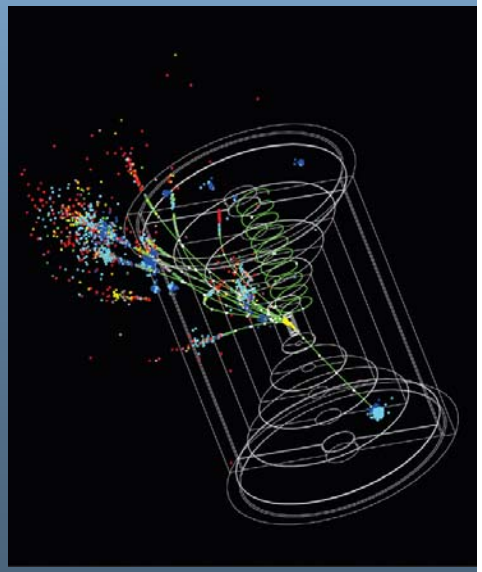
The Mysterious Frontiers of Our Universe, BIG and small

- What is it made of?
- How does it work?
- What is its geometry?
- How did it begin?



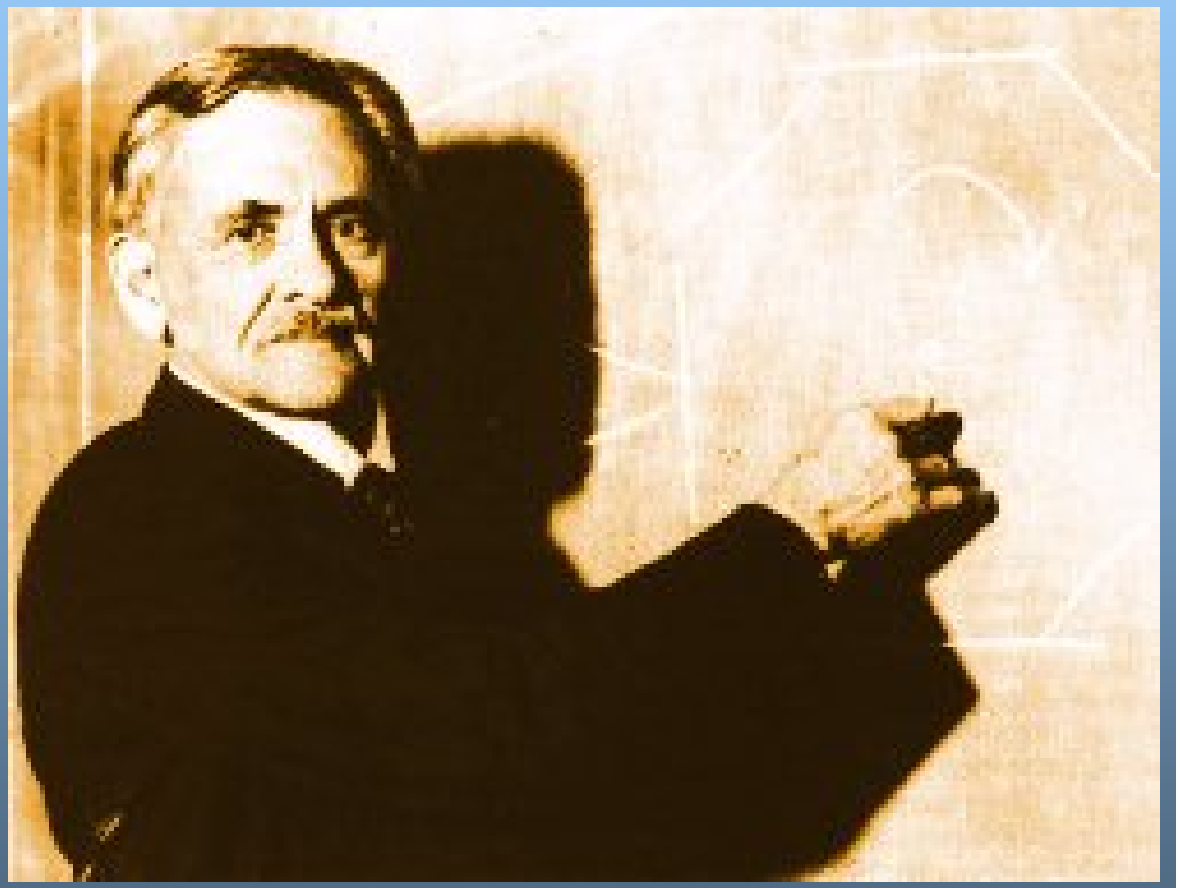
The End of Physics

"The more important fundamental laws and facts of physical science have all been discovered,

and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote."

The End of Physics

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



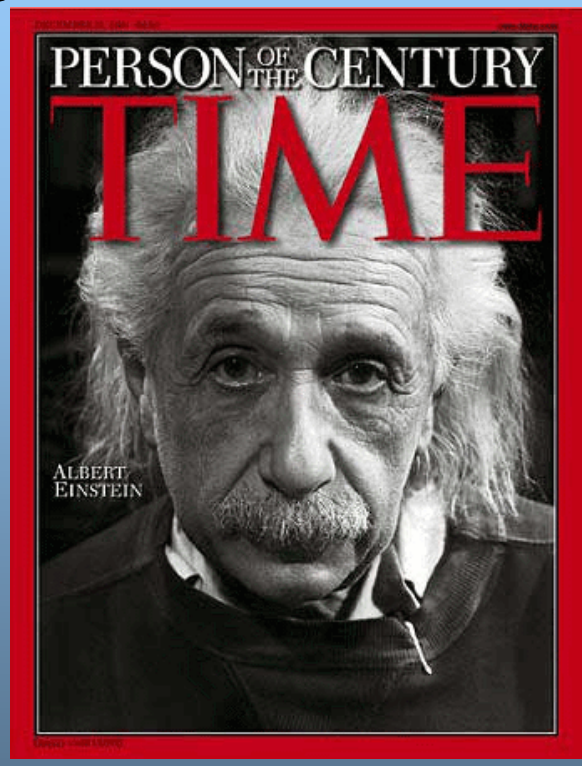
The Miracle Year - 1905

Relativity
Quantum Physics
Atoms

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

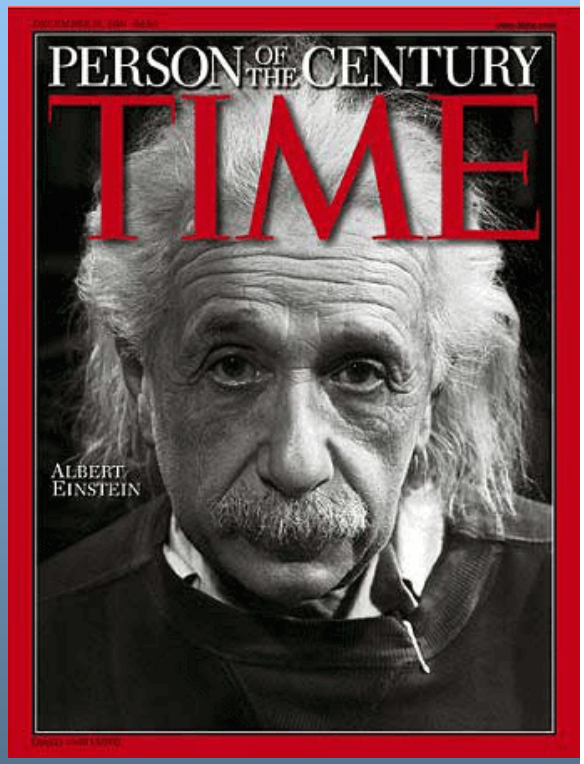
Einstein's Theoretical Discoveries

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



Einstein's Theoretical Discoveries

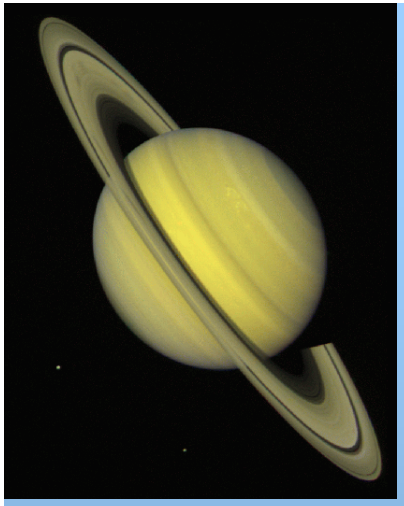
- Light comes in small packets - photons
- The speed of light is a constant
  - Independent of observer's motion
- $E=mc^2$
- Space is warped by massive objects
- "Cosmological constant"
- Many other important discoveries



- Remain central to our exploration of the universe

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.

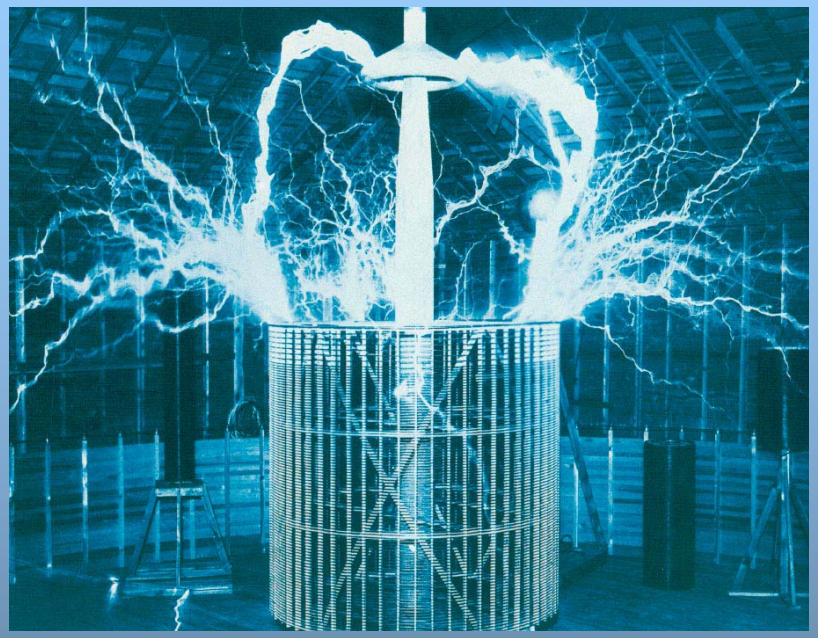


Einstein's Dream

To understand the underlying simplicity behind the vast complexities of Nature

Suspected gravity was a key

Unification – Einstein's Dream



Understand how nature's forces are related

electromagnetism and gravity

strong nuclear force

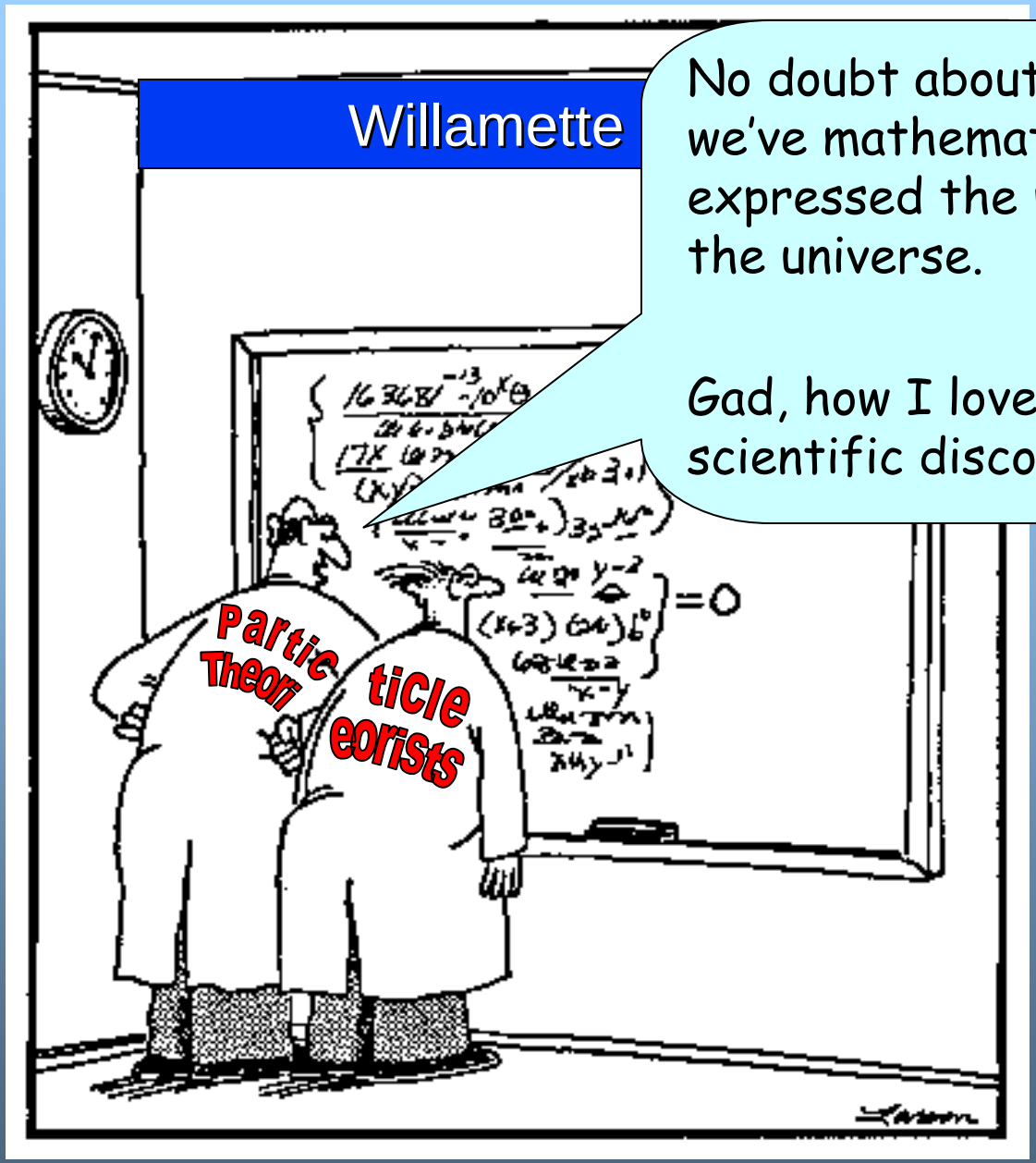
weak nuclear force

Einstein's Dream Today

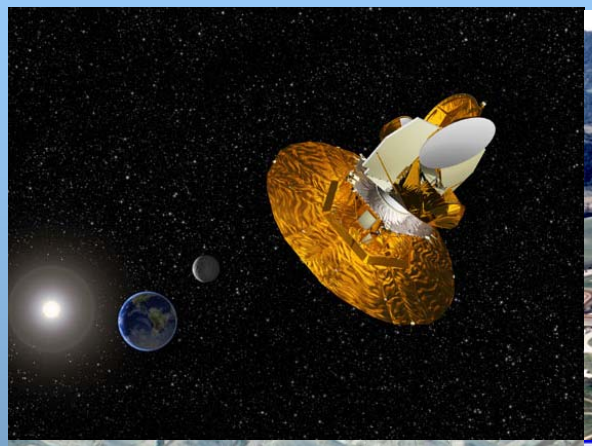
- Today, STRING THEORY
  - Unifies all forces
  - Overcomes inconsistencies between gravity and quantum mechanics
- **Ultimate Explanation?**
  - from the tiniest quanta to the cosmos
- The Dream Lives On
- Needs experimental verification

- There are encouraging signs that success is near

Willamette Hall


Willamette
No doubt about it Desh – we've mathematically expressed the purpose of the universe.
Gad, how I love the thrill of scientific discovery.
Partic
Theori
ticle
eorists

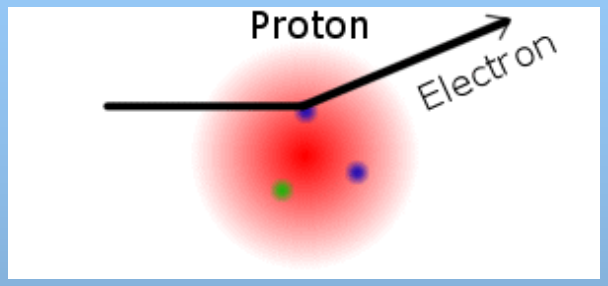
Modern scientific instruments



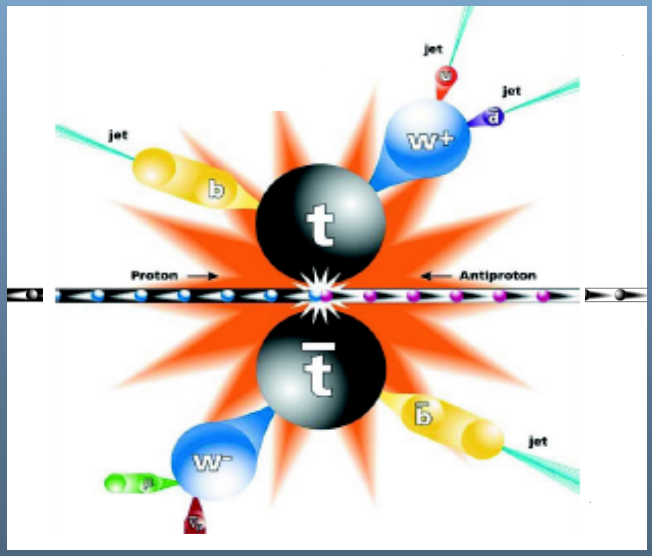



Particle Accelerators and Colliders

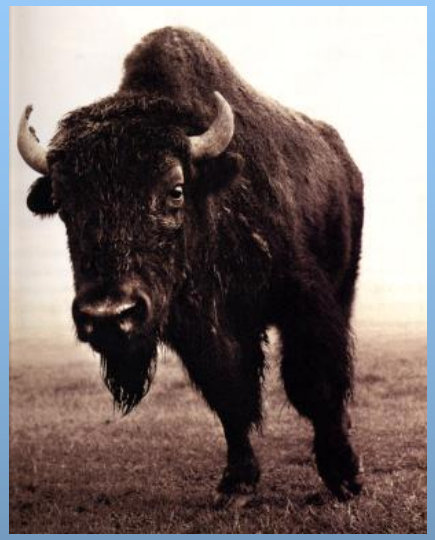
1. Super-microscope

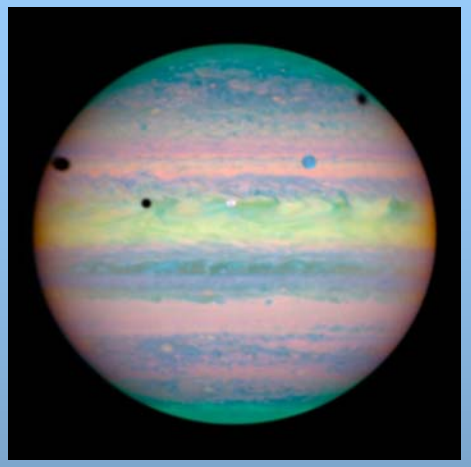


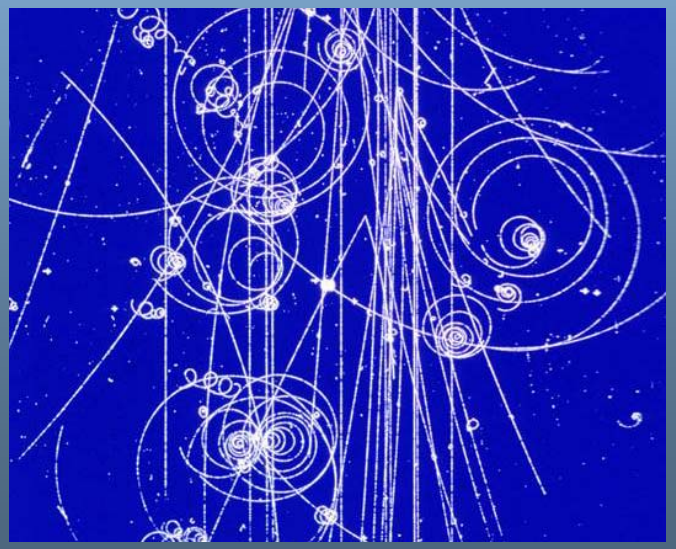
2. Creation of massive matter ($E=mc^2$)



What is matter?

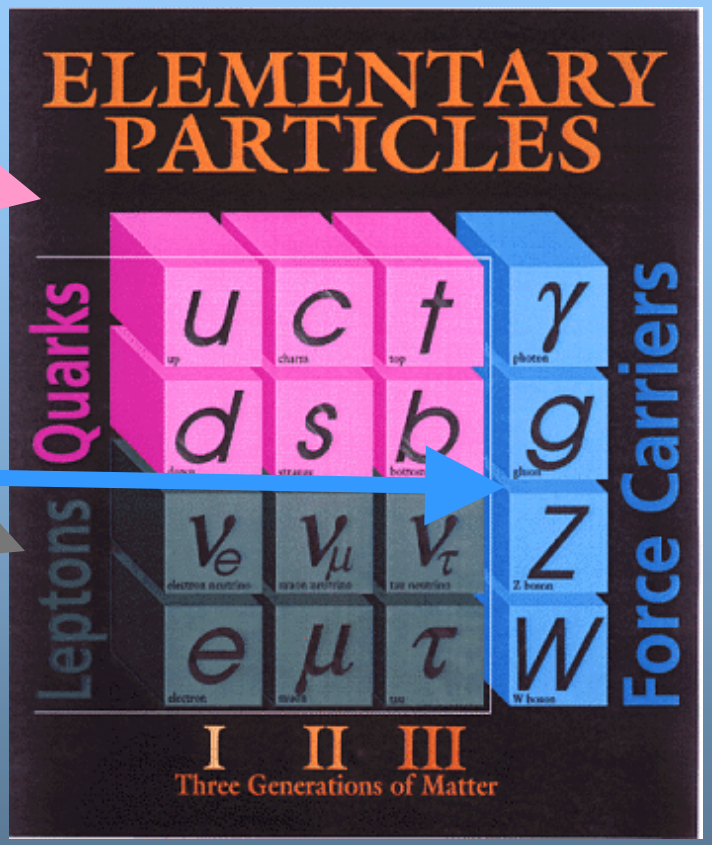






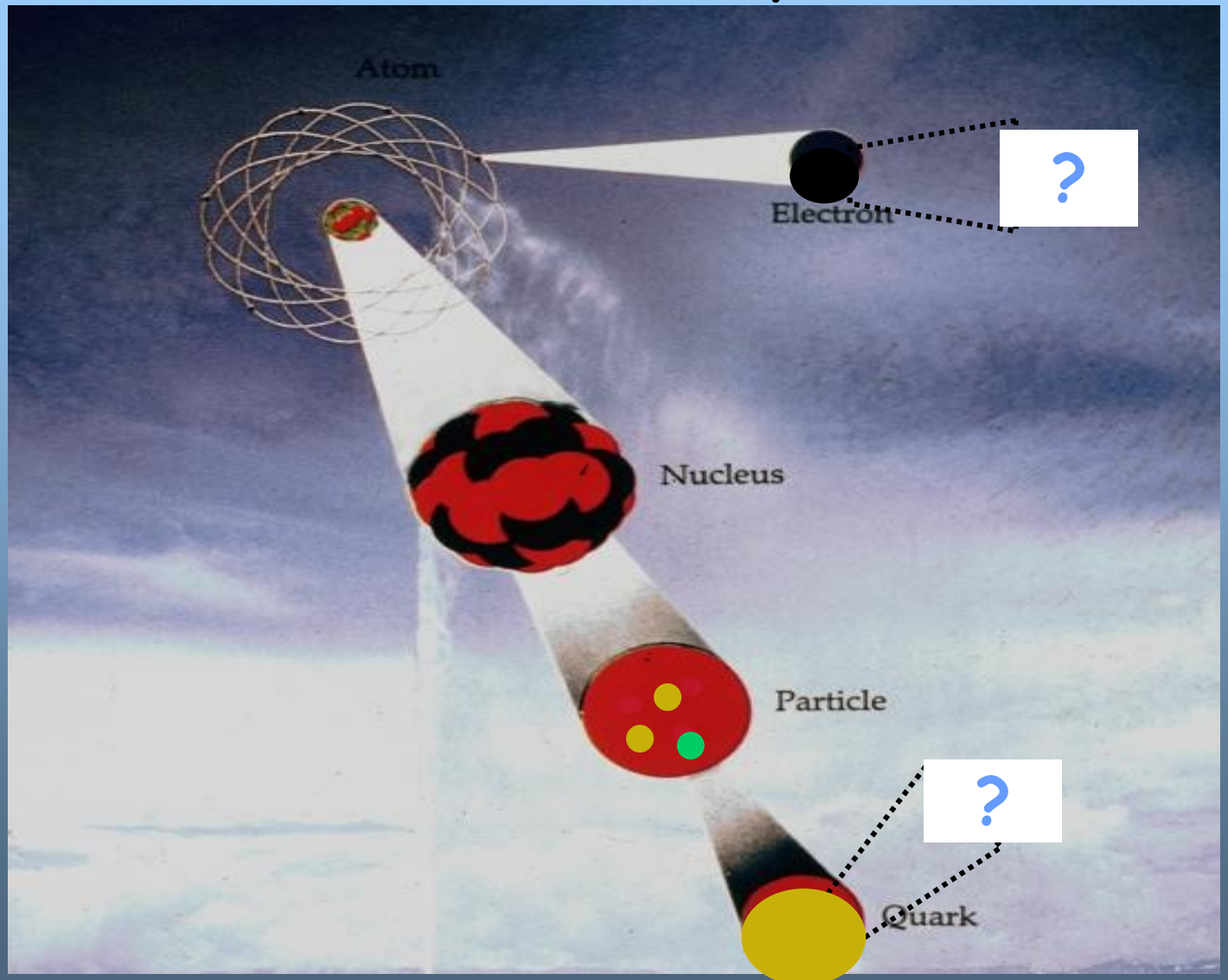
What is matter?

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

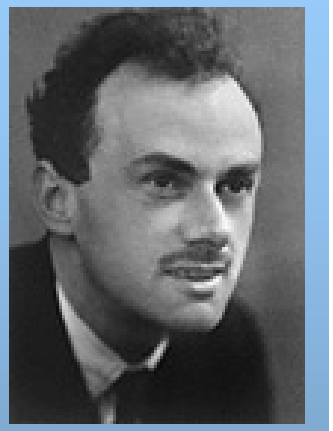


We have a precise understanding of matter and its behavior

The Structure of Matter



Symmetries of particles



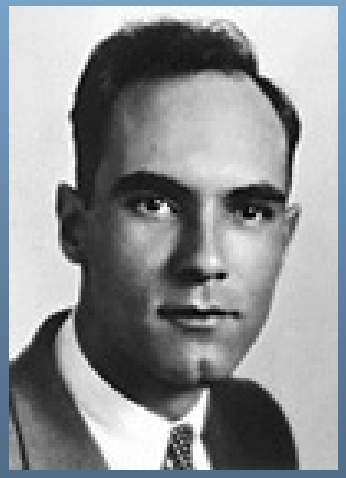
- 1928, Paul A.M. Dirac
  - Theory of the electron
  - Combining relativity and quantum mechanics

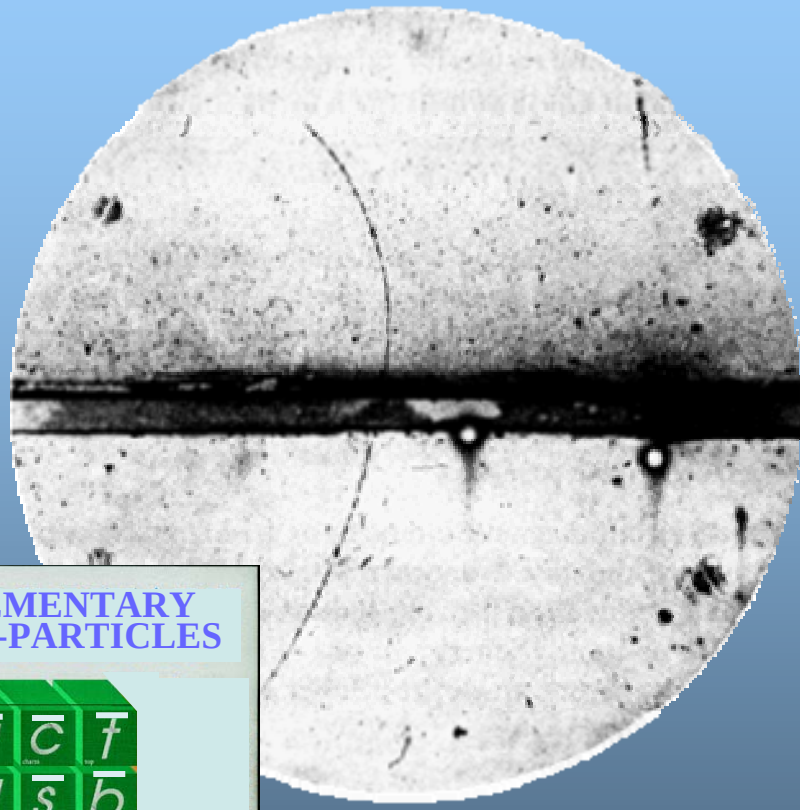
- He needed to assume there were partner particles for every known particle

  - ANTI-MATTER
  - DOUBLED THE NUMBER OF PARTICLES

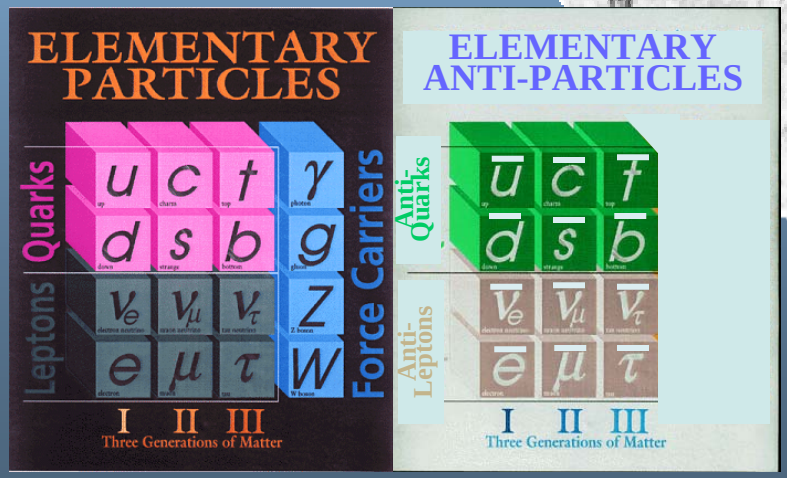
Discovery of Anti-Matter

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





All known particles have anti-particles



Dark Matter Halo

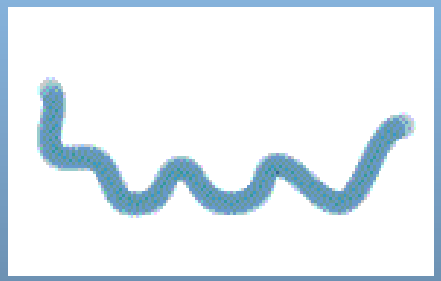
Hubble Data analyzed by Yale astrophysicists
***Astrophysical Journal 617**: L13-L16*

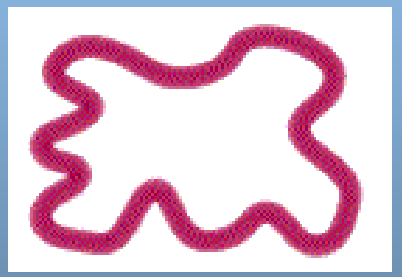
How did we first learn that galaxies are surrounded by dark halo?

Vera Rubin
1950s

SuperString Theory

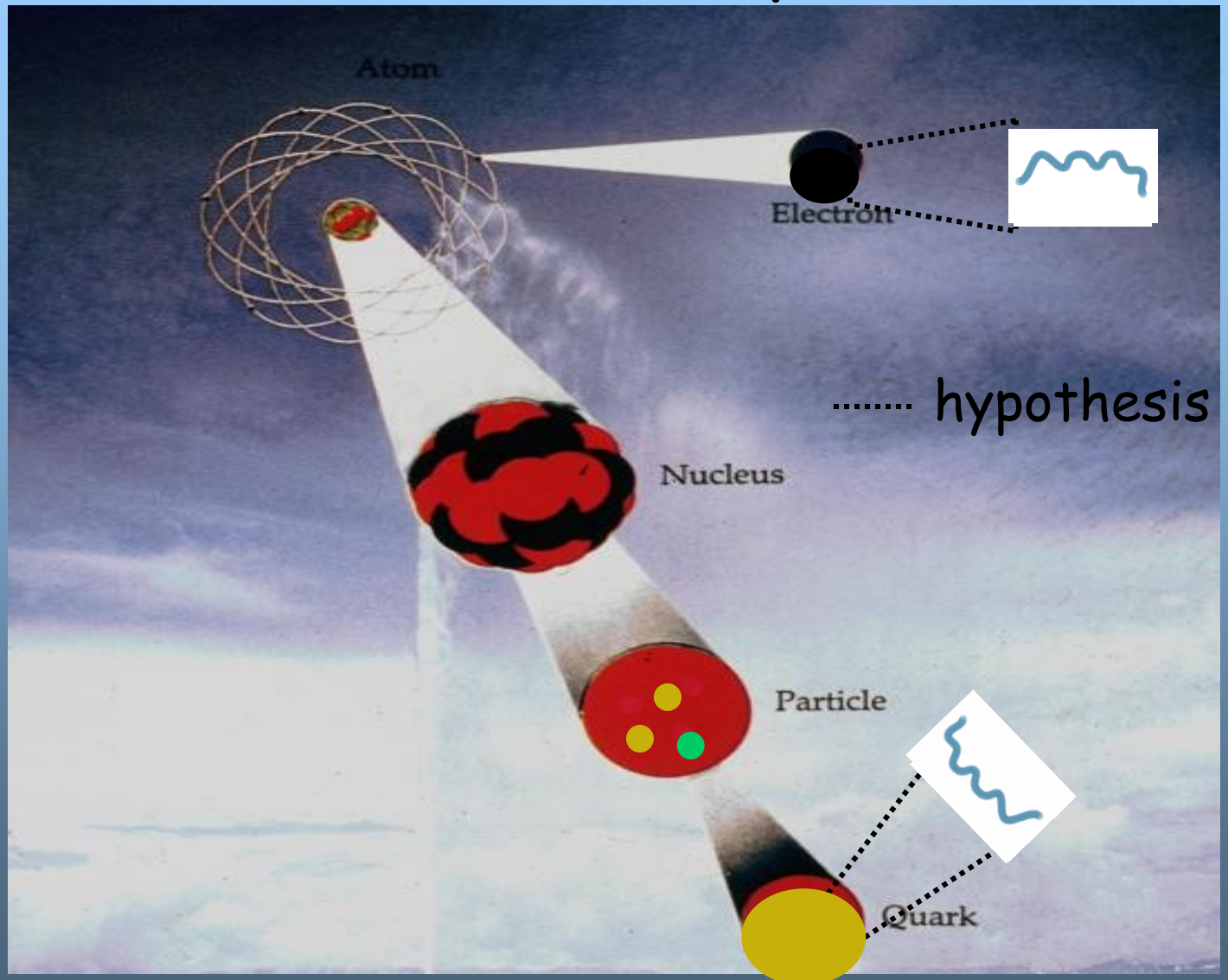
- Unifies all particles and all forces
  - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string





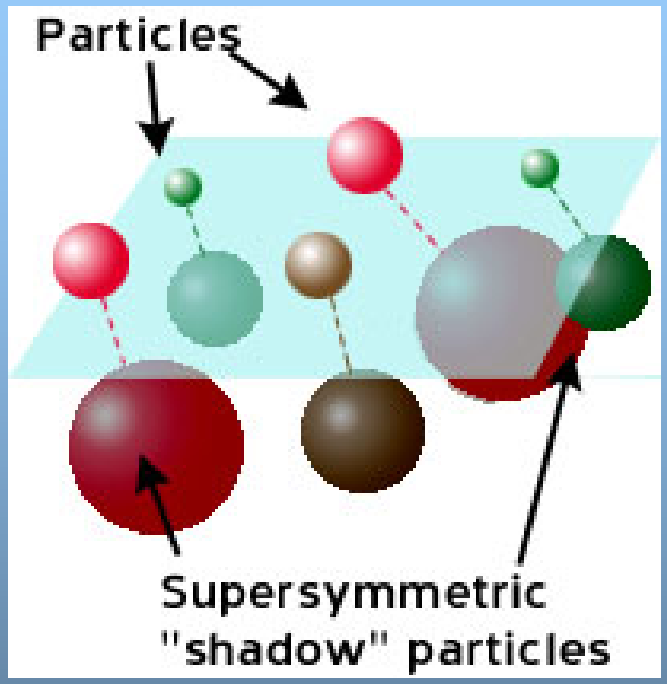
  - String is miniscule
    - Atom is 10,000,000,000,000,000,000,000,000 x bigger
  - Space is ten-dimensional (not 3D!)
  - A matching set of particles appear
    - the super-partners of ordinary particles

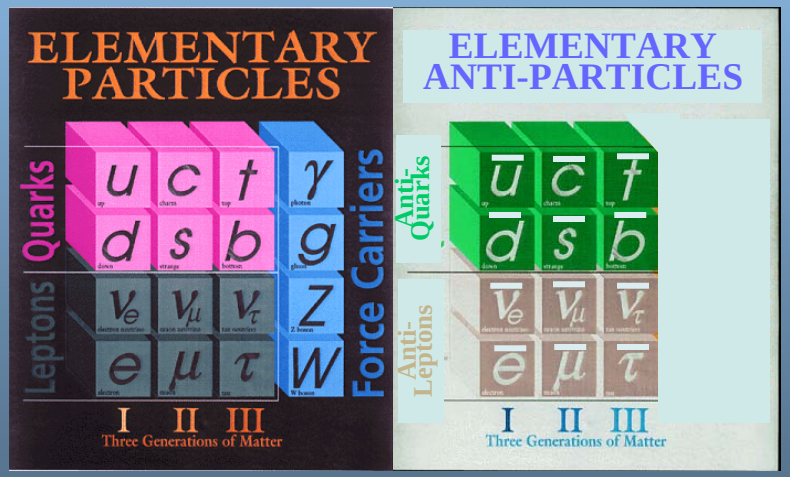
The Structure of Matter



Supersymmetry and Strings

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

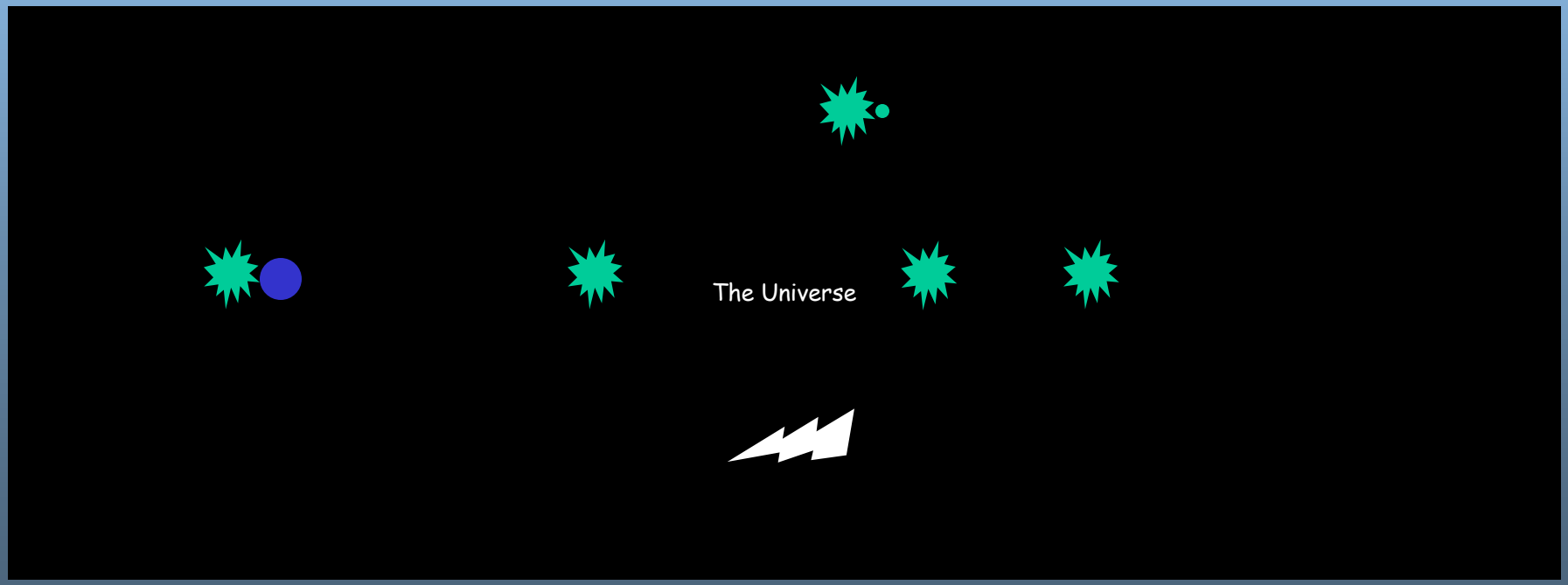




- The supersymmetric particles have just the properties expected of Dark Matter

Another puzzle
What gives matter mass?

- An ocean of Higgs Bosons - "Higgs Field"



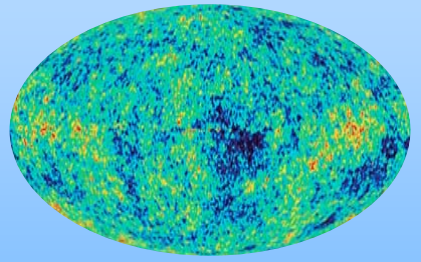
The Big Bang

- 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

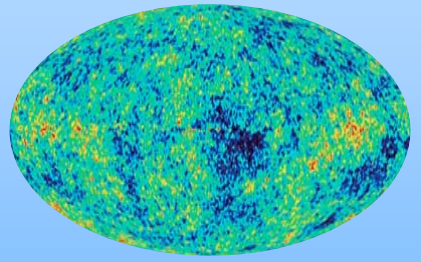
Probing the Big Bang



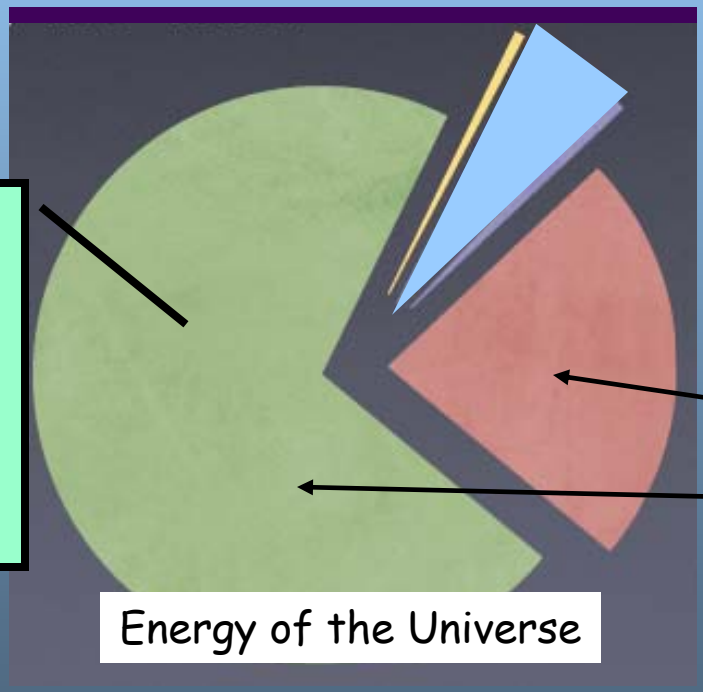
- The stars are a very small fraction

- 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



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

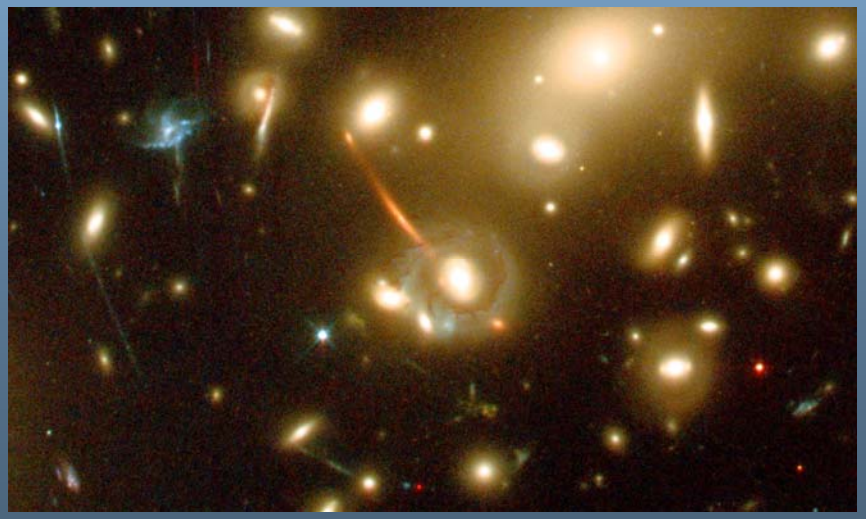
The Dark Side Controls the Universe

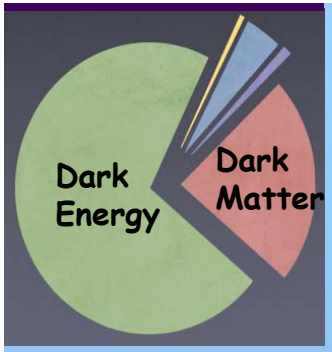
Dark Matter

HOLDS IT TOGETHER

Dark Energy

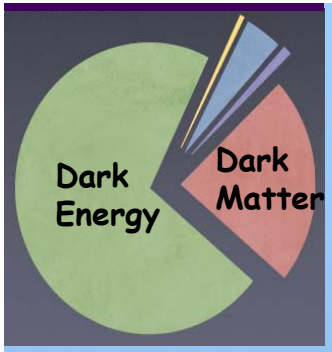
DETERMINES ITS DESTINY



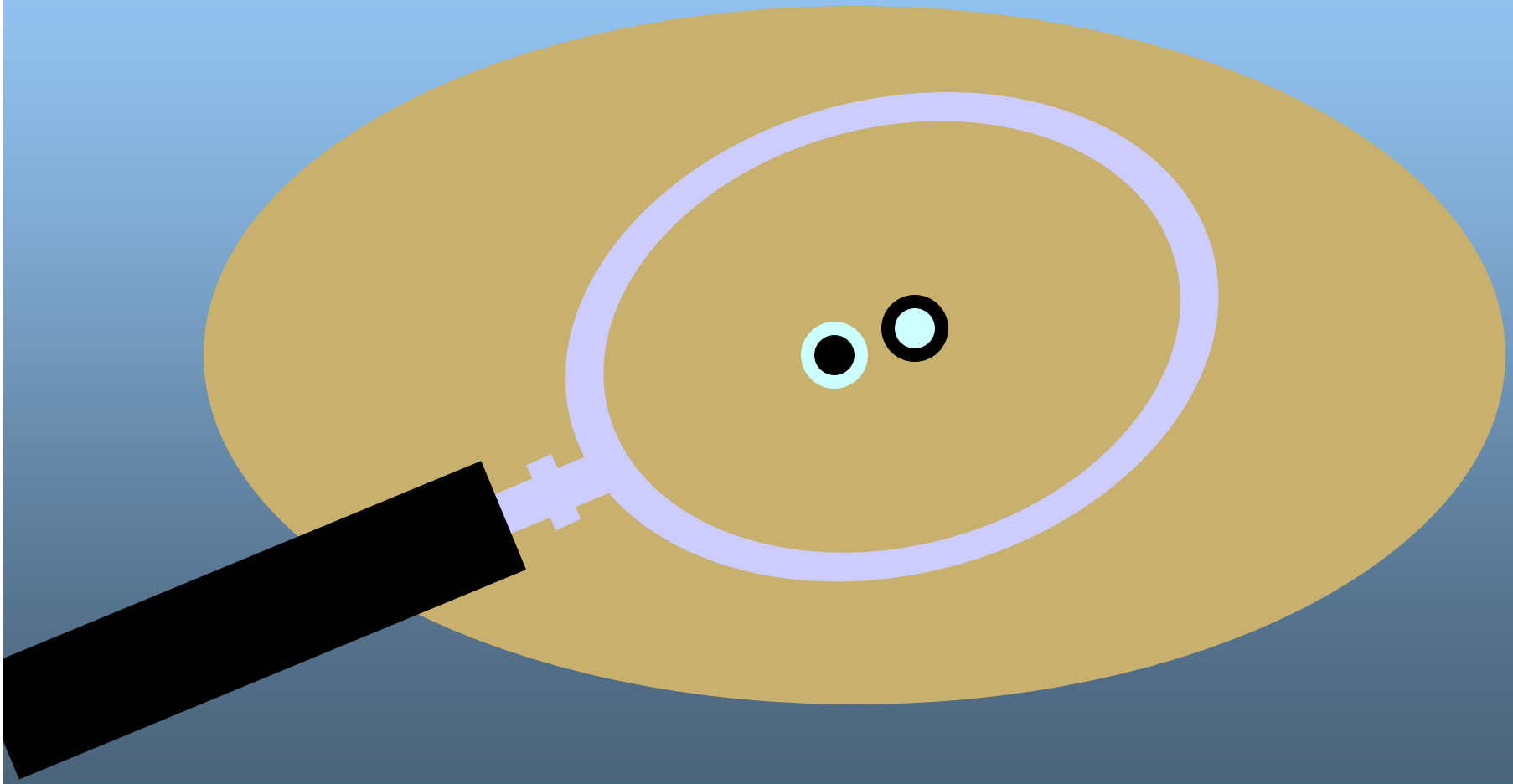


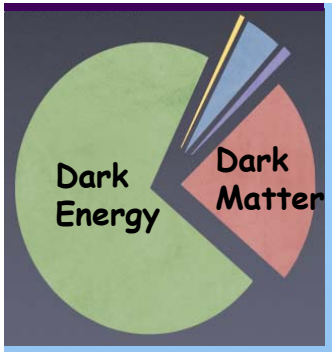
The Dark Energy
Something from Nothing

- 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

Something from Nothing

- 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

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

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:

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

ıpose a cutoff at a maximum wavevector k_{ma}

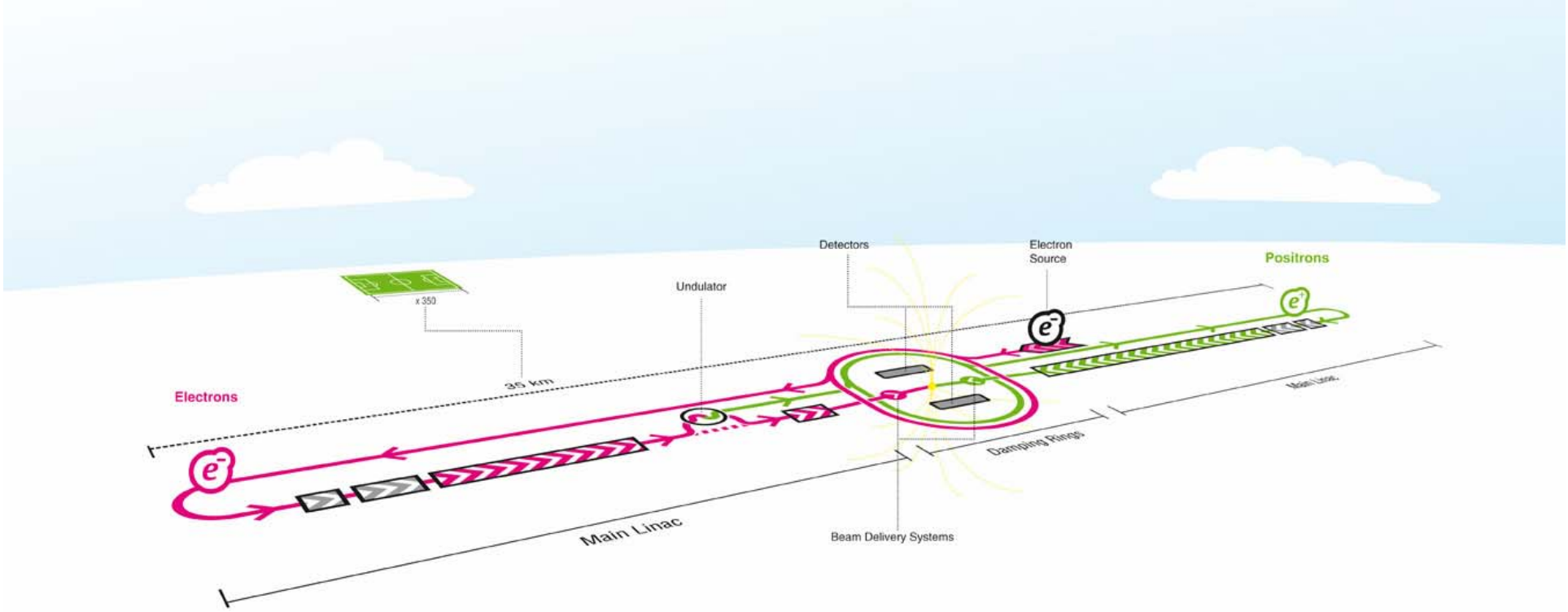
$$\rho_{vac} \equiv \lim_{L\to\infty} \frac{E_o}{L^3} = \frac{\hbar k_{max}^4}{32\pi^3}$$

Large Hadron Collider (LHC)
Geneva, Switzerland

Nearing Completion

Begins operation later this year

International Linear Collider (ILC)



Under development

Planned to begin operation last half of next decade

Our Mysterious Universe

- We are on the eve of a revolution in physics
  - Many mysteries
  - Solutions appear near
  - Deeper understanding of the universe itself

- Dark Matter particles – may appear soon in particle collider experiments

- Also
  - Gravity waves
  - Higgs Boson
  - Dark Energy
  - Other AMAZING Things

Stay Tuned!

Acknowledgements

RESEARCH SUPPORTED BY

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OFFICE OF SCIENCE

NATIONAL SCIENCE FOUNDATION

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