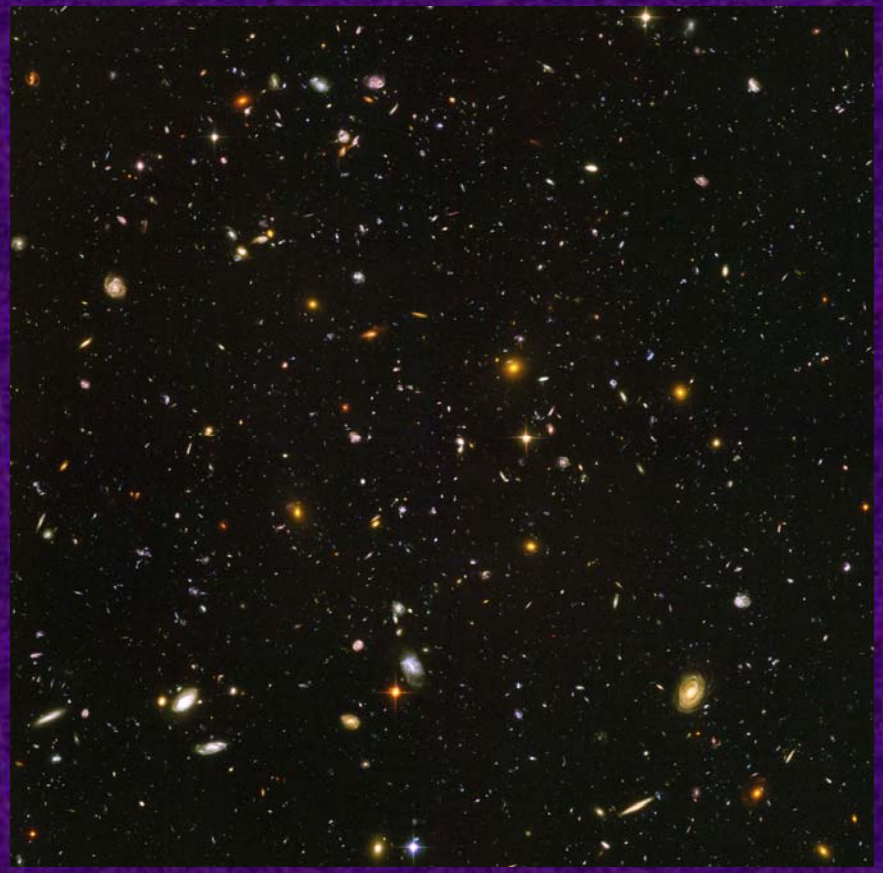
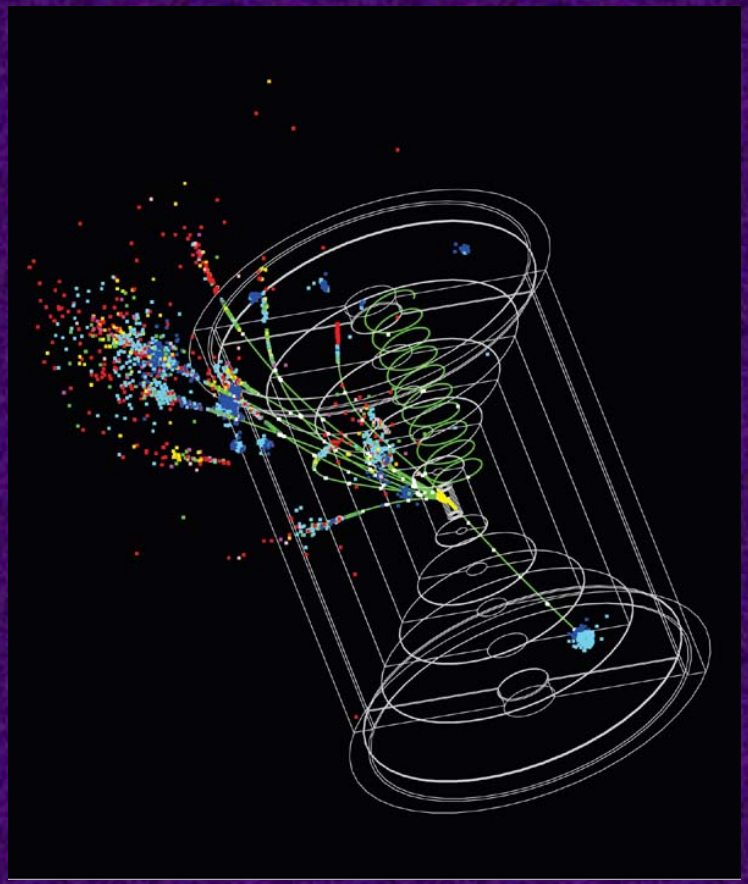
REALIZING EINSTEIN'S DREAM

Exploring Our Mysterious Universe





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Mysteries of the Universe

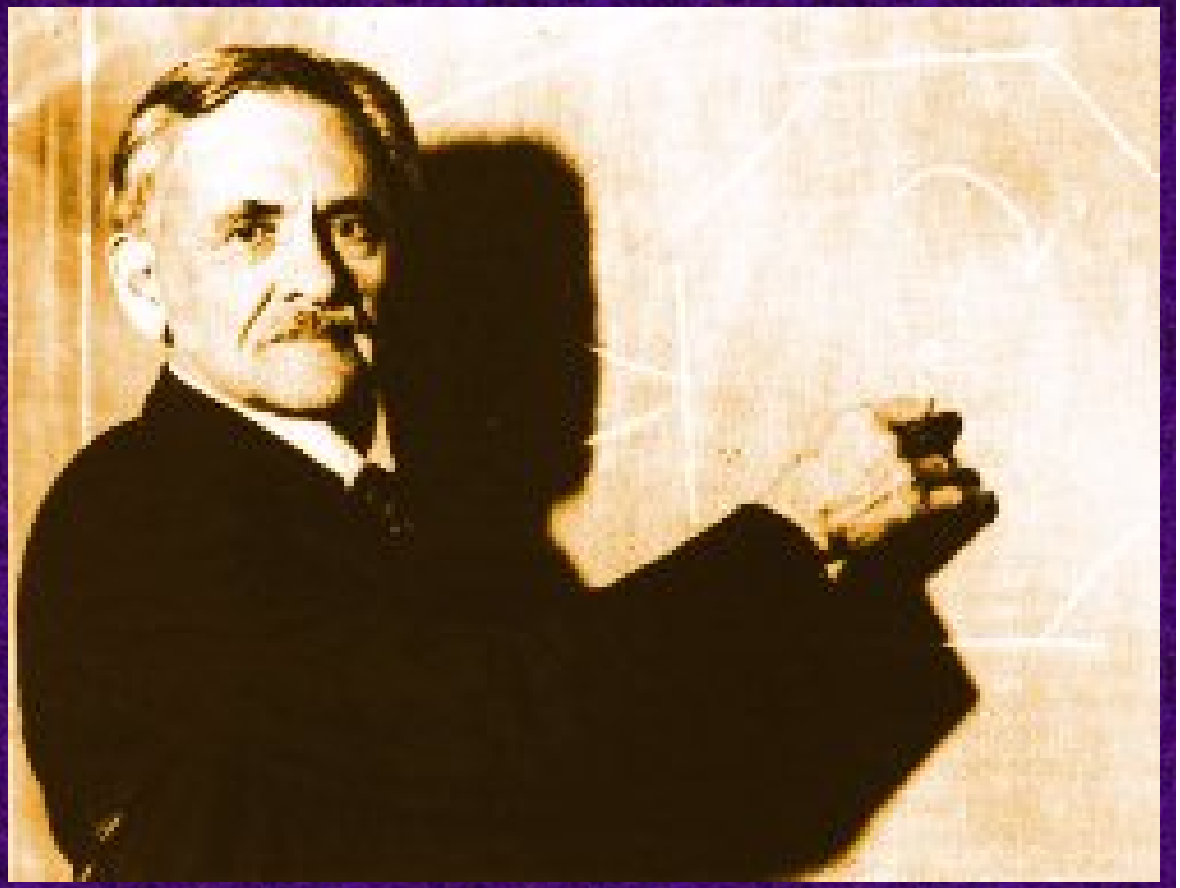
- Quarks
- Leptons
- Higgs Bosons
- Supersymmetric Particles
- SuperString Theory

- Dark Matter
- Dark Energy
  and the cosmological constant
- Accelerating Universe

- Gravity Waves
- Extra Dimensions

The End of Physics

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



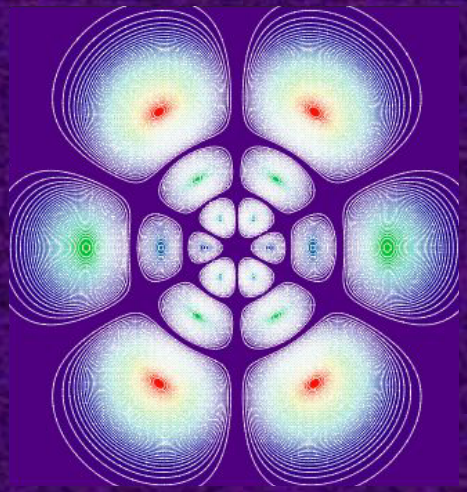
The Miracle Year - 1905

Relativity
Quantum Physics
Atoms

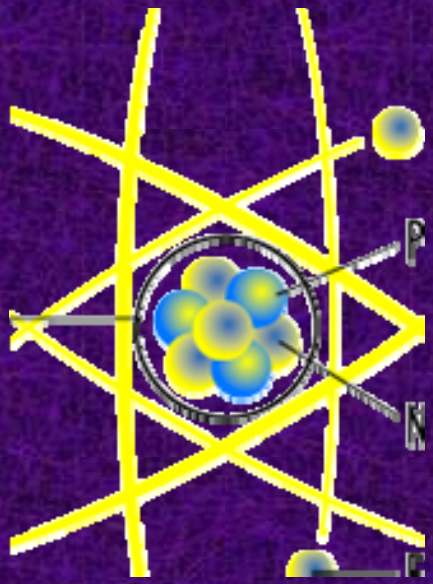
1915 -
General Theory of Relativity,
the theory of gravity,
based on warped space

Physics in 1905

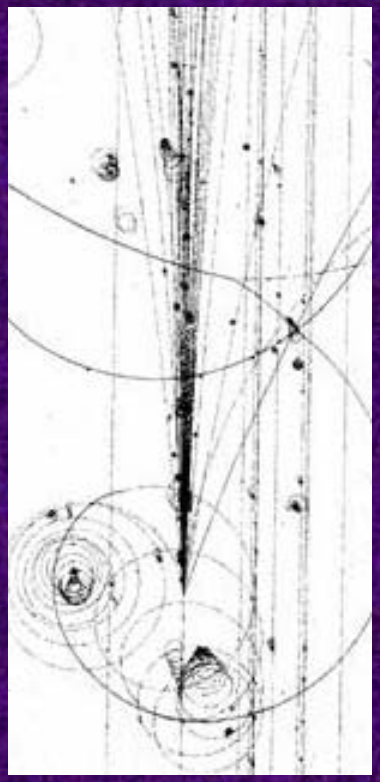
Missing from understanding of the Universe in 1905?



Quantum Mechanics



Nuclear Physics



Elementary Particles

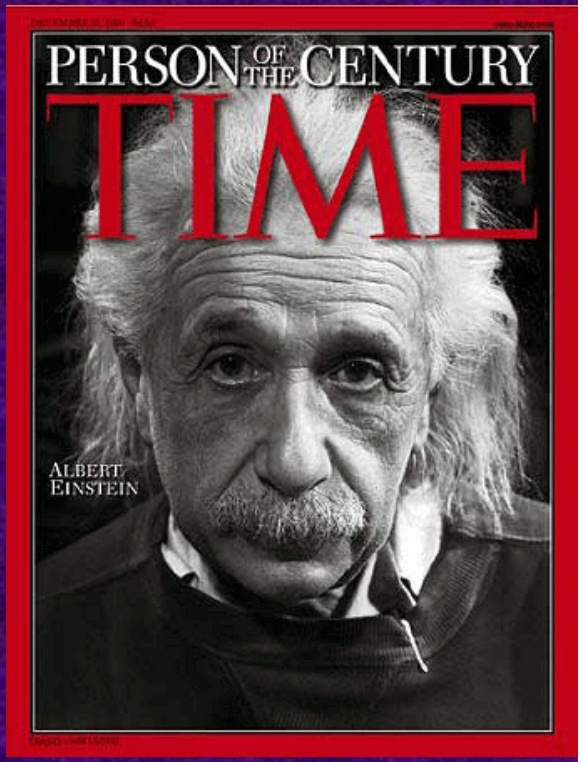
Physics in 1905

Missing from understanding of the Universe in 1905?

Edwin Powell Hubble
(1889-1953)

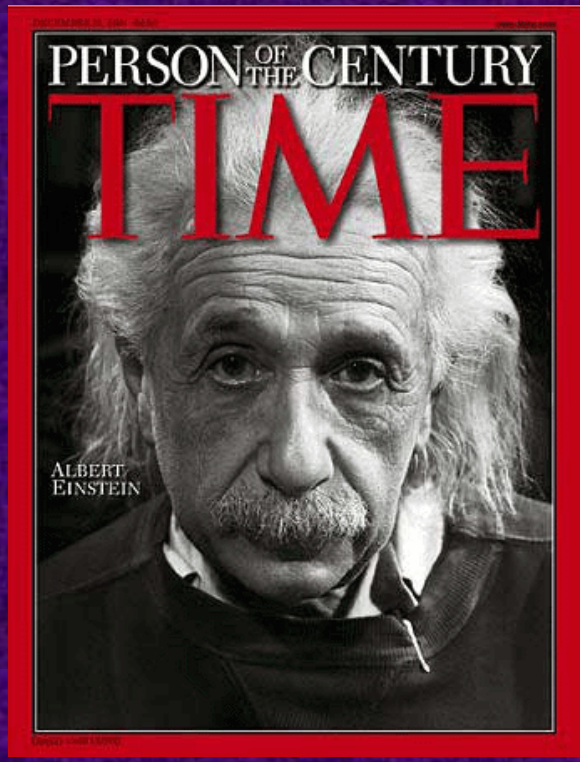
Einstein's Theoretical Discoveries

- Light comes in small packets - photons



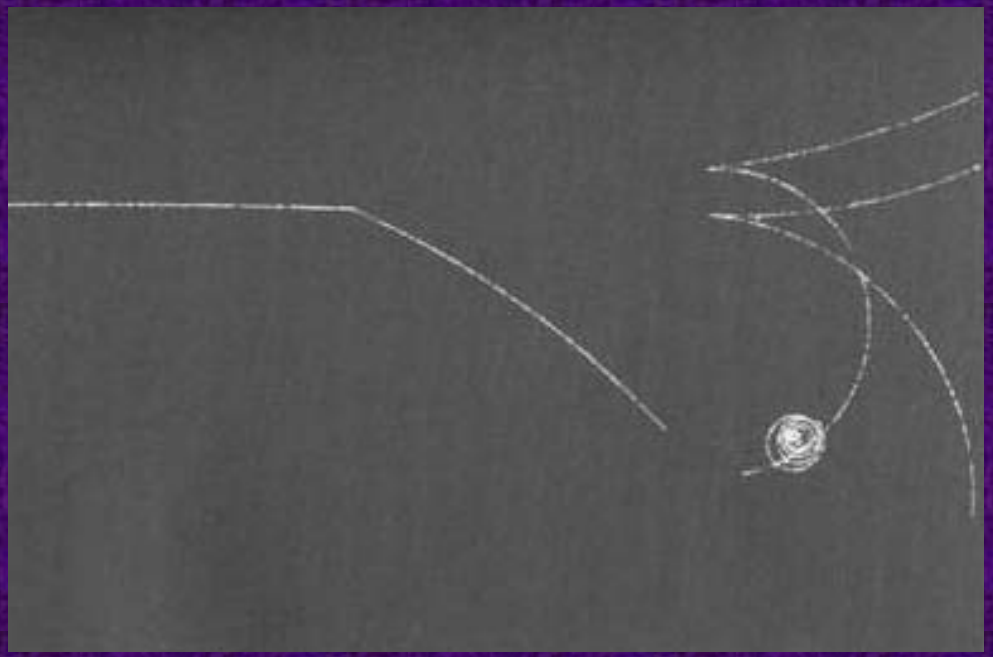
Einstein's Theoretical Discoveries

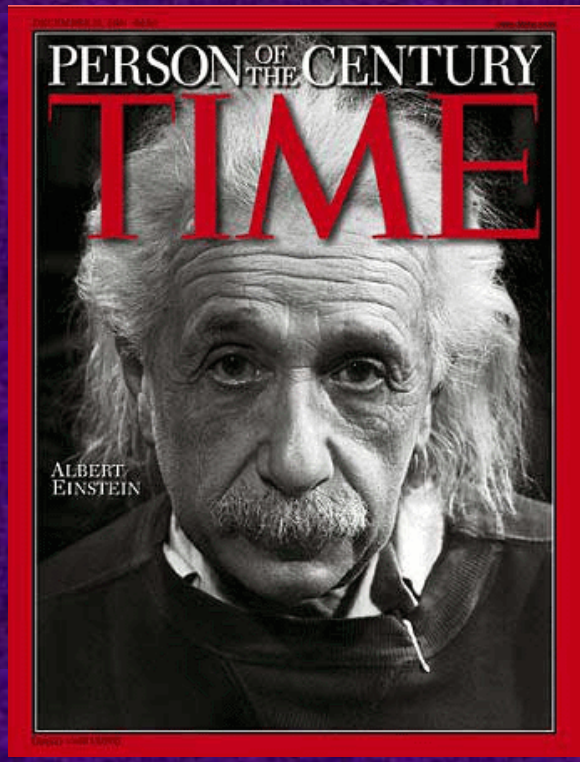
- Light comes in small packets – photons
- The speed of light is a constant
  - Independent of observer's motion



Einstein's Theoretical Discoveries

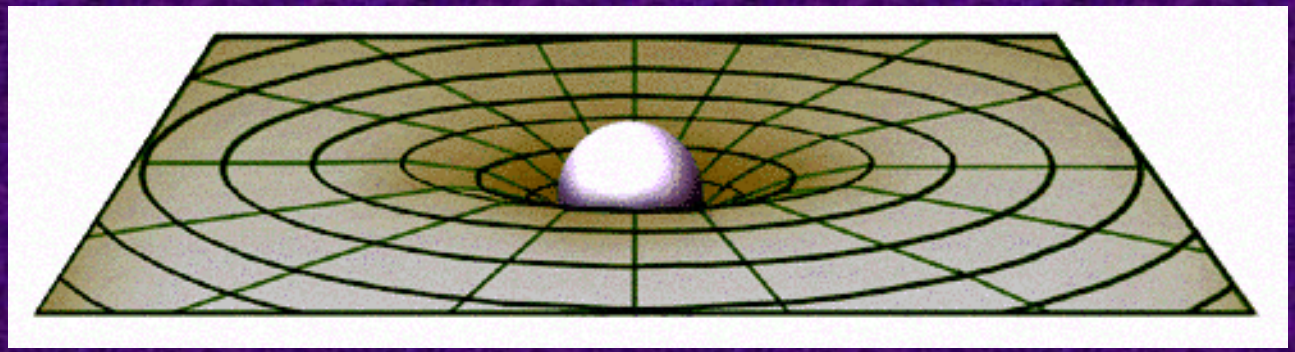
- Light comes in small packets - photons
- The speed of light is a constant
  - Independent of observer's motion
- $E=mc^2$

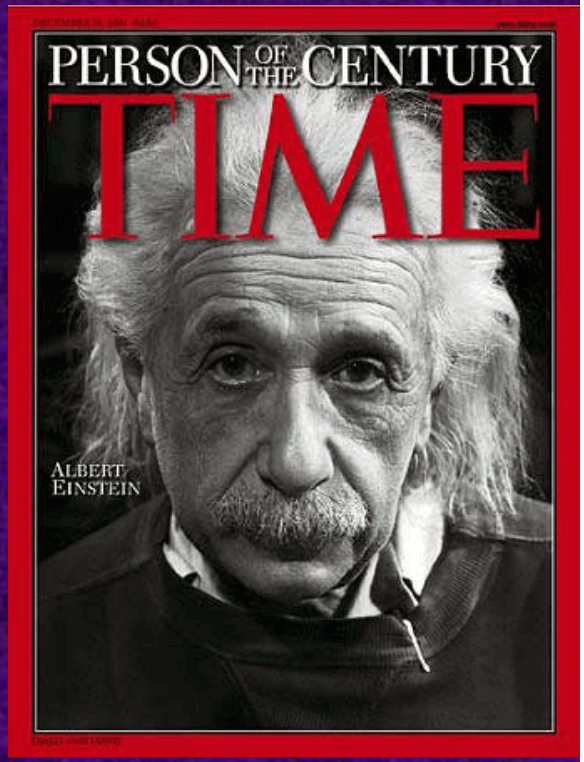




Einstein's Theoretical Discoveries

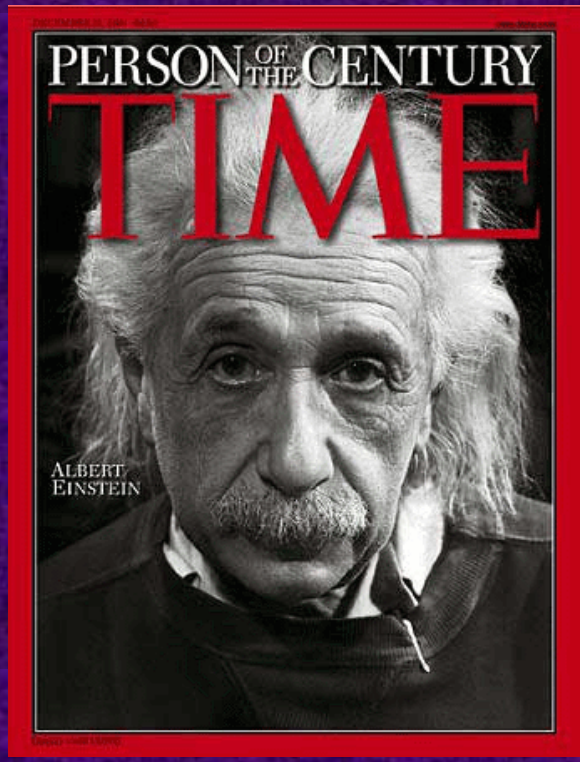
- Light comes in small packets - photons
- The speed of light is a constant
  - Independent of observer's motion
- $E=mc^2$
- Space is warped by massive objects





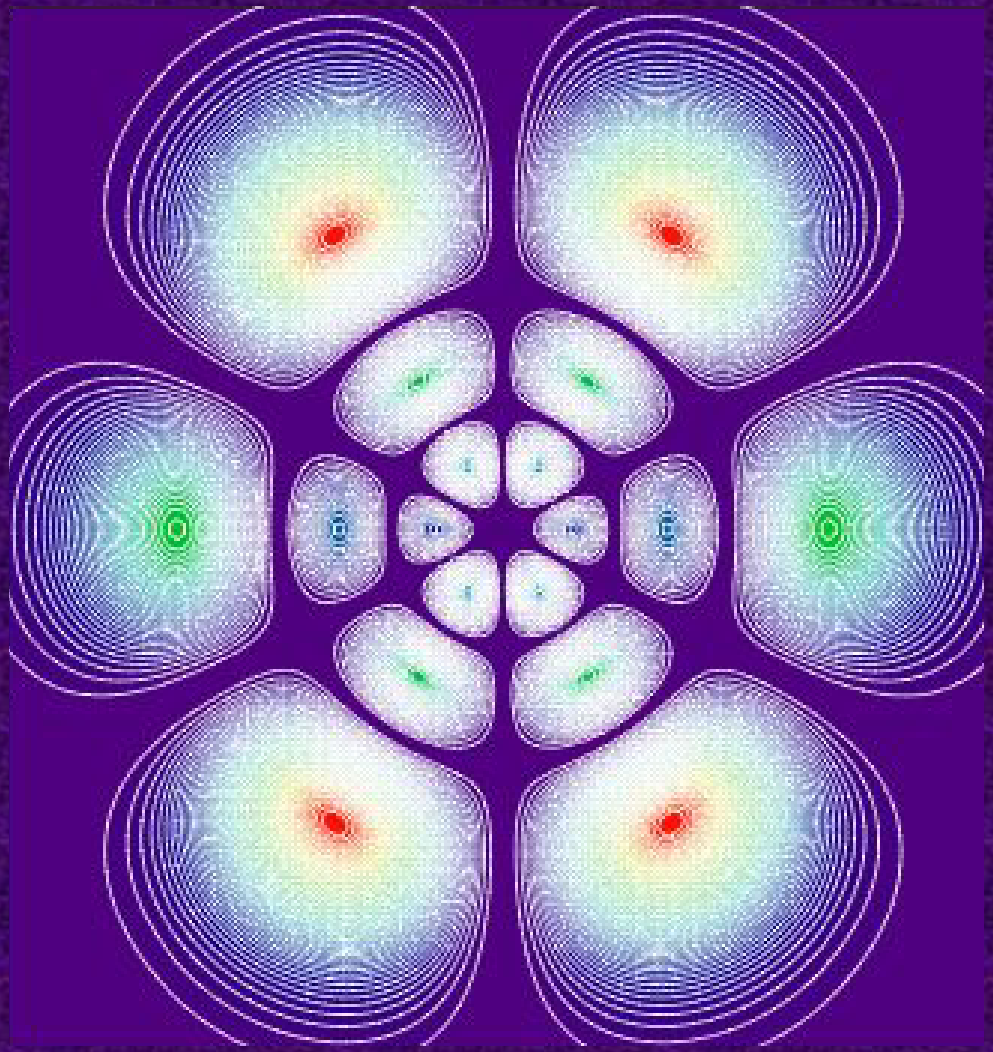
Einstein's Theoretical Discoveries

- 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 others



- Remain central to our exploration of the universe

Einstein and Quantum Mechanics



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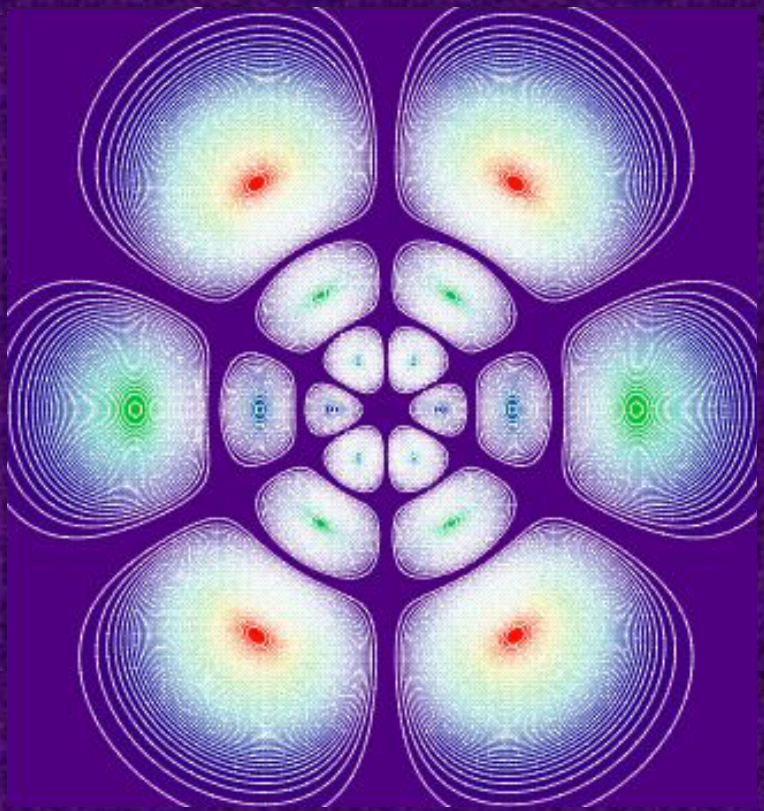
Quantum Mechanics and Gravity



Inconsistent?

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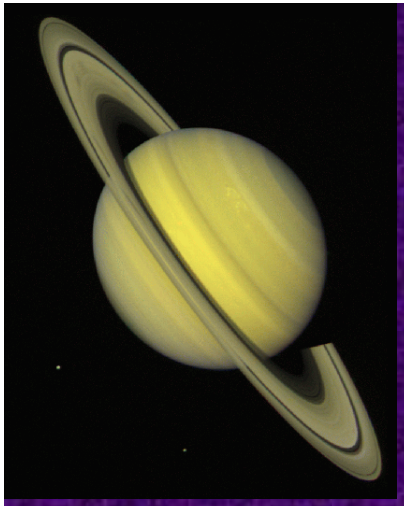
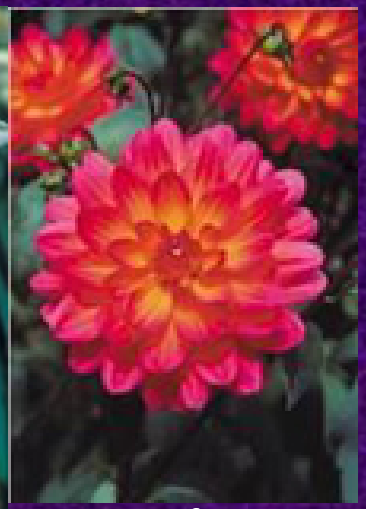


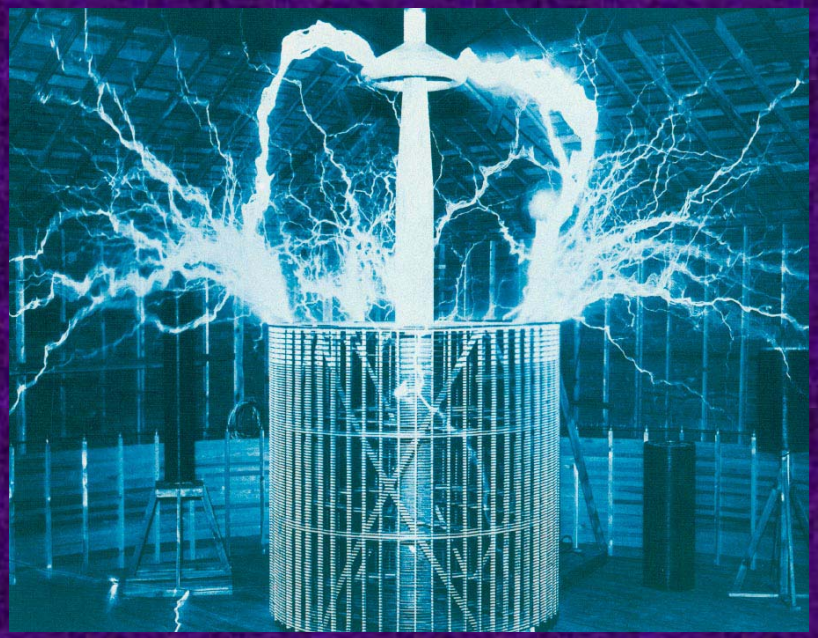
Einstein's Dream

To understand the underlying simplicity behind the vast complexities of Nature

Suspected <u>gravity</u> was a key



Unification



Understand how nature's forces are related

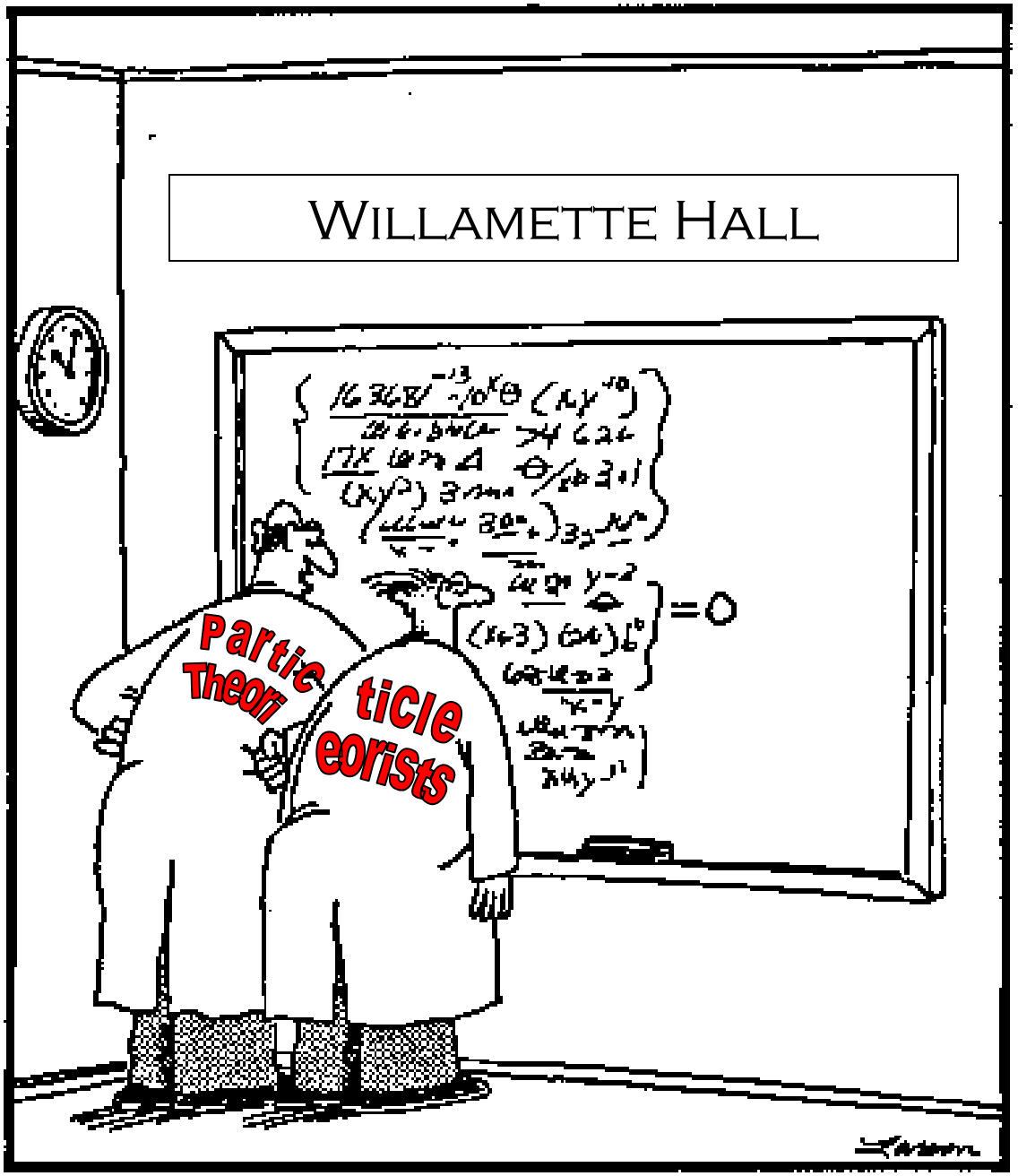
electromagnetism and gravity

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

- There are encouraging signs that success is near

Willamette Hall

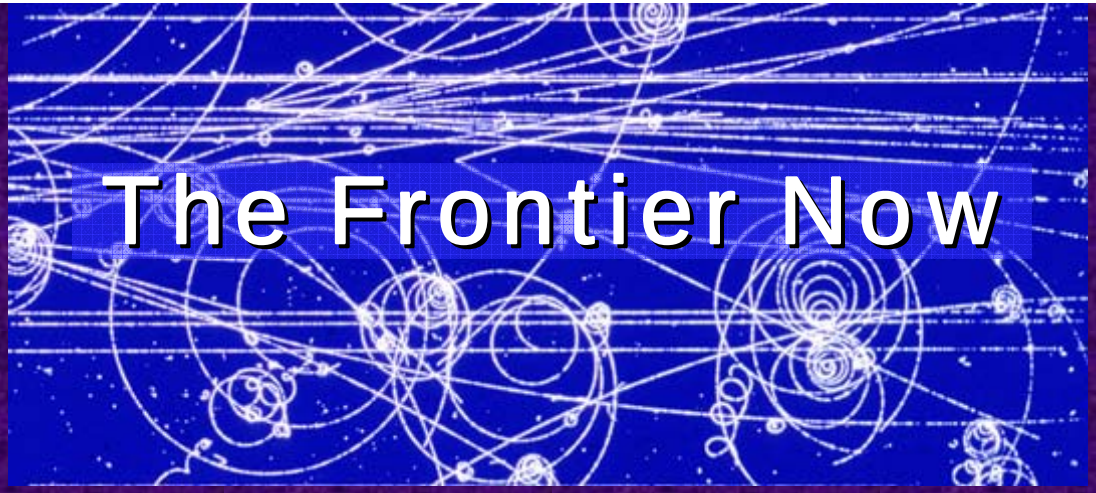


The Next Revolution

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

Recent discoveries

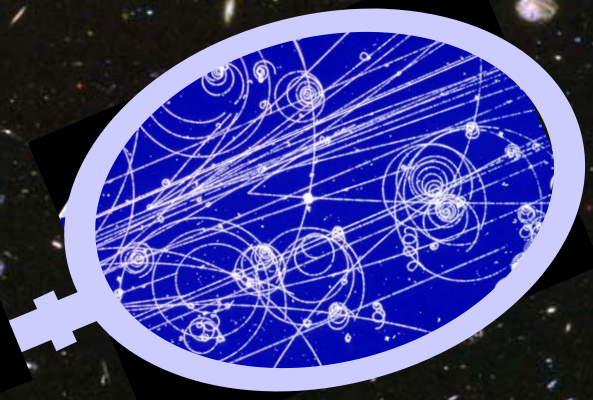
and powerful set of tools:



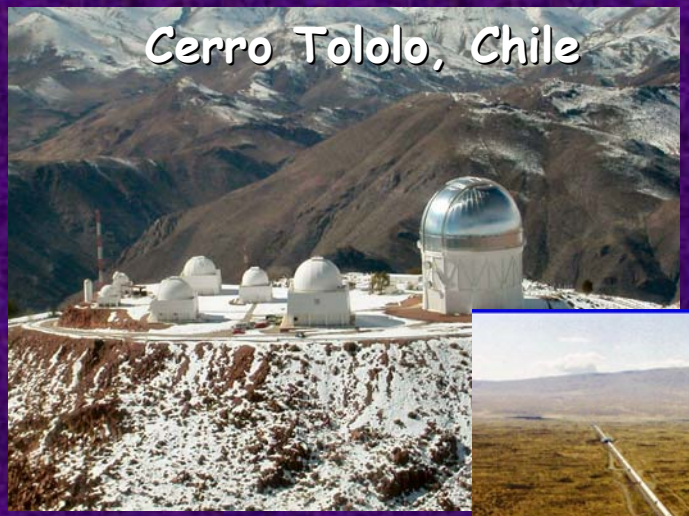
The Frontier Now

- 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



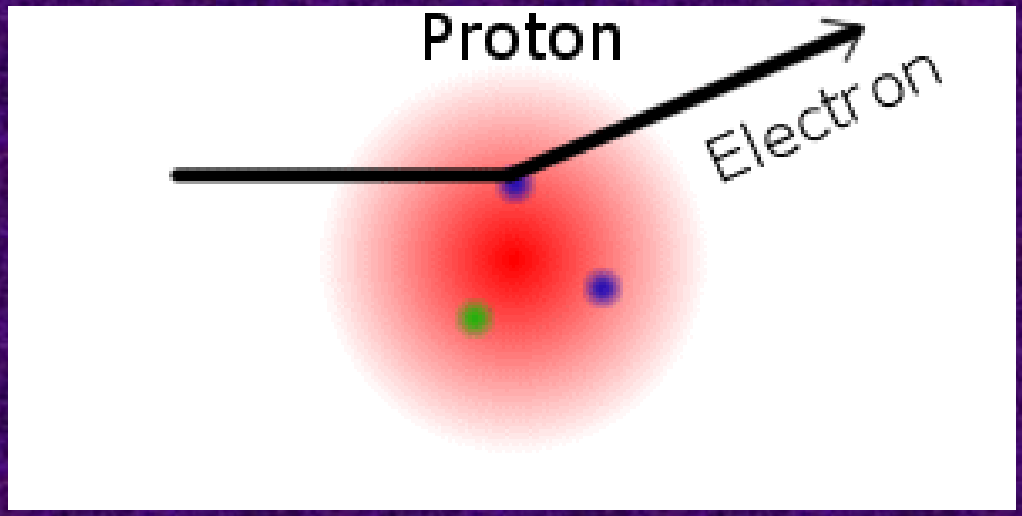
Modern scientific instruments



Particle Accelerators

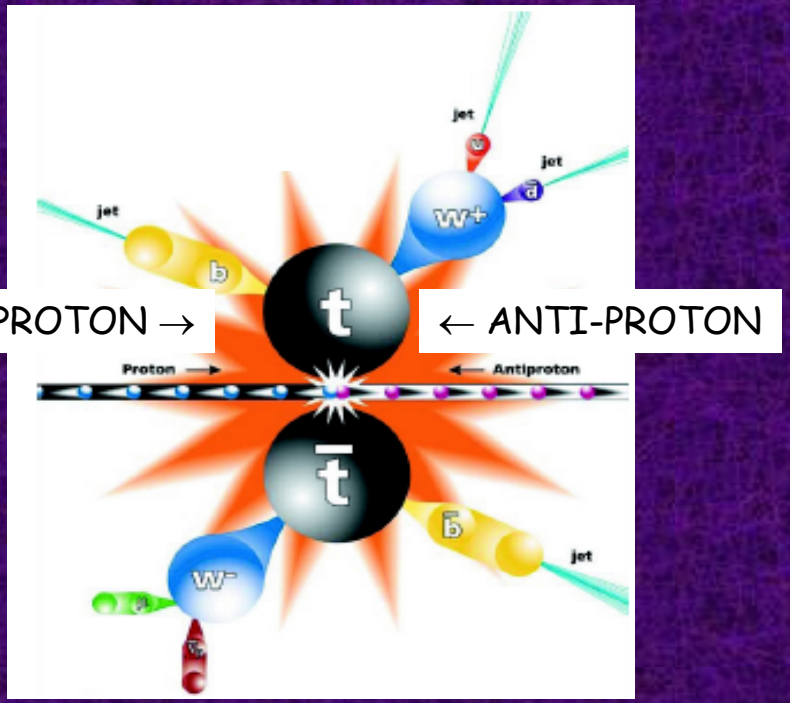
- probe laws of the cosmos in 2 ways

1. Super-microscope



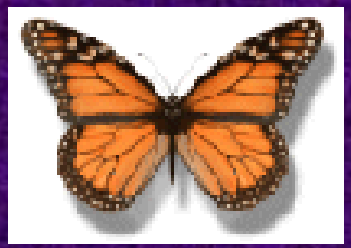
Particle Accelerators

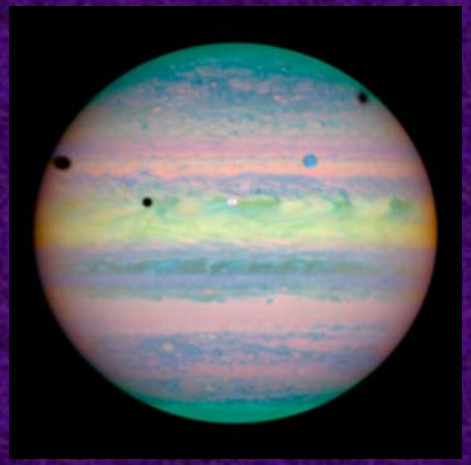
- probe laws of the cosmos in 2 ways
  2. Creation of massive matter ($E=mc^2$)
     - Heavy ordinary matter
     - Dark Matter

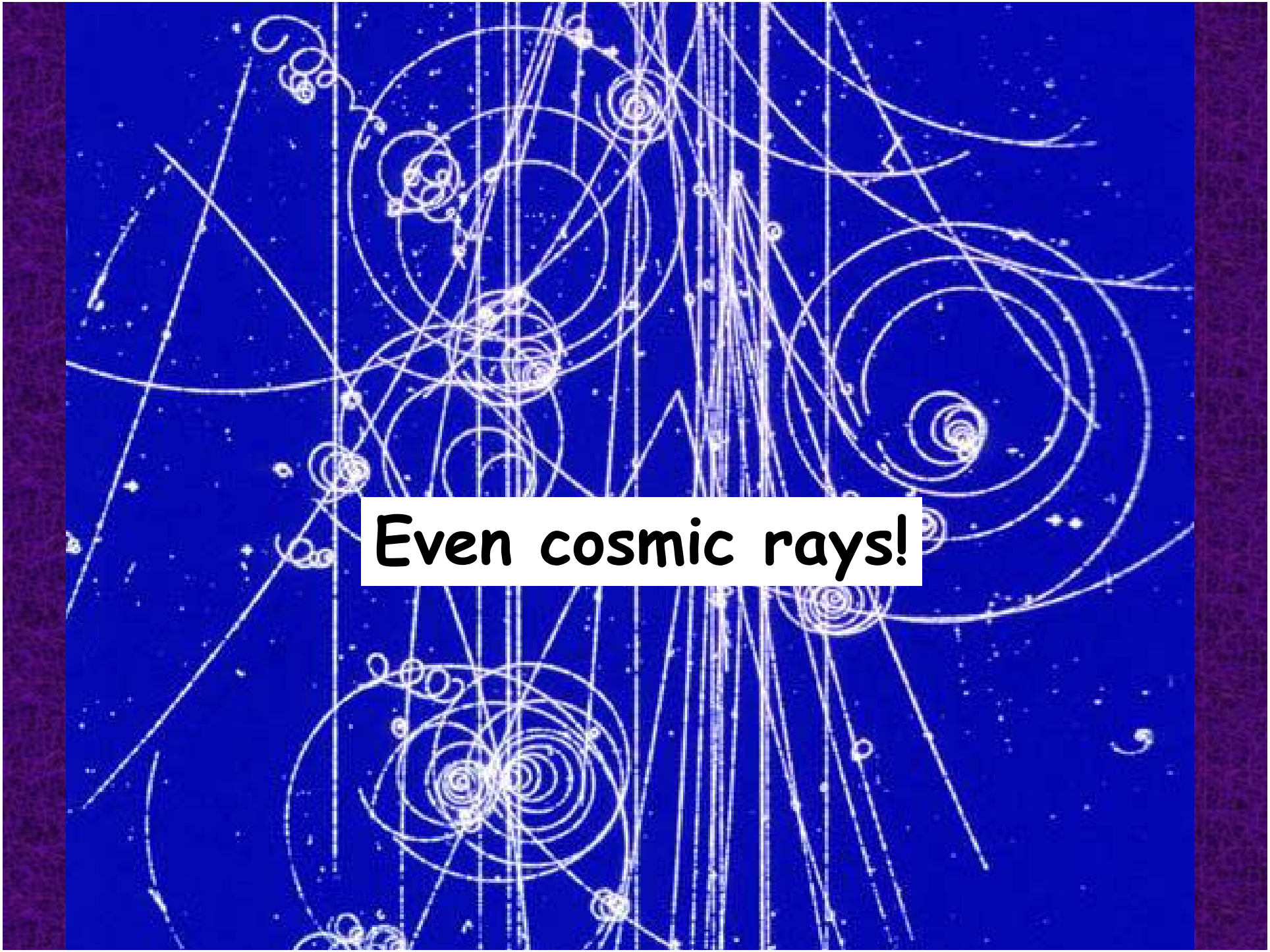


What is matter?

- 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 …

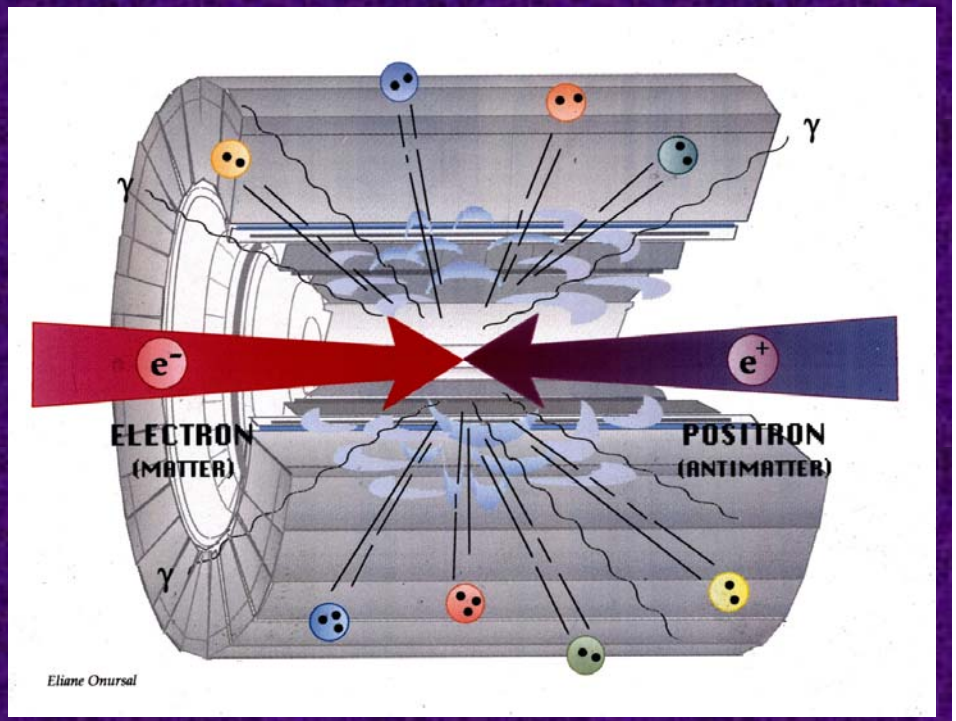





Even cosmic rays!

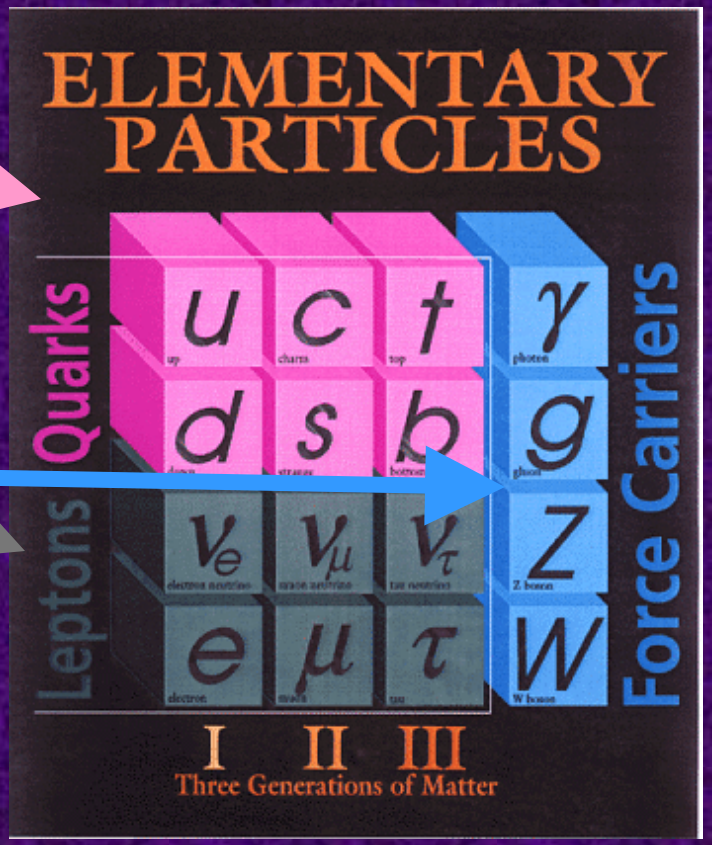
What is matter?

Experiments with particle colliders have advanced our detailed understanding of matter and how it behaves



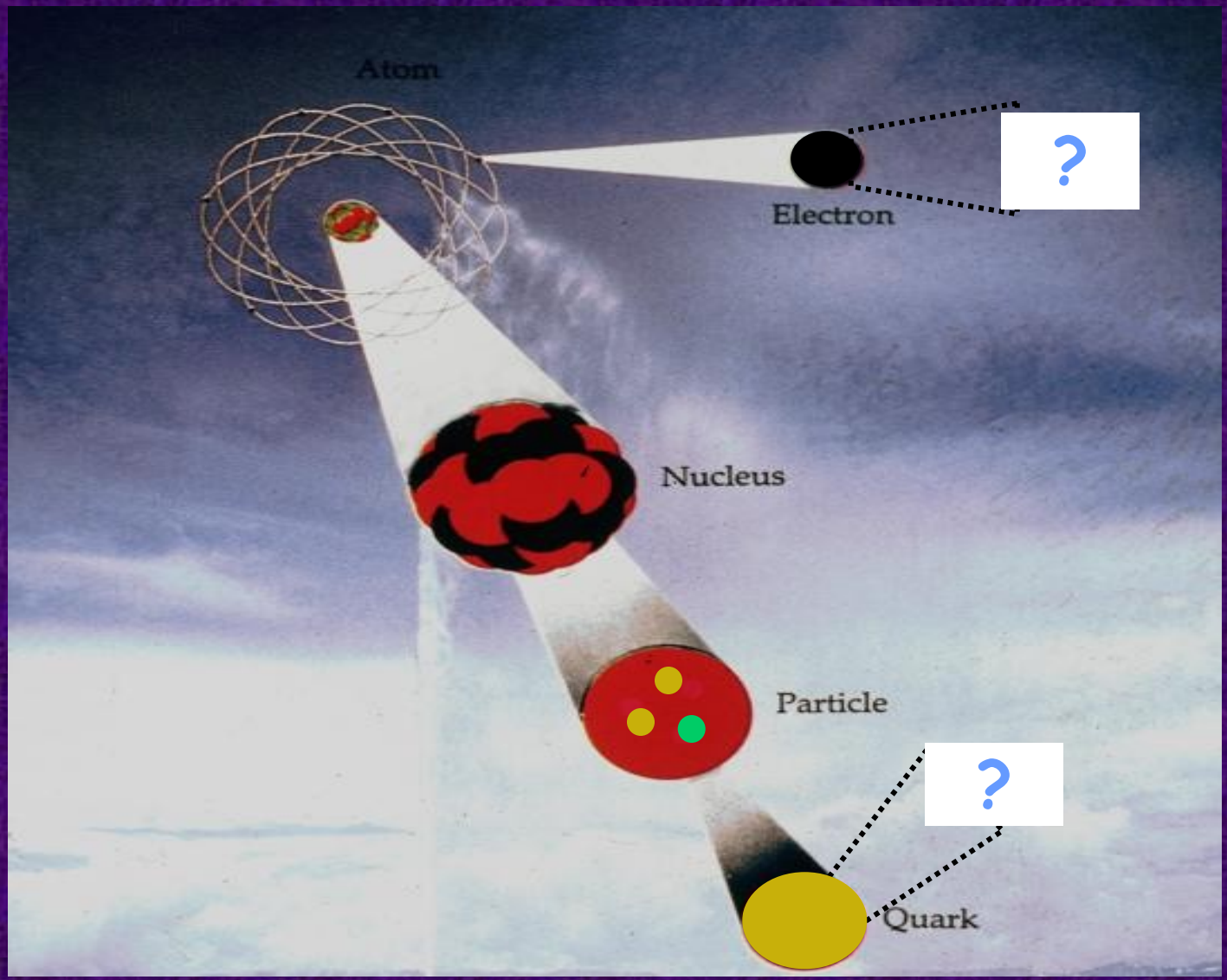
What is matter?

- **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

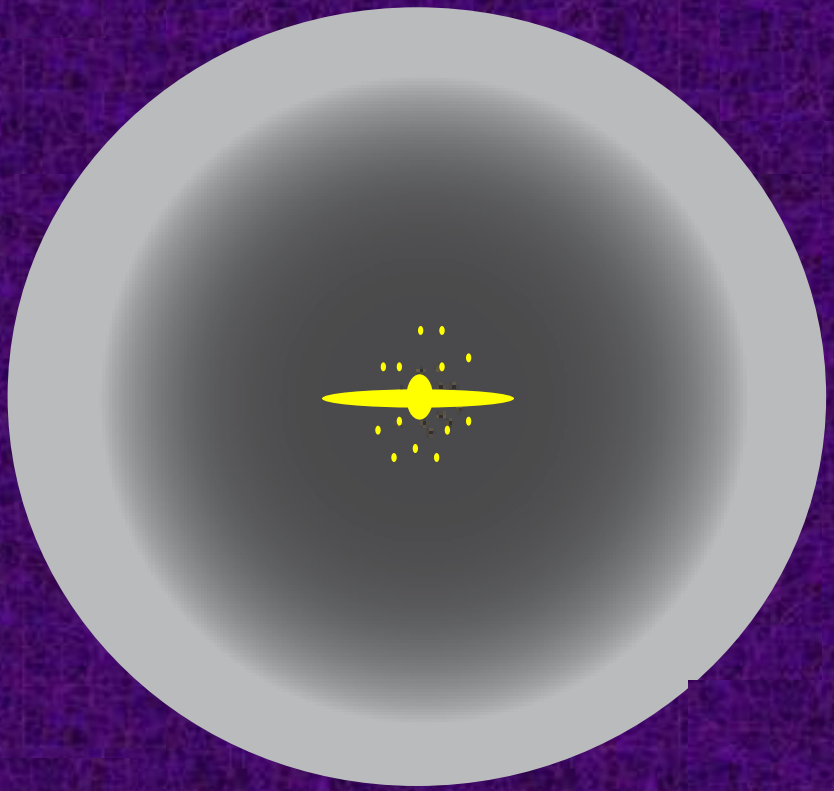
The Structure of Matter



Are atoms alone a sufficient basis for explaining the Universe?

No – not even close

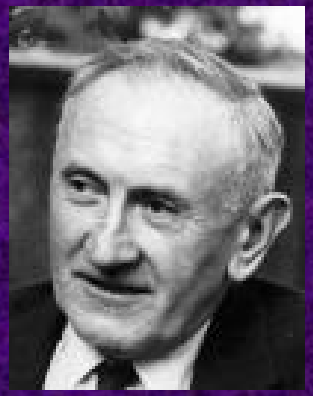
Halo of Dark Matter



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

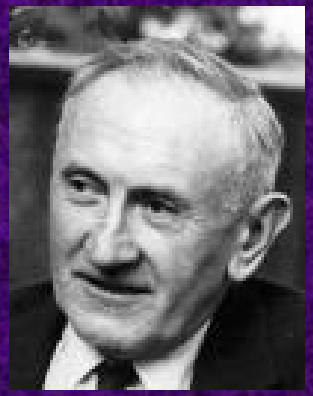
Vera Rubin
1950s

Dark Matter Evidence



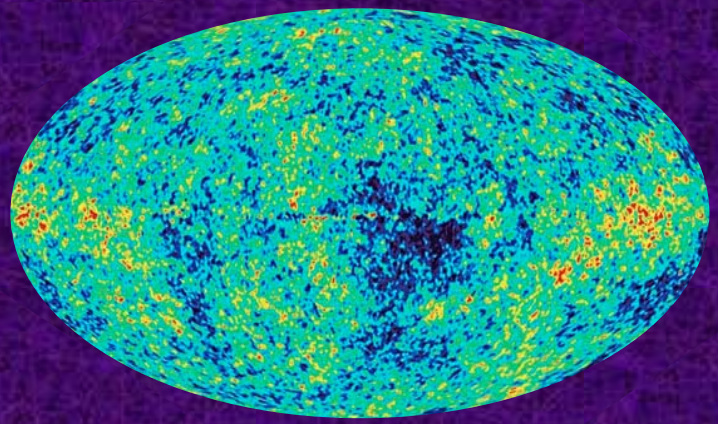
- 1930s motions of clusters of galaxies cannot be understood – Fritz Zwicky

Dark Matter Evidence

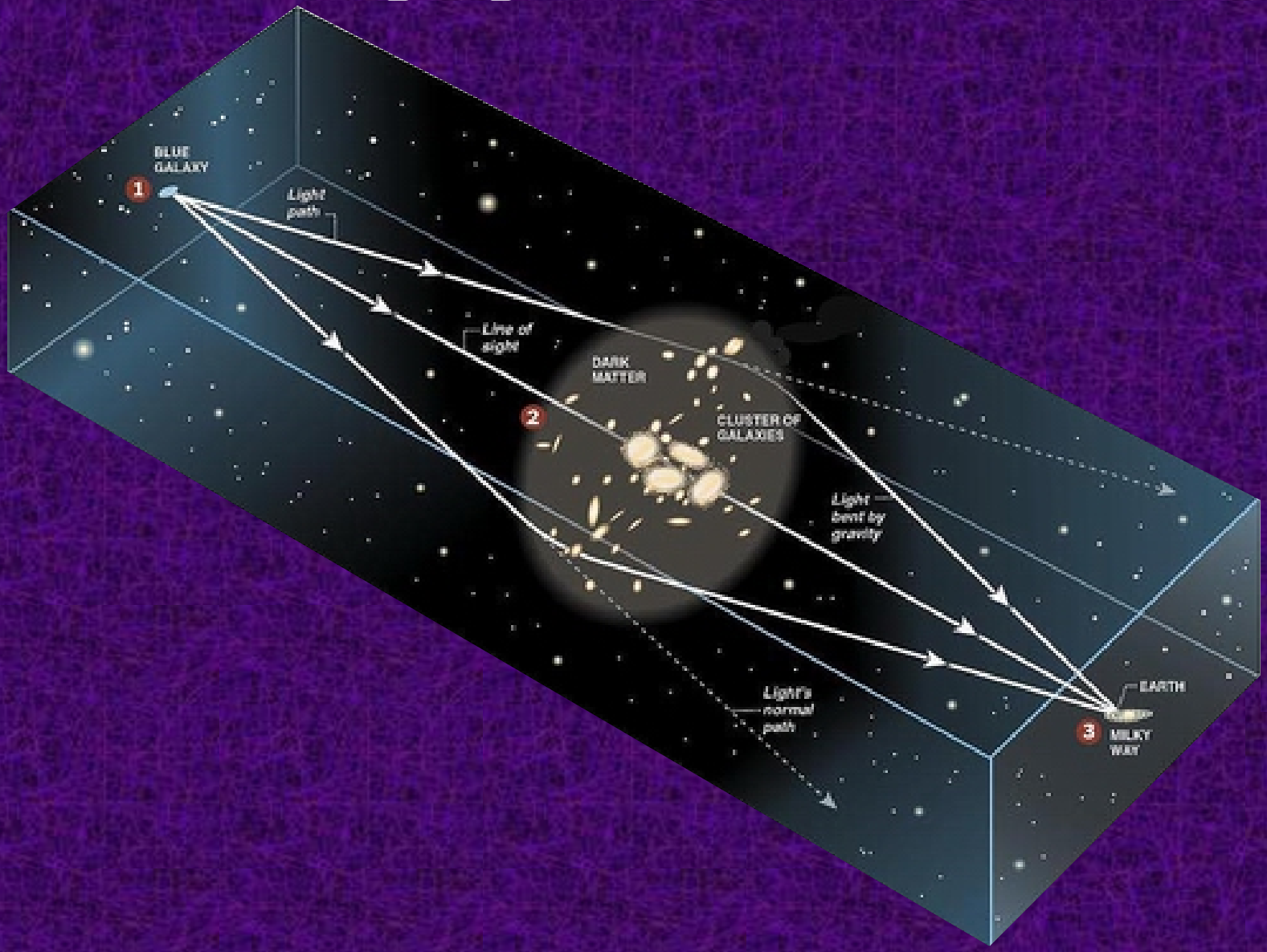


- 1930s motions of clusters of galaxies cannot be understood – Fritz Zwicky

- 1990-2000s Refined studies show dark matter dominance



Imaging Dark Matter



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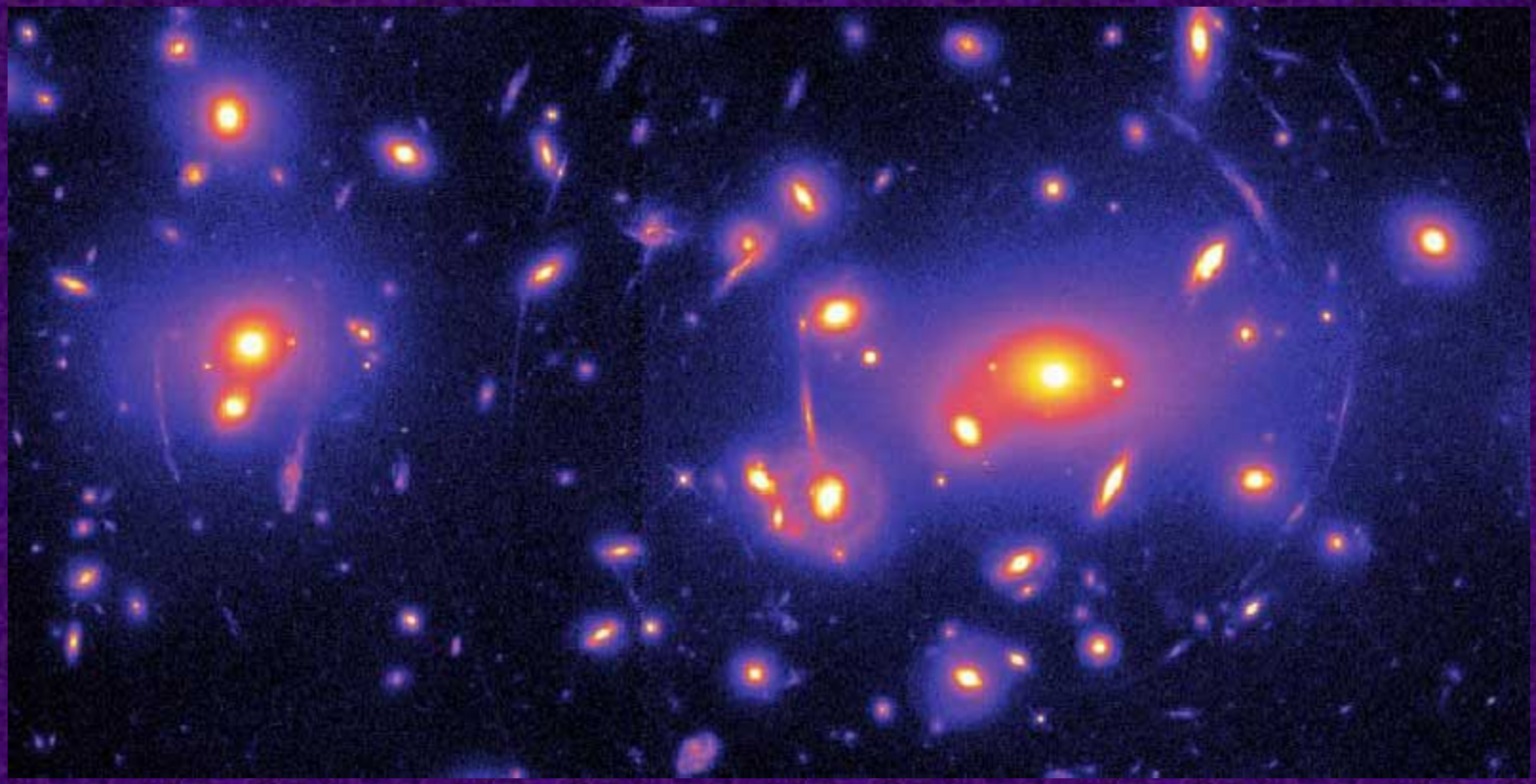


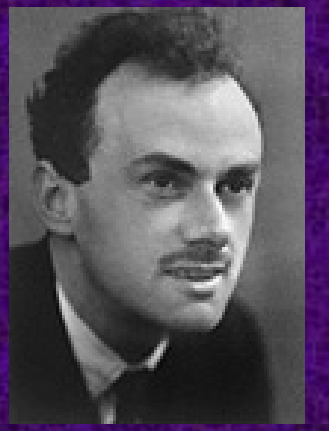
Hubble Data analyzed by Yale astrophysicists

Univ of Oregon Jim Brau May 19, 2005

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 in particles



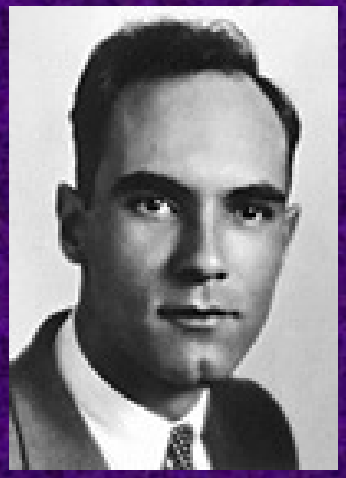
- 1928, Paul A.M. Dirac
  - Theory of the electron
  - Combining relativity and quantum mechanics

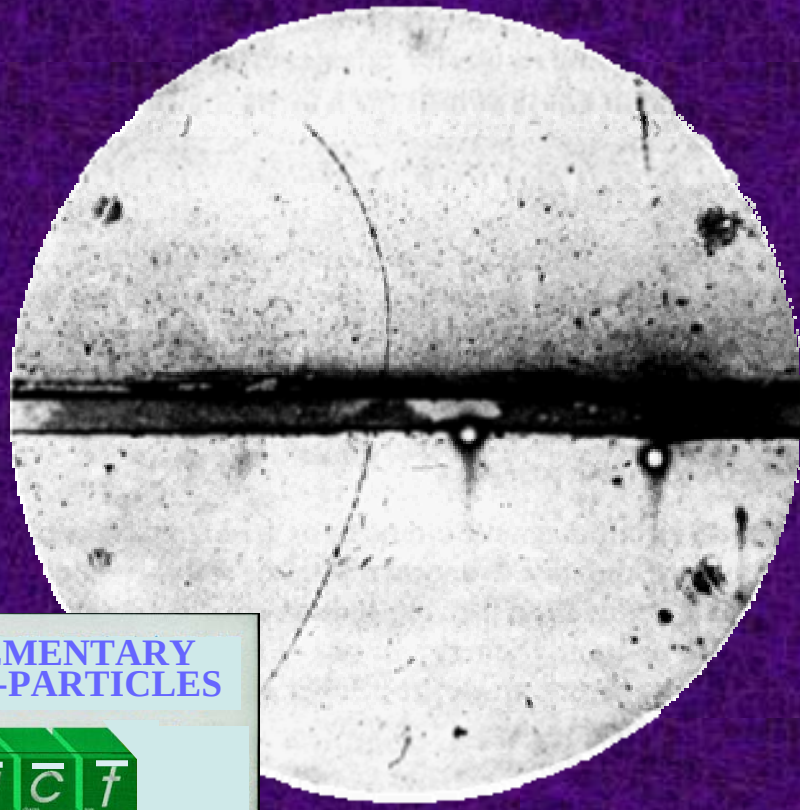
- He needed to assume there were partner particles for every known particle

  - ANTI-MATTER
  - DOUBLED THE NUMBER OF PARTICLES

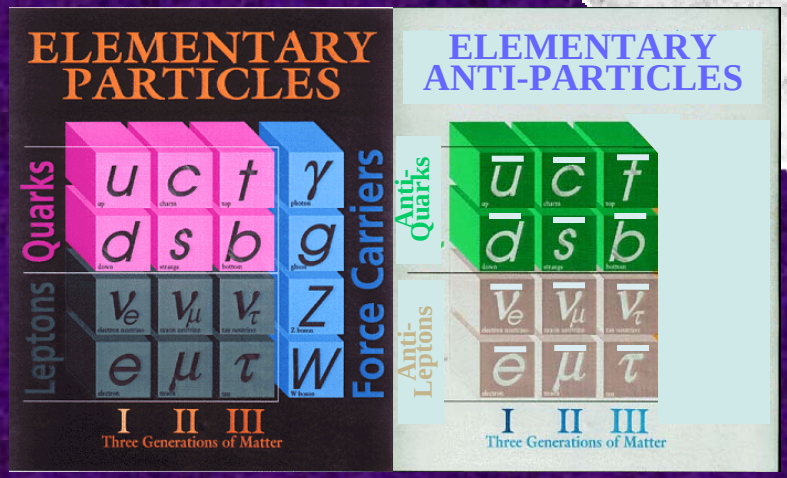
Discovery of Anti-Matter

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



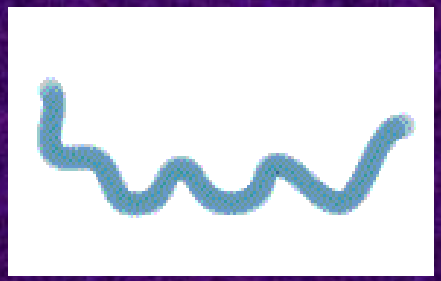


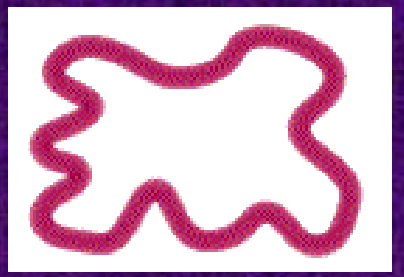
All known particles have anti-particles



SuperString Theory

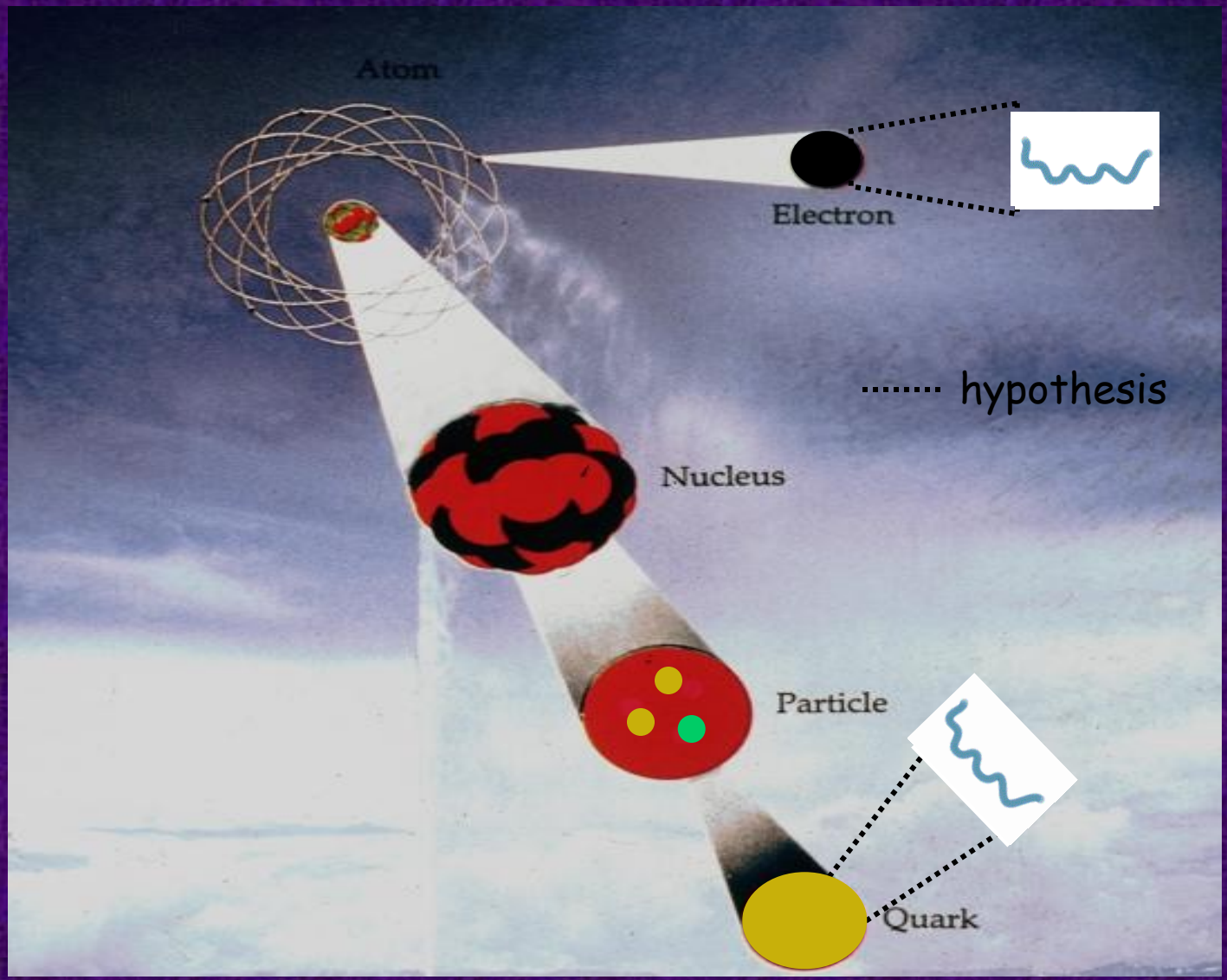
- Unifies all particles and all forces
  - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string





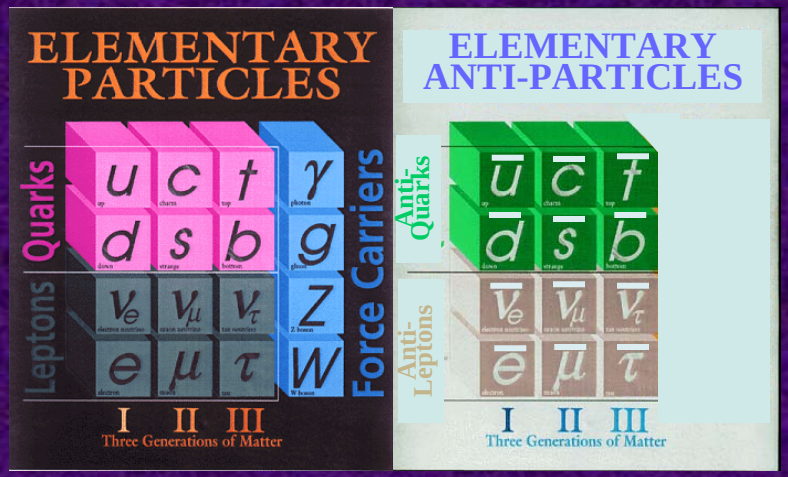
  - String is miniscule
    - Atom is 10,000,000,000,000,000,000,000,000 x bigger
  - Space is ten-dimensional (not 3D!)
  - A matching set of particles appear
    - the super-partners of ordinary particles

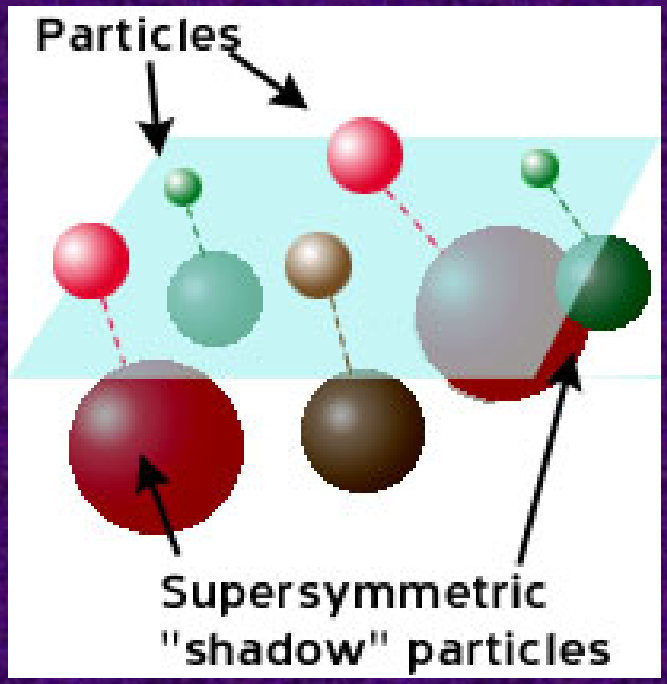
The Structure of Matter



Supersymmetry and Strings

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

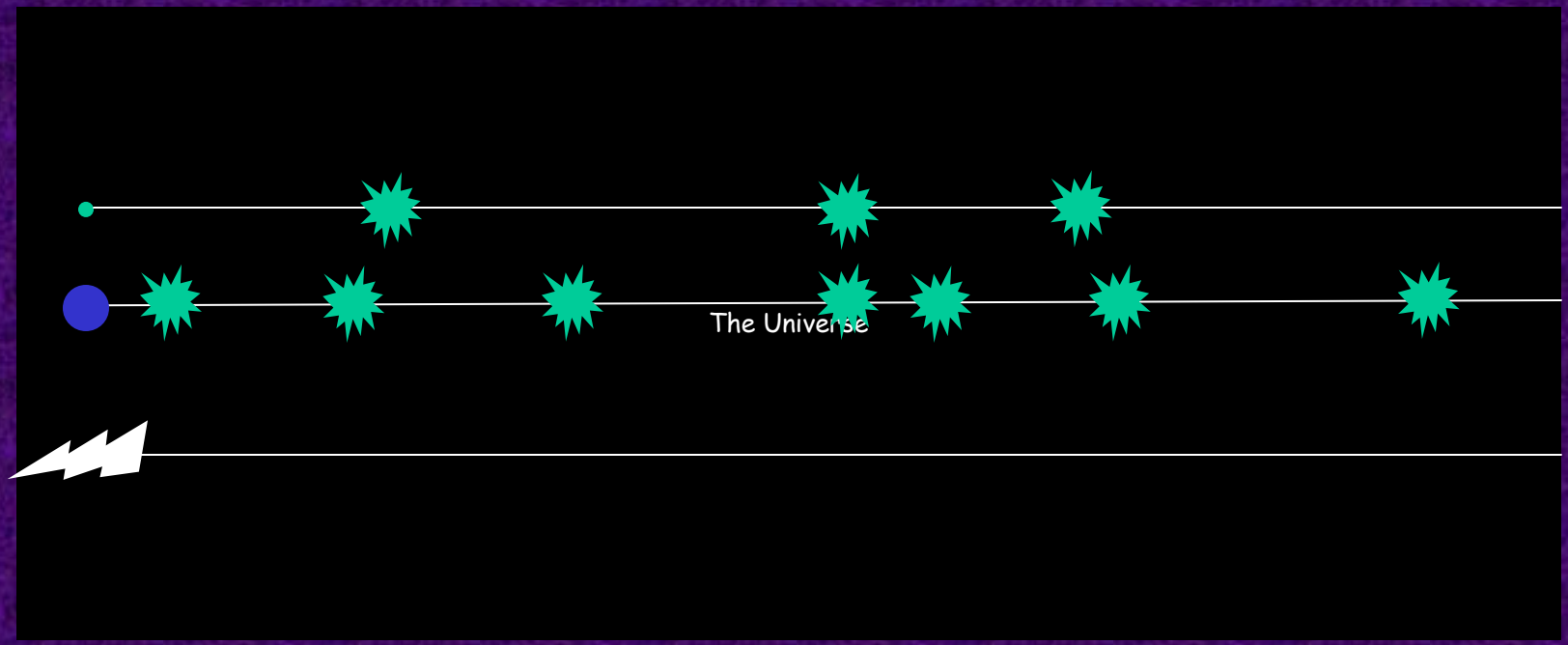




- The supersymmetric particles have just the properties expected of Dark Matter

Another puzzle
What gives matter mass?

- An ocean of Higgs Bosons - "Higgs Field"

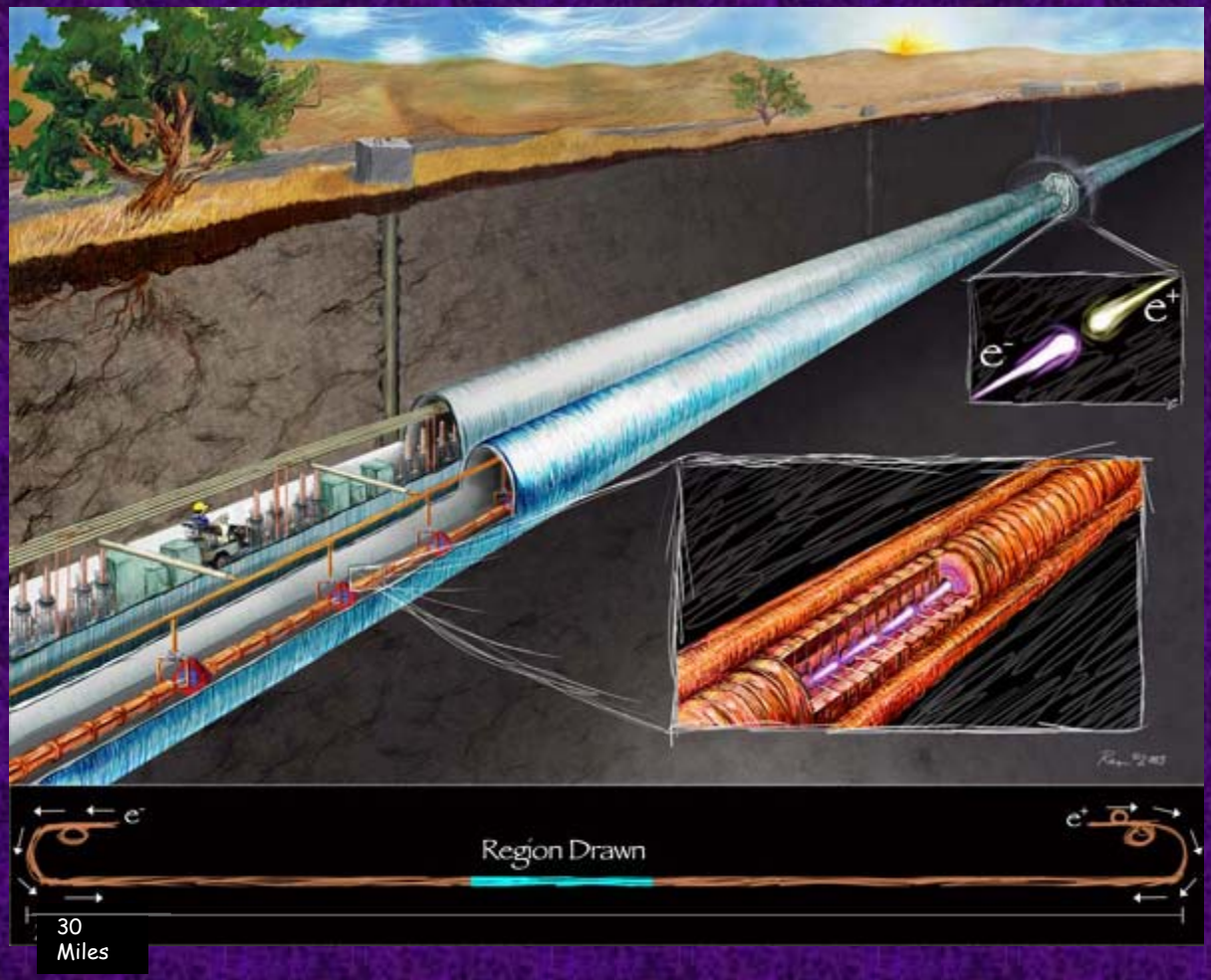


Large Hadron Collider (LHC)
Geneva, Switzerland

Nearing Completion

Begins operation in 2007

International Linear Collider (ILC)



Under development

Planned to begin operation soon after 2015

The Big Bang

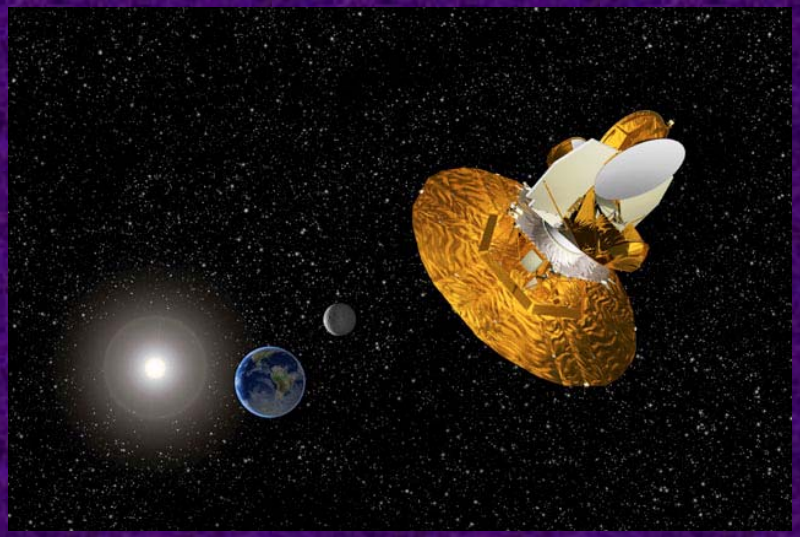
- Fundamental Physics needed to understand Big Bang

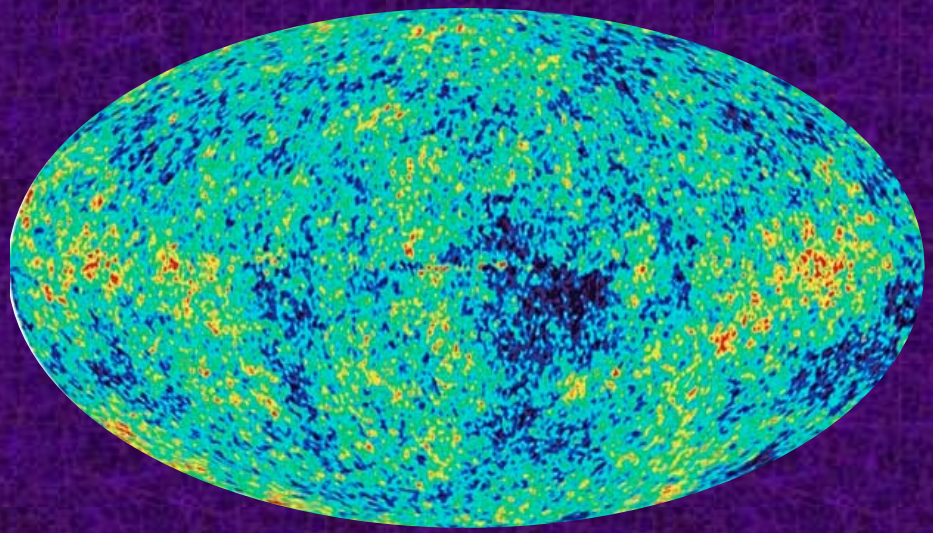
The Cosmic Fireball

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

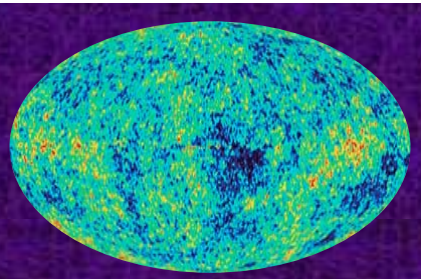
Probing the Big Bang

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

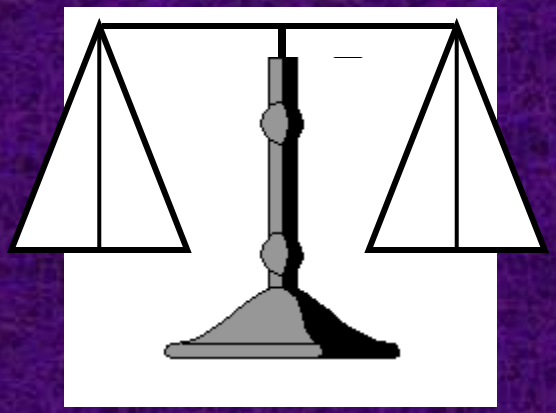




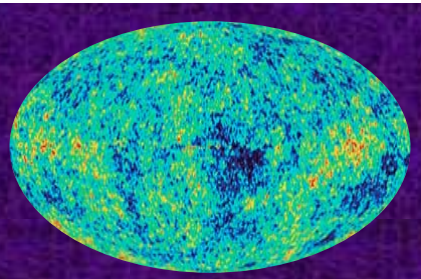
Probing the Big Bang



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



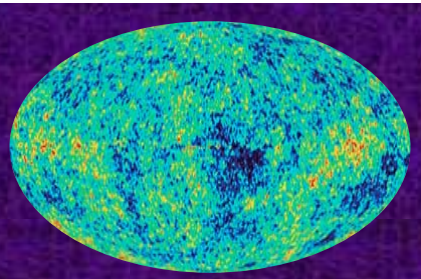
Probing the Big Bang



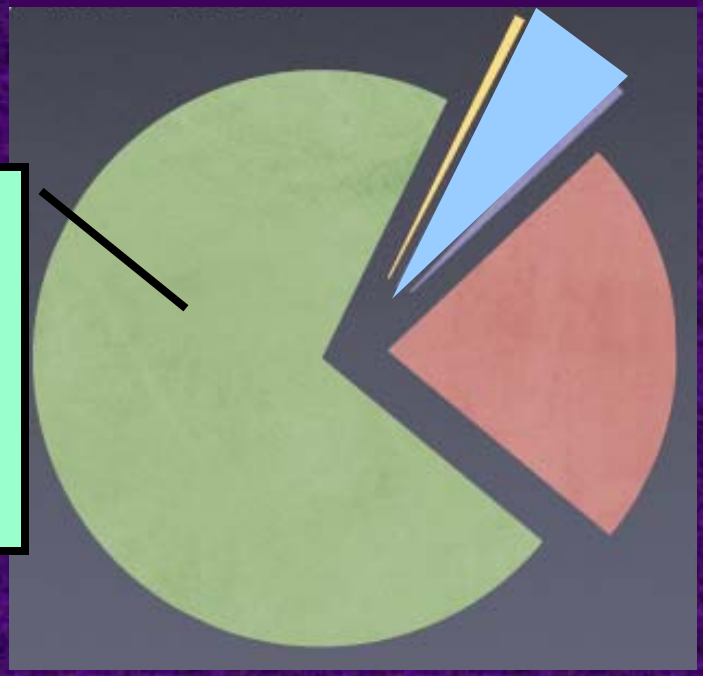
- The stars are a very small fraction

- Additional ordinary matter, Still a small fraction
- Anti- matter miniscule

Probing the Big Bang

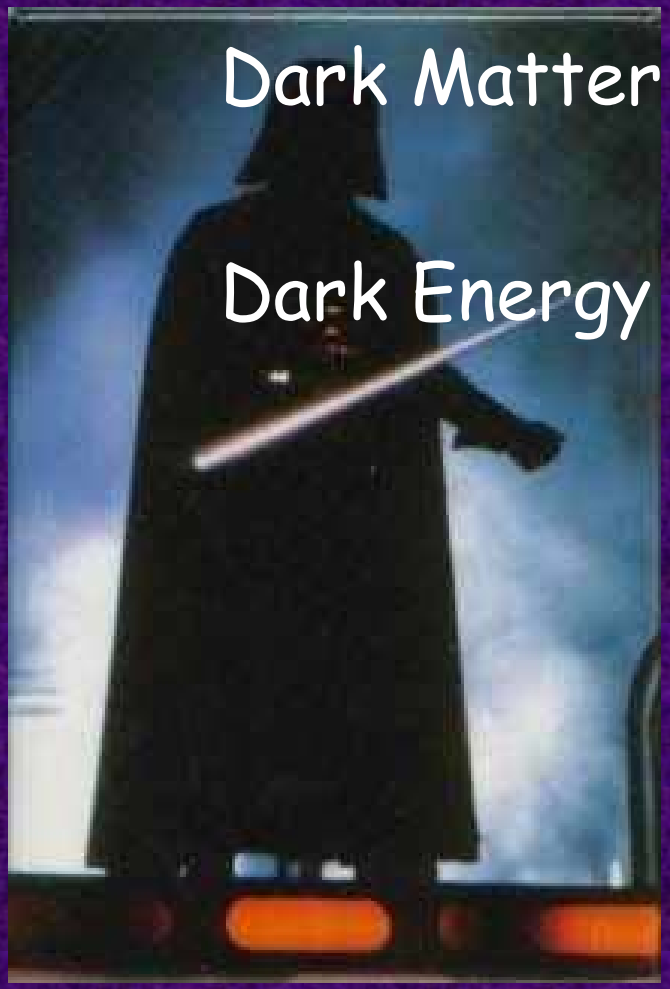


- The dominant "weight" of the universe is dark matter and dark energy



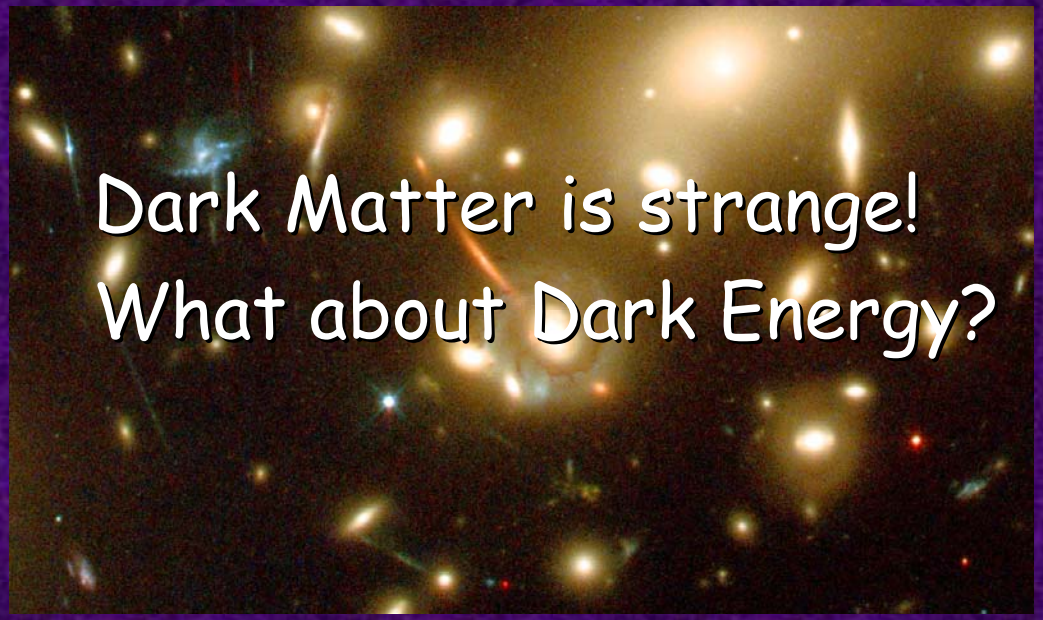
- Dark Energy Surprise
- Related to Einstein's Cosmological Constant

The Dark Side Controls the Universe

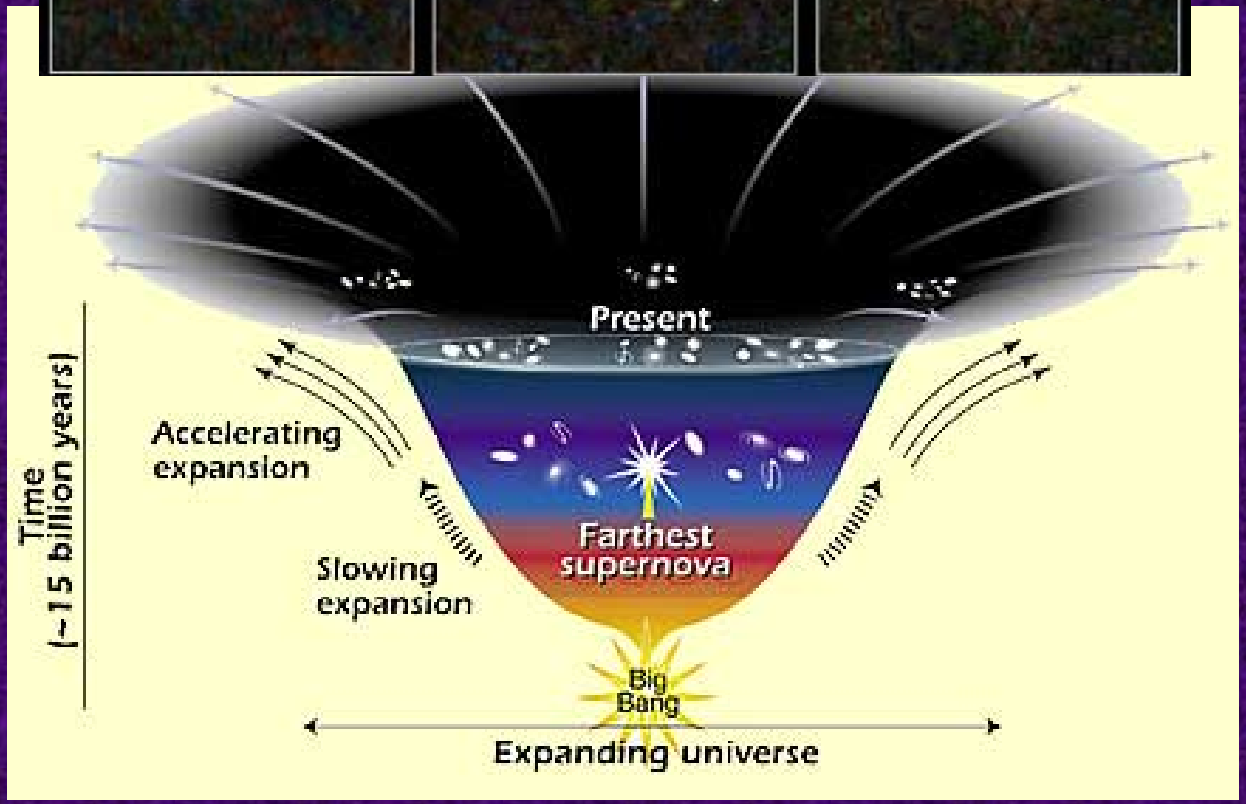


Dark Matter HOLDS IT TOGETHER

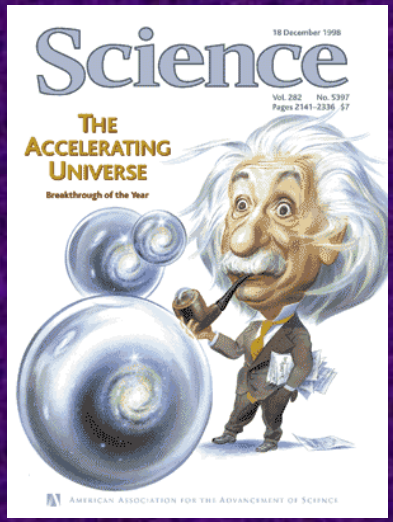
Dark Energy DETERMINES ITS DESTINY

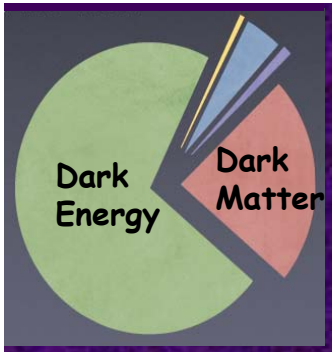


Measuring the Universe' Expansion



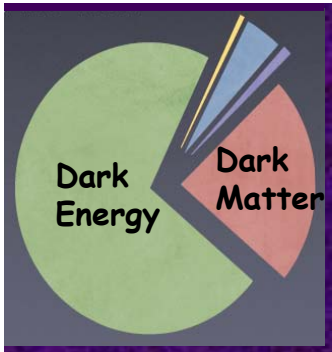
Acceleration Driven by Dark Energy





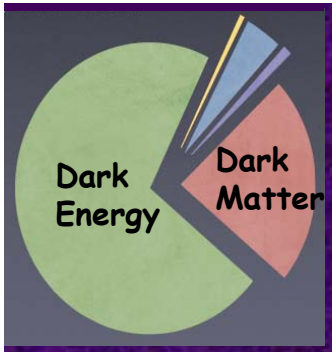
The Dark Energy
Something from Nothing

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

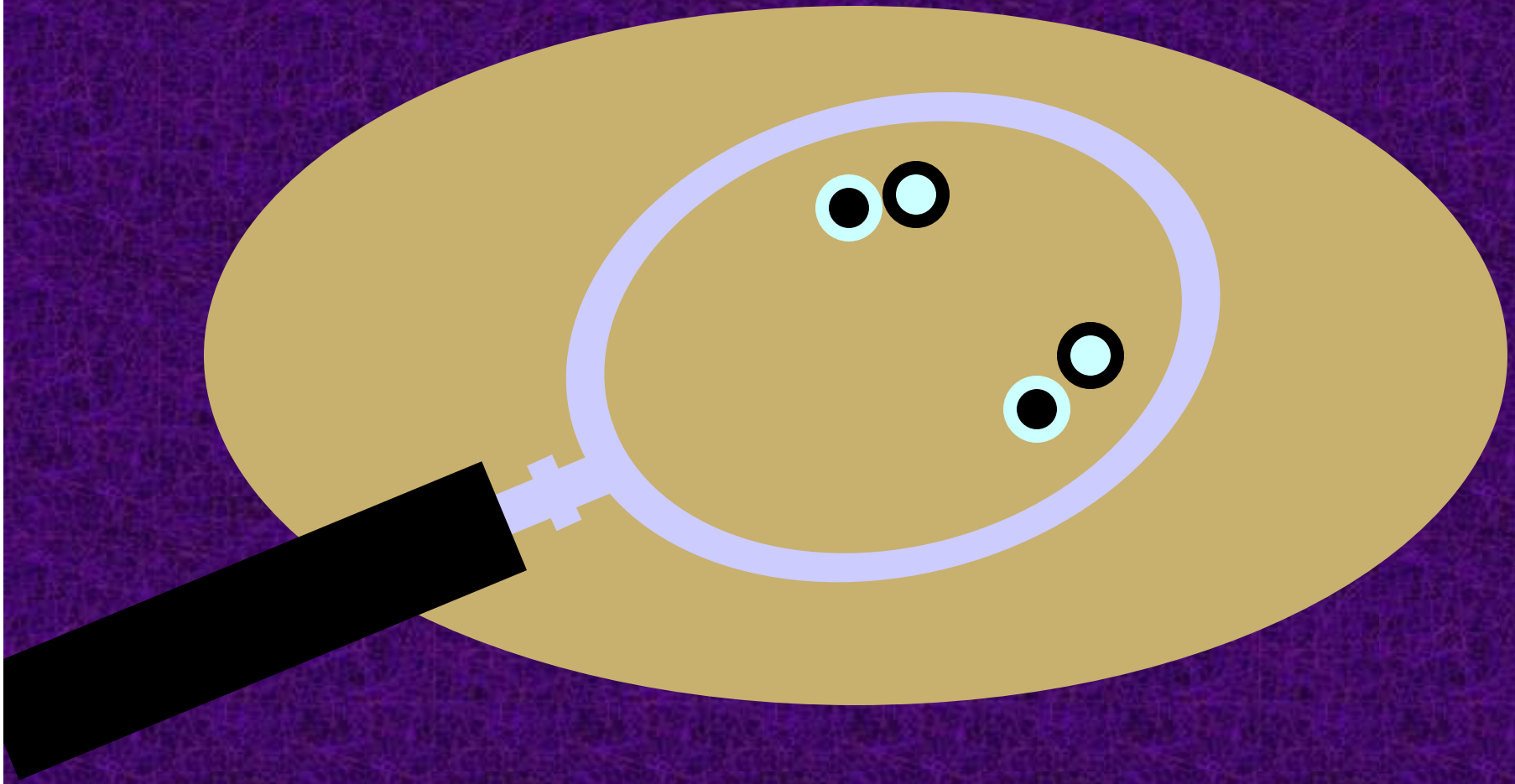


The Dark Energy
Something from Nothing

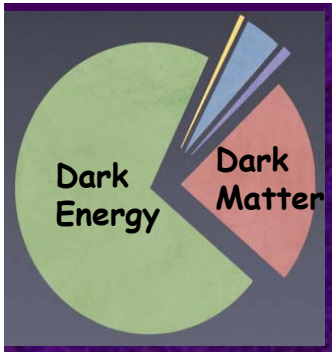
Empty Space



The Dark Energy
Something from Nothing



Univ of Oregon Jim Brau May 19, 2005



The Dark Energy
Something from Nothing

Quantum Fluctuations Create a "Dark Energy"

- Cosmological constant

Something from Nothing

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

uum energy is the sum of all the simple harı

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

λ) for the scalar field. This sum may be eva
go to infinity. The periodic boundary condi
eger values of n. There are then $Ldk/2\pi$ disc
es an integral:

$$E_o = \frac{1}{4\pi}\hbar L^3 \int \frac{\omega}{(2\pi)^3} d^3k$$

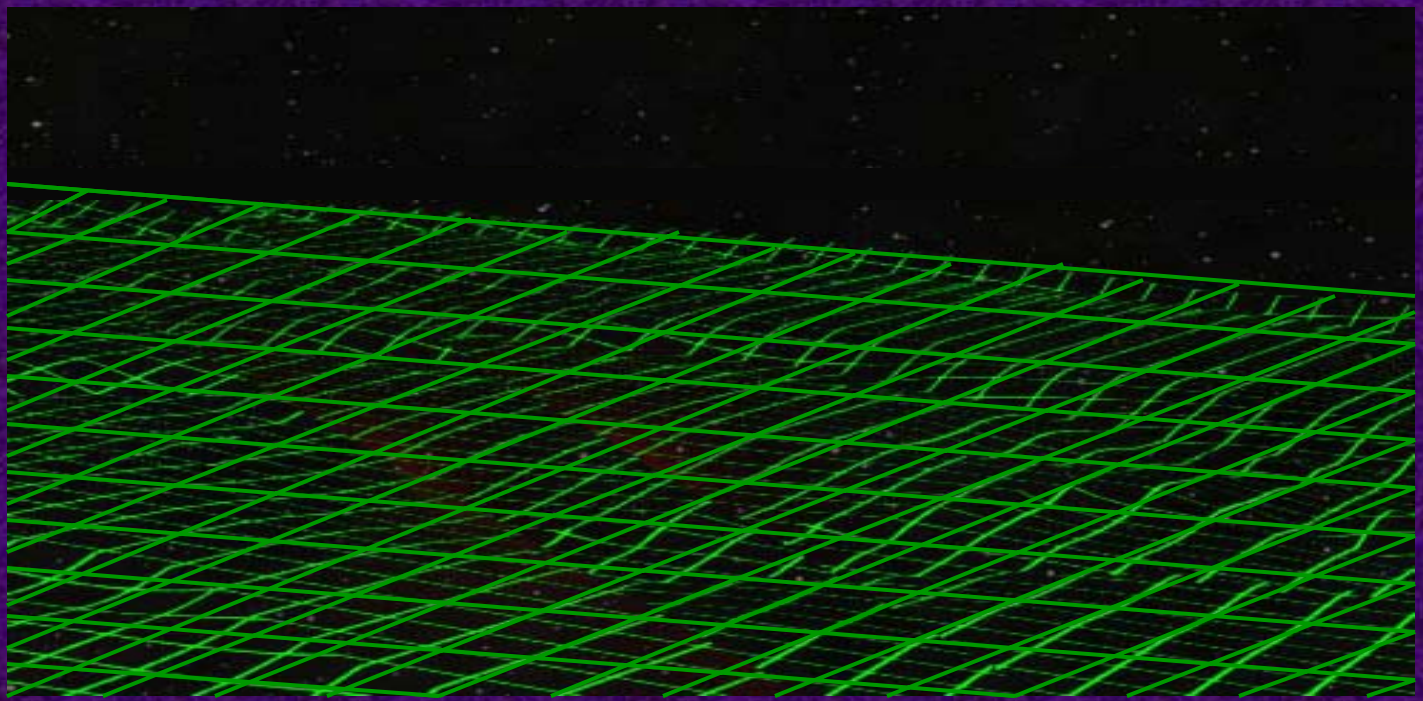
pose a cutoff at a maximum wavevector k_{ma}

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

- We can calculate the effect of these virtual particles on <u>Dark Energy</u>
  - This theoretical result is <u>too big</u>
  - By a factor of 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,
000,000,000,000,000,000,000,000,000,000,000,000,000
  - This is a BIG-time mystery
    - we know how the universe might make Dark Energy, but we don't know how to make so little

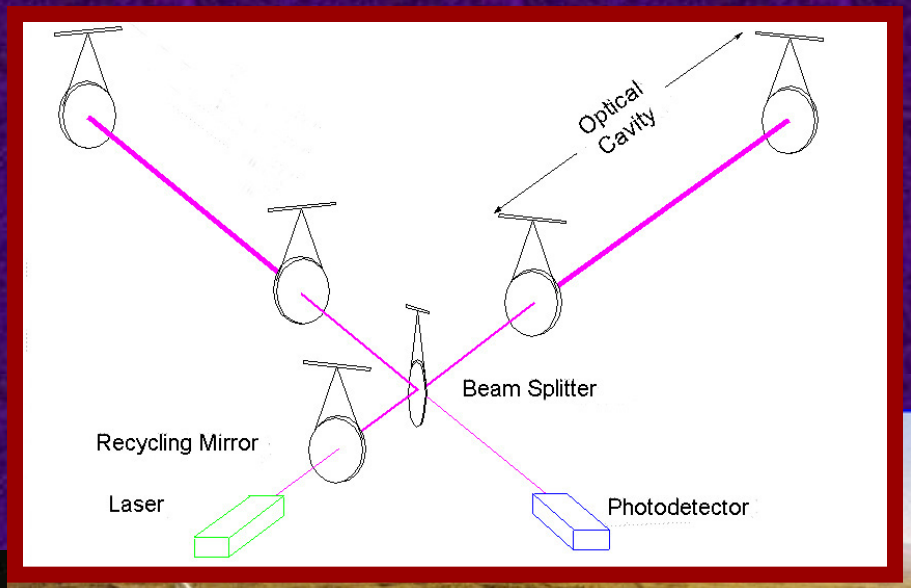
Seeking the Primordial Gravity Waves

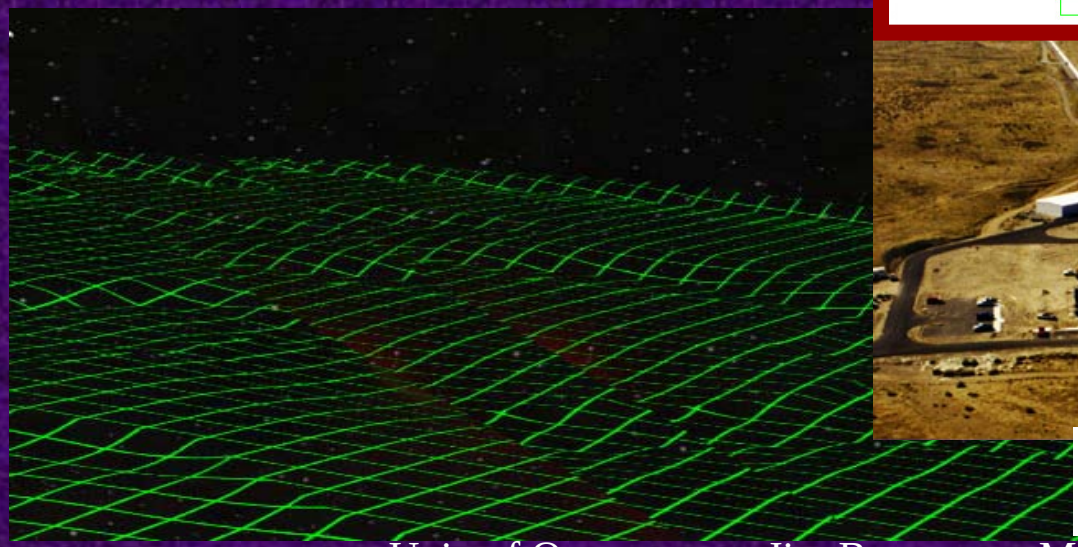
- The fabric of the universe
  is still rattling from the violent Big Bang

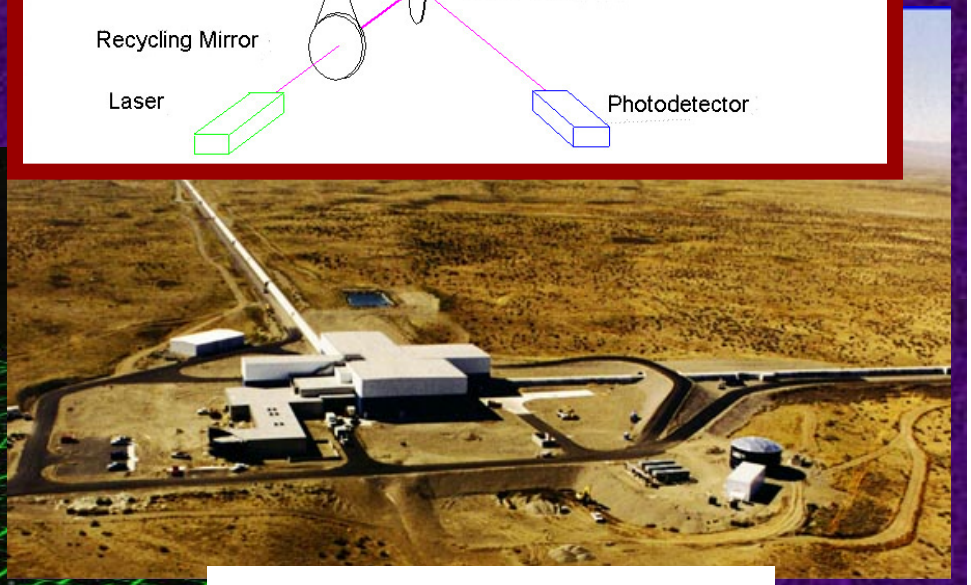


Primordial Gravity Waves

- LIGO looks for evidence of gravity waves

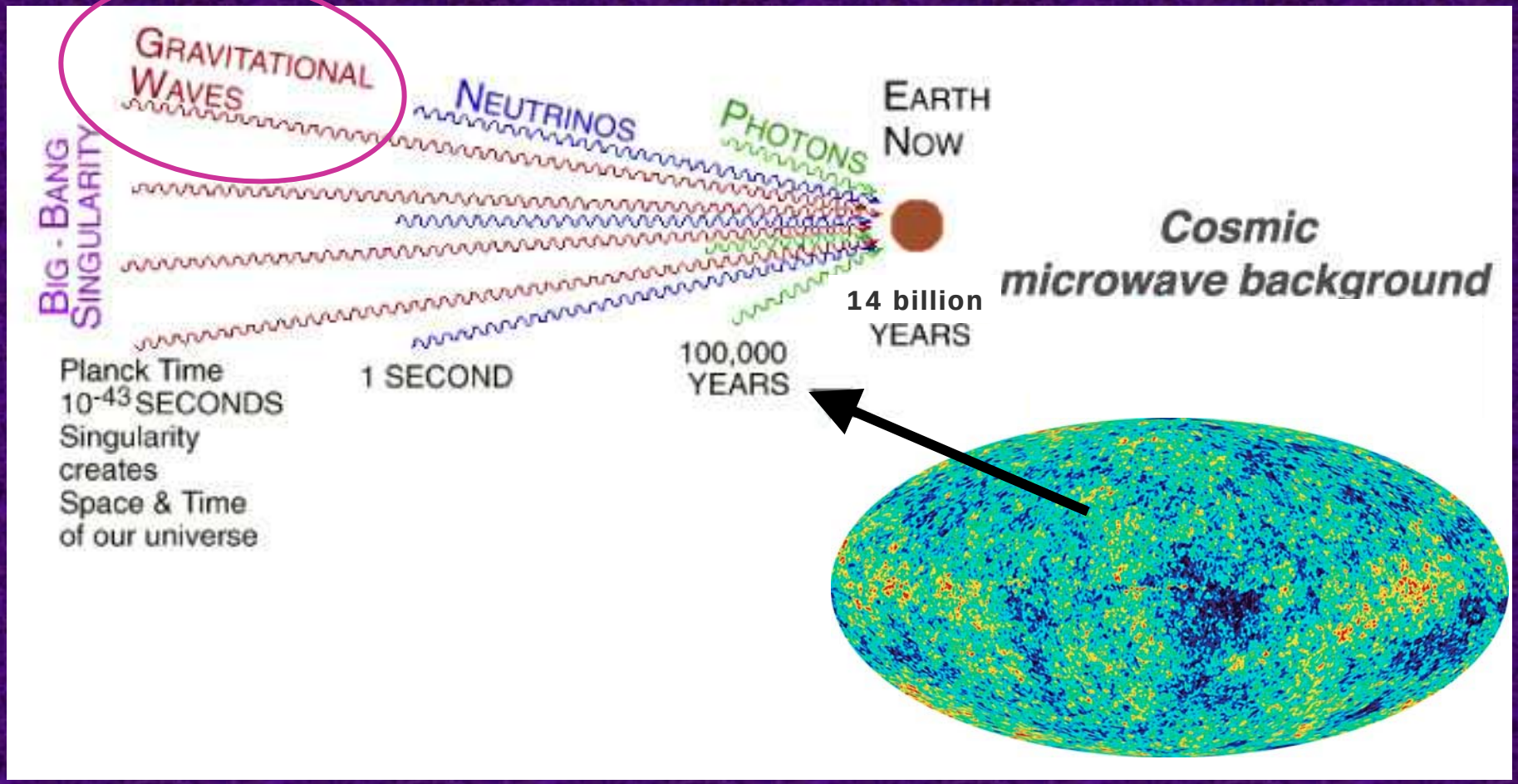






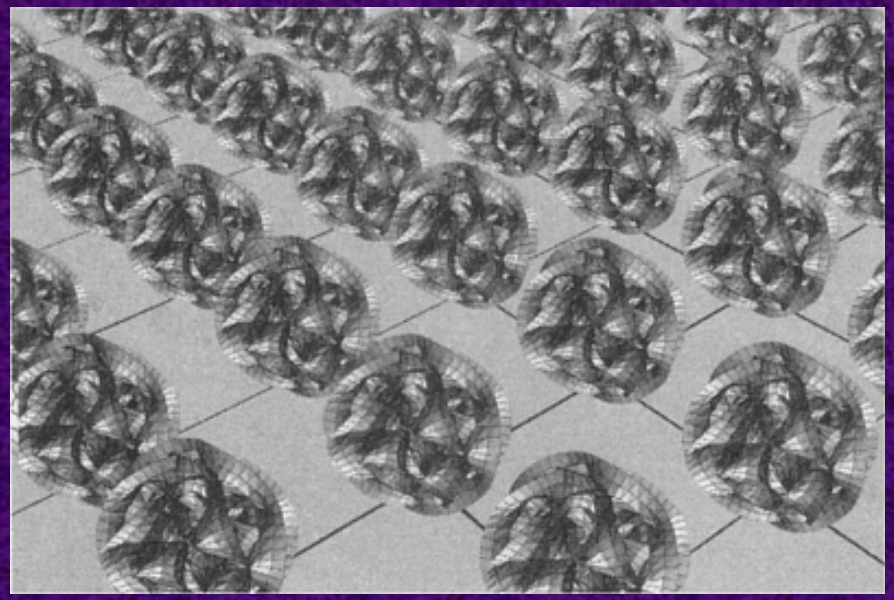
Hanford LIGO

Gravity Waves Probe the Extremely Early Universe



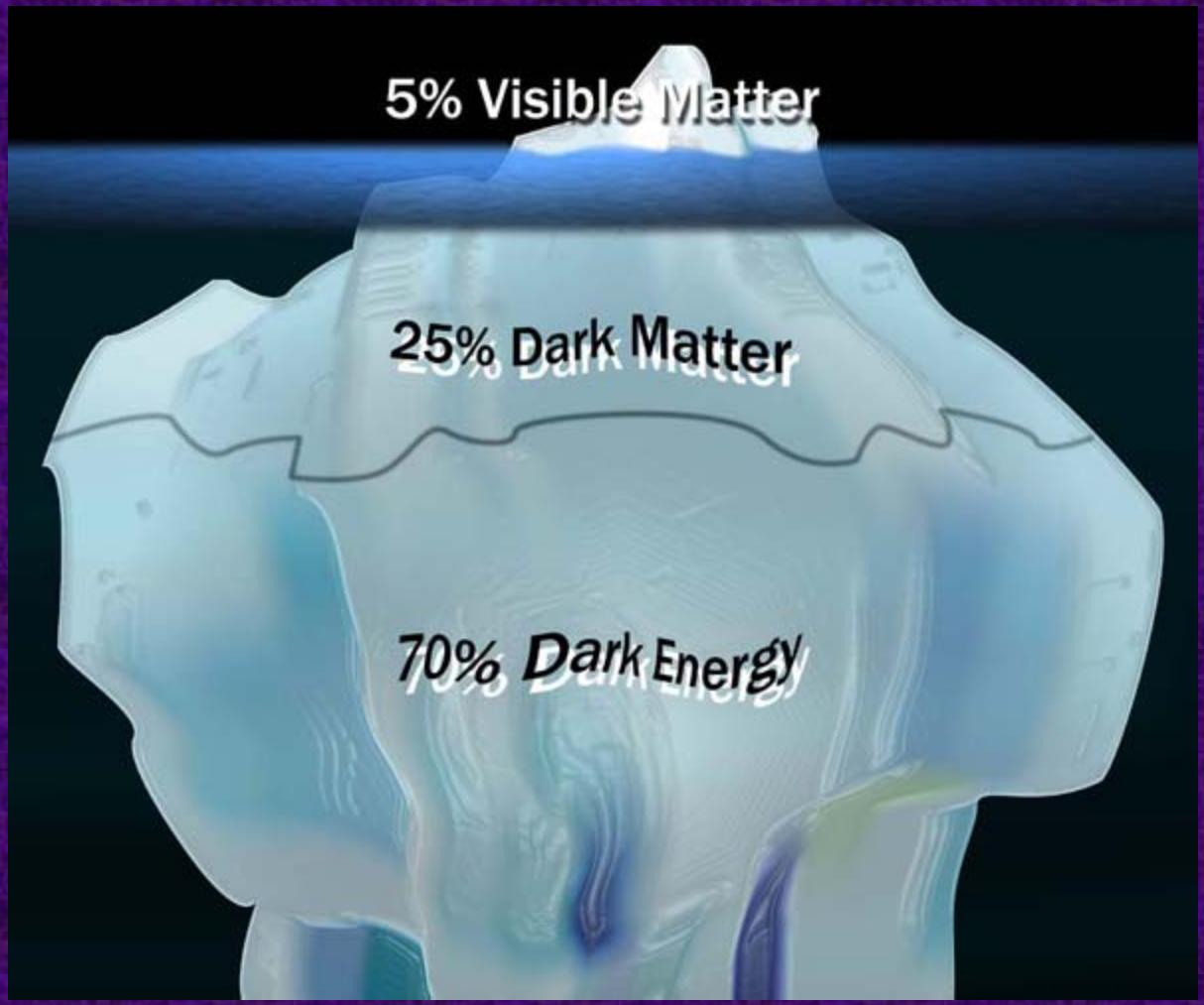
Extra Dimensions

- String Theory
  - 10-dimensional space



- Particle Collider Experiments are looking for these hidden dimensions

Our Mysterious Universe



Realizing Einstein's Dream

- We are on the eve of a revolution in physics
  - Many mysteries
  - Solutions appear near
  - Deeper understanding of the universe itself
- Gravity waves may image earliest moments of Big Bang
- Dark Matter particles – may appear soon in particle collider experiments
- Why is there mass? – Higgs Boson
- Dark Energy – this is the biggest mystery of all

Acknowledgements

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Department of Energy
OFFICE OF SCIENCE

NATIONAL SCIENCE FOUNDATION