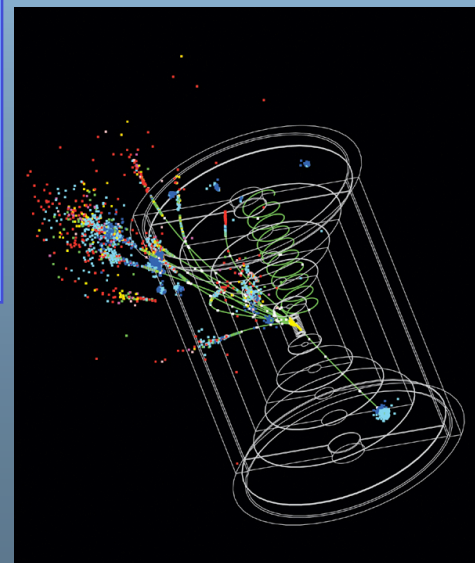




The Mysterious Frontiers of Our Universe, **BIG** and small



- 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 Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

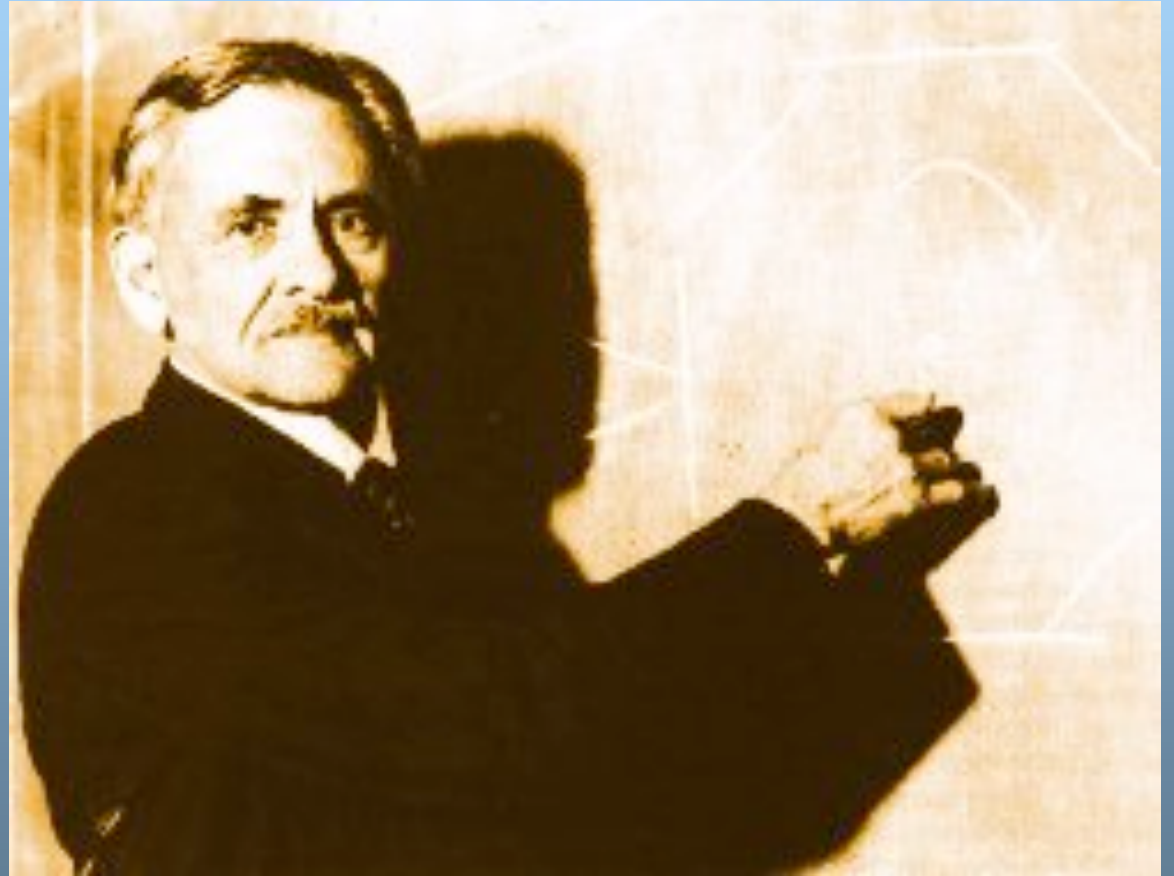
Jim Brau

July 16, 2007

2

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



The Mysterious Frontiers of Our Universe, BIG and small

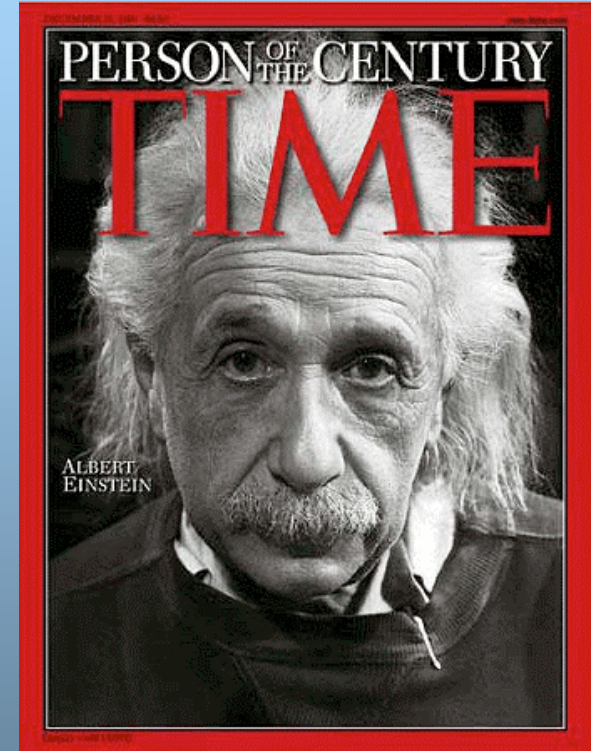
Rose City Astronomers

Jim Brau

July 16, 2007

Einstein's Theoretical Discoveries

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



The Mysterious Frontiers of Our Universe, BIG and small

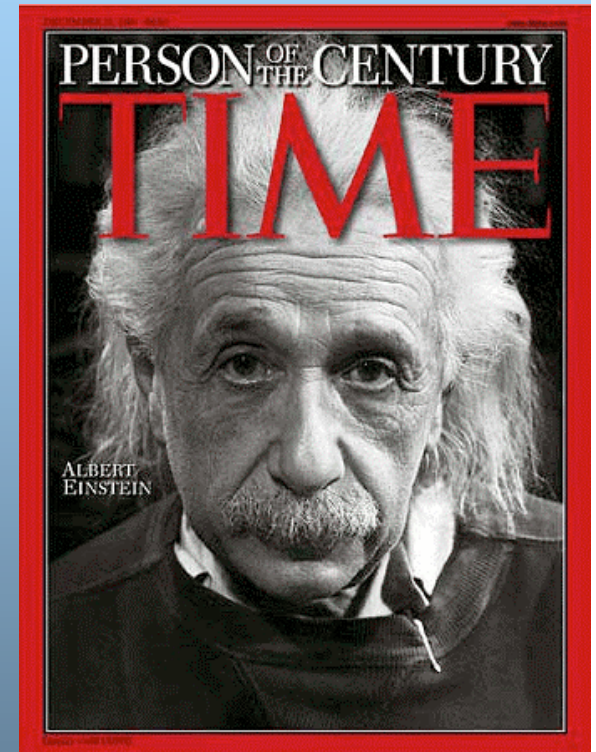
Rose City Astronomers

Jim Brau

July 16, 2007

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



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

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.

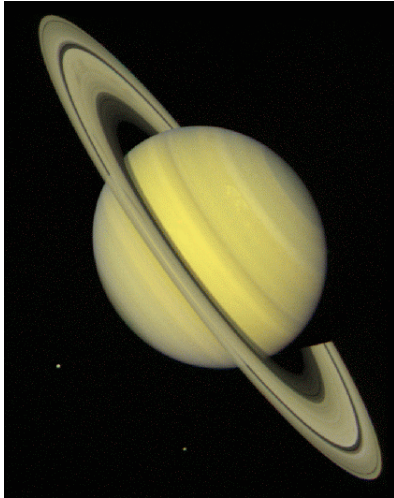


The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007



Einstein's Dream

To understand the underlying simplicity behind the vast complexities of Nature



Suspected gravity was a key



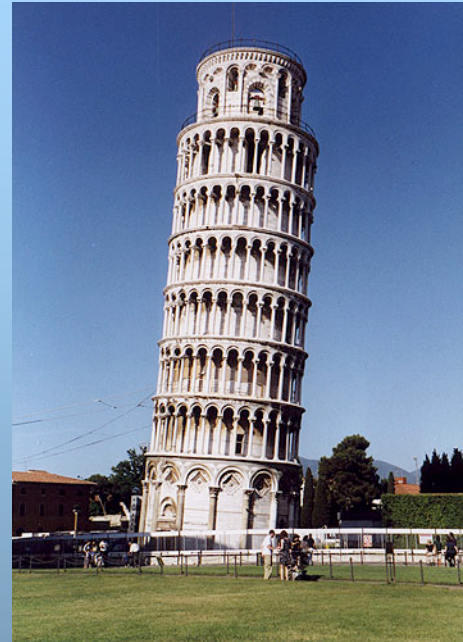
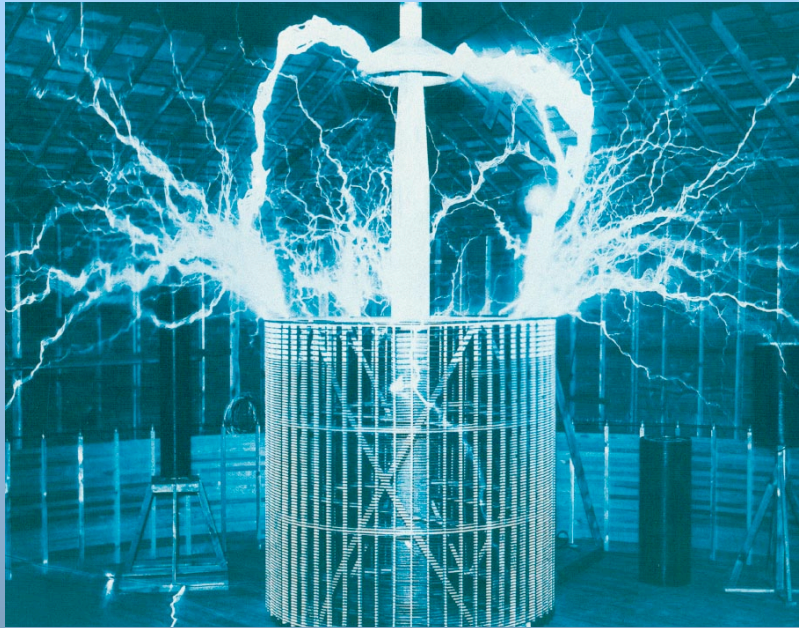
The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

Unification - Einstein's Dream



Understand how nature's forces are related

electromagnetism and gravity

strong nuclear force

weak nuclear force

The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

Einstein's Dream Today



Copyright California Institute of Technology. All rights reserved. Commercial use or modification of this material is prohibited.

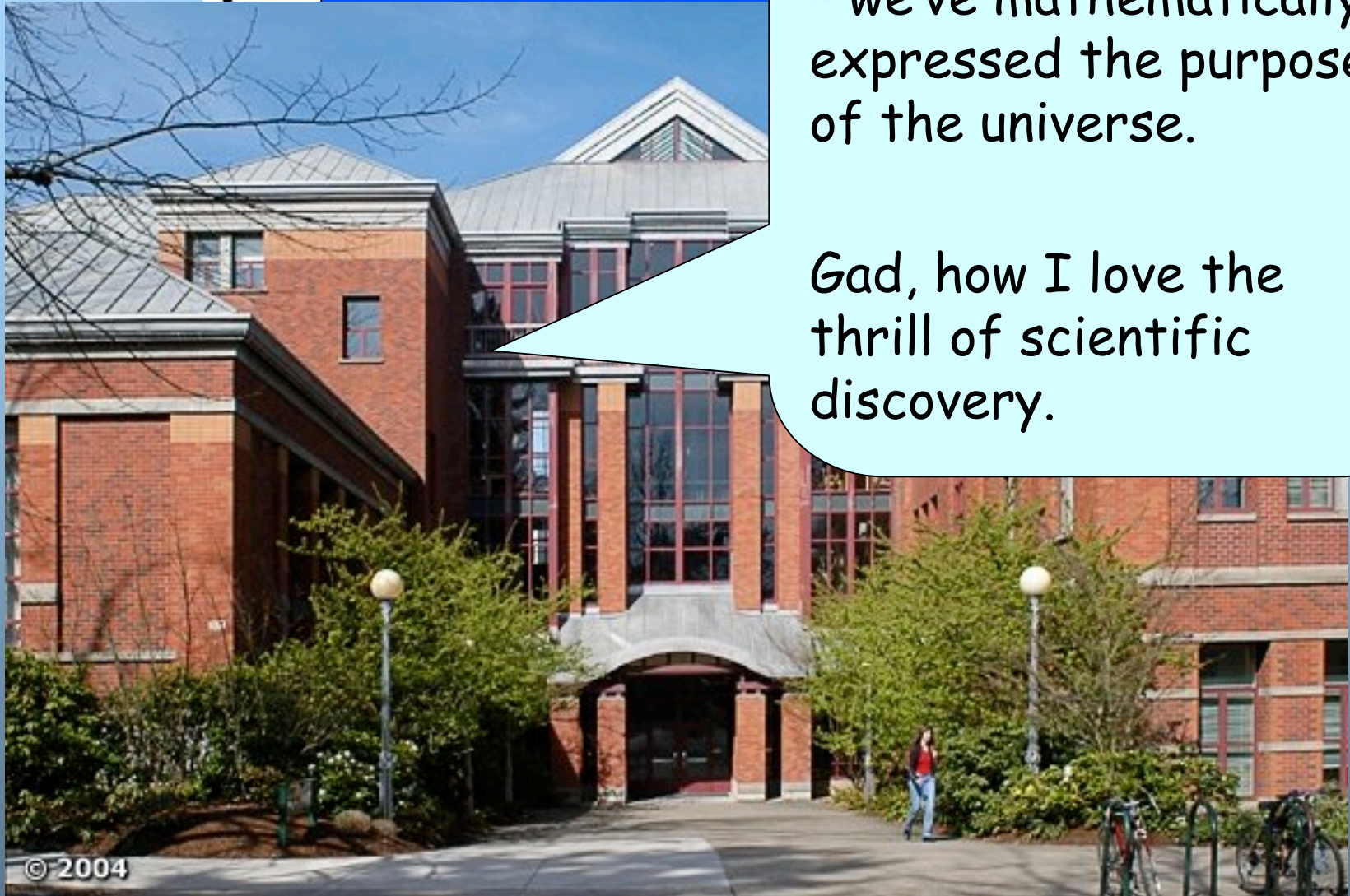
- Today, STRING THEORY
 - Unifies all forces
 - Overcomes inconsistencies between gravity and quantum mechanics
 - Ultimate Explanation?
 - from the tiniest quanta to the cosmos
 - The Dream Lives On
 - Needs experimental verification
-
- There are encouraging signs that success is near

The Mysterious Frontiers of Our Universe, BIG and small

WILLAMETTE

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

Gad, how I love the
thrill of scientific
discovery.

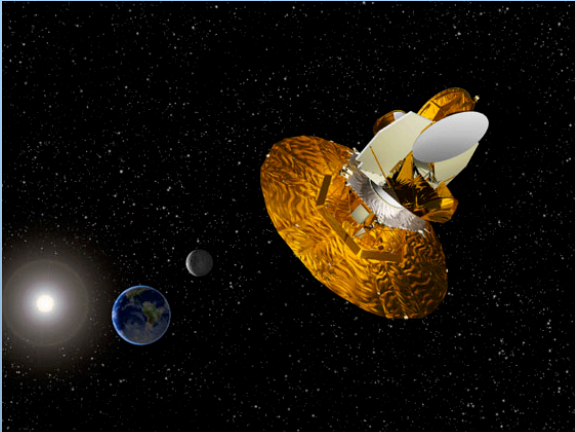


The Mysterious Frontiers of Our Universe, BIG and small
Rose City Astronomers

Jim Brau

July 16, 2007

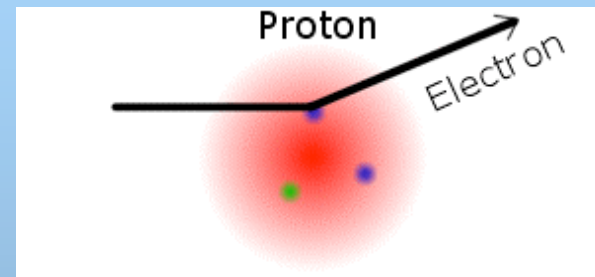
Modern scientific instruments



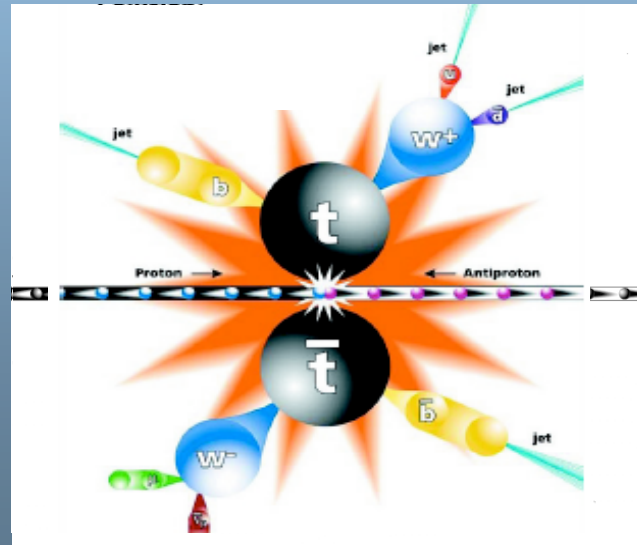
The Mysterious Frontiers of Our Universe, BIG and small
Rose City Astronomers Jim Brau July 16, 2007

Particle Accelerators and Colliders

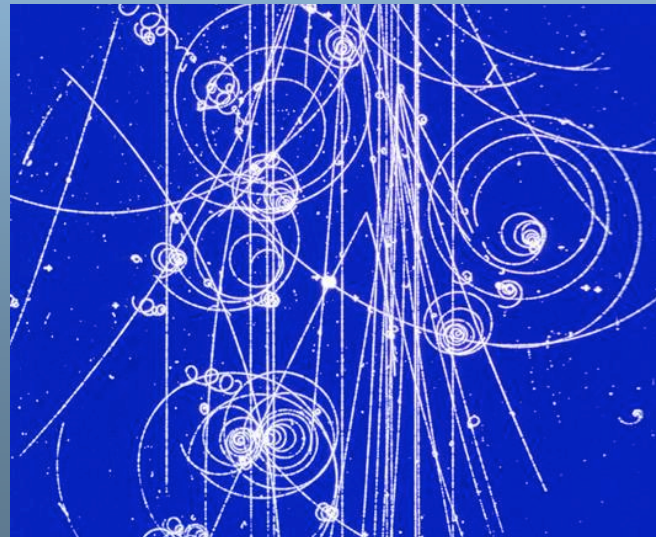
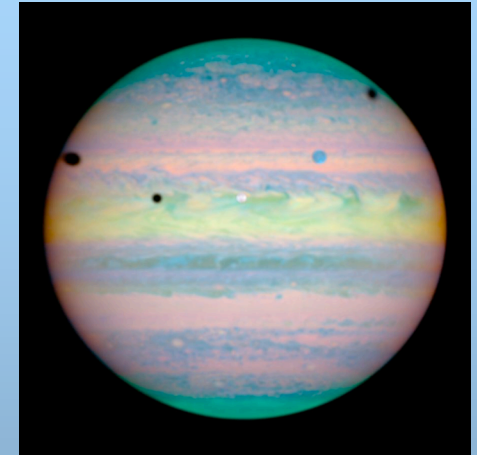
1. Super-microscope



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



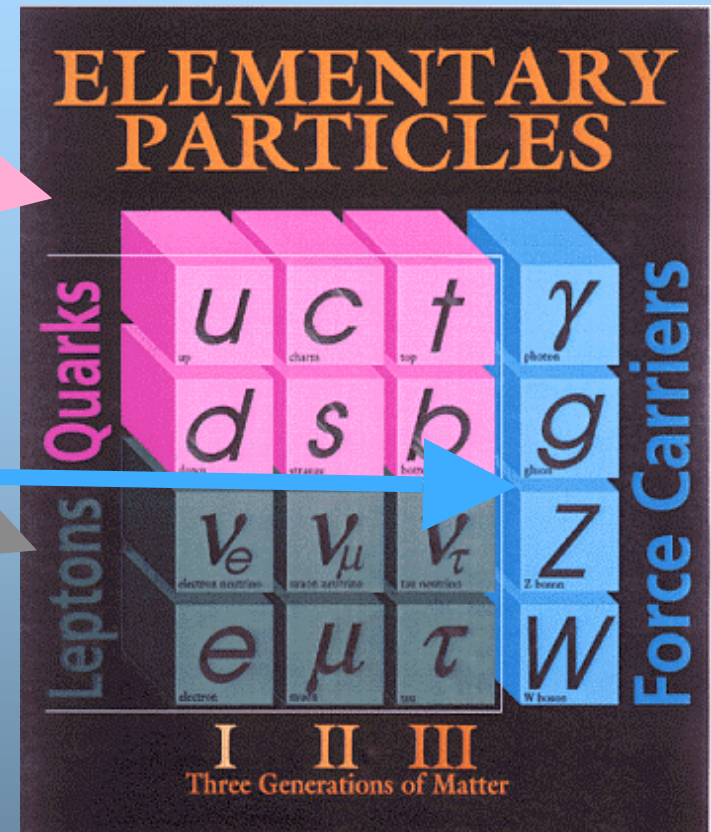
What is matter?



The Mysterious Frontiers of Our Universe, BIG and small
Rose City Astronomers Jim Brau July 16, 2007

What is matter?

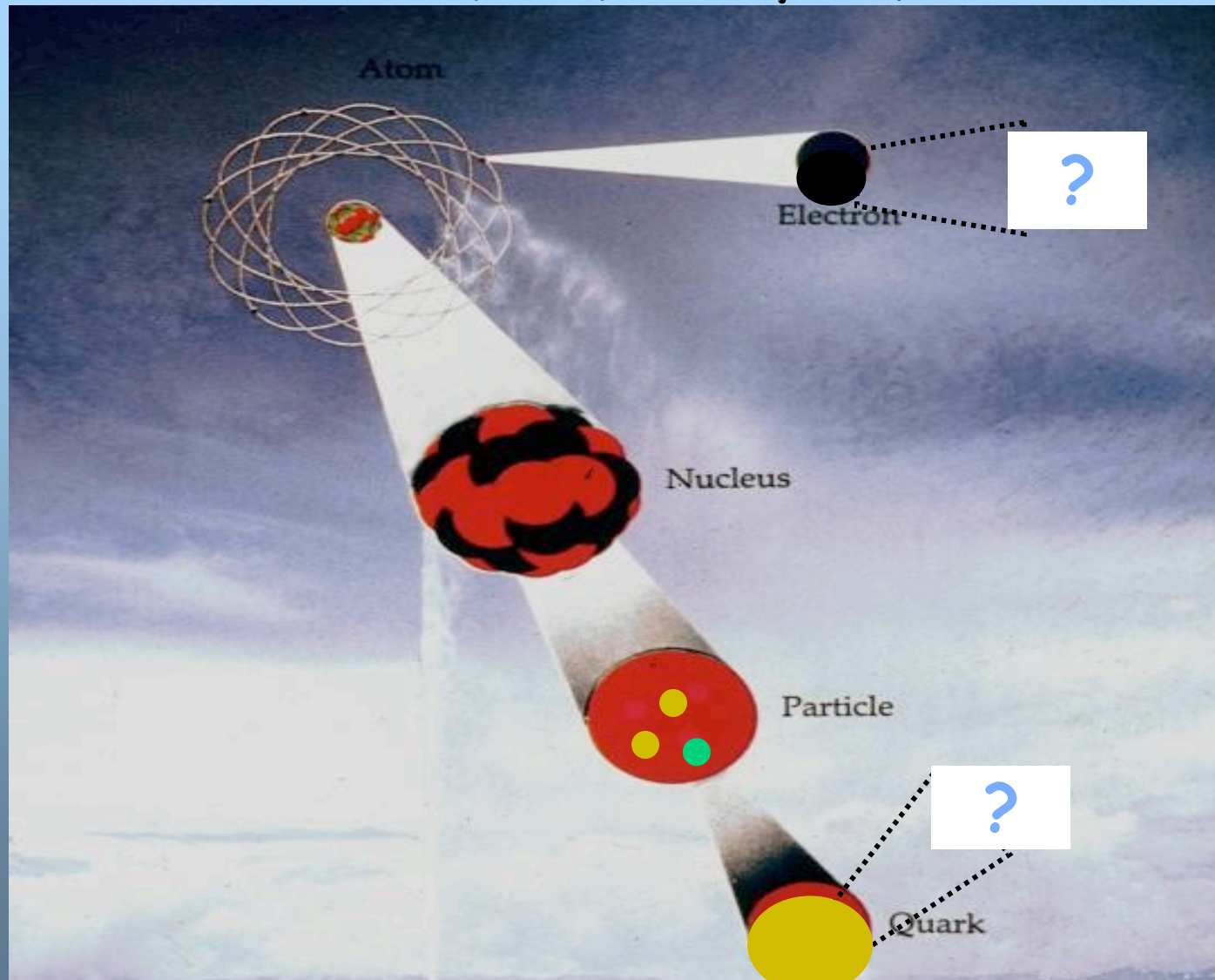
- **Quarks**
 - combine to make protons and neutrons
- **Leptons**
 - eg. electron, neutrino
- **Force Carriers**
 - defines behavior of matter



We have a precise understanding of matter and its behavior

The Mysterious Frontiers of Our Universe, BIG and small

The Structure of Matter



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

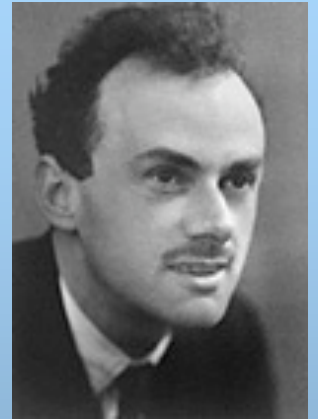
Jim Brau

July 16, 2007

16

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



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

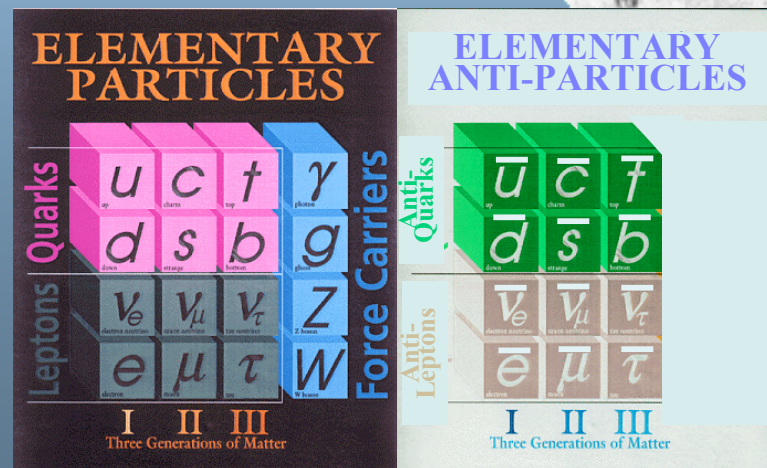
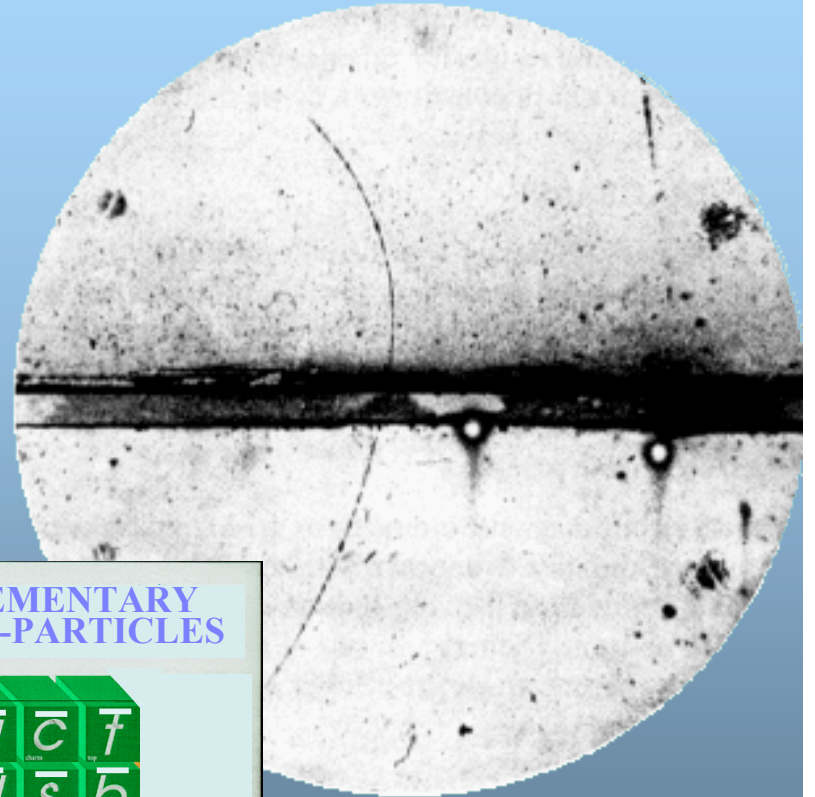
July 16, 2007

17

Discovery of Anti-Matter

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

All known particles have anti-particles



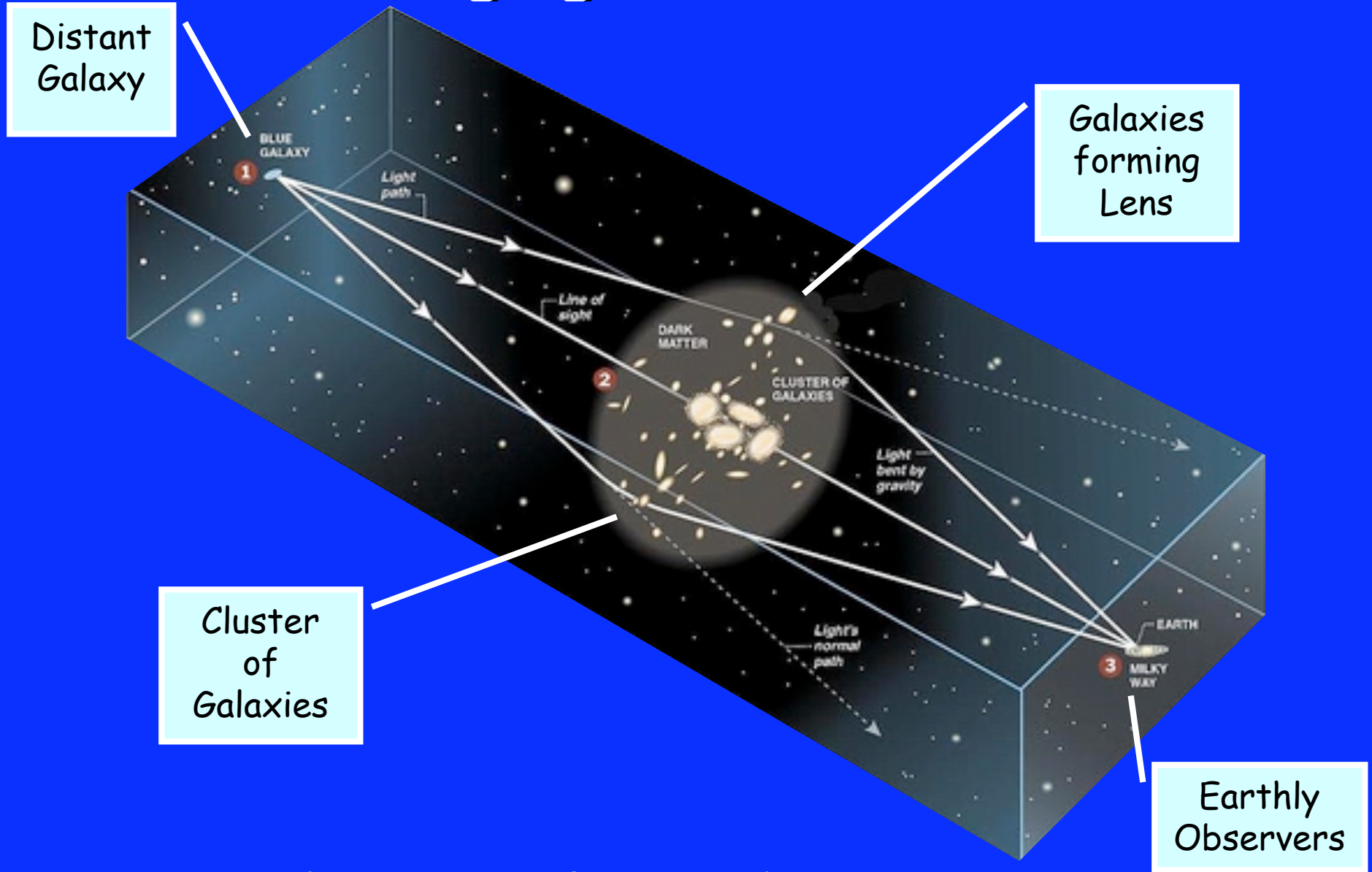
The Mysterious Frontiers of Our Universe, BIG and small

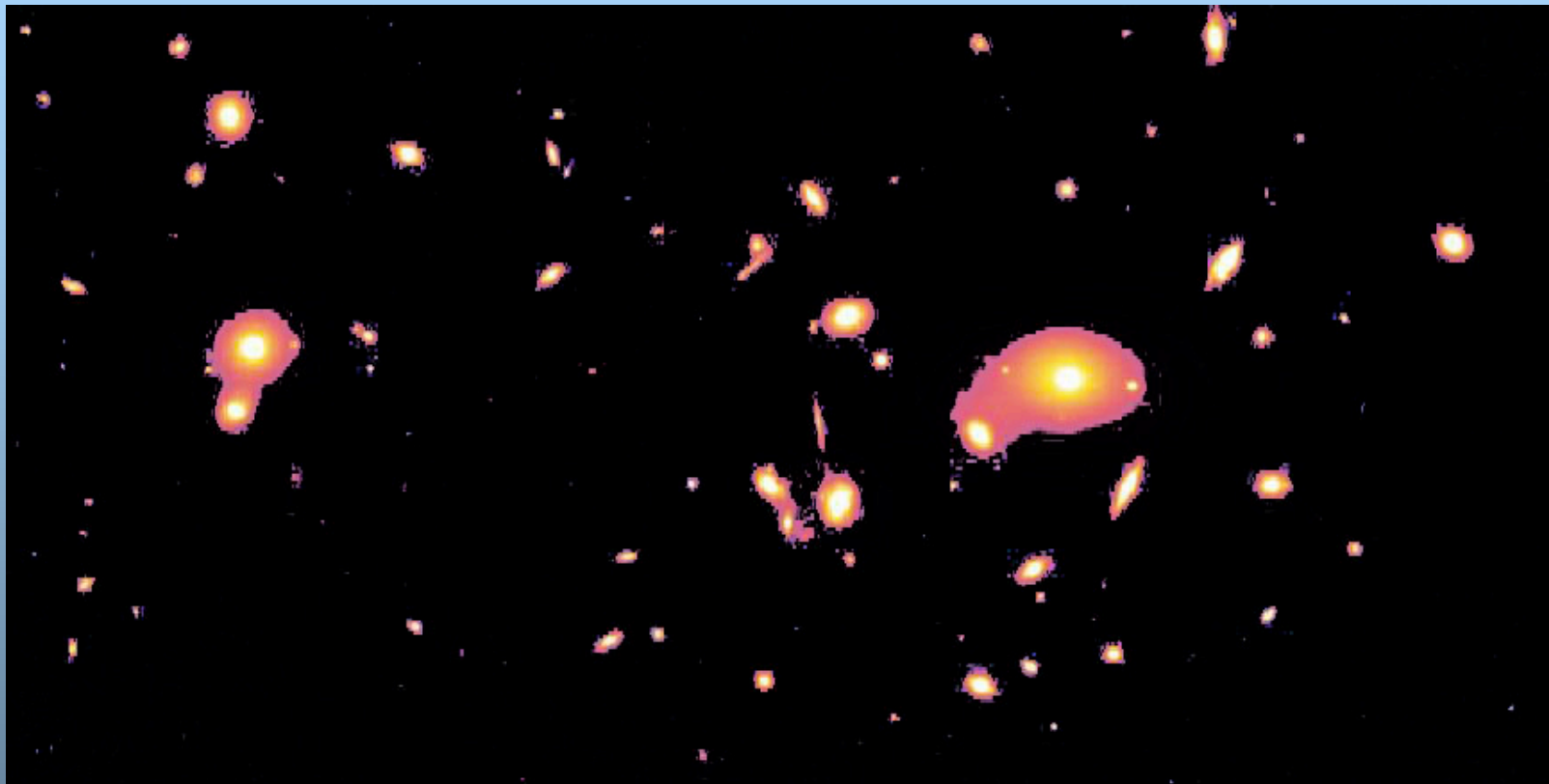
Dark Matter Halo



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

Imaging Dark Matter





The Mysterious Frontiers of Our Universe, BIG and small
Rose City Astronomers Jim Brau July 16, 2007

Dark Matter Halo



Dark Matter Dominates - what is it?

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

First Dark Matter Evidence



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



The Mysterious Frontiers of Our Universe, BIG and small

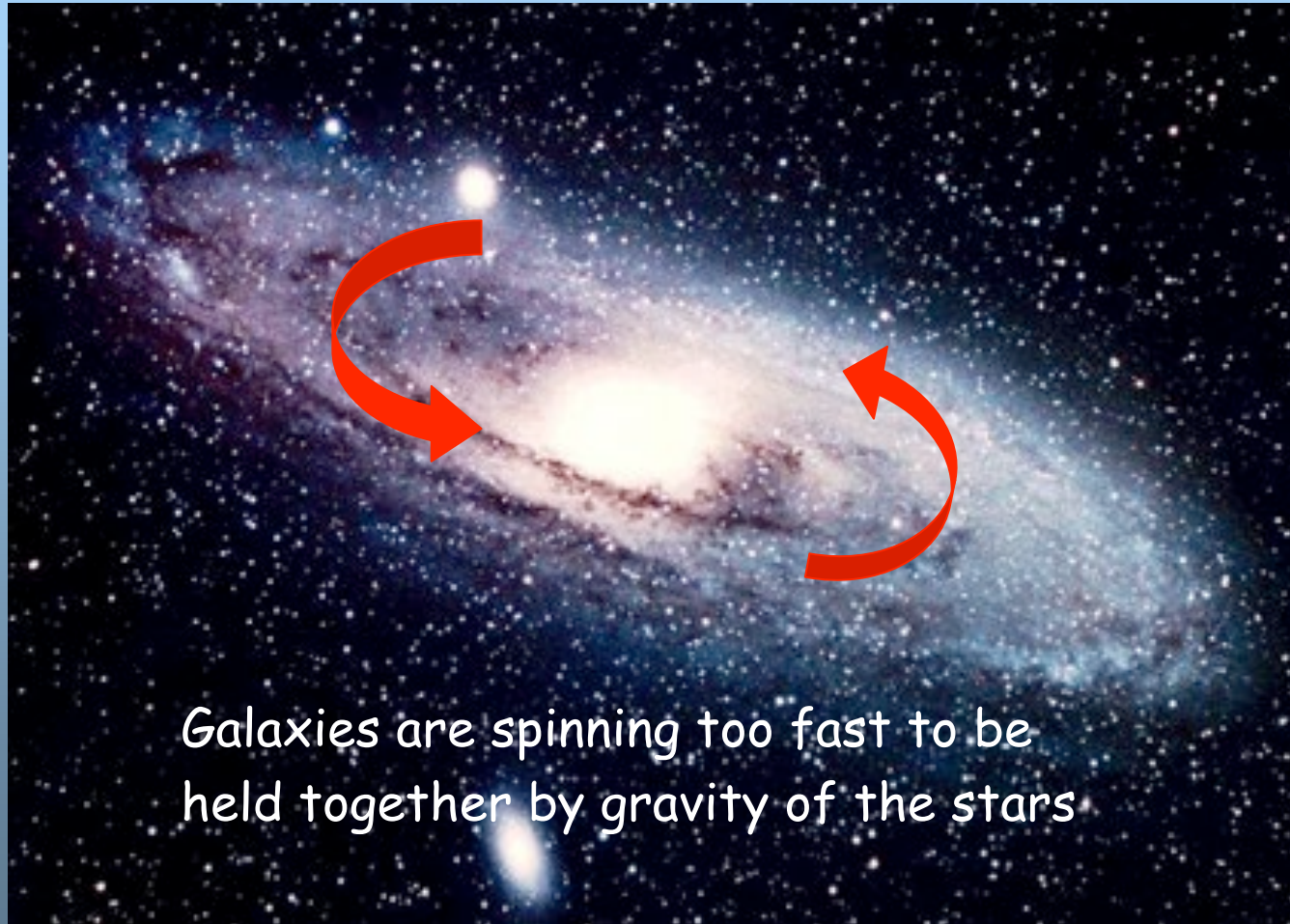
Rose City Astronomers

Jim Brau

July 16, 2007

23

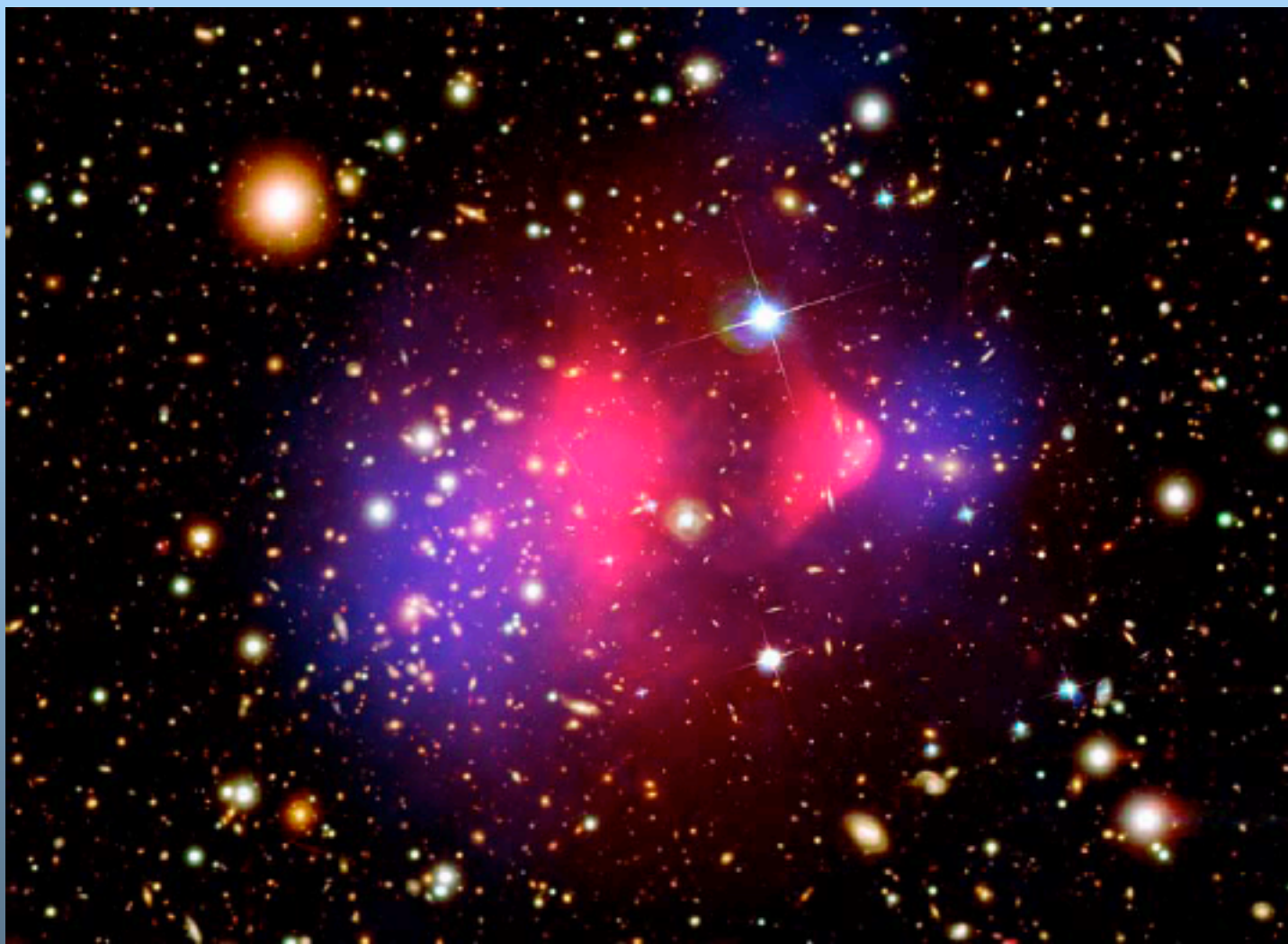
Further evidence for Dark Halo



Vera Rubin
1950s

Bullet Cluster

1E 0657-56



The Mysterious Frontiers of Our Universe, BIG and small

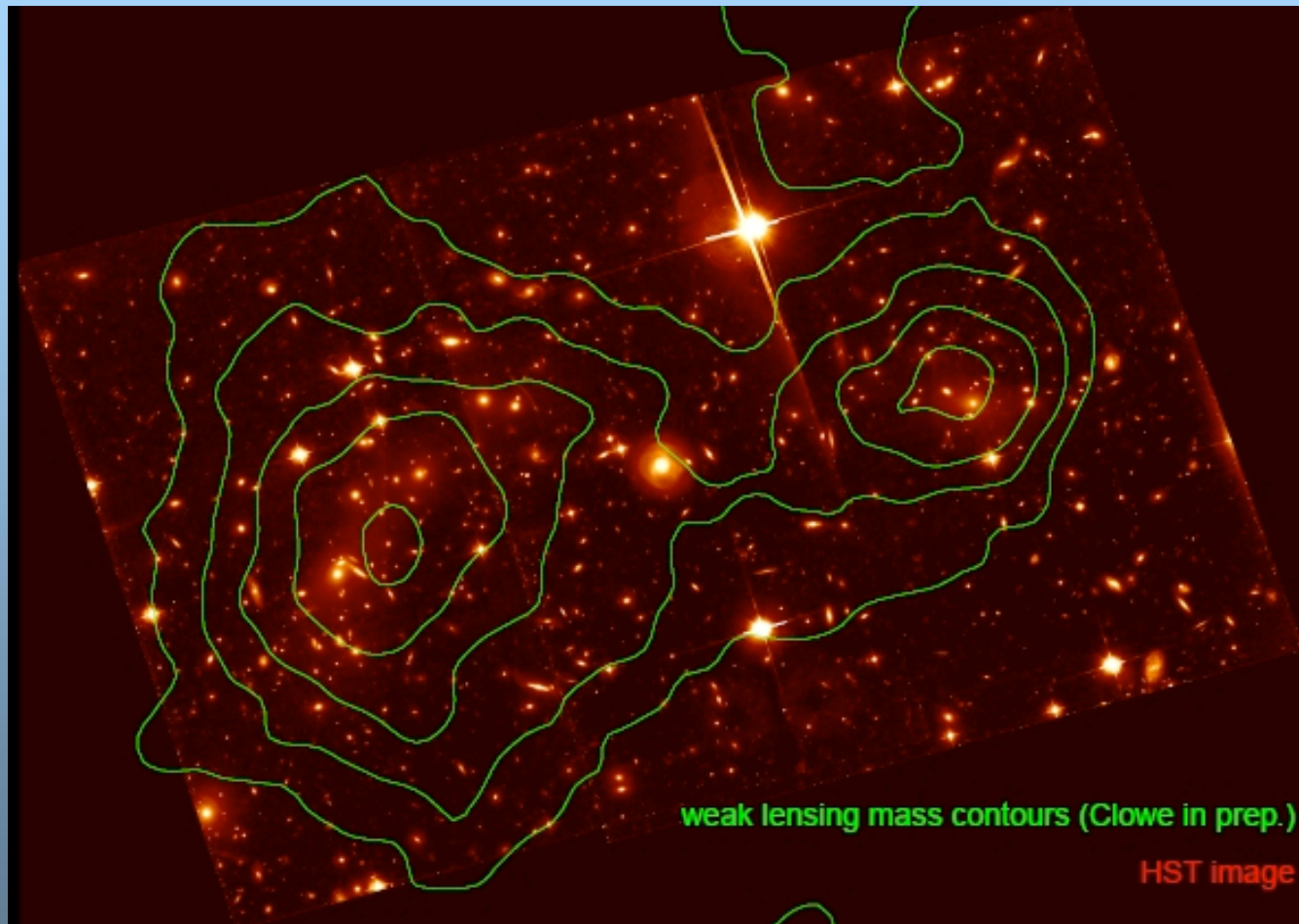
Rose City Astronomers

Jim Brau

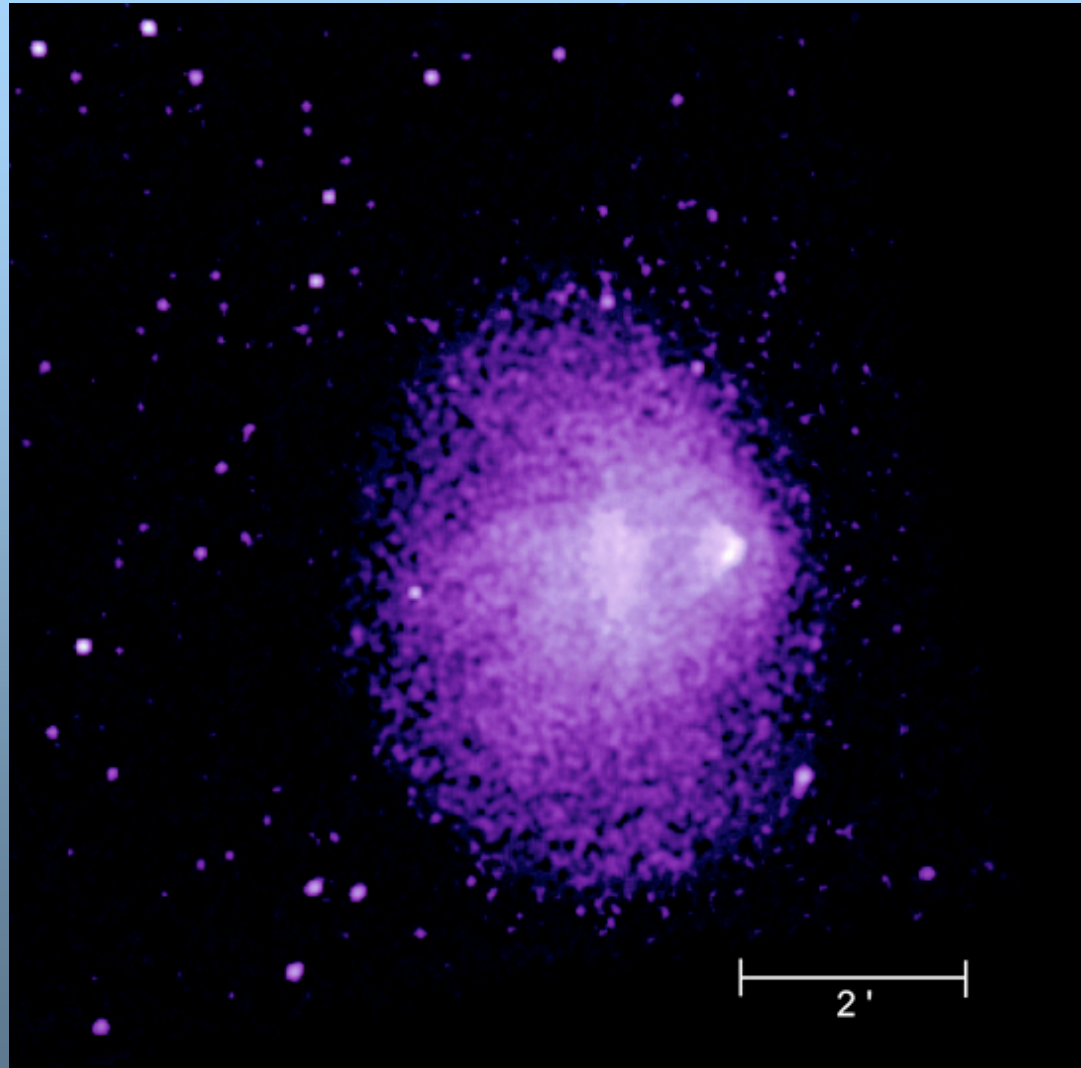
July 16, 2007

25

Bullet Cluster



Bullet Cluster - X rays



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

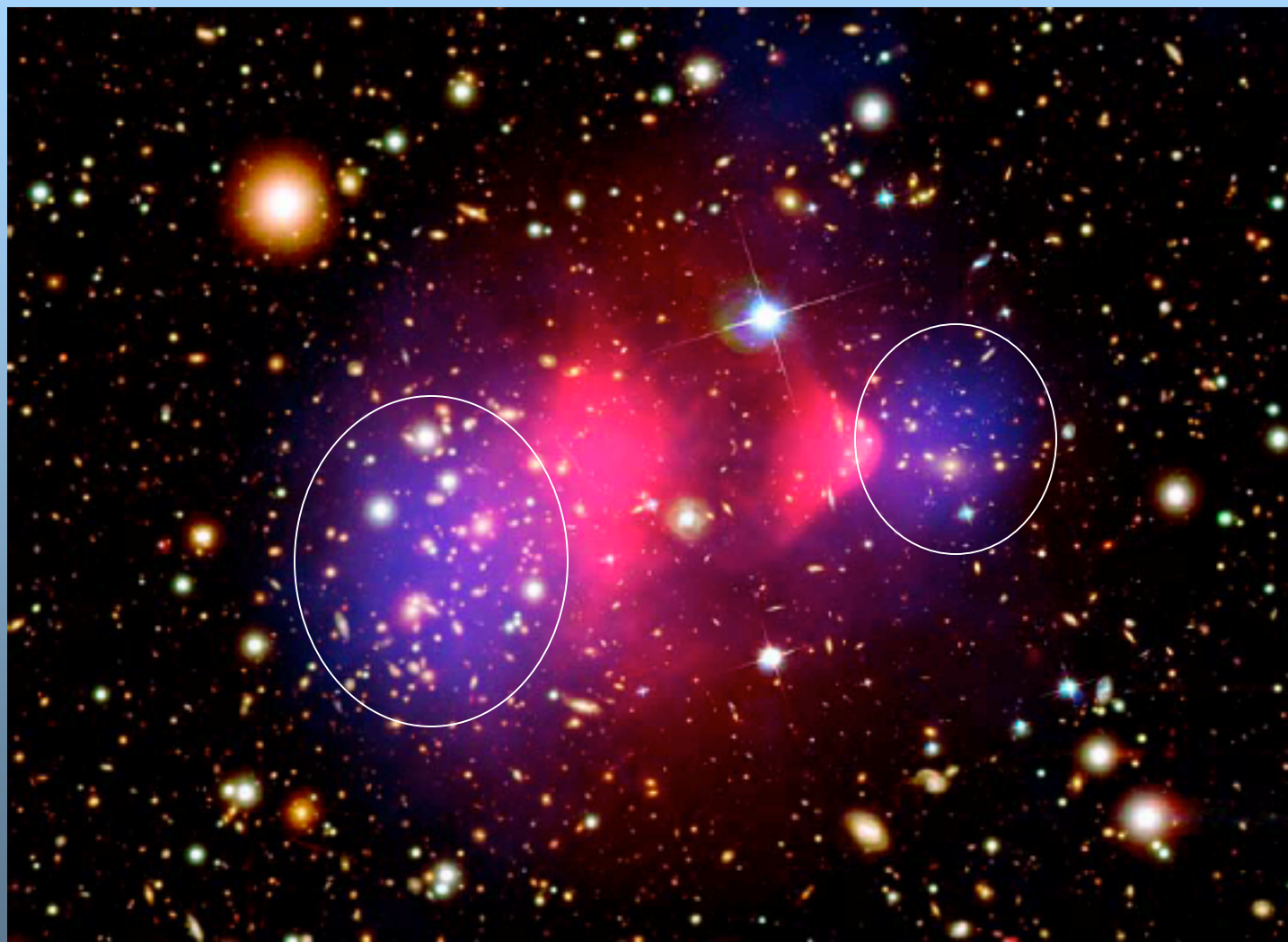
Jim Brau

July 16, 2007

27

Bullet Cluster

1E 0657-56



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

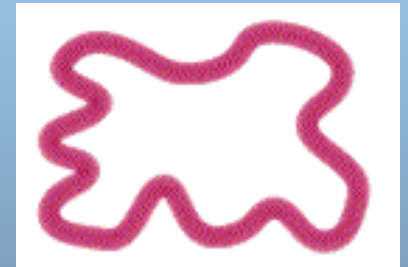
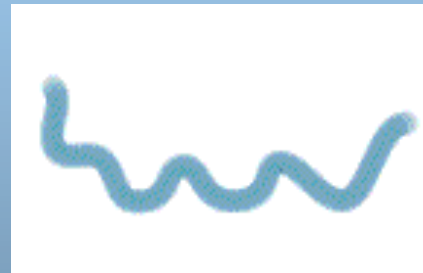
July 16, 2007

28

SuperString Theory



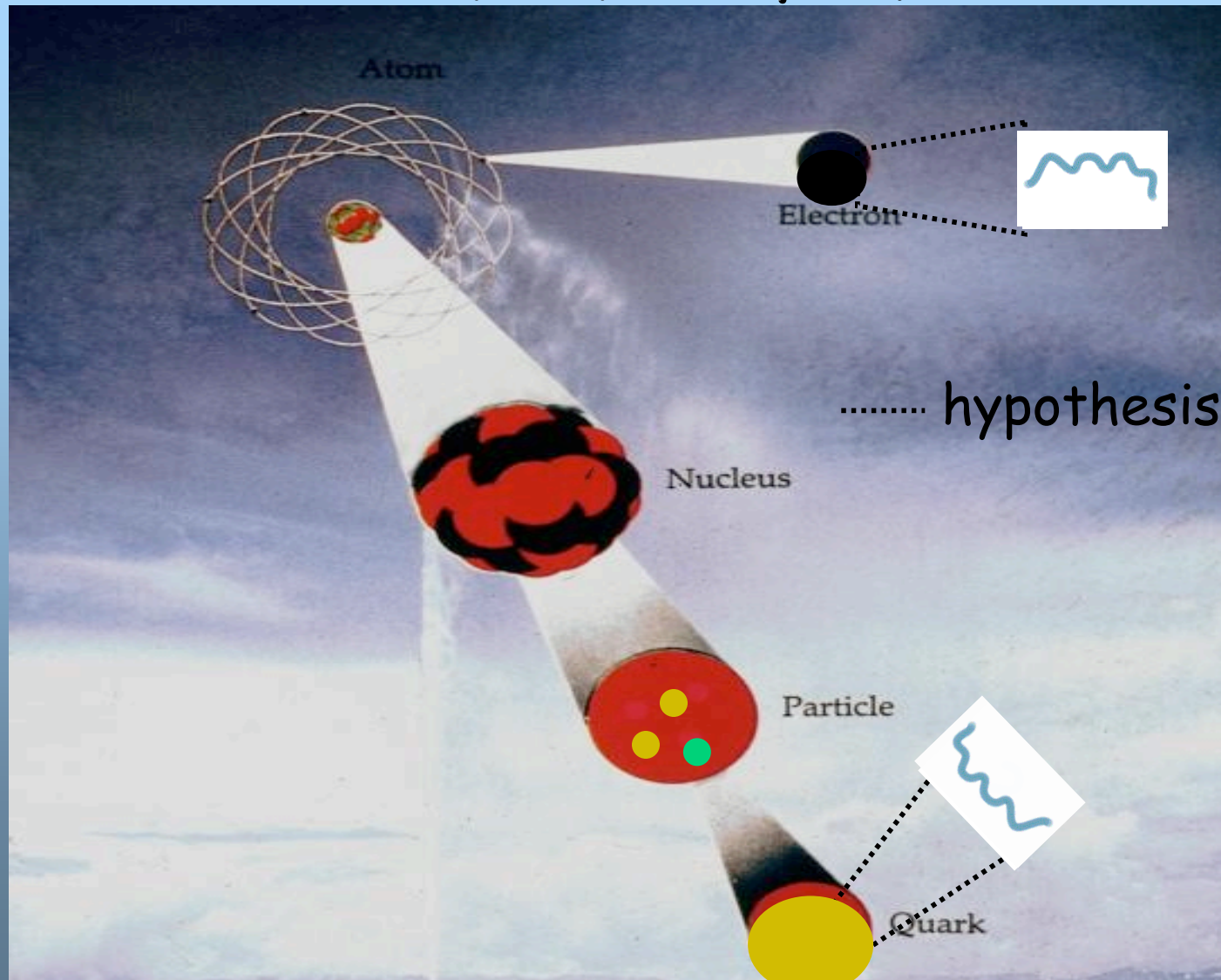
- Unifies all particles and all forces
 - gravity with quantum mechanics
- Fundamental particles are represented as vibrations on string



- 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 Mysterious Frontiers of Our Universe, BIG and small

The Structure of Matter



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

30

Supersymmetry and Strings

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

ELEMENTARY PARTICLES

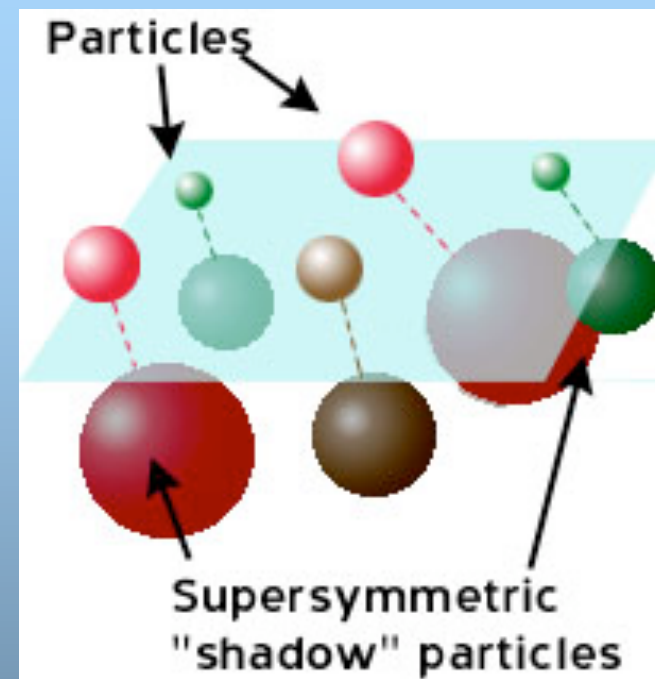
Quarks	u up	c charm	t top	γ photon
	d down	s strange	b bottom	g gluon
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z Z boson
	e electron	μ muon	τ tau	W W boson

I II III
Three Generations of Matter

ELEMENTARY ANTI-PARTICLES

Anti-Quarks	$\bar{u}$ up	$\bar{c}$ charm	$\bar{t}$ top
	$\bar{d}$ down	$\bar{s}$ strange	$\bar{b}$ bottom
Anti-Leptons	$\bar{\nu}_e$ electron antineutrino	$\bar{\nu}_\mu$ muon antineutrino	$\bar{\nu}_\tau$ tau antineutrino
	$\bar{e}$ positron	$\bar{\mu}$ antimuon	$\bar{\tau}$ antitau

I II III
Three Generations of Matter



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

The Mysterious Frontiers of Our Universe, BIG and small

Another puzzle

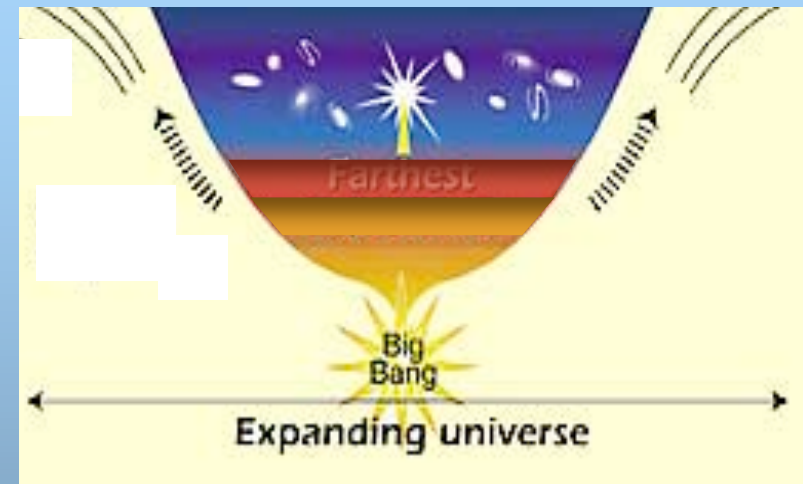
What gives matter mass?

- An ocean of Higgs Bosons - "Higgs Field"



The Big Bang

- Fundamental Physics needed to understand Big Bang



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

33

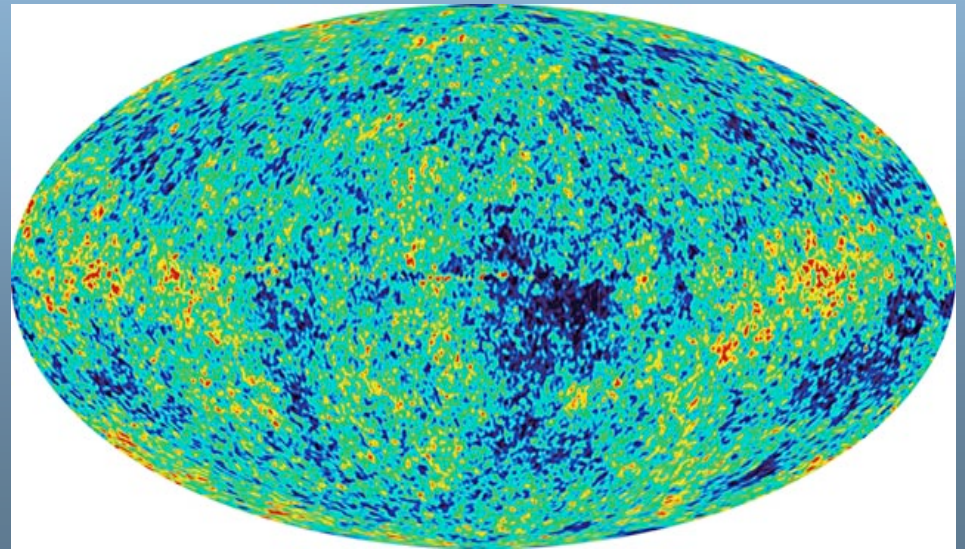
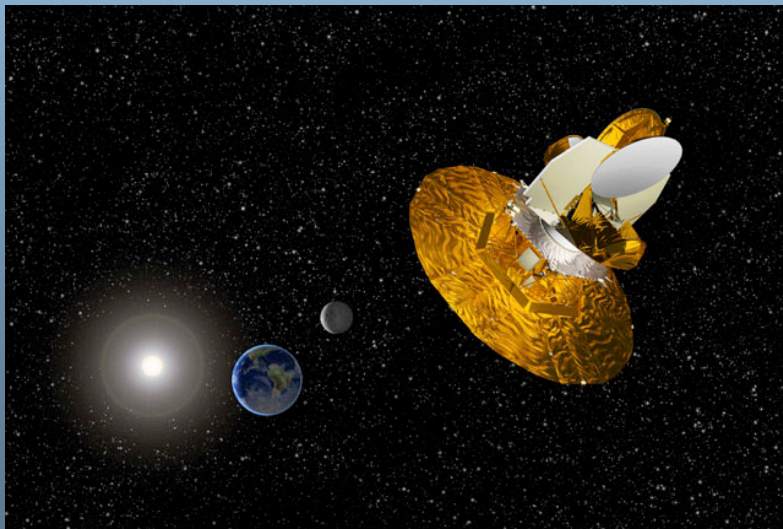
The Cosmic Fireball

- 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
- Latest - WMAP



The Mysterious Frontiers of Our Universe, BIG and small

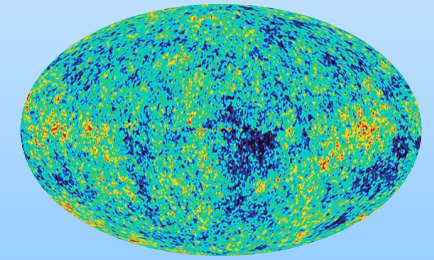
Rose City Astronomers

Jim Brau

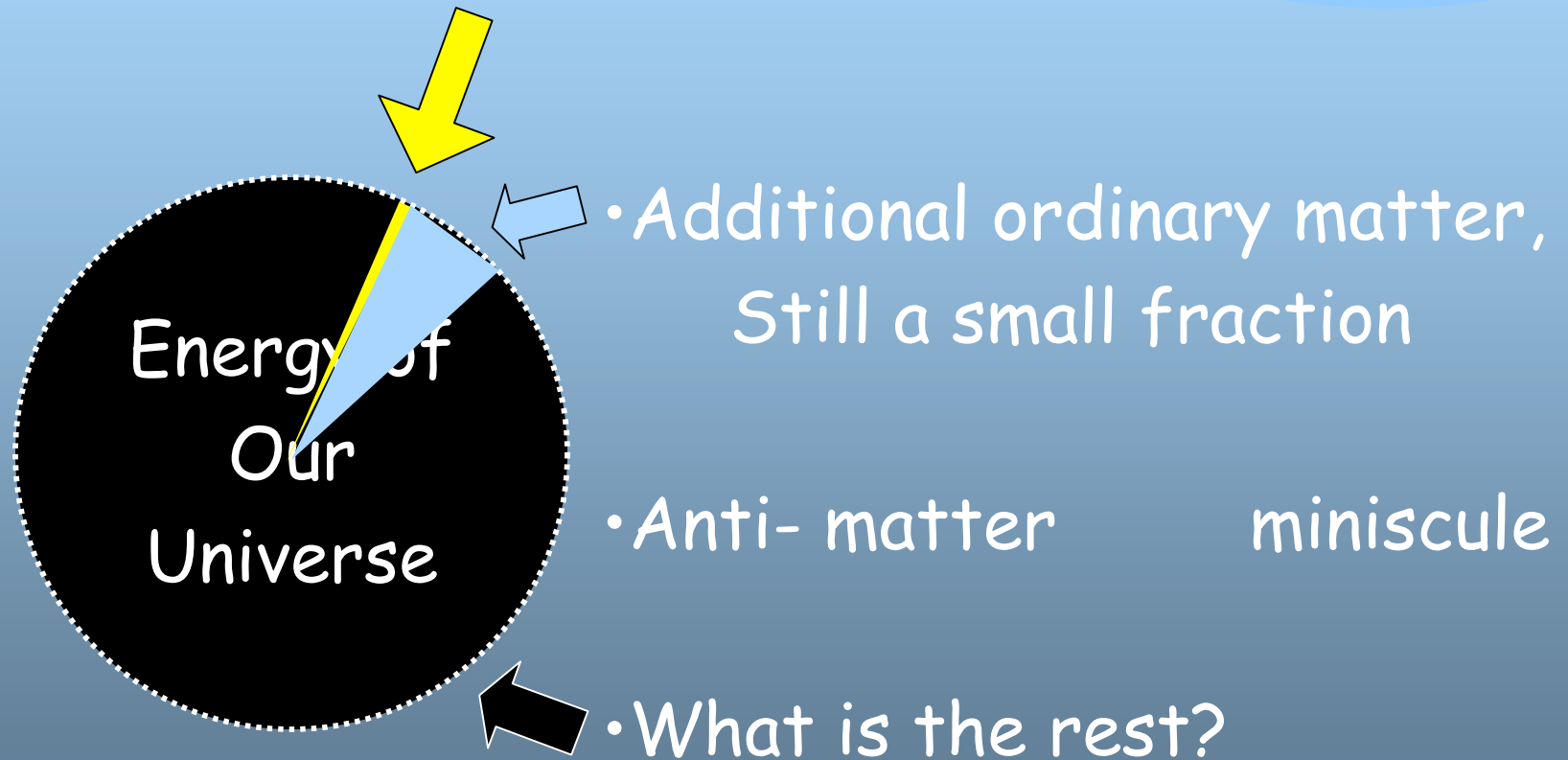
July 16, 2007

35

Probing the Big Bang

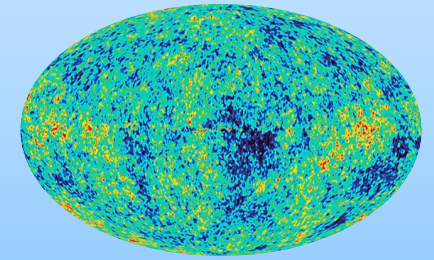


- The stars are a very small fraction

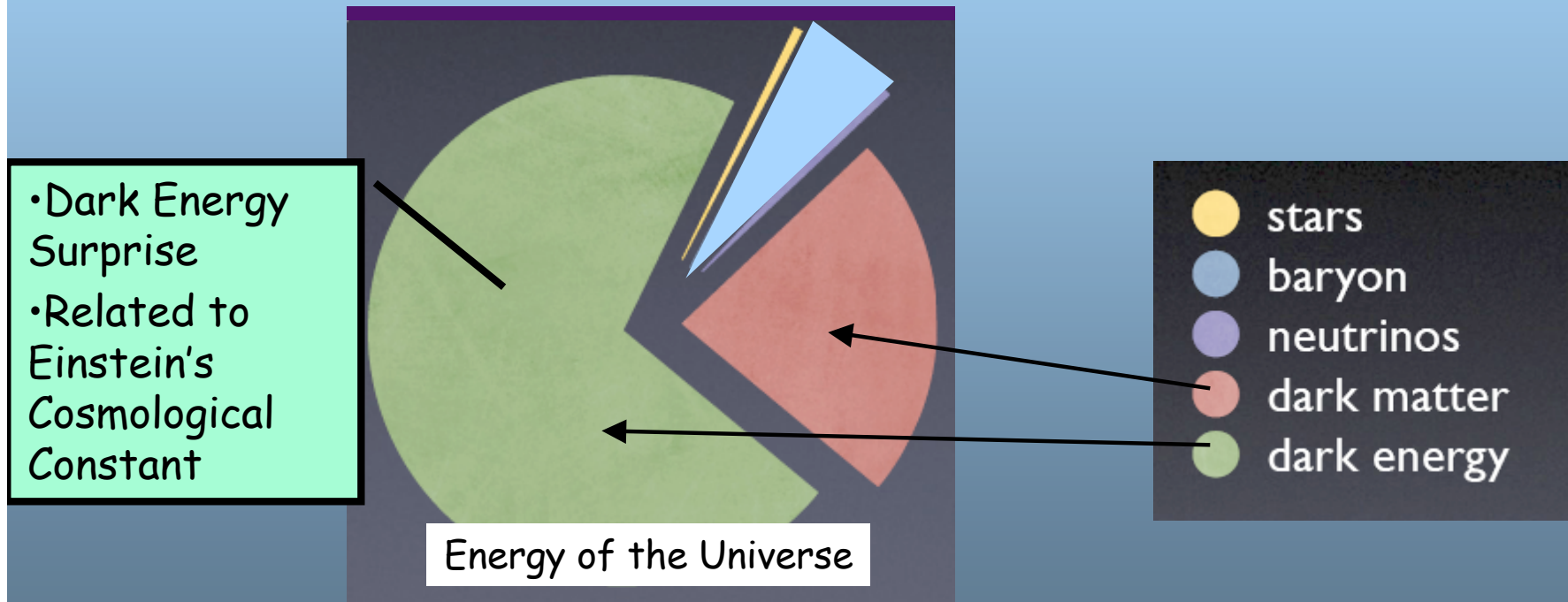


The Mysterious Frontiers of Our Universe, BIG and small

Probing the Big Bang



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



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

37

The Dark Side Controls the Universe

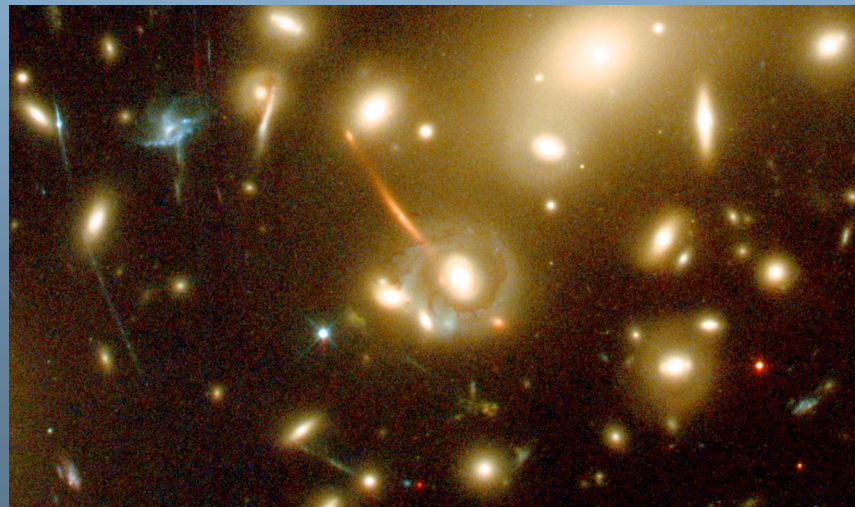


Dark Matter

HOLDS IT TOGETHER

Dark Energy

DETERMINES ITS DESTINY



The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

Jim Brau

July 16, 2007

38



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

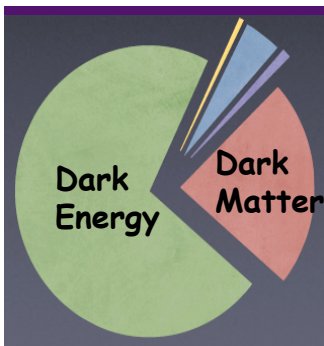
The Mysterious Frontiers of Our Universe, BIG and small

Rose City Astronomers

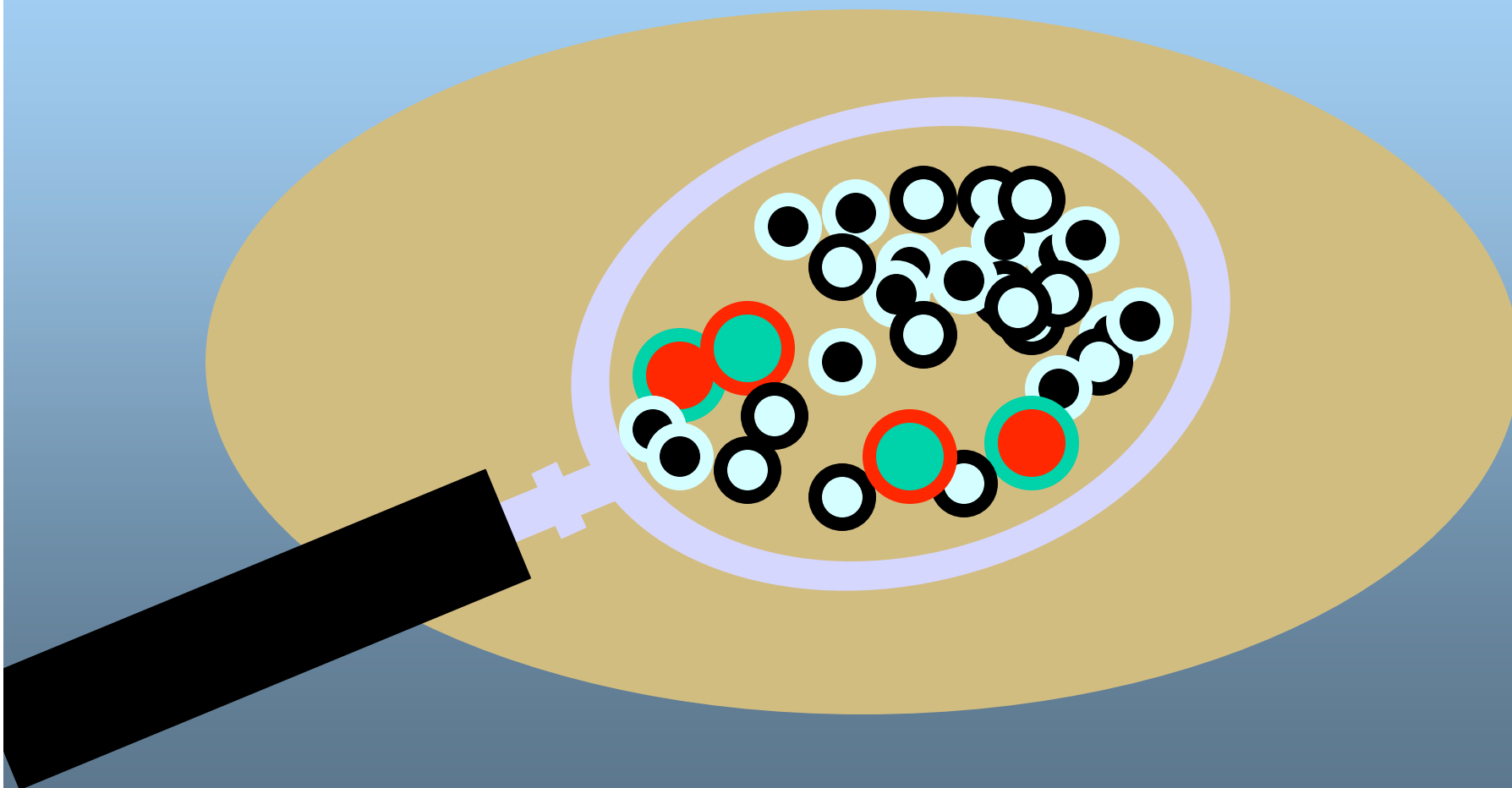
Jim Brau

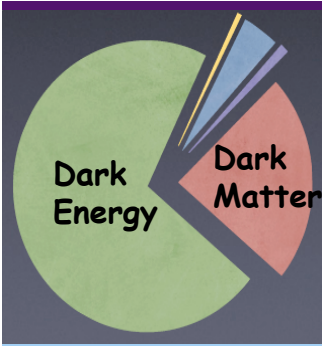
July 16, 2007

39



The Dark Energy Something from Nothing





The Dark Energy Something from Nothing

Quantum Fluctuations Create a "Dark Energy"
- Cosmological constant

Something from Nothing

- [illegible]

$$E_0 = \frac{1}{4\pi} \hbar \omega$$

uum energy is the sum of all the simple harmonic

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

λ_n) for the scalar field. This sum may be evaluated, and the terms may be made to go to infinity. The periodic boundary conditions are satisfied for integer values of n . There are then $Ldk/2\pi$ discrete values of k , and the sum becomes an integral:

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

impose a cutoff at a maximum wavevector k_{ma}

$$\rho_{vac} \equiv \lim_{L \rightarrow \infty} \frac{E_0}{L^3} = \frac{\hbar k_{max}^4}{32\pi^3}$$

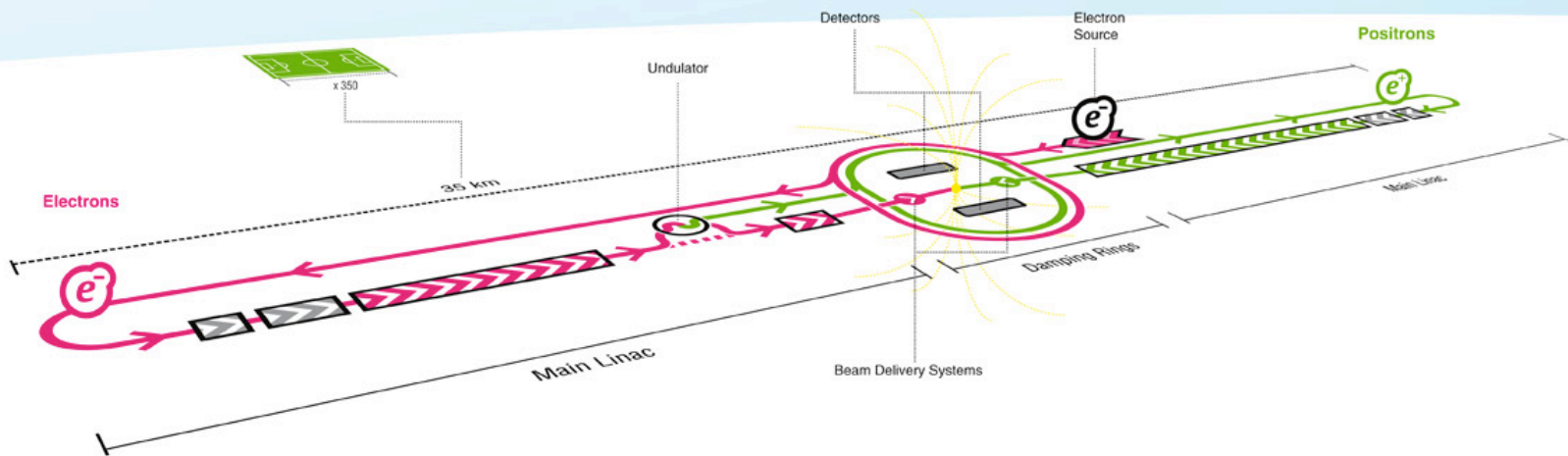
Large Hadron Collider (LHC) Geneva, Switzerland



Nearing
Completion

Begins operation
next year

International Linear Collider (ILC)



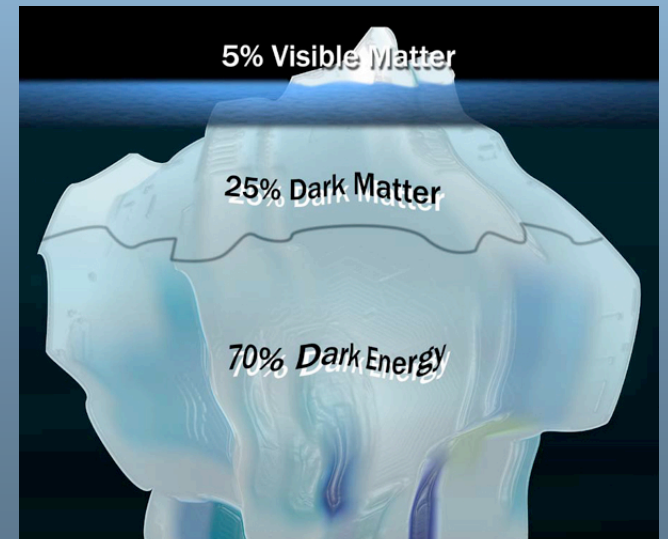
Under
development

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!



The Mysterious Frontiers of Our Universe, BIG and small

Acknowledgements

RESEARCH SUPPORTED BY

Department of Energy
OFFICE OF SCIENCE



NATIONAL SCIENCE FOUNDATION



Philip H. Knight