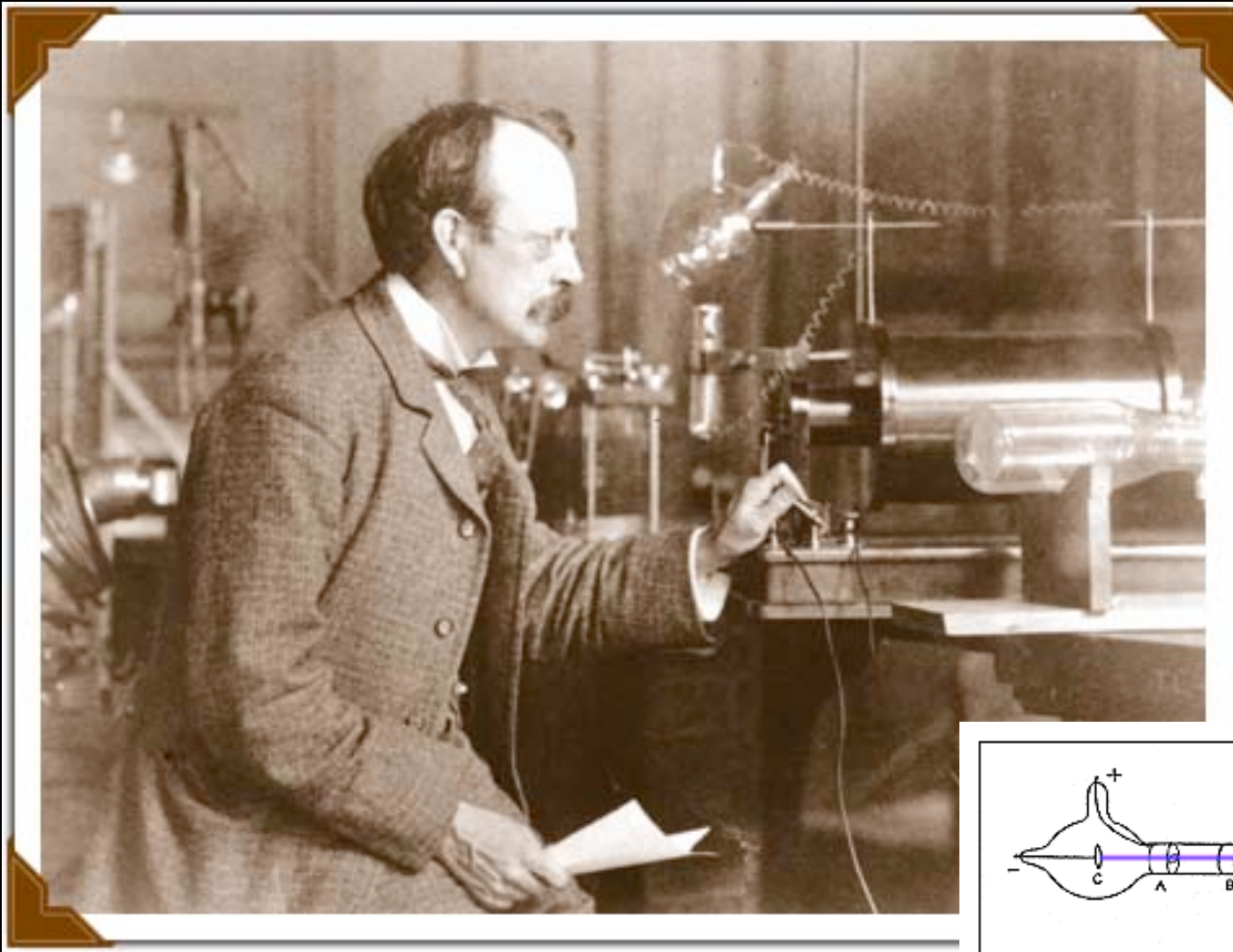
November 23, 2010

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

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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.



From the soundtrack of the film, Atomic Physics
copyright © J. Arthur Rank Organization, Ltd., 1948.

Credit: American Institute of Physics

20th Century Particle Physics Laboratories

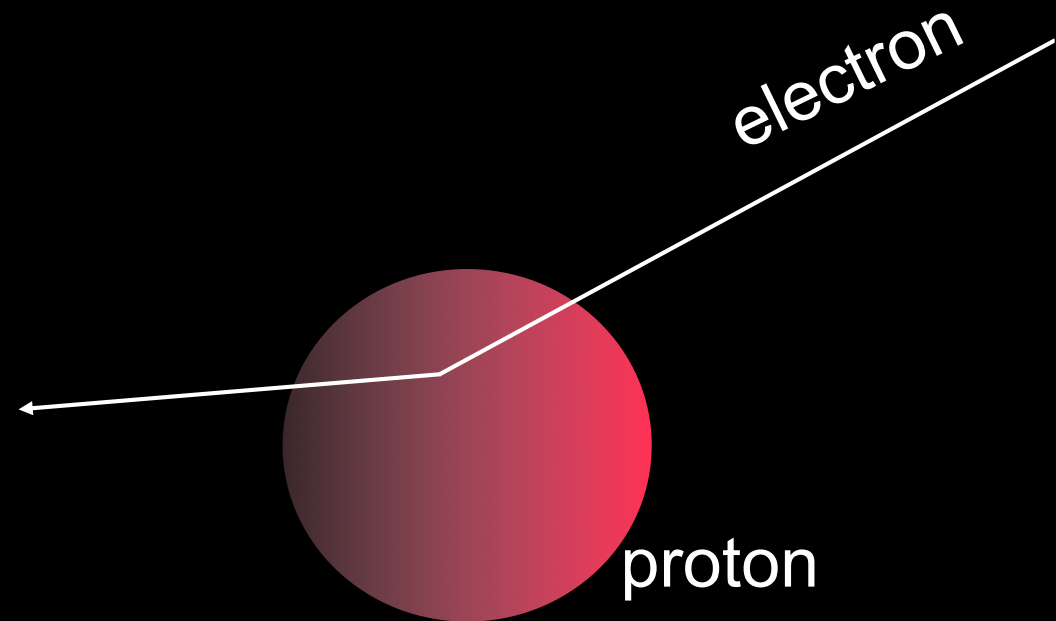
electron linear accelerator
at Stanford (SLAC)



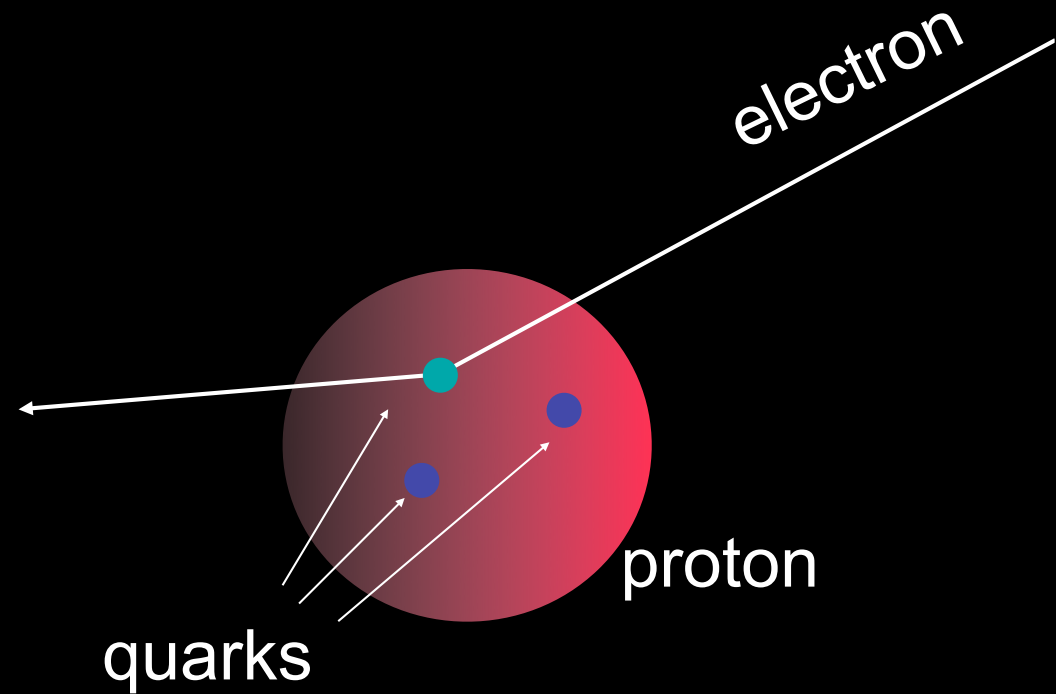
proton synchrotron
at Fermilab (near Chicago)



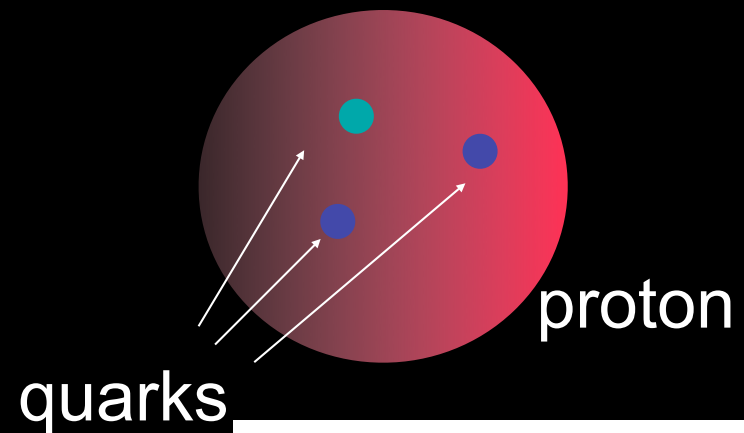
1969



1969 - Quarks discovered (inside atomic nucleus) Stanford



1969 - Quarks discovered (inside atomic nucleus) Stanford

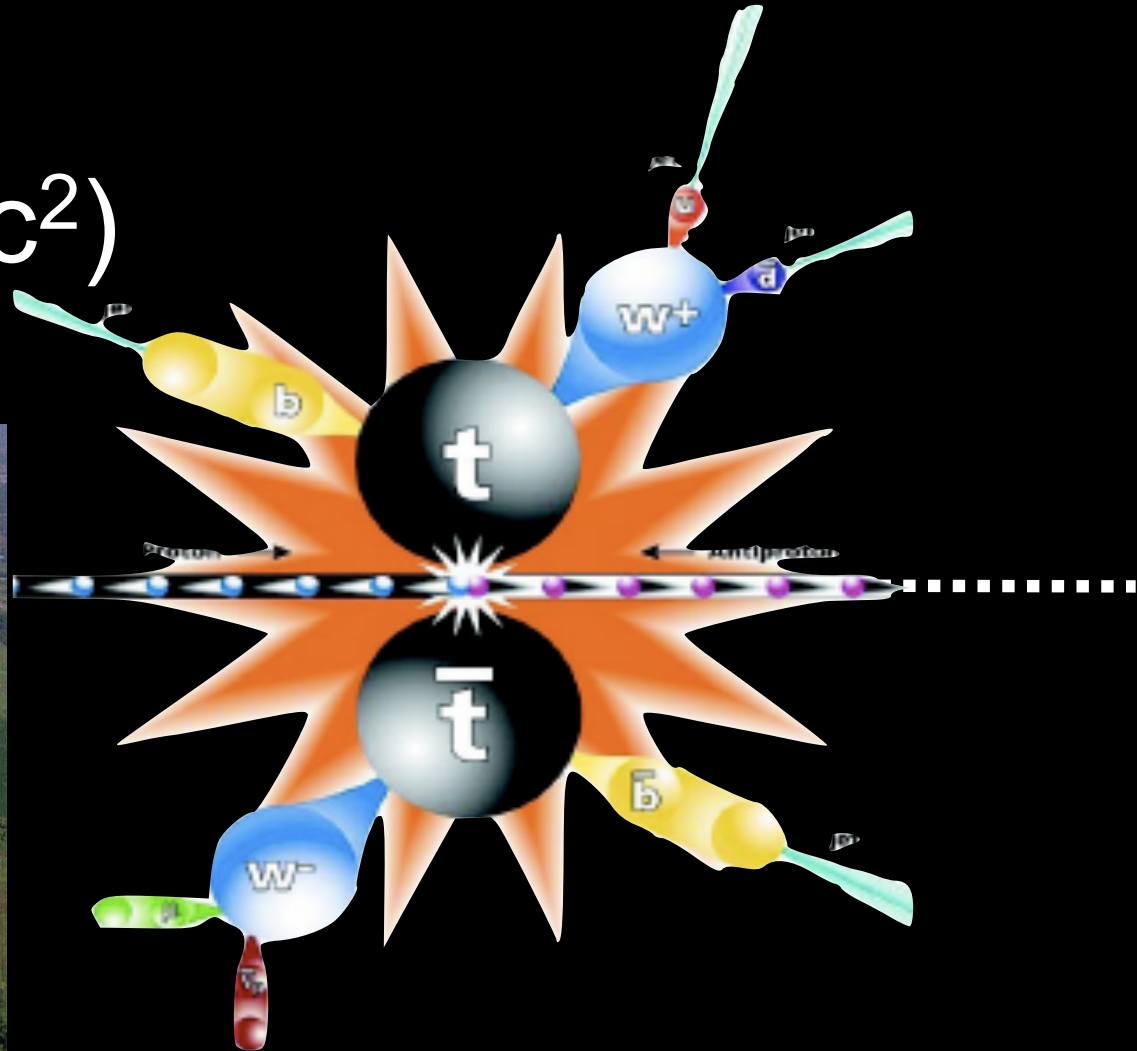


Jefferson Lab 
JLab continues this
exploration today

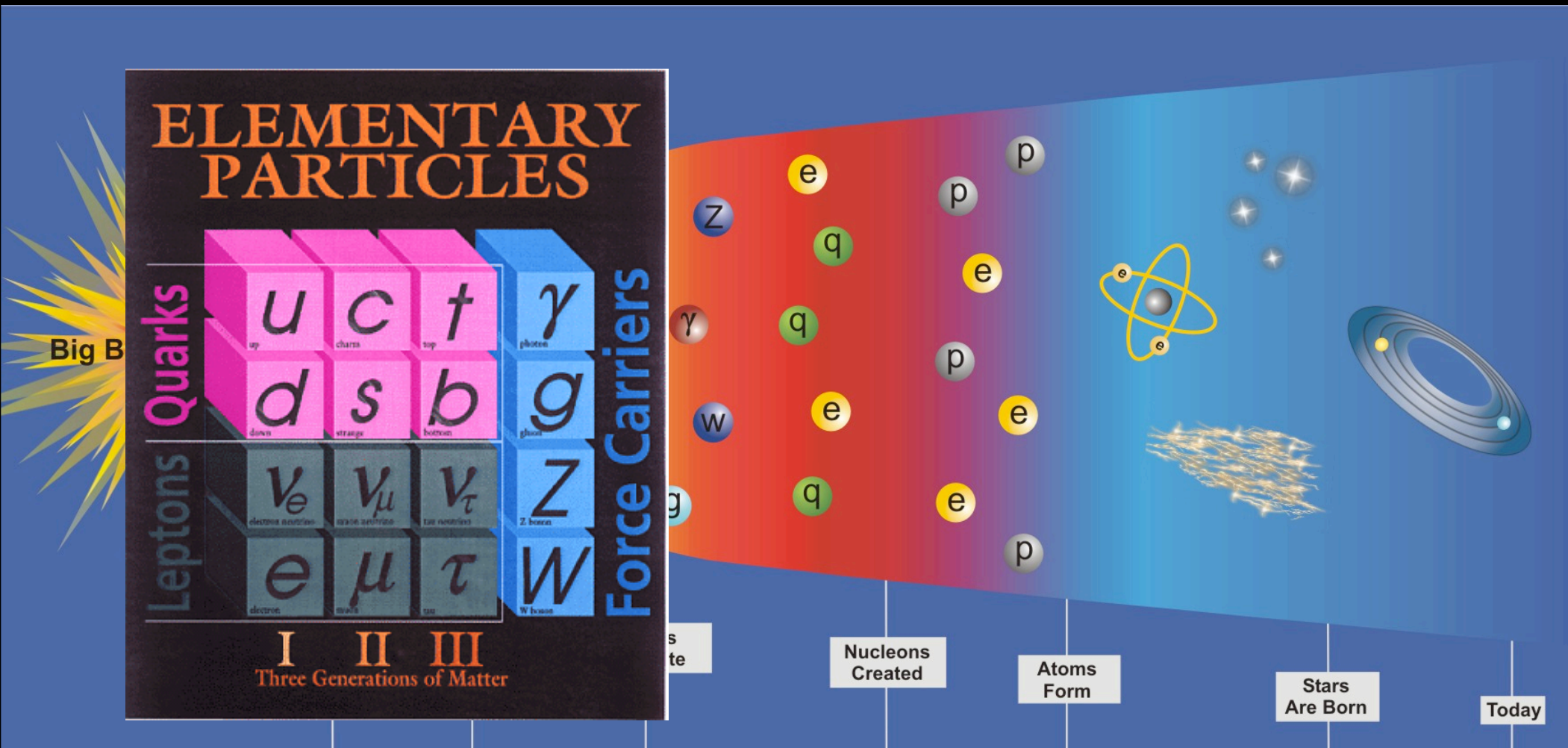
1995 - Top Quark Discovered at Fermilab



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

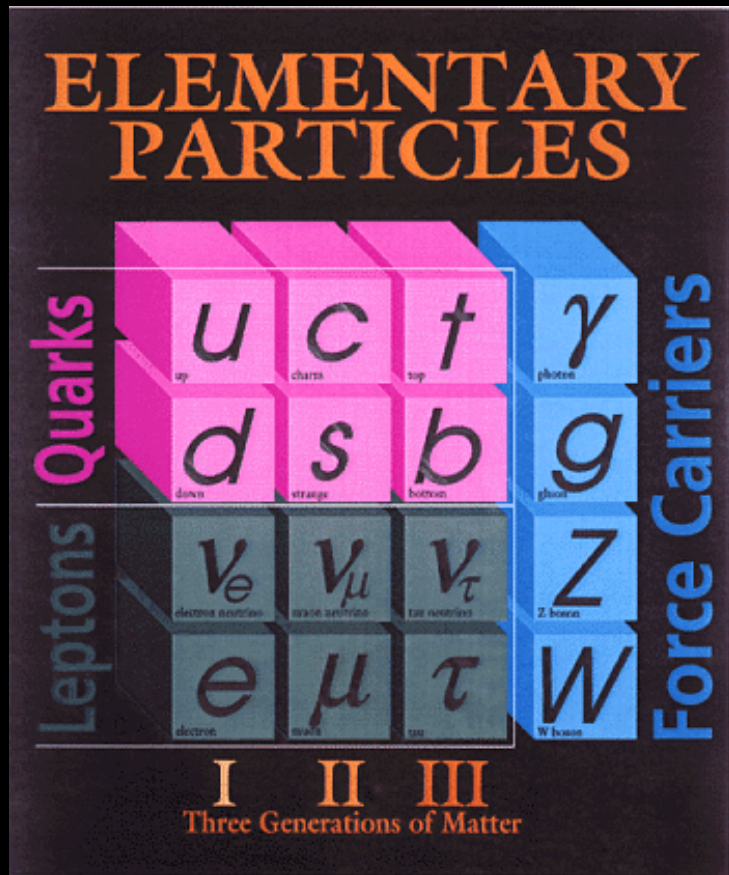


Particles



Particles and Forces

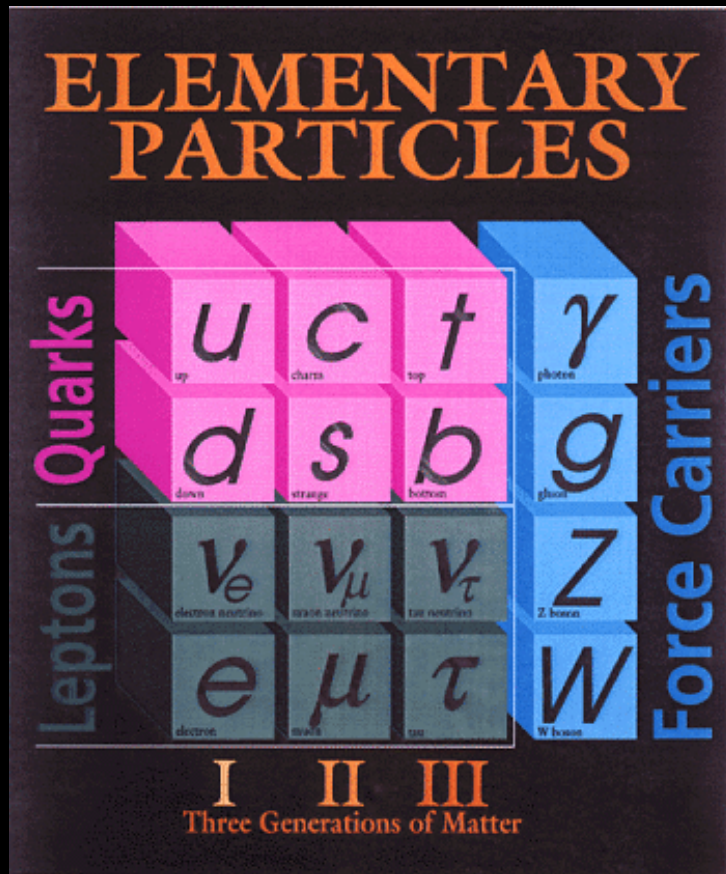
“interactions”



Particles and Forces

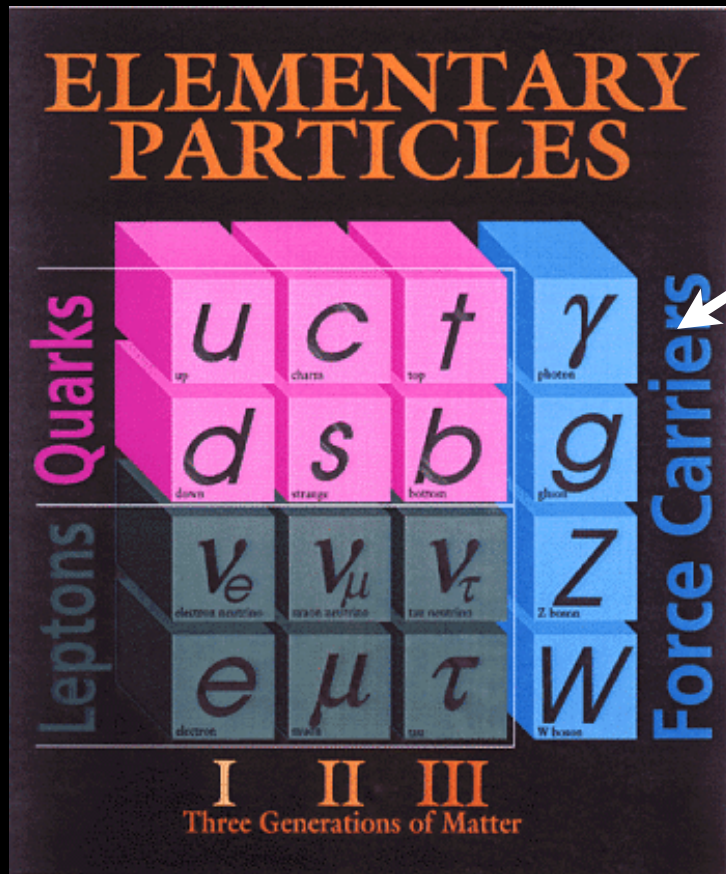
“interactions”

- Gravity - weakest

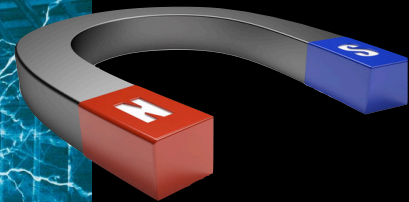
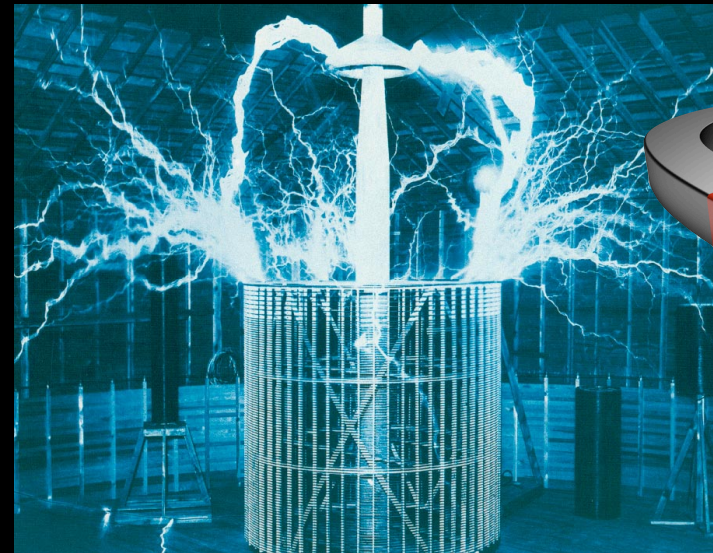


Particles and Forces

“interactions”

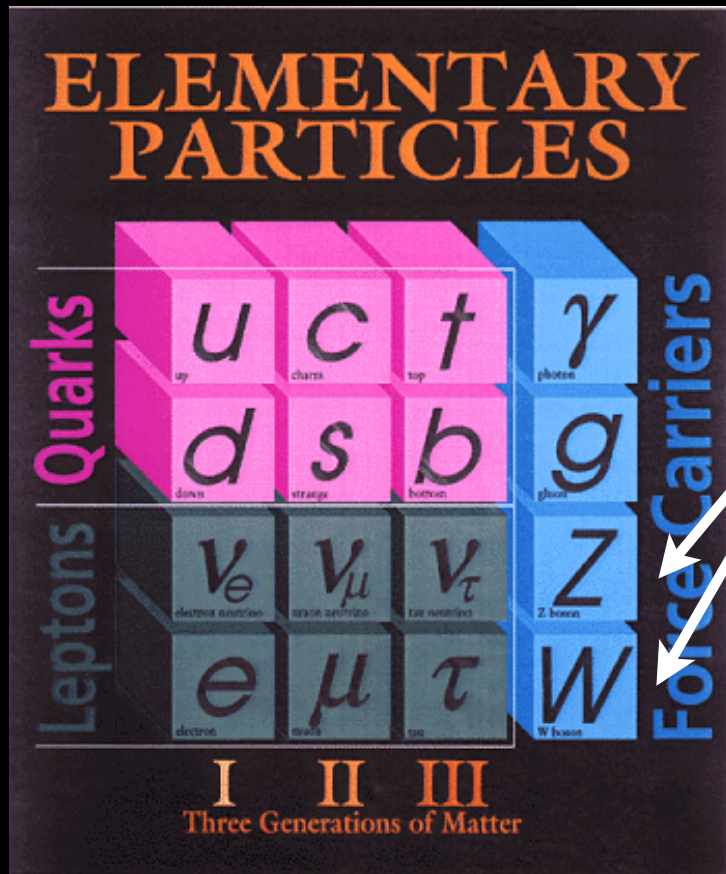


- Gravity - weakest
- Electromagnetism



Particles and Forces

“interactions”

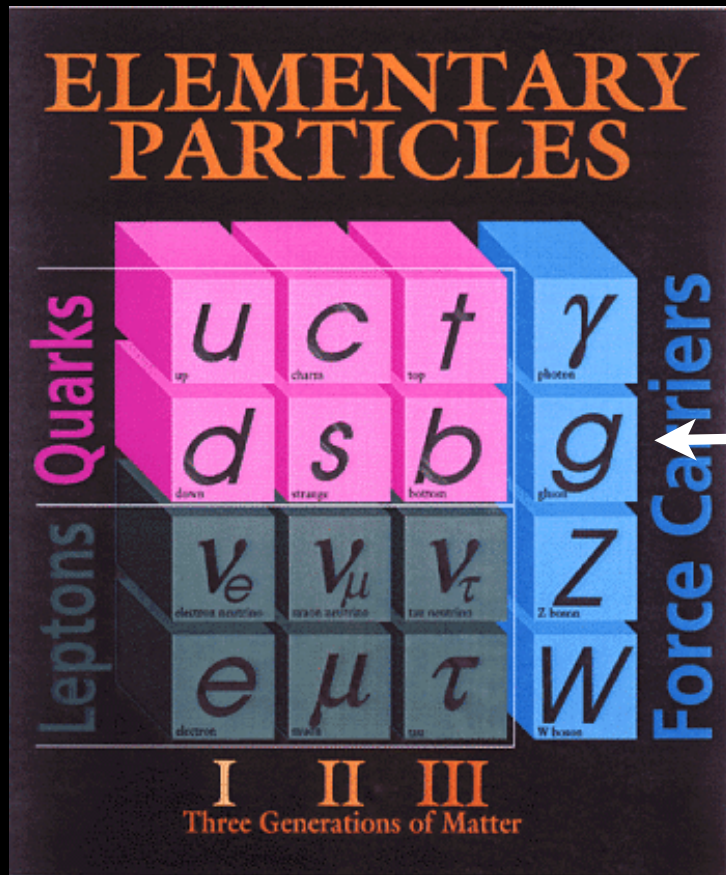


- Gravity - weakest
- Electromagnetism
- Weak Nuclear



Particles and Forces

“interactions”



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



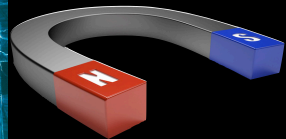
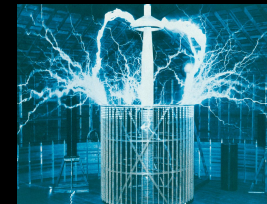
Forces

“interactions”

Are Forces Related?

1850

- Gravity
- Electricity
- Magnetism



Forces

“interactions”

Are Forces Related?

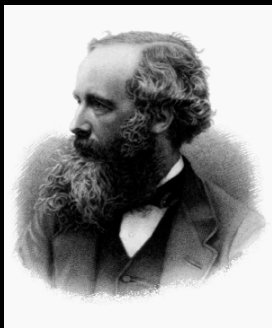
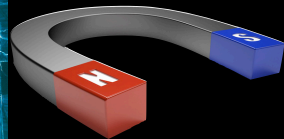
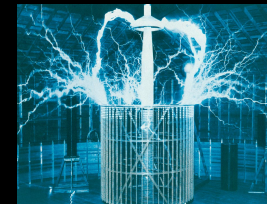
1864

Unified theory

- Electromagnetism
- Light (photons)



- Gravity
- Electricity
- Magnetism



Forces

“interactions”

Are Forces Related?

1950

- Gravity
- Electromagnetism
- Weak Nuclear
- Strong Nuclear



Forces

“interactions”

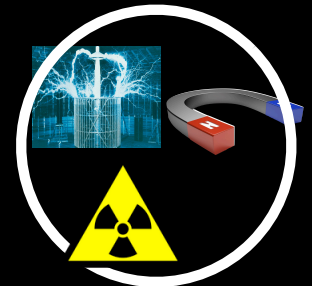
Are Forces Related?

2000

- Gravity

- { • Electroweak

- Strong Nuclear

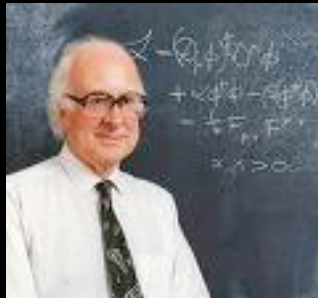


Forces

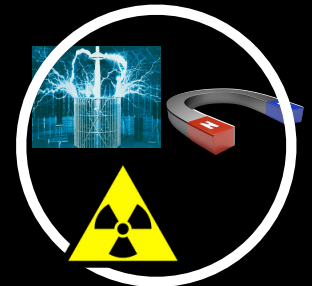
“interactions”

Are Forces Related?

Next Advance Expected
- discovery of
the Higgs Boson
at accelerators



- 2000
- Gravity
- Electroweak
- Strong Nuclear



Forces

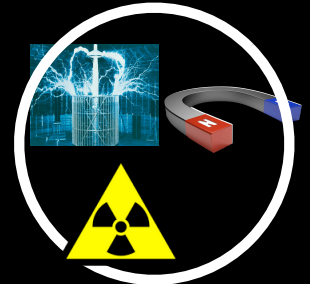
“interactions”

Are Forces Related?

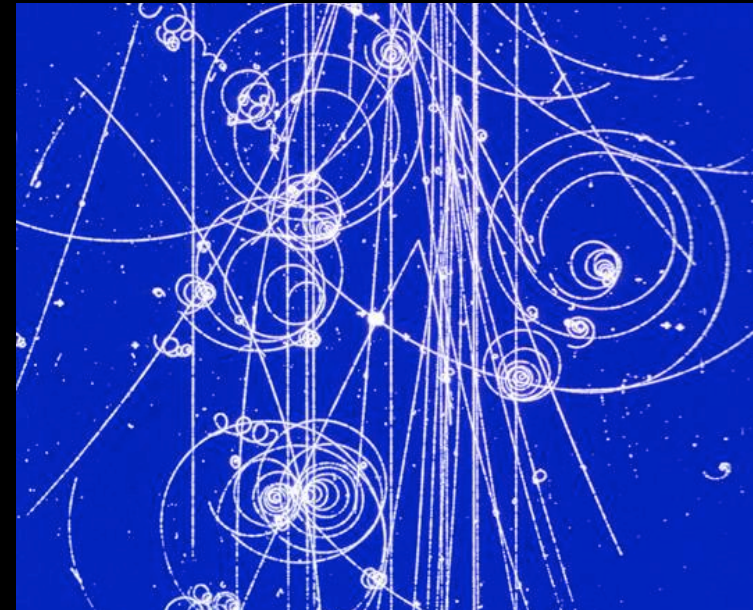
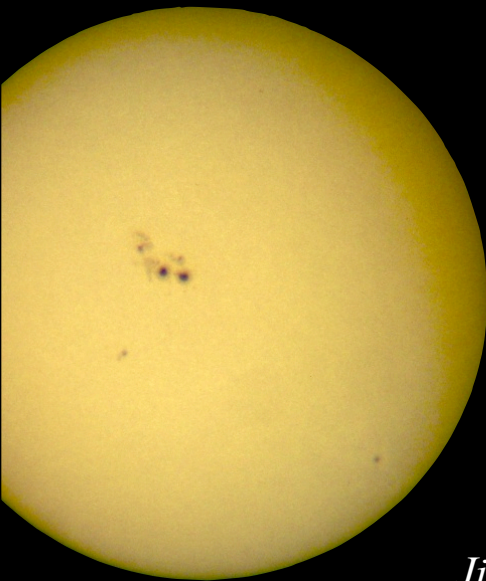
Are all forces related?
New particles would be
involved in any unification

(light new particles are
being searched for
at **Jefferson Lab**)

- 2000
- Gravity
- Electroweak
- Strong Nuclear



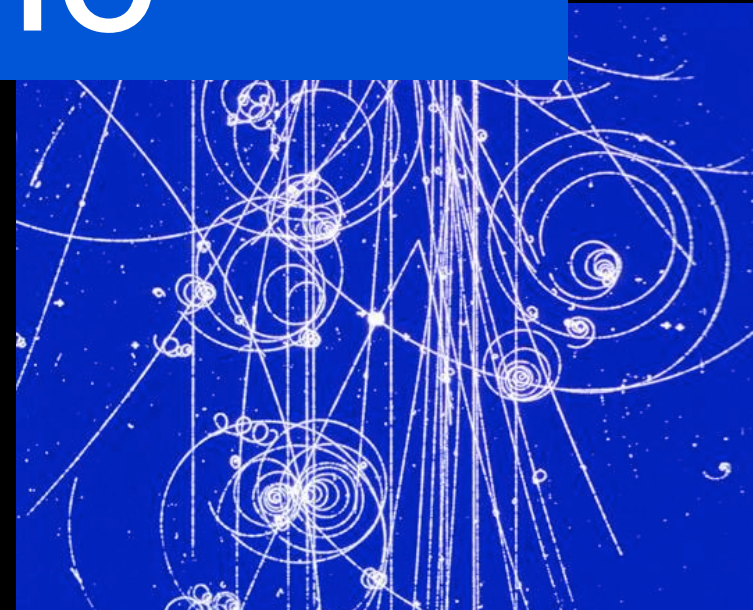
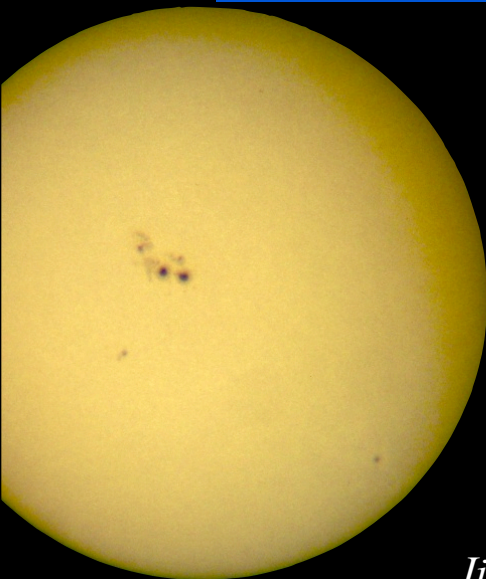
What is Matter?



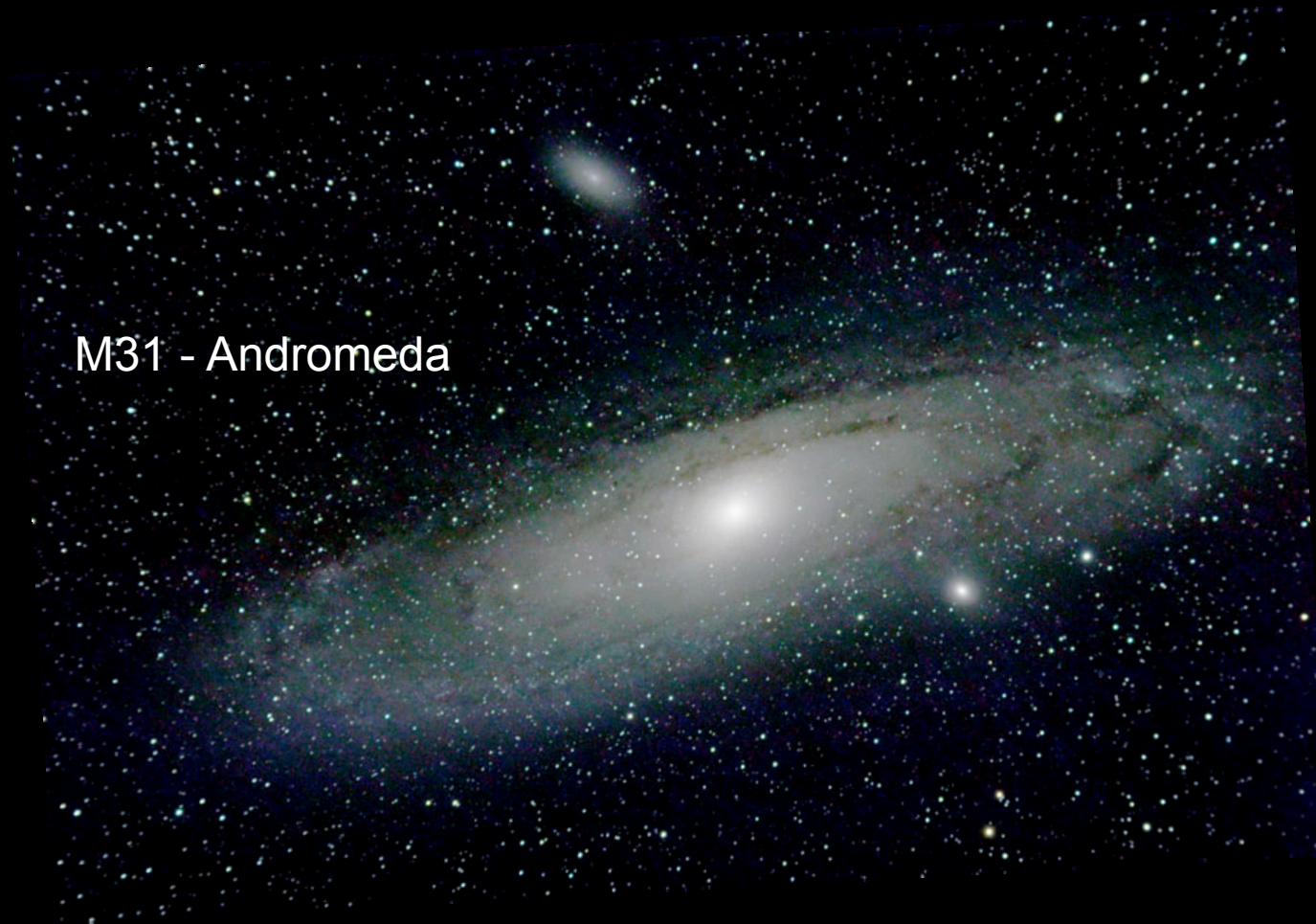
What is Matter?



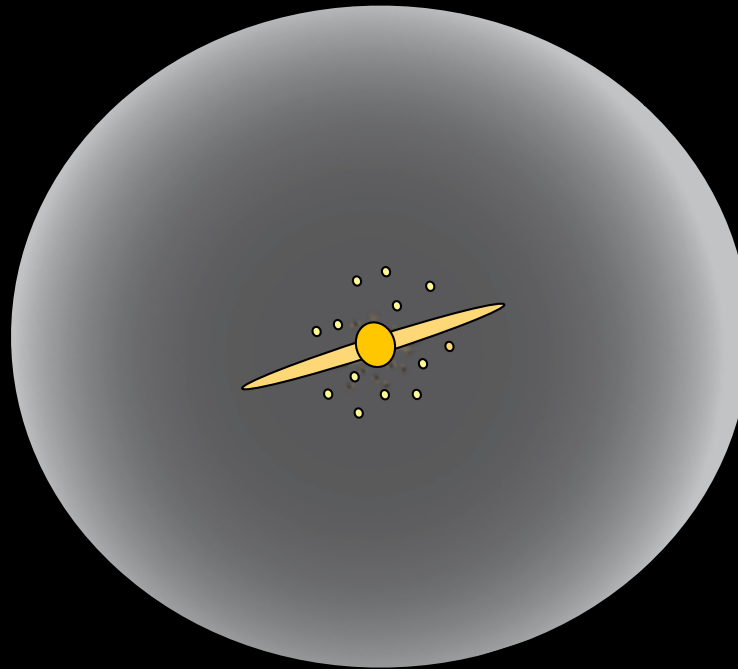
all Atomic



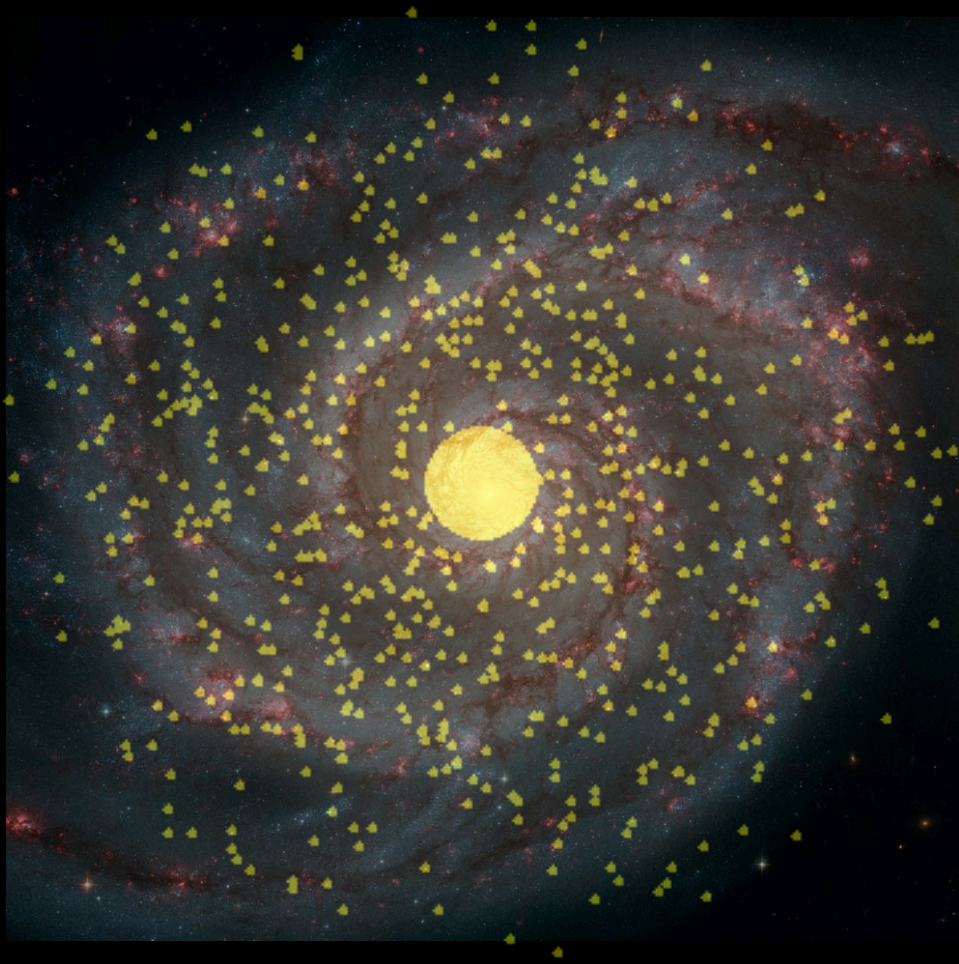
Halo of Dark Matter



Halo of Dark Matter



How we know dark halos surround galaxies?



Expected-
based on stellar mass



Observed-
reveals invisible (“dark”) mass



Vera Rubin
1950s

Early Dark Matter Evidence



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



Coma
Cluster

Dark Matter Dominates Atomic Matter

- Dark Matter of the Universe outweighs Atomic Matter by about 5 to 1
- What is it?
- We have good ideas, but only direct evidence will be definitive
- Accelerator experiments may discover the Dark Matter

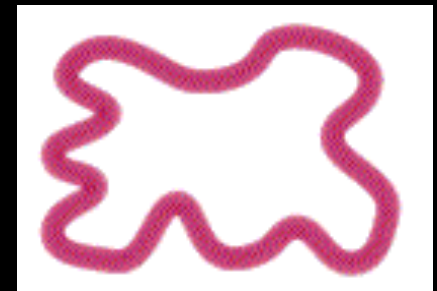
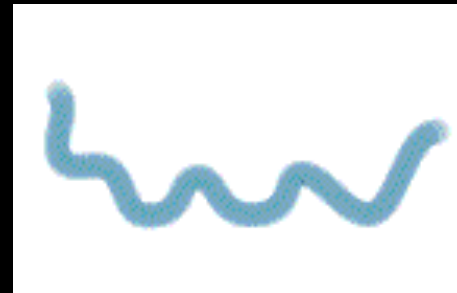


Candidate Theory Explains Dark Matter

SuperString Theory

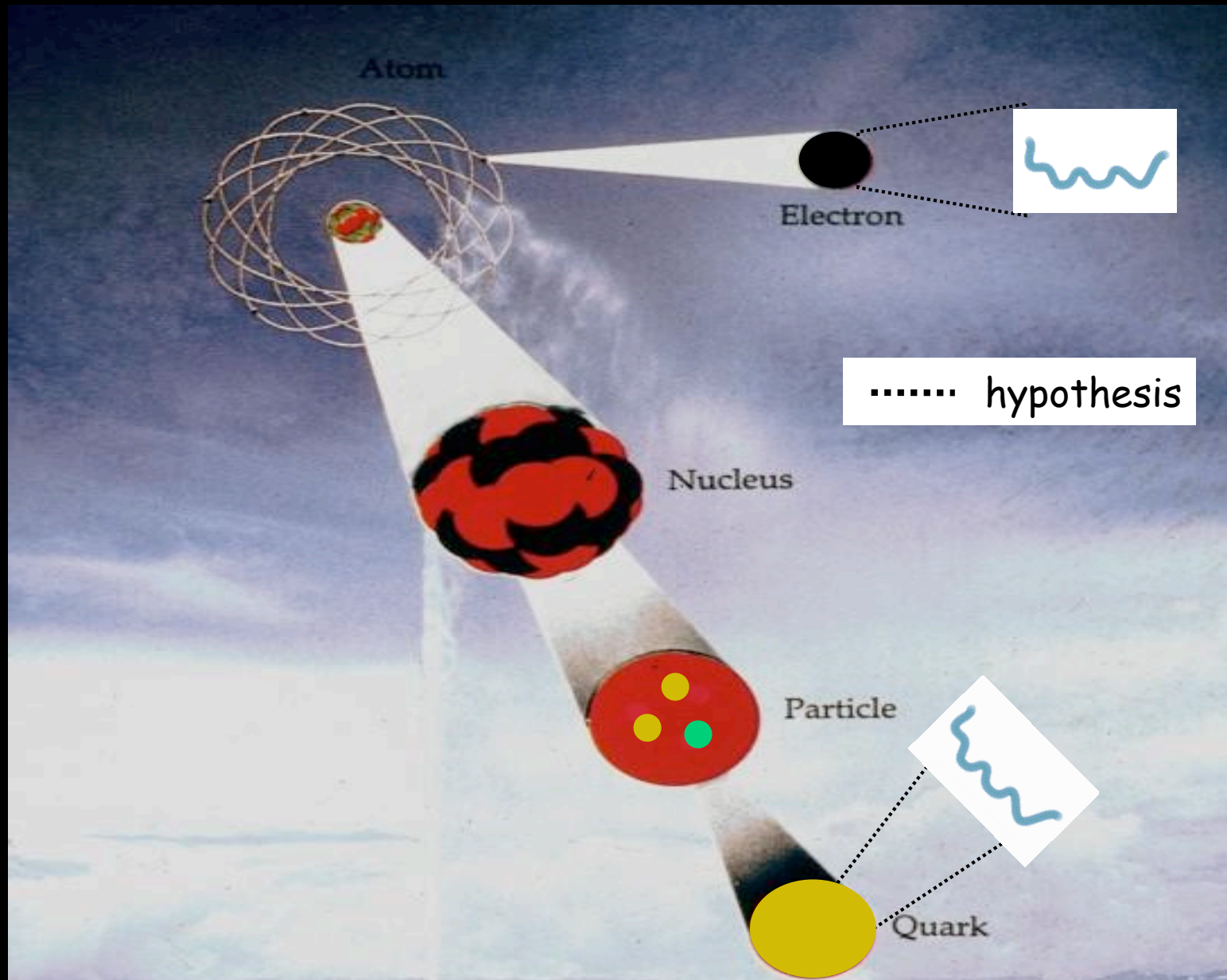


- Unifies all particles and all forces
 - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string



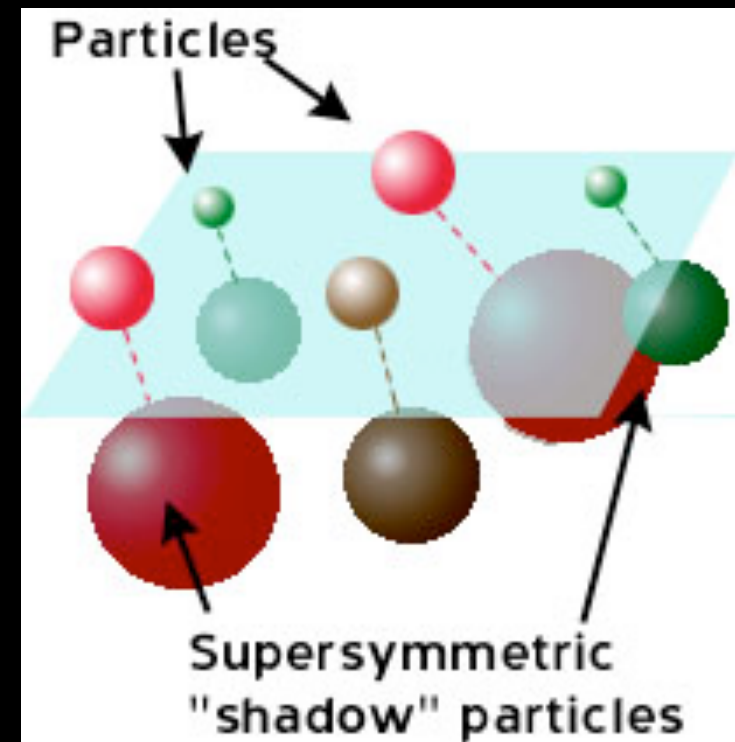
- Strings are miniscule
 - Atom is 10,000,000,000,000,000,000,000,000 x bigger
 - Dimension of String = 10^{-25} atomic size = 10^{-35} meters
- Requires another set of matching particles
 - the super-partners of ordinary particles

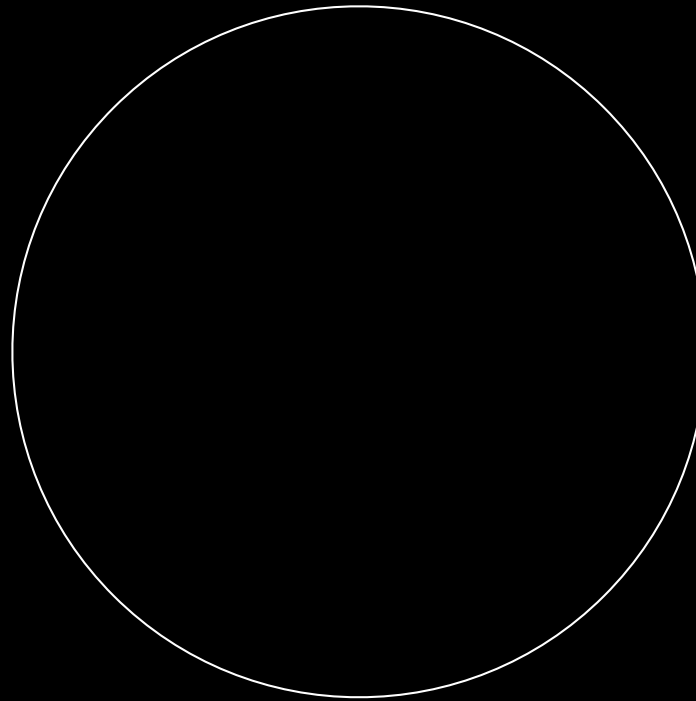
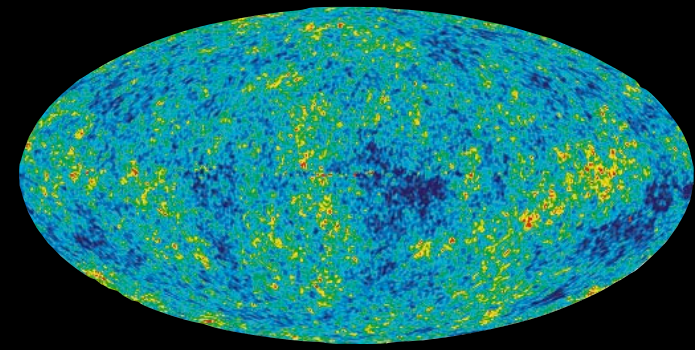
The Structure of Matter



Supersymmetry, Strings, and Dark Matter

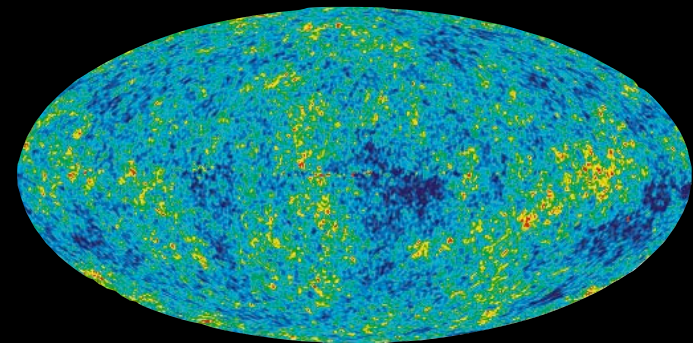
- History repeats?
- Just as with anti-matter,
New particles are predicted
- The supersymmetric particles
have just the properties
expected of Dark Matter



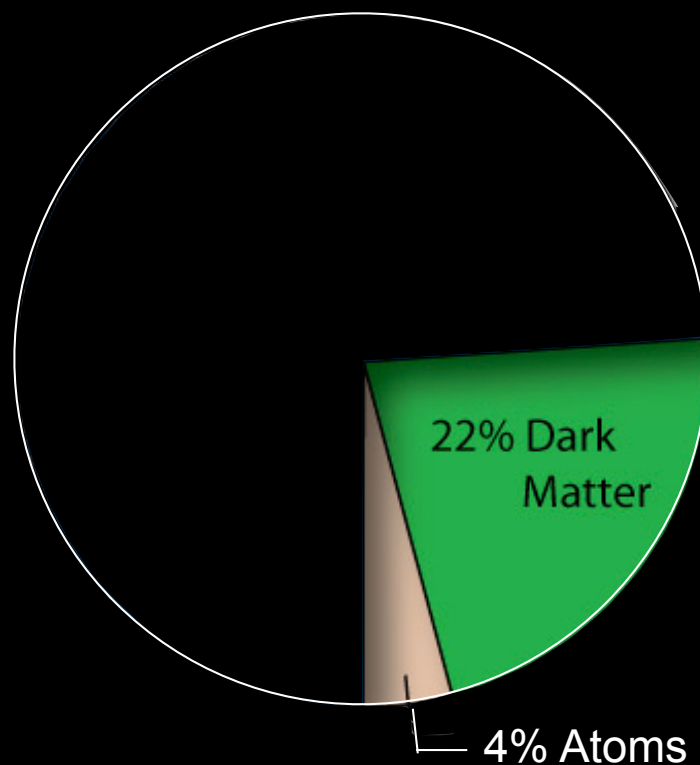


This pie represents
all the “stuff” in the
universe

The Matter Crisis



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



This pie represents all the “stuff” in the universe

Measuring Expansion of Universe

Distant Supernovae



Hubble Space Telescope - ACS

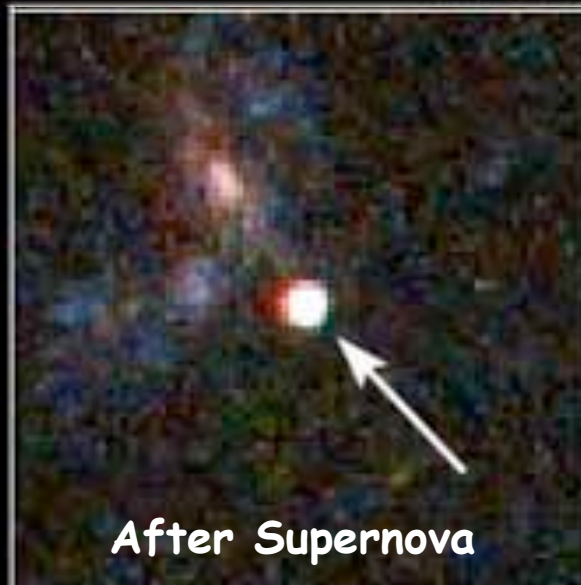


Measuring Expansion of Universe

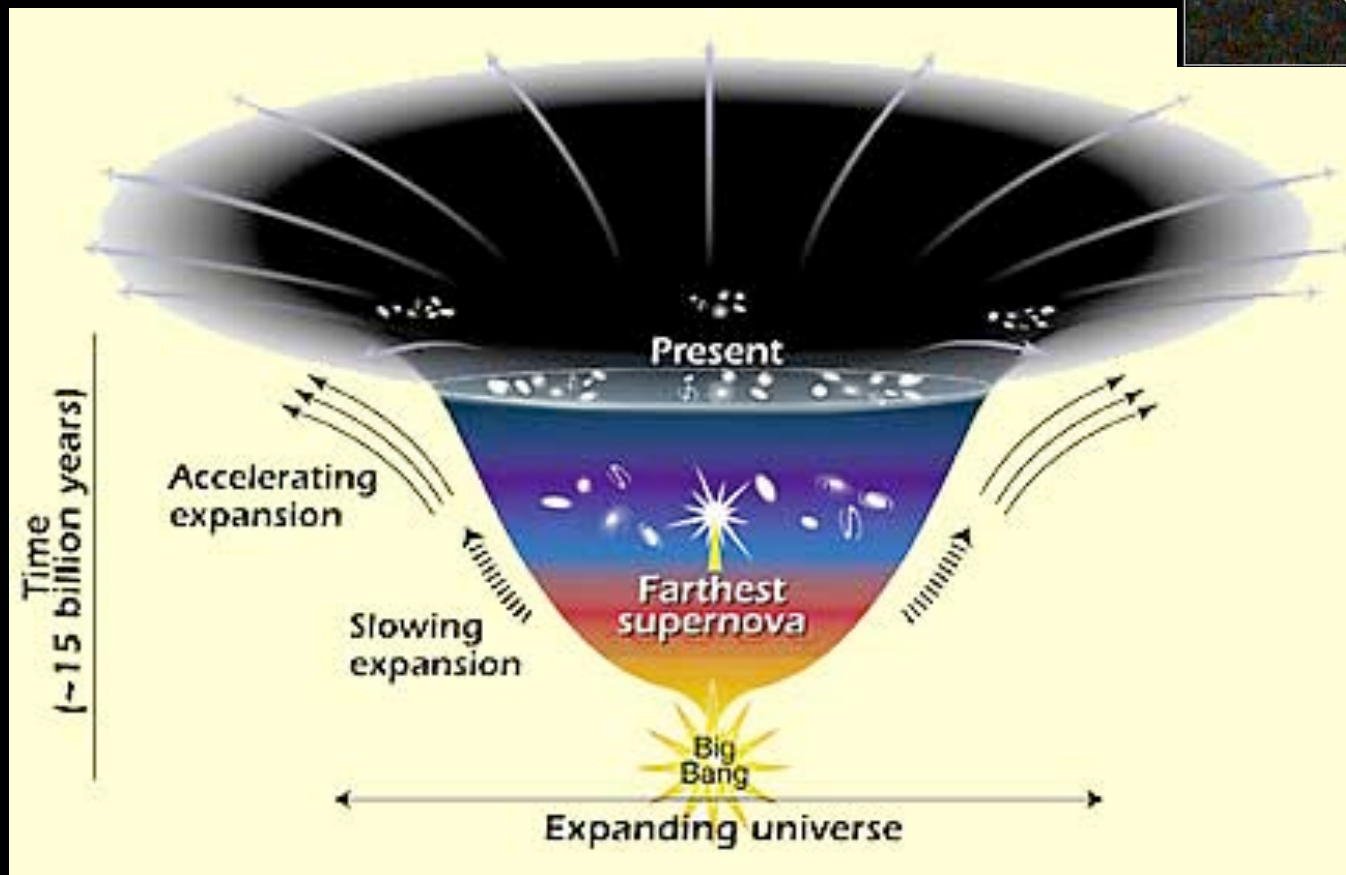
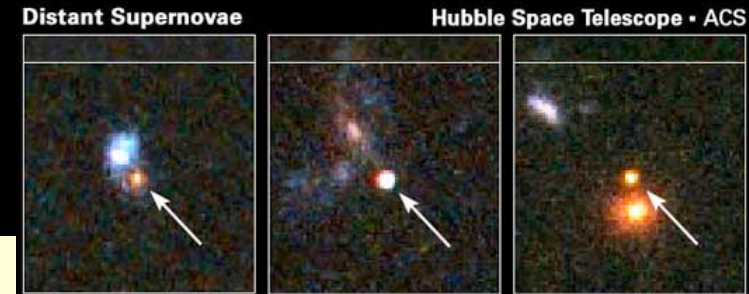
Distant Supernovae



Hubble Space Telescope - ACS



Measuring Expansion of Universe

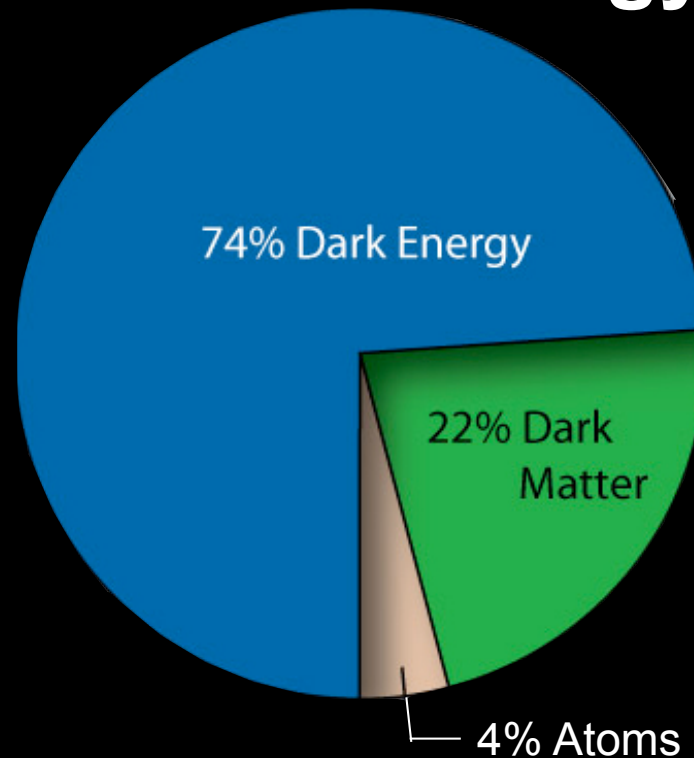


Expansion of
the Universe
is
Accelerating

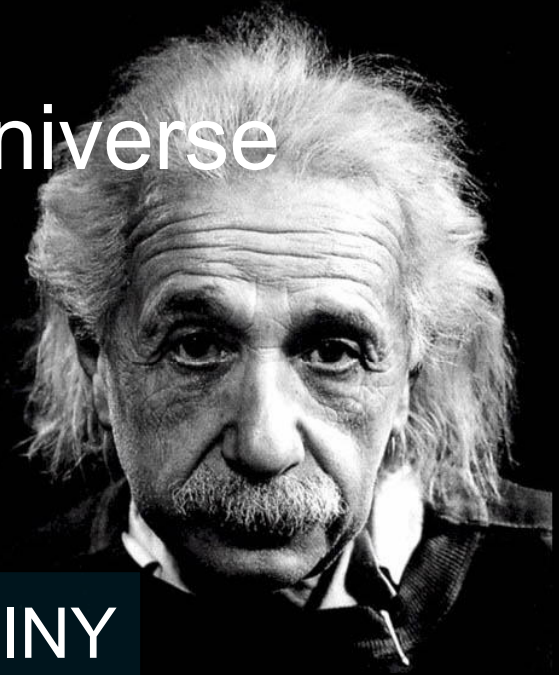
Driven by
Dark Energy

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

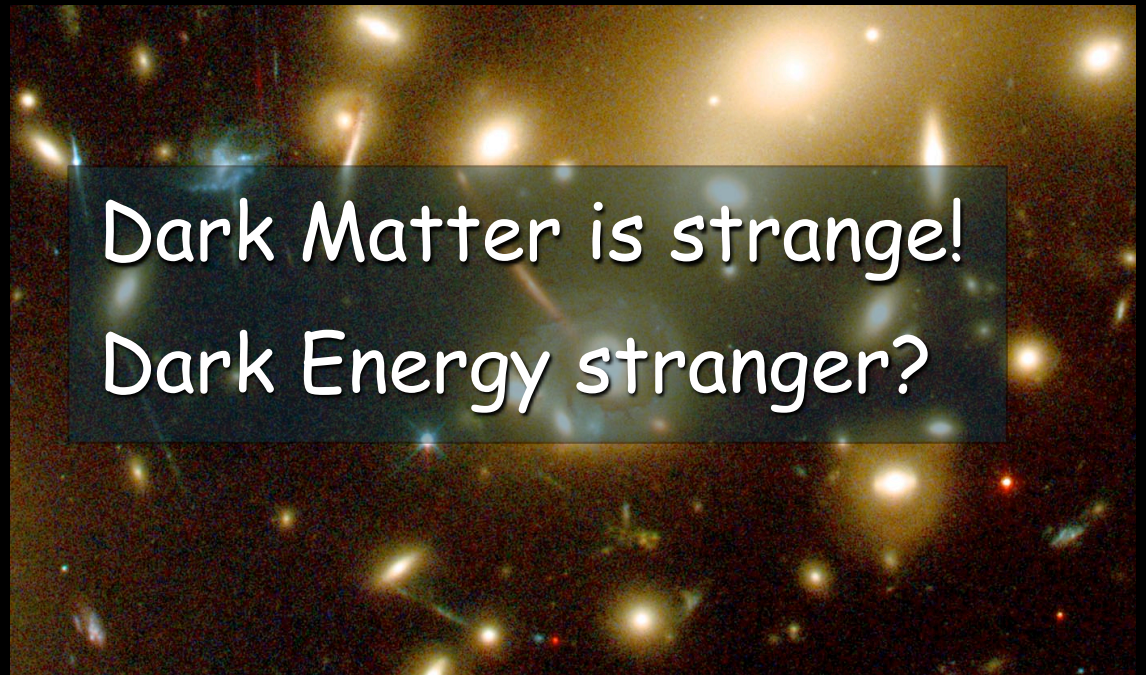


Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY



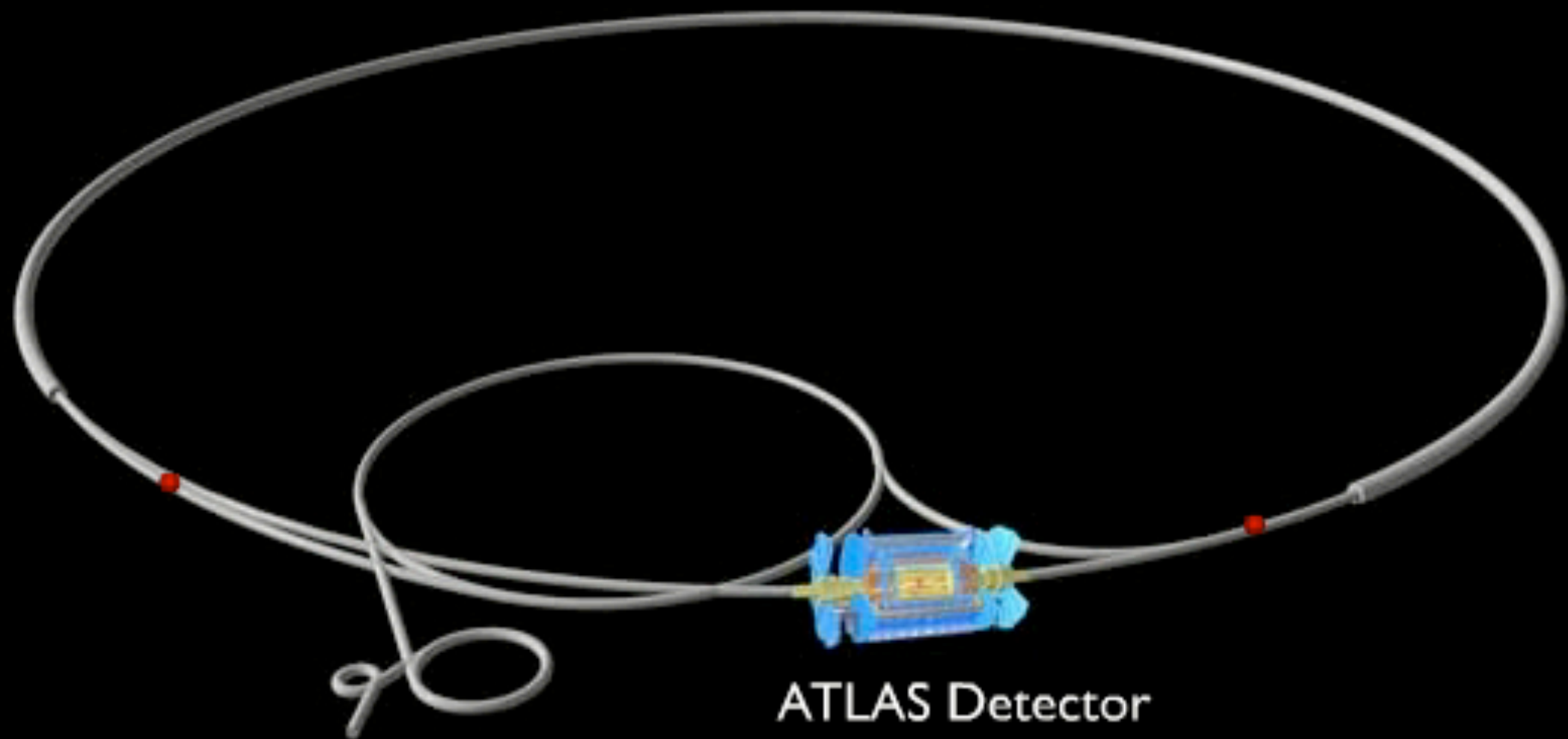
Dark Matter is strange!
Dark Energy stranger?



Large Hadron Collider (LHC) Geneva, Switzerland



Large Hadron Collider



Large Hadron Collider (LHC) Geneva, Switzerland

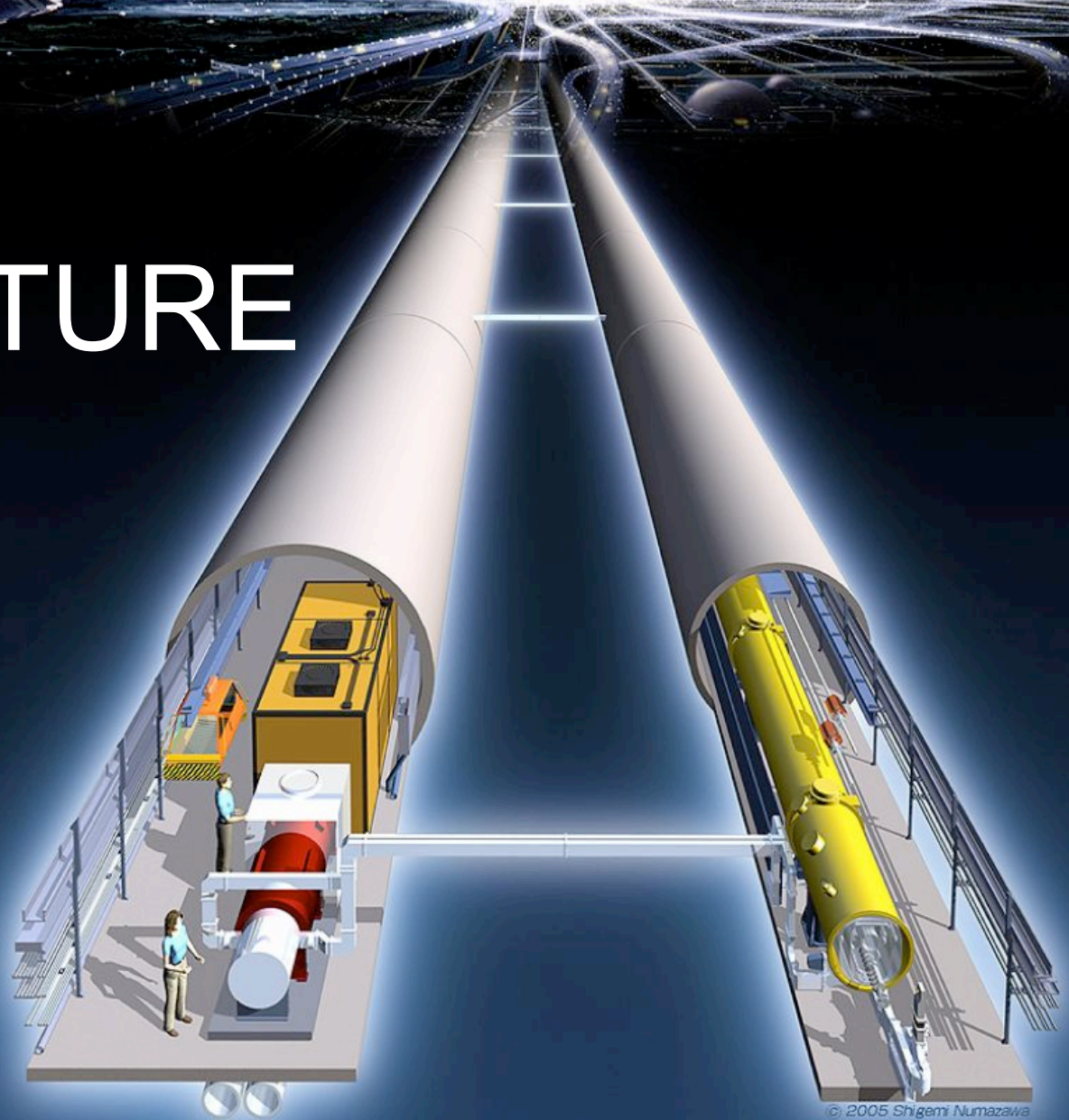
Operating since
2009

Searching
for Dark Matter,
Higgs Bosons,
other New Particles
and Forces

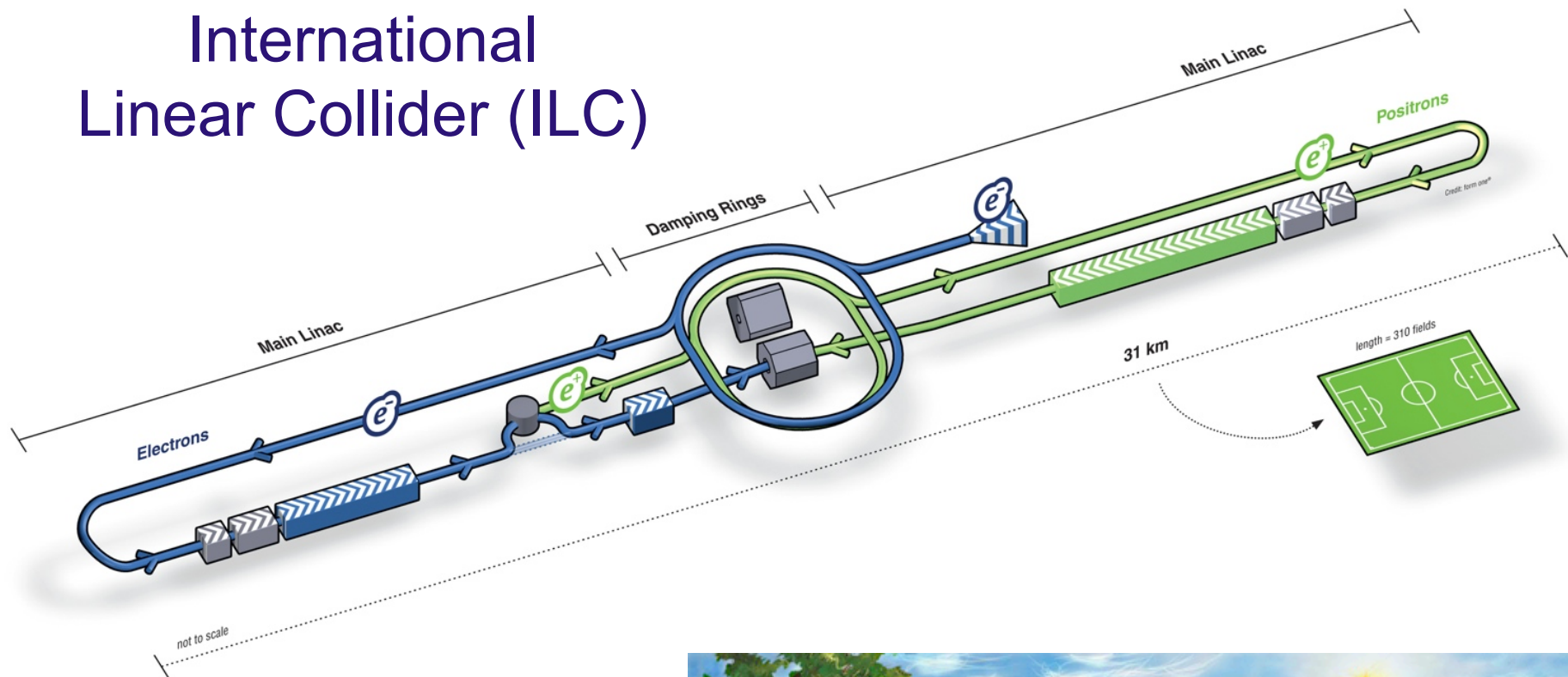


Linear Collider

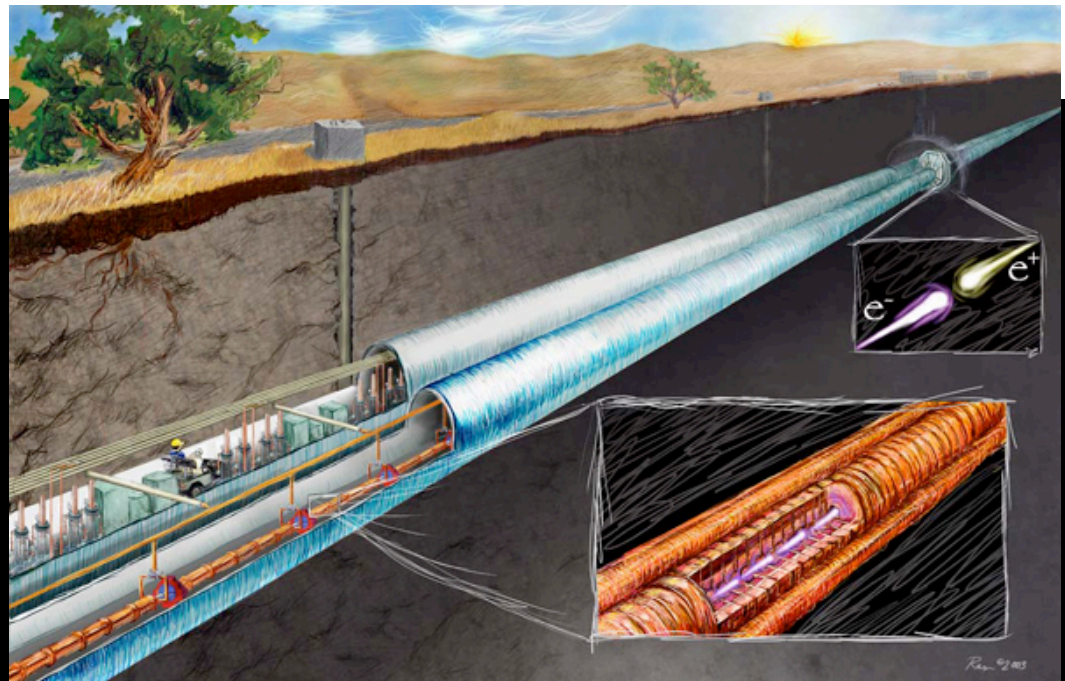
FUTURE



International Linear Collider (ILC)



FUTURE



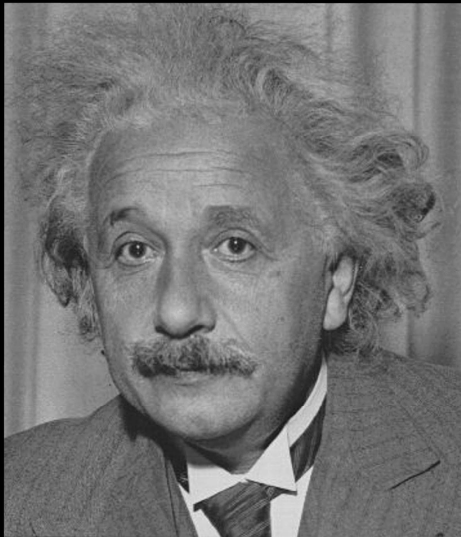
Scientific Goals of the LHC and the ILC

- 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

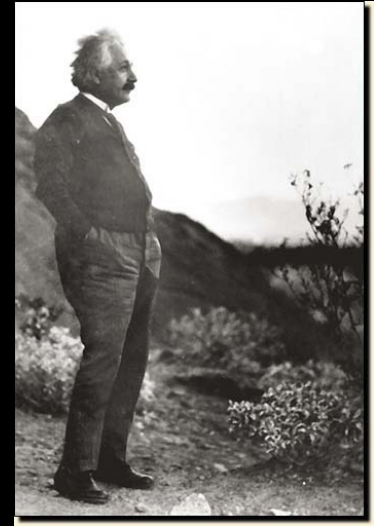
- Big Bang occurred 13.7 billion years ago
 - expanding Universe, cosmic fireball, other observables
- Universe expanded and cooled; fundamental particles condensed into structures
- Accelerators have revealed fundamental particles and their interactions
- Dark Matter dominates mass of the Universe
 - 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.*



Jim Brau

JLab Science Series



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.

November 23, 2010

Nature
intended me
for the tranquil
pursuits of
science,
by rendering
them my
supreme
delight.



Acknowledgements

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OFFICE OF SCIENCE



NATIONAL SCIENCE FOUNDATION



Philip H. Knight