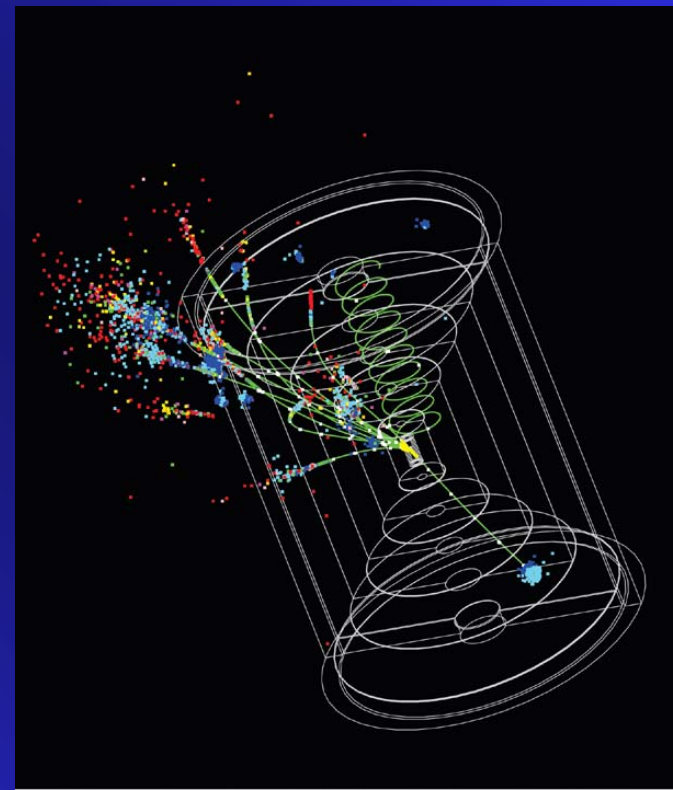


REALIZING EINSTEIN'S DREAM

Exploring Our Mysterious Universe



Jim Brau - Univ. of Oregon

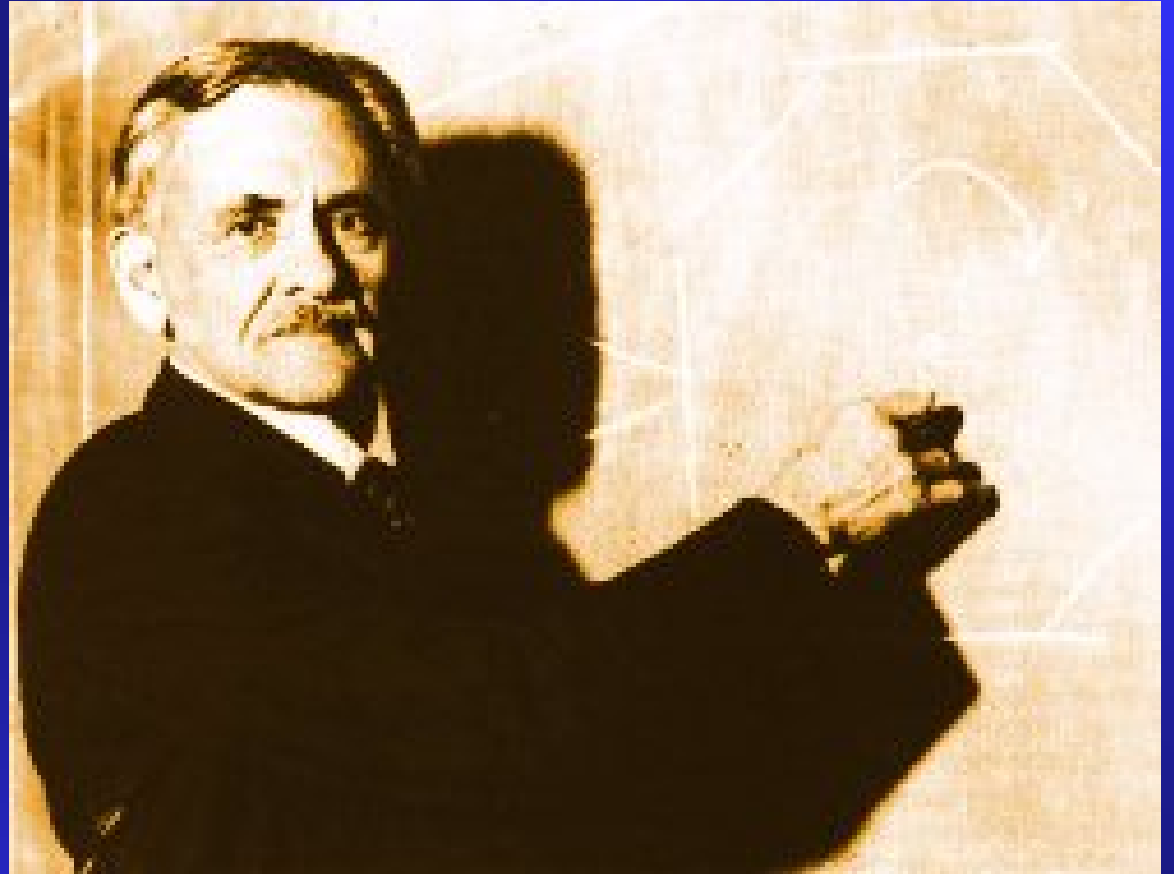


Bend, Oregon

August 10, 2006

The End of Physics

Albert A. Michelson,
at the dedication of
Ryerson Physics Lab,
U. of Chicago, 1894



The Miracle Year - 1905

Relativity
Quantum Physics
Atoms

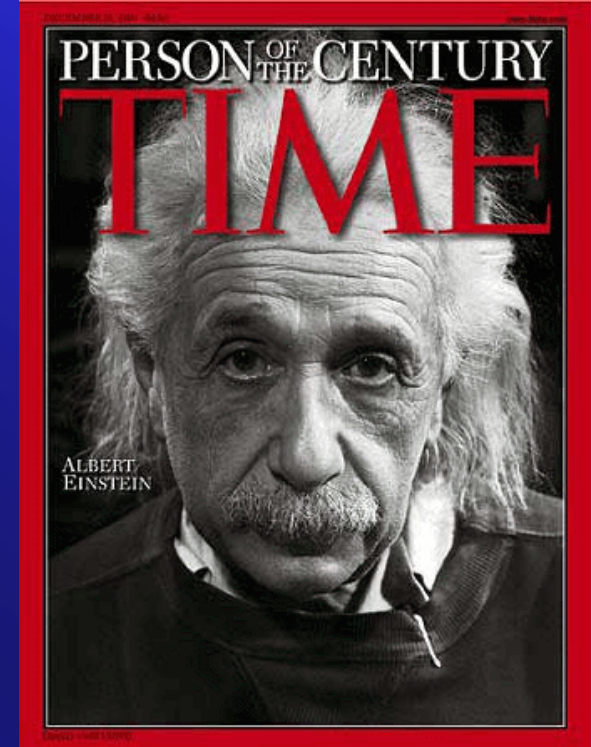
1915 -

General Theory of Relativity,
the theory of gravity,
based on warped space



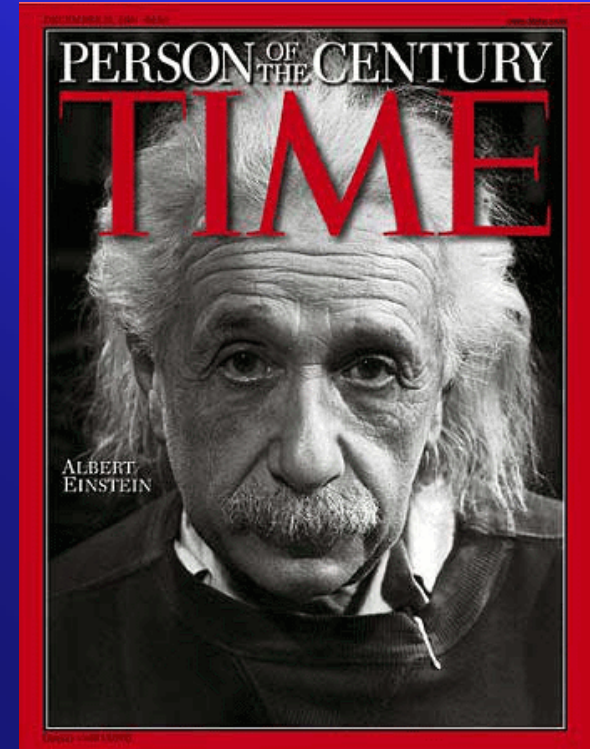
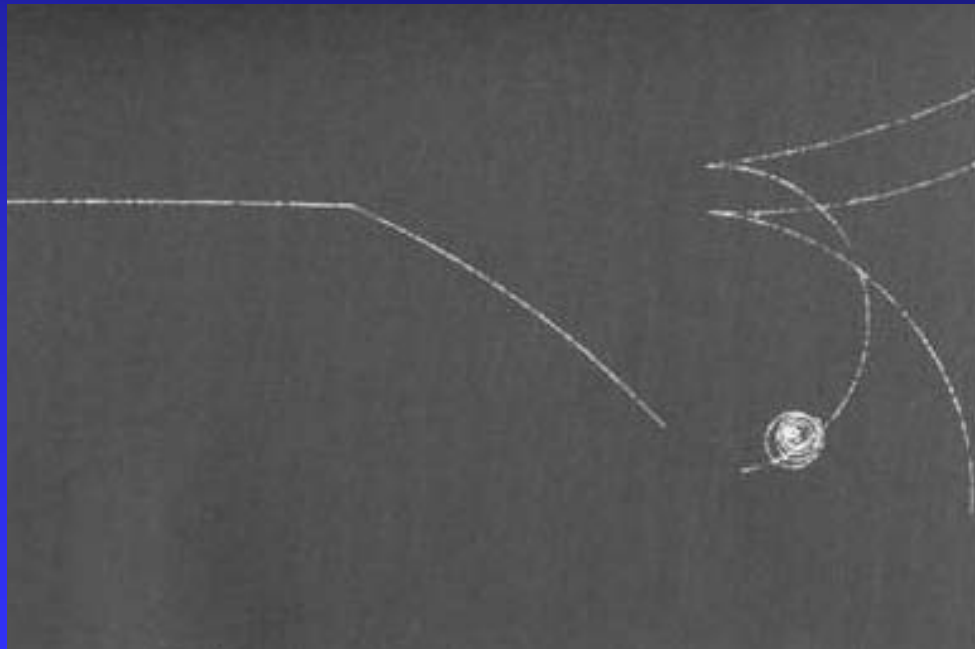
Einstein's Theoretical Discoveries

- Light comes in small packets - photons
- The speed of light is a constant
 - Independent of observer's motion



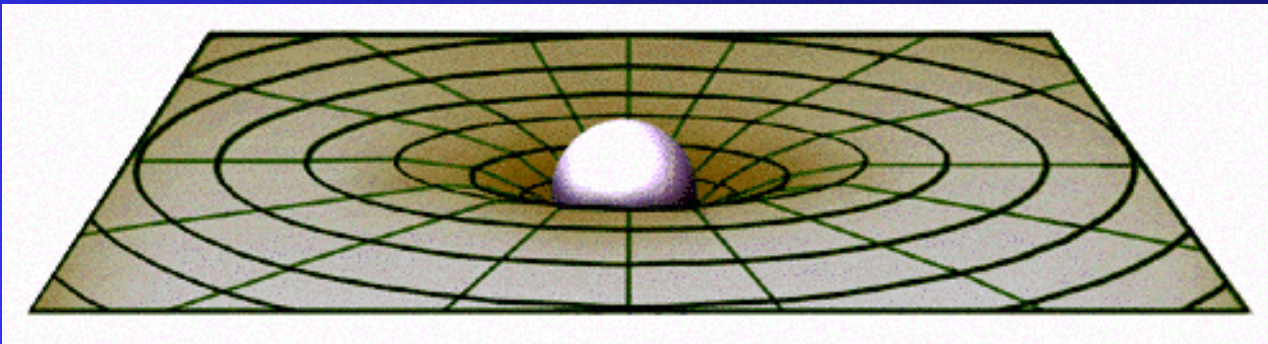
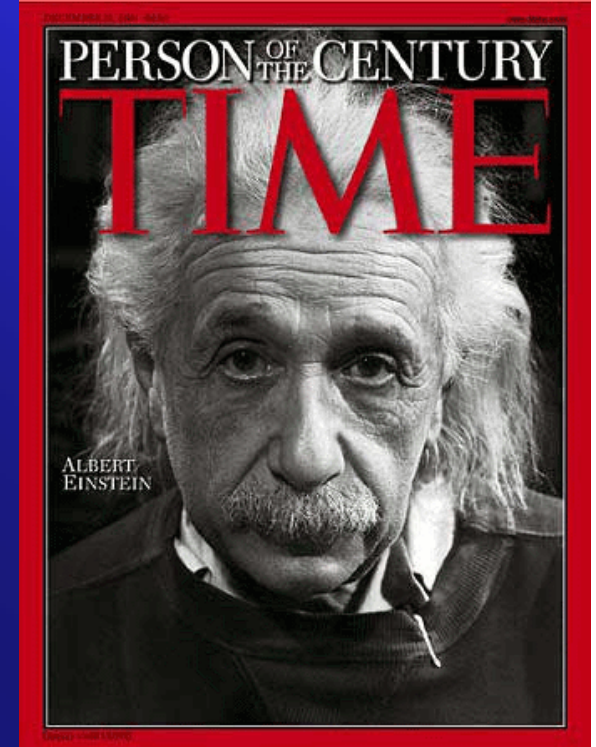
Einstein's Theoretical Discoveries

- Light comes in small packets - photons
- The speed of light is a constant
 - Independent of observer's motion
- $E=mc^2$



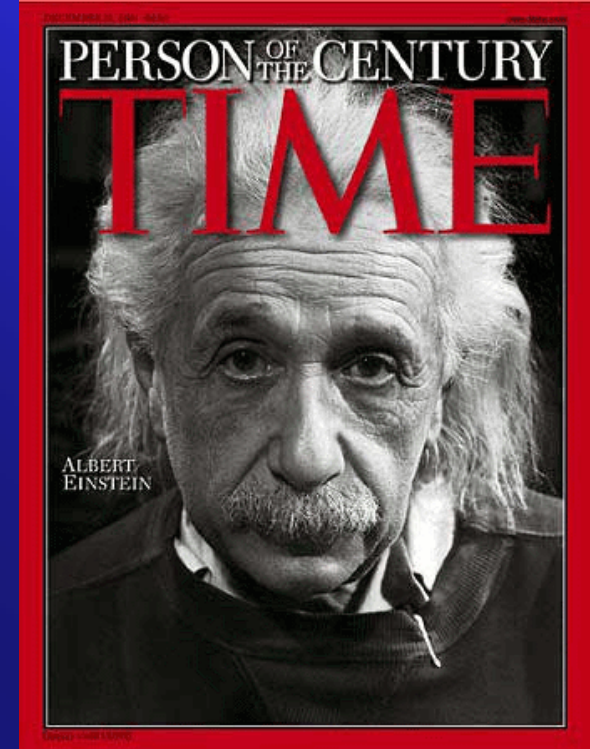
Einstein's Theoretical Discoveries

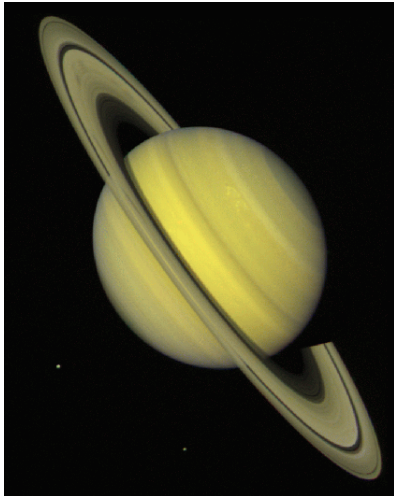
- Light comes in small packets - photons
- The speed of light is a constant
 - Independent of observer's motion
- $E=mc^2$
- Space is warped by massive objects



Einstein's Theoretical Discoveries

- Light comes in small packets - photons
 - The speed of light is a constant
 - Independent of observer's motion
 - $E=mc^2$
 - Space is warped by massive objects
 - "Cosmological constant"
 - Many other important discoveries
-
- Remain central to our exploration of the universe





Einstein's Dream

To understand the underlying simplicity behind the vast complexities of Nature



Suspected gravity was a key



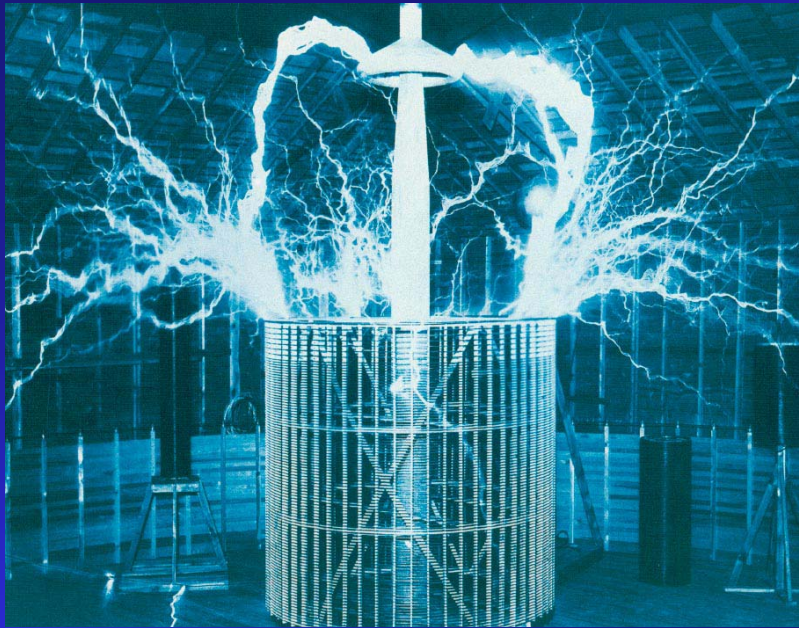
Jim Brau - Univ. of Oregon



Bend, Oregon

August 10, 2006

Unification - Einstein's Dream



Understand how nature's forces are related

electromagnetism and gravity

strong nuclear force

weak nuclear force

Einstein's Dream Today

- Today, STRING THEORY
 - Unifies all forces
 - Overcomes inconsistencies between gravity and quantum mechanics
 - Ultimate Explanation?
 - from the tiniest quanta to the cosmos
 - The Dream Lives On
 - Needs experimental verification
-
- There are encouraging signs that success is near



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Willamette Hall



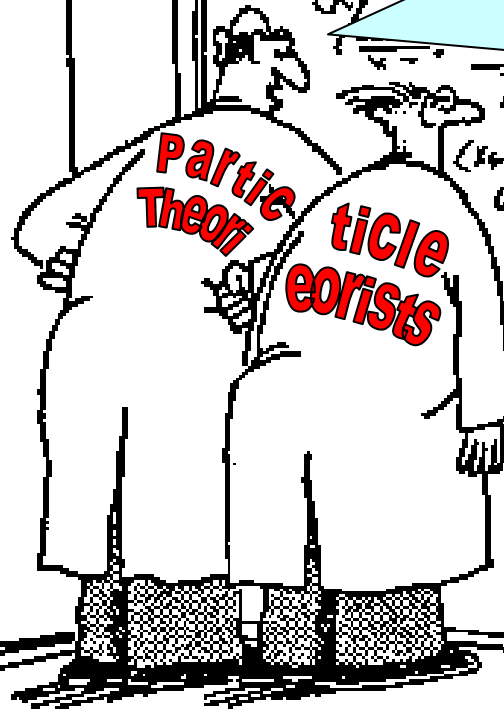
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Bend, Oregon

August 10, 2006

Willamette



No doubt about it Desh - we've mathematically expressed the purpose of the universe.

Gad, how I love the thrill of scientific discovery.

The Next Revolution

Today on the threshold of a revolution in understanding of the Universe

Recent discoveries

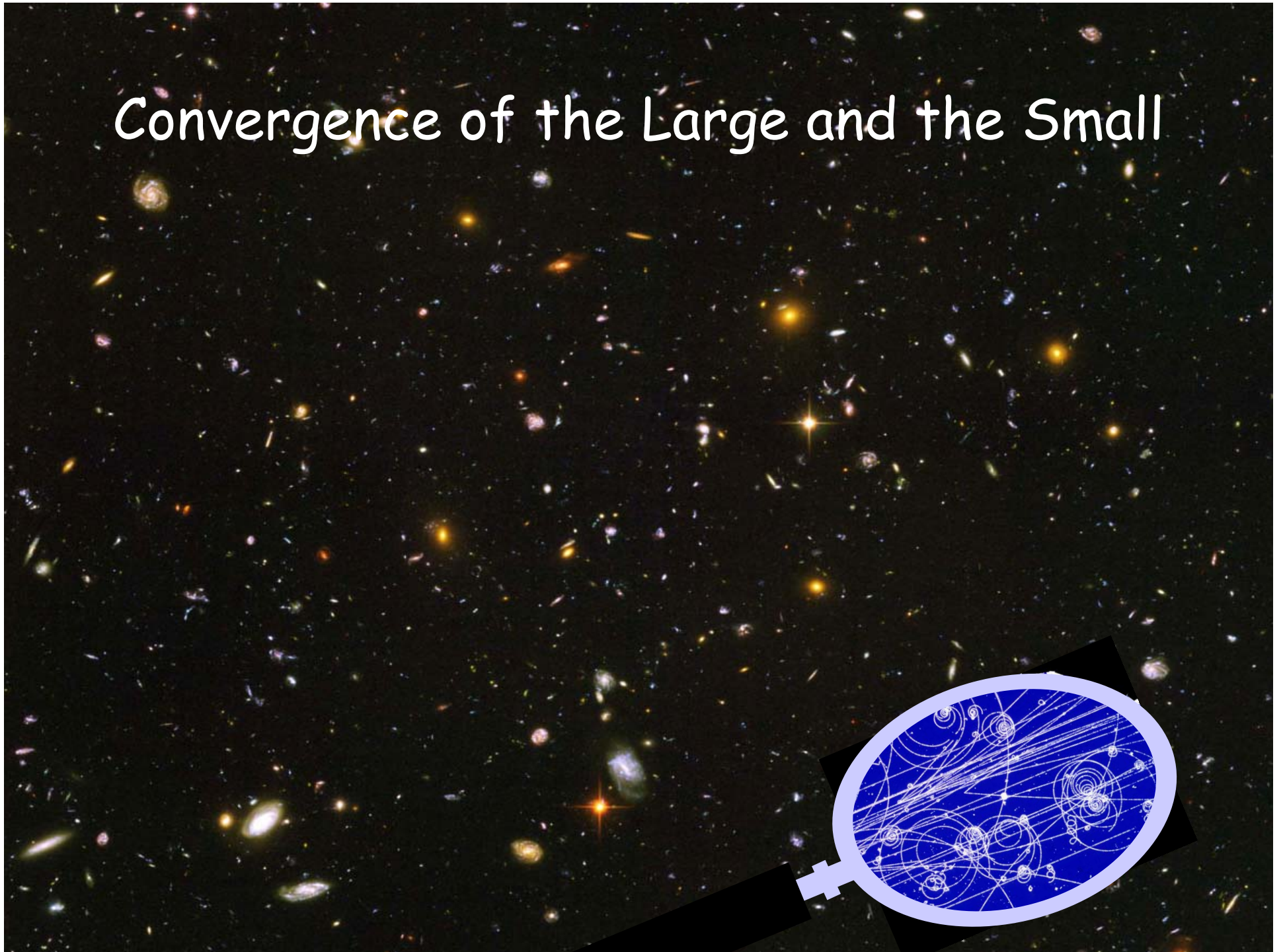
and powerful set of tools:



The Frontier Now

- What is the universe made of?
 - Ordinary matter and the known forces? Or more?
- How does it work?
 - From the sub-atomic to the cosmic scale
- How many spatial dimensions are there?
 - Just 3, or more (hidden dimensions)
- Why does matter have mass?
- What was the Big Bang?

Convergence of the Large and the Small



Mysteries of the Universe

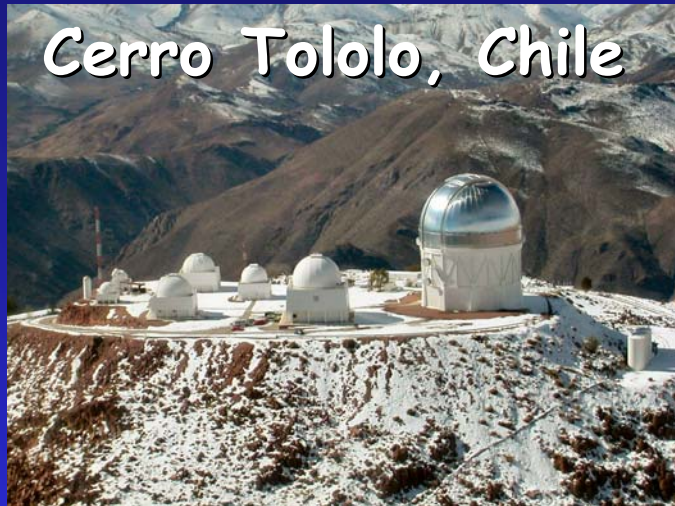
- Quarks
- Leptons
- Higgs Bosons
- Supersymmetric Particles
- SuperString Theory
- Dark Matter
- Dark Energy and the "cosmological constant"
- Accelerating Universe
- Gravity Waves
- Extra Dimensions

Modern scientific instruments



Pine Mountain Observatory

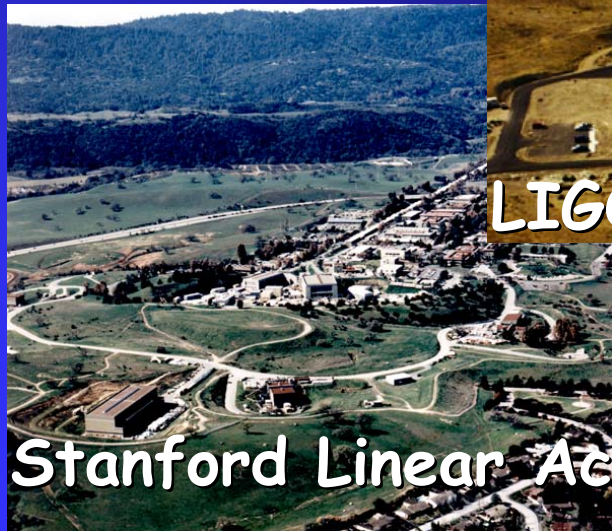
Modern scientific instruments



Cerro Tololo, Chile



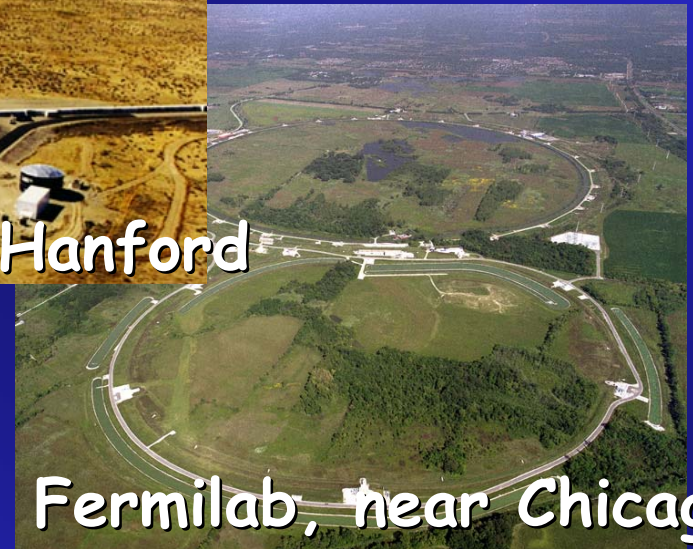
Hubble Space Telescope



Stanford Linear Accelerator



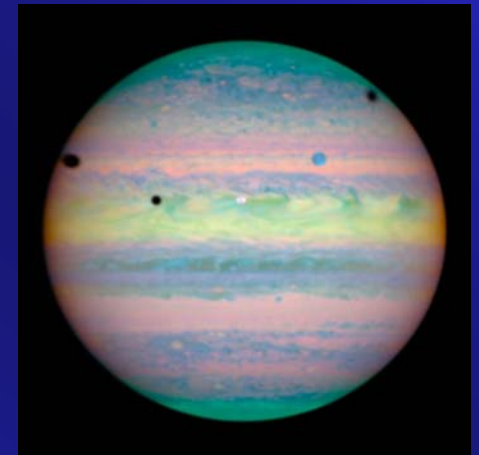
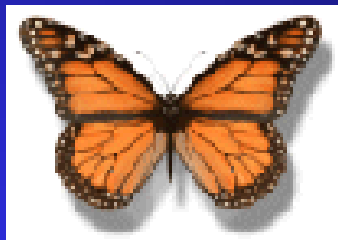
LIGO Laboratory, Hanford



Fermilab, near Chicago

What is matter?

- All matter we are familiar with is composed of atoms, or parts of atoms
 - Living things - butterflys, elephants, people ...
 - Inanimate things - rocks, watches, cannonballs ...
 - Astrophysical objects - planets, moon, stars, asteroids ...





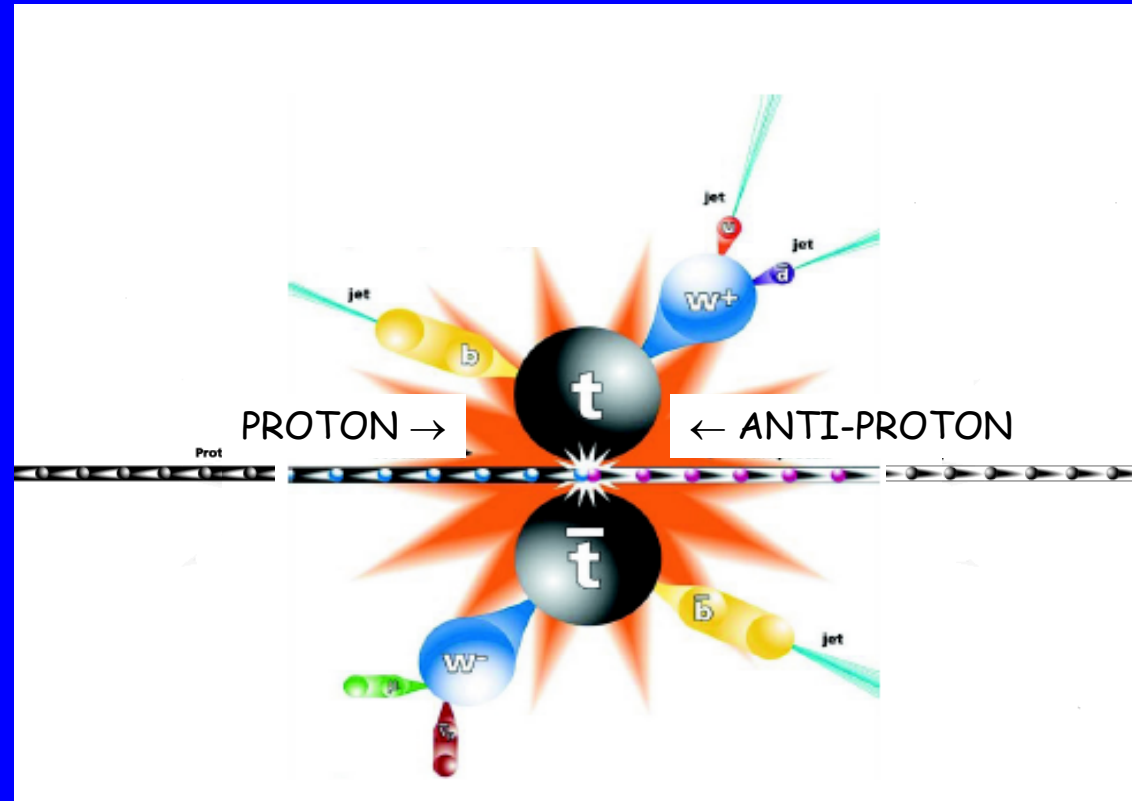
Even cosmic rays!

The image displays a dense network of white lines on a dark blue background, representing particle tracks. These tracks include straight lines, spirals, and complex, overlapping paths, suggesting the interaction and deflection of particles like cosmic rays. The overall appearance is that of a particle detector's output, such as a bubble chamber or cloud chamber photograph.



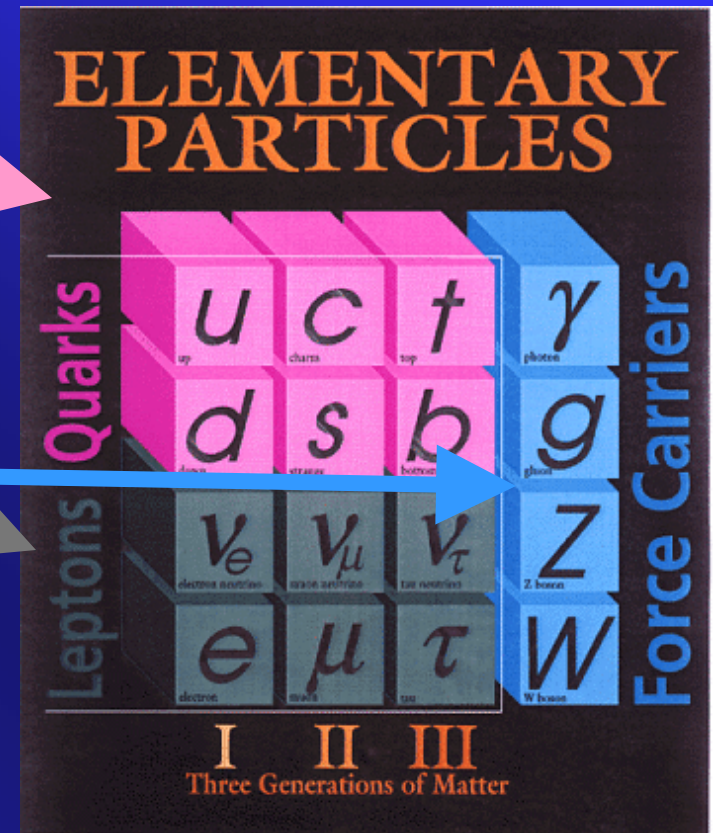
What is Matter?

Particle collider experiments
detailed understanding of matter
and how it behaves



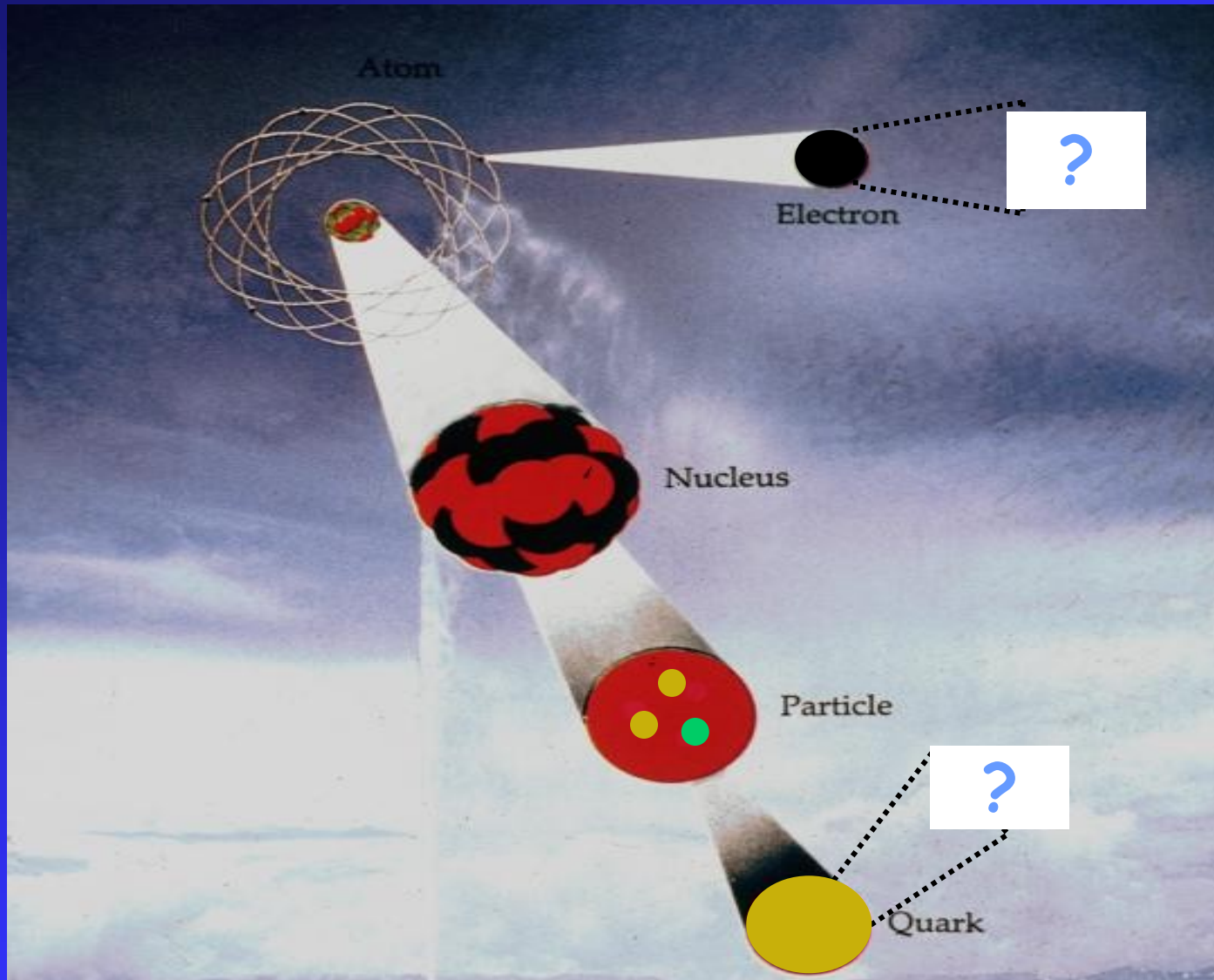
What is matter?

- **Quarks**
 - combine to make protons and neutrons
- **Leptons**
 - eg. electron, neutrino
- **Force Carriers**
 - defines behavior of matter



We have a precise understanding of matter and its behavior

The Structure of Matter

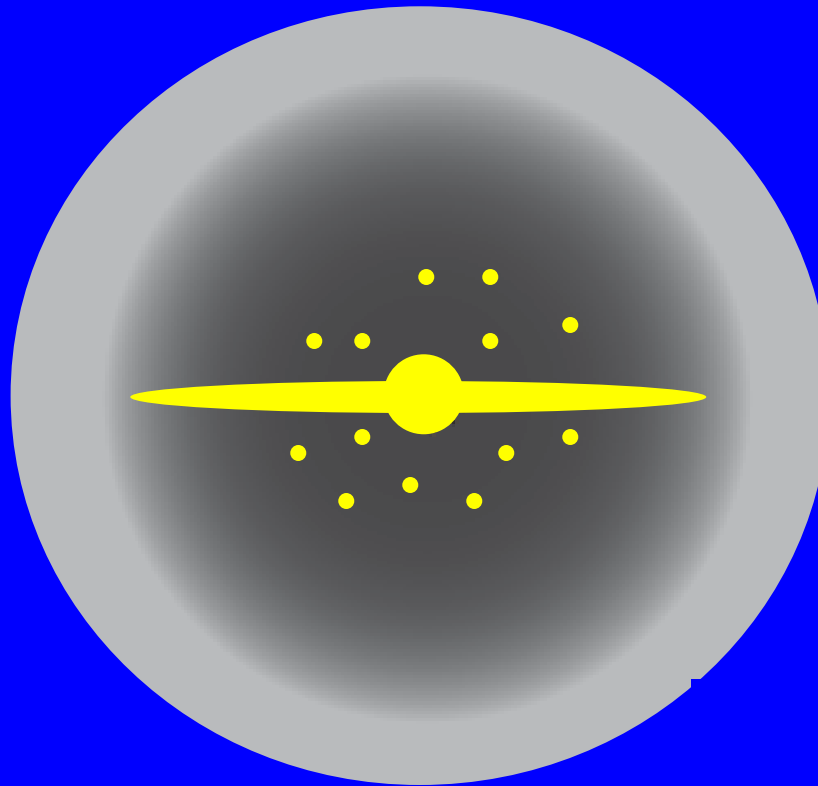


Are atoms alone a sufficient basis
for explaining the Universe?

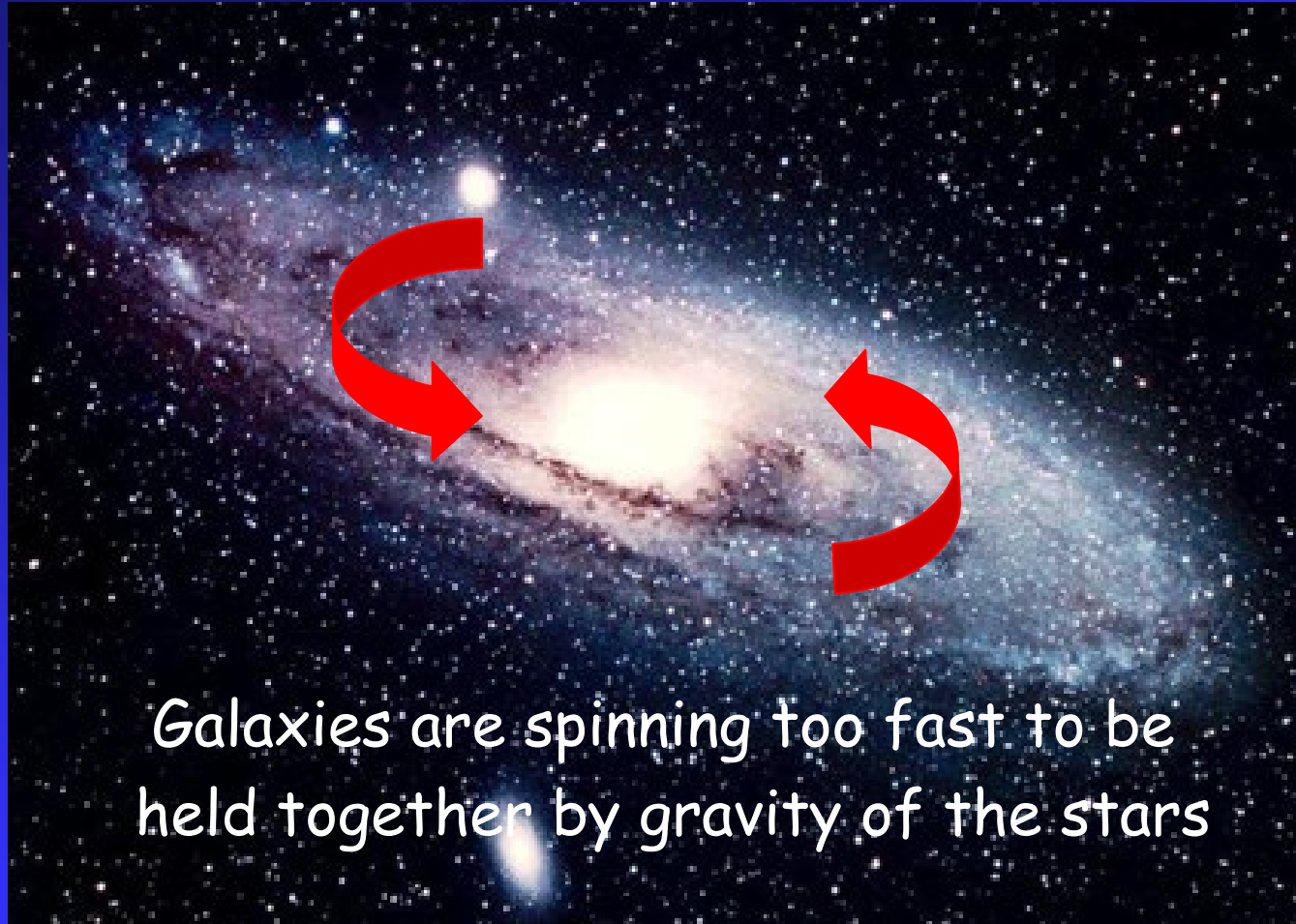


No - not even close

Halo of Dark Matter

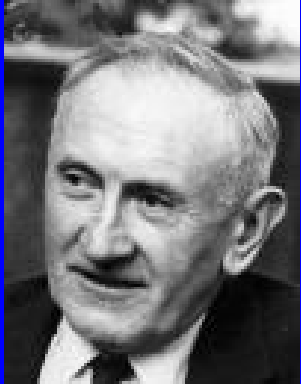


How do we know that galaxies are surrounded by dark halo?



Vera Rubin
1950s

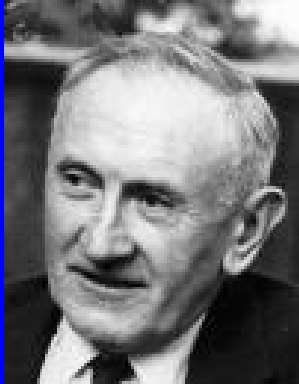
Dark Matter Evidence



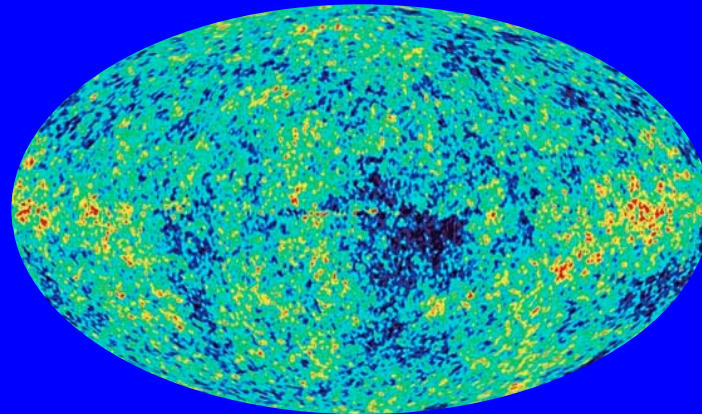
- 1930s motions of clusters of galaxies cannot be understood - Fritz Zwicky



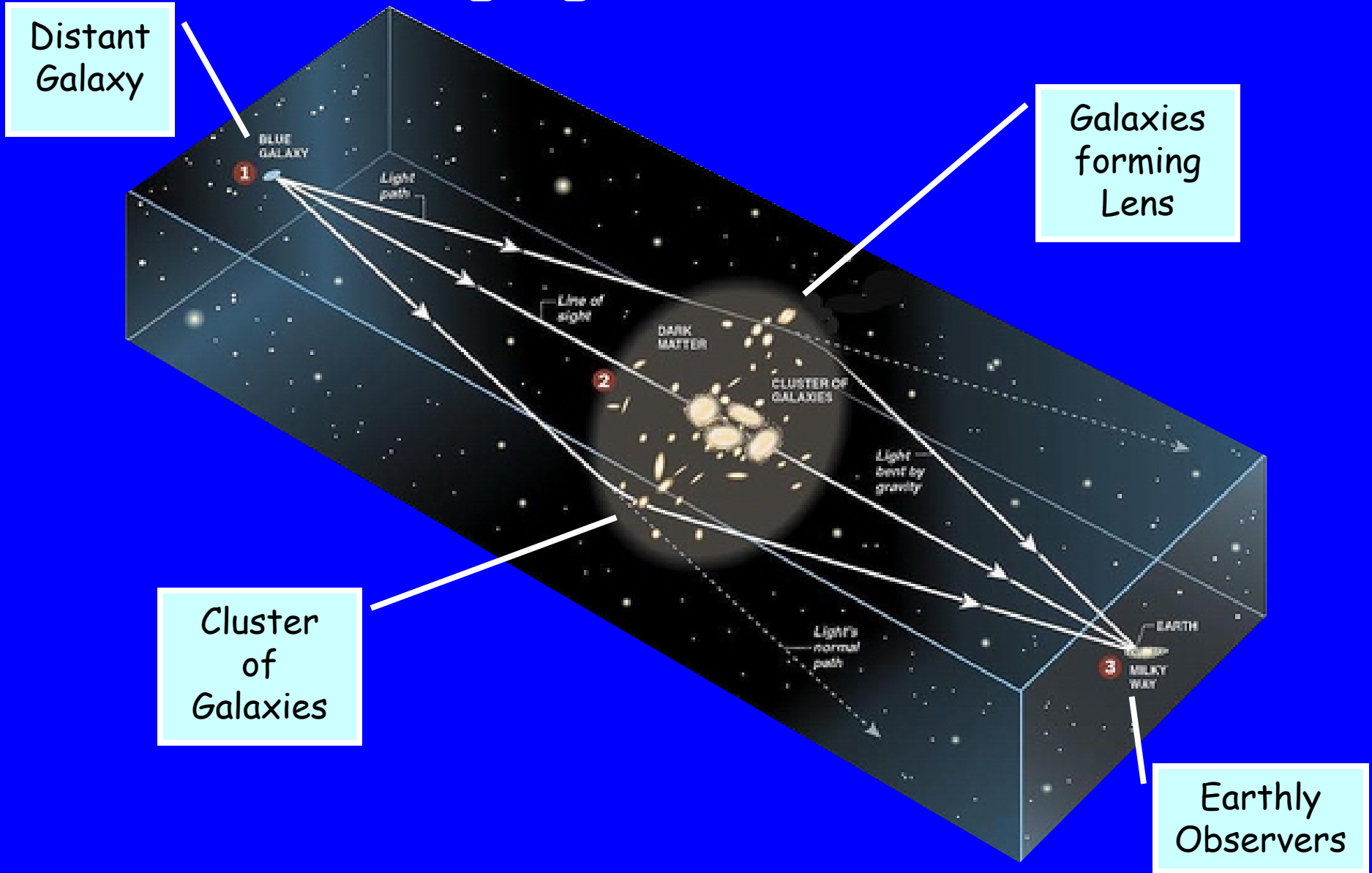
Dark Matter Evidence



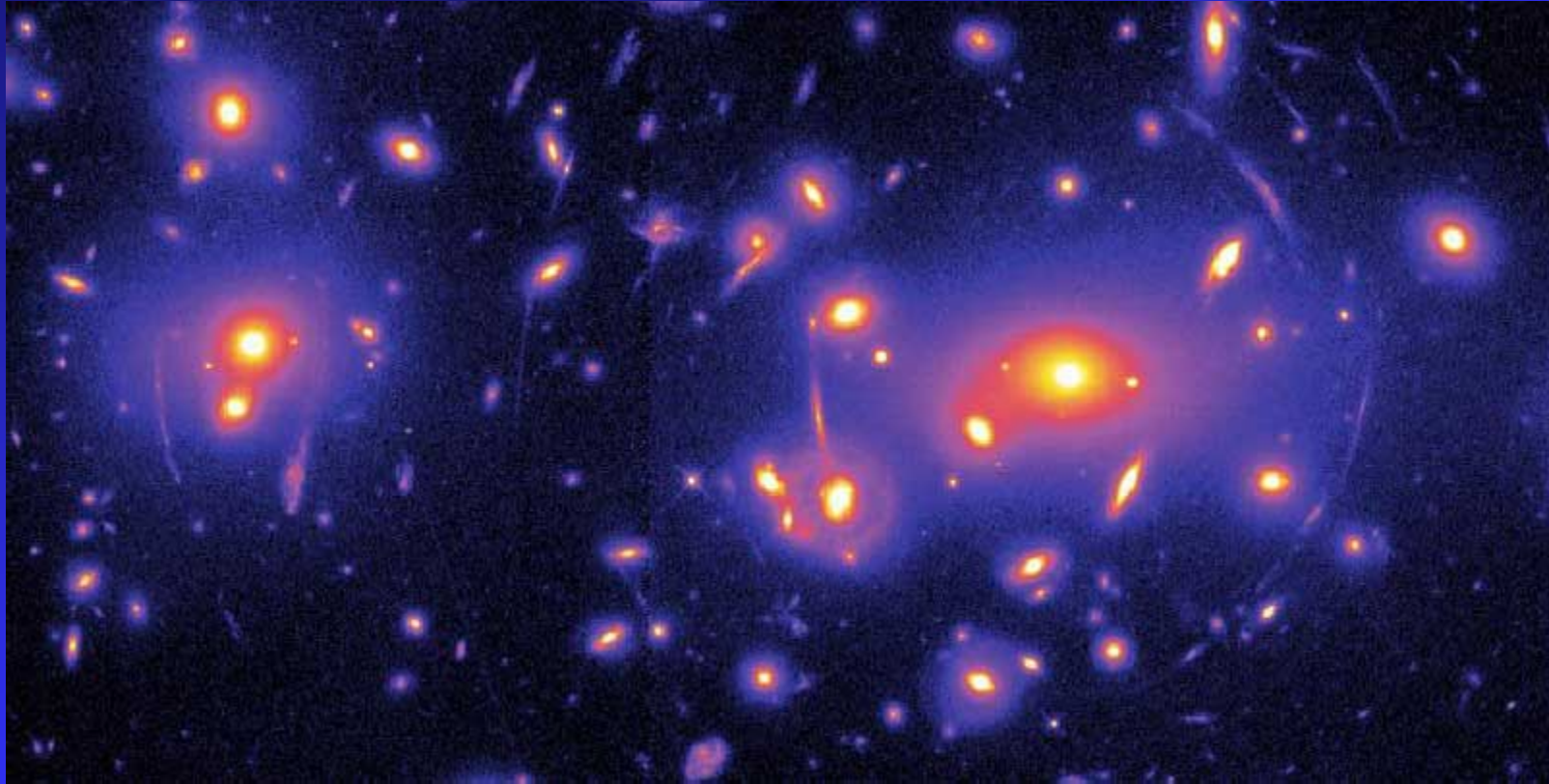
- 1930s motions of clusters of galaxies cannot be understood - Fritz Zwicky
- 1990-2000s Refined studies show dark matter dominance



Imaging Dark Matter



Imaging Dark Matter



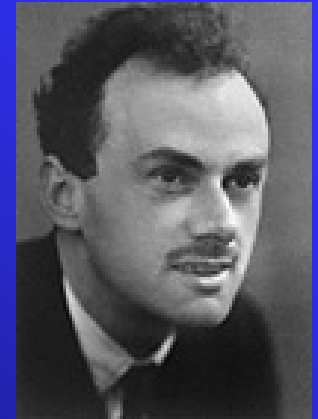
Hubble Data analyzed by Yale astrophysicist

Observing Galaxies

- There must be a dominant presence of a dark form of matter
 - It is invisible!
 - We "see" it through gravitational effects
 - this is the only way we know it exists
 - What is it?
 - Is it just faint, ordinary matter?
 - Most likely not
 - Promising candidate - exotic type of fundamental particle which is anticipated by particle theory
 - Supersymmetric particle (Neutralino)

Symmetries of particles

- 1928, Paul A.M. Dirac
 - Theory of the electron
 - Combining relativity and quantum mechanics
- He needed to assume there were partner particles for every known particle
 - ANTI-MATTER
- DOUBLED THE NUMBER OF PARTICLES

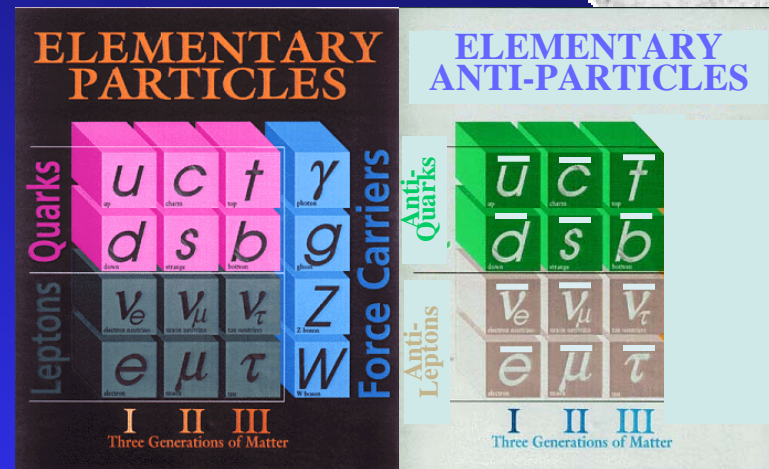
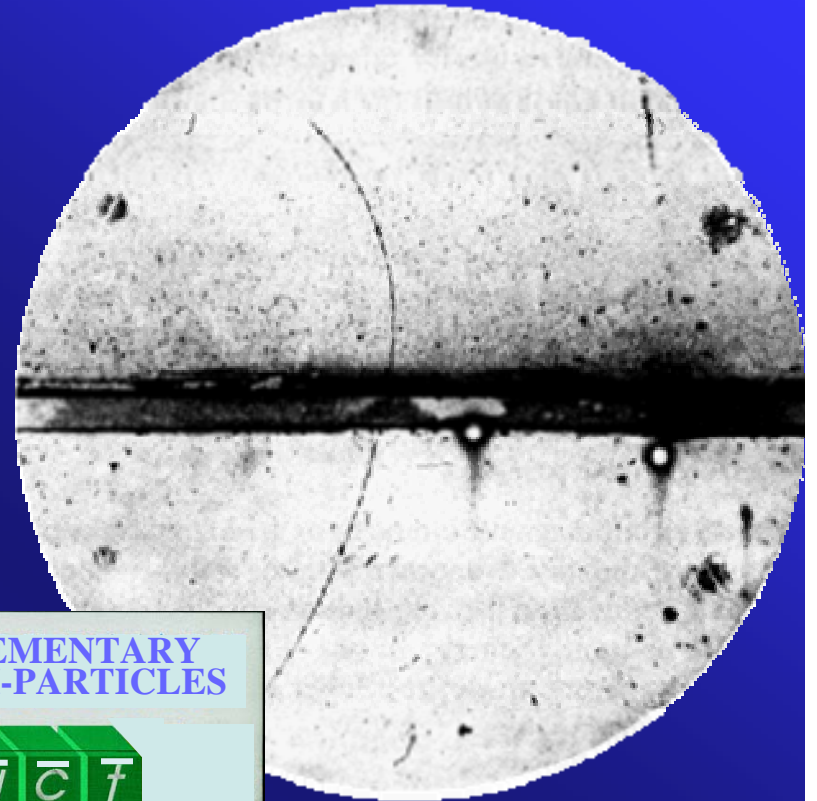


Discovery of Anti-Matter

- 1932 - Carl Anderson
 - The anti-electron, or positron



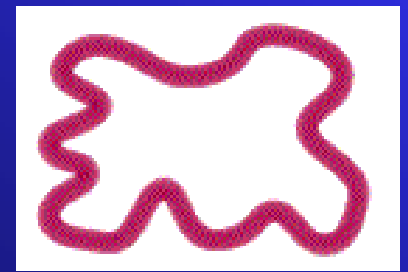
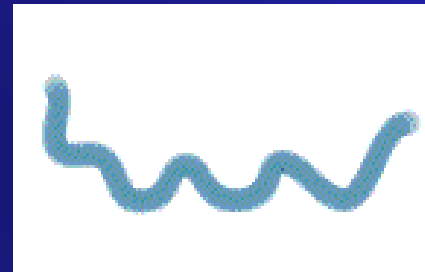
All known particles have anti-particles



SuperString Theory

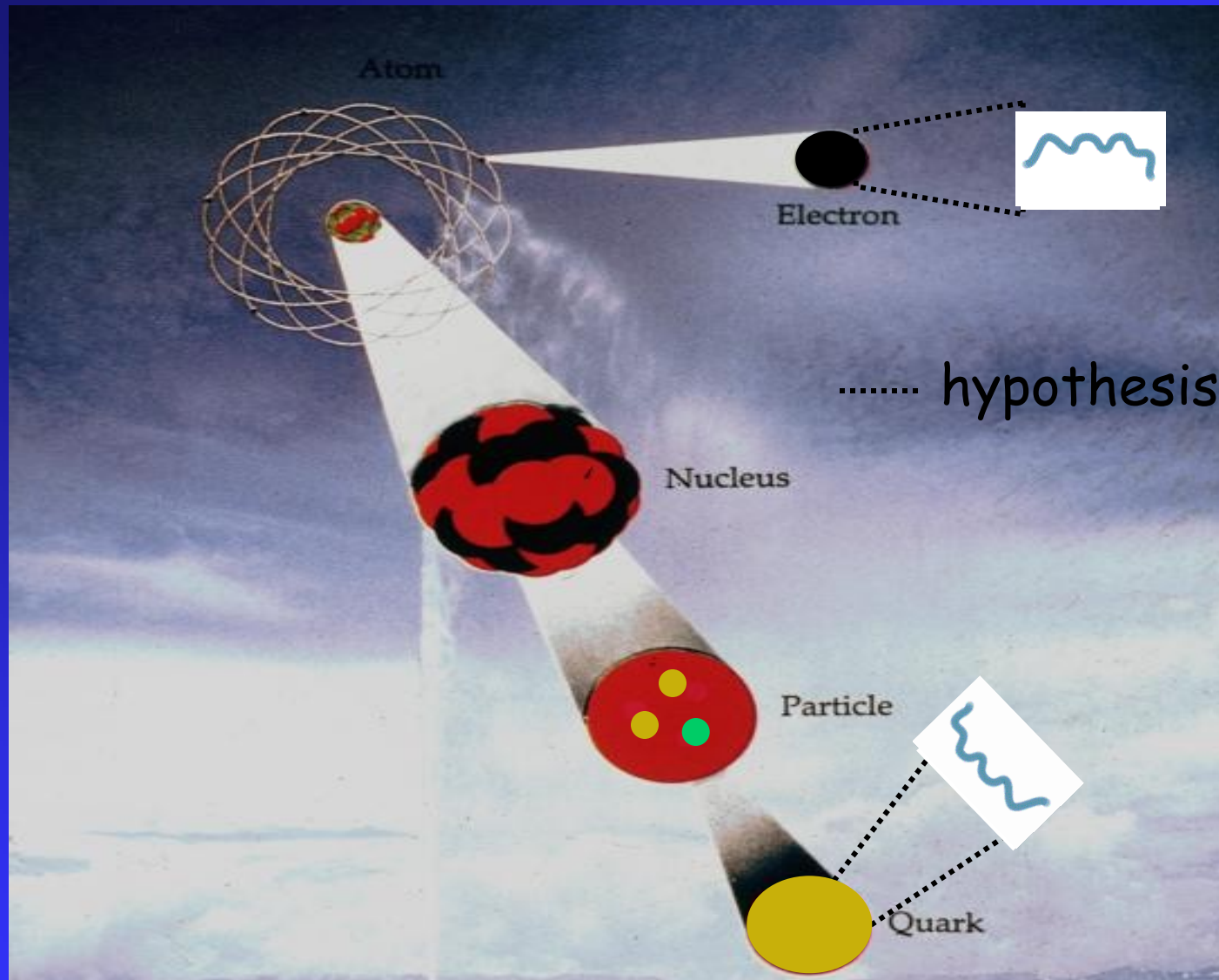


- Unifies all particles and all forces
 - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string



- String is miniscule
 - Atom is 10,000,000,000,000,000,000,000,000 x bigger
- Space is ten-dimensional (not 3D!)
- A matching set of particles appear
 - the super-partners of ordinary particles

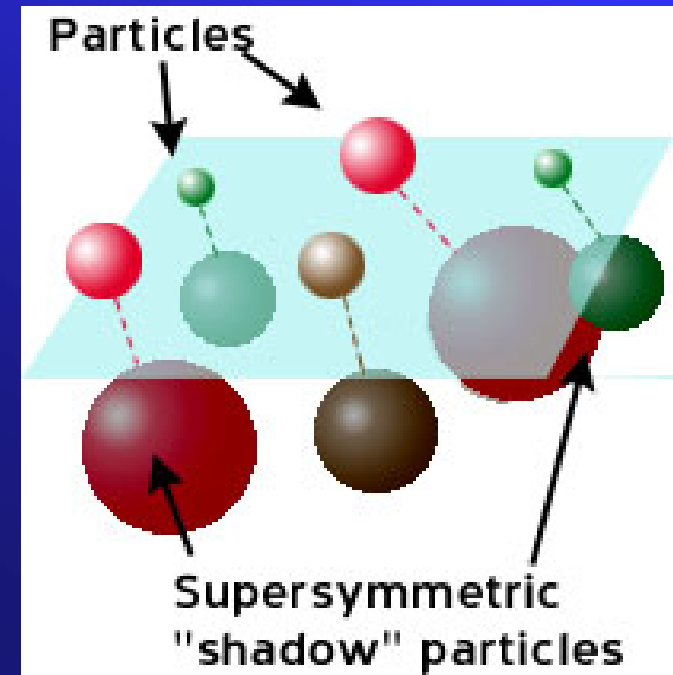
The Structure of Matter



Supersymmetry and Strings

- History repeats?
- Just as for anti-matter,
 - New particles are required to make successful theory

ELEMENTARY PARTICLES				ELEMENTARY ANTI-PARTICLES				
Quarks	u	c	t	γ	Anti-Quarks	\bar{u}	\bar{c}	\bar{t}
	d	s	b	g		\bar{d}	\bar{s}	\bar{b}
Leptons	ν_e	ν_μ	ν_τ	Z	Anti-Leptons	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$
	e	μ	τ	W		\bar{e}	$\bar{\mu}$	$\bar{\tau}$
I II III Three Generations of Matter					I II III Three Generations of Matter			

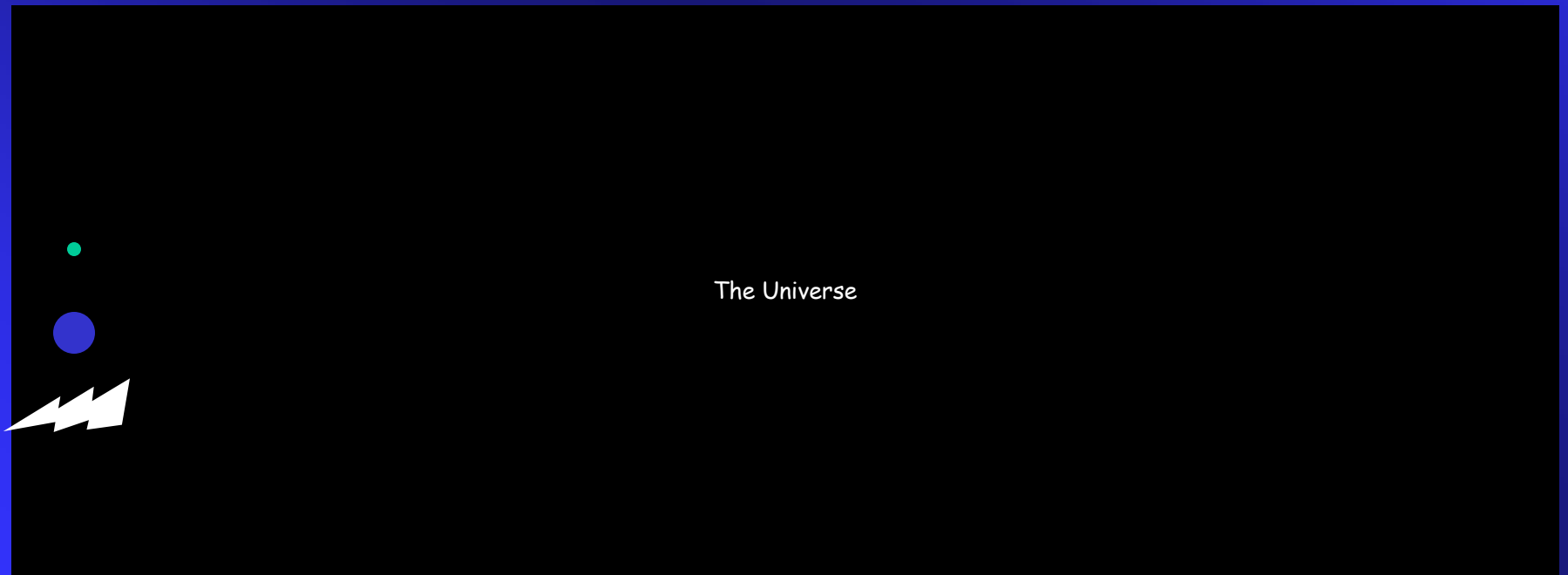


- The supersymmetric particles have just the properties expected of Dark Matter

Another puzzle

What gives matter mass?

- An ocean of Higgs Bosons - "Higgs Field"



Large Hadron Collider (LHC) Geneva, Switzerland

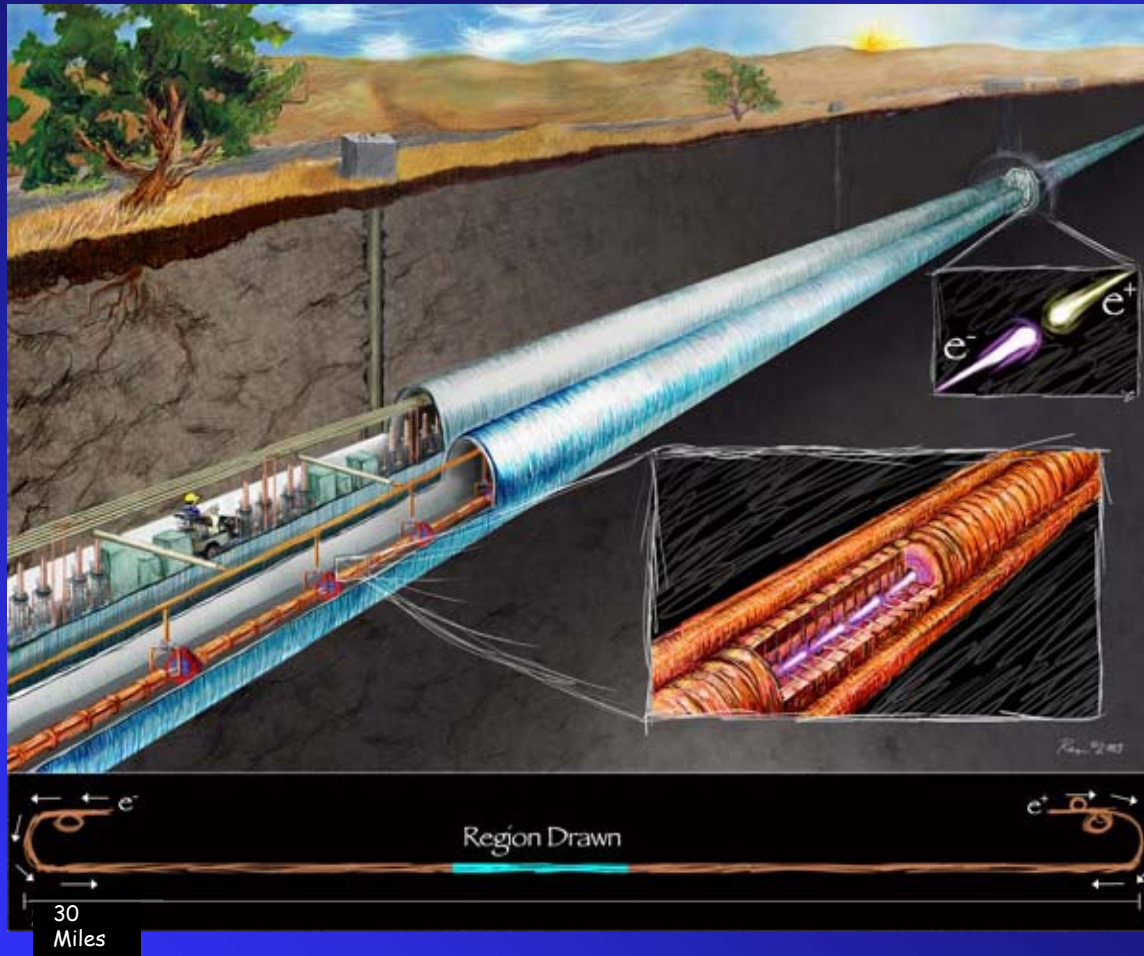


Nearing
Completion

Begins operation in
2007

Scientific agenda:
Higgs Boson, Dark Matter,
Extra Dimensions, New
Forces, Unexpected

International Linear Collider (ILC)



Under
development

Planned to begin
operation soon
after 2015

(extending discoveries of
Large Hadron Collider)

Scientific agenda:

Higgs Boson, Dark Matter,
Extra Dimensions, New
Forces, Unexpected

The Big Bang

- Fundamental Physics needed to understand Big Bang



The Cosmic Fireball

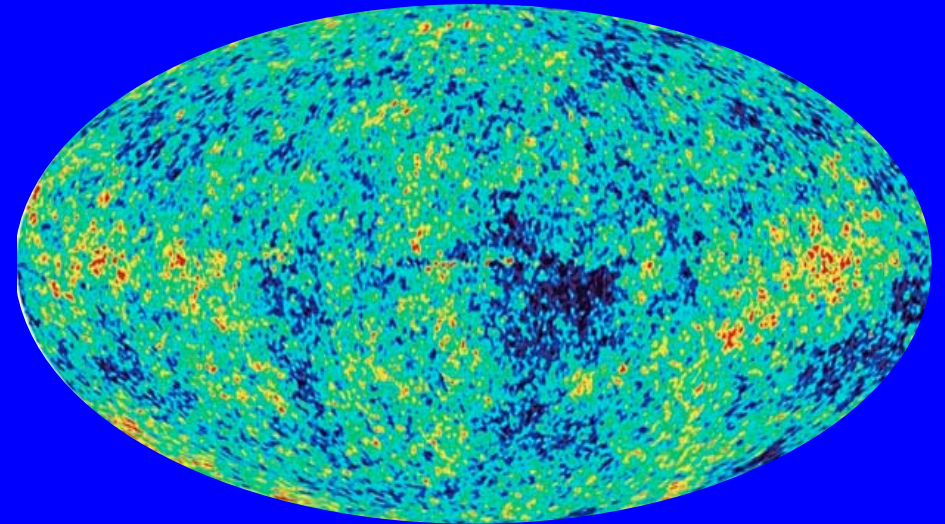
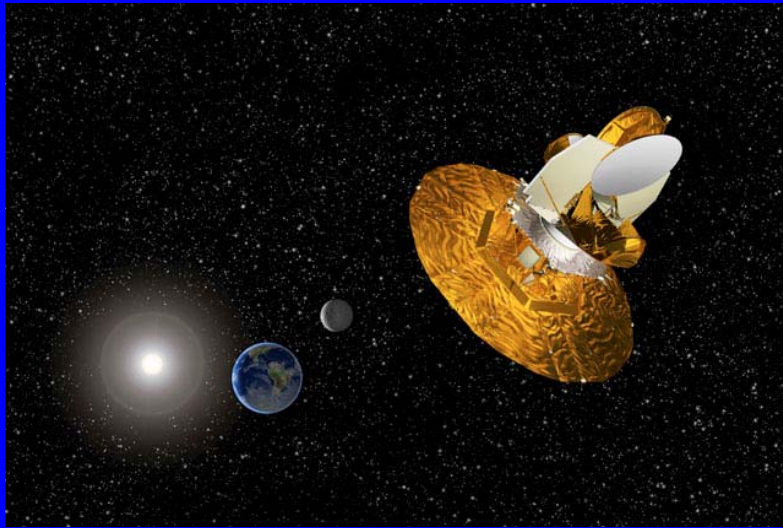


- Visible remnant of the Big Bang
 - microwaves in the sky
 - traveling through space for 14 billion years

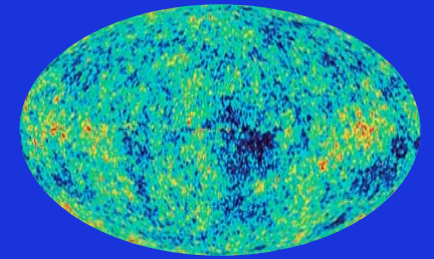


Probing the Big Bang

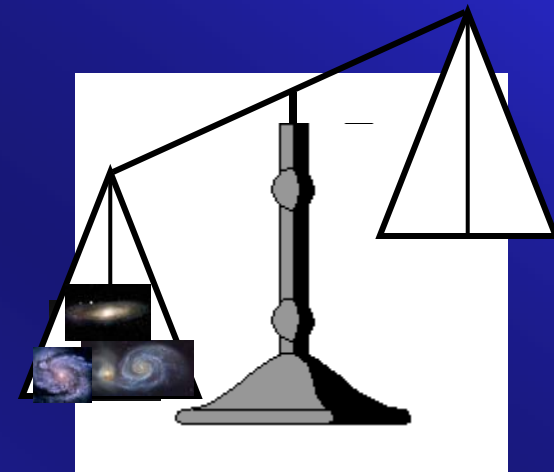
- Studied since 1965 discovery
- Series of increasingly more sensitive experiments
- Lastest - WMAP



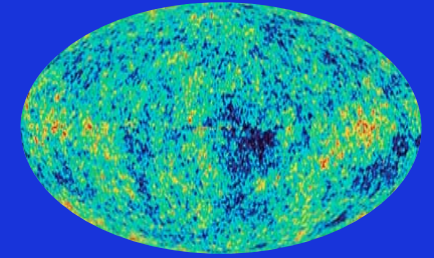
Probing the Big Bang



- Analysis of the WMAP data is equivalent to "weighing" the universe



Probing the Big Bang



- The stars are a very small fraction

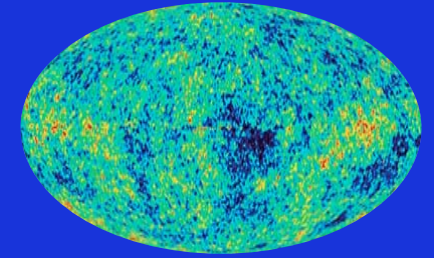


• Additional ordinary matter,
Still a small fraction

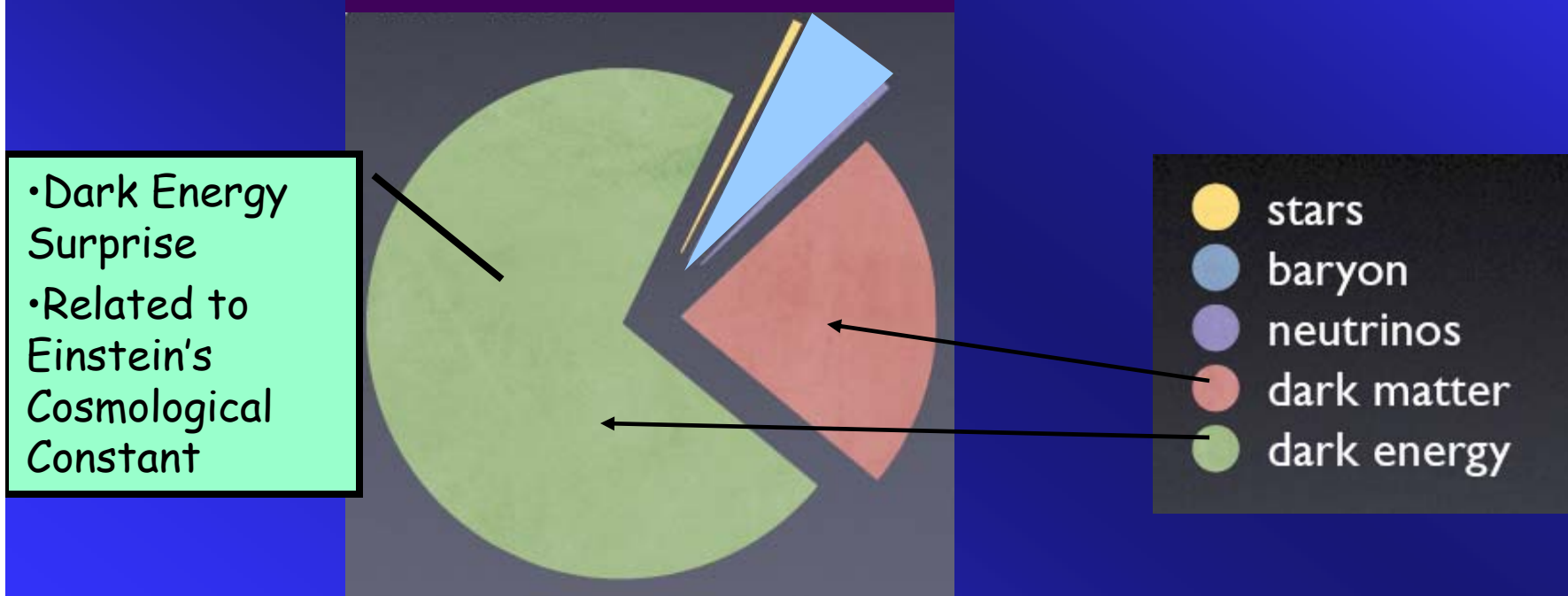
• Anti-matter miniscule

• What is the rest?

Probing the Big Bang



- The dominant "weight" of the universe is dark matter and dark energy

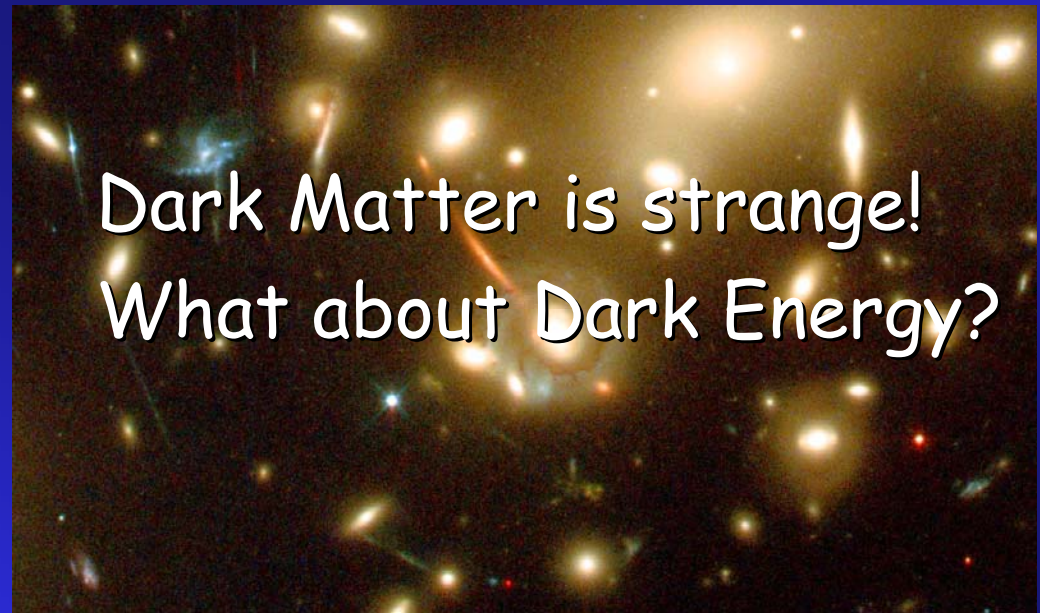


The Dark Side Controls the Universe



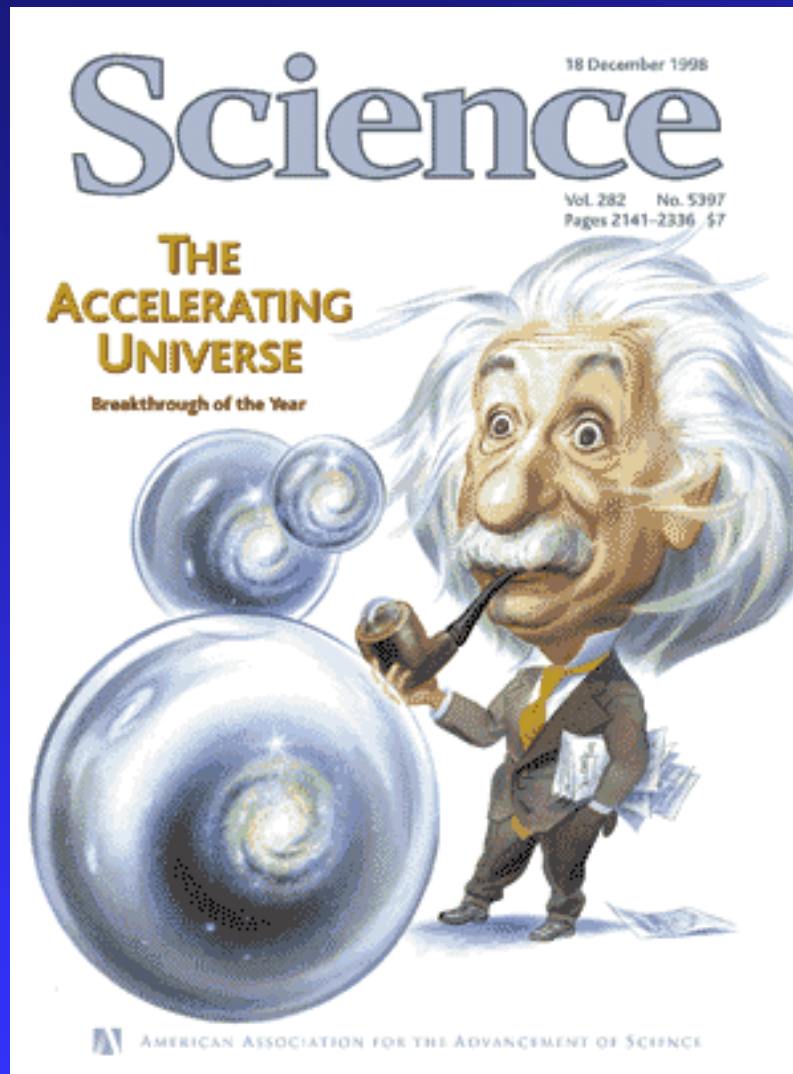
Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY



Dark Matter is strange!
What about Dark Energy?

Measuring the Universe' Expansion

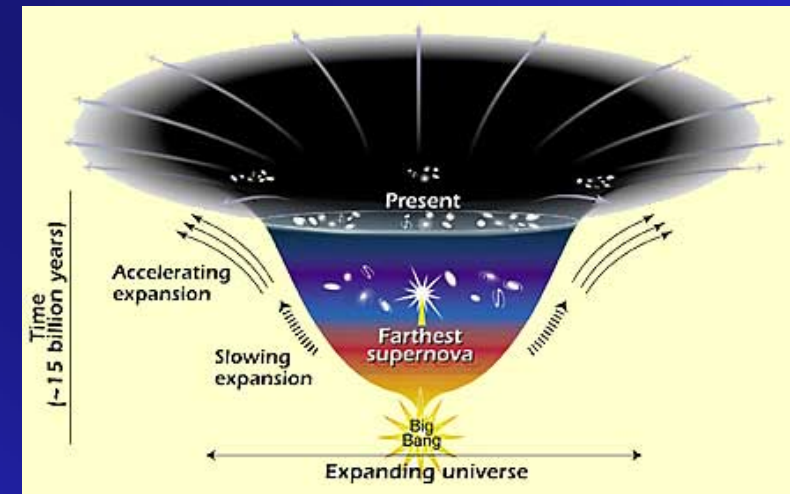


Jim Brau - Univ. of Oregon

Bend, Oregon

August 10, 2006

Acceleration
thought to be
driven by
"Dark Energy"





The Dark Energy

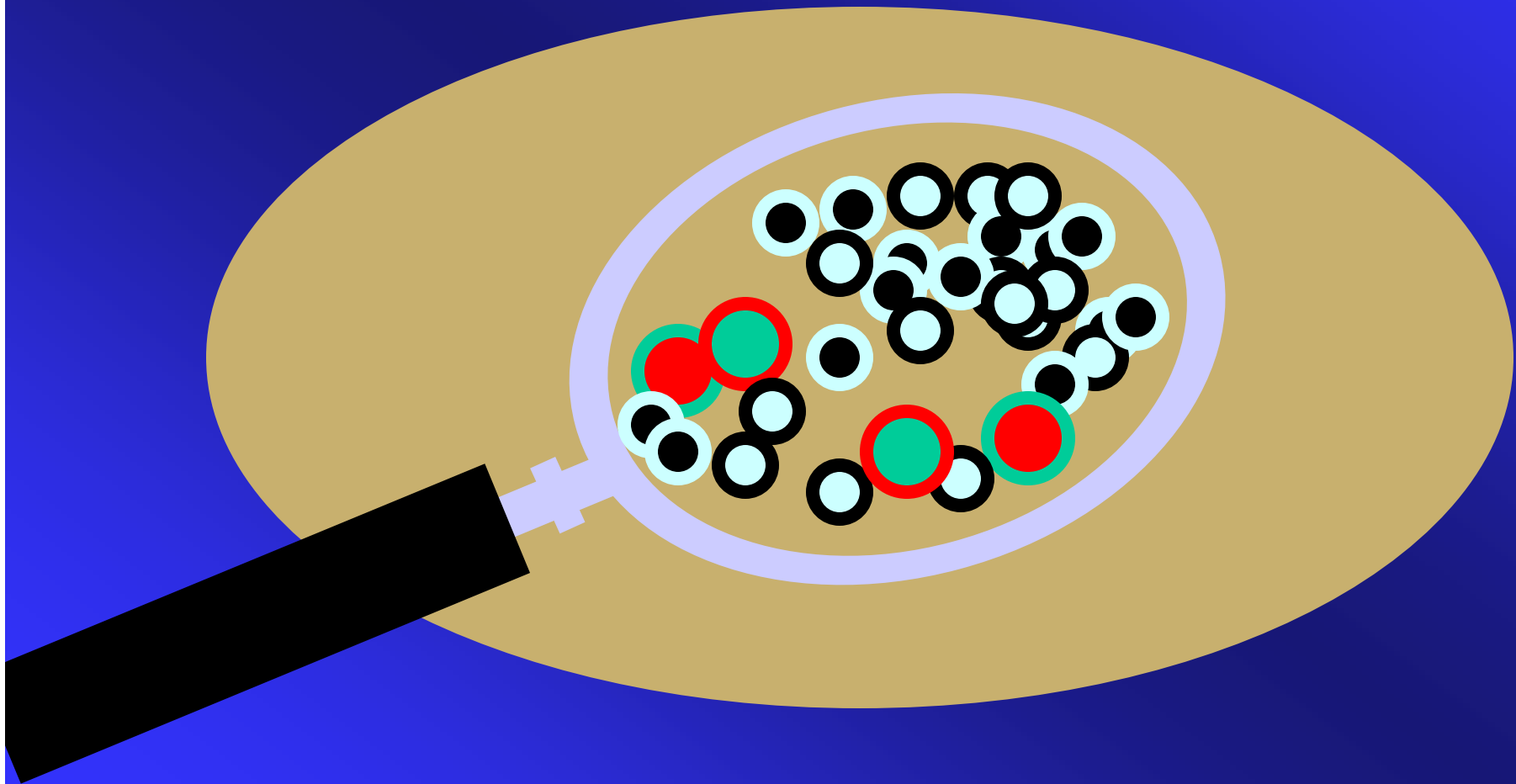
Something from Nothing

- The closest realization of "nothing" is the vacuum - "empty space"
- Quantum physics -> no truly empty space
- "Empty space" filled with "temporary" particles



The Dark Energy

Something from Nothing



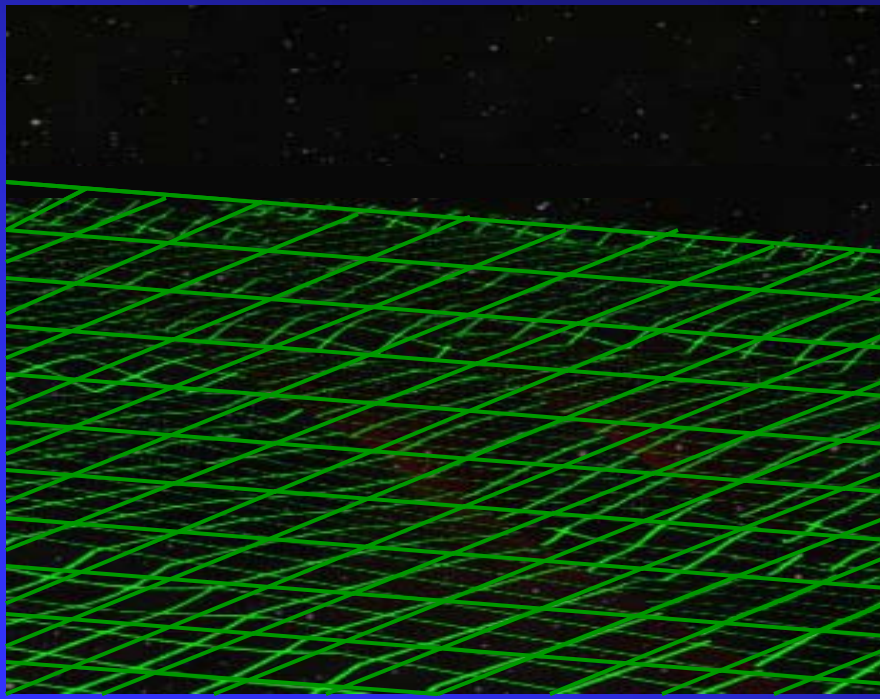


The Dark Energy Something from Nothing

Quantum Fluctuations Create a "Dark Energy"
- Cosmological constant

Seeking the Primordial Gravity Waves

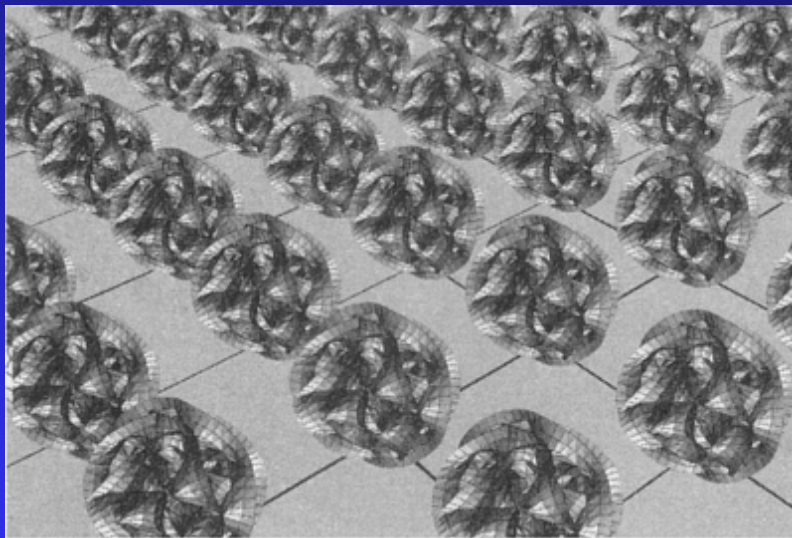
- The fabric of the universe is still rattling from the violent Big Bang



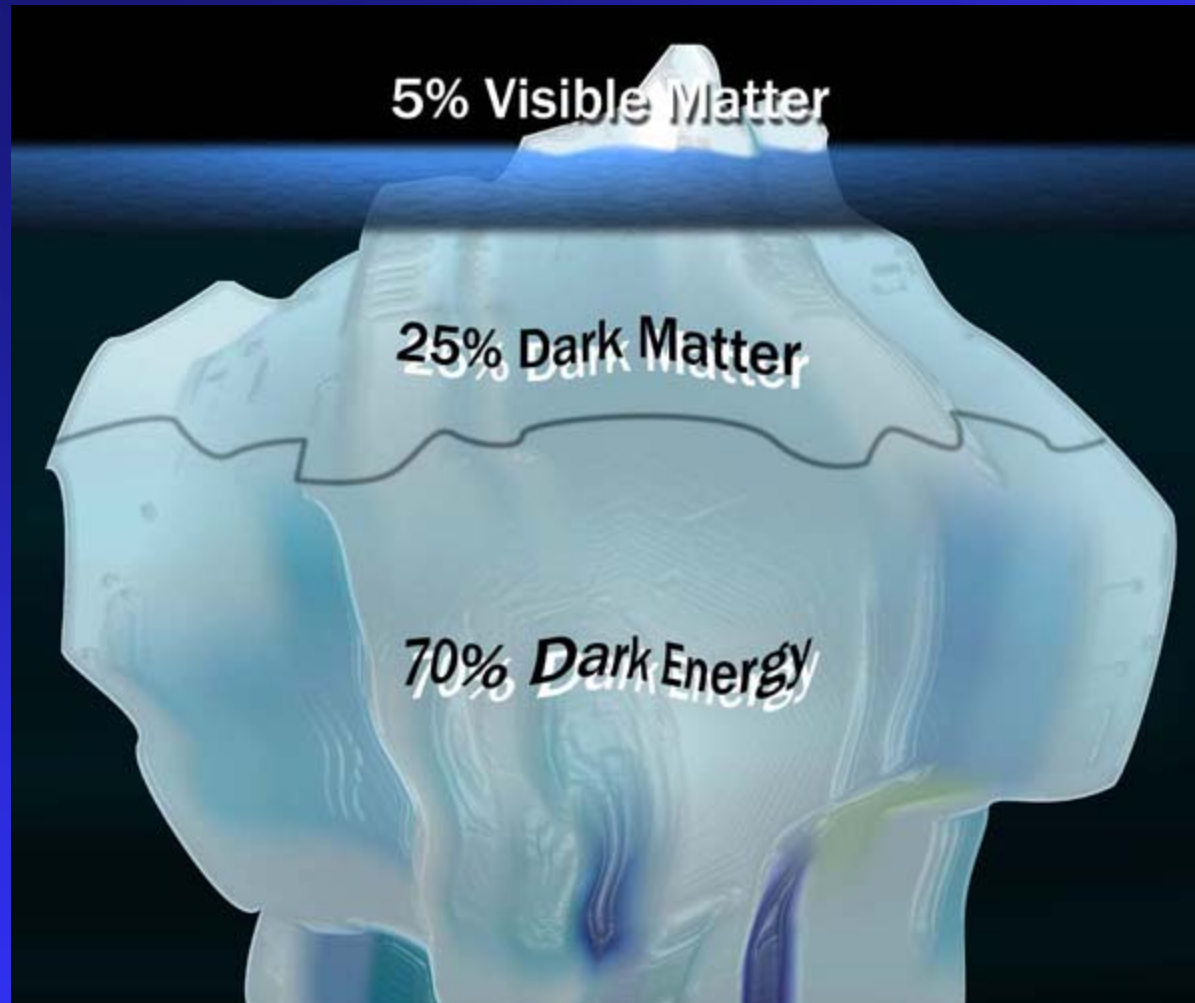
Hanford LIGO

Extra Dimensions

- String Theory
 - 10-dimensional space
- Particle Collider Experiments are looking for these hidden dimensions



Our Mysterious Universe



Realizing Einstein's Dream

- Now on eve of revolution in physics
 - Many mysteries
 - Solutions appear near
 - Deeper understanding of the universe itself
- Dark Matter particles - may appear soon in particle collider experiments at accelerators
- Why is there mass? - Higgs Boson
- Dark Energy - this is the biggest mystery of all
- Combined study by astrophysical observatories, and ground-based particle colliders needed

Acknowledgements



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Department of Energy
OFFICE OF SCIENCE



NATIONAL SCIENCE FOUNDATION

