



THE PARTICLES OF NATURE

Exploring Our Universe
With Particle Accelerators

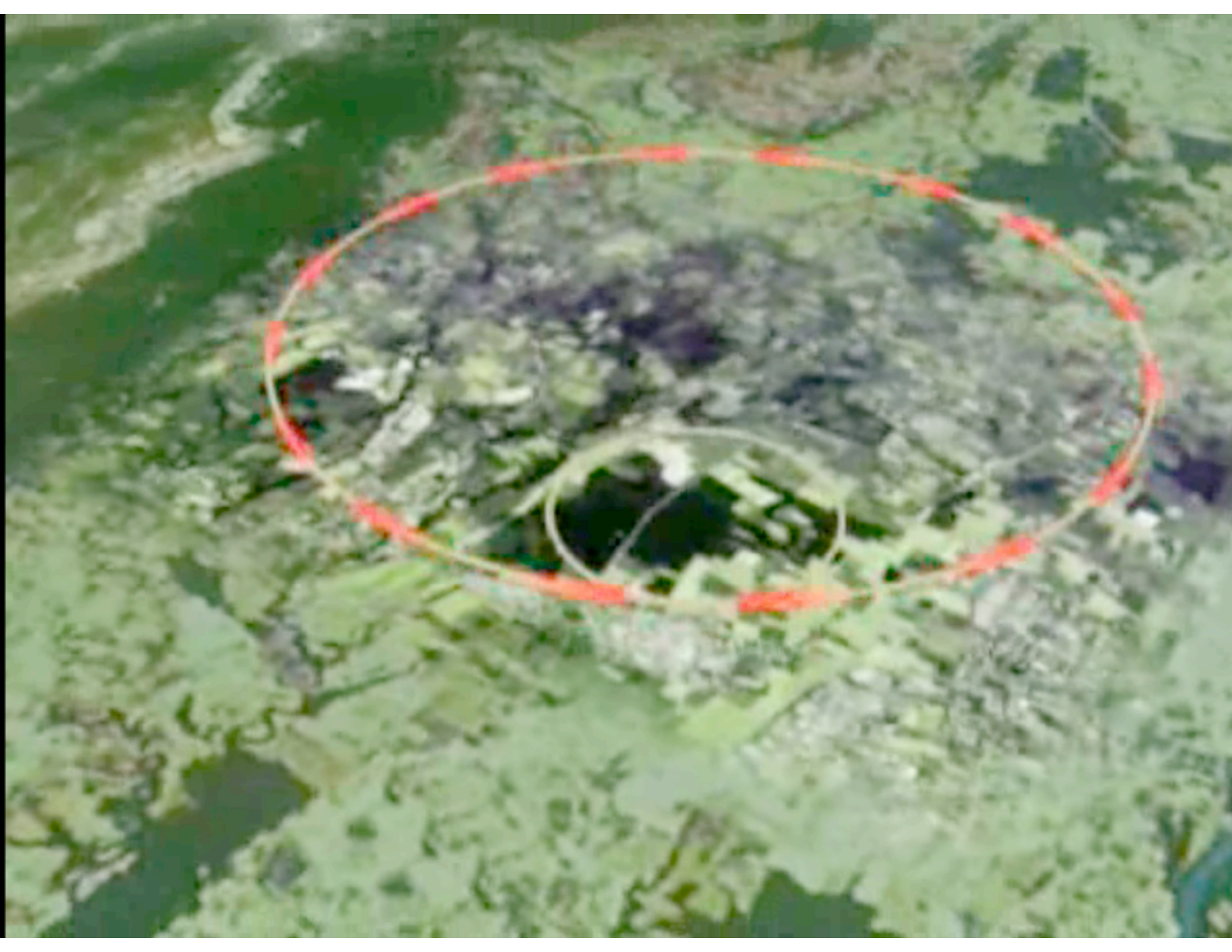
Wally Pacholka / AstroPics.com



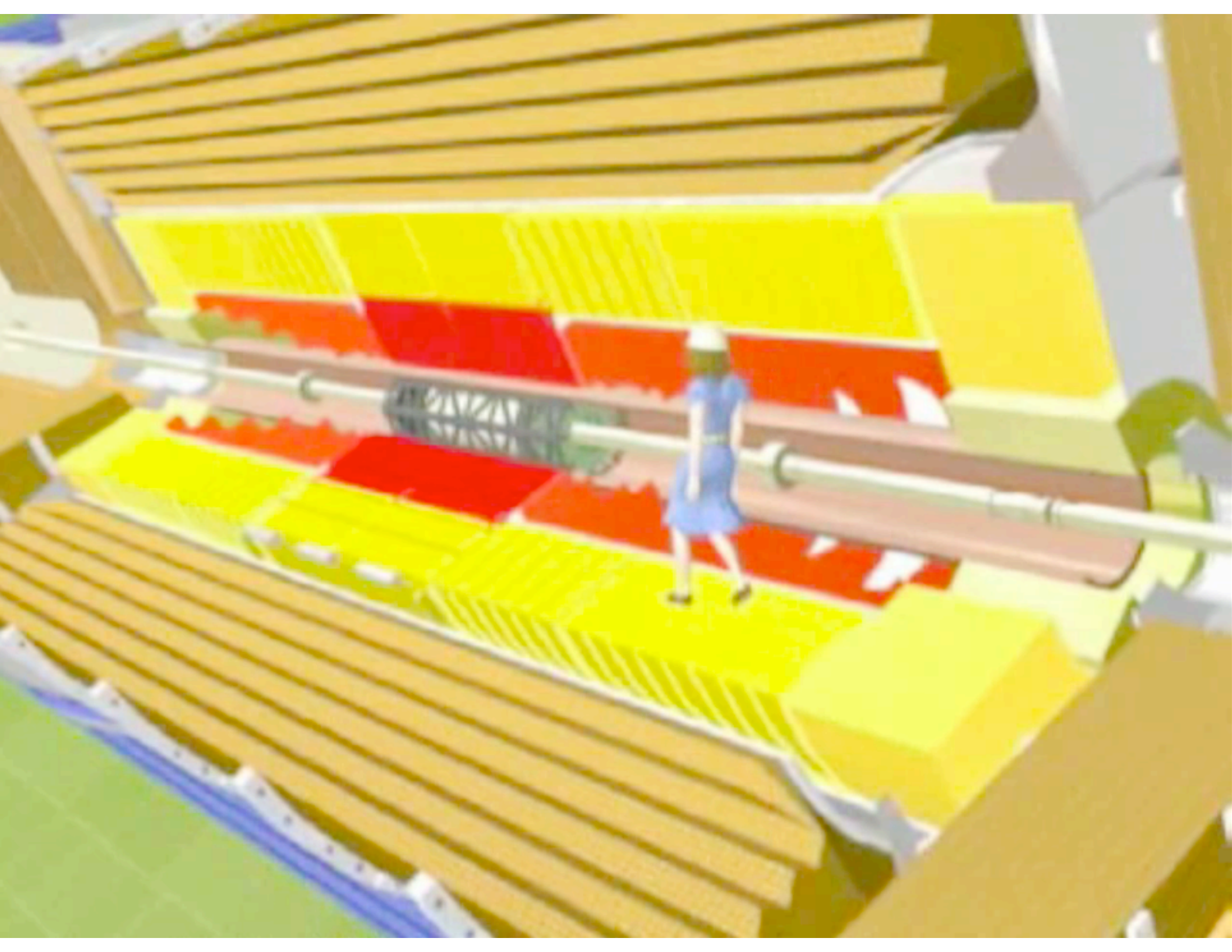
Jim Brau

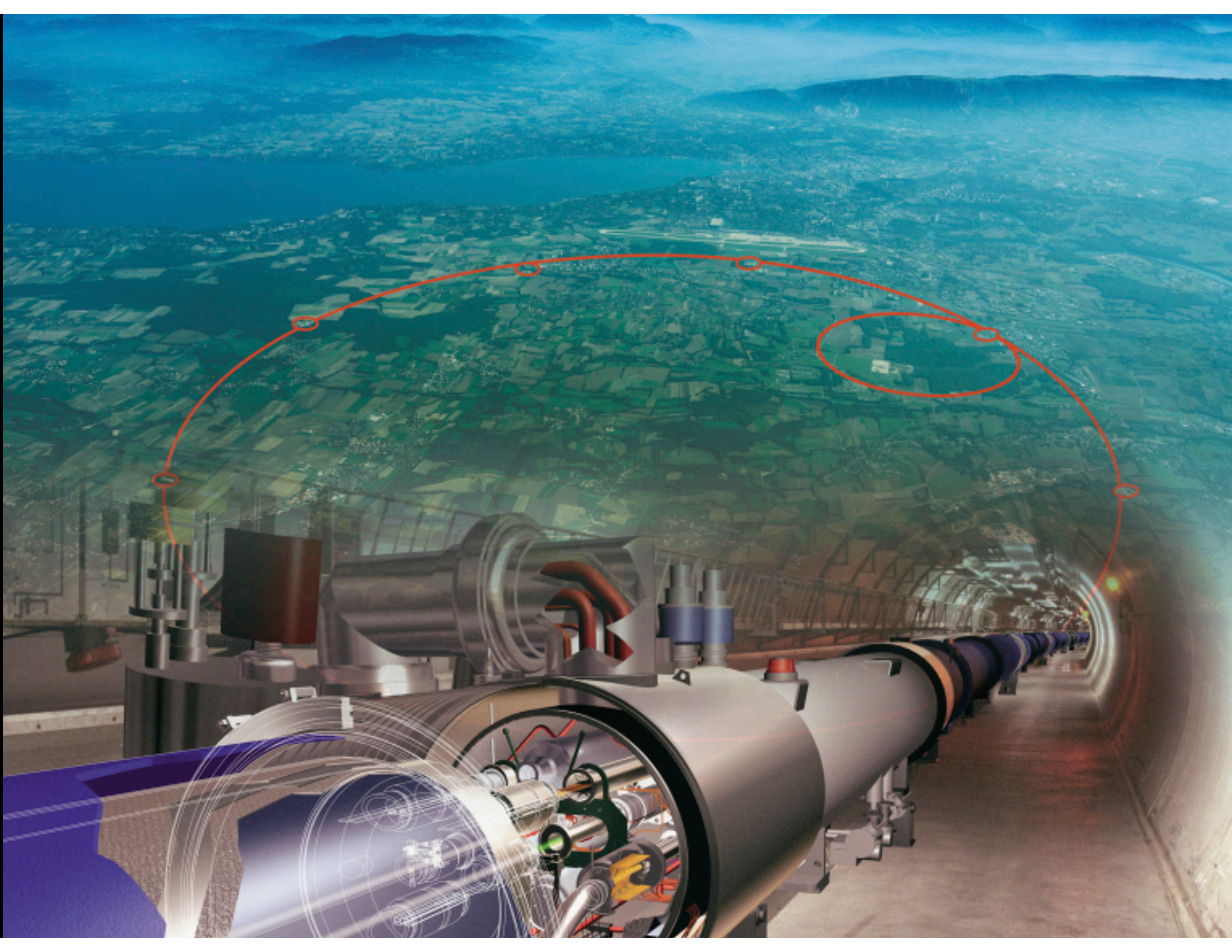
Astronomy 123

January 25, 2011

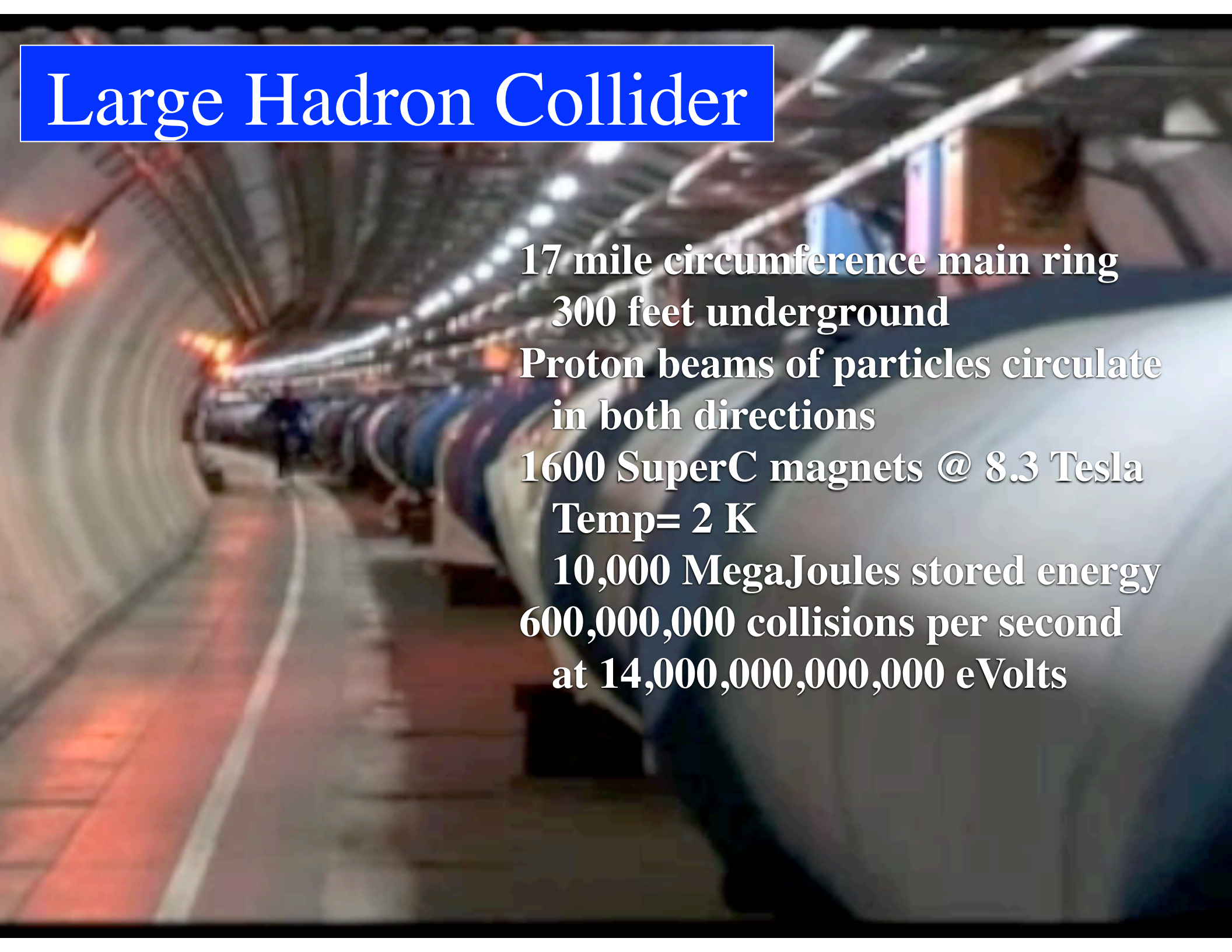








Large Hadron Collider

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

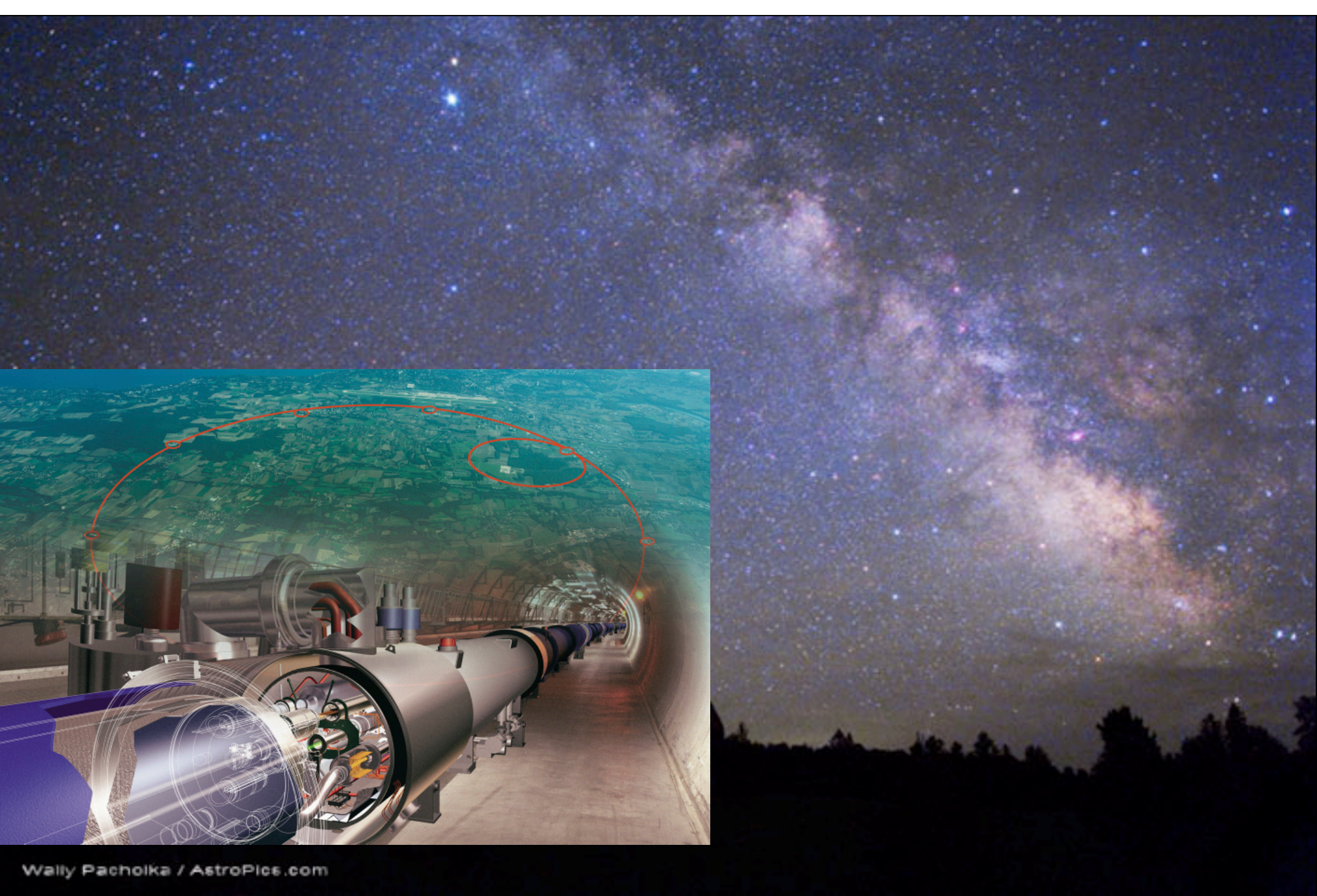
1600 SuperC magnets @ 8.3 Tesla
Temp= 2 K

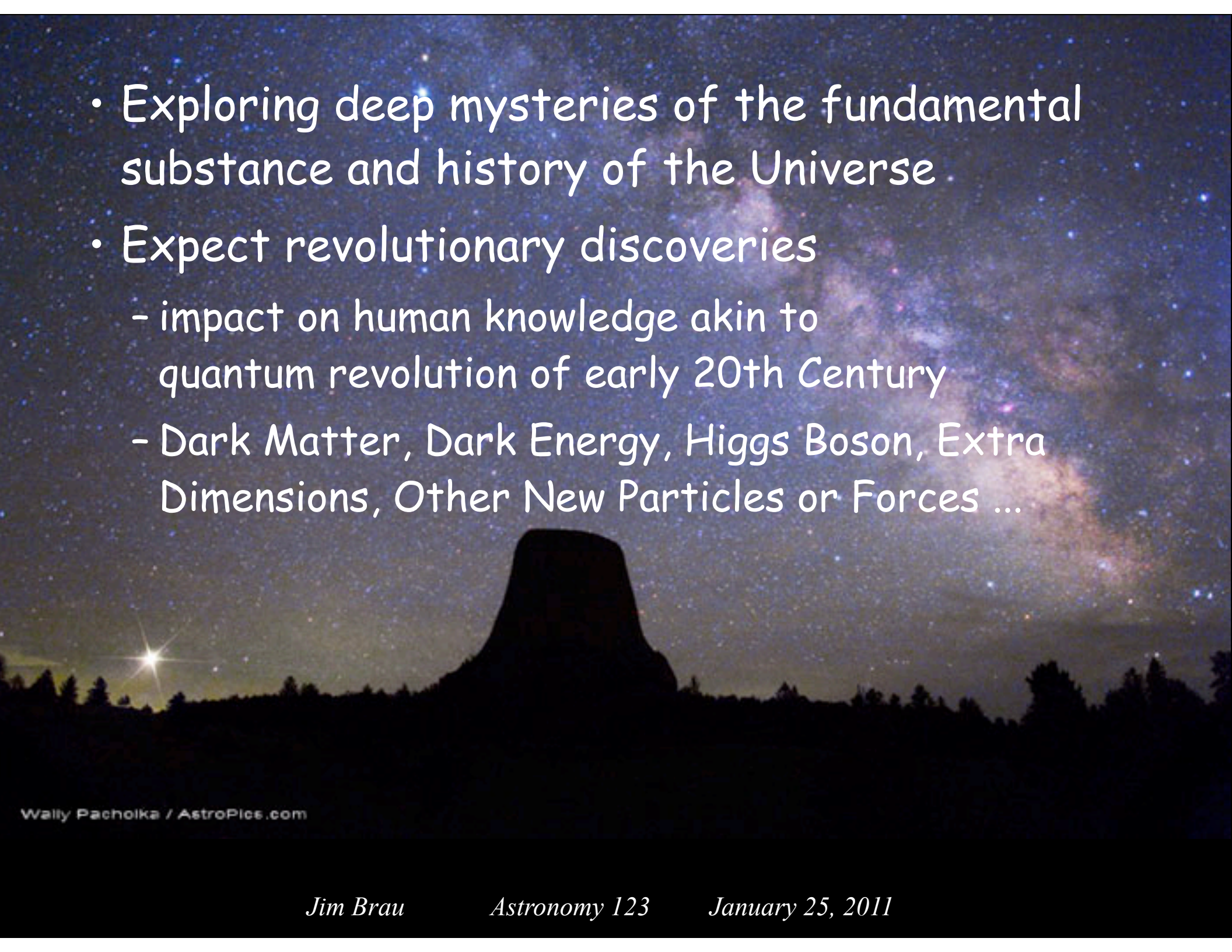
10,000 MegaJoules stored energy
600,000,000 collisions per second
at 14,000,000,000,000 eVolts

Large Hadron Collider



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



- 
- 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



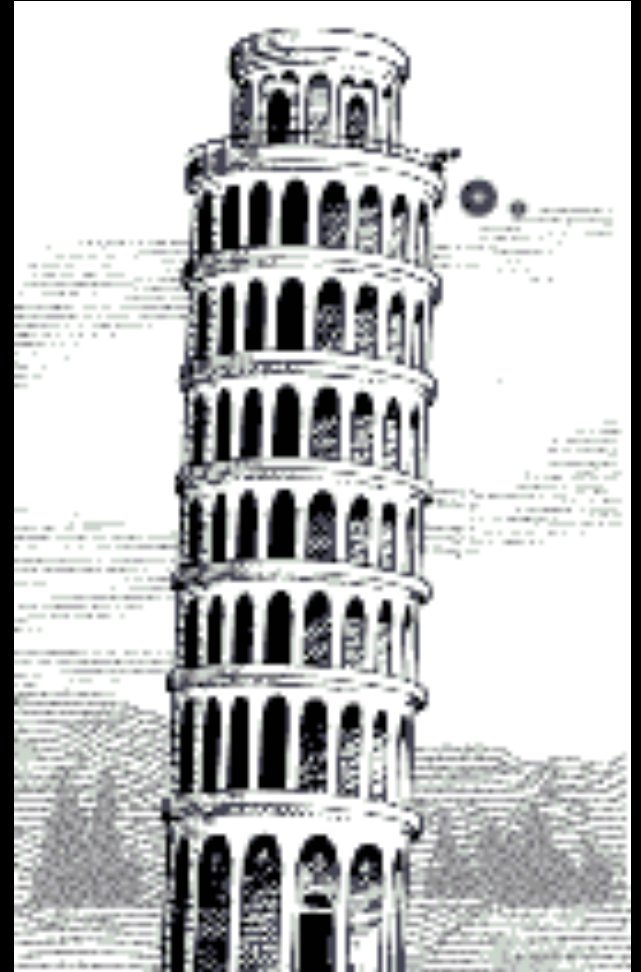
image from Science 16 January 2009

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Galileo Galilei



<http://physics-animations.com>

image from Science 16 January 2009

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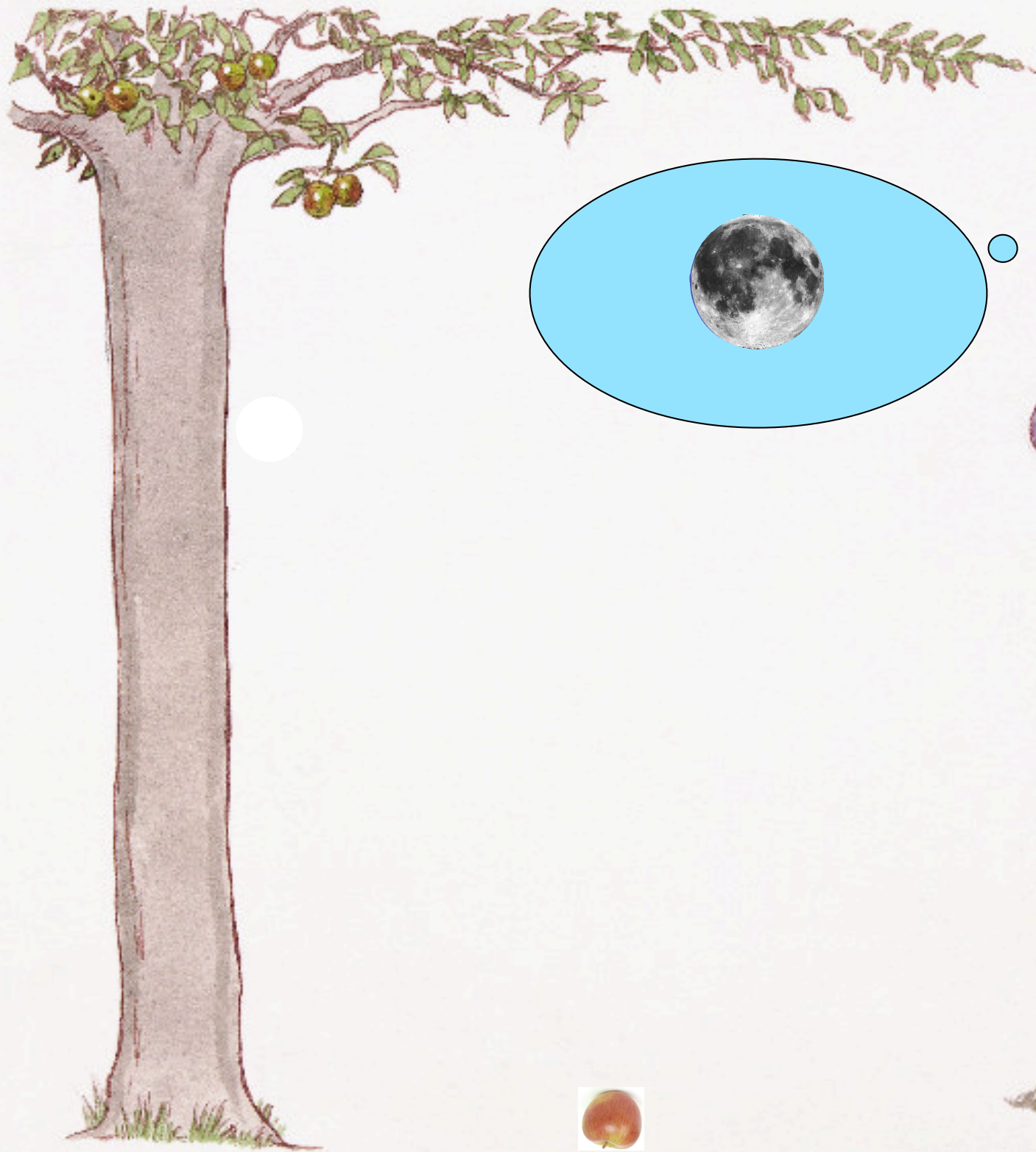
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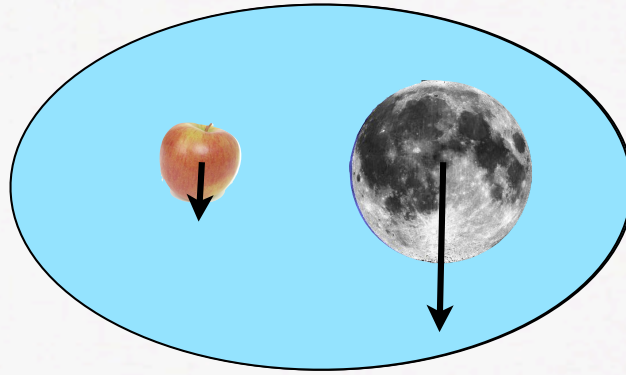
Sir Isaac Newton (1642-1727)

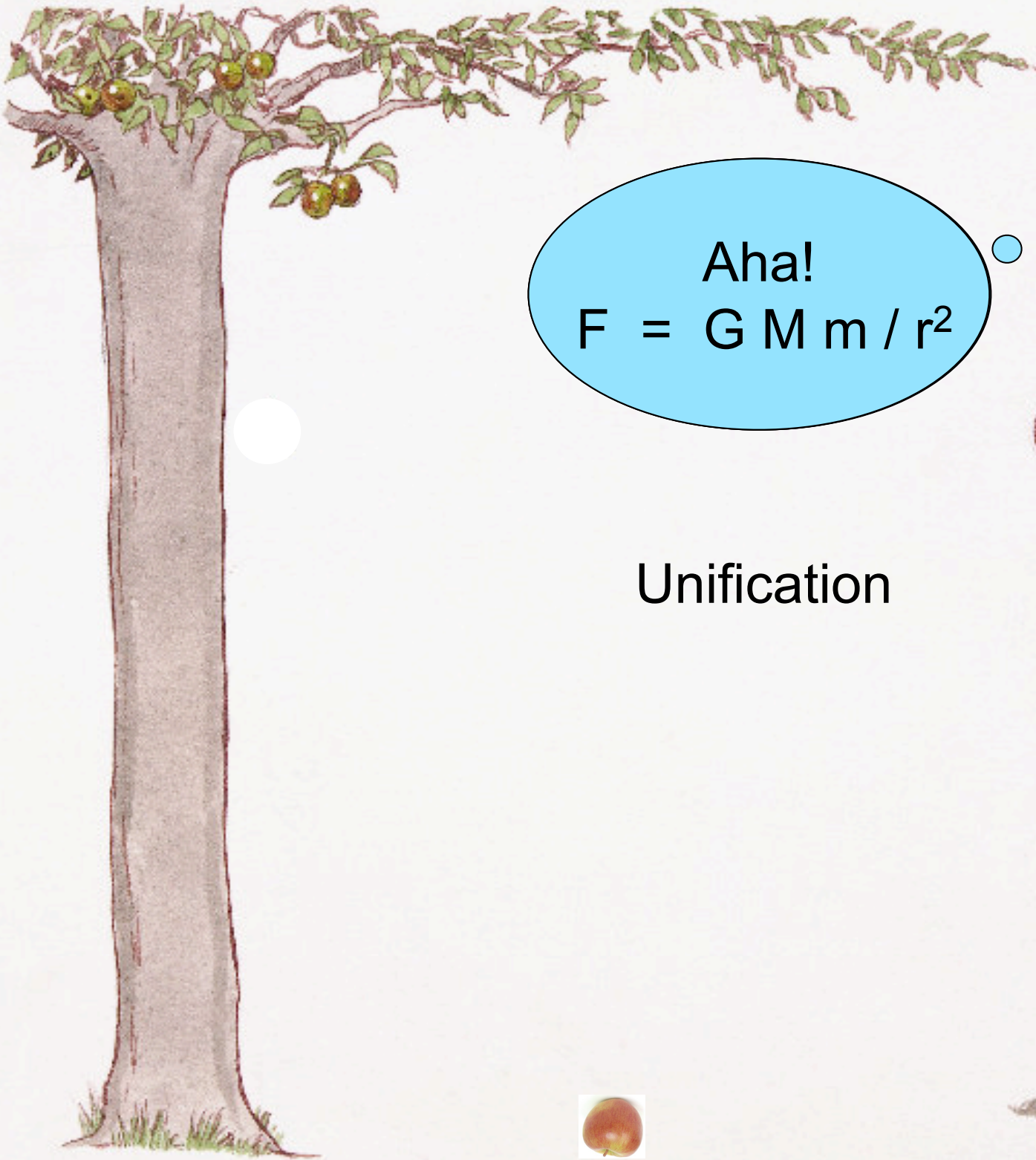












Aha!
$$F = G M m / r^2$$

Unification



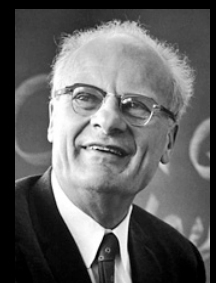
A bright sun is visible in the upper left quadrant of the image, shining through a clear blue sky. Large, fluffy white clouds are scattered across the sky, particularly concentrated on the right side and bottom. The sun's light creates a soft glow and some lens flare effects.

What is the Sun's source of energy

Solar Energy

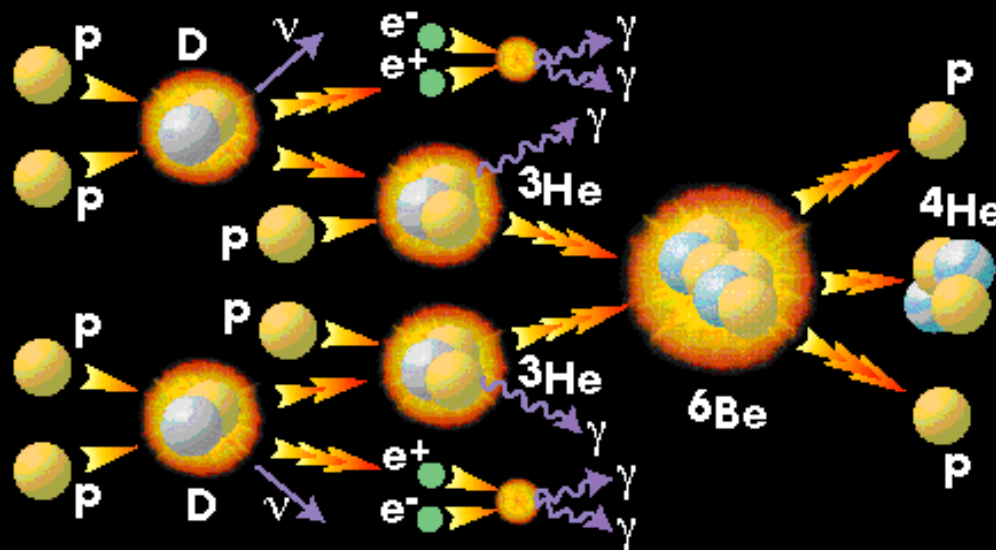


- What is the Sun's source of energy?
 - 19th Century - Chemical reactions? (burning)
 - Predicted solar lifetime too short - only 20,000 years
 - Evidence on Earth for much longer duration
 - 20th Century
 - Einstein's relativity $E=mc^2$
 - discovery of atomic nucleus and nuclear reactions



Solar Energy

- What is the Sun's source of energy?



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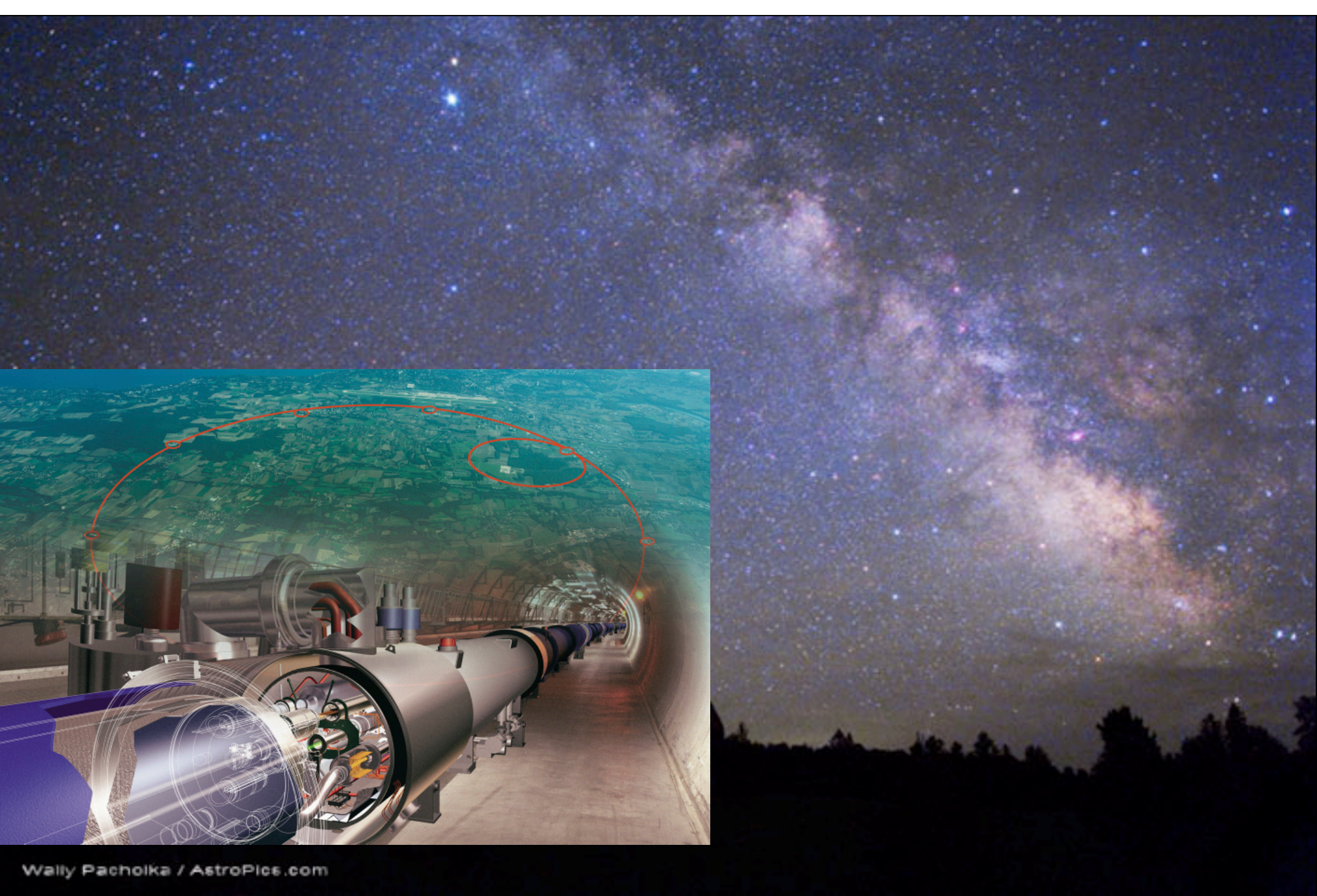
Enough energy
for the Sun to shine
for ten billion years

Relativity

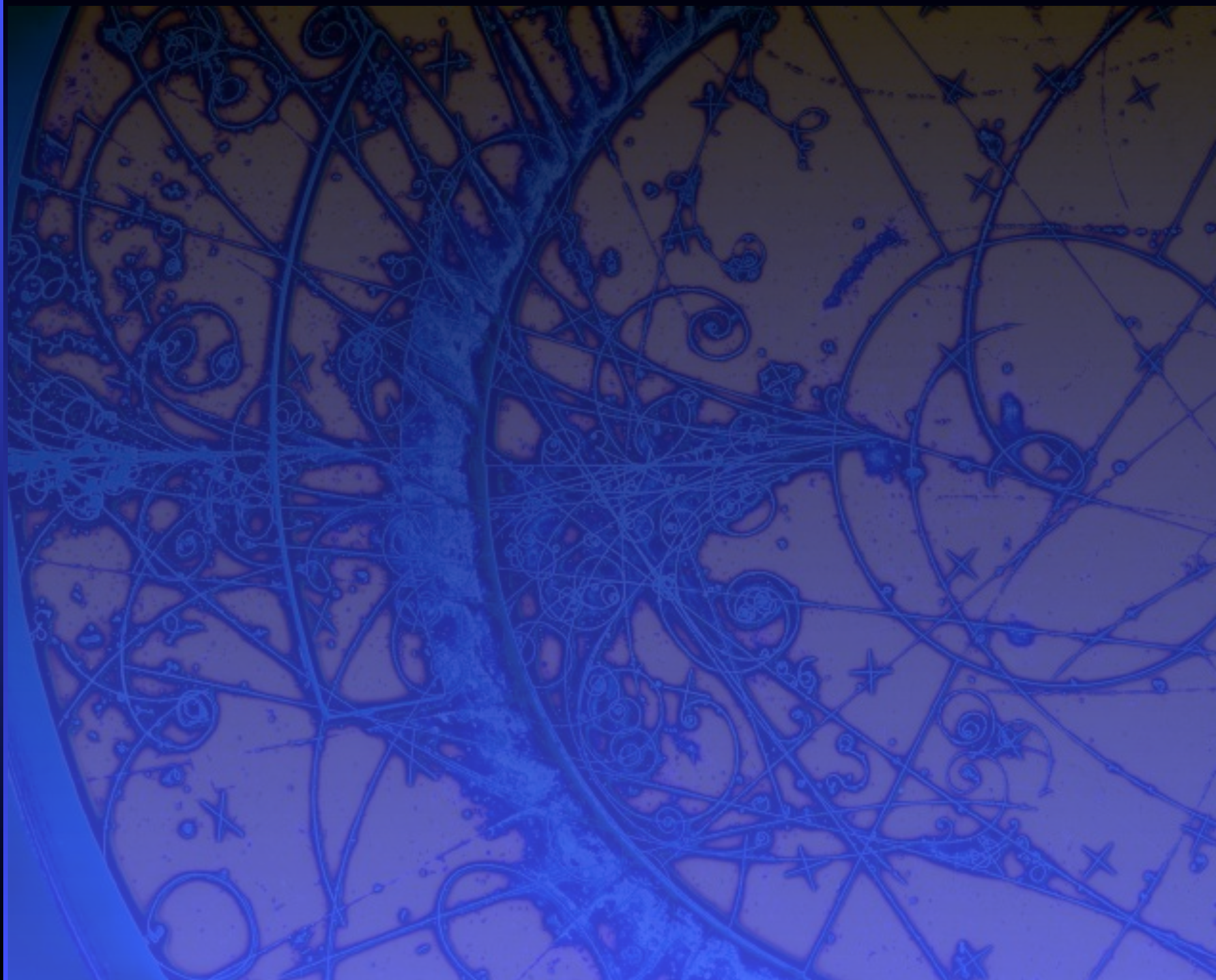
- When a man sits with a pretty girl for an hour, it seems like a minute.
- But let him sit on a hot stove for a minute—and it's longer than any hour.
- That's relativity.

A. Einstein





Wally Pacholka / AstroPics.com



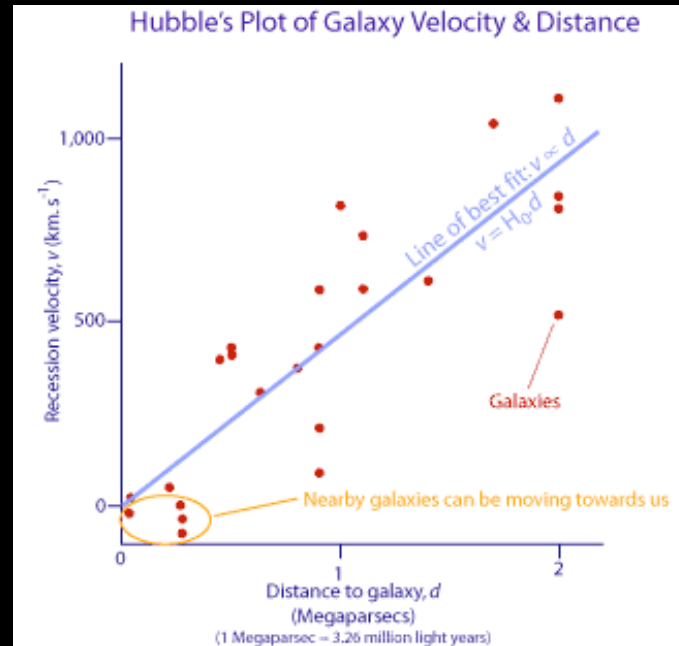
1929 - Hubble Discovered Universe is Expanding



First evidence that Universe began with a Big Bang



Edwin Powell Hubble
(1889-1953)



1929



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www.MrEclipse.com

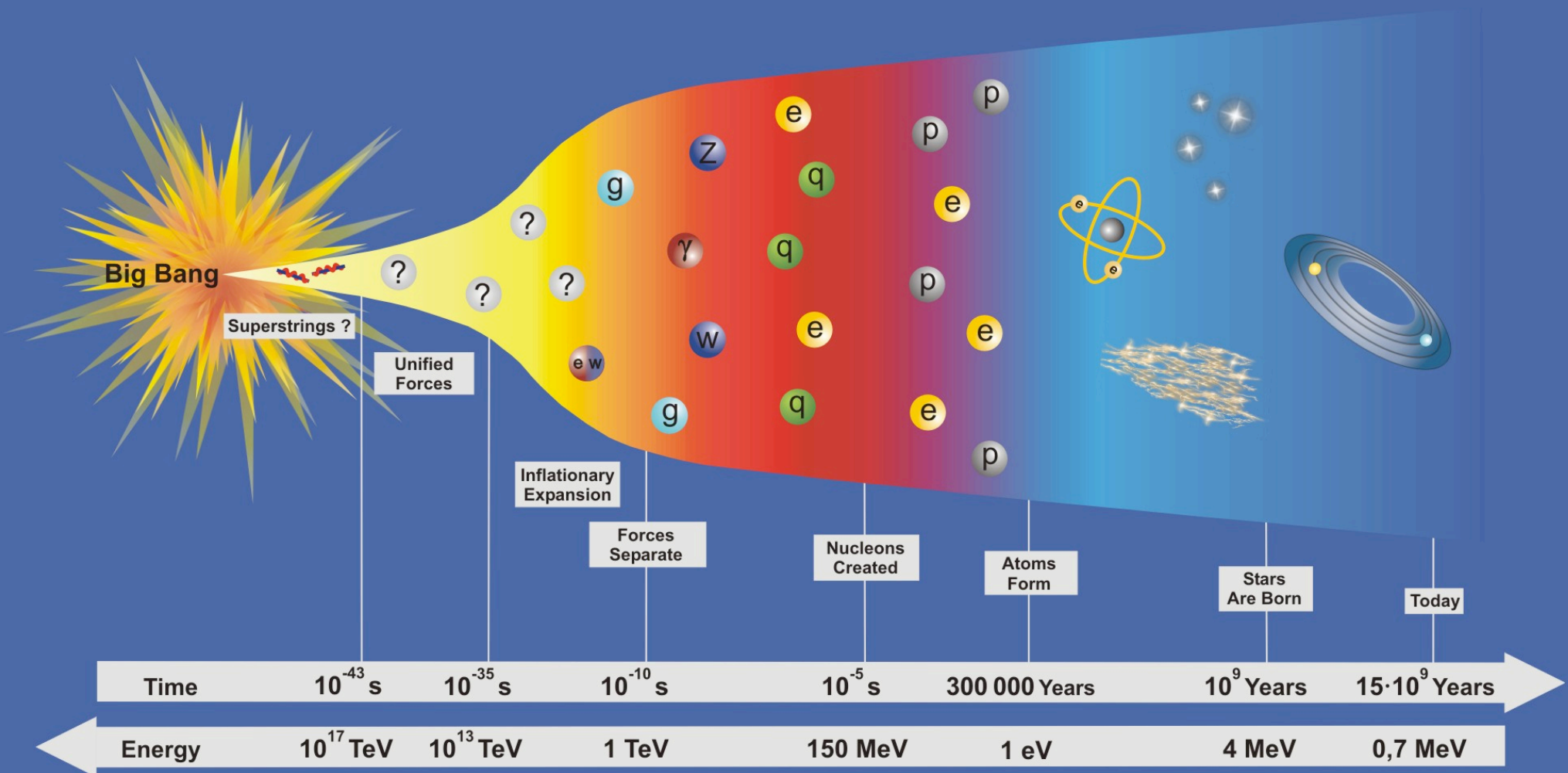


Universe's Glow
in Microwaves
discovered in 1965

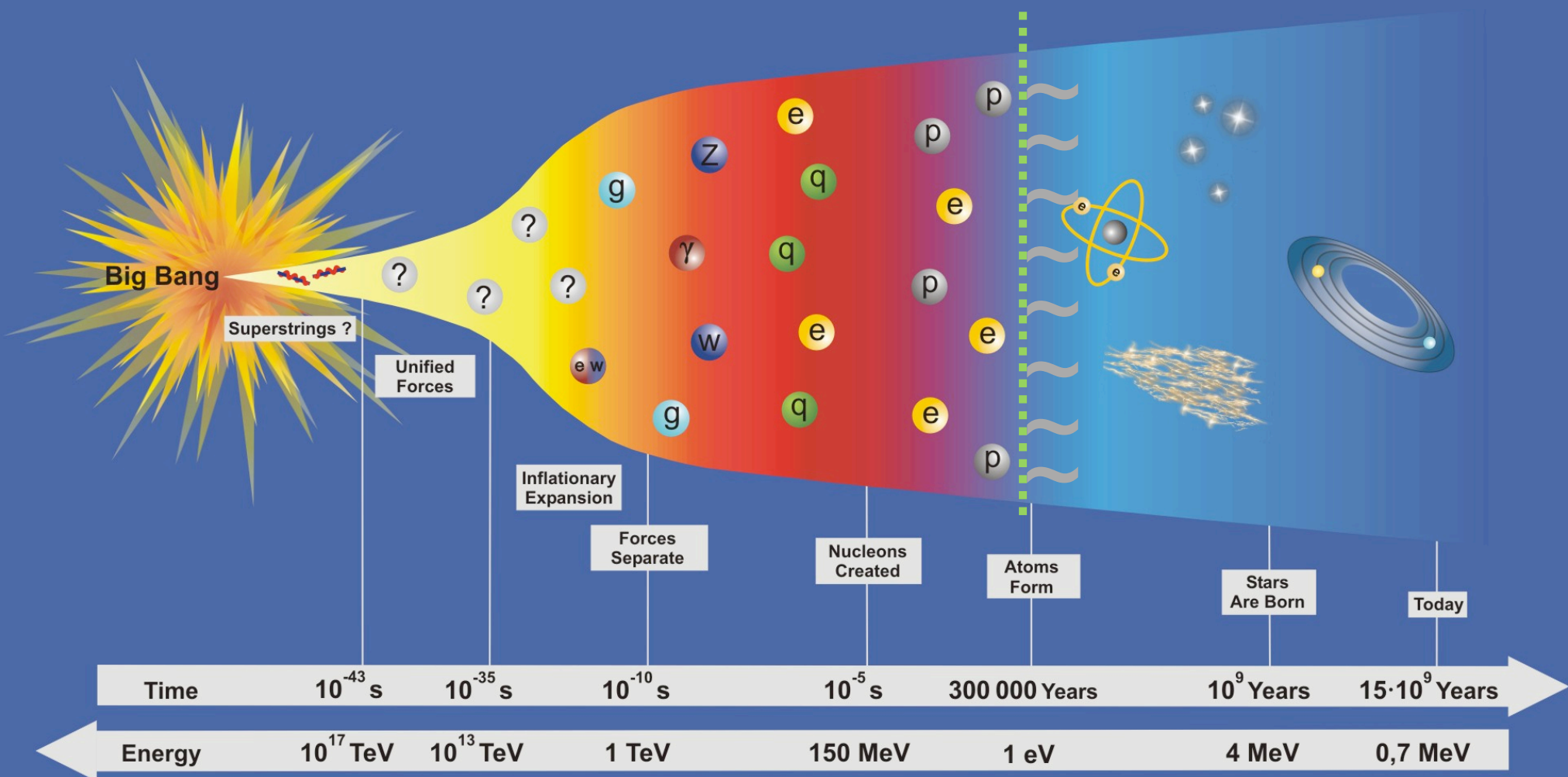
*predicted following
Hubble's discovery*

*confirmed early
universe of Big Bang*

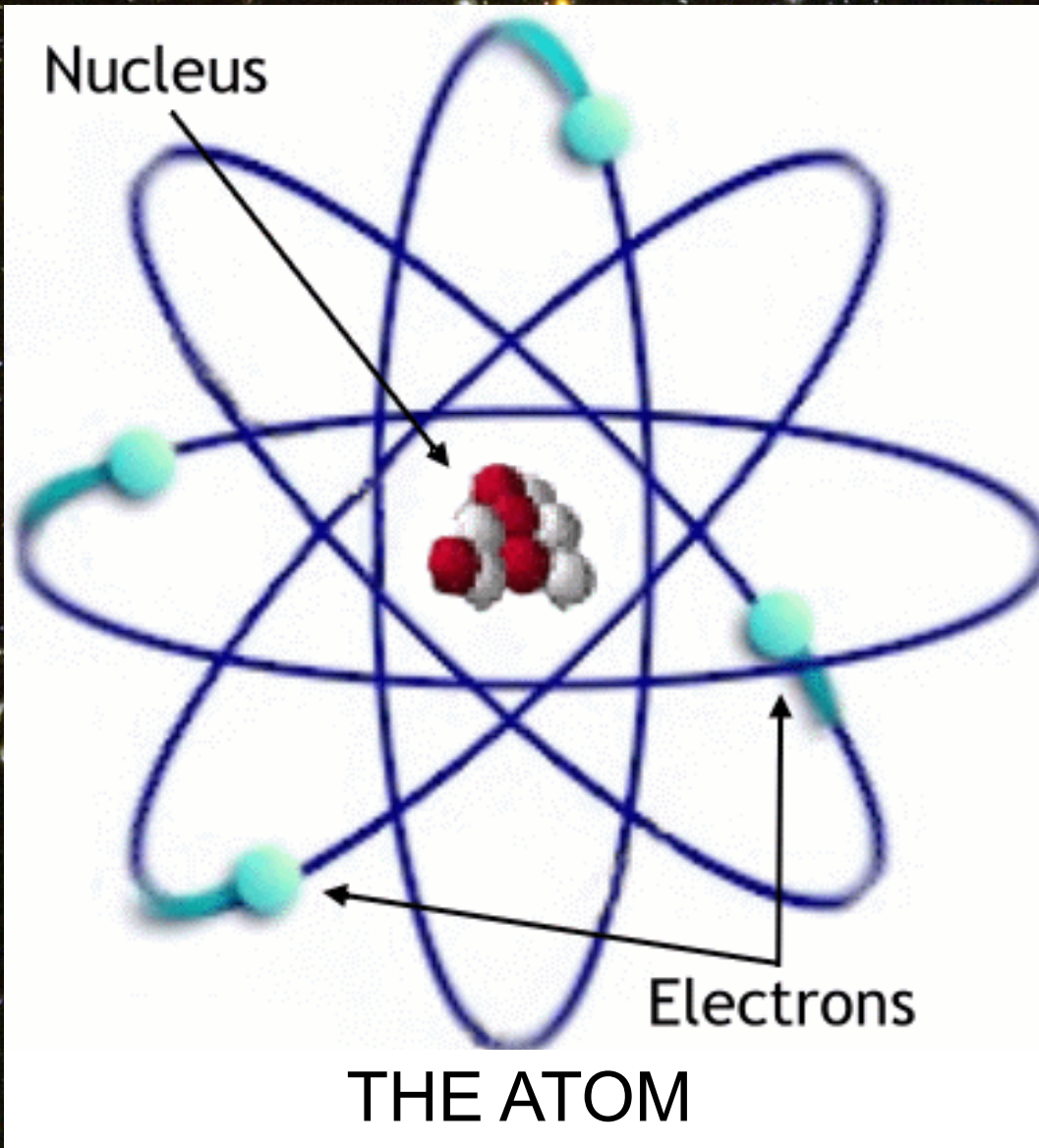
Big Bang



Big Bang



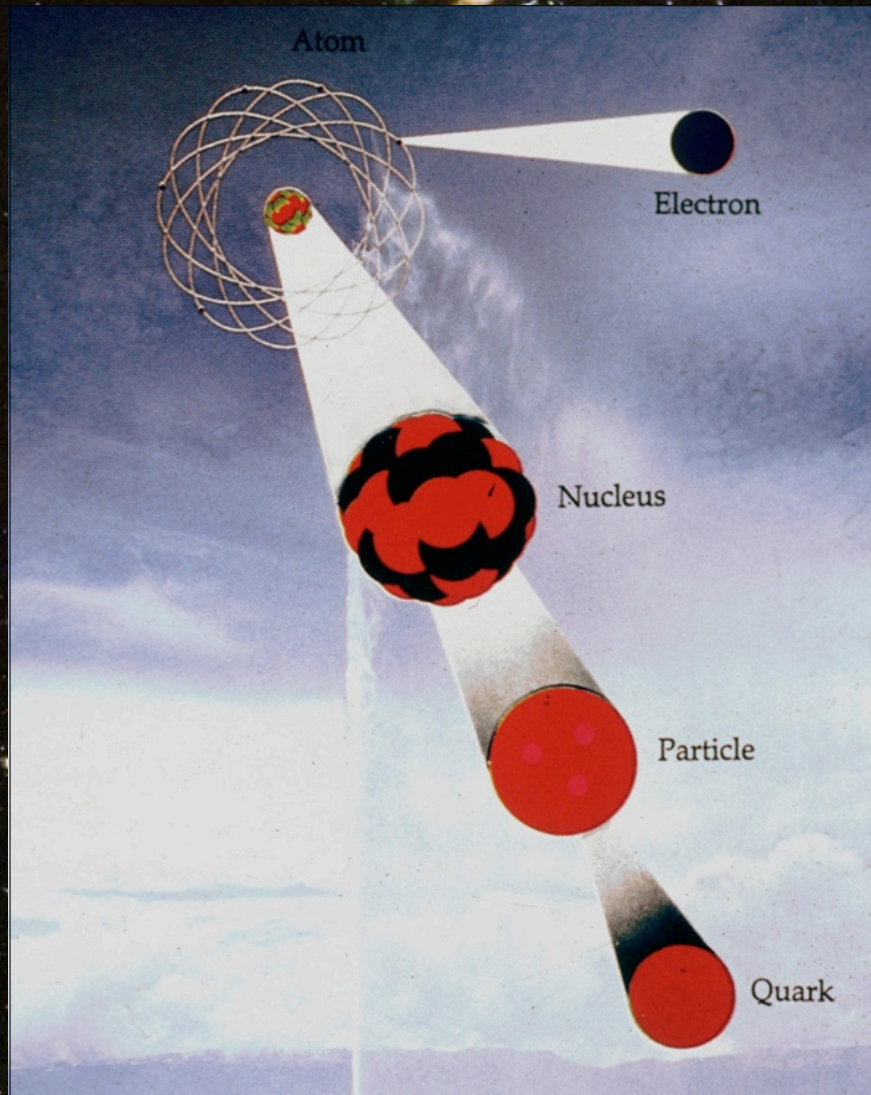
The Universe is Made of Particles



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

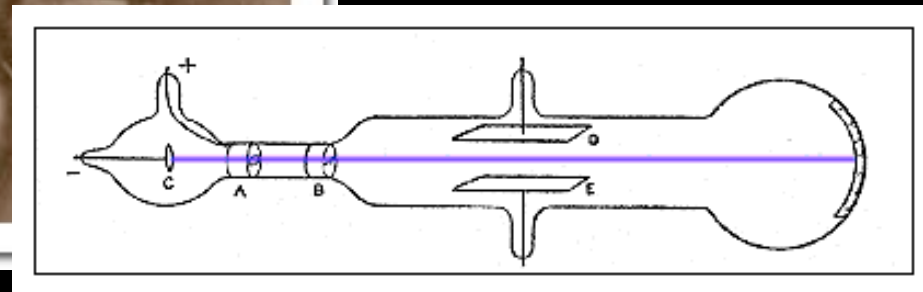
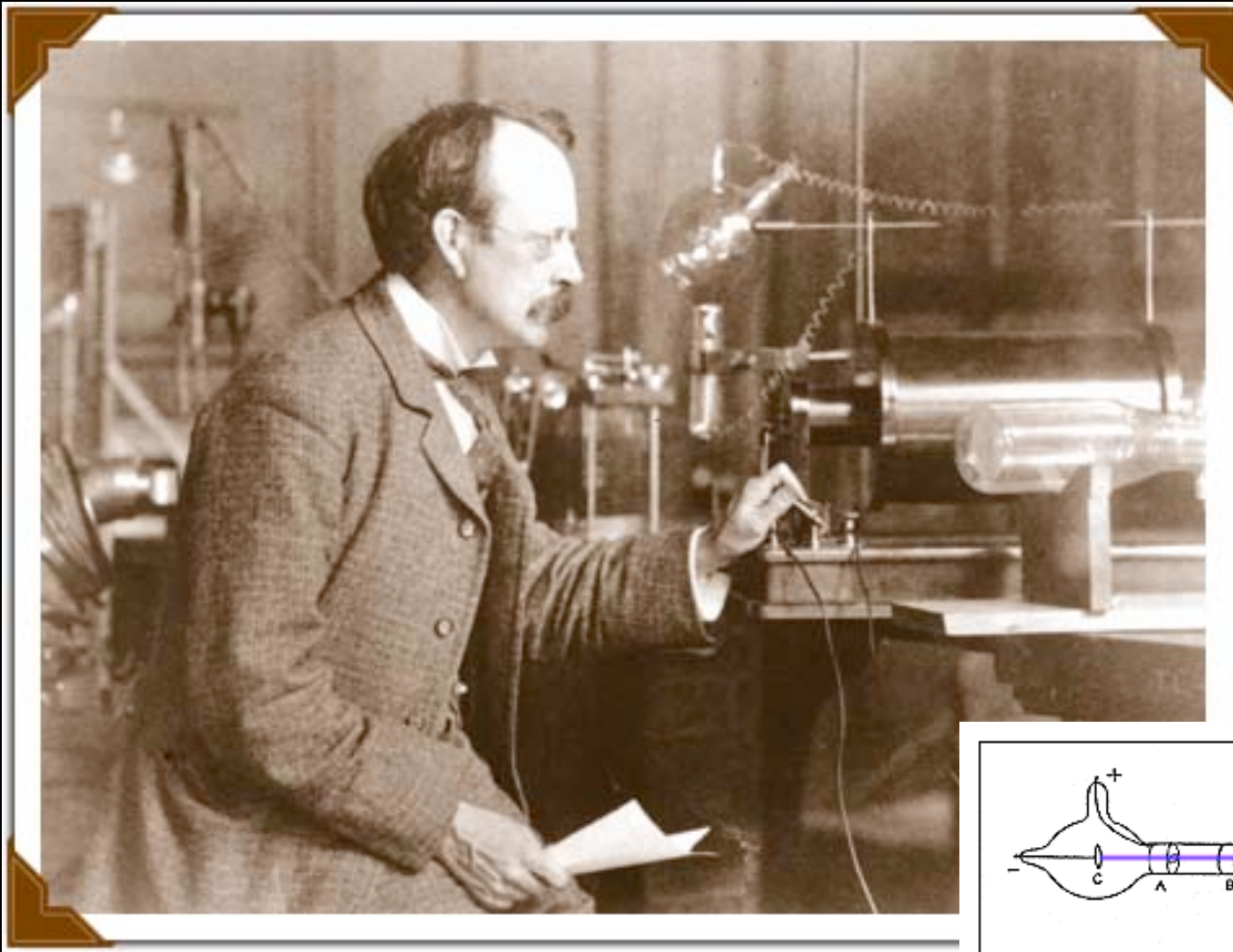
January 25, 2011

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.



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

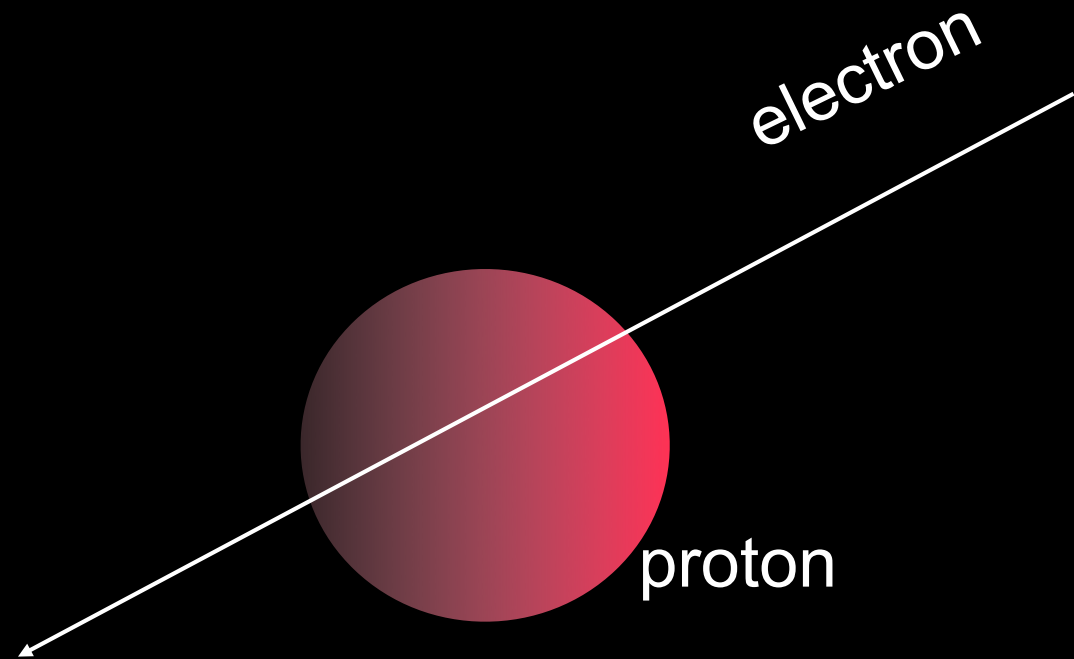
electron linear accelerator
at Stanford (SLAC)



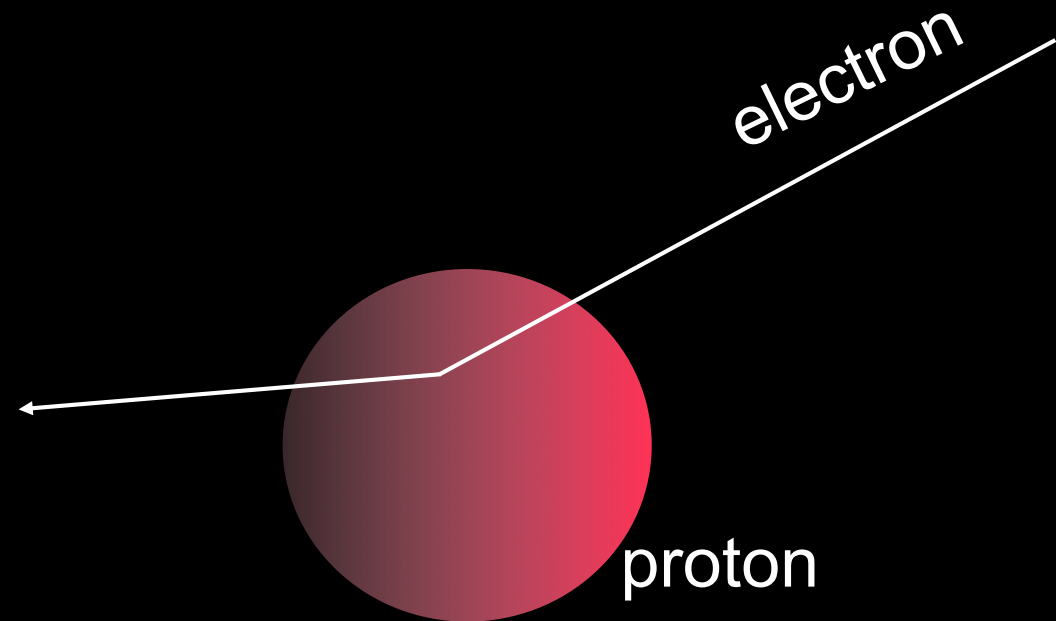
proton synchrotron
at Fermilab (near Chicago)



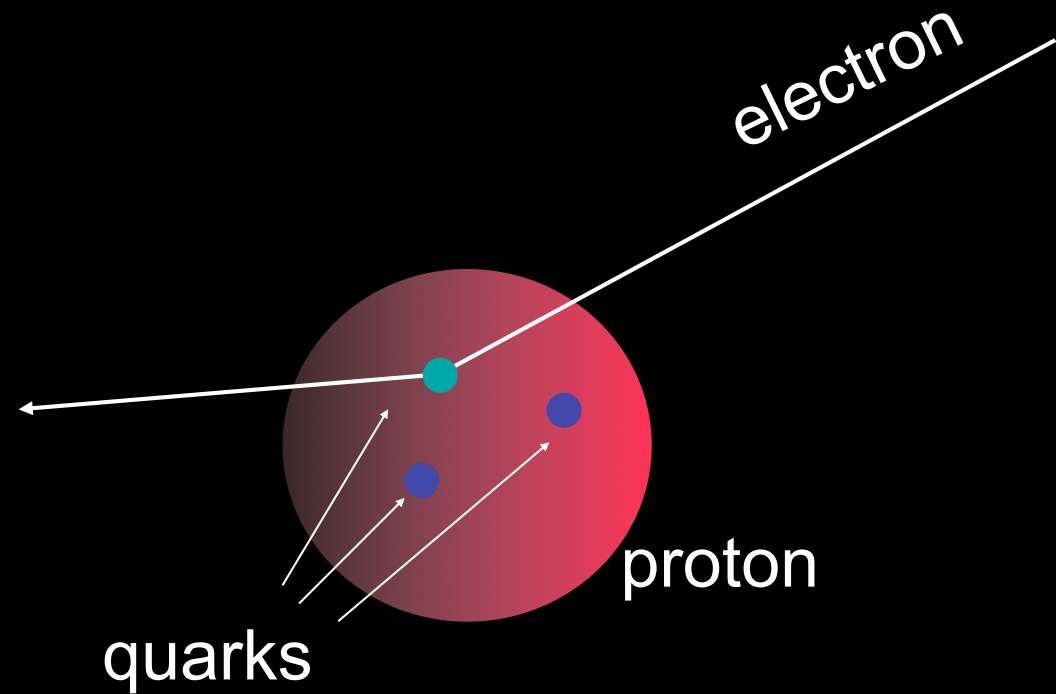
1969



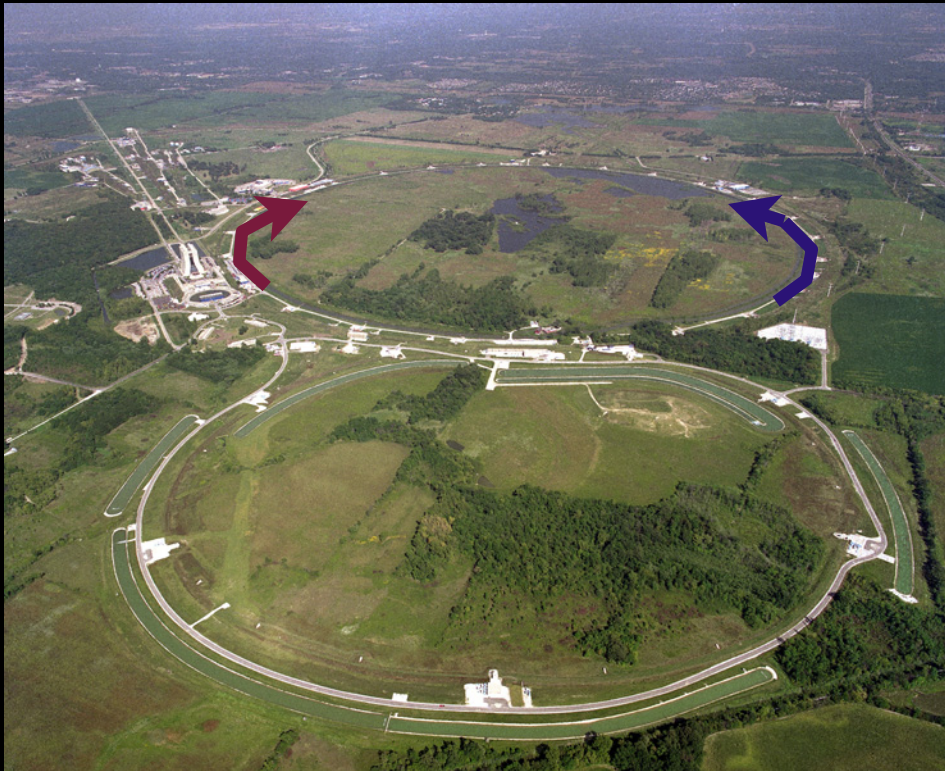
1969



1969 - Quarks discovered (inside atomic nucleus) Stanford



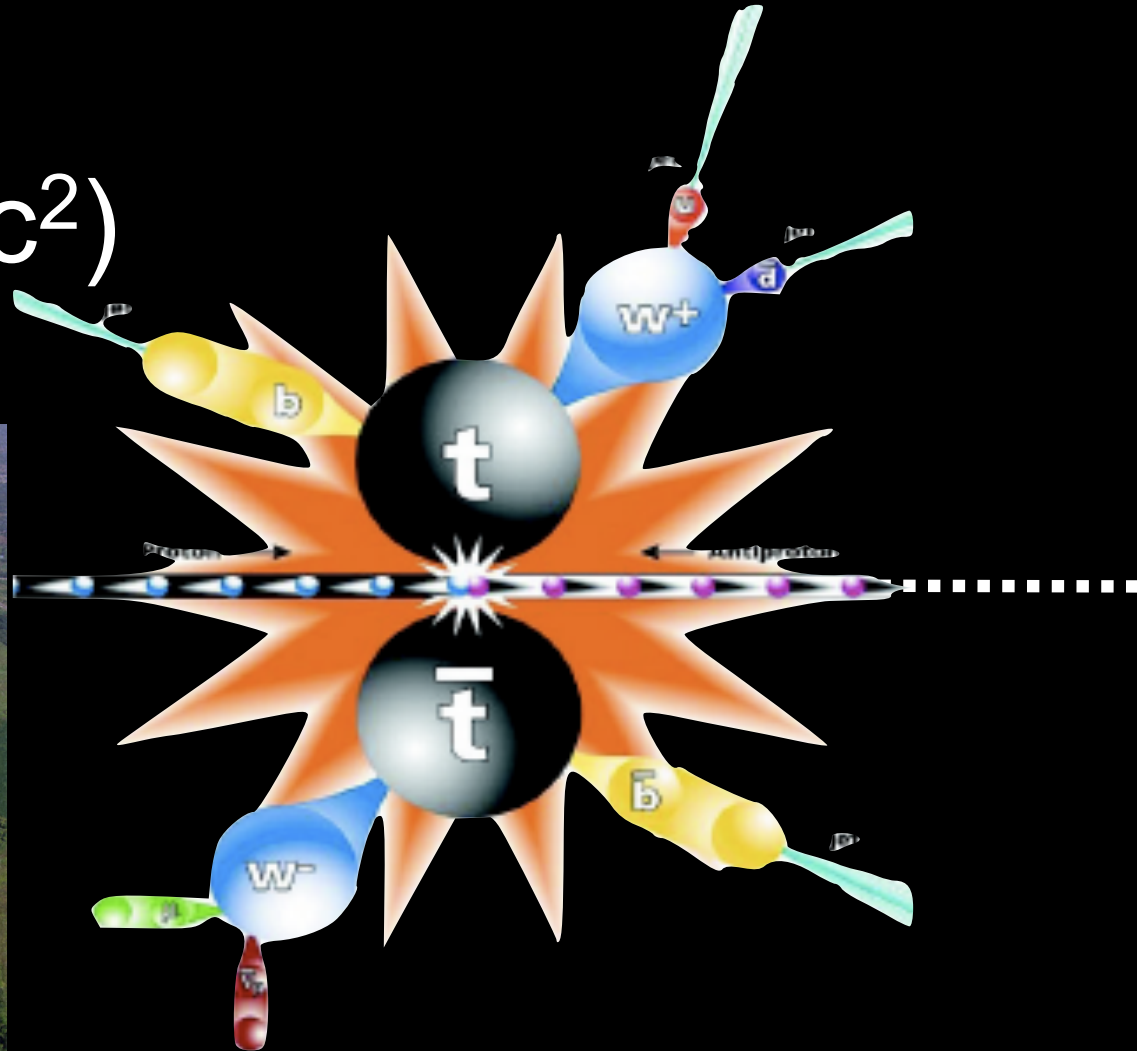
1995 - Top Quark Discovered at Fermilab



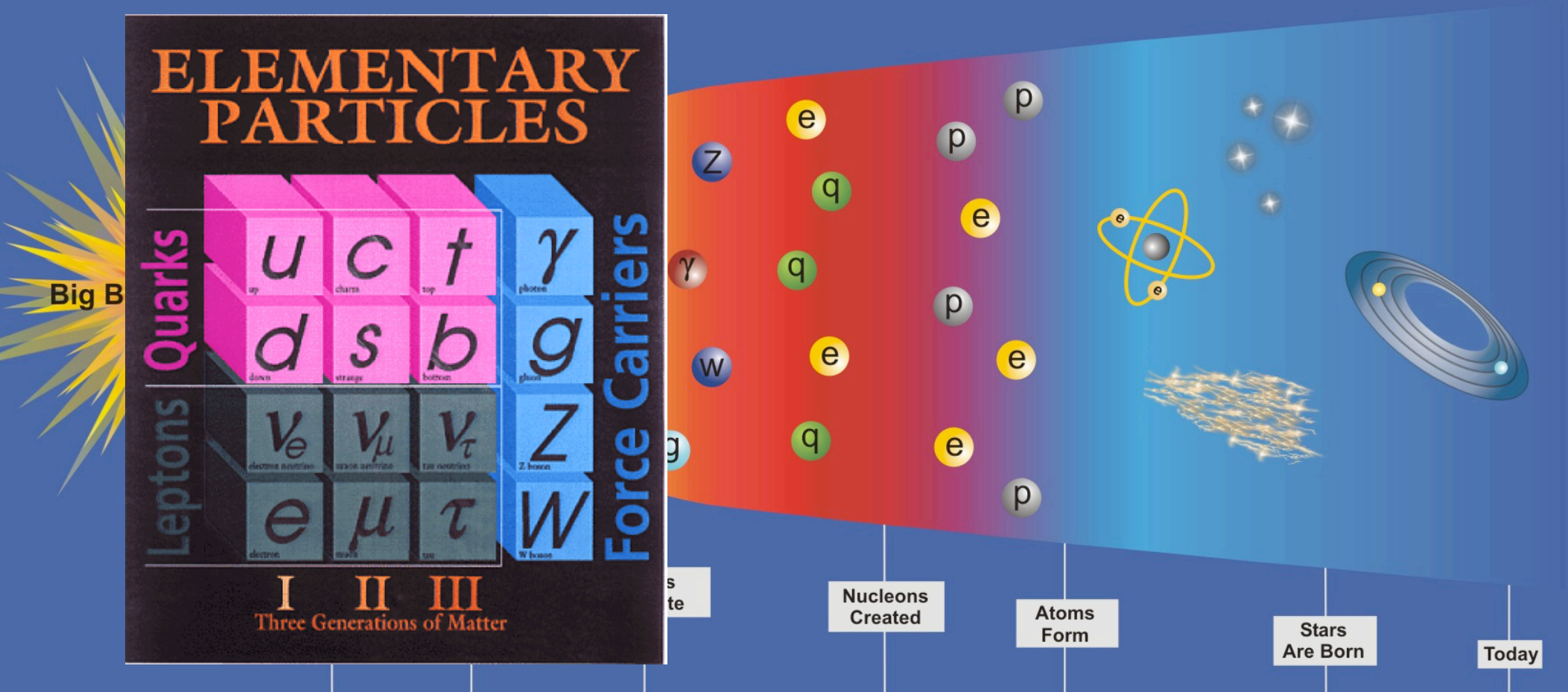
1995 - Top Quark Discovered at Fermilab



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

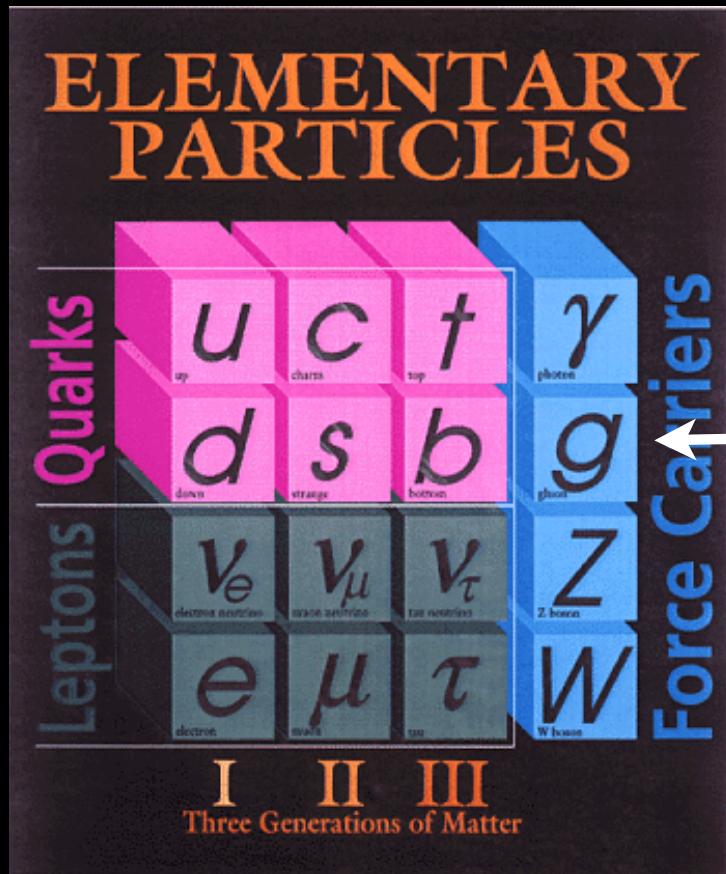


Particles



Particles and Forces

“interactions”



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



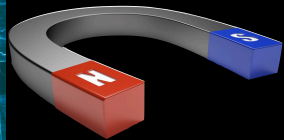
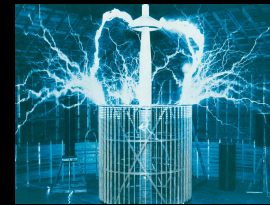
Forces

“interactions”

Are Forces Related?

1850

- Gravity
- Electricity
- Magnetism



Forces

“interactions”

Are Forces Related?

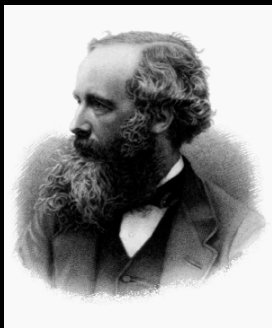
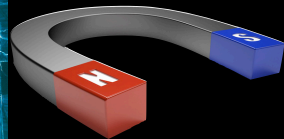
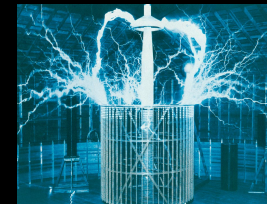
1864

Unified theory

- Electromagnetism
- Light (photons)



- Gravity
- Electricity
- Magnetism



Forces

“interactions”

Are Forces Related?

1950

- Gravity
- Electromagnetism
- Weak Nuclear
- Strong Nuclear



Forces

“interactions”

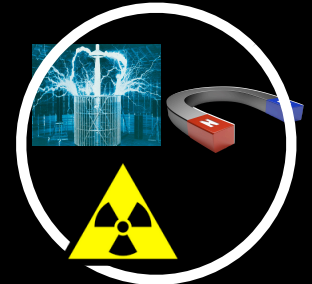
Are Forces Related?

2000

- Gravity

- { • Electroweak

- Strong Nuclear

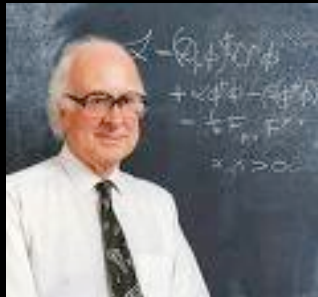


Forces

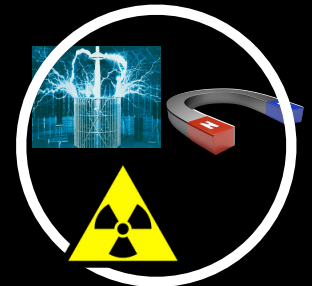
“interactions”

Are Forces Related?

Next Advance Expected
- discovery of
the Higgs Boson
at accelerators



- 2000
- Gravity
- Electroweak
- Strong Nuclear



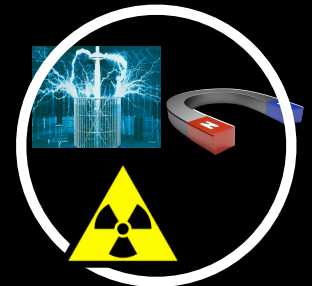
Forces

“interactions”

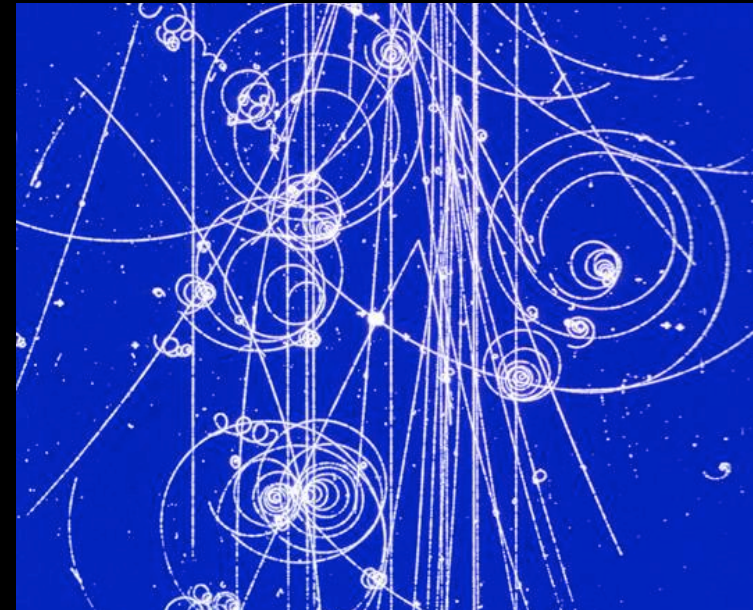
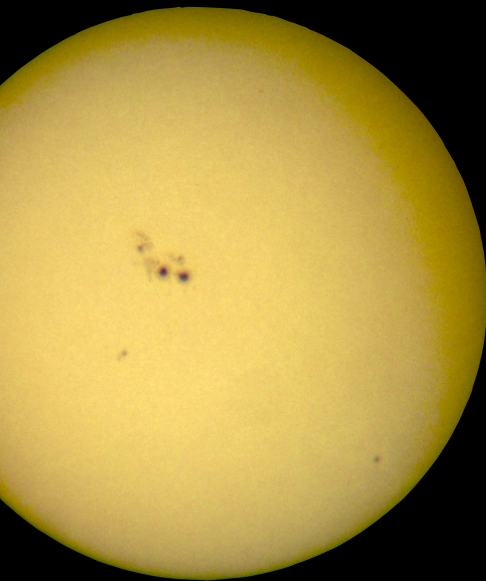
Are Forces Related?

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

- 2000
- Gravity
- Electroweak
- Strong Nuclear



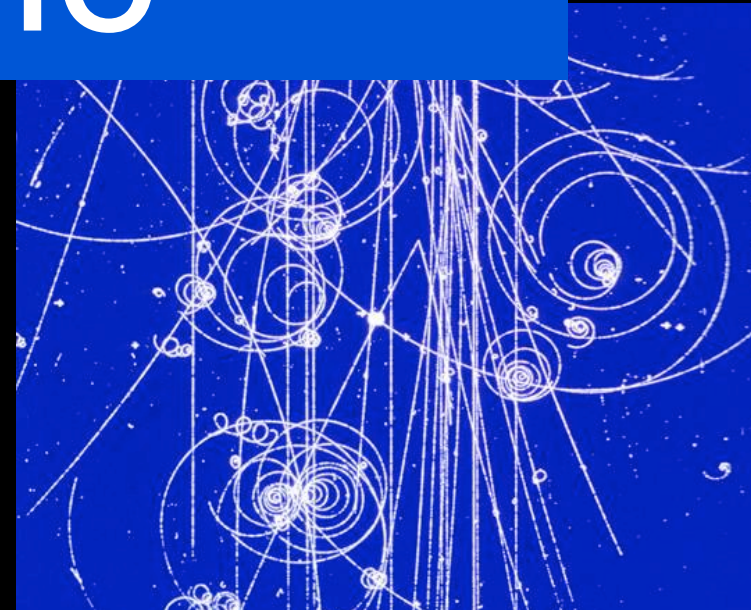
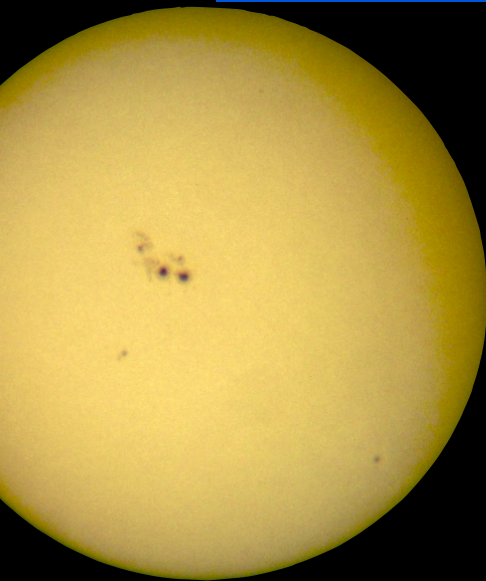
What is Matter?



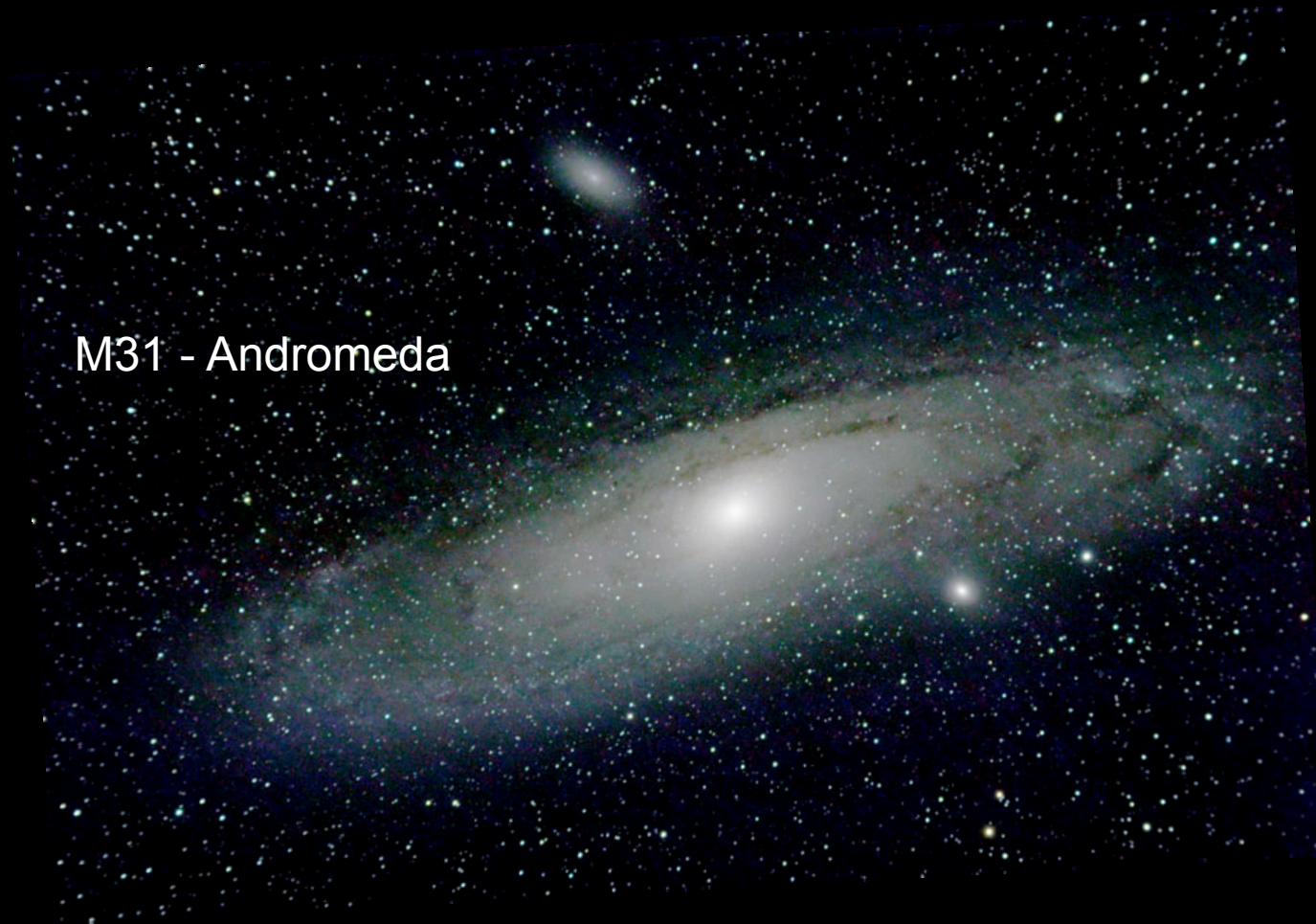
What is Matter?



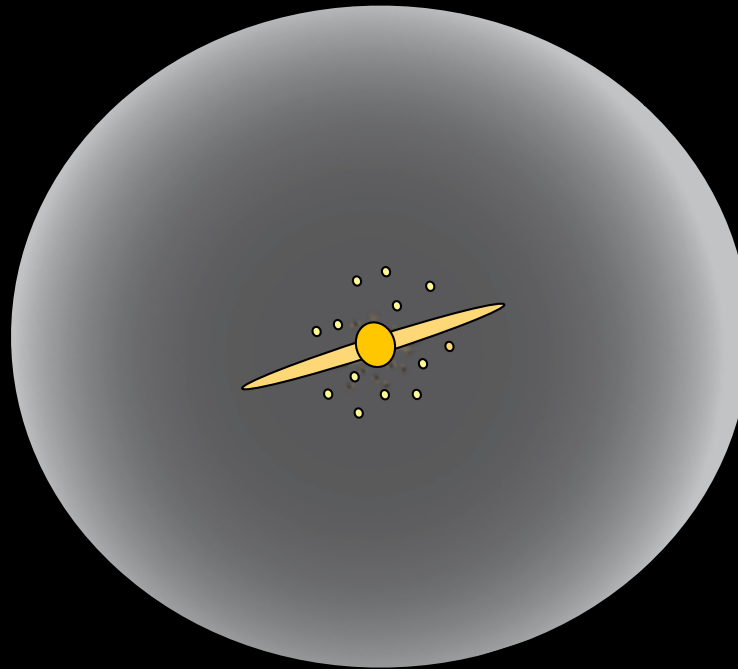
all Atomic



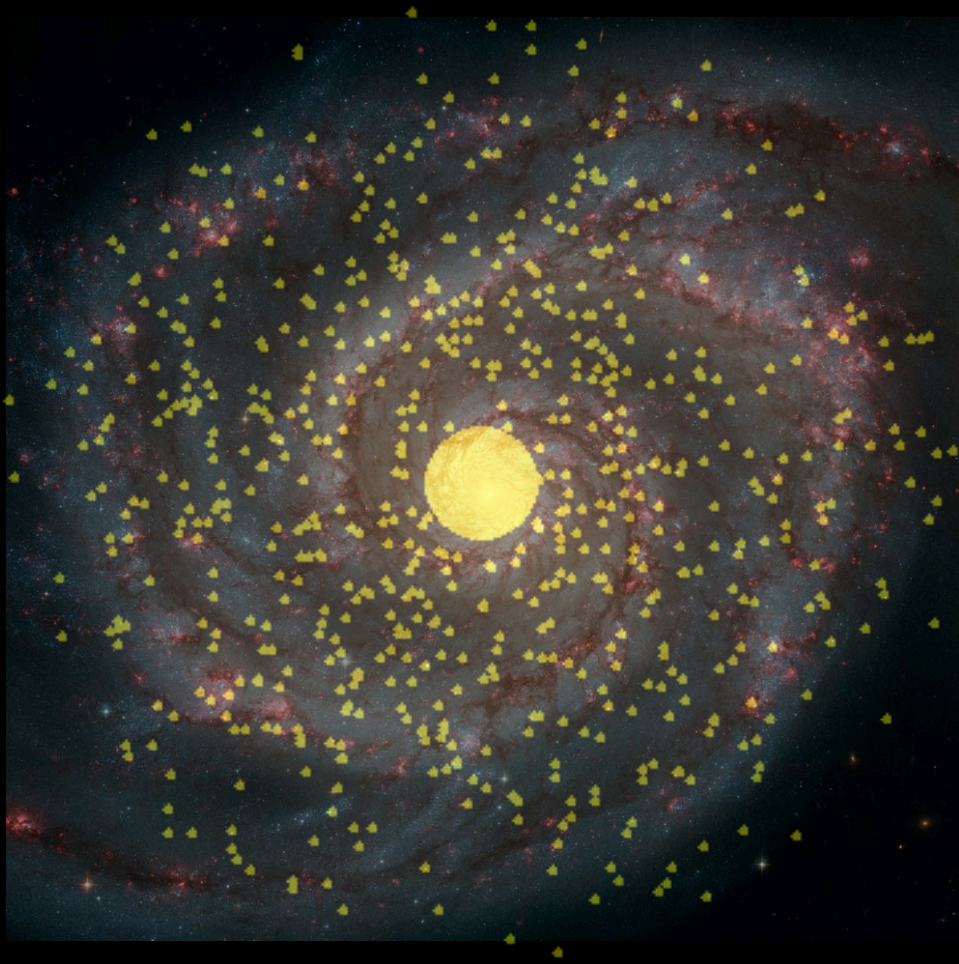
Halo of Dark Matter



Halo of Dark Matter



How we know dark halos surround galaxies?



Expected-
based on stellar mass

Jim Brau



Observed-
reveals invisible ("dark") mass



Vera Rubin
1950s

Astronomy 123

January 25, 2011

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

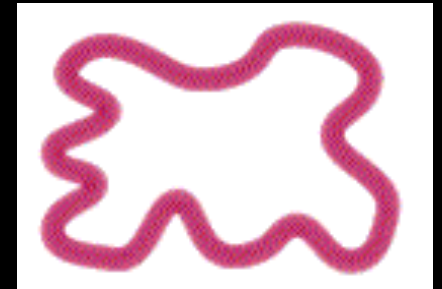
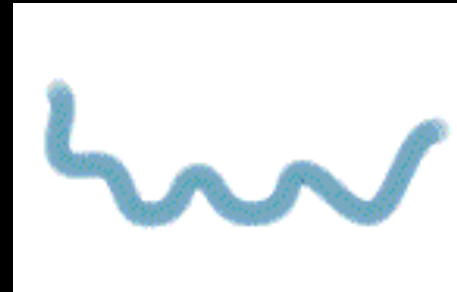


Candidate Theory Explains Dark Matter

SuperString Theory



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



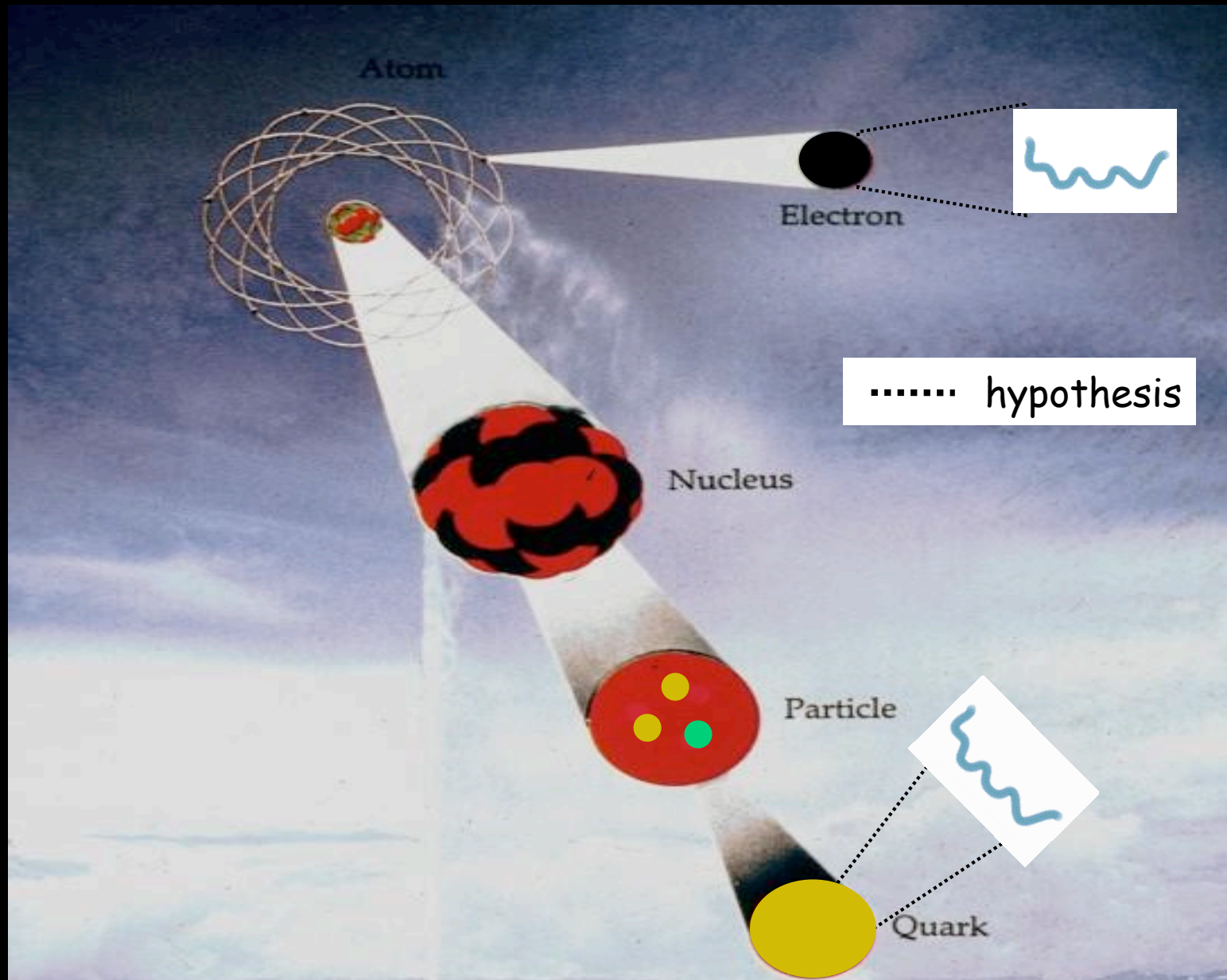
- Strings are miniscule

- 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

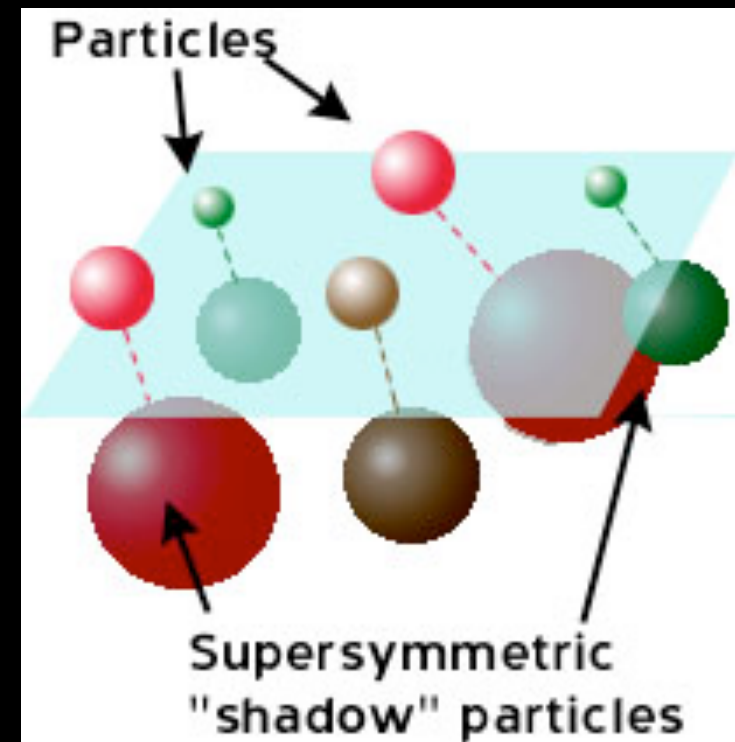
- the super-partners of ordinary particles

The Structure of Matter

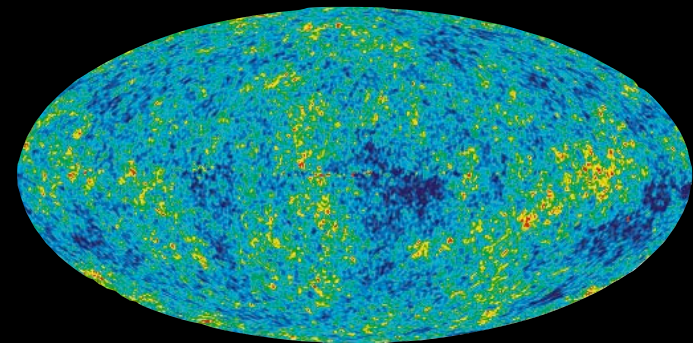


Supersymmetry, Strings, and Dark Matter

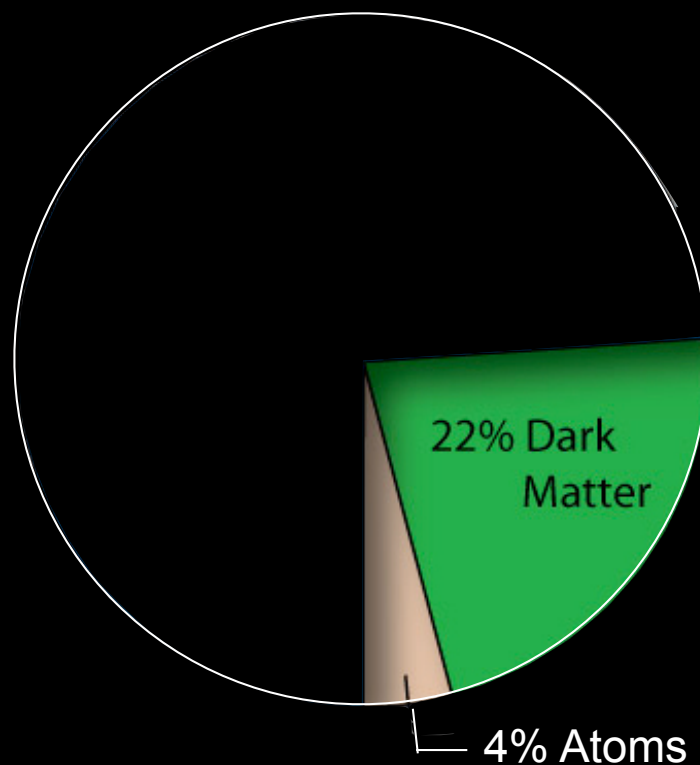
- History repeats?
- Just as with anti-matter,
New particles are predicted
- The supersymmetric particles
have just the properties
expected of Dark Matter



The Matter Crisis



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



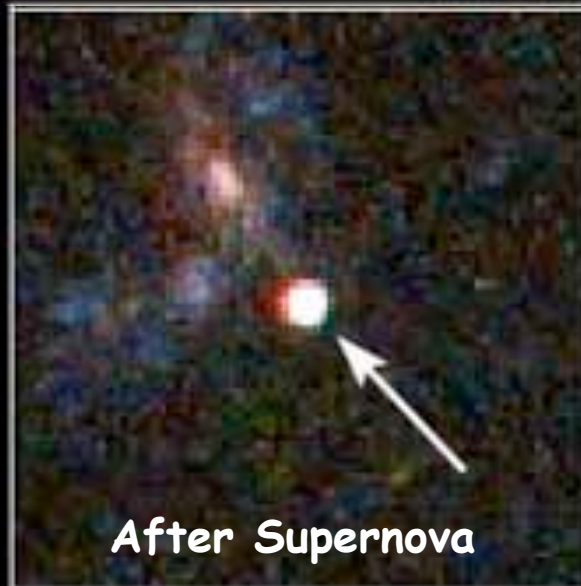
This pie represents all the “stuff” in the universe

Measuring Expansion of Universe

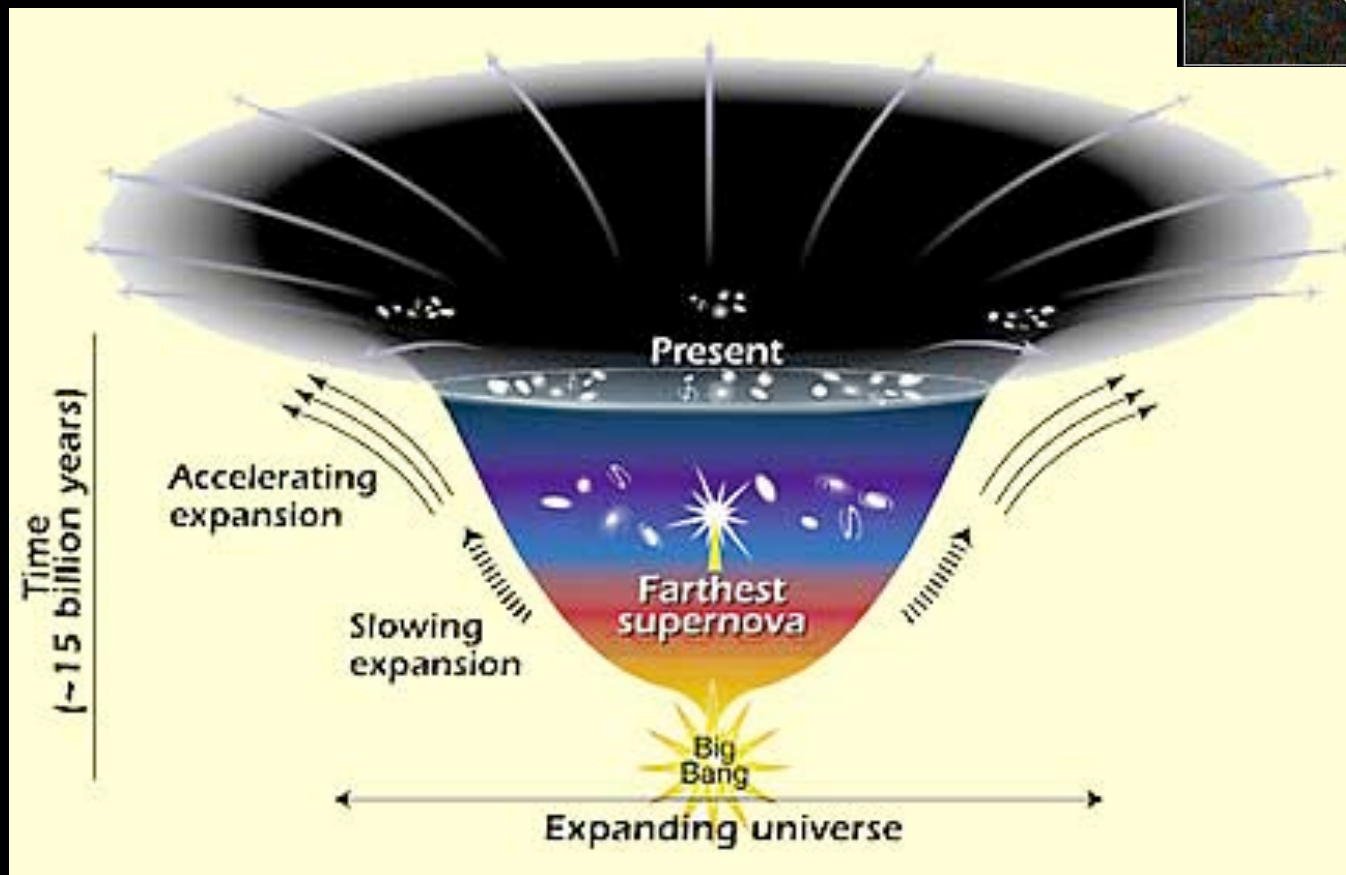
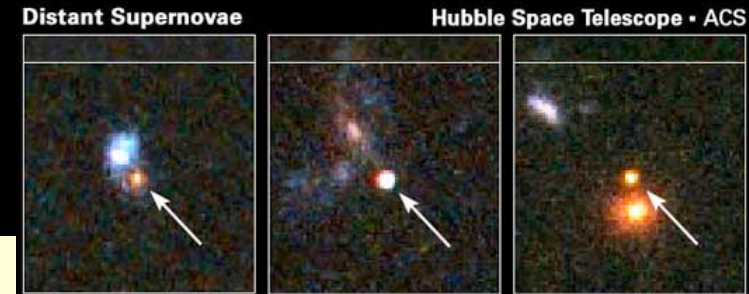
Distant Supernovae



Hubble Space Telescope - ACS



Measuring Expansion of Universe

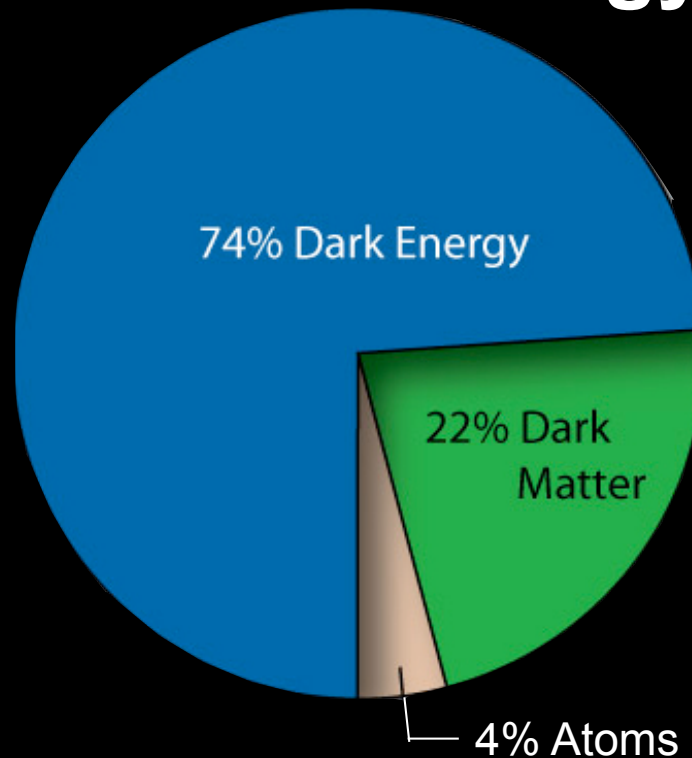


Expansion of
the Universe
is
Accelerating

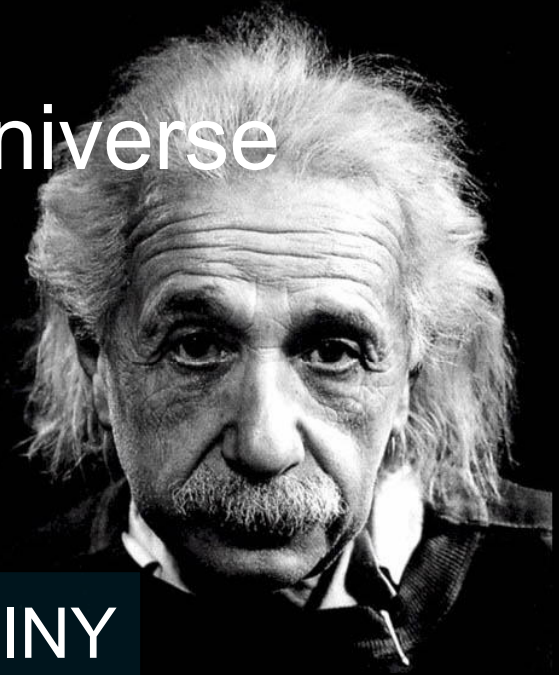
Driven by
Dark Energy

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

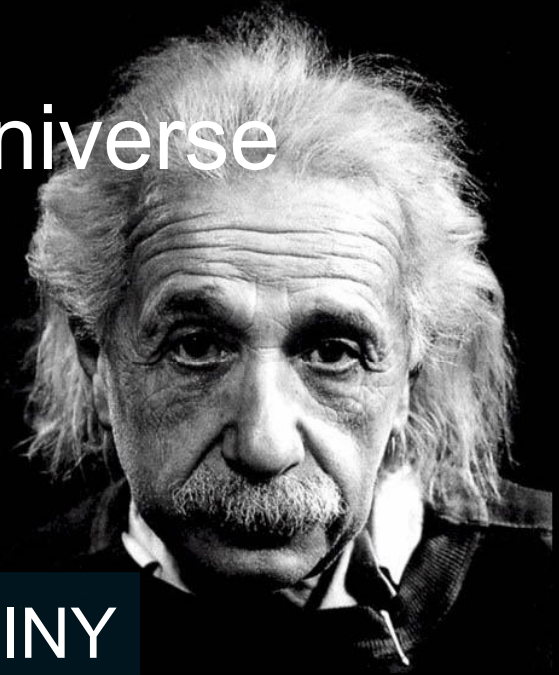


Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY



The Dark Side Controls the Universe

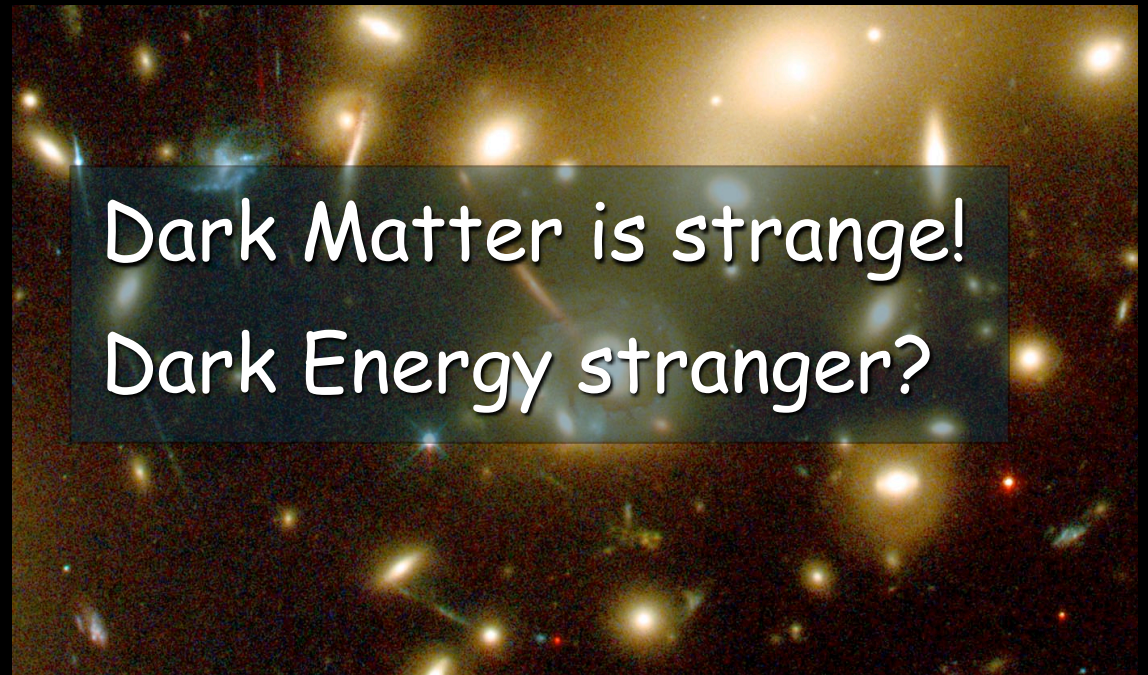


Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY



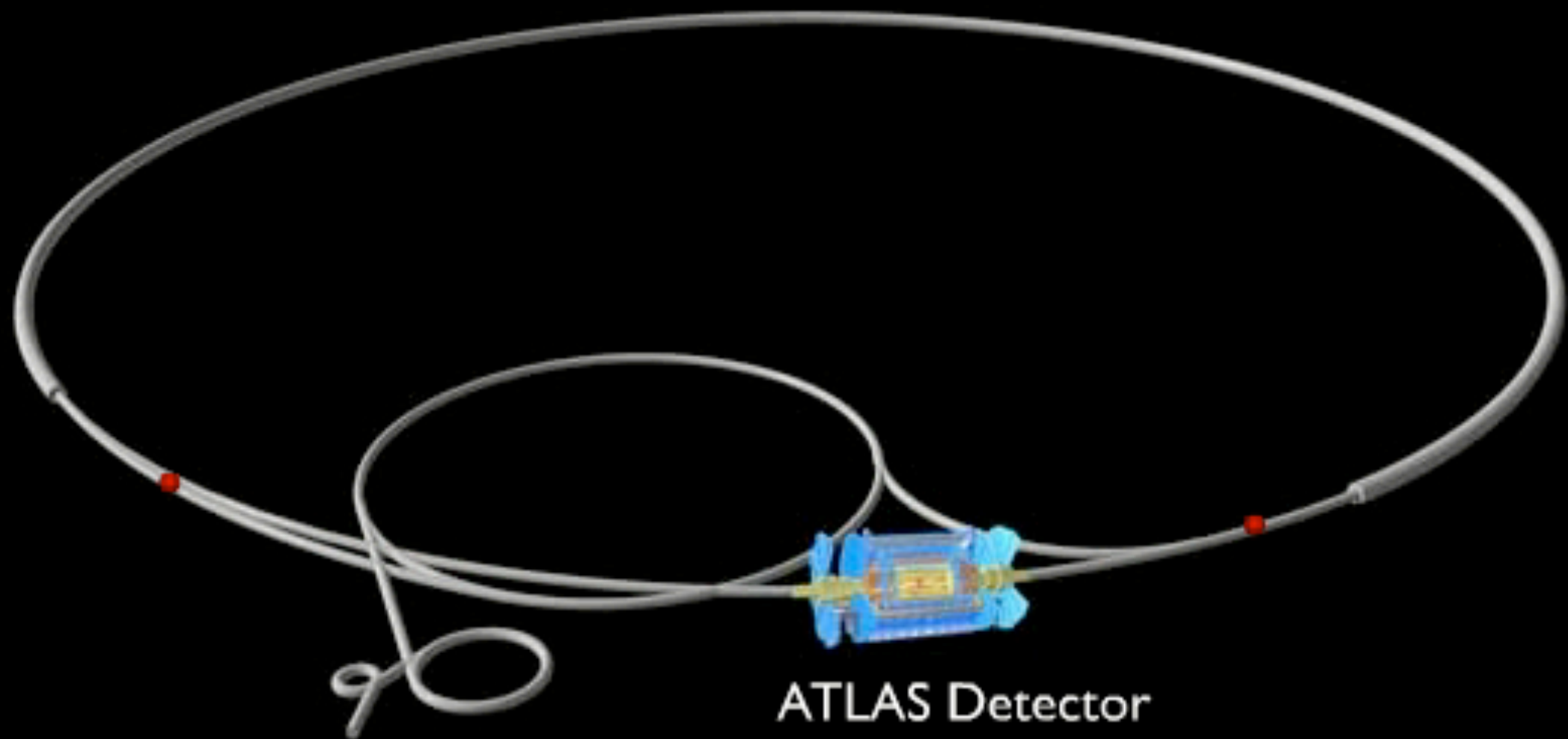
Dark Matter is strange!
Dark Energy stranger?



Large Hadron Collider (LHC) Geneva, Switzerland



Large Hadron Collider



Large Hadron Collider (LHC) Geneva, Switzerland

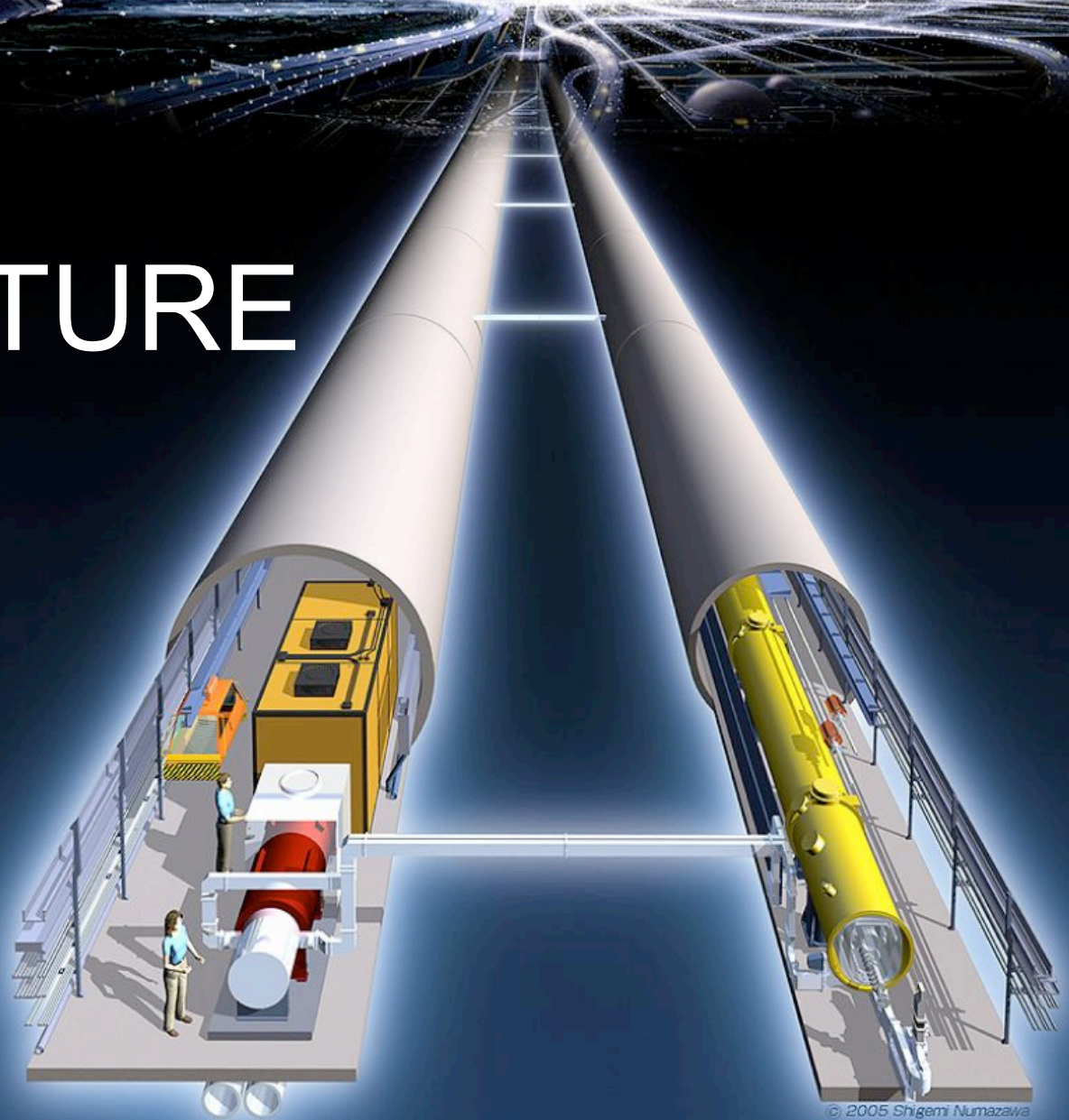
Operating since
2009

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

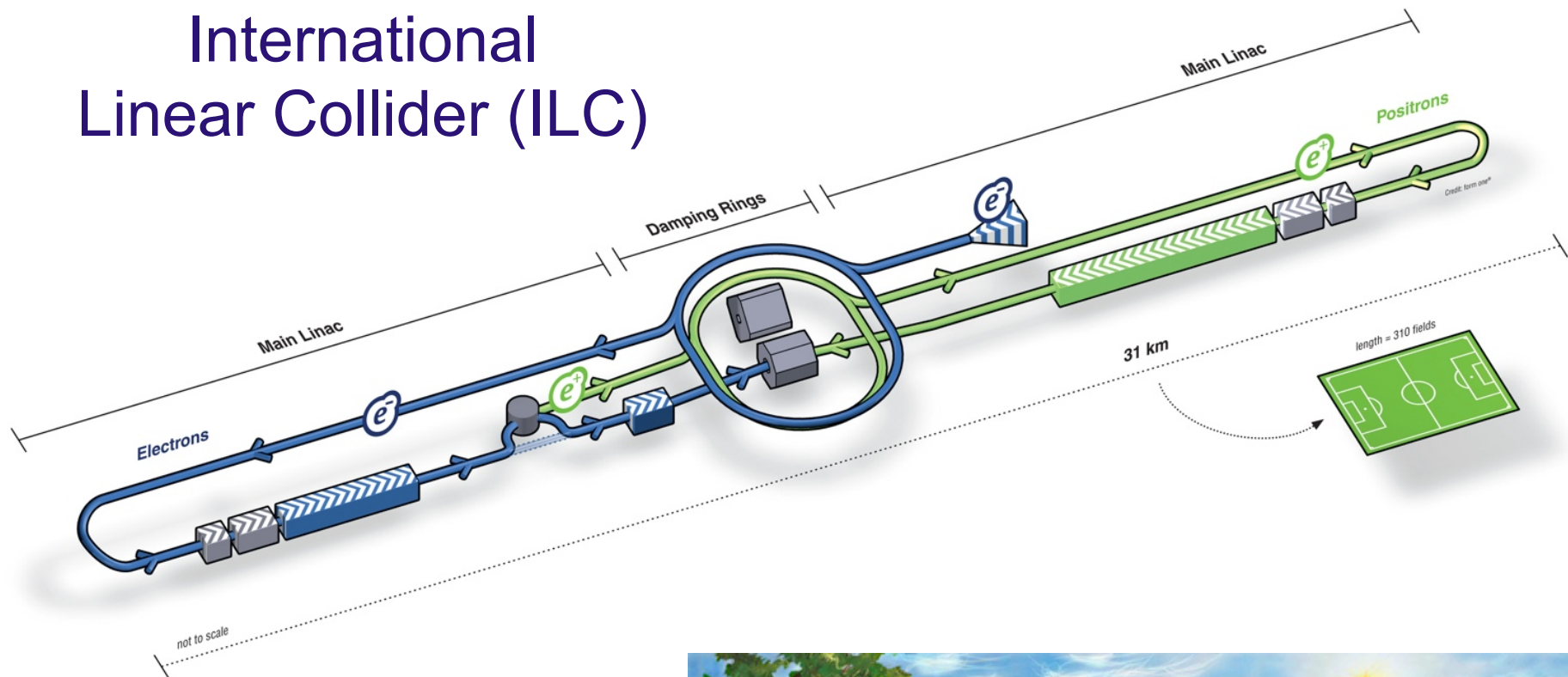


Linear Collider

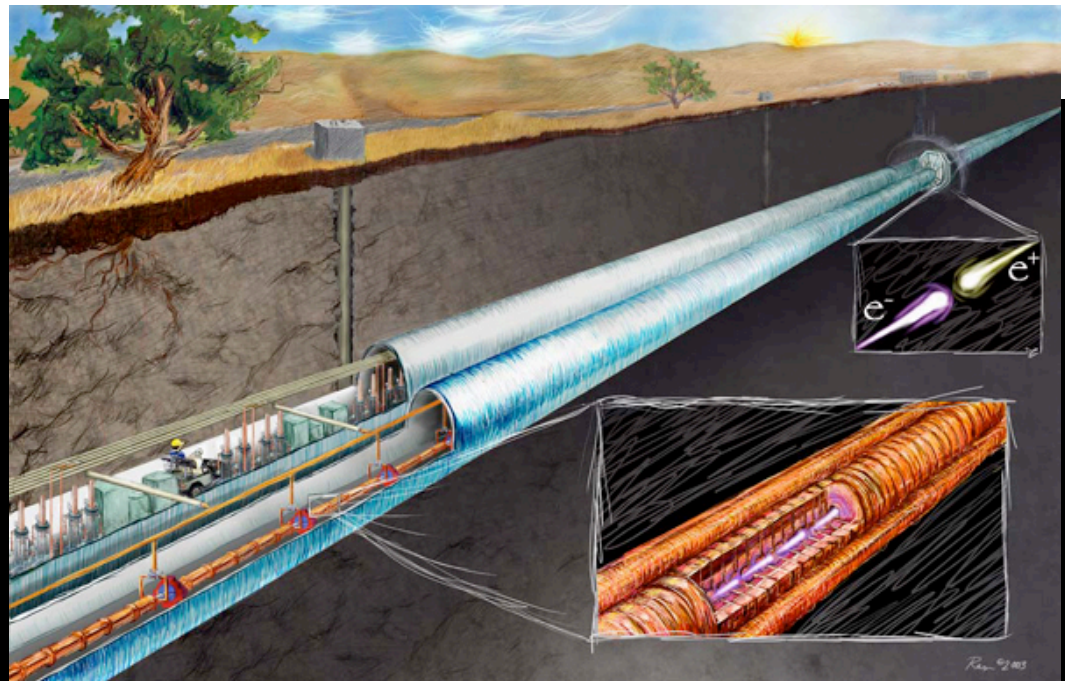
FUTURE



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)