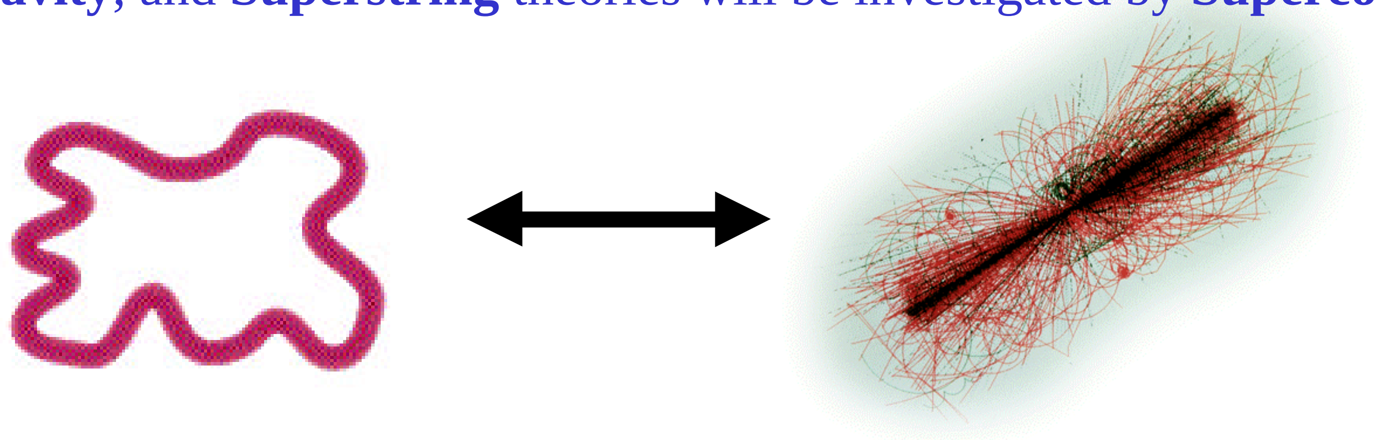
The "Super" Era of Sub-Atomic Particle Physics

Jay Hauser

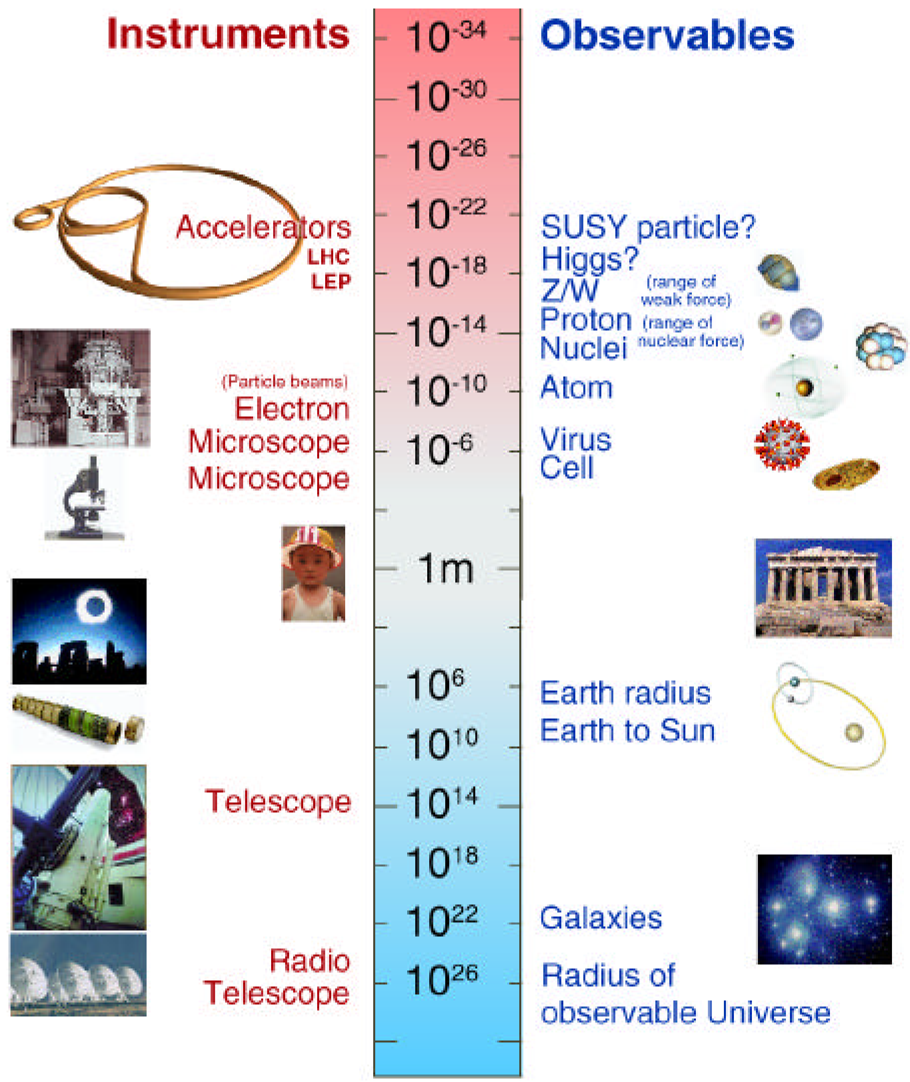
Abstract:

Particle physics has now moved into the "Super" era, in which **Supersymmetry**, **Supergravity**, and **Superstring** theories will be investigated by **Supercolliders**.



A Supercollider is being built in Europe which may produce Dark Matter and other particles predicted by the Super-theories. This machine will produce a huge amount of data, and finding these particles will be like finding a few needles in a 100-million-ton haystack. This amazing machine and the upcoming search for these particles will be described.

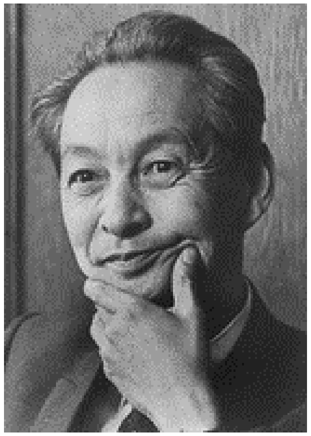
Science Tools:
the Very Large and the Very Small



Outline of Talk

- Fundamental physics of the latter 20th Century
  - 1) Relativity + Quantum Mechanics = Field Theory
  - 2) the Standard Model of forces ($4 \rightarrow 3$)
- Fundamental physics of the 21st Century
  - 1) Unified Forces ($3 \rightarrow 2$) or ($3 \rightarrow 1$) ?
  - 2) Supersymmetry?
  - 2) String Theory?
- Particle physics with Supercolliders
  - Two important experiments: CDF and CMS
- Particle physics and the creation of the universe

Field Theory: Pioneers of "Quantum Electrodynamics"



Sin-Itiro Tomonaga
Japan

Tokyo University of Education
Tokyo, Japan

1906 - 1979

Richard P. Feynman
USA

California Institute of Technology
Pasadena, CA, USA

1918 - 1988

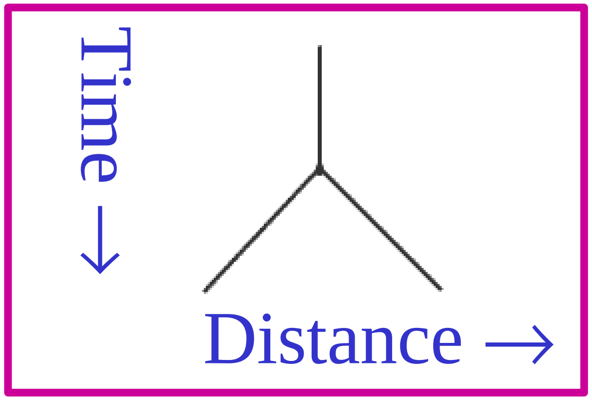
Julian Schwinger
USA

Harvard University
Cambridge, MA, USA

1918 - 1994

"Feynman Diagram" for calculations:

- **Point-like particles are represented as <u>lines</u> and interactions as <u>points</u> in a space-time plot:**



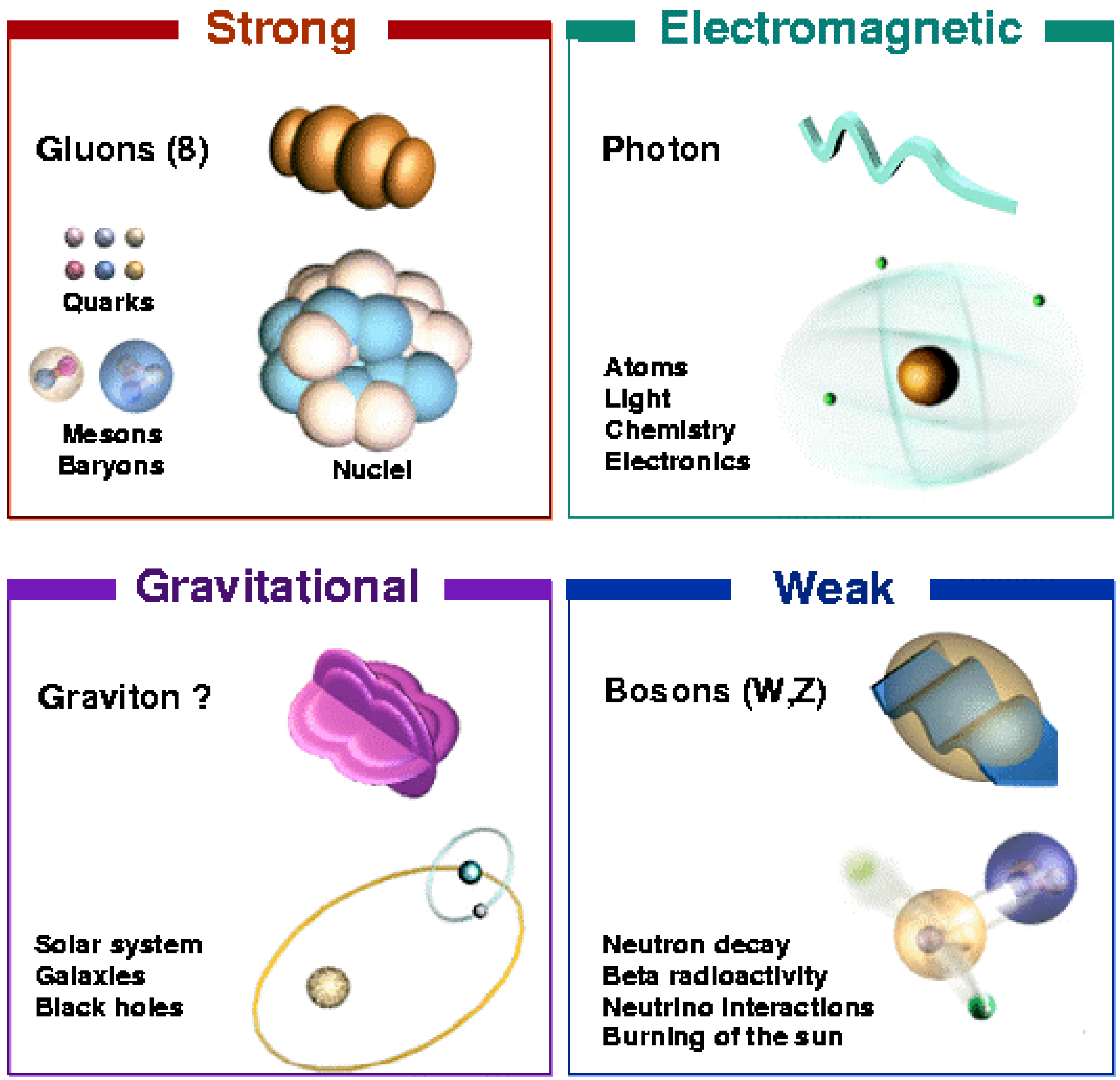
A Tale of 4 Forces:

2 familiar forces:

- **Gravity**: planets, galaxies, falling apples
- **Electro-magnetism**: chemistry, atoms, electronics

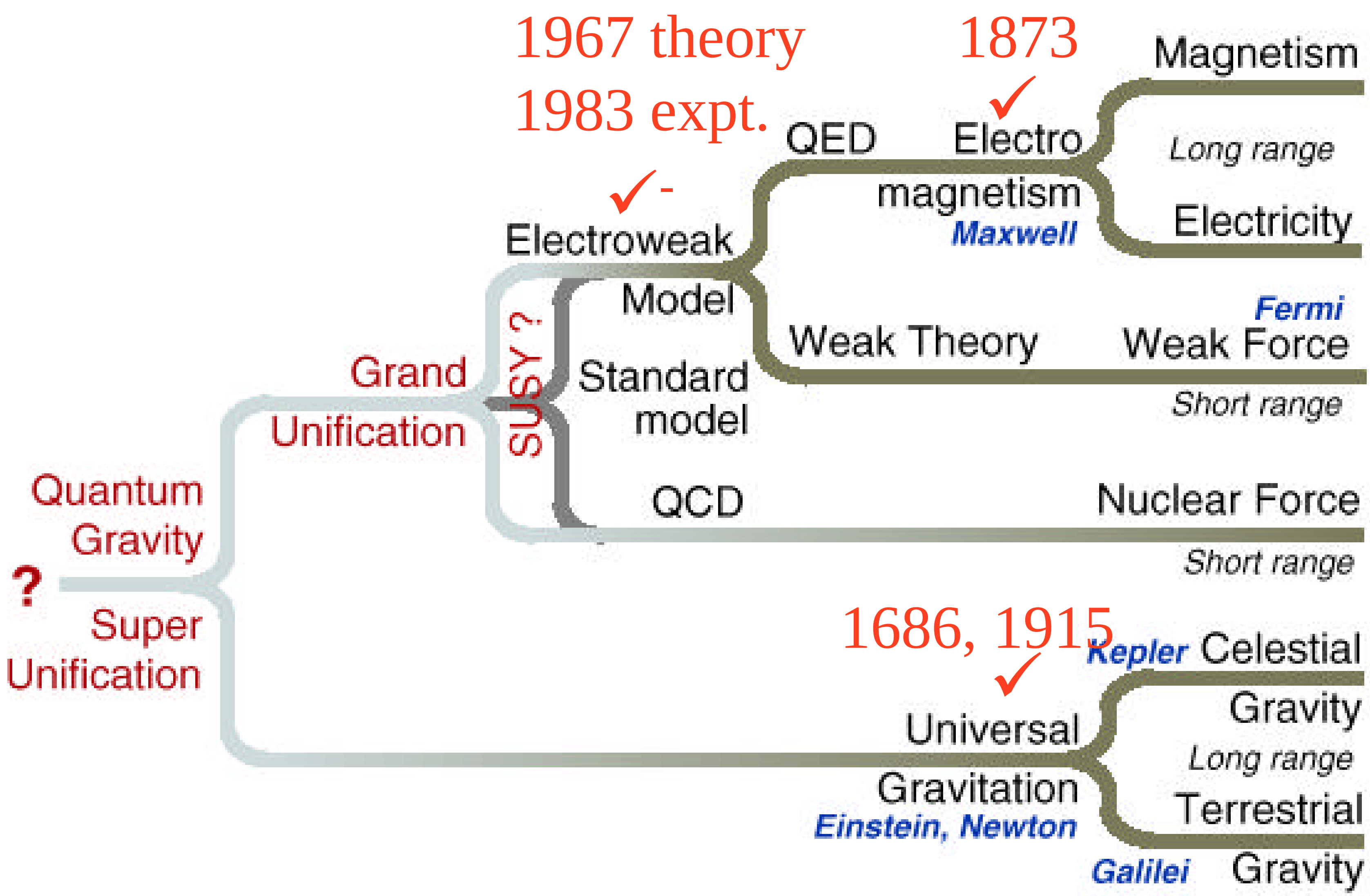
2 other forces:

- **Strong** force holds protons and neutrons together in nuclei against repellant electrical force
- **Weak** force powers the sun and causes some kinds of radioactivity (beta decay)



The particle drawings are simple artistic representations

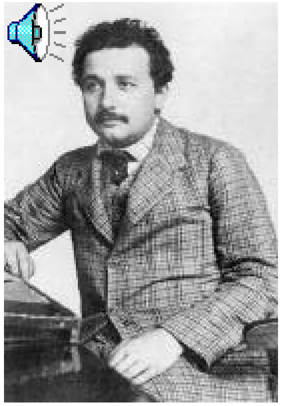
Ideas of Force Unification



At What Energy is Unification Obvious?

- Weak and ElectroMagnetic (EM) forces: about 100 GeV
  - The theory hinges on the "Higgs" particle, energy<1000 GeV
  - Enigmatic Higgs particle is not yet observed, does it exist?
- Weak, EM, and Strong forces: about 10^{15} GeV
  - Protons very slowly decay away - gulp!
  - It's very difficult to keep the Higgs energy <<10^{15} GeV: need Supersymmetric particles with energy<1000 GeV
- Above plus Gravity: about 10^{19} GeV

Recall Einstein:
Energy=Mass*c²
($E=mc^2$)



What's Supersymmetry?

Most elementary particles are spinning...

Supersymmetry is a kind of "Spin symmetry":

Electron has Spin ⟷ "Selectron" has no Spin

Higgs has no Spin ⟷ "Shiggs" has Spin

Supersymmetry doubles the list of elementary particles

No Supersymmetry particles yet observed, but recall (?)

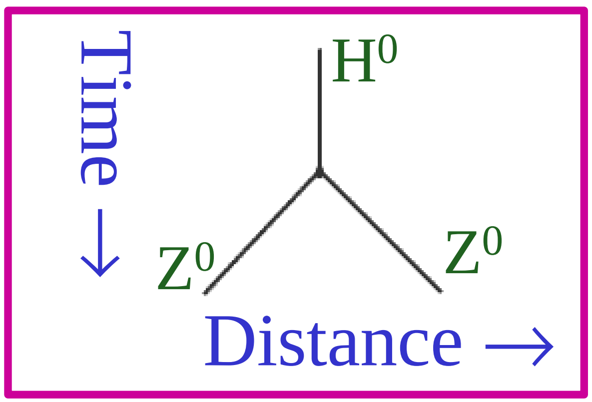
- Anti-electron was predicted in 1927 (Dirac) and discovered in 1931 (Anderson)
- *Every* particle has an anti-particle (from Field Theory)

Field Theory versus String Theory

The "Feynman Diagram":

- **Point ● particles are represented as lines in space-time**
- **Interaction (force) is represented by point vertex:**

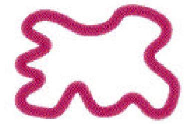
Higgs particle "decay"



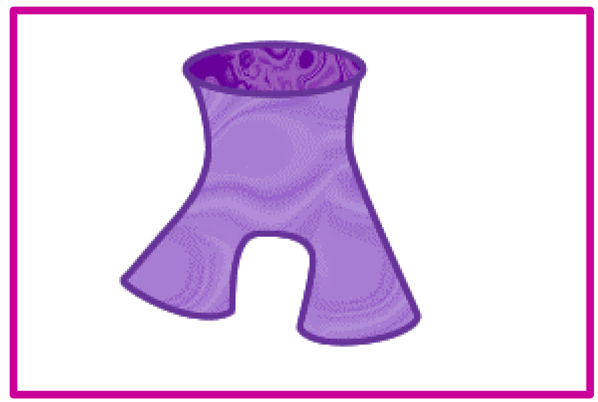
Point vertex causes infinities!

Cumbersome remedies were found...

Ed Witten and Colleagues:

- **Particles are strings** 
- **Represented as surfaces in space-time**
- **Interact at vertex:**

String theory version



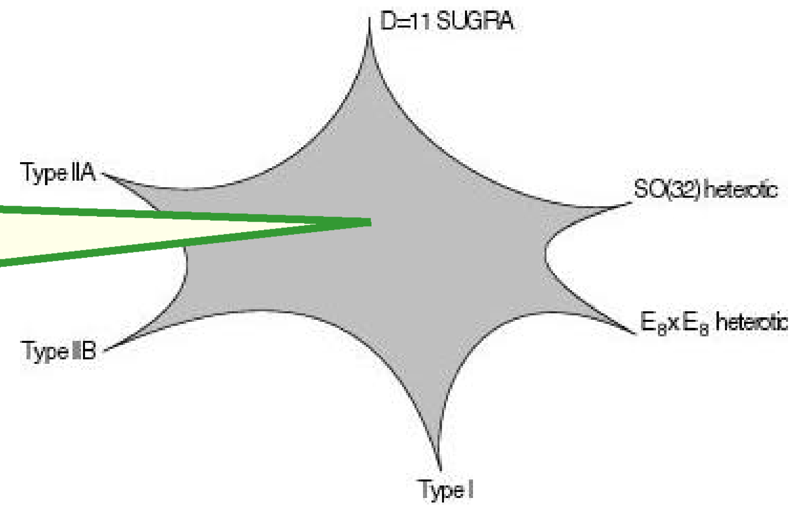
No points - infinities are gone!

But strings require extra dimensions!

More String Theory

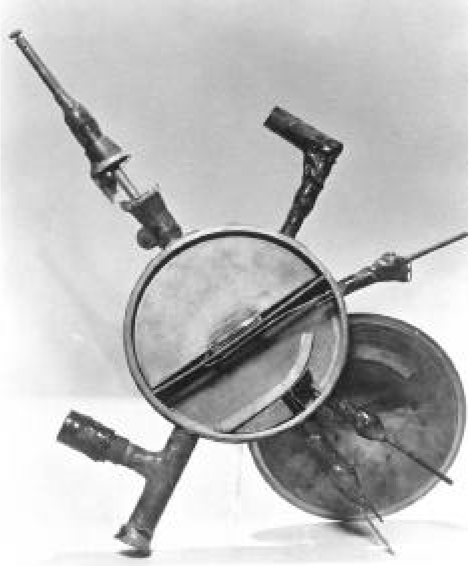
Type	Spacetime Dimensions	Details
Bosonic	26	Only bosons, no fermions means only forces, no matter, with both open and closed strings. Major flaw: a particle with imaginary mass, called the tachyon
I	10	Supersymmetry between forces and matter, with both open and closed strings, no tachyon, group symmetry is SO(32)
IIA	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, massless fermions spin both ways (nonchiral)
IIB	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, massless fermions only spin one way (chiral)
HO	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, heterotic, meaning right moving and left moving strings differ, group symmetry is SO(32)
HE	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, heterotic, meaning right moving and left moving strings differ, group symmetry is E8 x E8

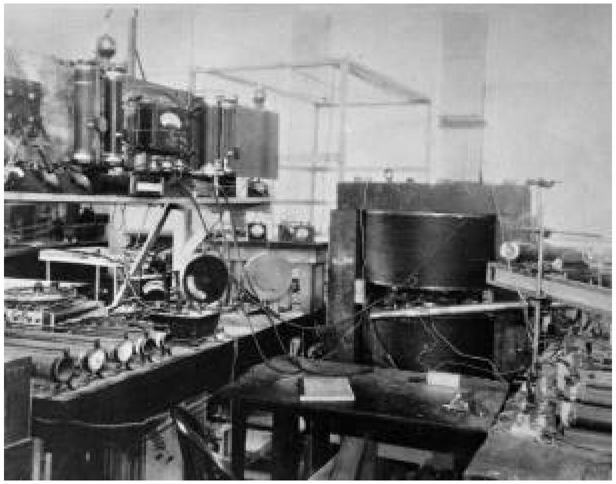
Recent discovery:
different theories are all contained in M-Theory!



Accelerators: Bigger, and Stronger Magnets $\longrightarrow$ Higher Energy

1931 Lawrence and Livingston operate the first Cyclotron



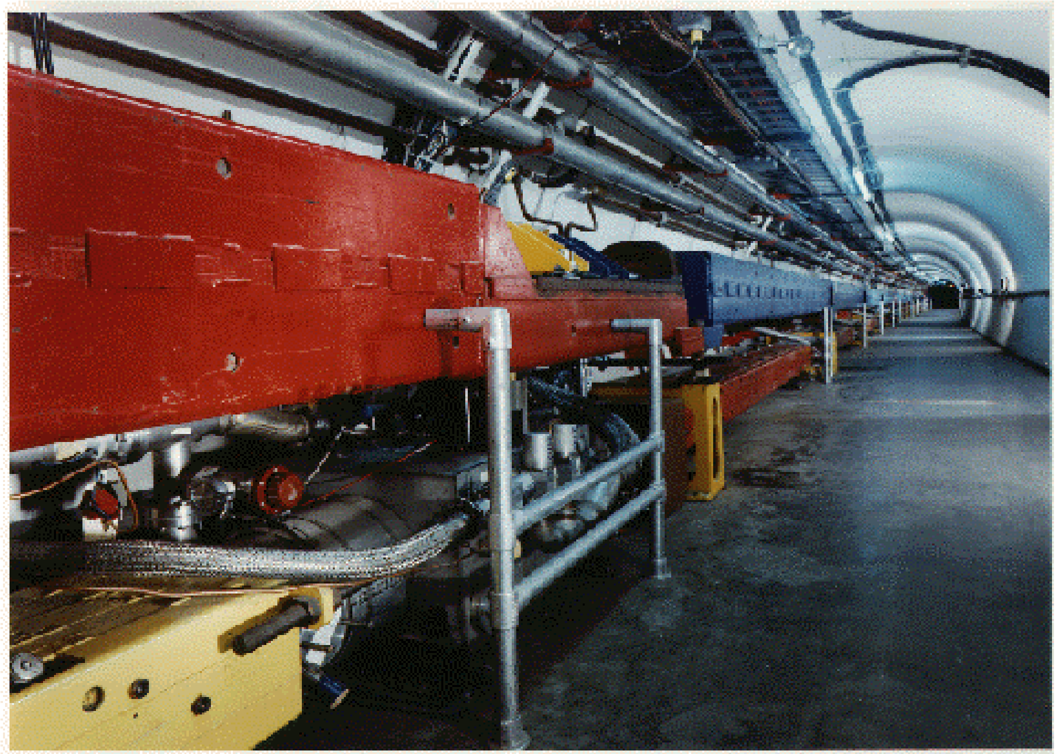


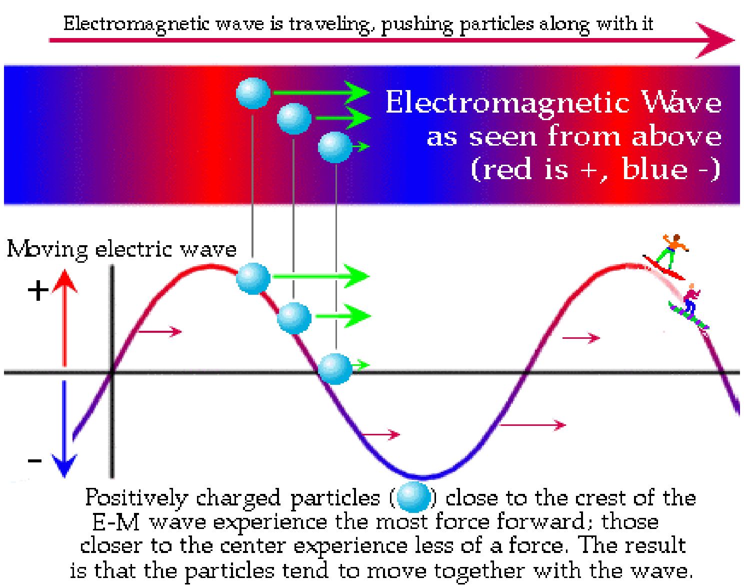
Berkley 11 inch

This is still pre-WW II

Modern Particle Accelerators

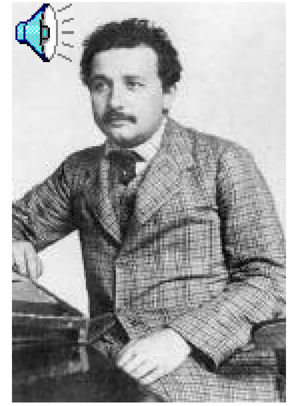
The particles are guided around a ring by strong magnets so they can gain energy over many cycles and then remain stored for days





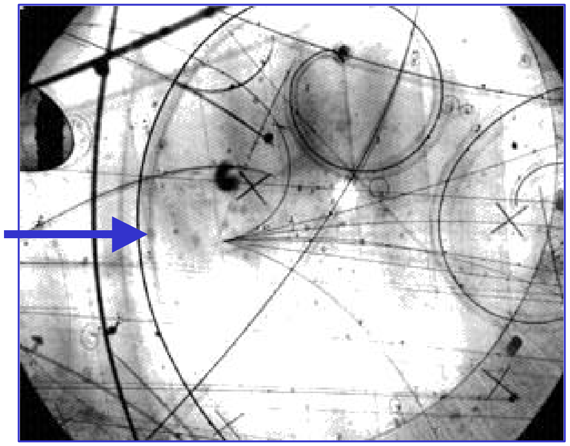
The particles gain energy by surfing on the electric fields of well-timed radio oscillations (in a cavity like a microwave oven)

Making new particles: use $E=mc^2$



I) Old way: beam hits stationary target

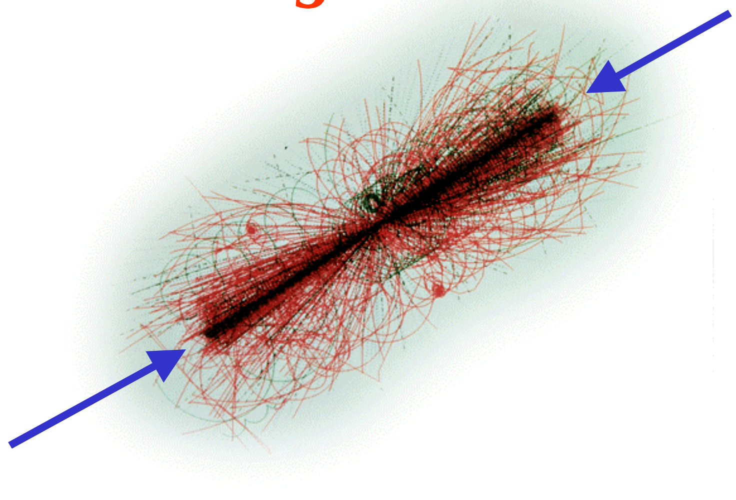
Beam particle: E

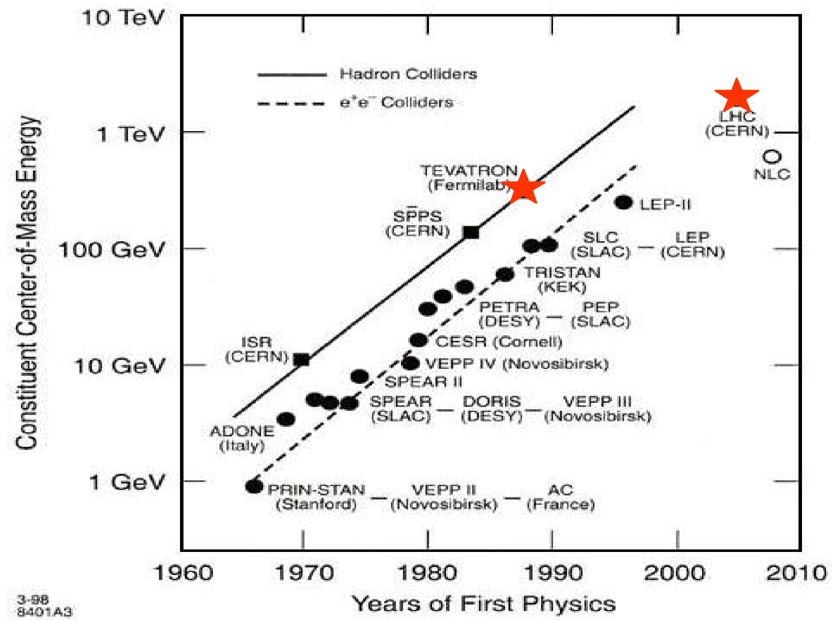


New particles produced:

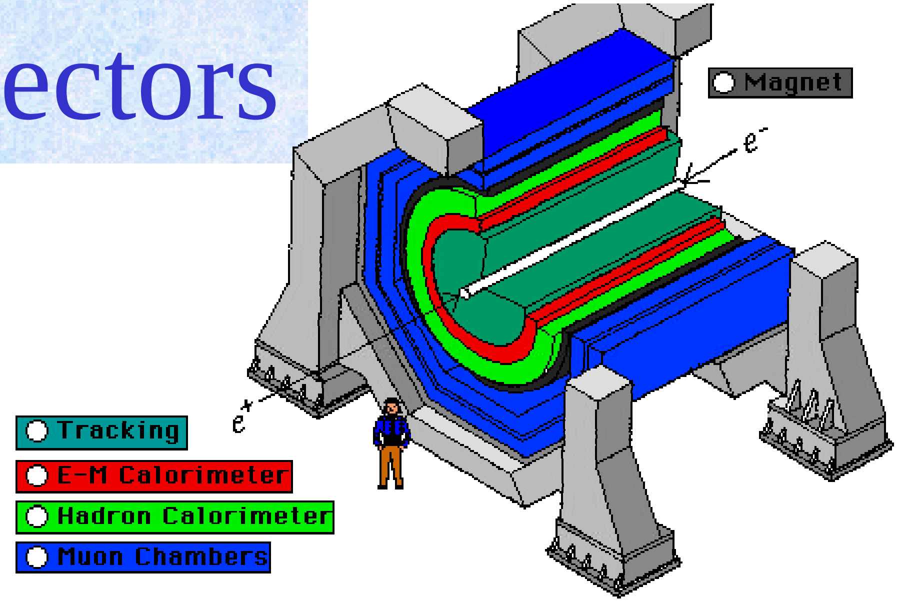
$$E=(m_1+m_2+\ldots)c^2$$

II) For more energy: use *colliding* beams



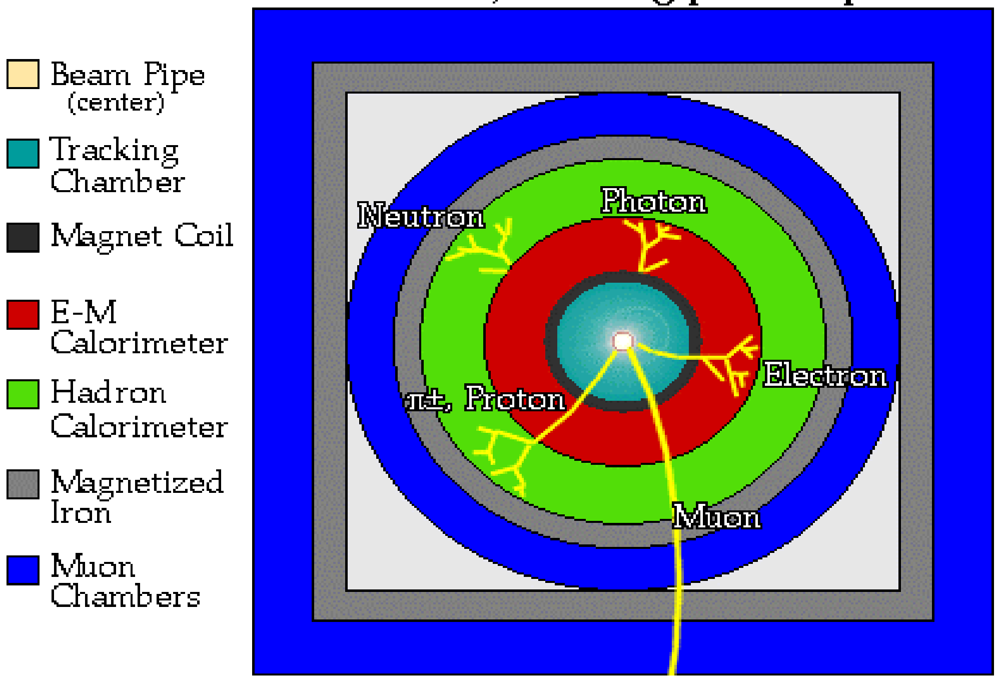


Particle Physics Detectors



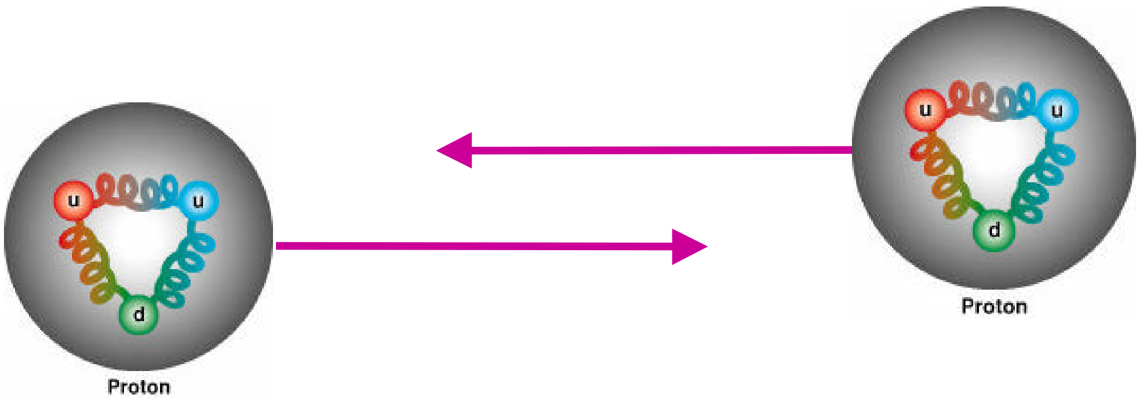
- A tracking chamber measures the energies of charged particles (with aid of a big magnet to bend them)
- A calorimeter measures energies of neutral particles
- A muon system sees only penetrating muon particles
- Used to take pictures (bubble chambers), now we use fully electronic readout

A detector cross-section, showing particle paths



Colliding Proton/Antiproton Beams

Like throwing bags of marbles at each other at high velocity:



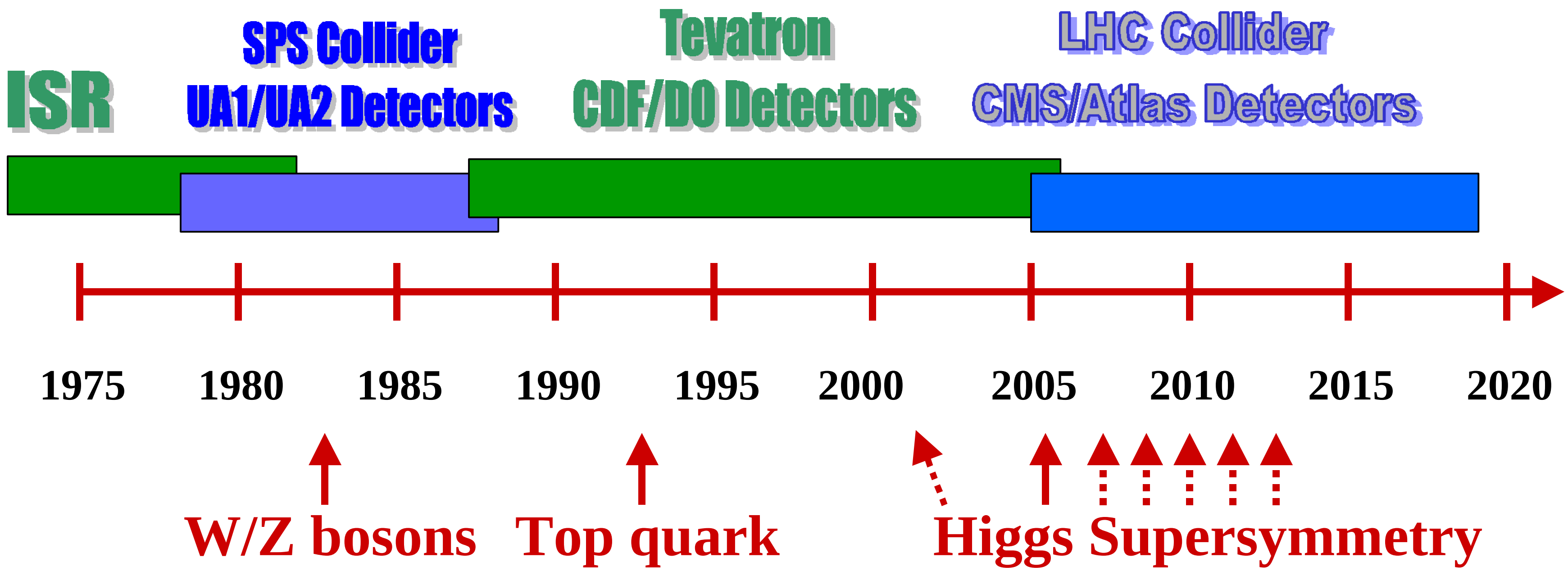
Marble-marble collisions are interesting, not bag-bag collisions

Fortunately this can be deciphered

- the number and arrangements of the “marbles” has been measured by other experiments

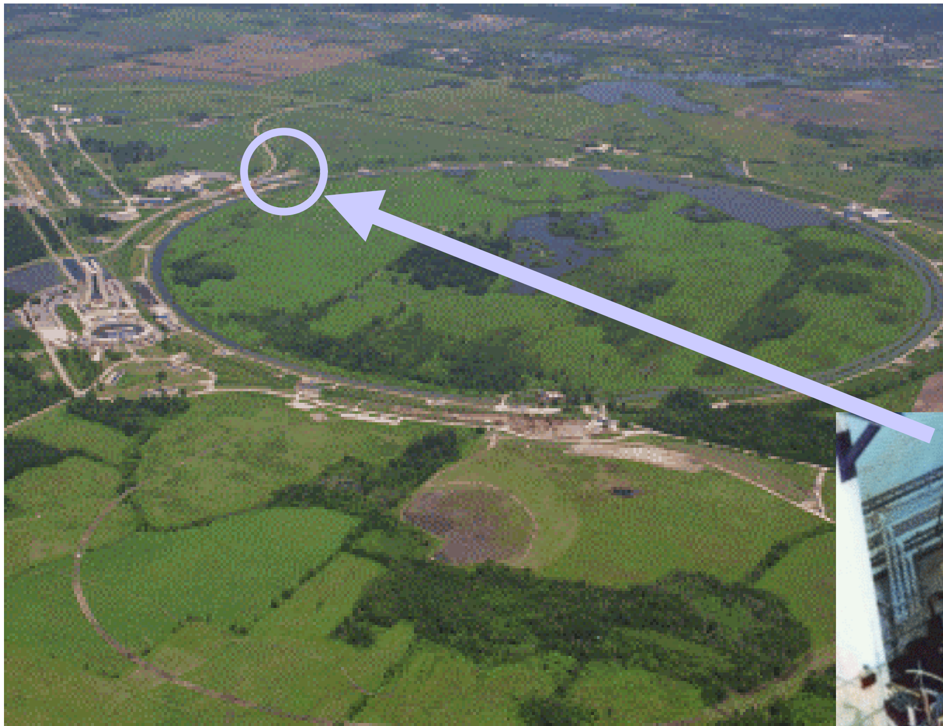
Proton Collider Discoveries

Timeline of accelerators, detectors, and discoveries:



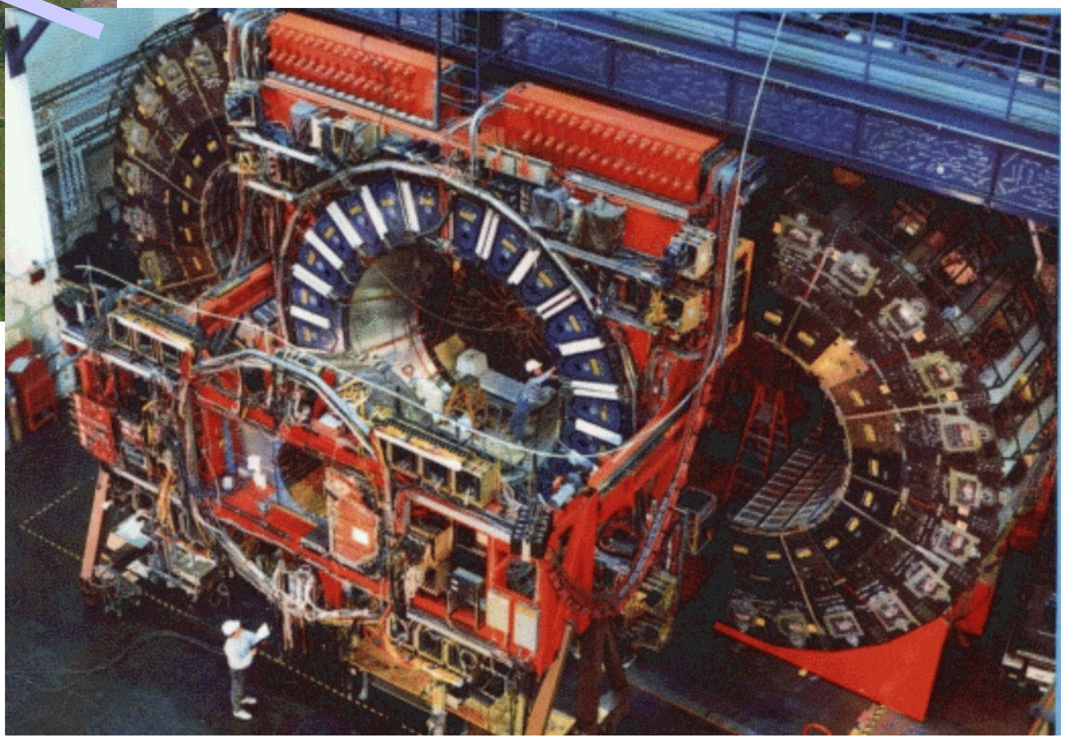
Other possibilities: heavy Z's, right-handed W's, CP violation in B decays, heavy stable particles, composite quarks or leptons, leptoquarks, ...

Proton-Antiproton Collisions at Fermilab (Chicago)

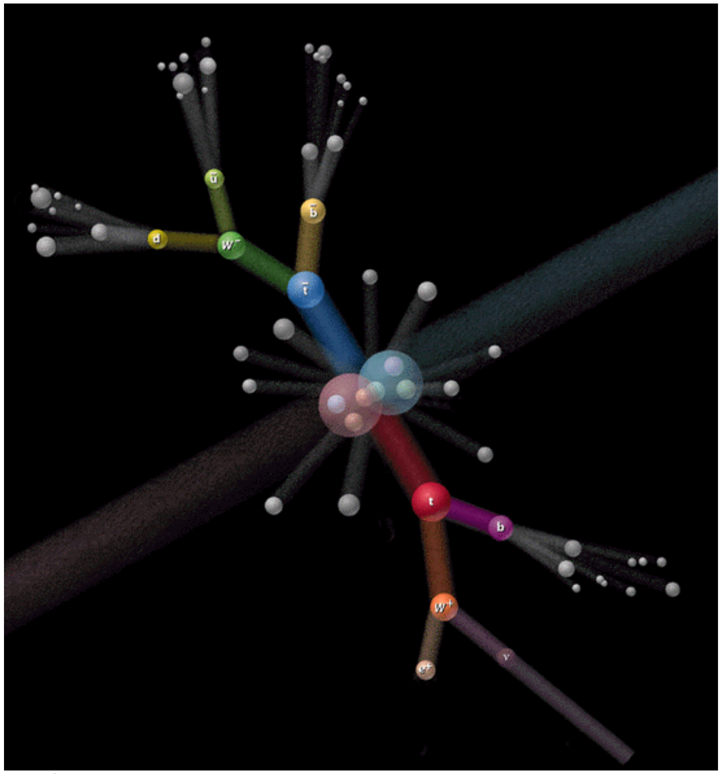


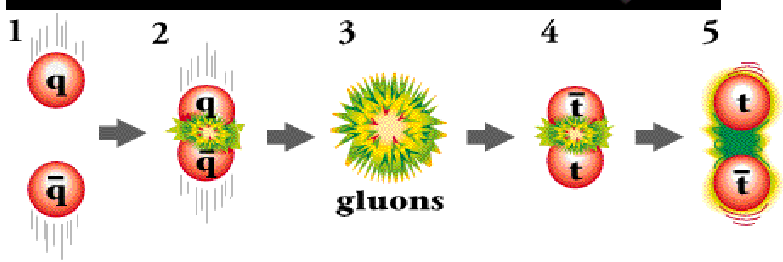
The Tevatron accelerator, 6 km circumference

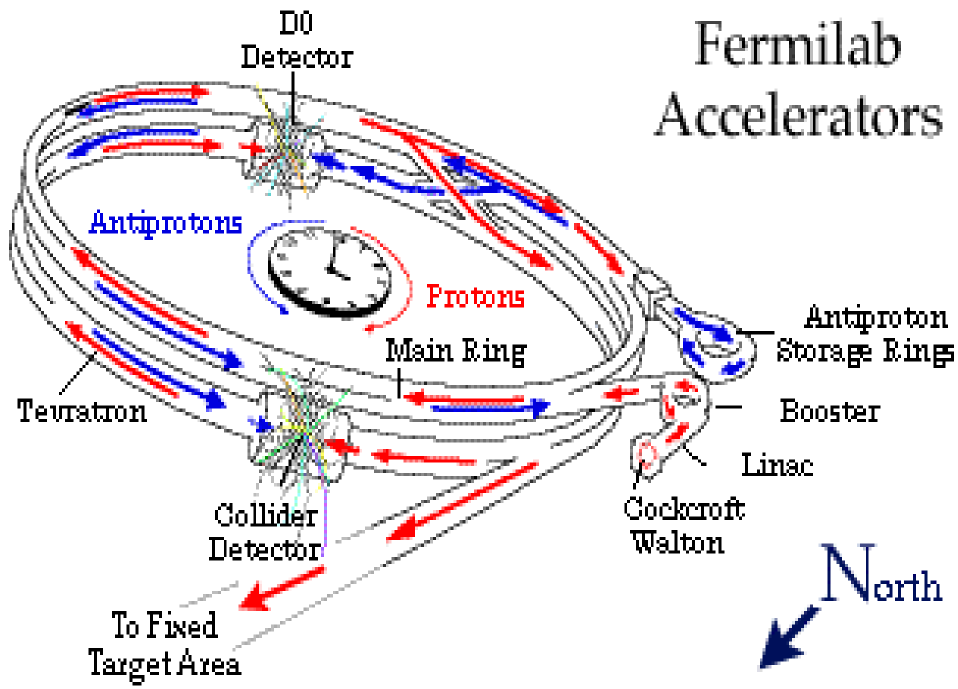
The CDF (Collider Detector at Fermilab) experiment



Discovery of the top quark in 1995

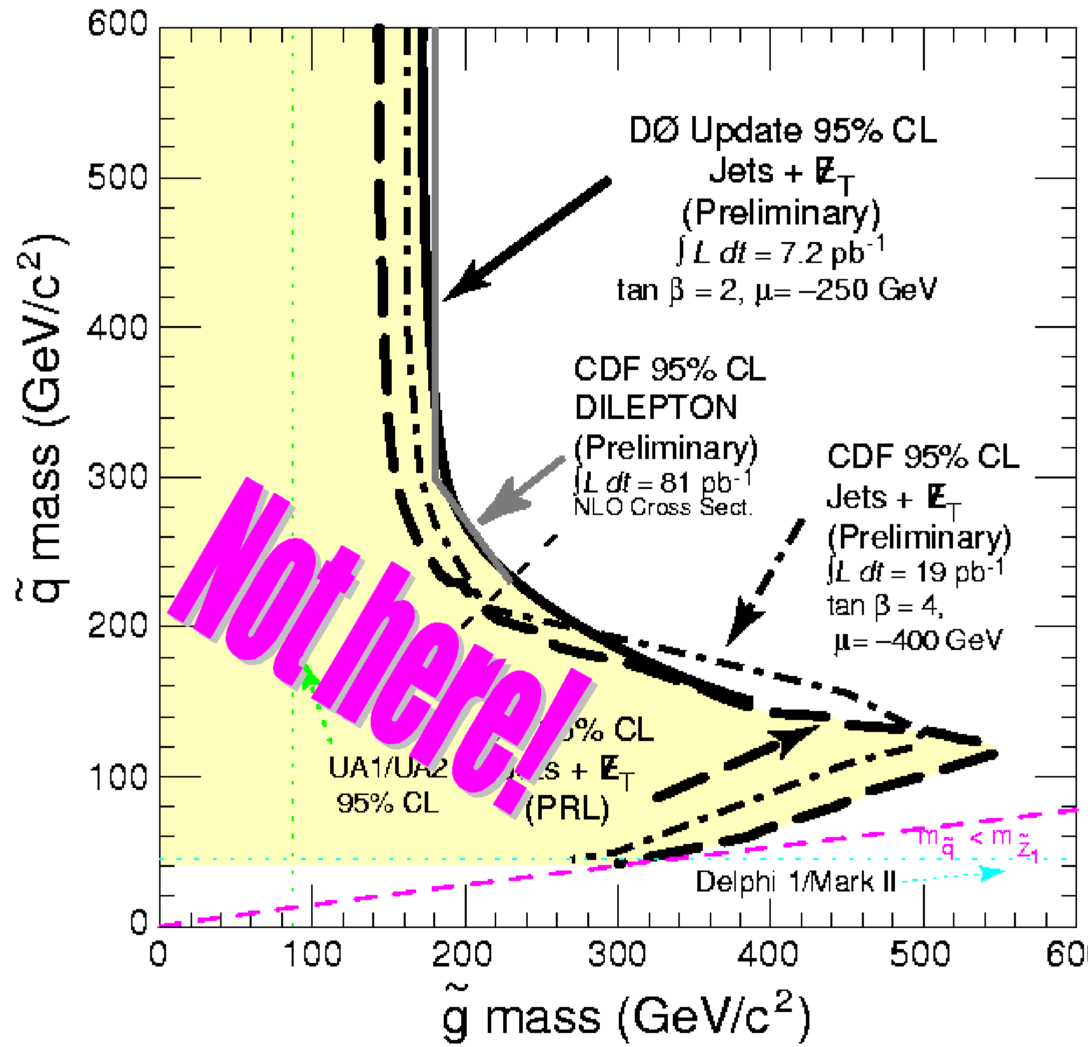




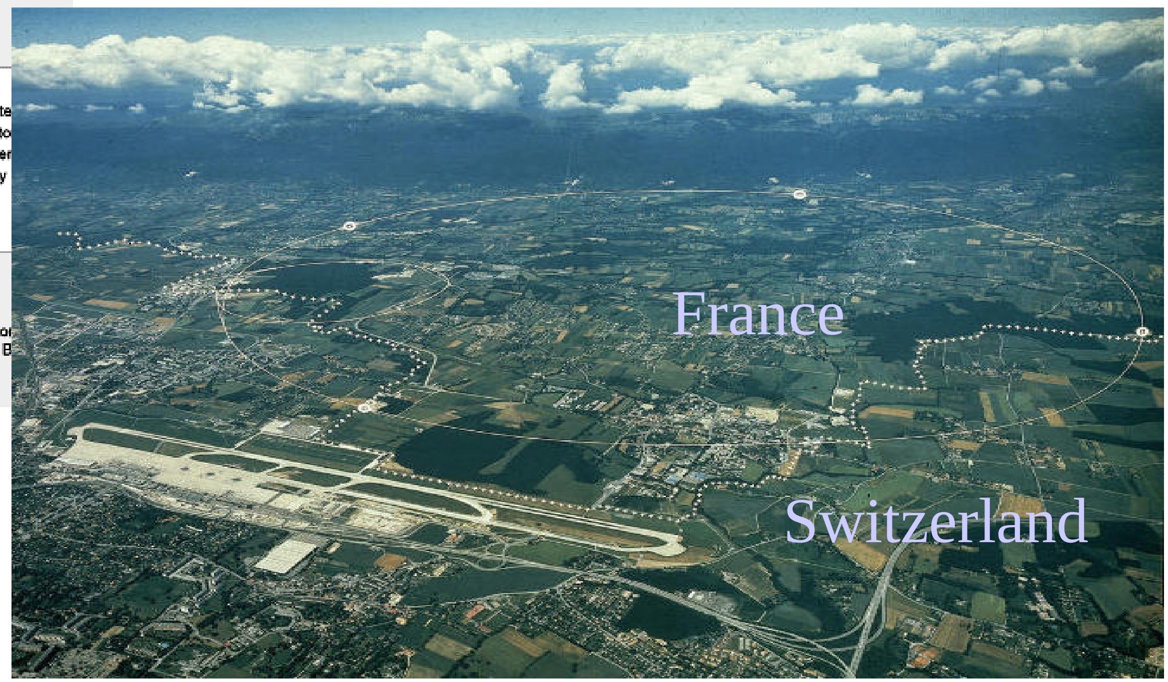


The top quark has a mass of 175 GeV, as much as an atom of gold

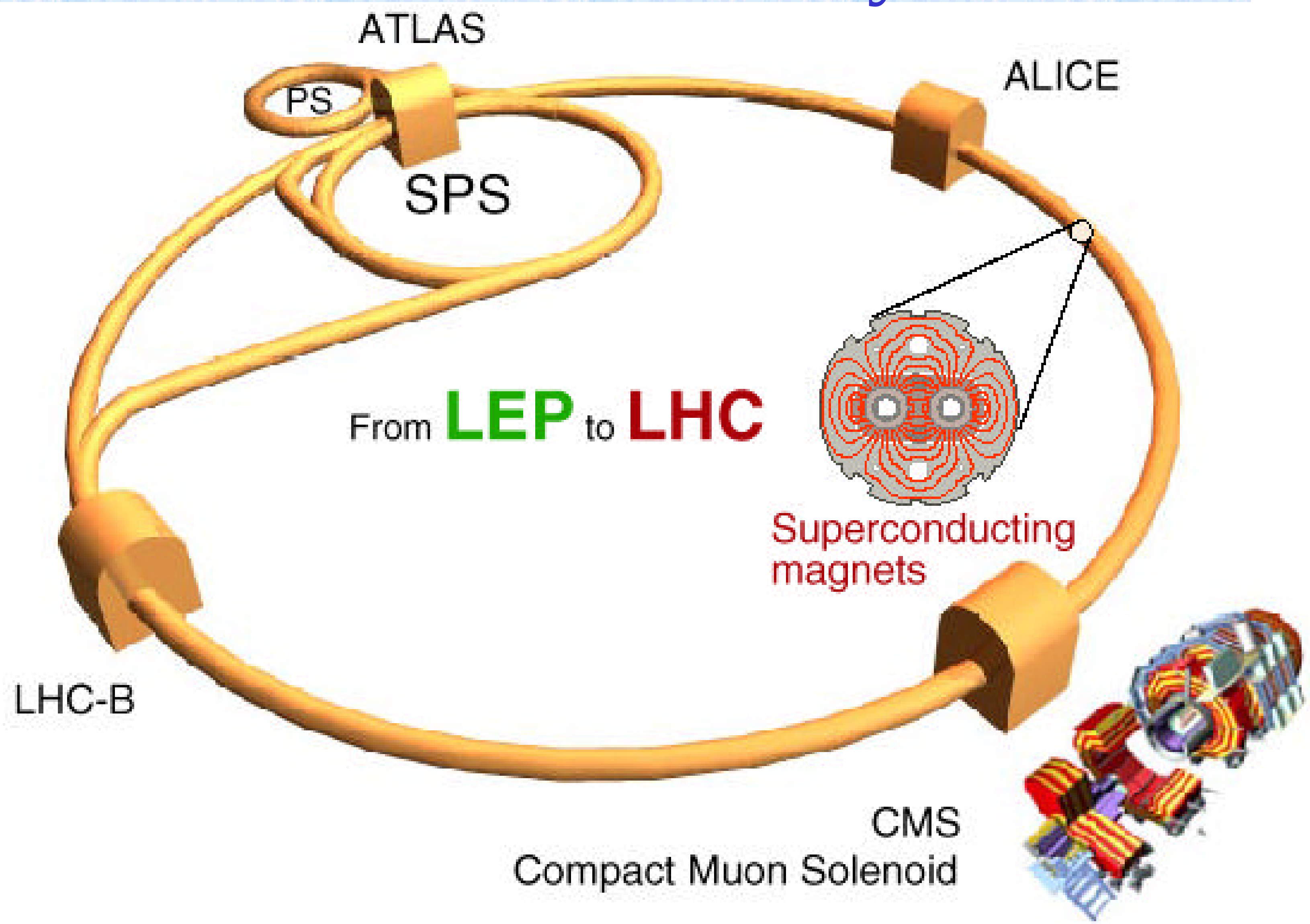
We Looked for Supersymmetric Quarks and Gluons



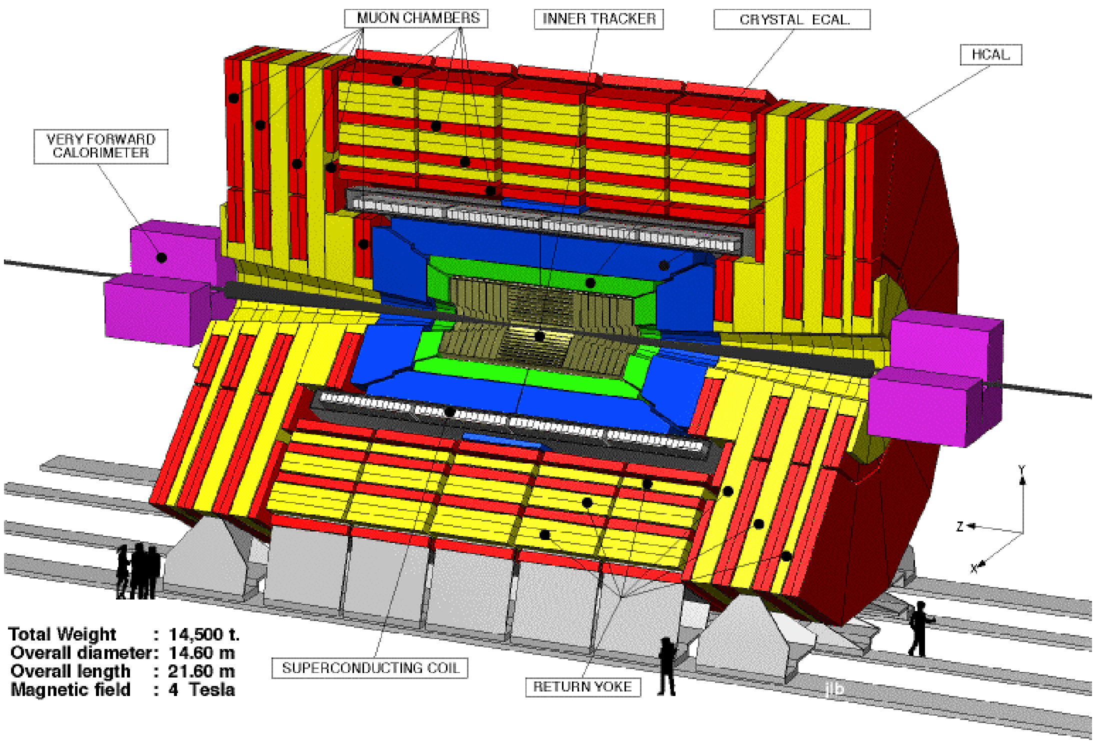
The CERN Laboratory near Geneva, Switzerland

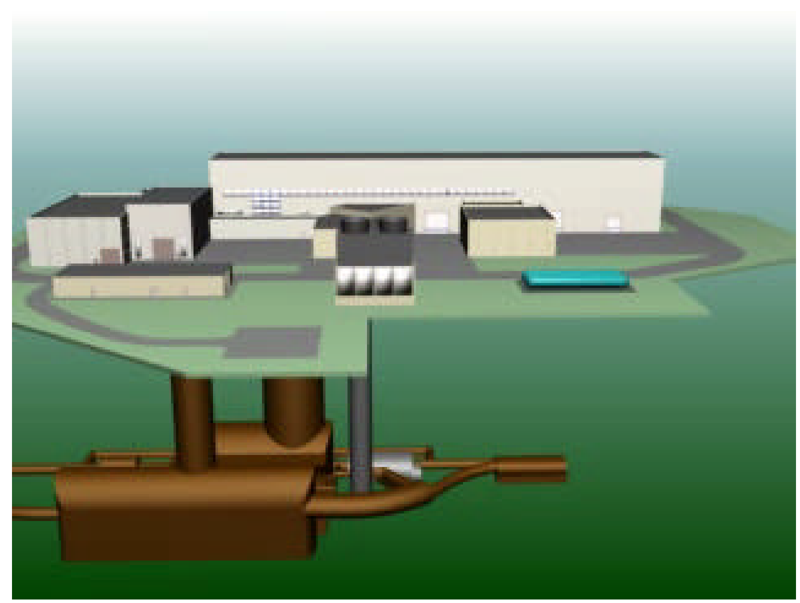


The LHC Accelerator at the CERN Laboratory

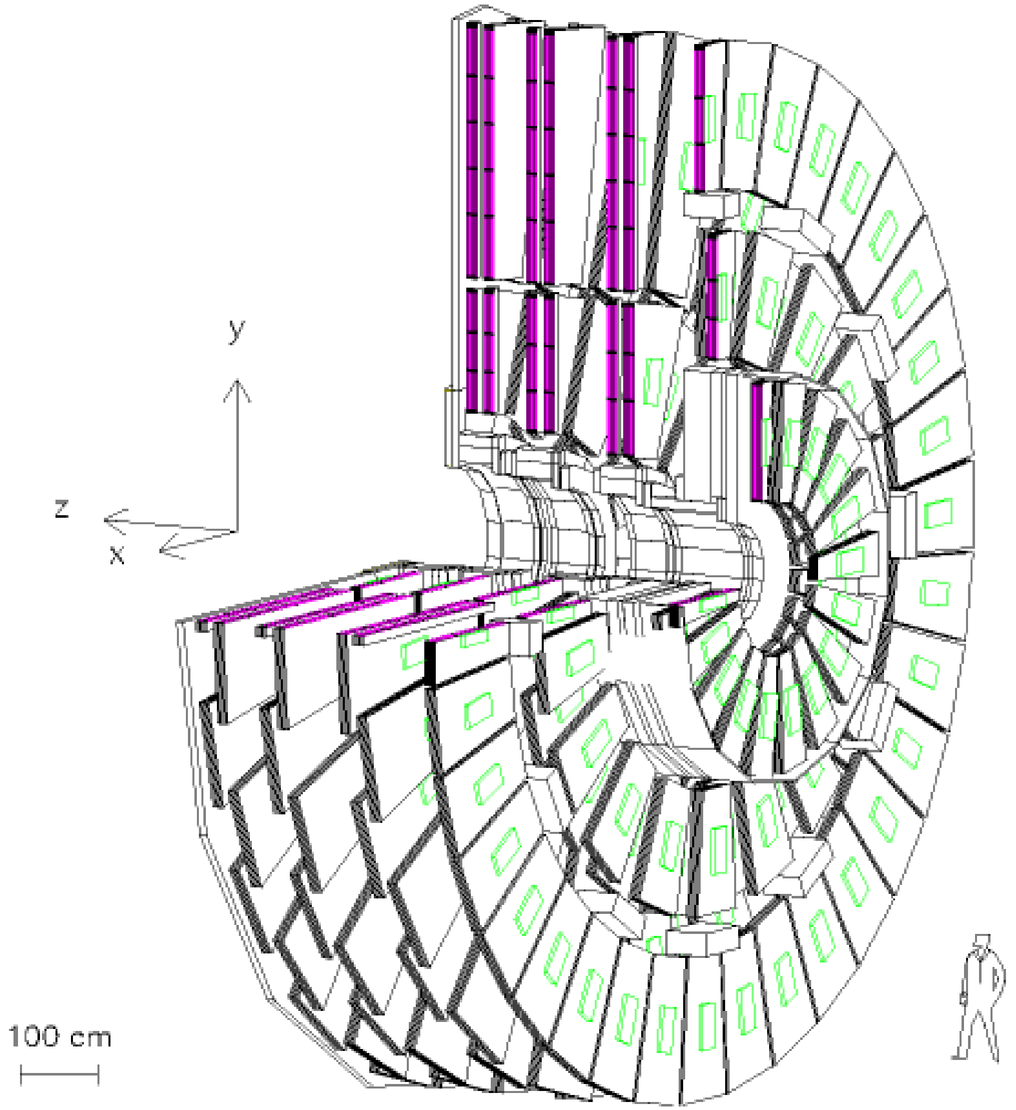


The CMS Experiment at CERN





The CMS Endcap Muon System



- Chambers produced at Fermilab
- Equipping with electronics and testing at UCLA
- 300,000 data channels “trigger” electronics built by UCLA
- Support from UC Riverside and UC Davis scientists

Data Analysis

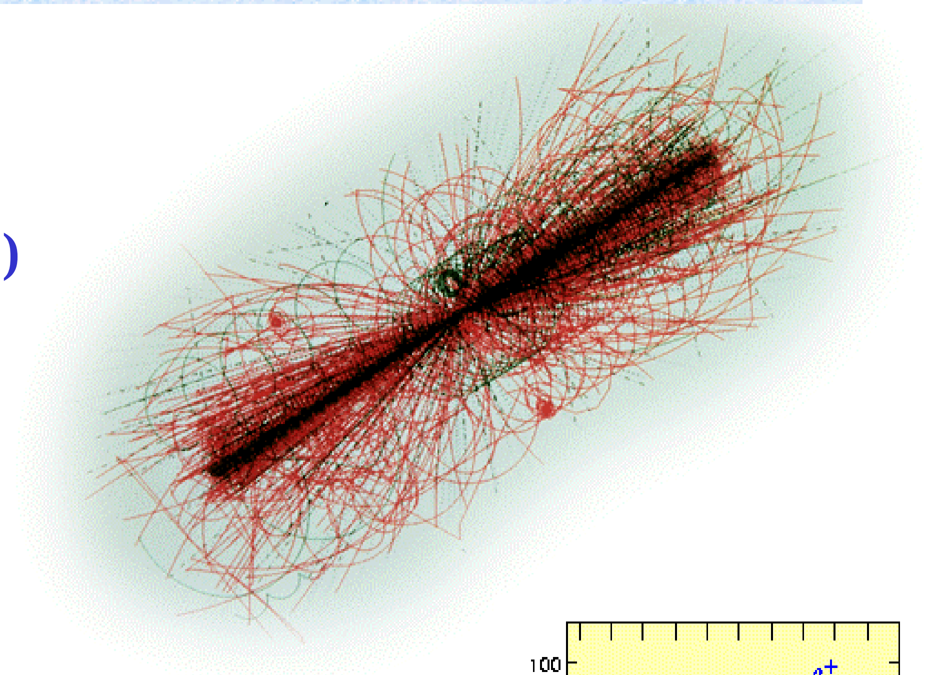
Start from:

40 million events/sec

x10 million sec/year (30% run eff.)

x10 years

=4x10^{15} events



End result:

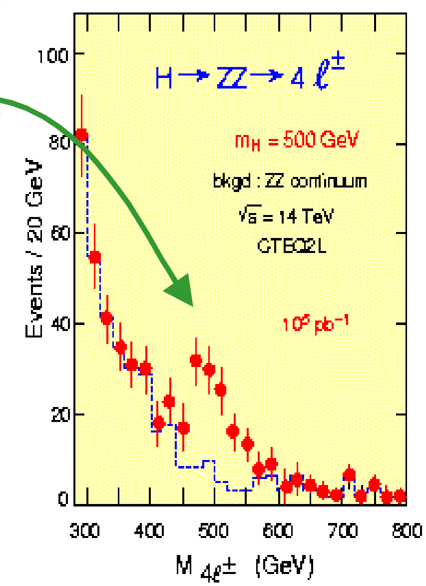
Search for Higgs particle

Look for data > background rate

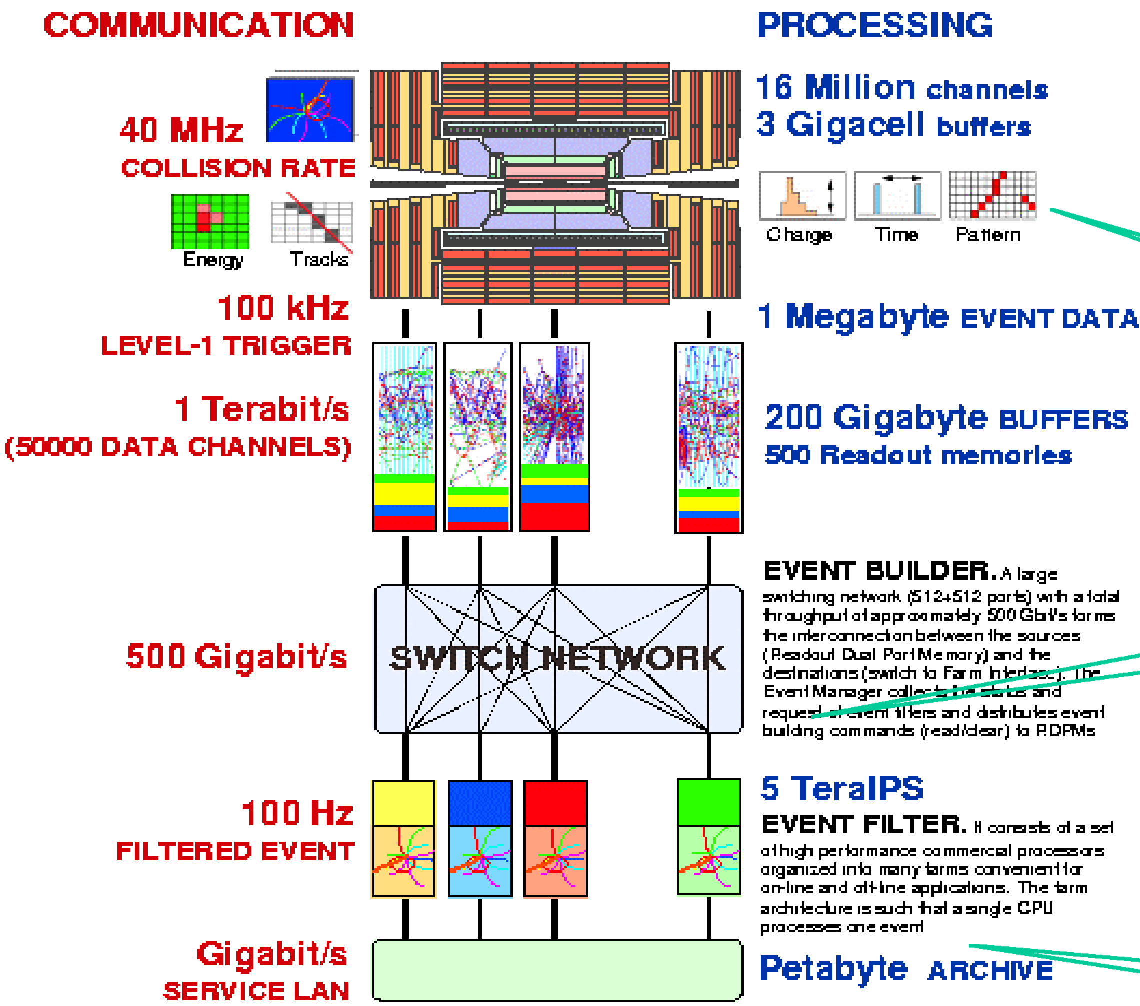
~40 events excess

10^{-14} factor:

Each Higgs event is like a 1g needle in a 100 million metric ton haystack



How to Find Needles in Large Haystacks...



Multi-step approach:

I) Special-purpose 40 MHz Electronics

“Level 1 Trigger”

UCLA

II) Fast “online” Computers

“Level 2 Trigger”

UCSD & UCLA

III) “Offline” Analysis

Crunch *Petabyte* data store

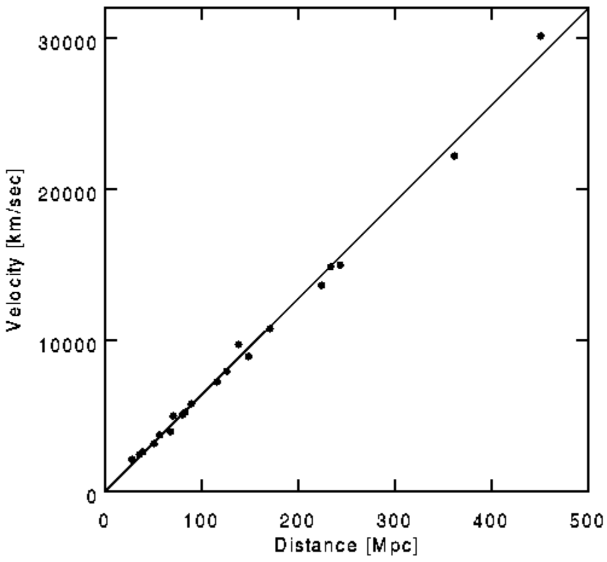
(1 Million Gigabytes)

Caltech

Evidence for the "Big Bang"

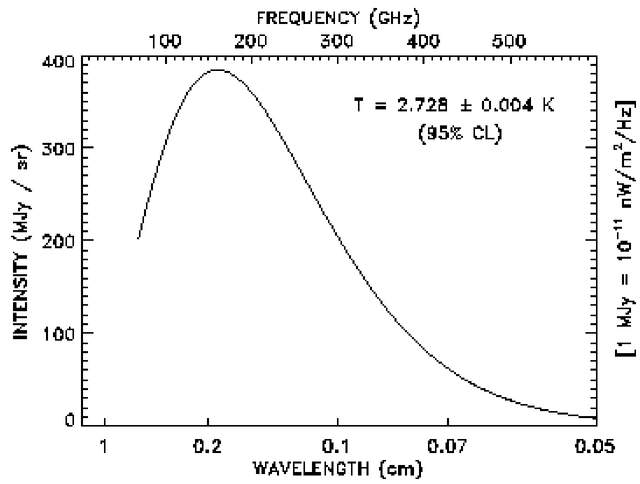
Hubble (1929):

Other galaxies are moving away from us, the universe is expanding like a balloon!



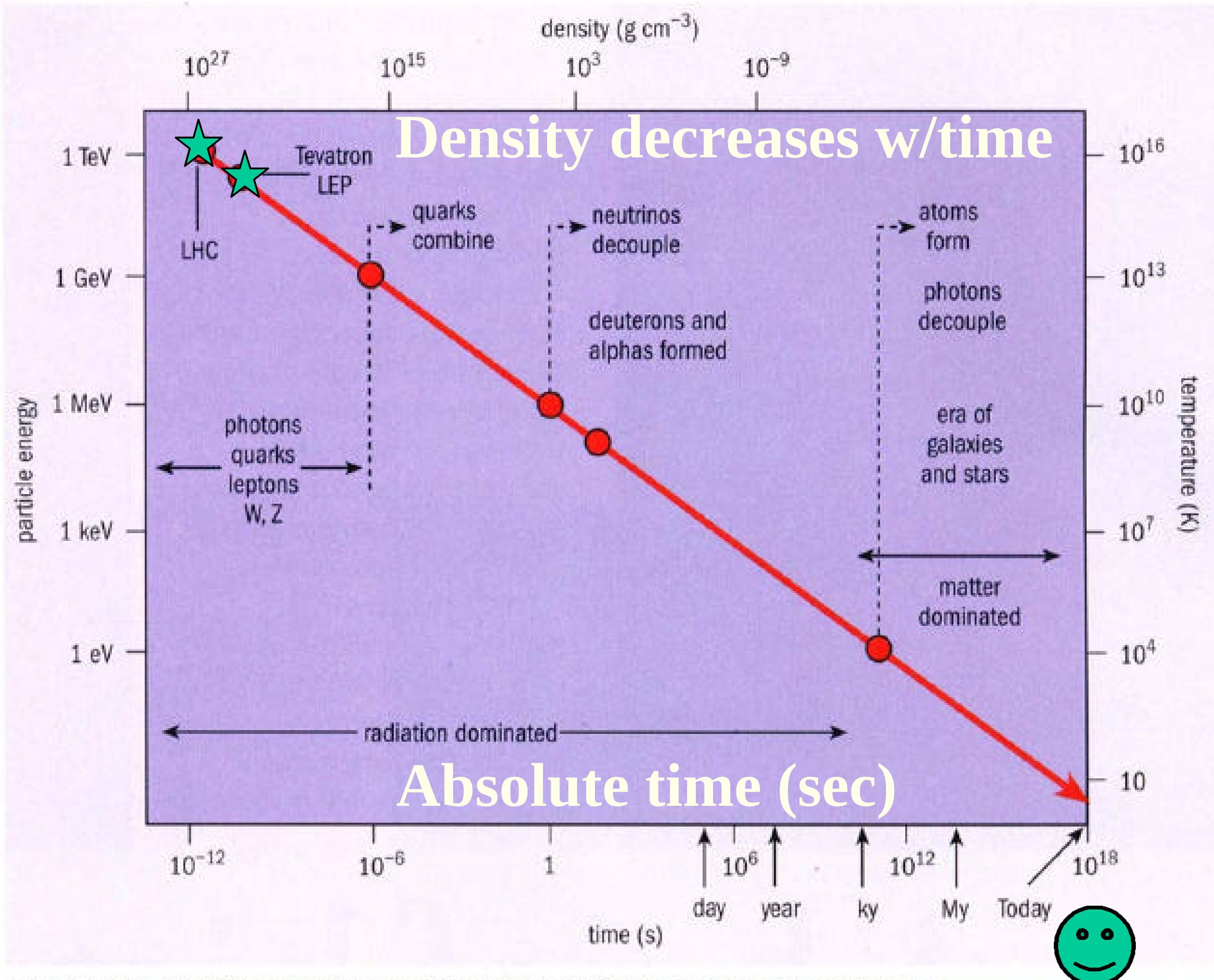
The universe started out hot and has been cooling ever since:

Predicts a 3° (absolute) radiation everywhere from the Big Bang!



History of the Universe 001

Energy decreases w/time



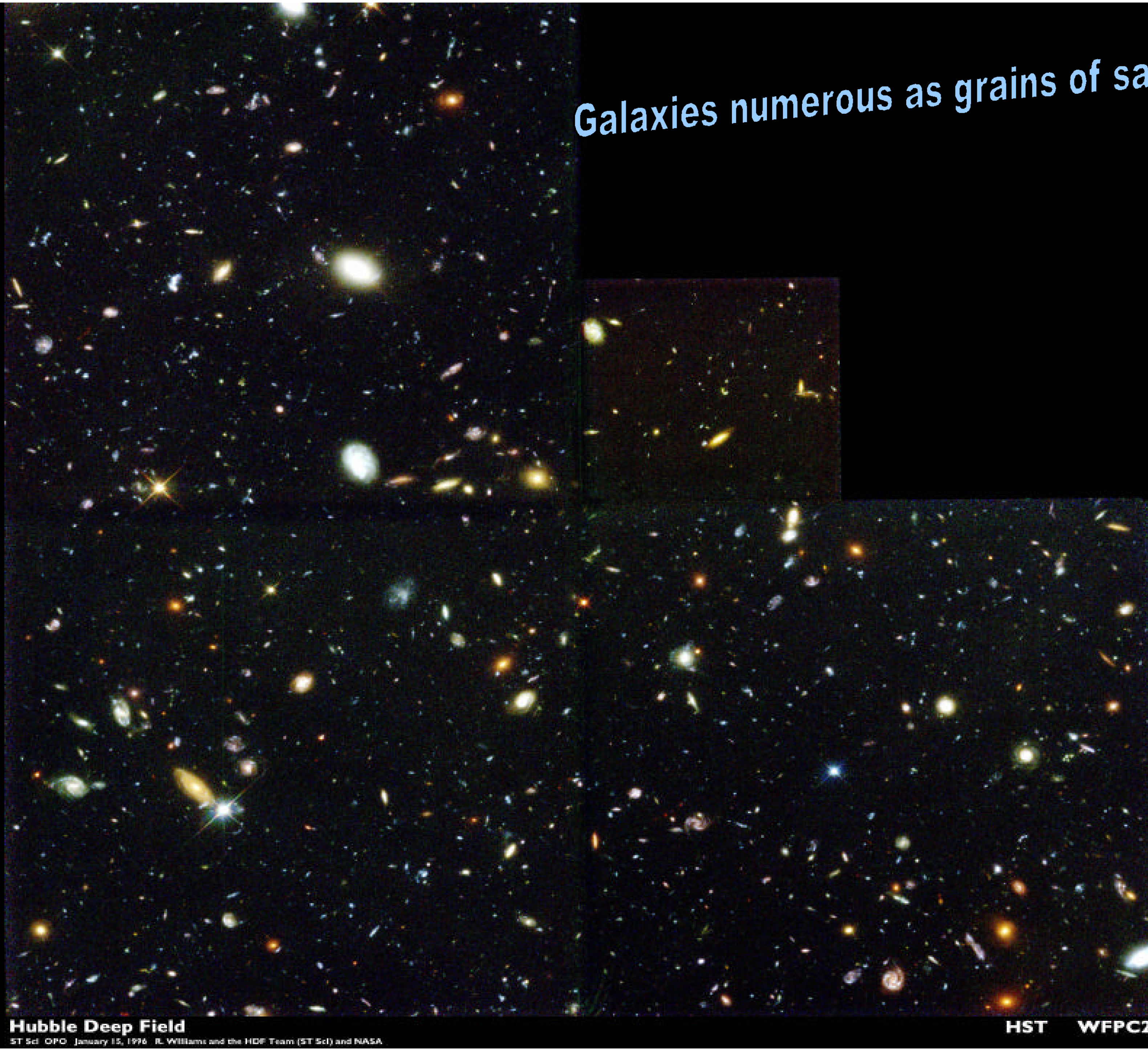
Big physics machines can reproduce the conditions of the early universe.

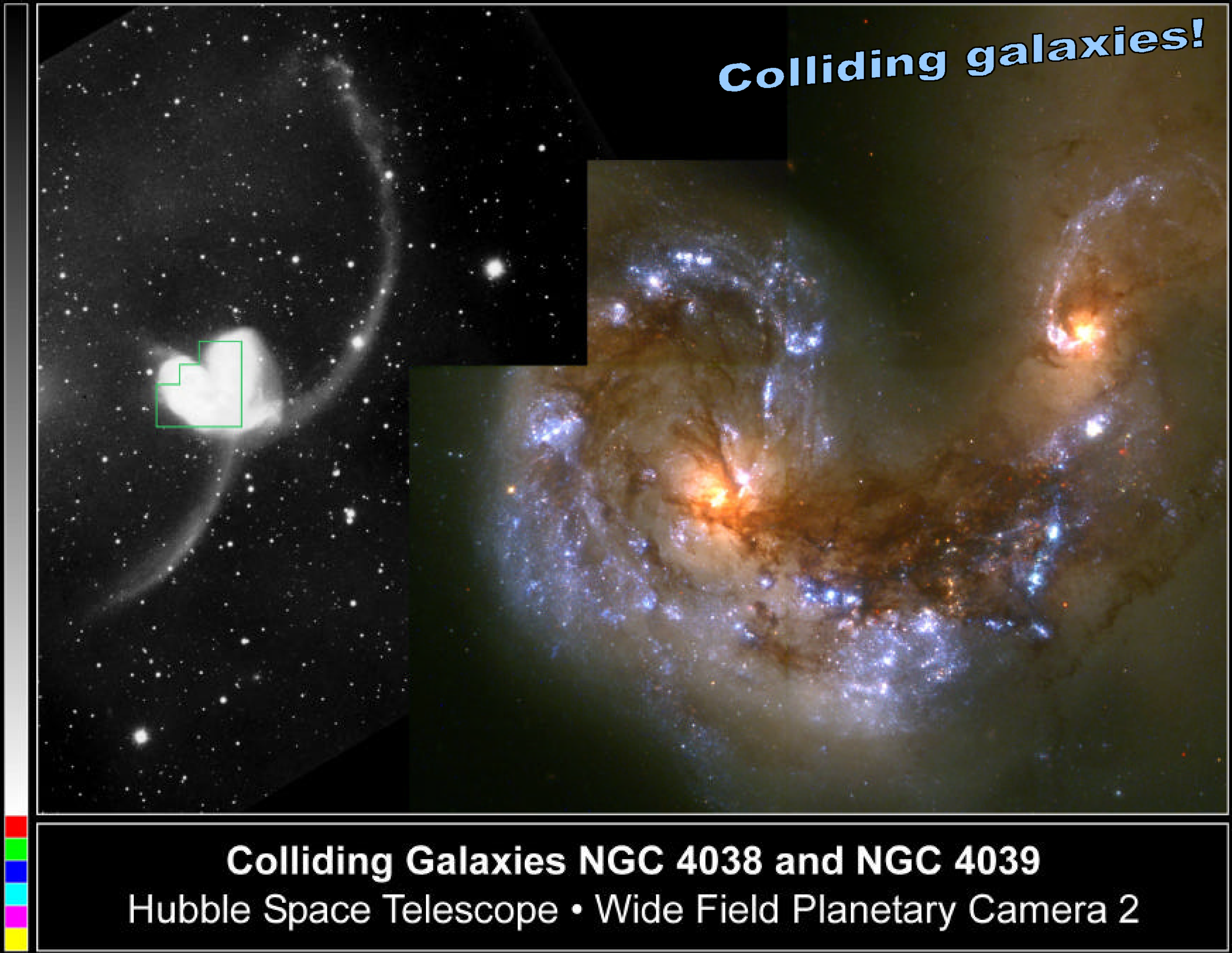
Temp. decreases w/time

10^{18} sec: A Beautiful Universe!

- Galaxies numerous as grains of sand!
- Colliding galaxies spewing lots of energy!
- Gravity lenses formed by huge galaxy clusters!
- Neutron stars!
- Black holes!
- Places where stars are being born today!
- Wispy, elegant clouds of gas - nebulae!
- Planets around our own and other suns!

Galaxies numerous as grains of sand!

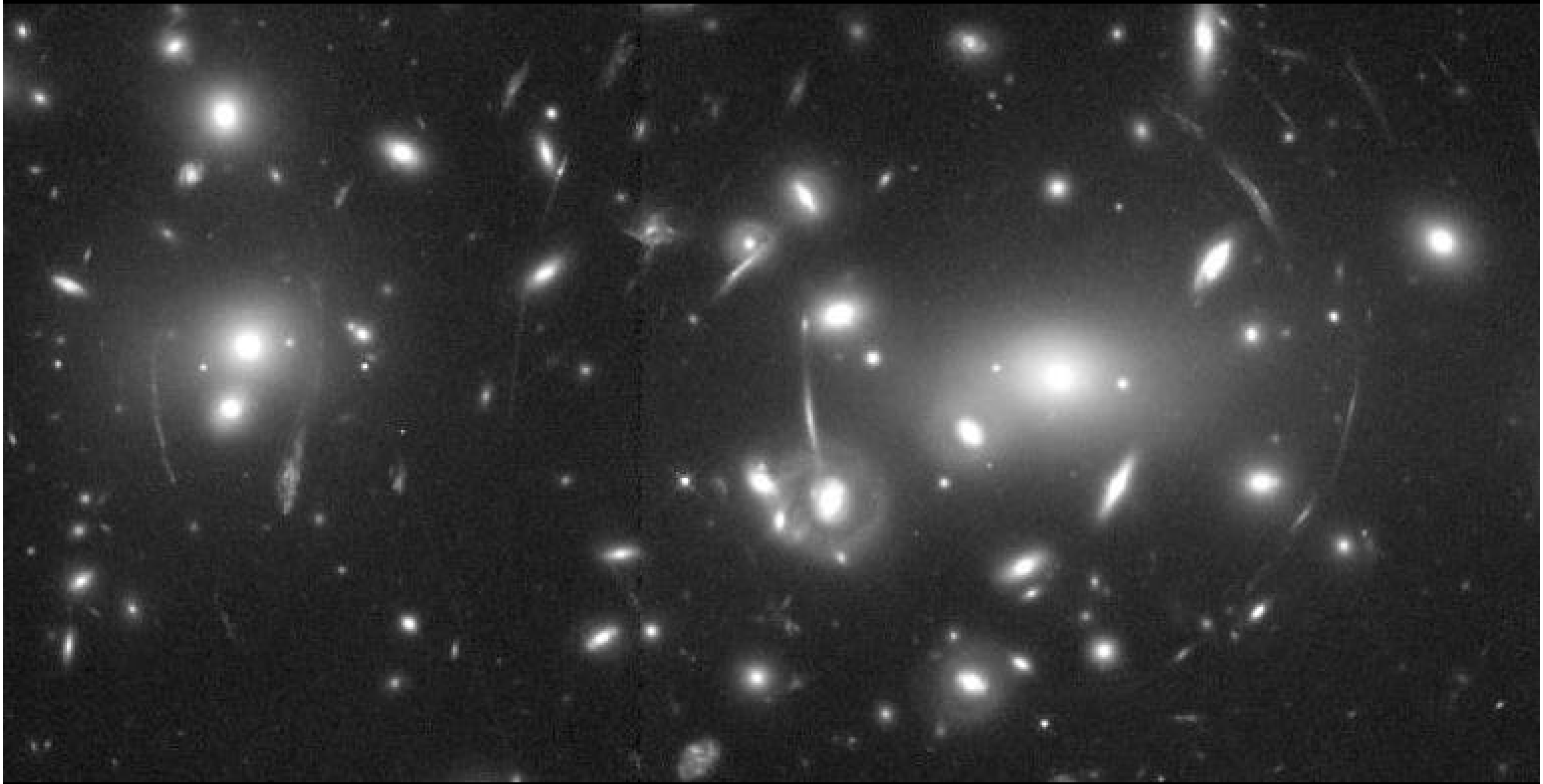


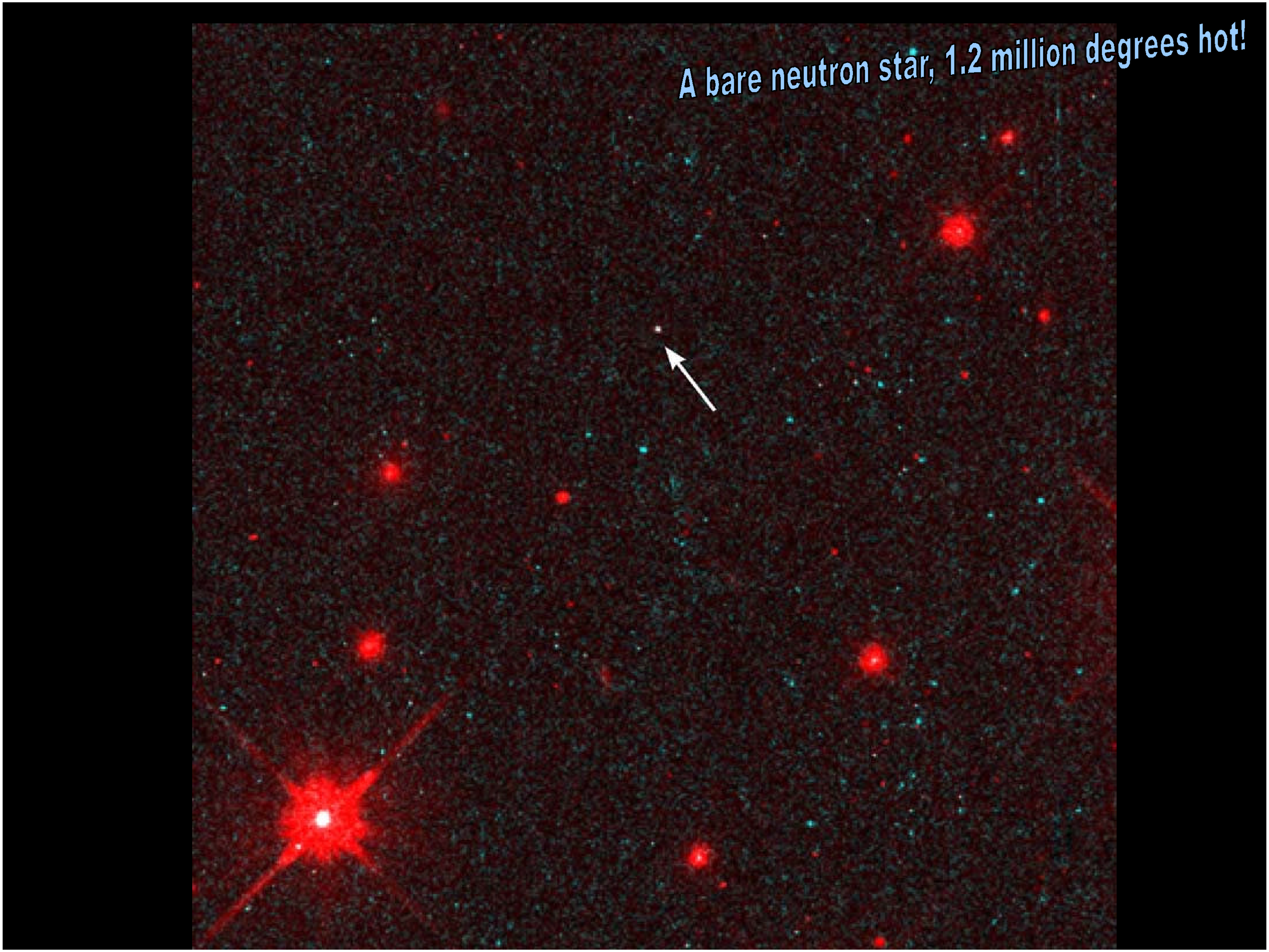


Colliding Galaxies NGC 4038 and NGC 4039
Hubble Space Telescope • Wide Field Planetary Camera 2

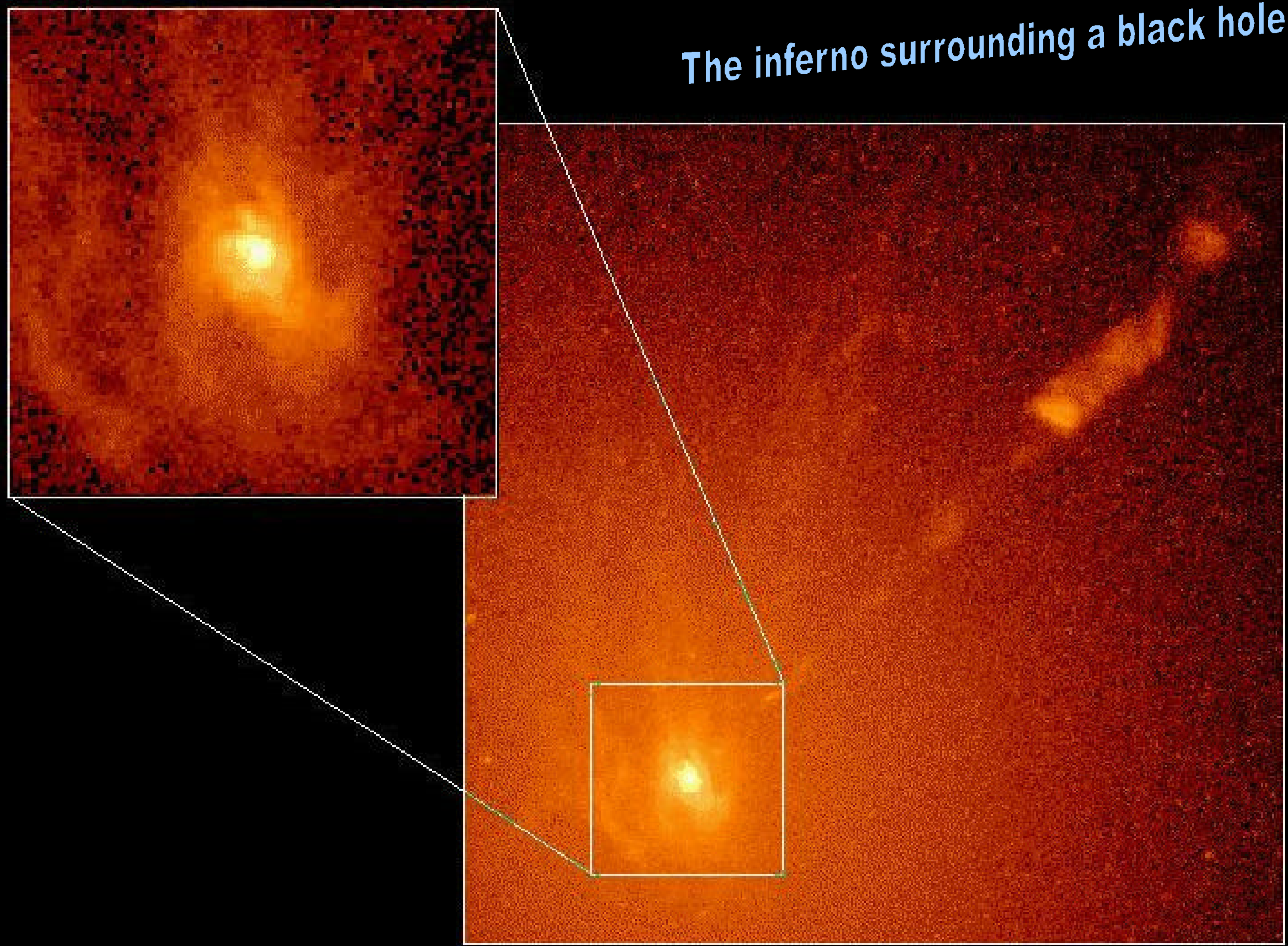
PRC97-34a • ST ScI OPO • October 21, 1997 • B. Whitmore (ST ScI) and NASA

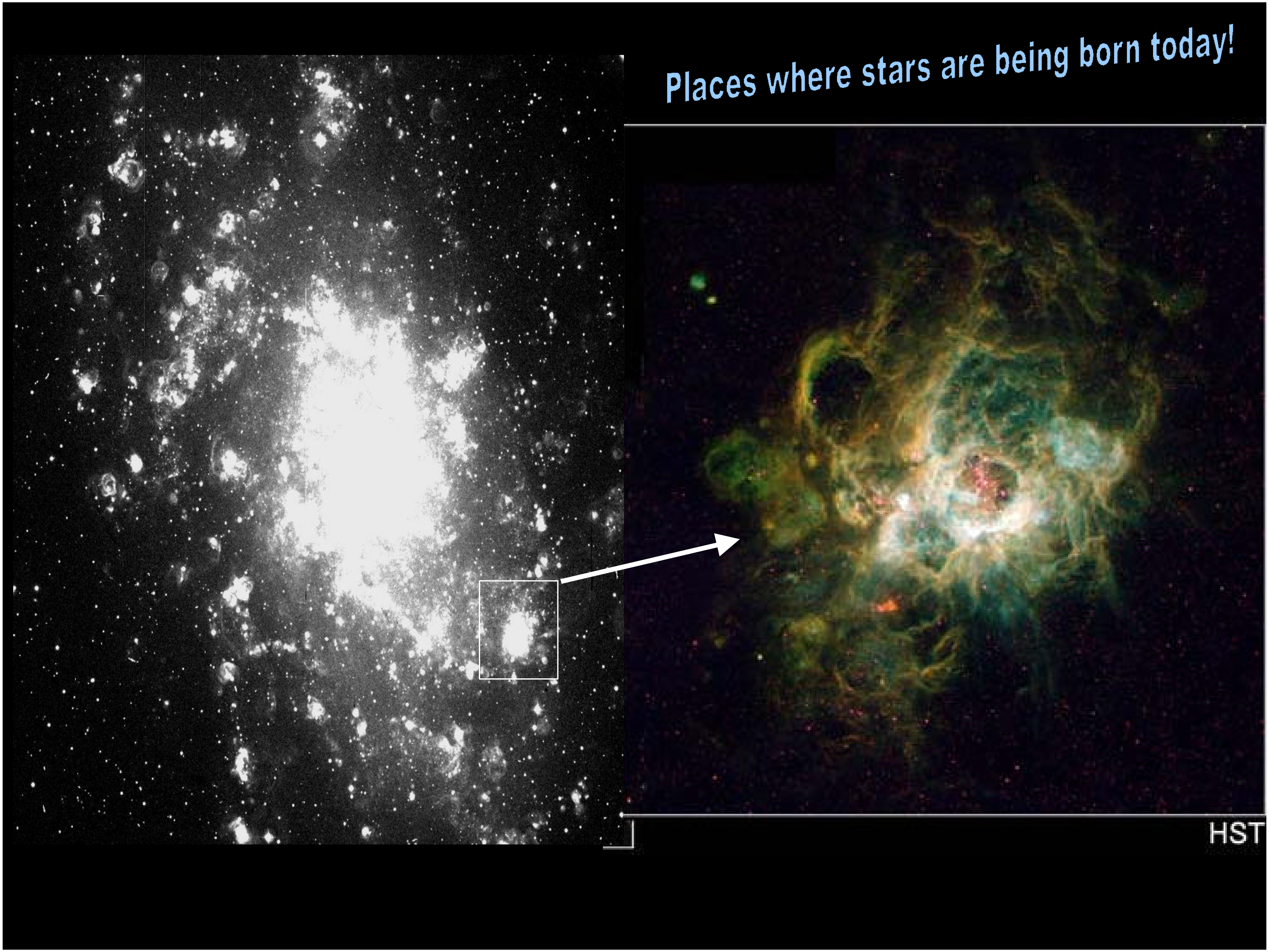
Gravity bends light!



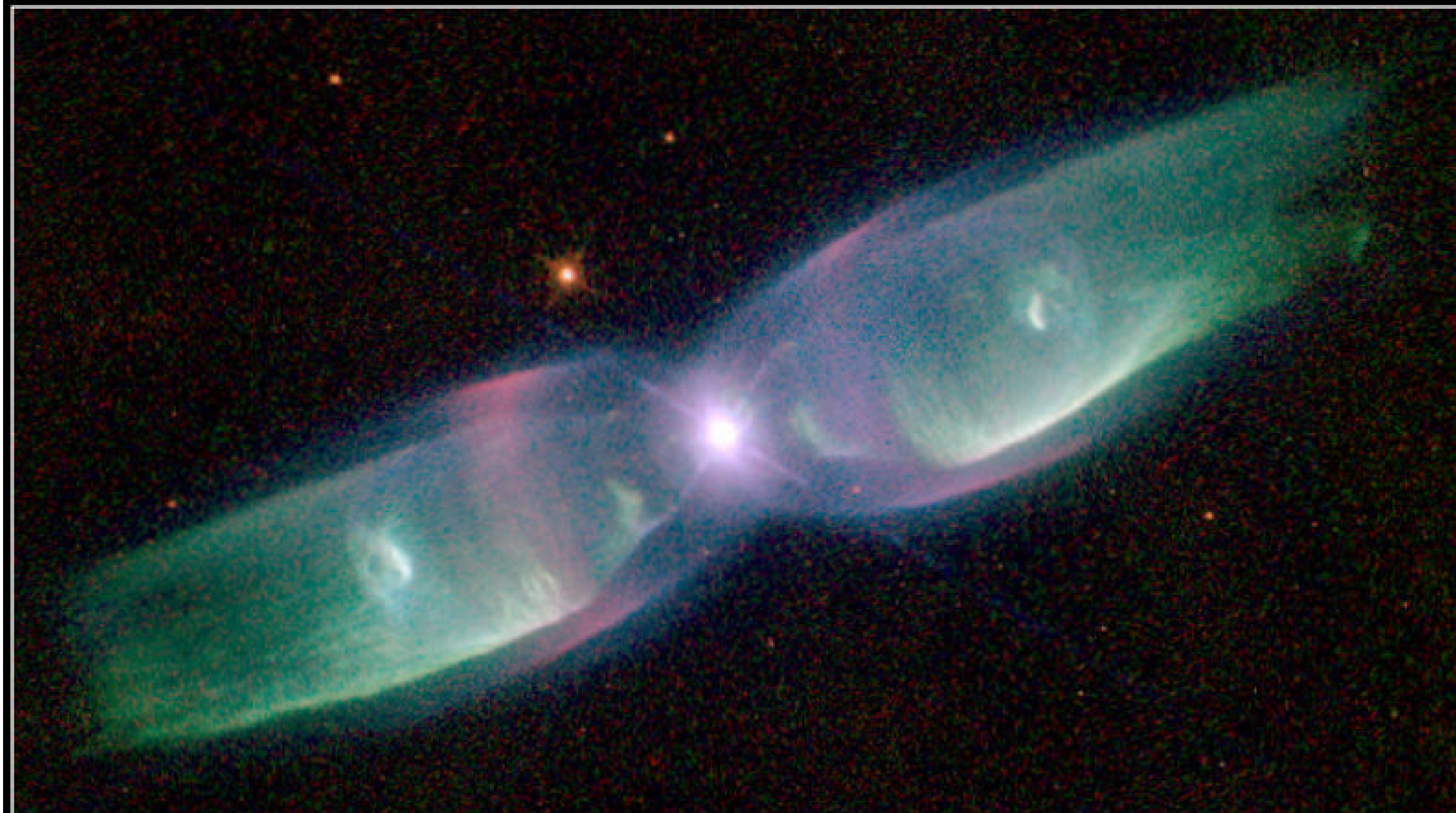

A bare neutron star, 1.2 million degrees hot!

The inferno surrounding a black hole!




Places where stars are being born today!
HST

Beautiful gas cloud - nebula - around a star!

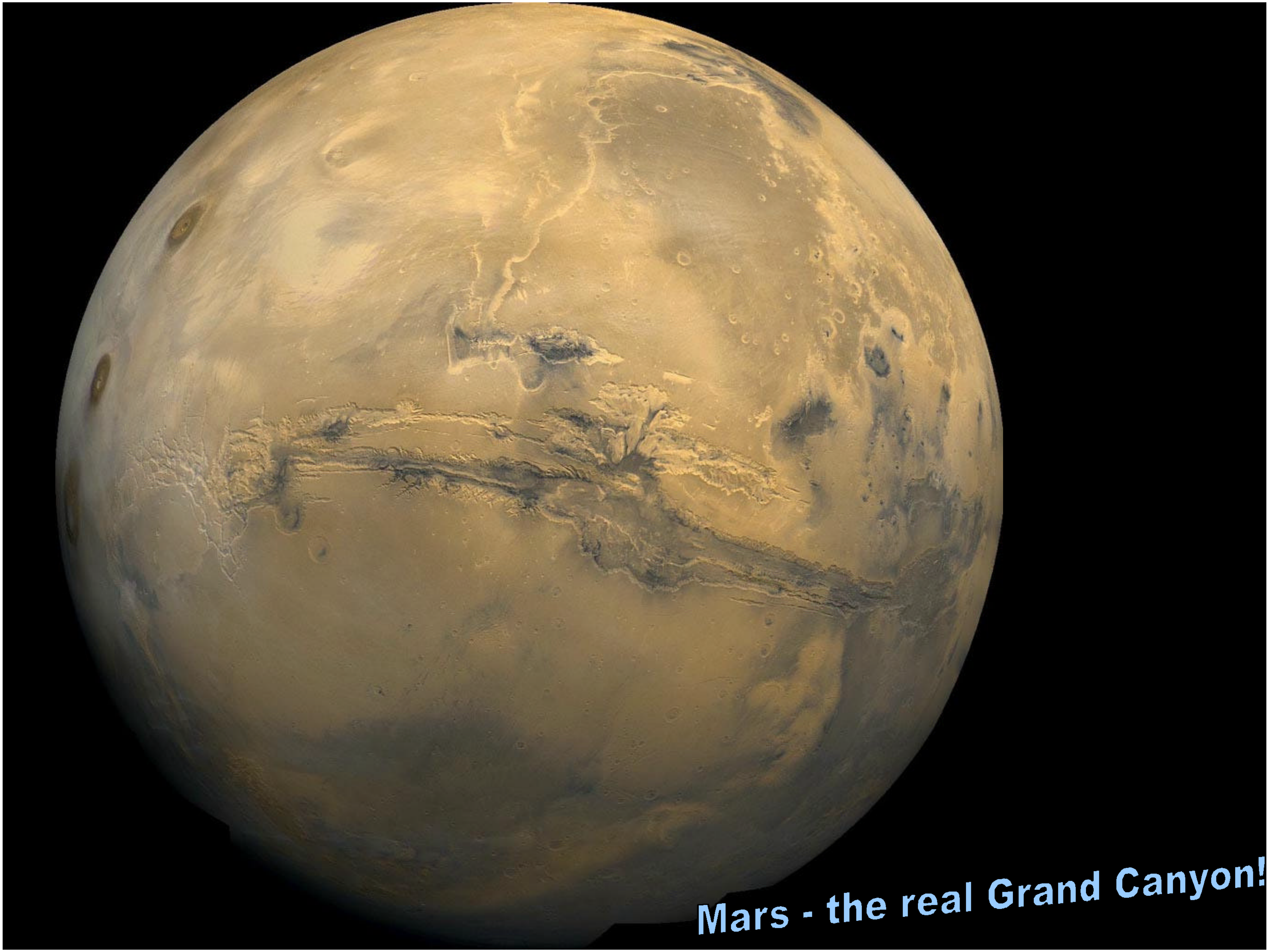


Planetary Nebula M2-9 HST • WFPC2

PRC97-38a • ST ScI OPO • December 17, 1997

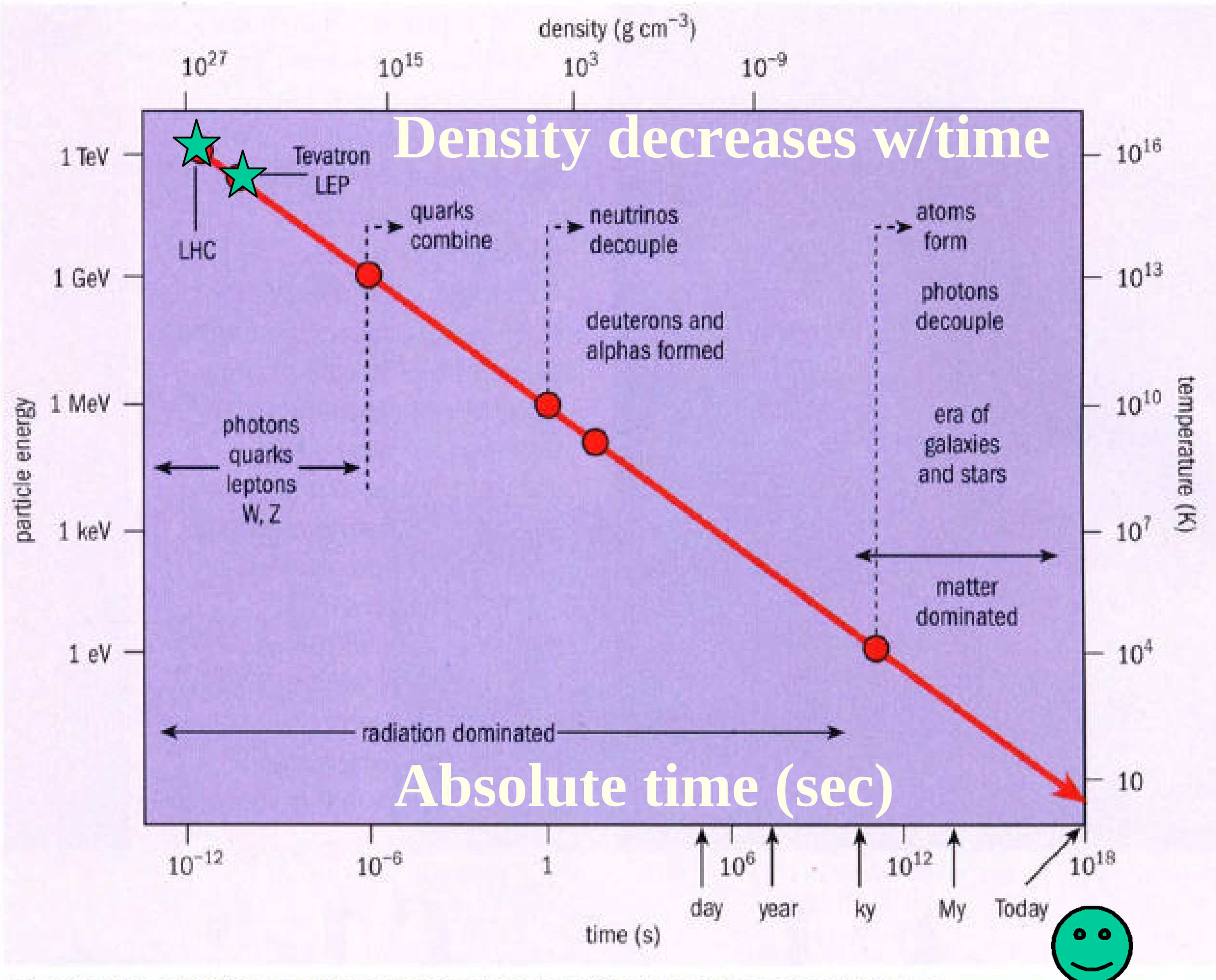
B. Balick (University of Washington) and NASA


Another beautiful nebula!


Mars - the real Grand Canyon!

History of the Universe 001

Energy decreases w/time



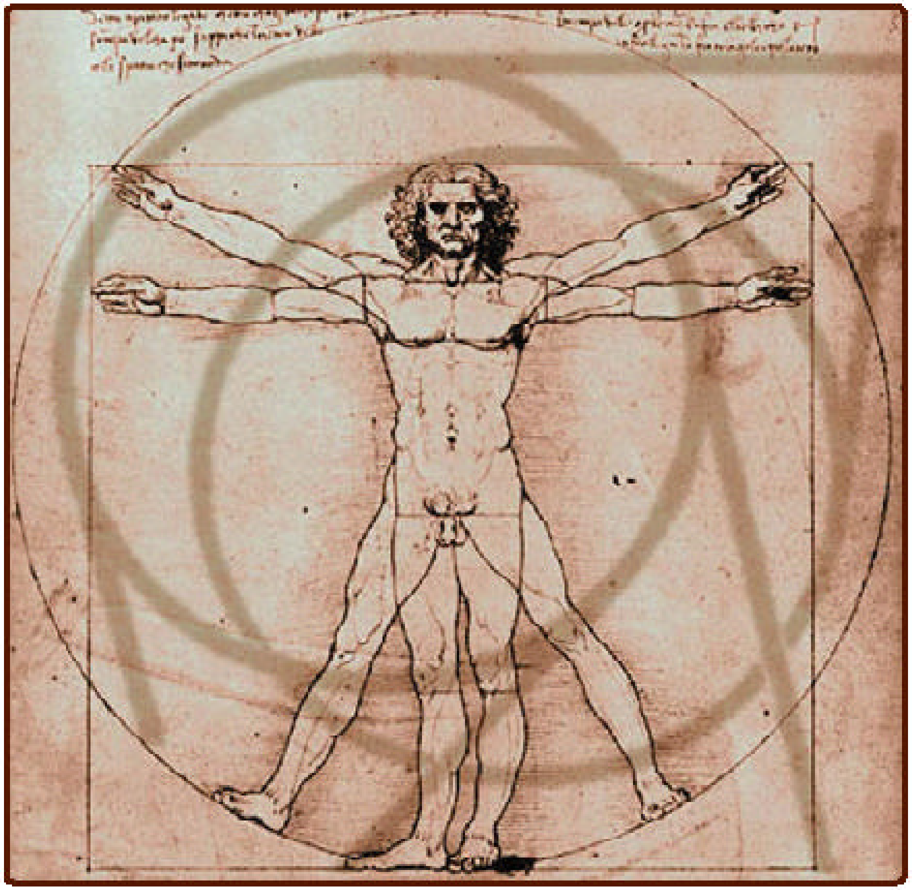
Big physics machines can reproduce the conditions of the early universe.

Temp. decreases w/time

Let's Go Back in Time

15000 million years

Man begins to wonder where it all came from



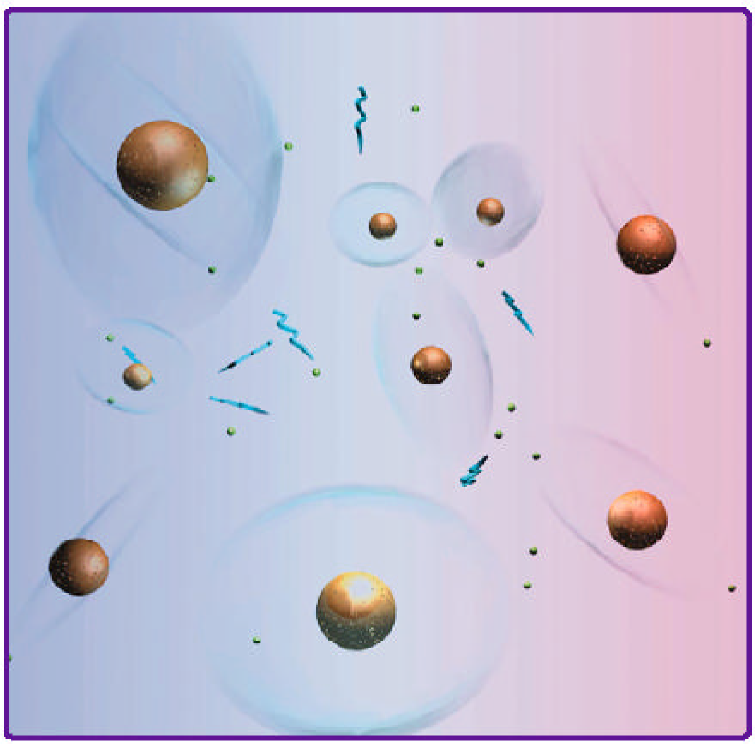
1000 million years

Galaxies begin to form

Well-Understood History

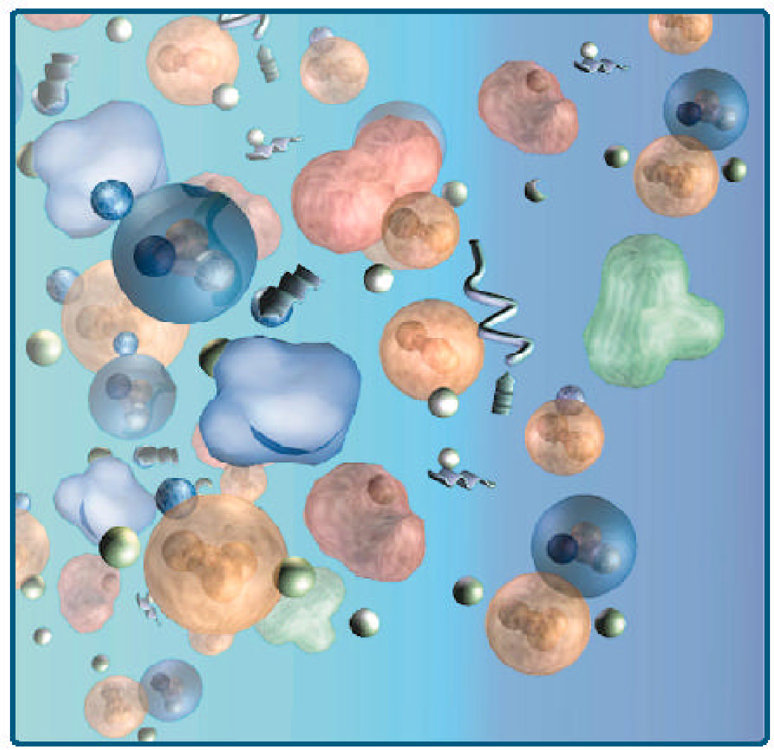
Atoms and light era
300000 years

The Universe becomes transparent and fills with light



Nuclei are formed
100 s

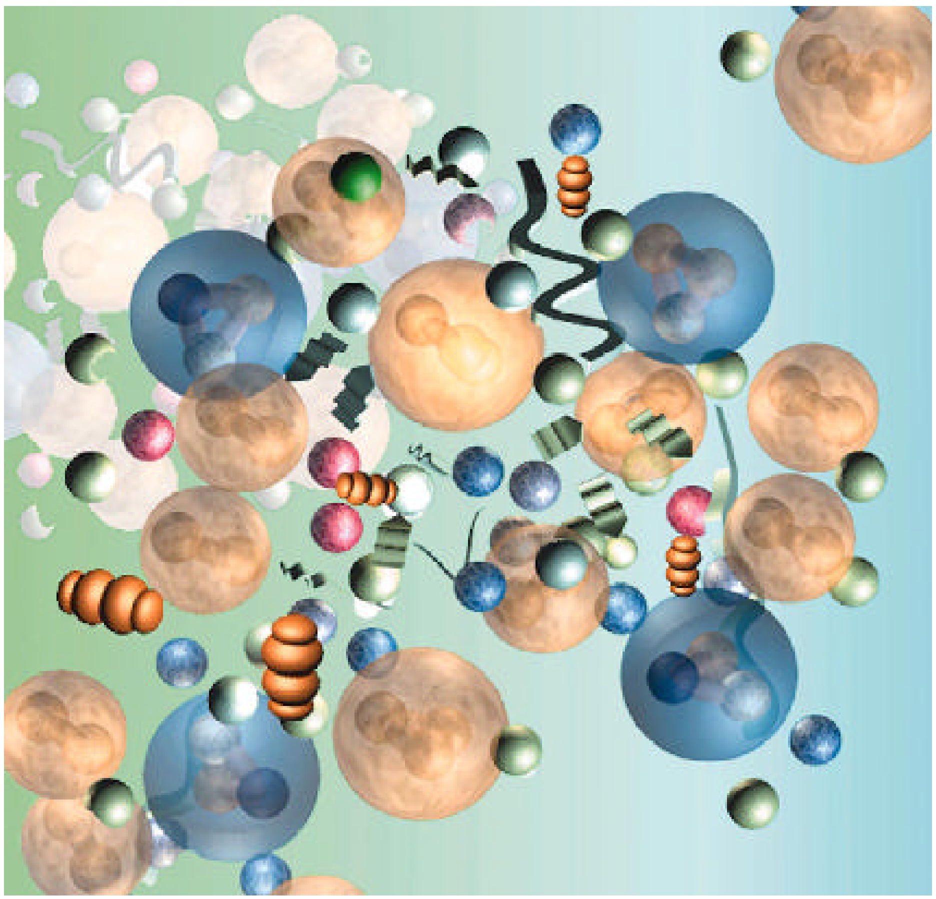
Protons and neutrons combine to form helium nuclei



Partly Understood History

10^{-4} sec

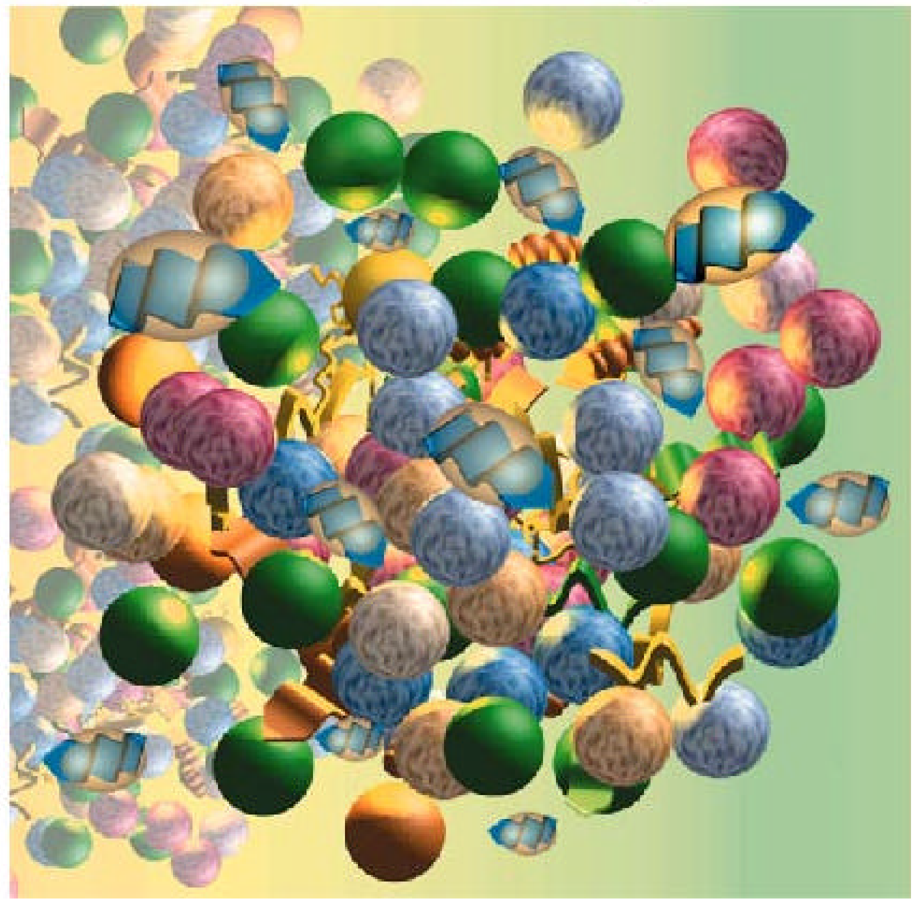
Quarks combine to make protons and neutrons



Electroweak era

10^{-10} s

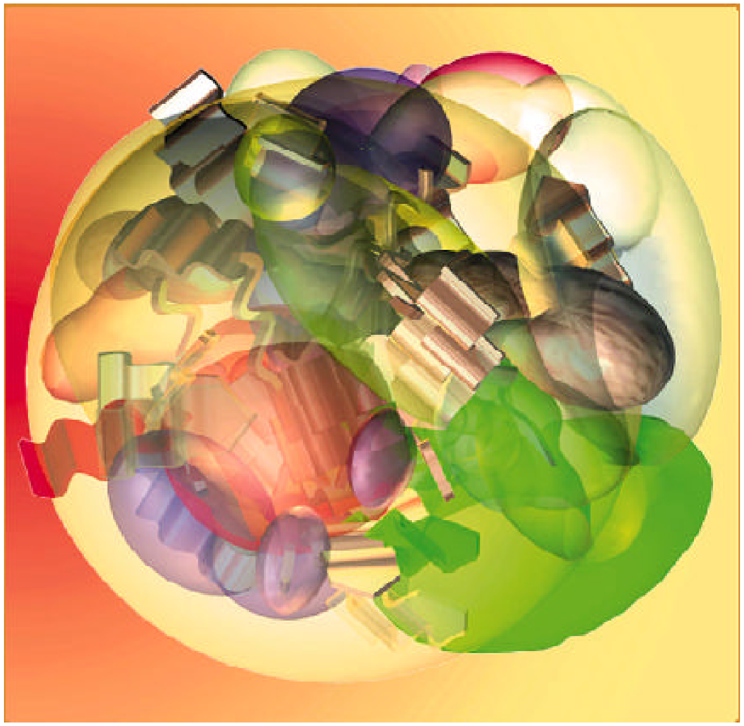
Electroweak force splits

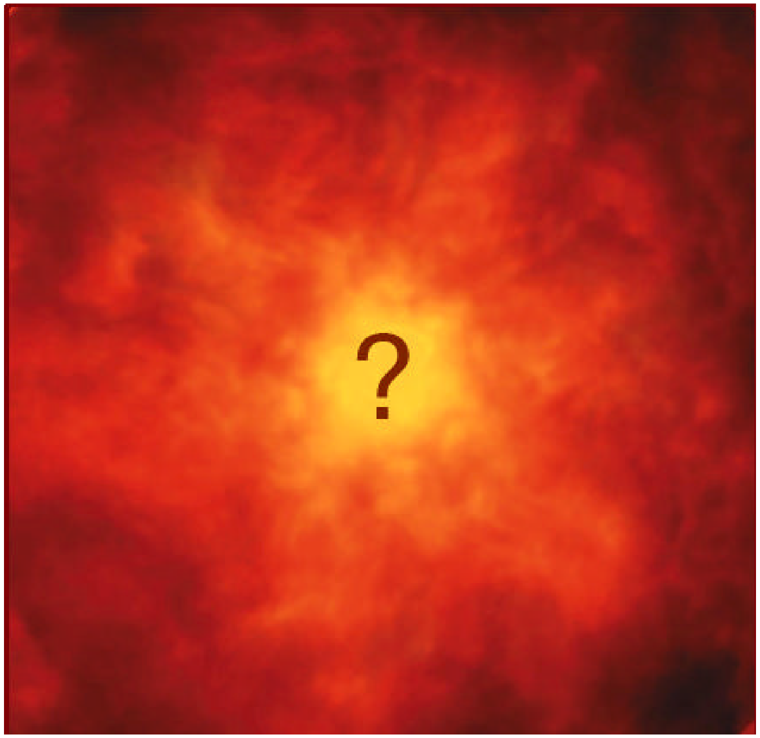


Grand Unification Era (10^{-35}s)

Inflation is coming to an end,

temperature is 10^{27}K





Quantum Gravity Era (10^{-43}s)

At this time gravity becomes distinct from the other forces through spontaneous symmetry breaking

Where Did it All Come From?

- Supercollider experiments explore the beginning...
- Unification of Electromagnetic and Weak forces
  - Previous unification: Electric & Magnetic forces
    - Electric power generation (Faraday's Law)
    - Light, radio, X-rays, etc (full Ampere's Law)
- Supersymmetry
  - Double the known number of elementary particles
  - The lightest Supersymmetry particle would be "Dark Matter" (the unknown 90-99% of the mass of the universe)
  - Allows unification of the 3 non-gravity forces
  - Shed light on Superstrings

Good Web Links

- This talk on my web site: http://www.physics.ucla.edu/~hauser/homepage/present_research.html
- Superstrings: http://www.superstringtheory.com/index.html
- Ned Wright's cosmology tutorial: http://www.astro.ucla.edu/~wright/cosmolog.htm
- Particle physics tutorial: http://ParticleAdventure.org/
- Fermilab home page: http://www.fnal.gov/
- CERN public home page: http://public.web.cern.ch/Public/
- Hubble Space Telescope and other astronomy pictures: start at http://dir.yahoo.com/Science/Astronomy/Pictures/