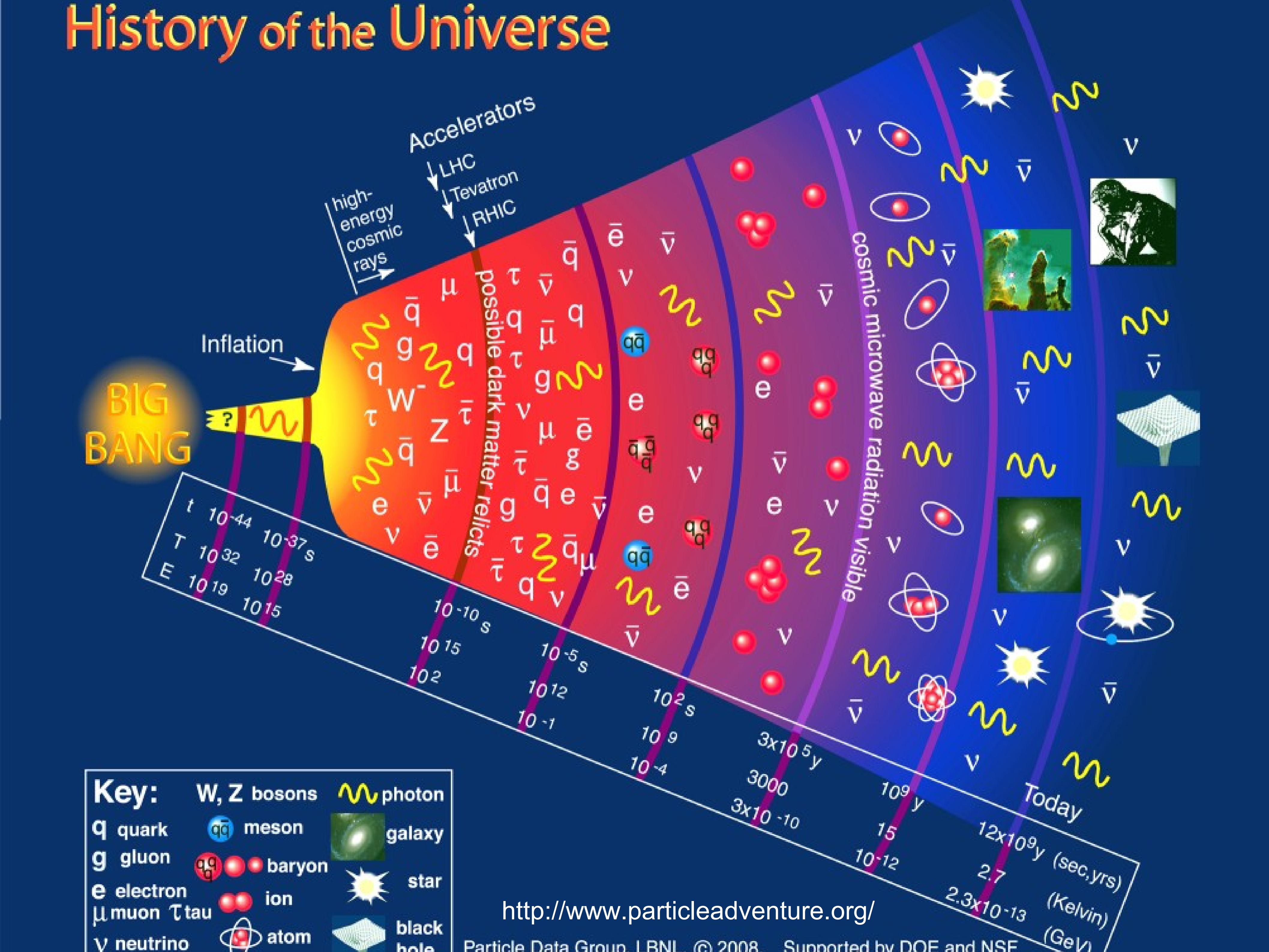
The First Three Minutes of the Universe

Dr. Russell Herman
Mathematics and Statistics
Physics and Physical Oceanography

http://www.dimijianimages.com/More-p20-Madagascar-p7/night-sky-from-Madagascar-gallery.htm

Known Universe

- Age - 13.7 billion years old
- Size - >93 billion lights years across
- Density - 9.9×10^{-30} gms/cubic centimeter.
- Appears to consist of
  73% dark energy,
  23% dark matter
  4% ordinary matter.
- Black holes, white dwarfs, galaxies, stars, planets, comets, asteroids, WIMPs, MACHOs, ...



http://www.particleadventure.org/

In the beginning ...

http://www.spaceandmotion.com/cosmology-history-astronomy-universe-space.htm

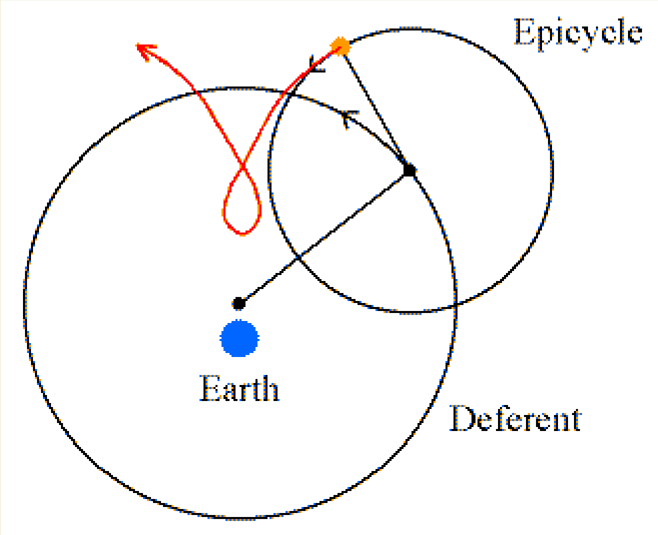
- **Thales of Miletus (624 BC – 546 BC)**
- **Pythagoras (585-497 BC)**
  Harmony of the Spheres
- **Socrates (469-399 BC)**
- **Democritus (460-370 BC)**
- **Plato (427-347 BC)**
- **Aristotle (384-322 BC)**
- **Archimedes (287-212 BC)**

Earth is fixed and immovable,
stars fixed in sky, planets = wanderers

- **Hipparchus (190-120 BC) - seasonal inconsistencies**

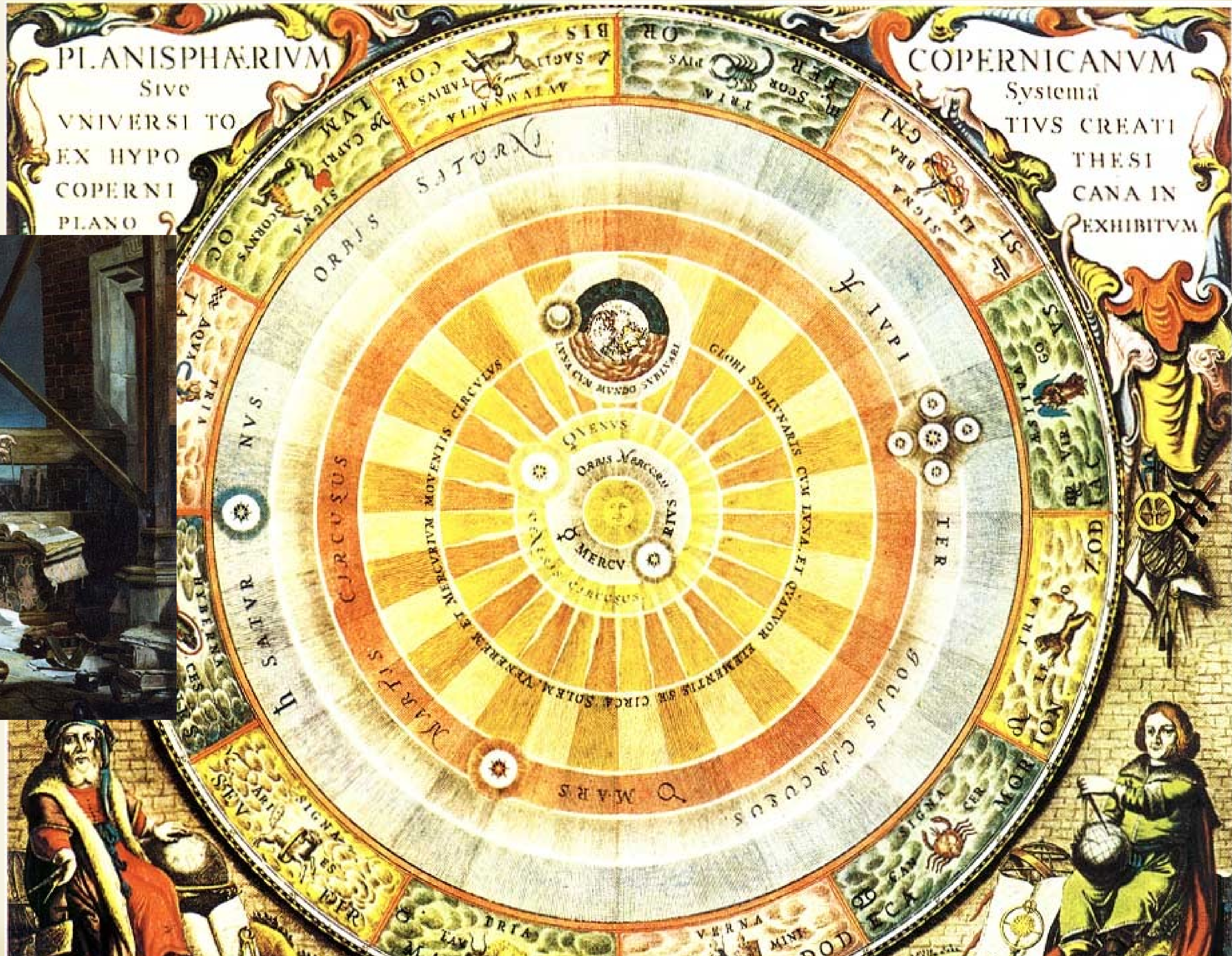
Geocentric System
Ptolemy (85-165)

http://www.sacred-texts.com/eso/sta/sta03.htm



http://www.daviddarling.info/images/epicycle.gif

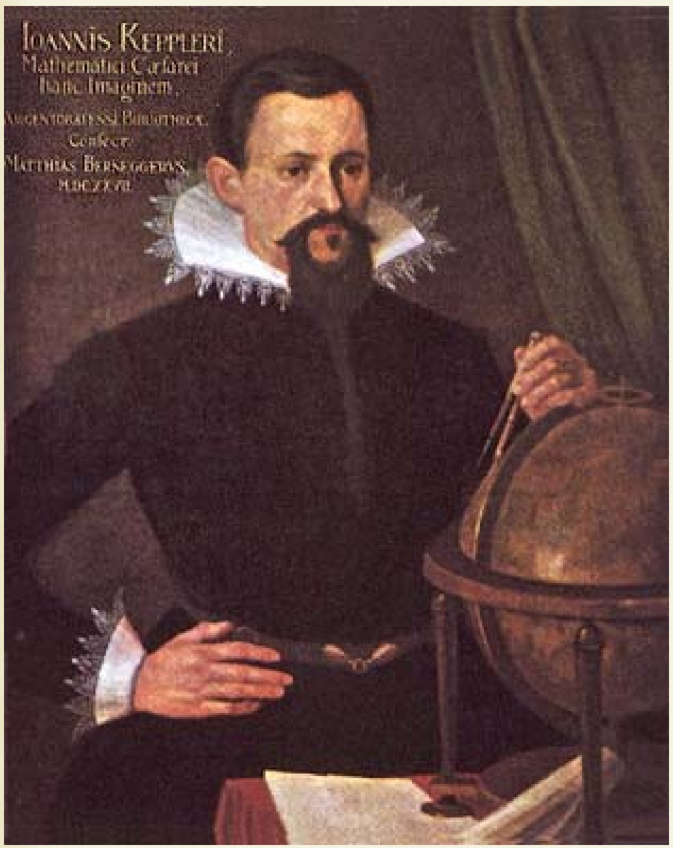
Heliocentric System
Copernicus (1473-1543)



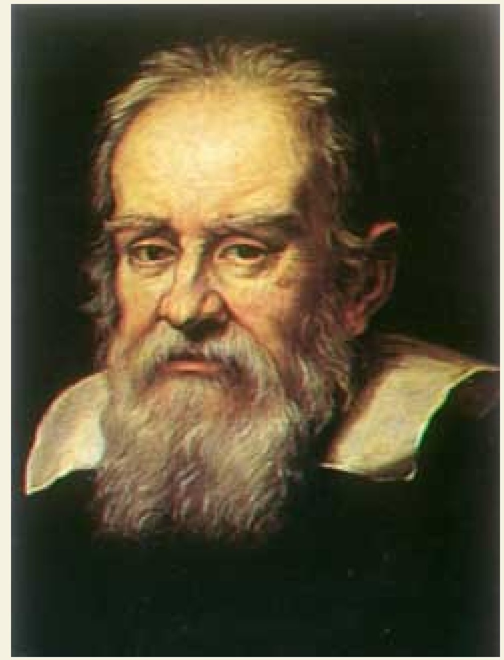
Scientific Deductions

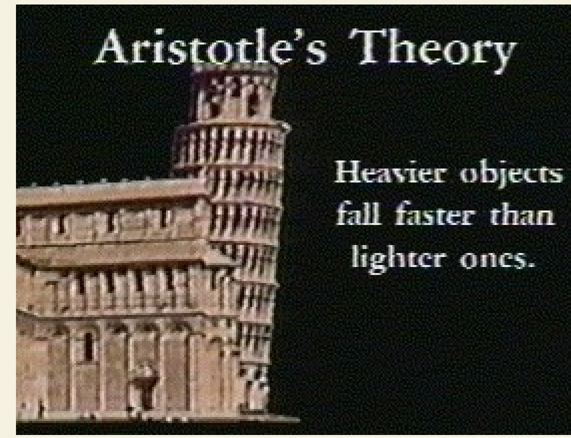
Tycho Brahe (1546-1601)

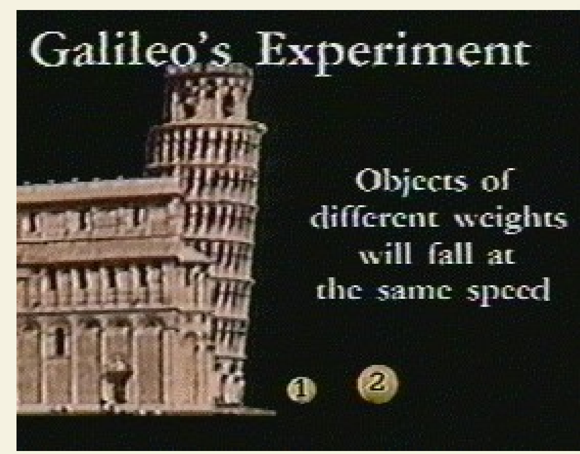
Johannes Kepler (1571-1630)



Galileo Galilei (1564-1642)







The Clockwork Universe

Sir Isaac Newton (1642-1727)

- **Principia (1689)**

  ***Philosophiae Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy)* (1687)**

  Laws of Motion

  Law of Gravitation

  Kepler's Laws Explained

  Calculus

Unification

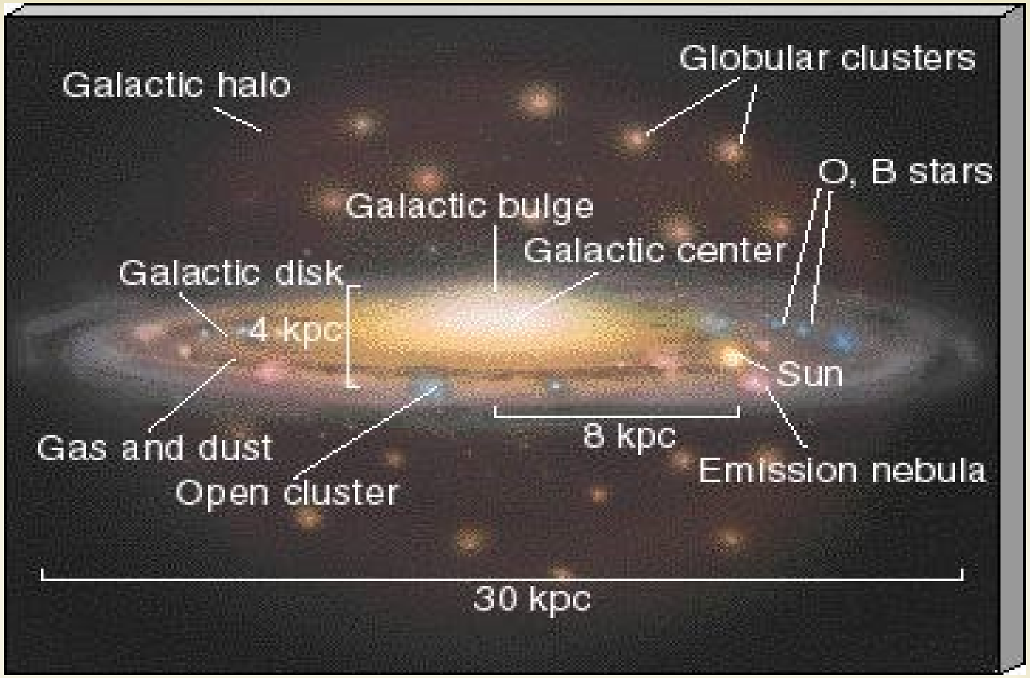
... the force responsible for bodies falling on the Earth is the same as that causing the moon to follow its orbit.

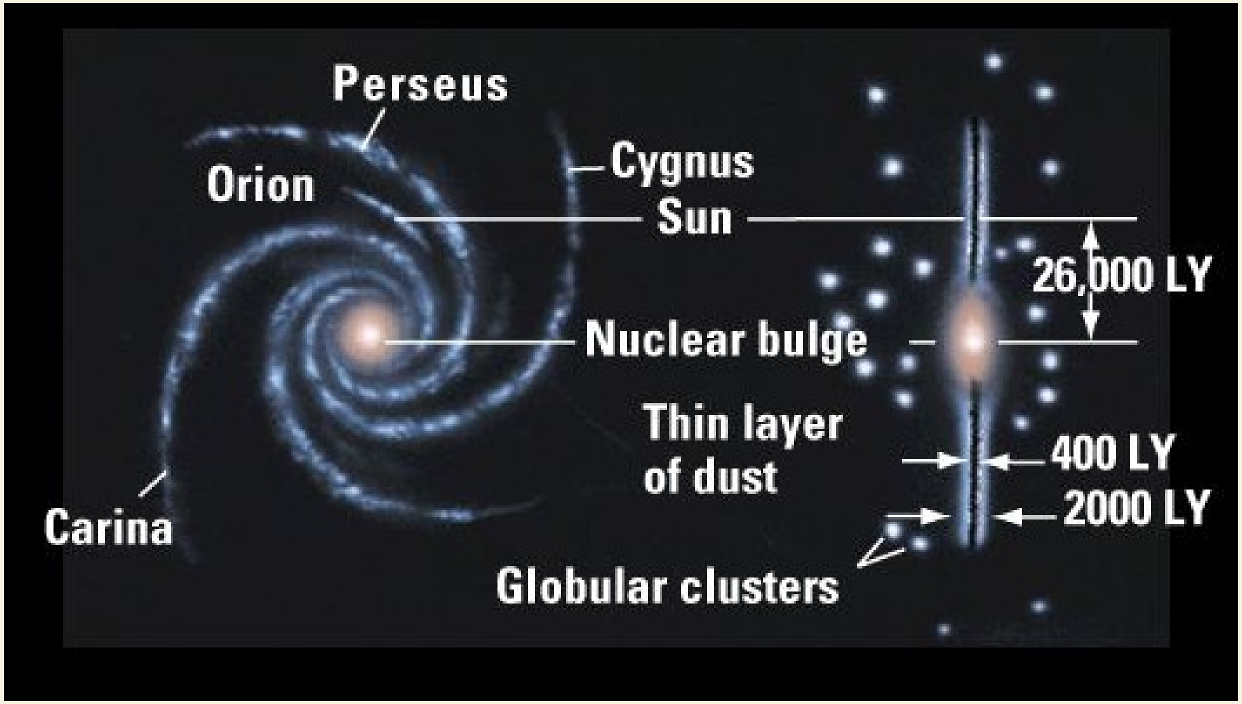
http://upload.wikimedia.org/wikipedia/commons/thumb/b/b2/Isaac_Newton.jpeg/481px-Isaac_Newton.jpeg

The Milky Way

- ~$4x10^{11}$ stars
- ~$>6x10^{11}$ sun mass
- ~$M_{ave} = 0.3$ sun

How do we know?



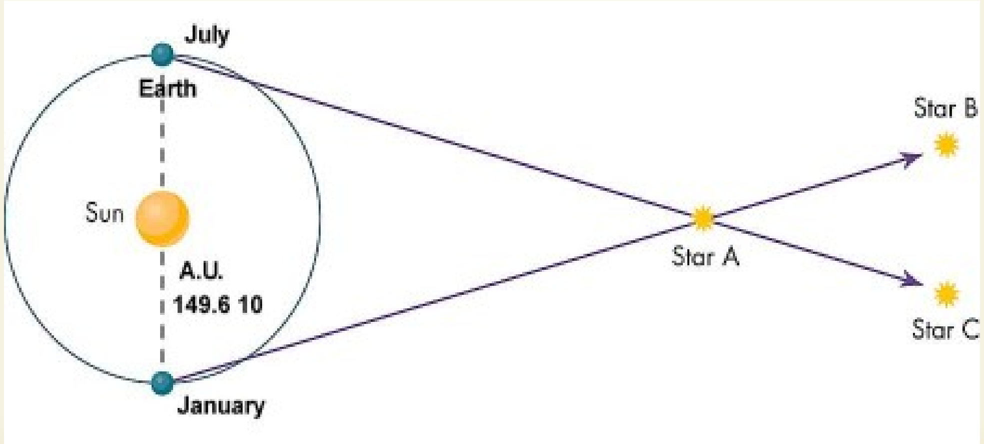


http://zebu.uoregon.edu/~imamura/123/lecture-2/lecture-2.html

Distances & the Milky Way Galaxy

- **Frederick William Herschel (1738-1822)**
  - Built telescopes, discovered Uranus
  - Measured stellar distances
  - Stars distributed in a pancake shape – Milky Way
  - 1000 siriometers x 100 siriometers
  - Asteroids, infrared radiation ...

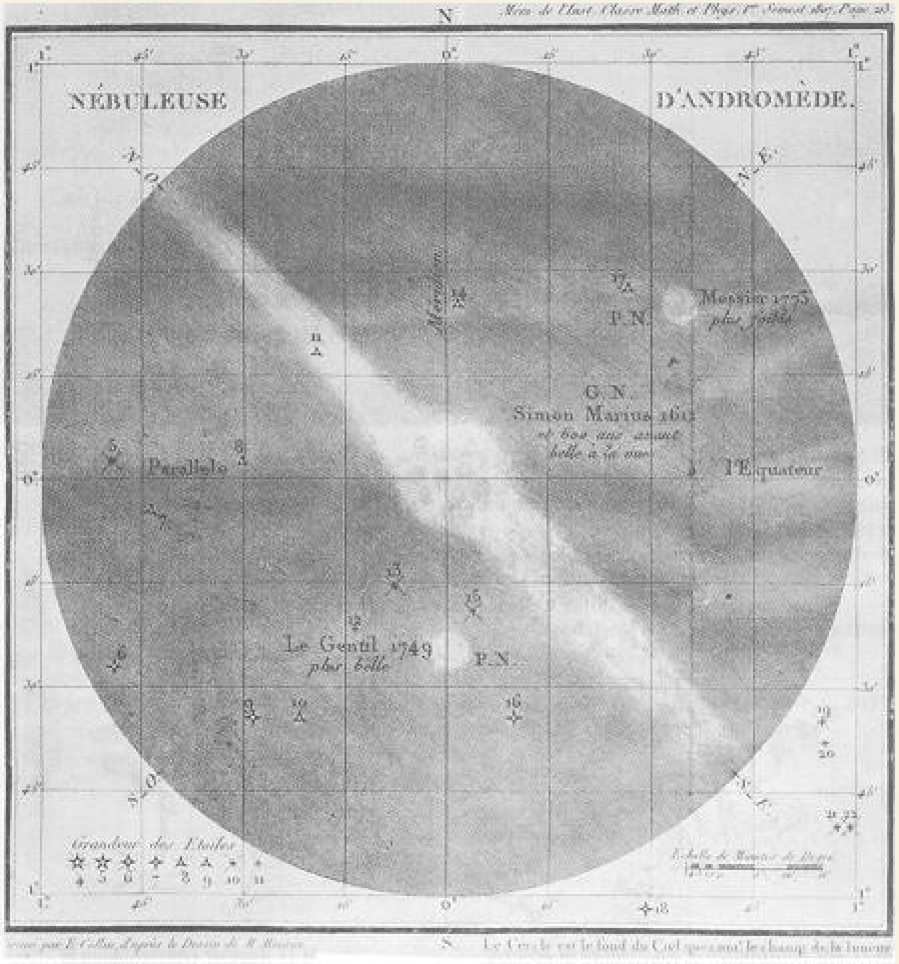
- **Friedrich Wilhelm Bessel (1784-1846)** – 28 years
  - Used parallax to establish stellar distances in km



The Search for Nebulae

- **Charles Messier** (1730-1817)
  - Catalog of 103
    - Crab Nebulae M1
    - Andromeda N. M31

Are they in Milky Way or beyond?



- **William/Caroline Hershel**
  - Cataloged 2500 nebulae
  - Sited a star in some – perhaps solar system birth
  - Therefore, in Milky Way
- **Immanuel Kant** (1724-1804)
  - Believed nebulae were beyond Milky Way

  - Messier Catalog http://www.seds.org/MESSIER/data2.html

"The Great Debate" Shapley-Curtis Debate - 1920

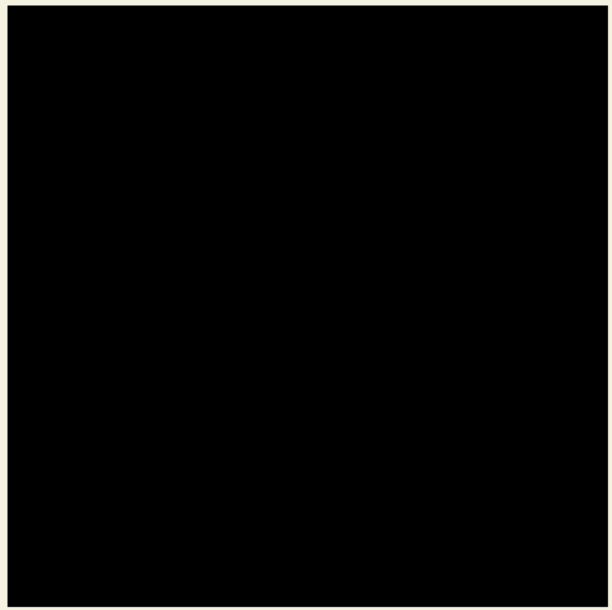
Are distant nebulae relatively small and within our galaxy, or are they large, independent galaxies?

- Harlow Shapley (1885-1972)
  - Nebulae part of galaxy
  - Sun in outer regions of galaxy
- Herbert Doust Curtis (1872-1942)
  - Nebulae outside galaxy
  - Sun at center
- Walter Baade (1893-1960) – Milky Way is typical galaxy!

http://en.wikipedia.org/wiki/Image:Andromeda_galaxy.jpg

Why is the night sky dark?

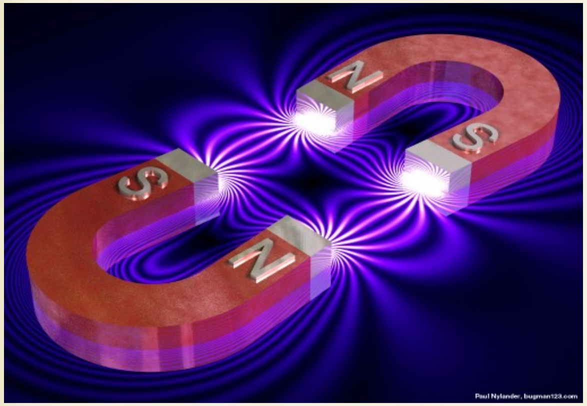
Olber's Paradox - 1823



http://en.wikipedia.org/wiki/Olbers'_paradox

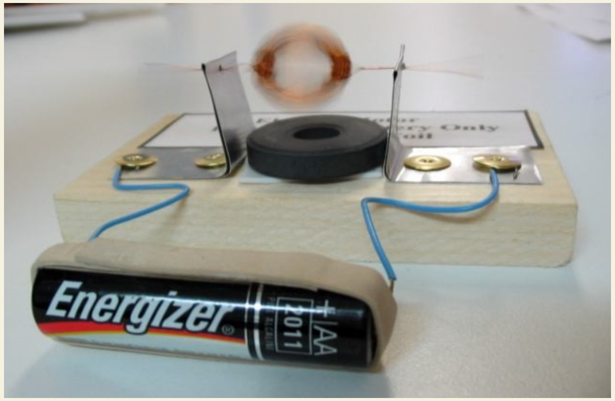
Electricity and Magnetism

- **Magnetism**
  - **Lode stones**
  - **Compasses**
- **William Gilbert (1544-1603)**
- **Thomas Browne (1605-1682)**
- **Benjamin Franklin (1706-1790)**
- **Luigi Galvani (1737-1798)**
- **Alessandro Volta (1745-1827)**



Electromagnetism

- André-Marie Ampère, (1775 - 1836)
- Hans Oersted (1777-1851)
  current deflects compass needles
- Georg Simon Ohm (1789-1854)
- Joseph Henry (1797-1878)
  electromagnetic induction, first motor, telegraph
- Michael Faraday (1791-1867)
  electrolysis, motors, induction coils, ...



http://hilaroad.com/camp/projects/magnet.html

Electromagnetic Waves

- **James Clerk Maxwell (1831-1879)**

  - Theory of electromagnetism.

  - Predicted the electromagnetic waves.

  - Electromagnetic waves travel at

  c = 299,792,458 m/s = 186,000 mi/s

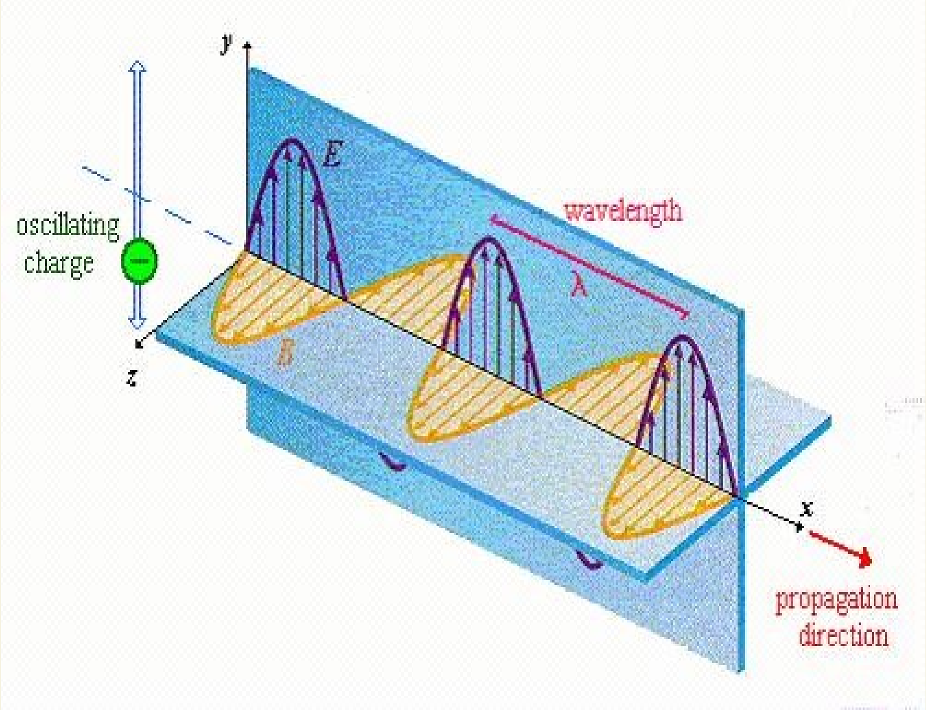
- **Heinrich Hertz (1857-1894)**

  - sent the first radio waves (1888)

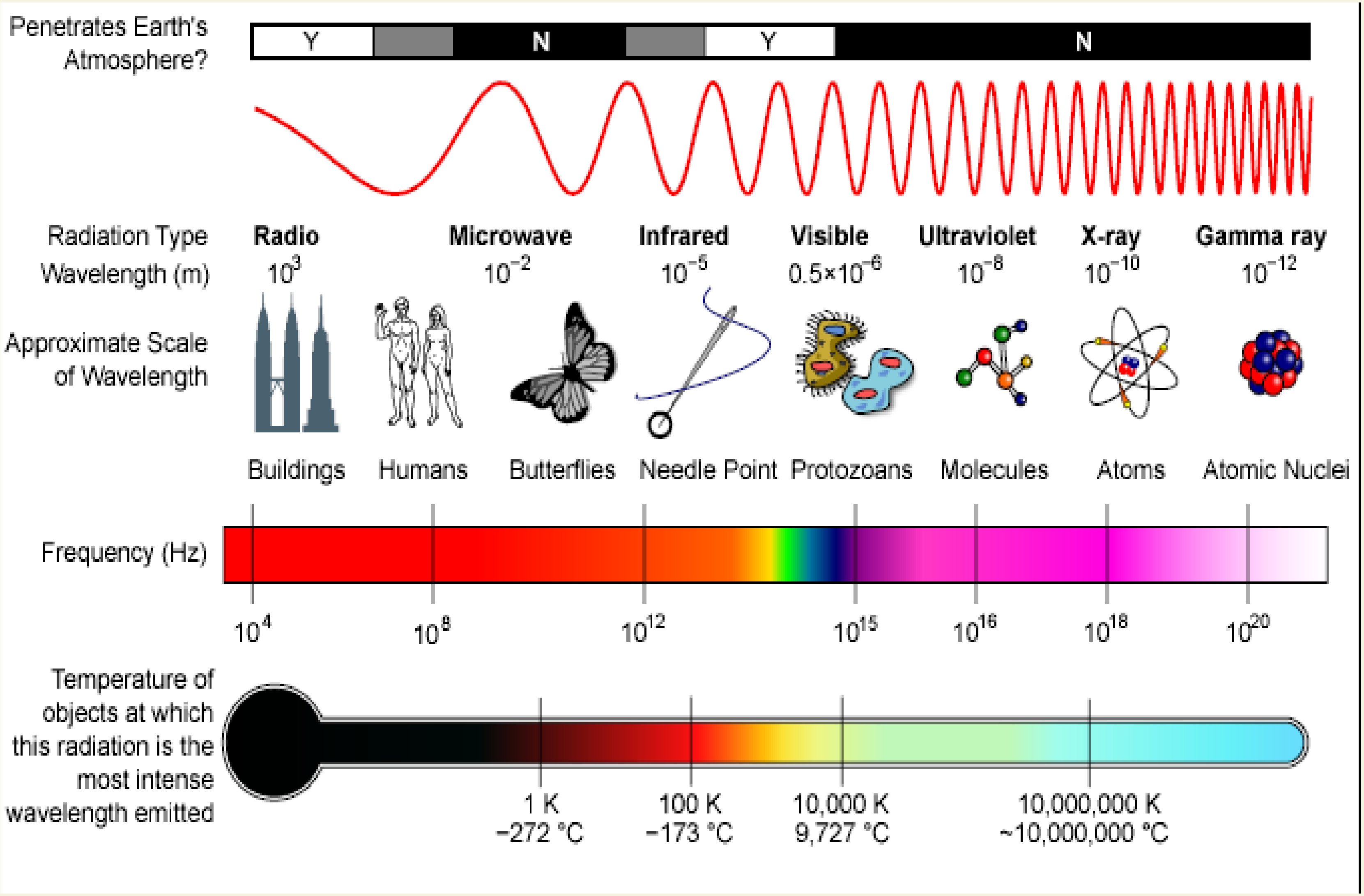
  What is the medium?
  Luminiferous Aether

- **Michelson-Morley (1887)**

  - could not detect it.



EM Spectrum



http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Spectroscopy

Ionized gas gives off radiation

- **Johann Balmer 1885**

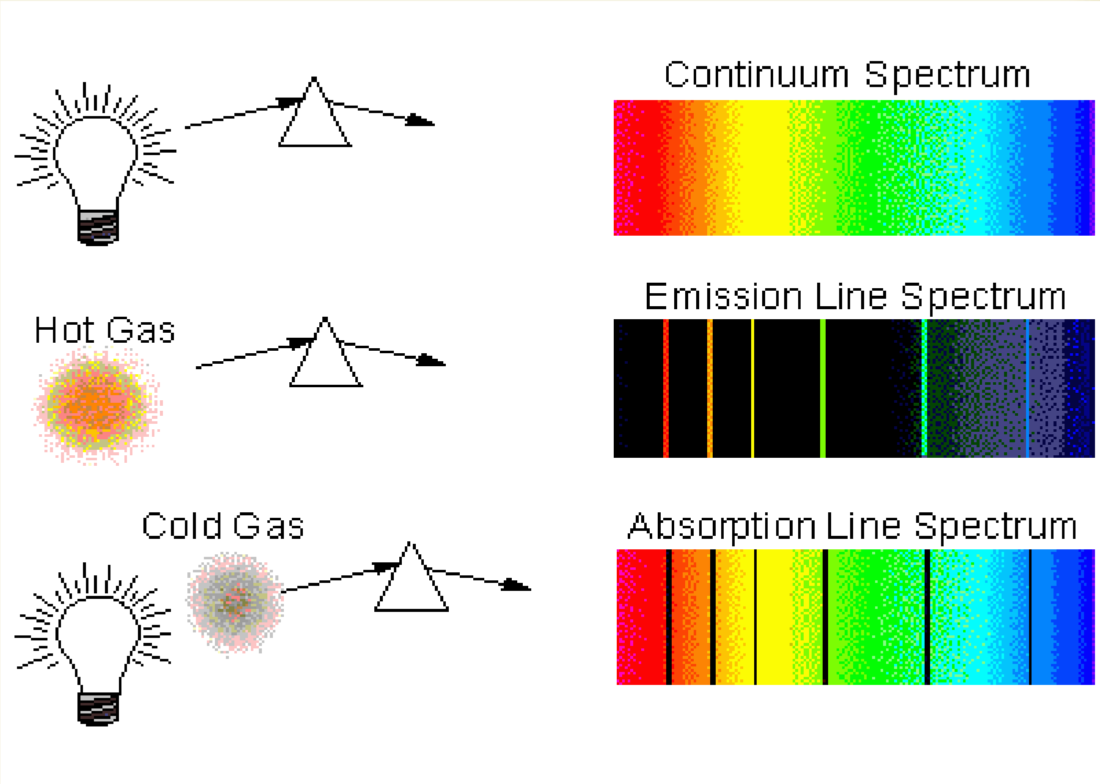
  Spectral Lines: Hydrogen
  410, 434, 486, 656 nm

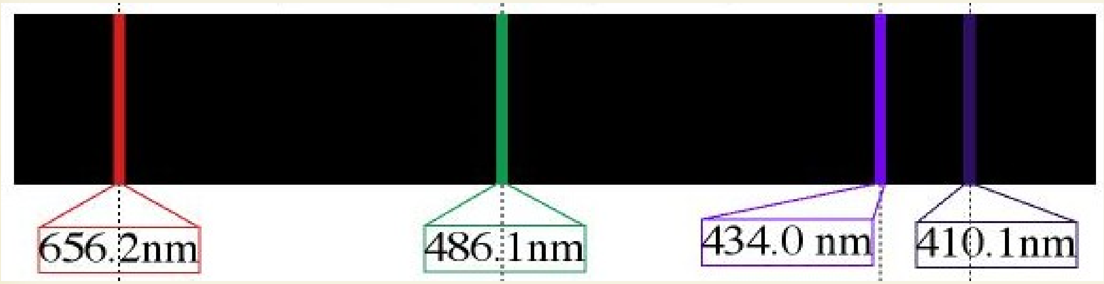
  Empirical Formula:

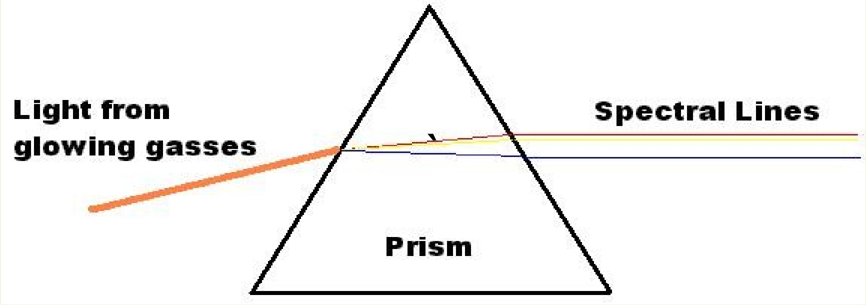
  $$\lambda = R\,(1/4 - 1/n^2)$$

  Predicted 5th-7th lines

- **Lyman and Paschen Series**







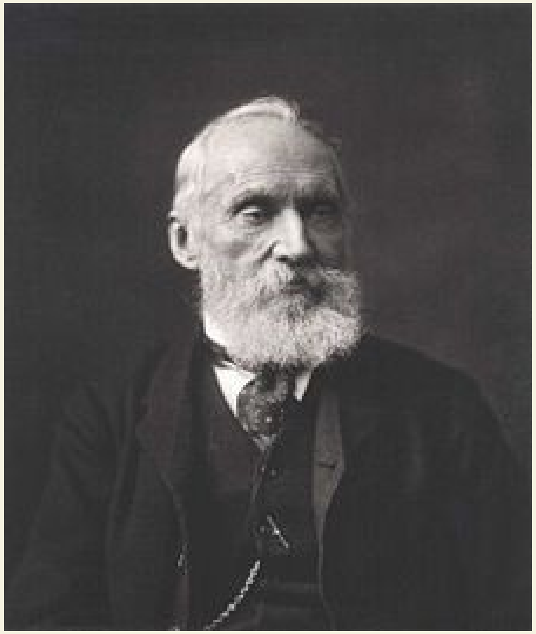
Laws of Thermodynamics

- **James Joule (1818-1889)**
  Mechanical Equivalent of Heat
- **Engines: Watt, Carnot, Kelvin, Clausius, Carnot**
- **Laws of Thermodynamics**
  1. Adding heat energy or doing work on a body increases internal energy.
  2. A body will not spontaneously get hotter.
- **Joseph Stefan (1835-1893)** and **Ludwig Boltzmann (1844-1906)**

  Heated bodies Radiate - Stefan-Boltzmann Law
  Radiation from blackbody proportional to T^4.

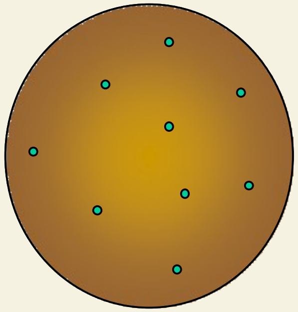
Physics Revolutions

William Thomson, (1824 – 1907)
1st Baron Kelvin (**Lord Kelvin**)



"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." - 1900

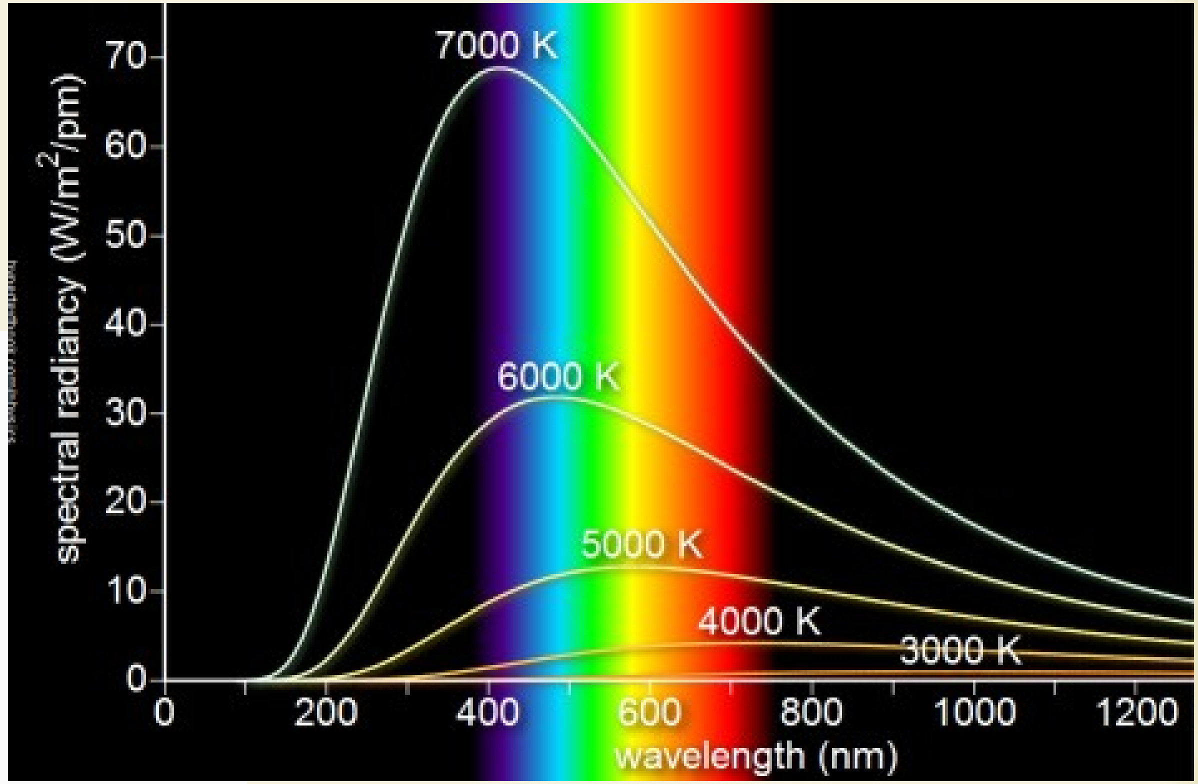
1895 **Wilhelm Röntgen** discovers X-rays.
1898 **Marie and Pierre Curie** separate radioactive elements.
1898 **Joseph Thomson** measures electron, **"plum-pudding" model of the atom**
- a slightly positive sphere with small, raisin-like negative electrons.

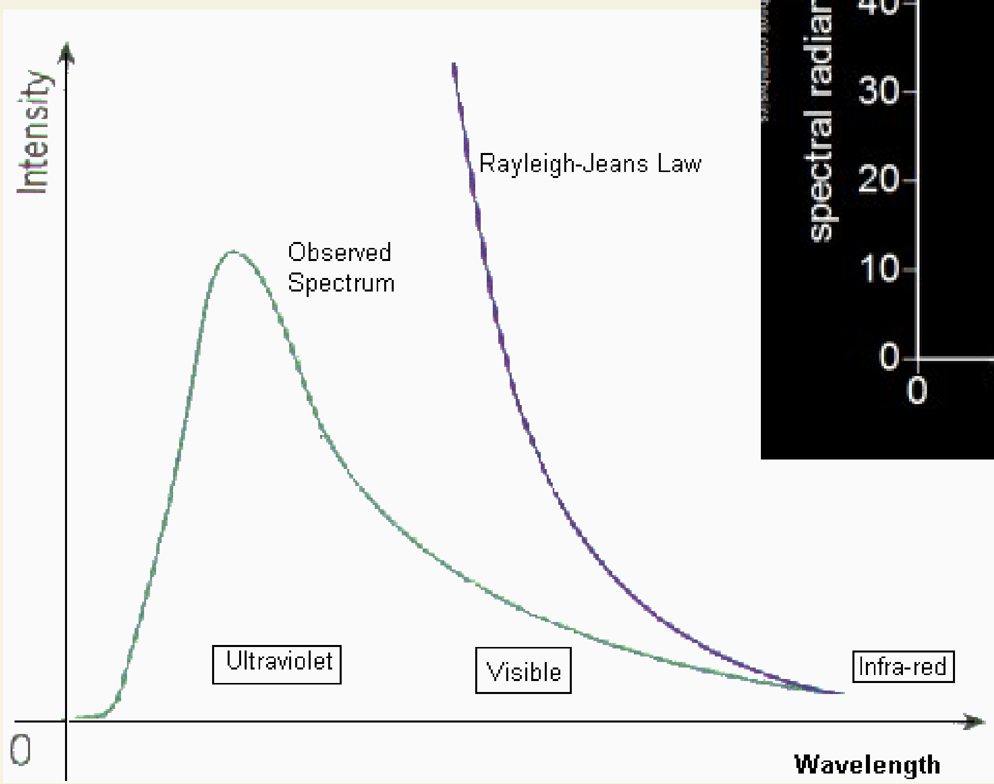


Blackbody Spectrum

Blackbody - a theoretical object that absorbs 100% of the radiation that hits it.

Wien's Law (1896)
Rayleigh - Jeans Law (1900)





Ultraviolet Catastrophe "... when you turn on your toaster, you are instantly fried by a massive gamma ray burst, since your little blackbody toaster should emit infinite energy at the shortest wavelengths."

Quantum Theory

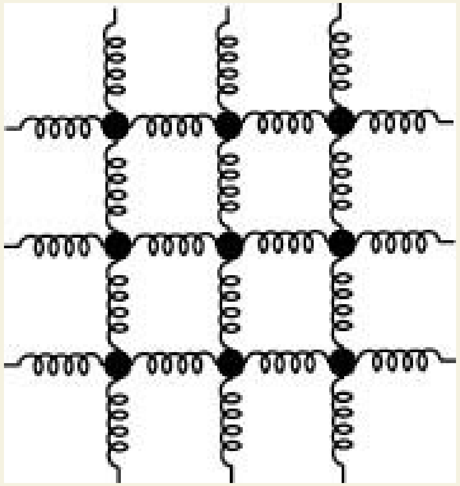
Max Planck
(Karl Ernst Ludwig Marx Planck 1858-1947)

oscillators can only vibrate at discrete frequencies:

$$E_n = n(hf),\ n = 1,2,3 \ldots.$$

Thus, the energy difference

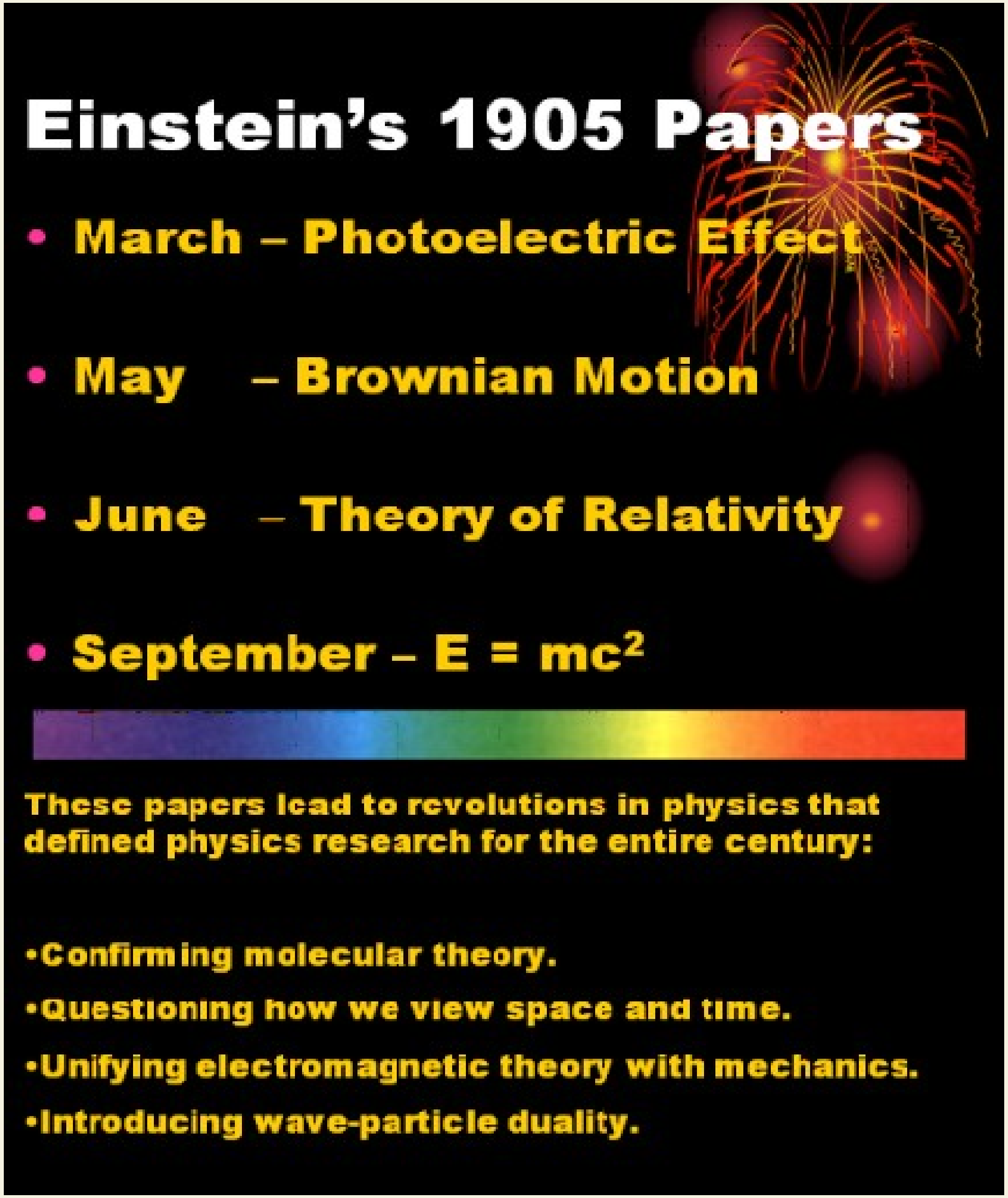
$$\Delta E = hf,$$

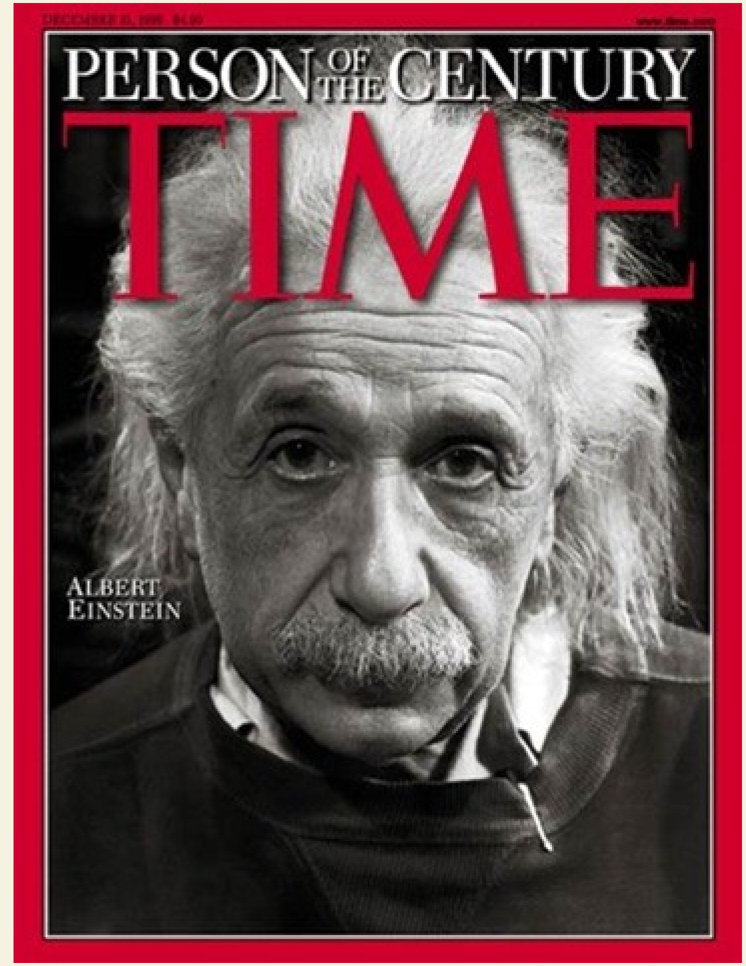


where Planck's constant is given by

$$h = 6.63 \times 10^{-34}\ \text{Js}$$

Albert Einstein(1879-1955)





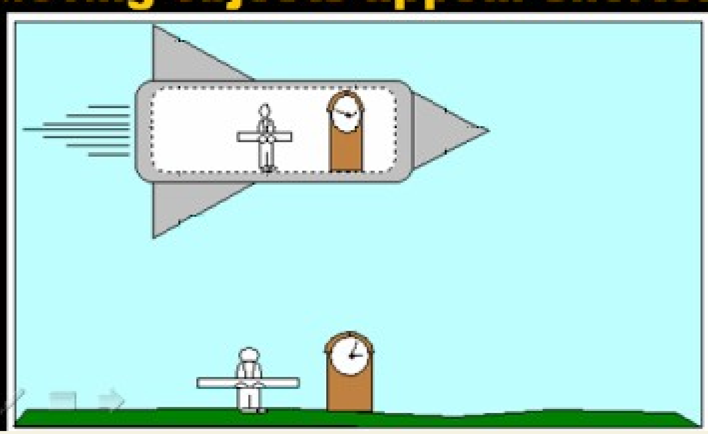
Relativity and Quantum Theory

Theory of Relativity

Physics looks the same to all observers moving at a constant velocity

The speed of light in a vacuum is the same for all observers

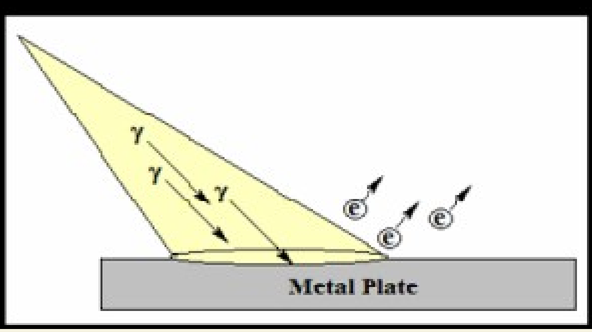
- There is no absolute time or position
- Moving clocks tick slower.
- Moving objects appear shorter.



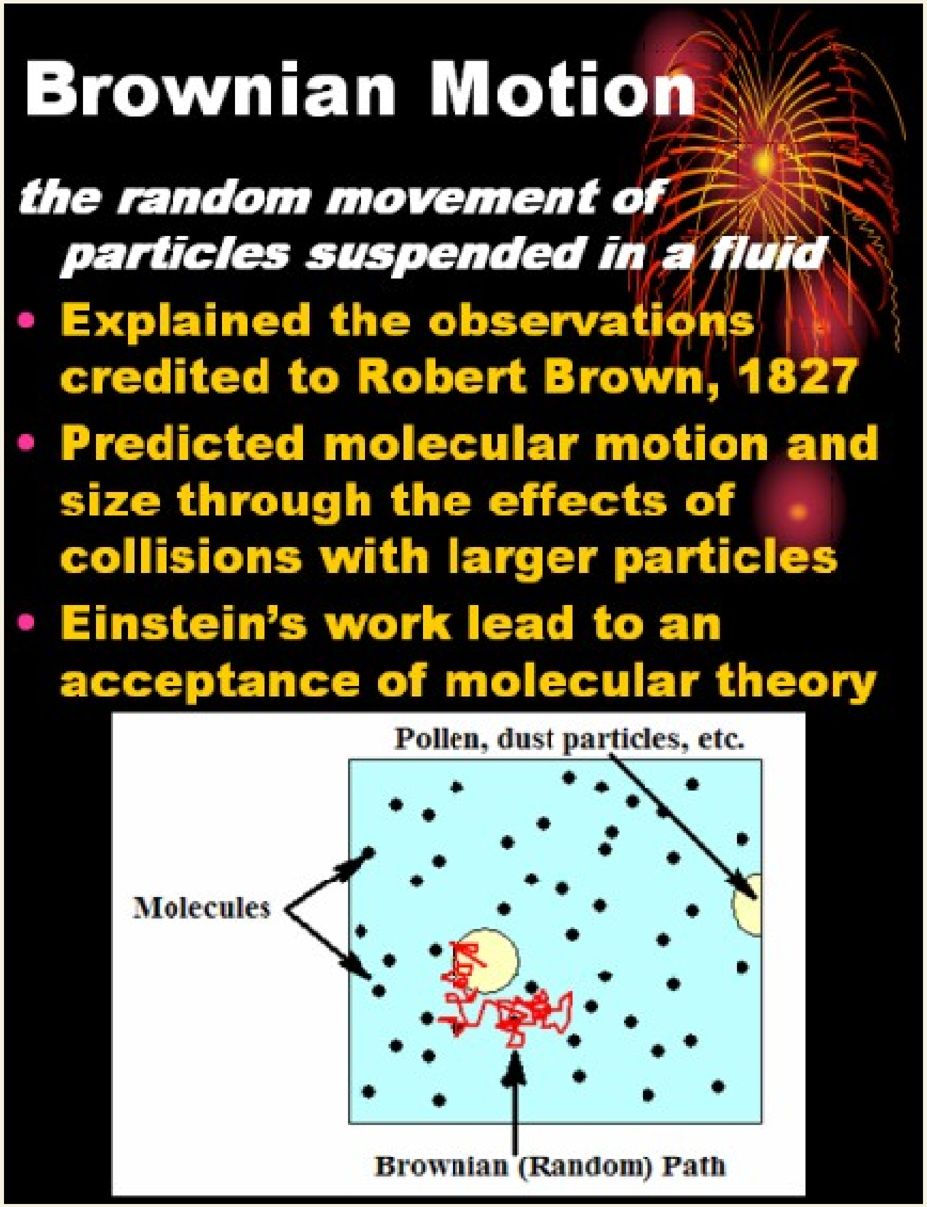
Photoelectric Effect

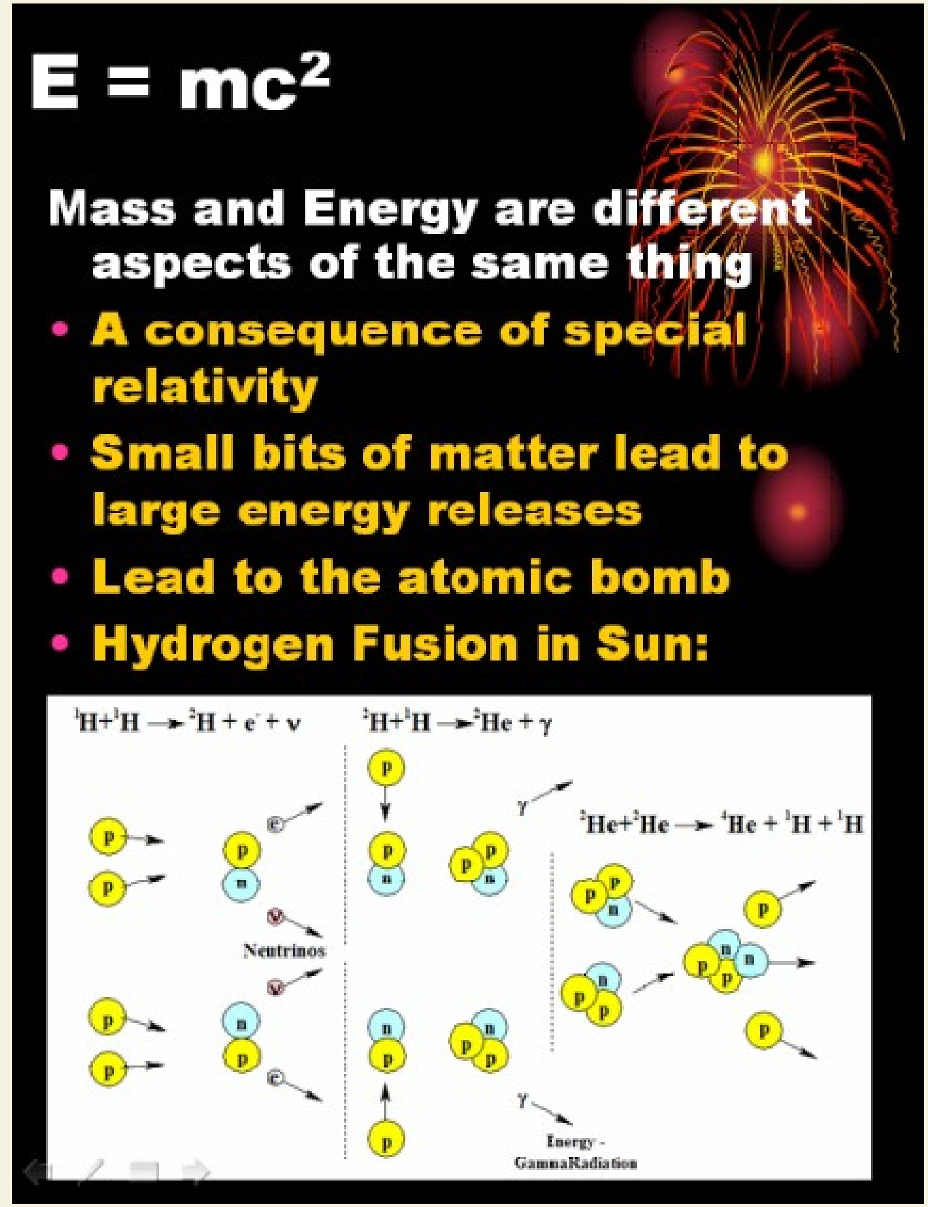
Light can cause currents

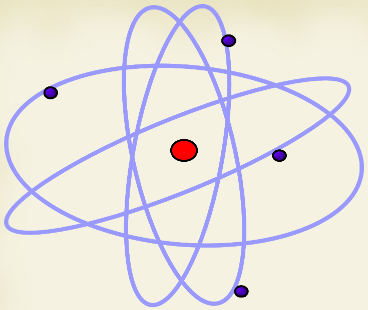
- Electrons can be ejected from irradiated metal plates.
- Light can be act like either particles (quanta) or waves.
- Extended Planck's ideas of energy quantization.
- Lead to explanation of electromagnetic spectra,
- Lead to the development of lasers, transistors and other applications.



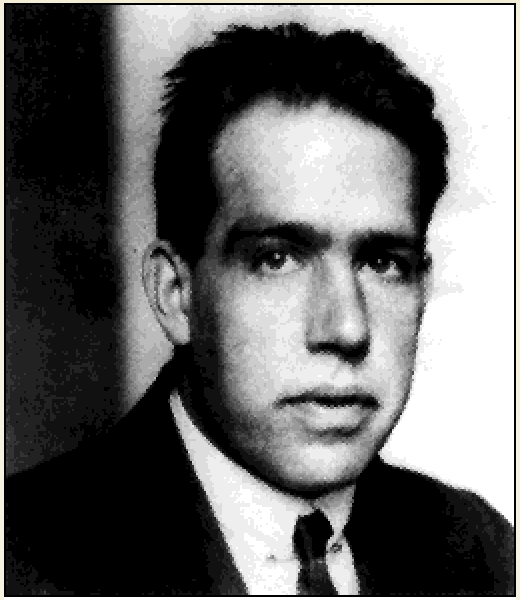
Other Papers







Bohr's Atom - 1913

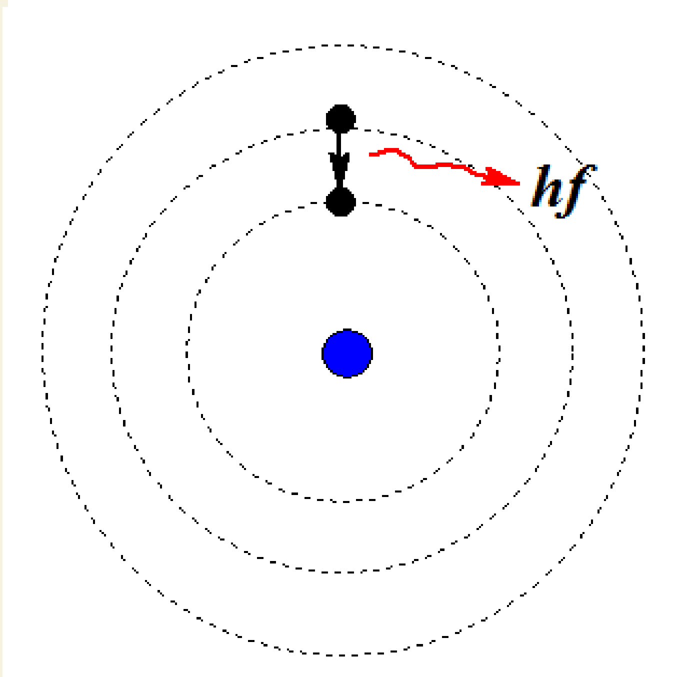


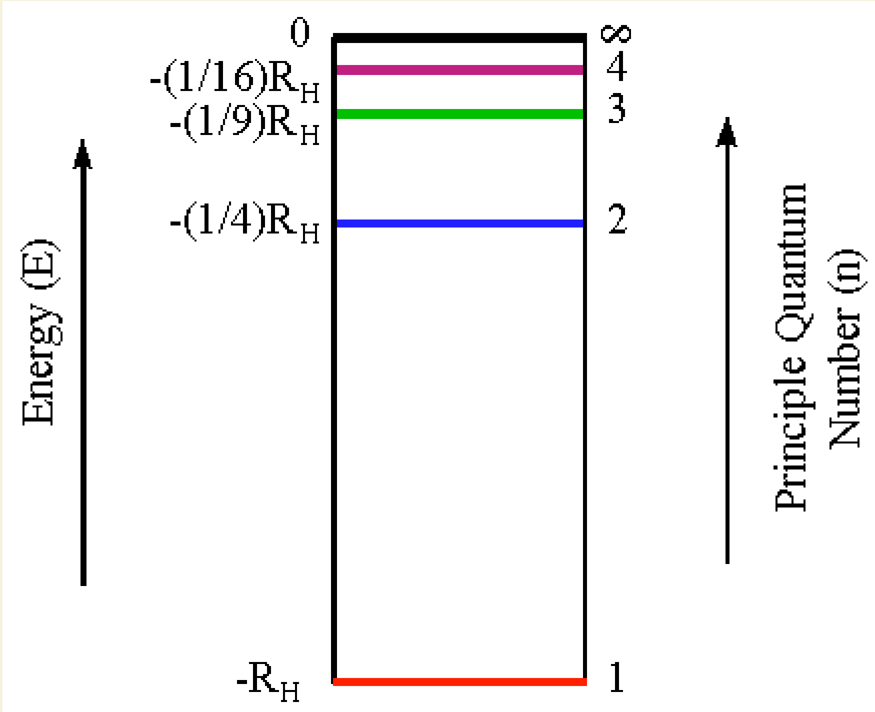
Neils Bohr

Niels Bohr (1885-1962)

Electrons move in specific orbits.
Accelerating electrons radiate at specific energies.

$$E_n = R_H(1/m^2 - 1/n^2)$$





Early History - Quantum Mechanics

1900 - Planck Explains Blackbody Radiation

1905 - Einstein - the Photoelectric Effect, Photons

1913 - The Bohr Model for Hydrogen

1916 - Confirmation of photon, Millikan

1923 - Compton Effect – X-Ray Scattering

1924 – de Broglie - Particles Behave Like Waves

1925 - Matrix Mechanics - Heisenberg

1926 - Derivation of Planck's Law – Dirac

1926 – Wave Mechanics - Schrödinger

1927 - The Uncertainty Prinicple - Heisenberg

1927 - Davisson-Germer Verified deBroglie's idea

1928 - Relativistic Quantum Mechanics - Dirac

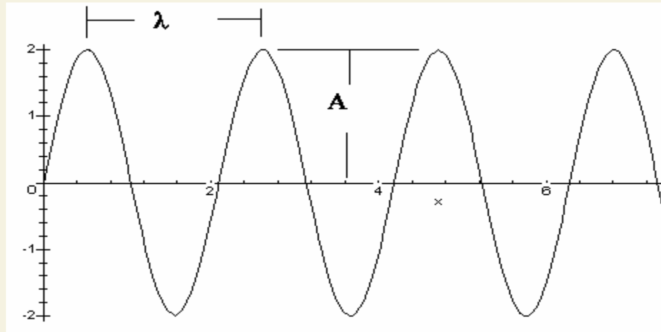
What are Waves?

Characteristics

Wavelength

Frequency

Wavespeed

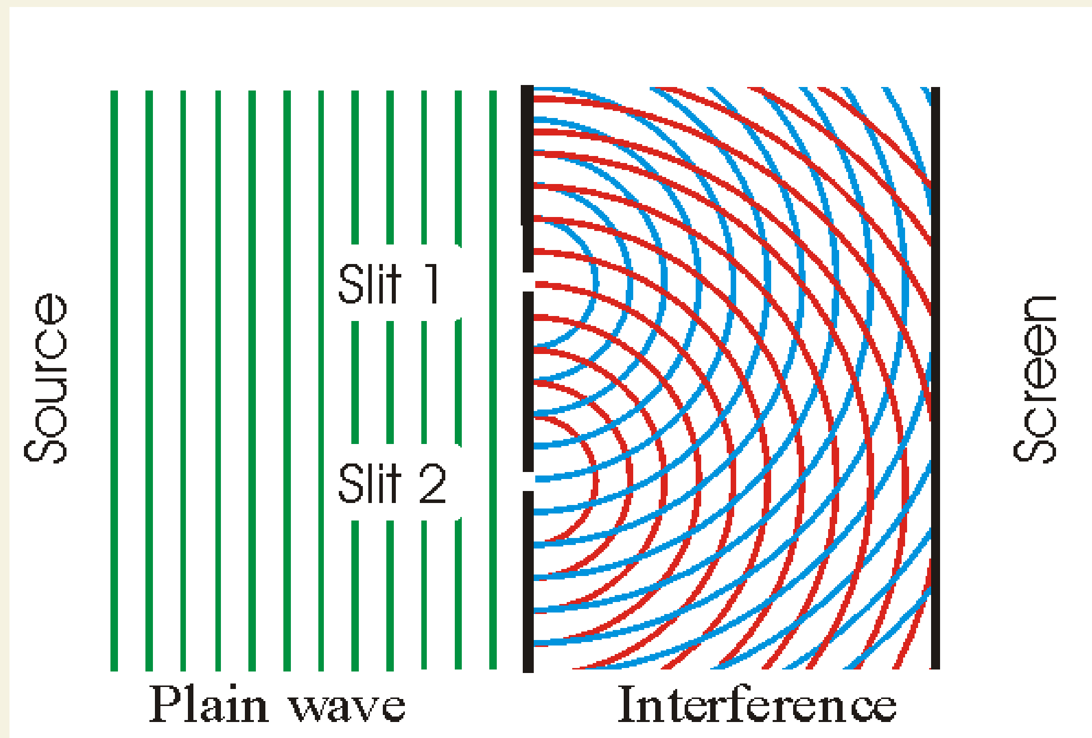


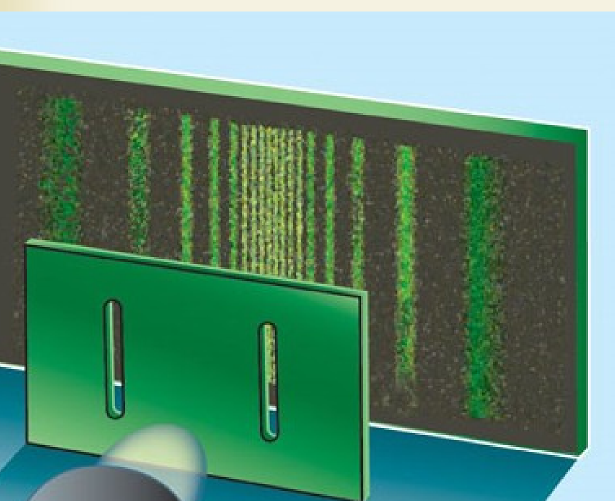
Behavior

Superposition

Interference

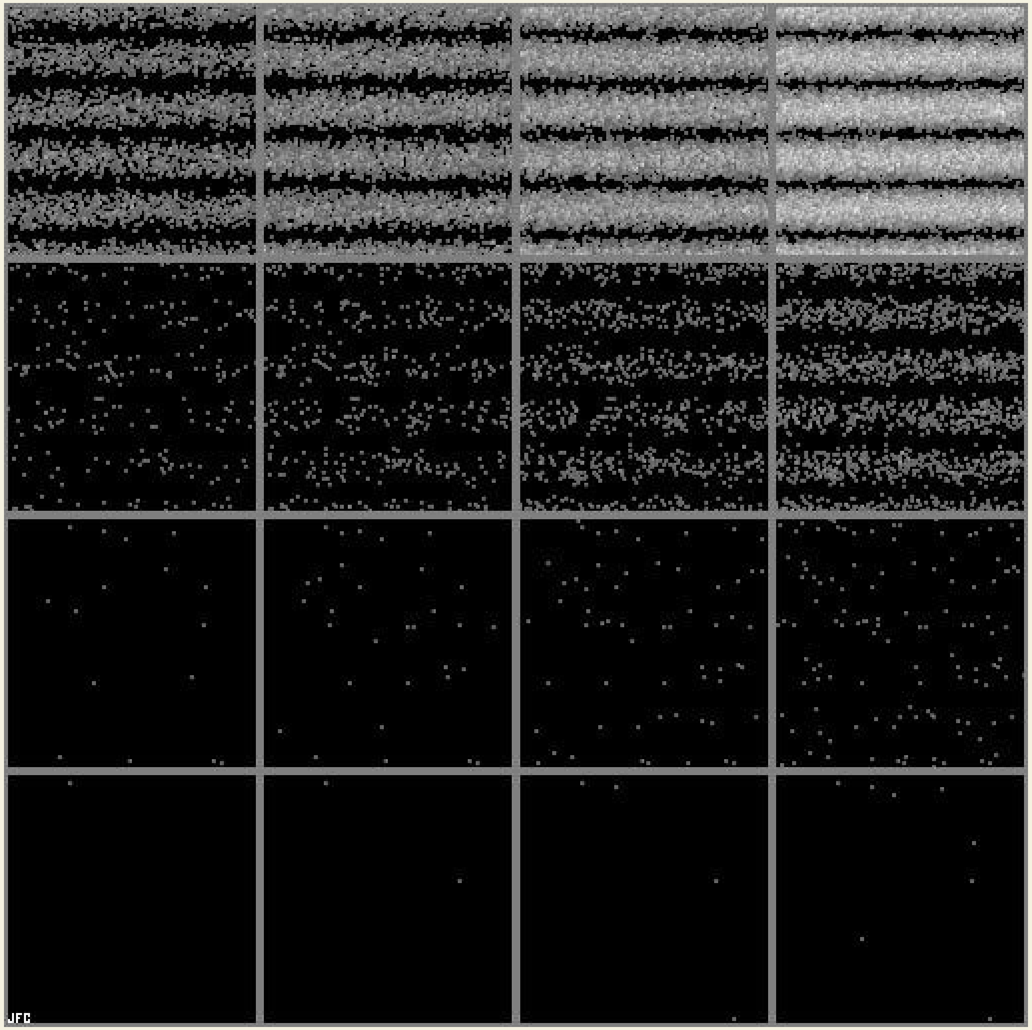
Diffraction





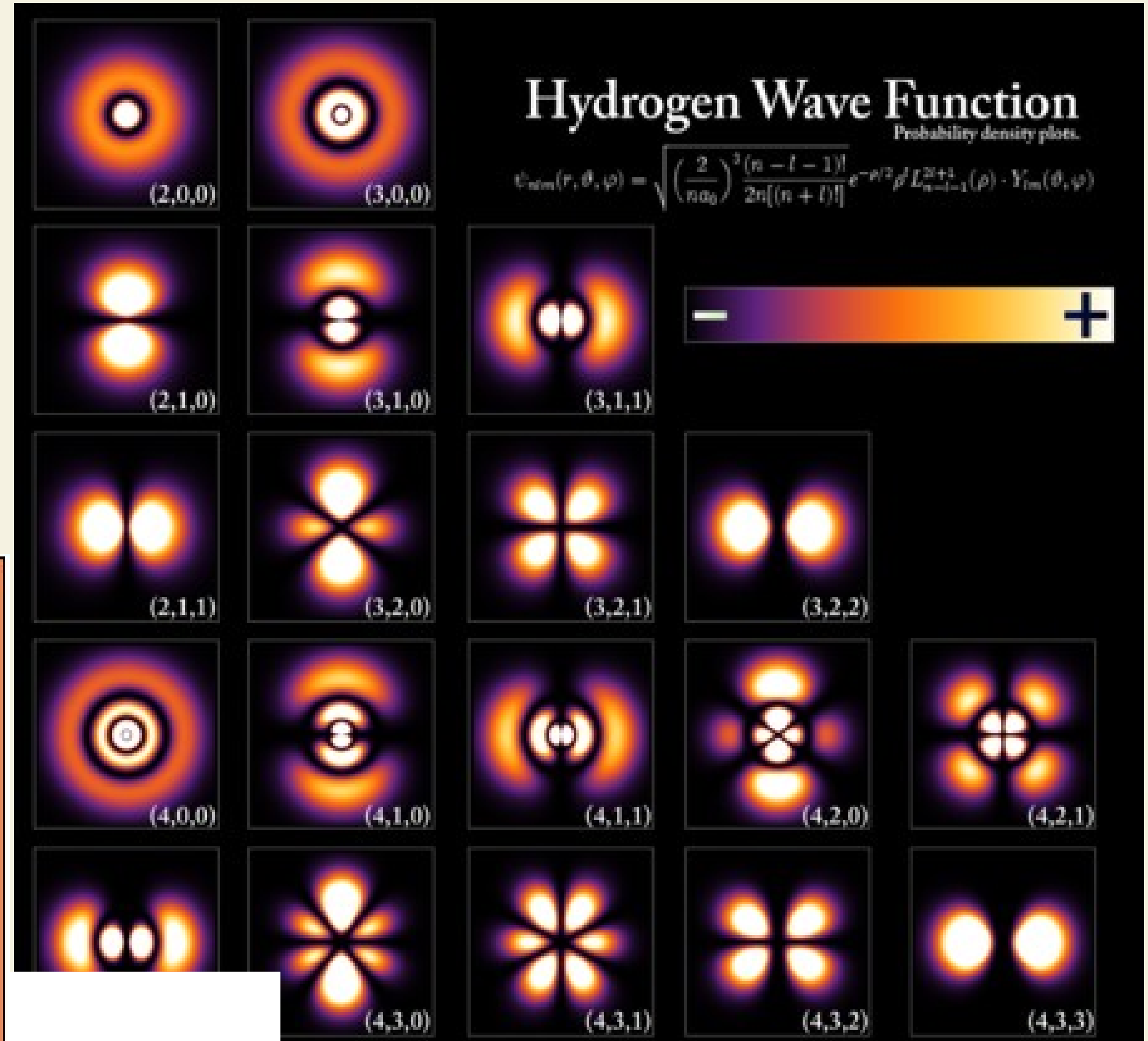
Electron Diffraction - 1929

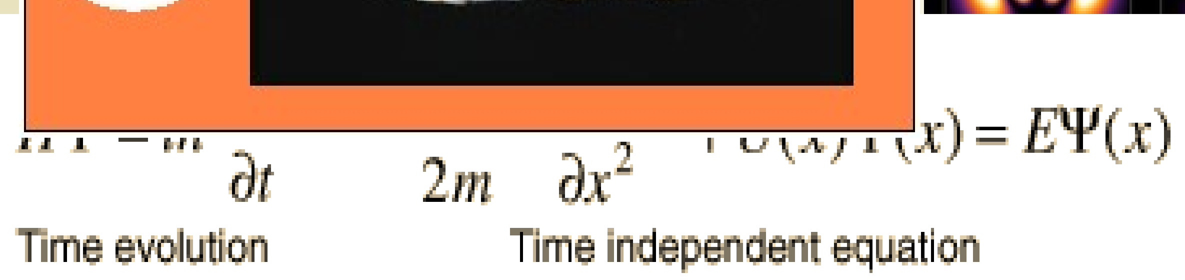
- George Paget Thomson (1892-1975)
- Clinton Joseph Davisson (1881-1958)
- Lester Halbert Germer (1896-1971)



Erwin Schrödinger (1887-1961)

- Matter Waves
- Predicted
  Hydrogen Spectrum
- Needed Interpretation
- Leads to ...

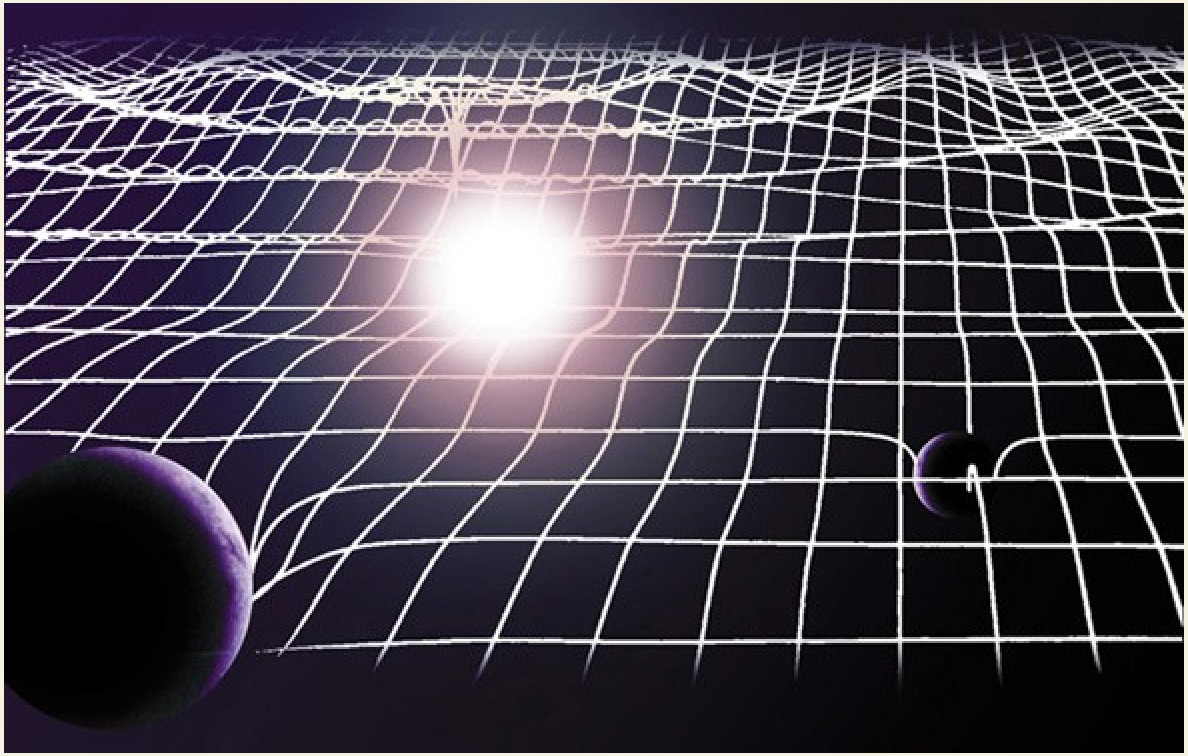




Paradigm Shifts

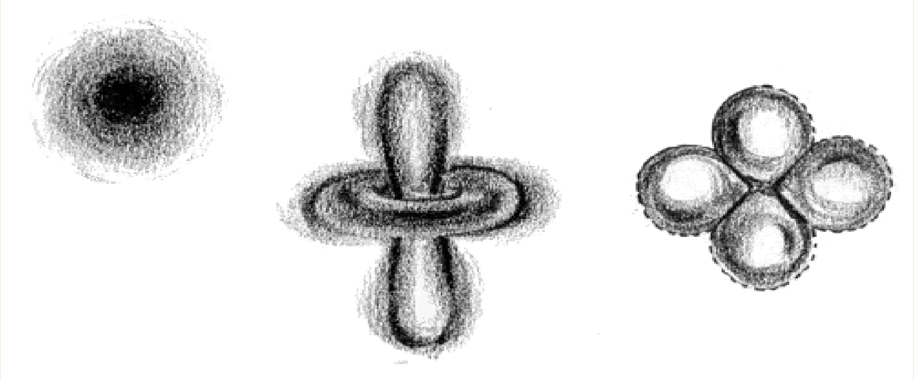
Relativity

Space and Time not absolute, not Euclidean



Quantum Mechanics

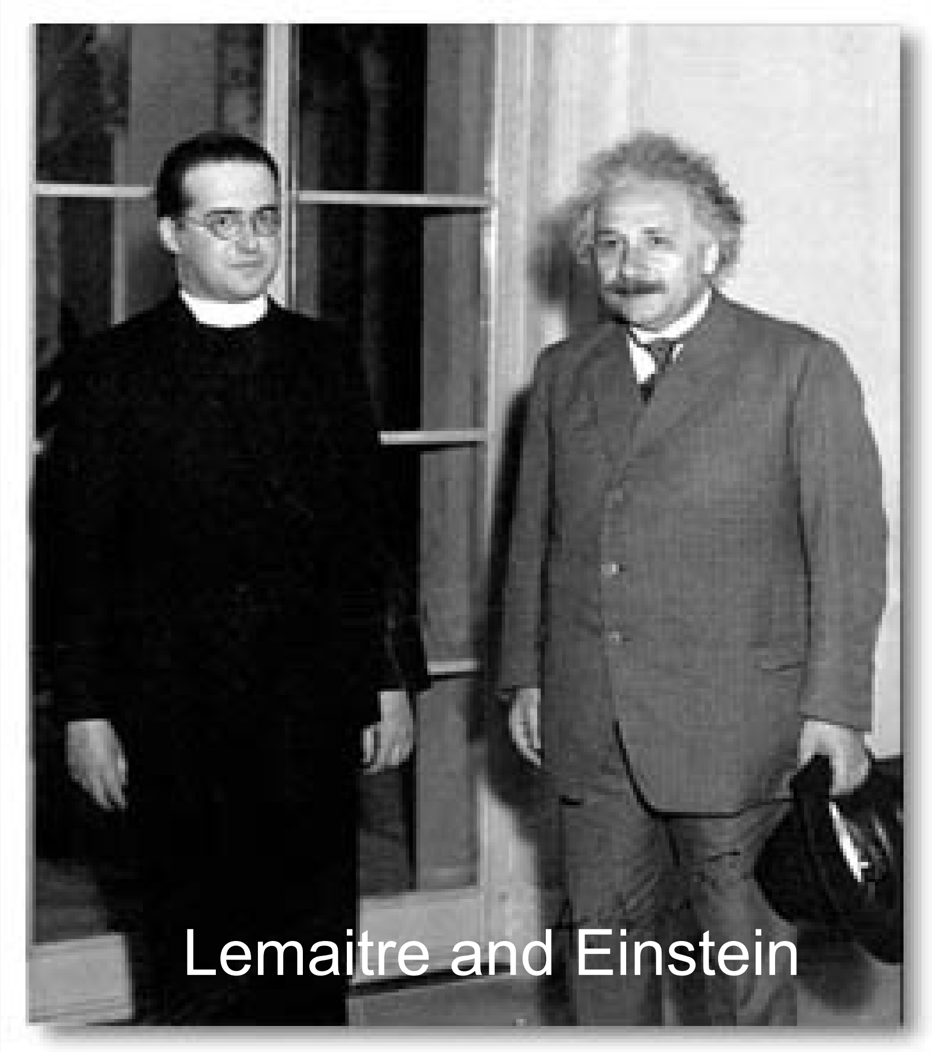
Loss of Determinism



http://www.zamandayolculuk.com/cetinbal/AE/Deformation.jpg

Pre-Modern Cosmology

- 1915 General Relativity
- 1916 Schwarschild
- 1917 de Sitter
- 1922 Friedman
- 1927 Lemaitre
- 1929 Hubble
- 1932 Einstein-de Sitter
- 1948 Gamow - CMB
- 1950 Hoyle – Steady State
- 1965 Penzias and Wilson

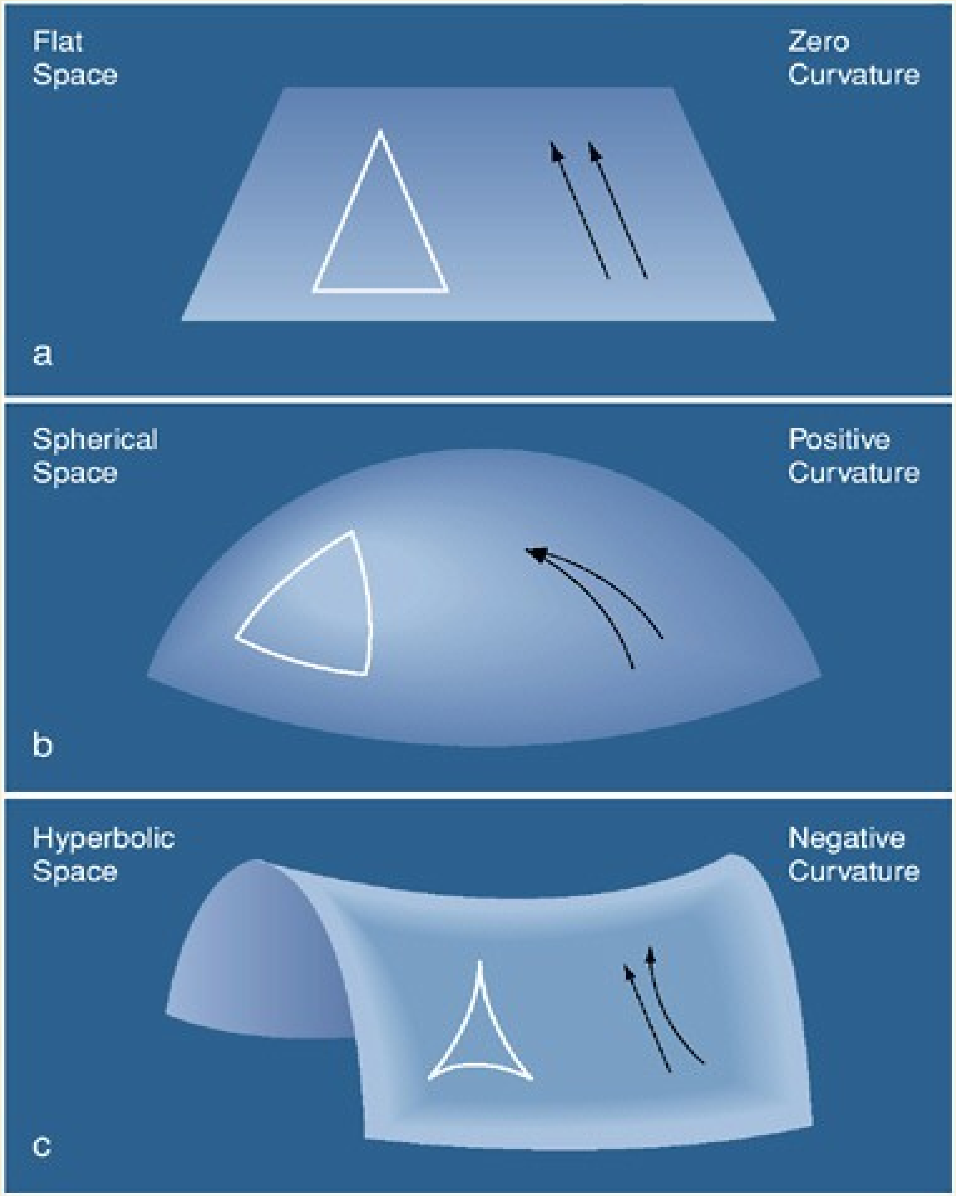


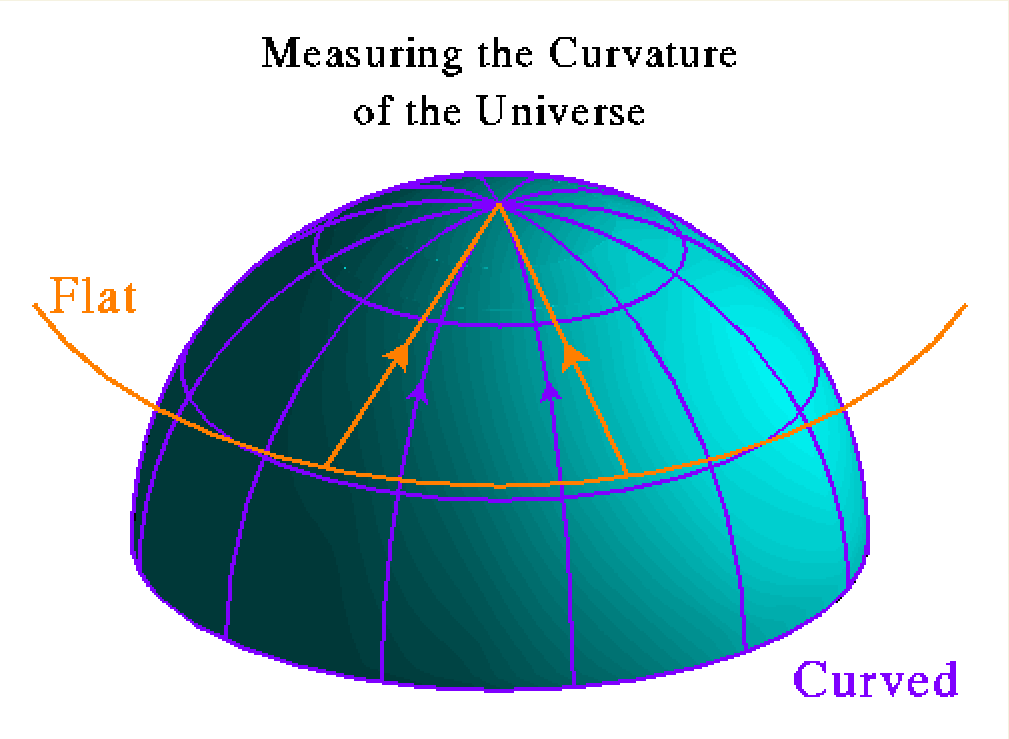
http://www.catholiceducation.org/articles/science/sc0022.html

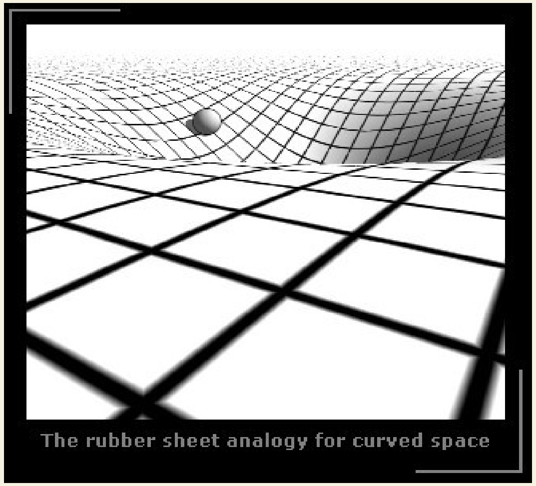
General Relativity

- **Einstein - 1915**
  - Newton's gravitational attraction replaced
  - Curvature of spacetime tells bodies how to move
  - Bodies tell spacetime how to curve
- **Karl Schwarzschild (1873-1916)**
  - Papers on spherical solution sent from WWI front
  - Einstein presented Feb 24, 1916

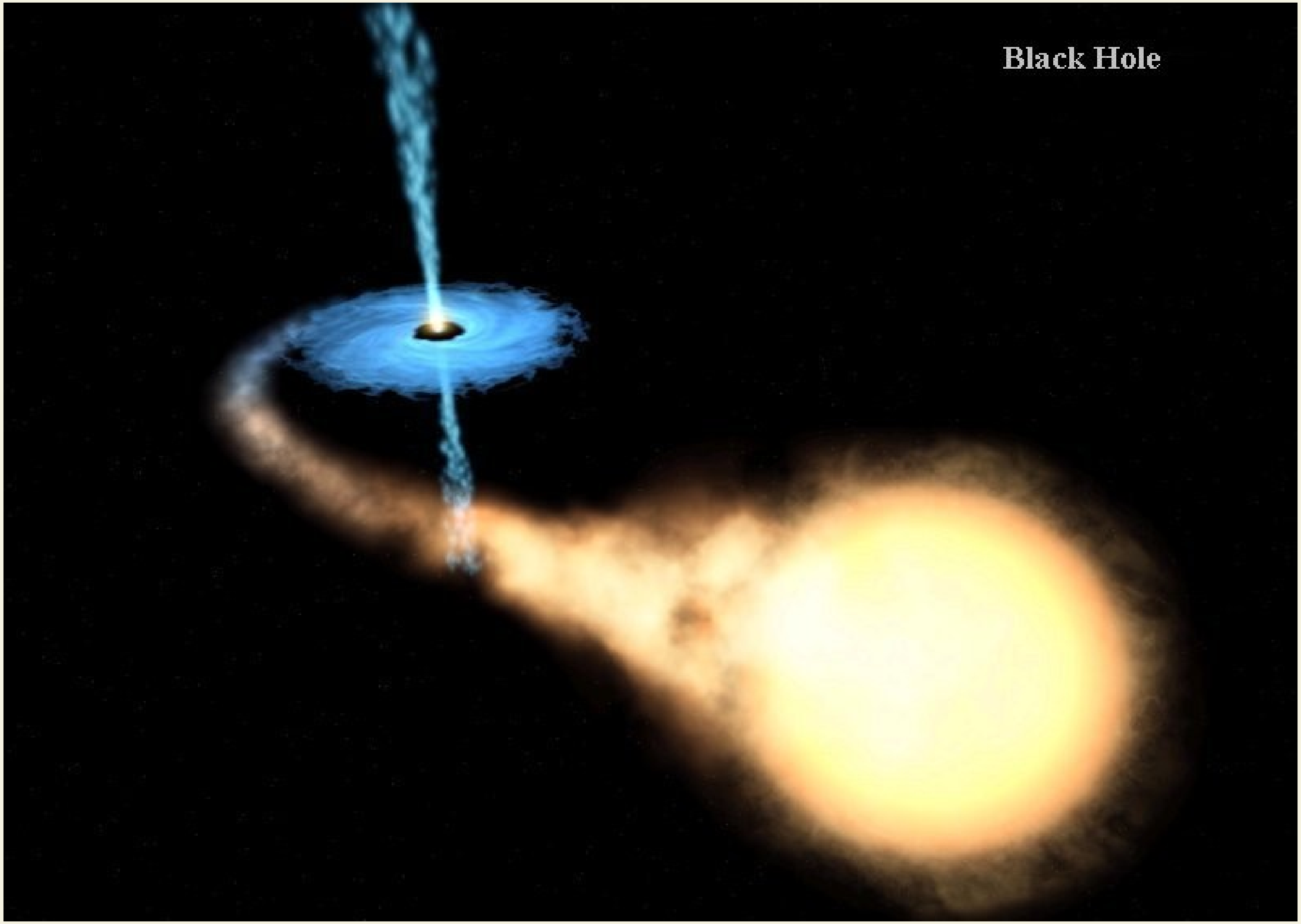
Curved Space







Black Holes



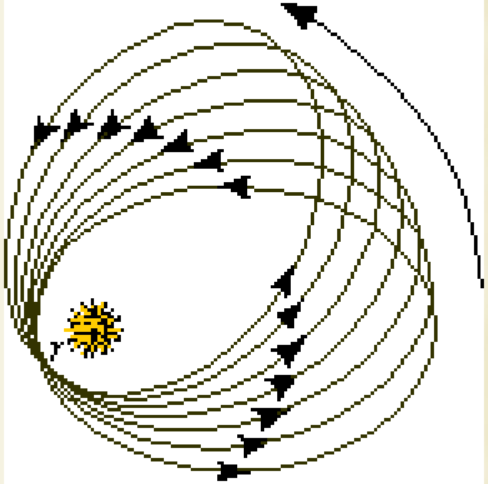
Testing of General Relativity

New Theories need to derive known results & predict new results

- **Mercury's Orbit Precession**

  1858 Urbain Le Verrier – 531/574 arcsec/century

  Nov 18, 1915 Einstein – GR gives 574!



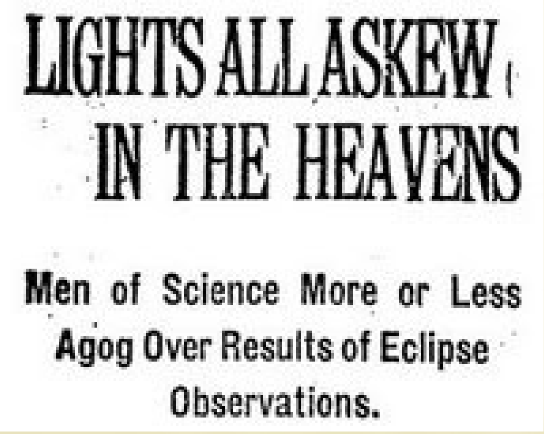
- **Bending of Light**

  Erwin Freundlich – 1912

  Crimea – Aug 21, 1914

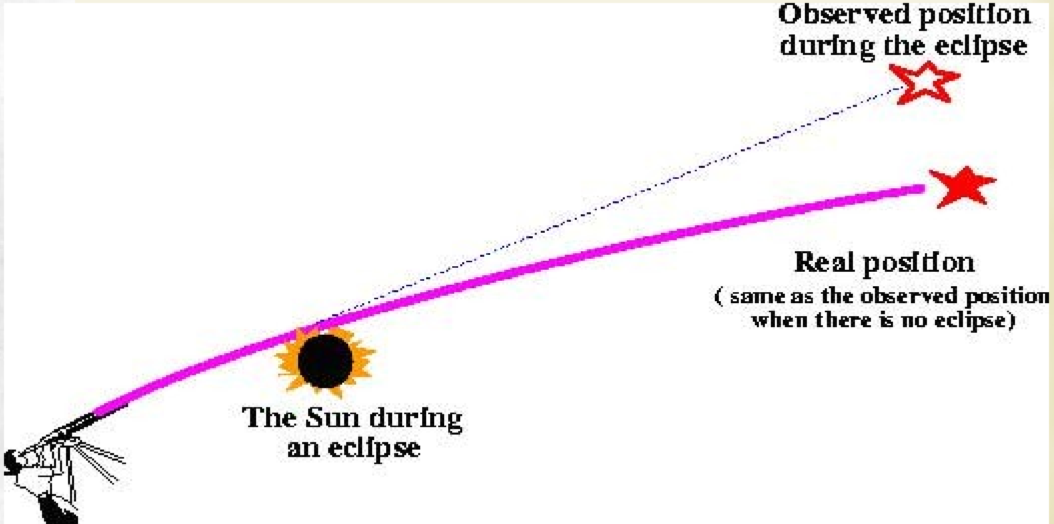
  Sir Arthur Eddington

  Brazil – May 29, 1919



LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.



1917- Cosmological Considerations

Cosmological Considerations of the General Theory of Relativity, Einstein

Cosmological Principle

The universe is the same everywhere

Homogeneous

The universe looks the same from every point

Isotropic

The universe looks the same in every direction

Einstein's Model – Not Static!

All bodies attract leading to collapse – unstable universe!

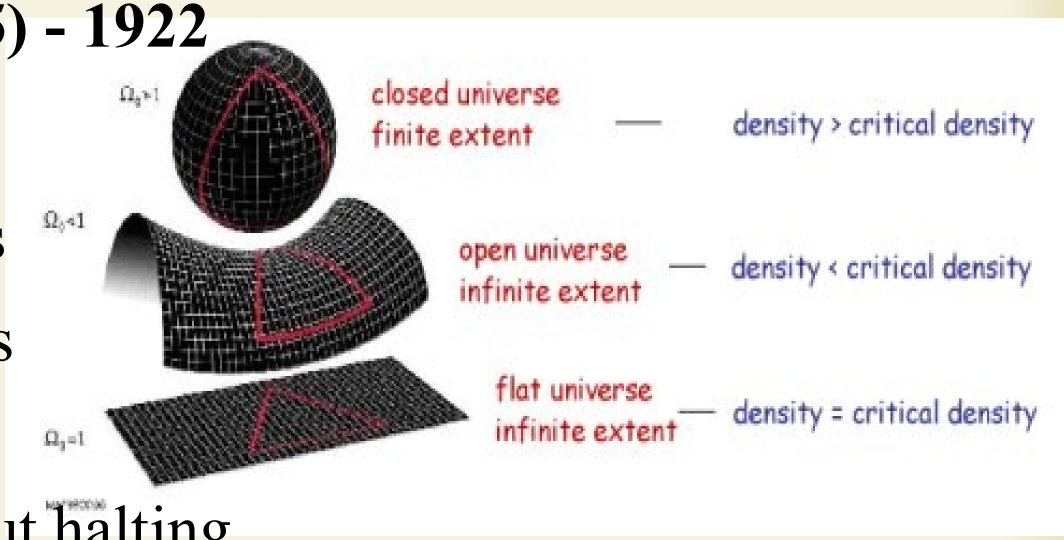
Fudge Factor - "his greatest blunder"

Einstein adds **cosmological constant**, Λ

Provides a repulsion of masses

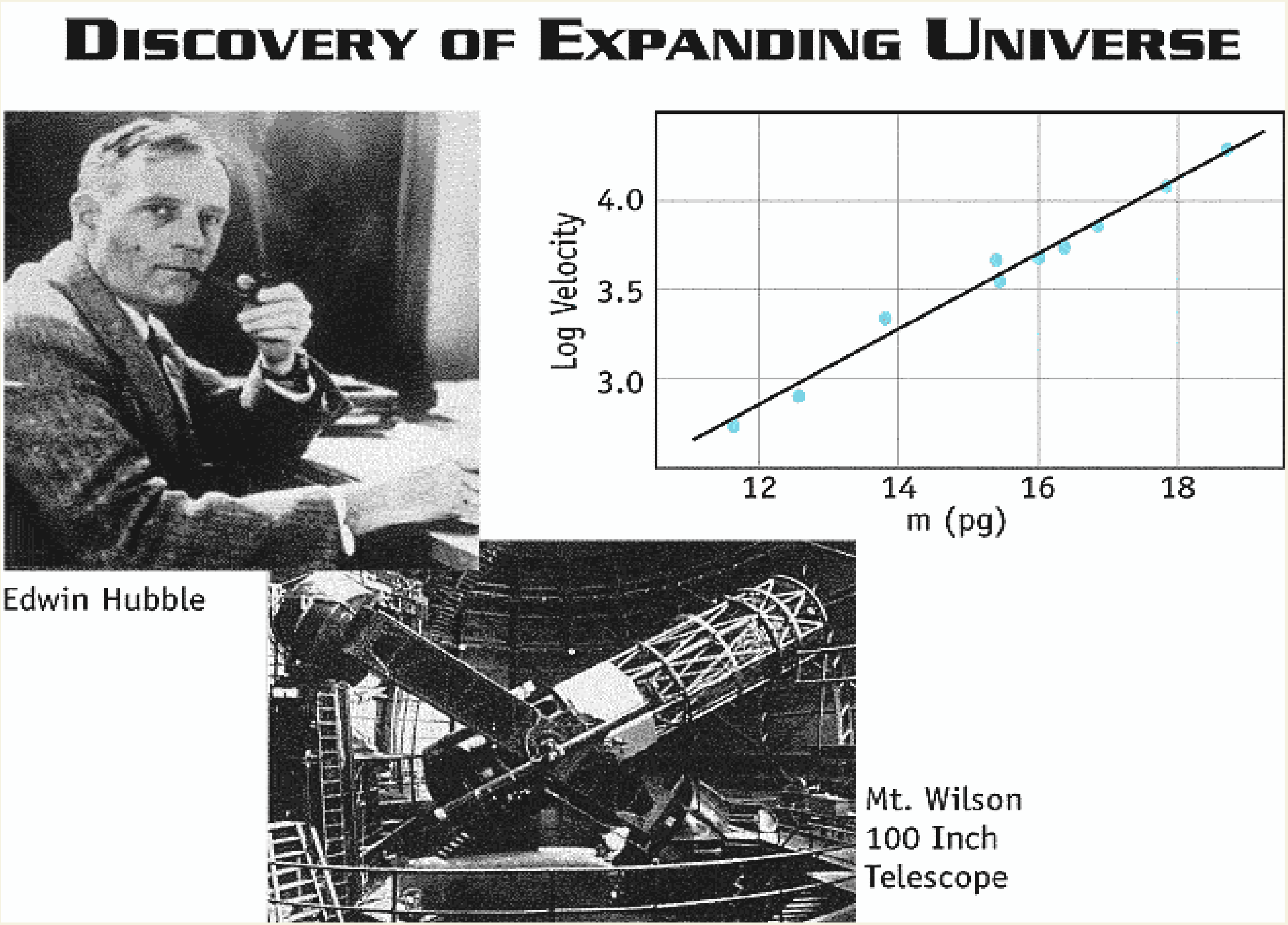
New Theories

- **Aleksandr Friedmann (1888-1925) - 1922**
  - Gave universe an initial kick
  - Initial density gave three scenarios
    - Low density – forever expands
    - High density – re-contracts
    - Critical density – slows without halting



- **George Lemaitre (1894-1966) - 1927**
  - Physicist and Priest, worked with Eddington
  - Rederived Friedmann's work
  - Consequence - traced back in time to moment of creation
  - Proposed cosmic rays came from early universe
- **Both rejected by Einstein!**

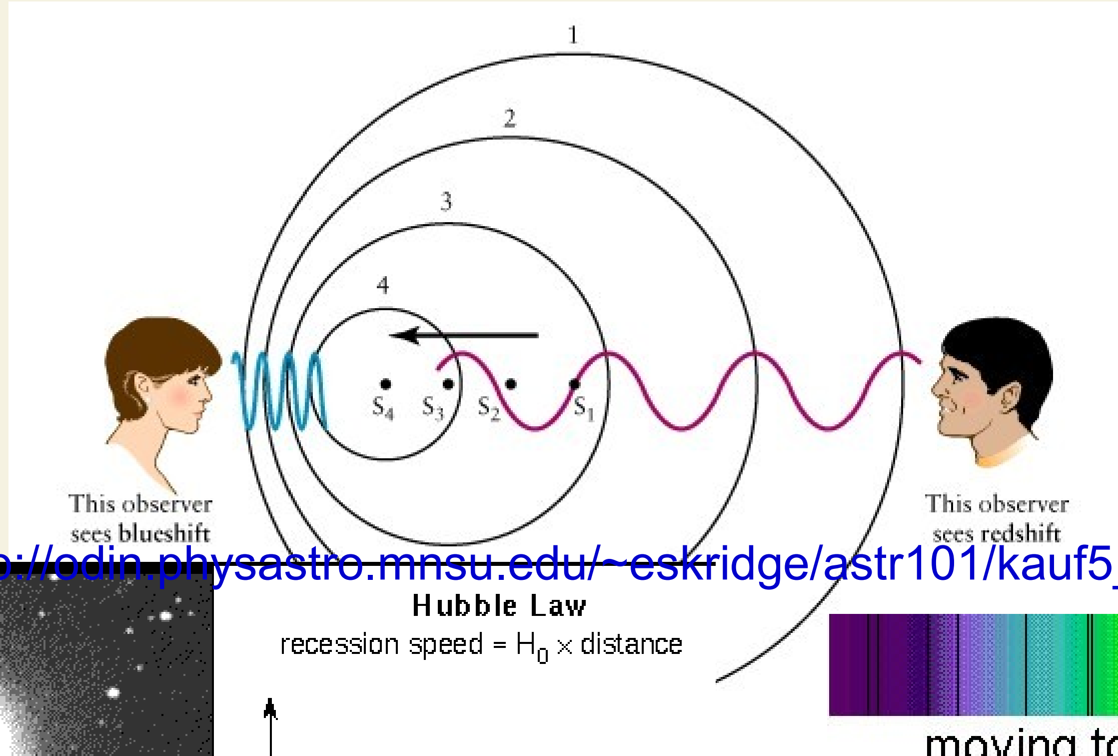
Edwin Powell Hubble (1889-1953)



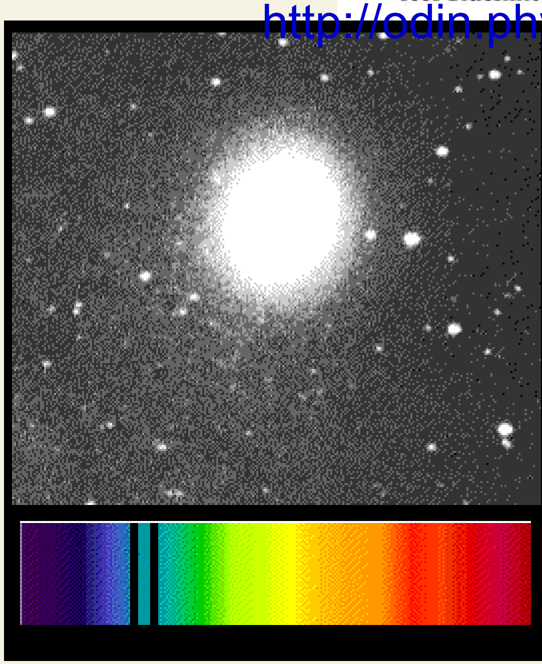
http://map.gsfc.nasa.gov/media/ContentMedia/990044b.gif

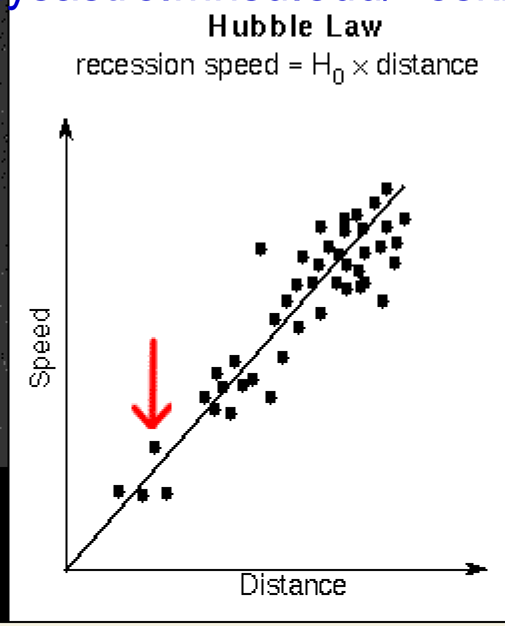
Doppler Effect

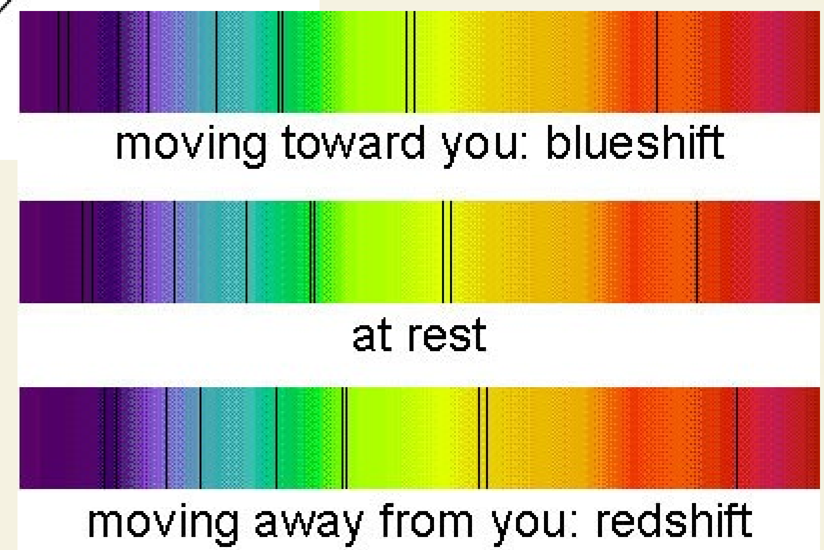
Christian Andreas Doppler (1803-1853)



http://odin.physastro.mnsu.edu/~eskridge/astr101/kauf5_23.JPG





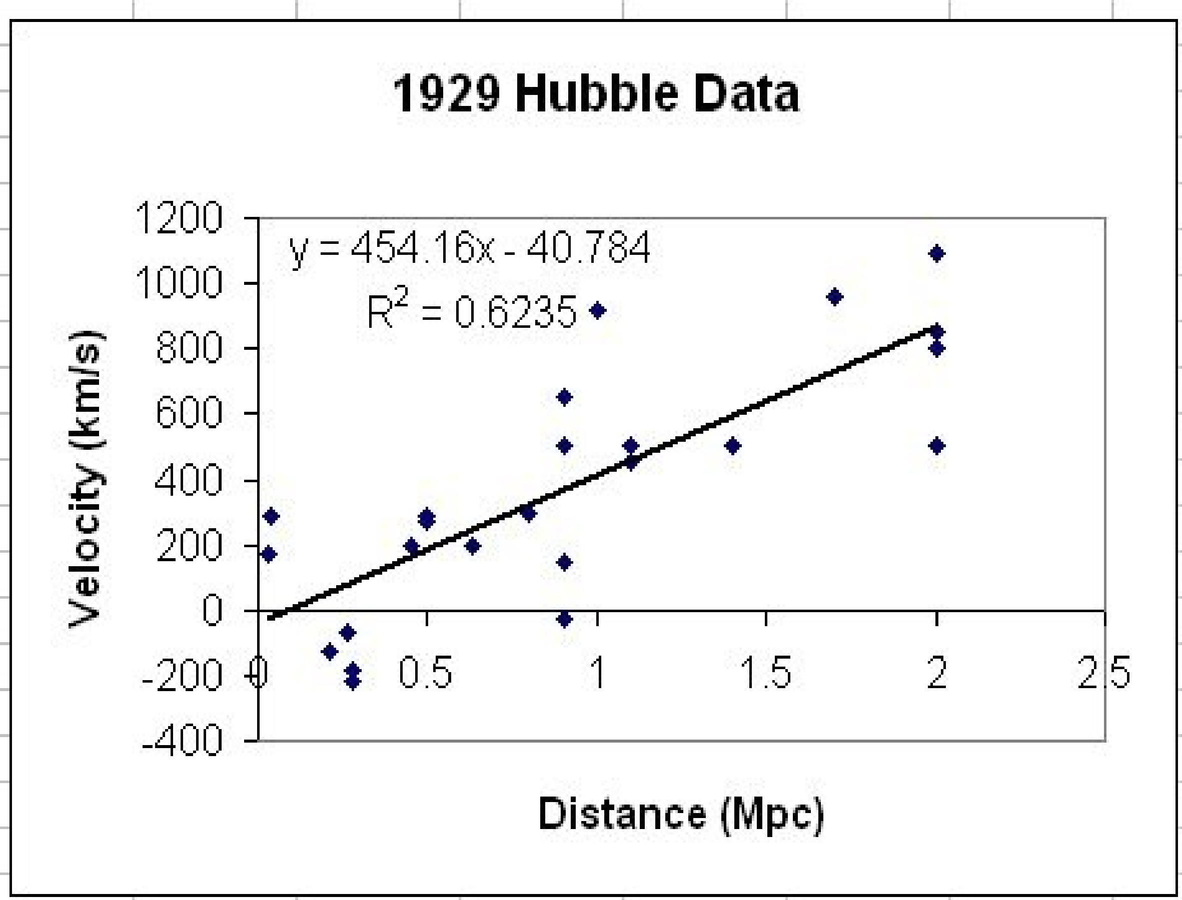


http://universe-review.ca/F02-cosmicbg.htm

http://snap.lbl.gov/images/redshift.jpg

Hubble's Constant: $v = H_0 d$

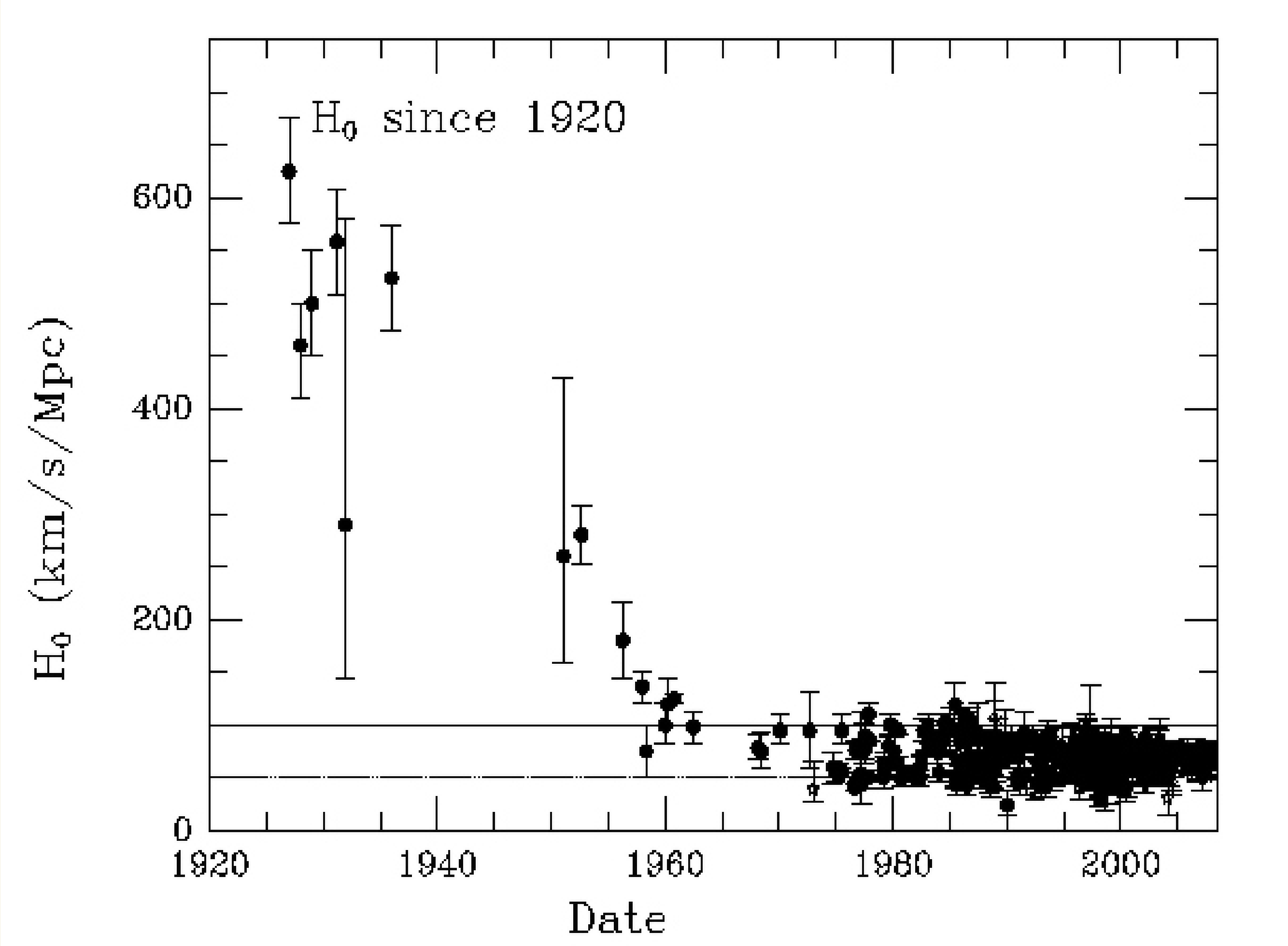
Dist (Mpc)	V (km/s)
0.032	170
0.034	290
0.214	-130
0.263	-70
0.275	-185
0.275	-220
0.45	200
0.5	290
0.5	270
0.63	200
0.8	300
0.9	-30
0.9	650
0.9	150
0.9	500
1	920
1.1	450
1.1	500
1.4	500
1.7	960
2	500
2	850
2	800
2	1090



Slope	454	km/s/Mpc
1 Mpc =	3.09E+19	km
H_0 =	1.47E-17	s^{-1}
T = 1/H_0 =	2.16E+09	yr

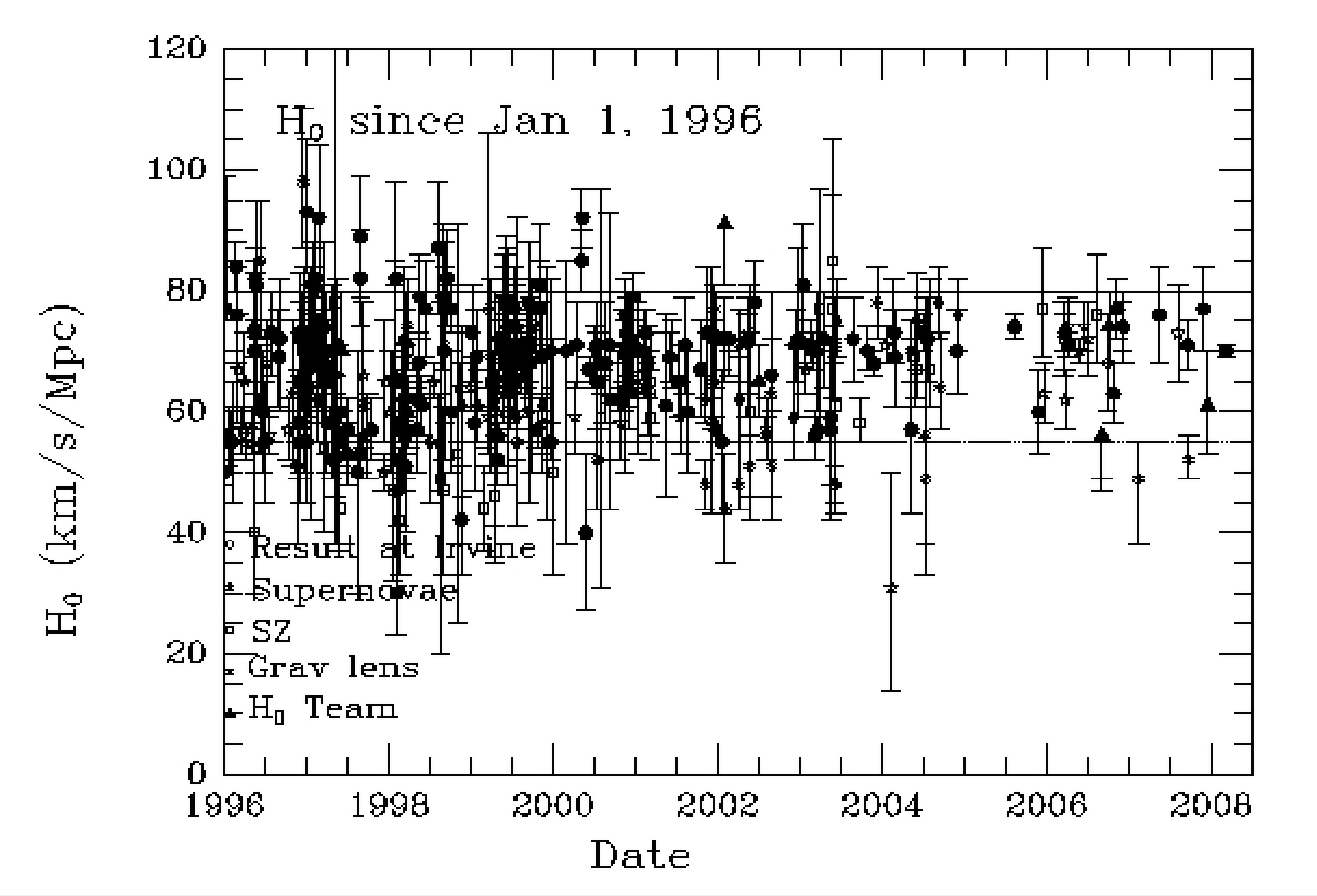
H0 and the Age of the Universe

- **Age** = $1/H_0$ = 1/454 km/s/Mpc = 2 billion yrs
- **BUT** – 1930 - Geologists, "Earth 3 billion yrs old!"



http://cfa-www.harvard.edu/~huchra/hubble/

And the winner is ...



http://cfa-www.harvard.edu/~huchra/hubble/

Age of Universe

Current Value H_0: 72 +/- 8 km/s/Mpc

1 Mpc = 3.086 x 10^{22} m – try Google!

1 km/s/Mpc = 3.24 x 10^{-20} 1/s

$1/H_0 = 4.286 \times 10^{17}$ s

= **13.6 Gyr**

WMAP – 13.7 +/- 0.13 Gyr

If flat and matter dominated – $2/(3H_0)$ – 9 Gyr

Big Bang vs Steady State Models

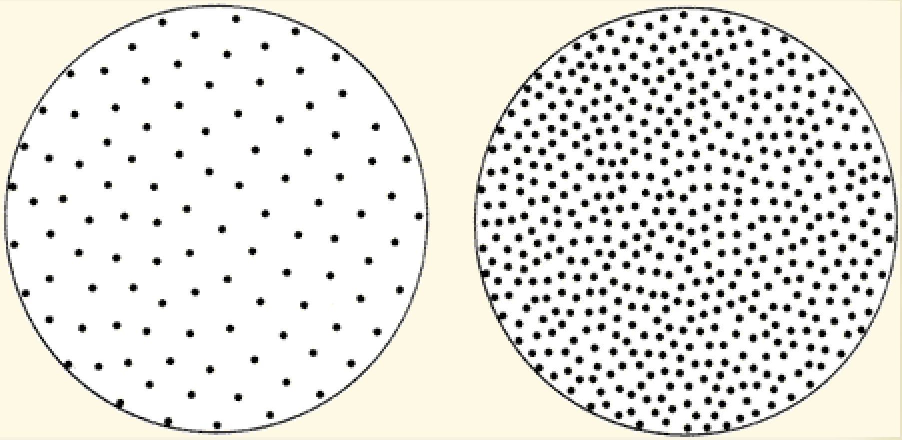
Gamow, Alpher, Herman - 1948

Expansion and cooling of universe
Initial state - infinite density and temperature.
"Ylem" = protons, neutrons, and electrons in an ocean of radiation.
Computer calculation of nuclear processes
Gave off radiation => the universe is now 5K

Hoyle, Bondi, Gold - 1950

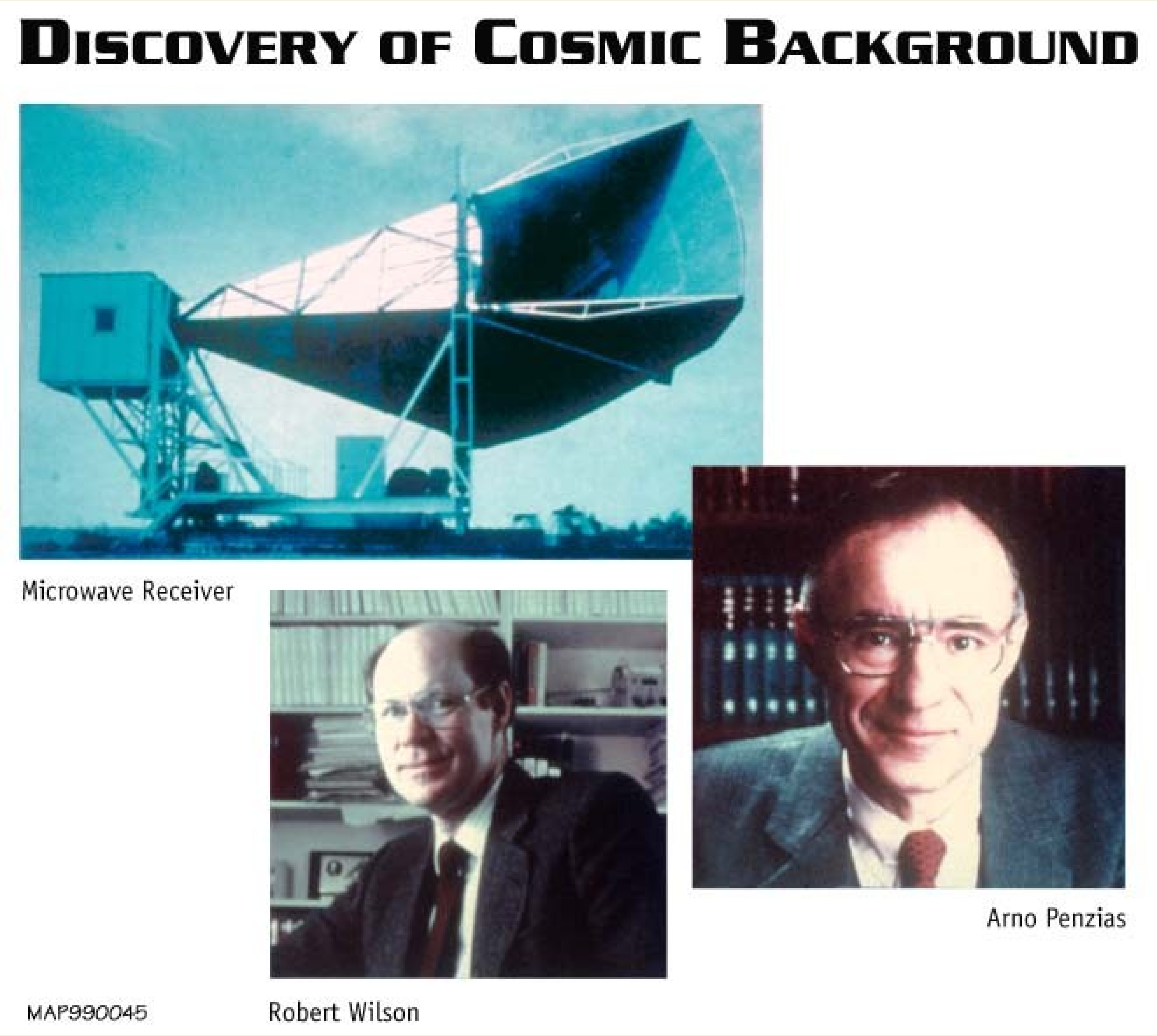
In a steady state universe the density would remain constant.

1 – Age of Universe
2 - The rate of expansion of the universe.
  Big Bang - rate would slow
  Steady State-rate would remain constant.



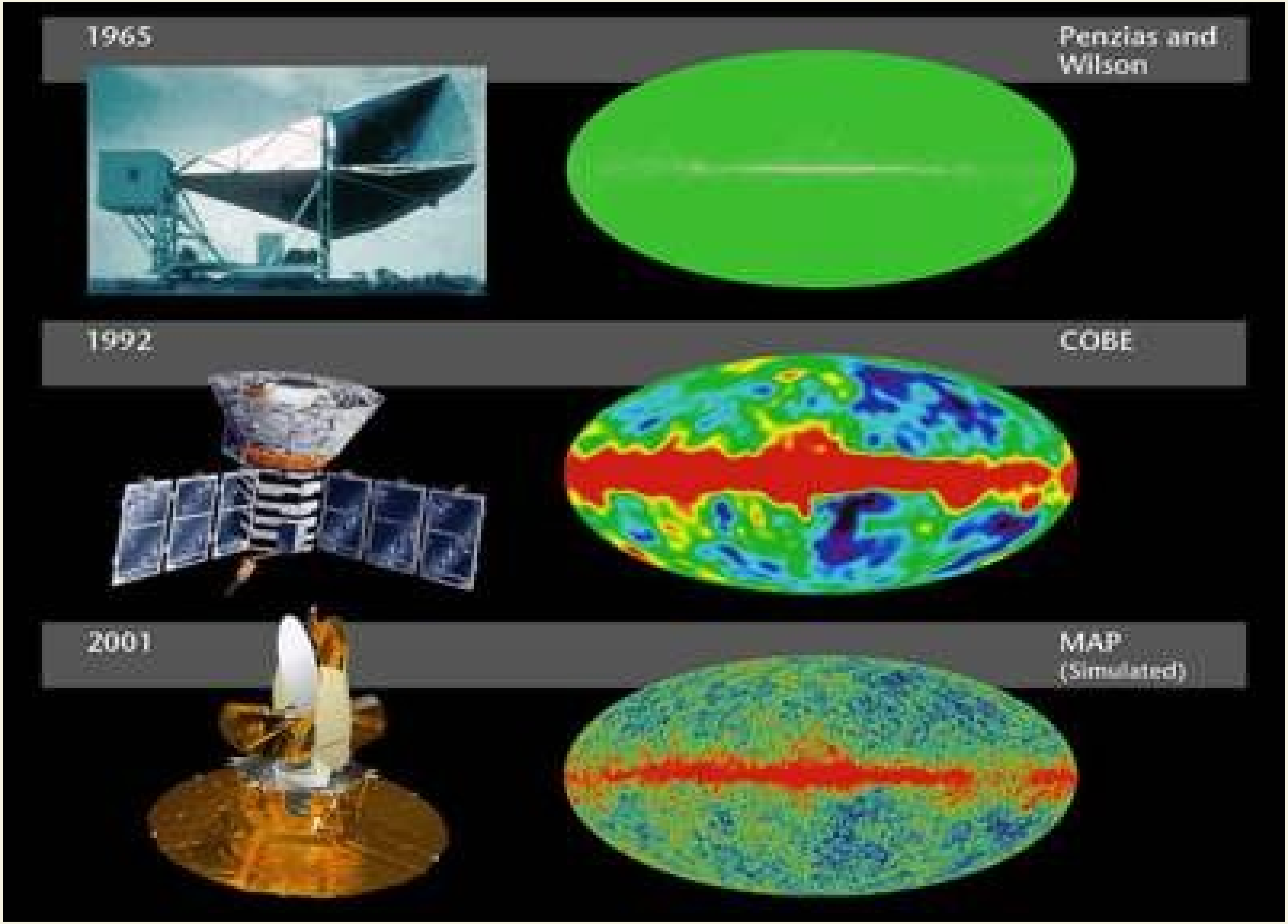
http://www.aip.org/history/cosmology/ideas/bigbang.htm

Arno Penzias and Robert Wilson - 1965



http://www.jca.umbc.edu/~george/images/cosmology/penzias_wilson_pic.jpg

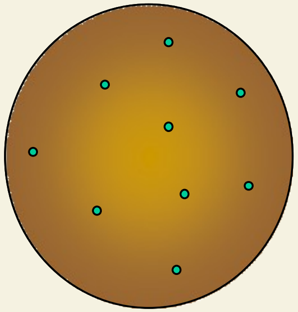
Cosmic Microwave Background

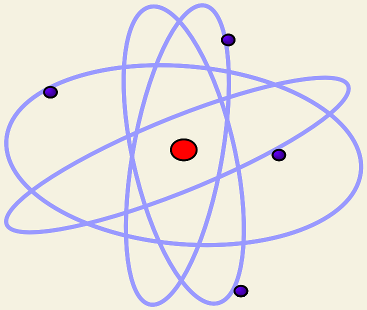


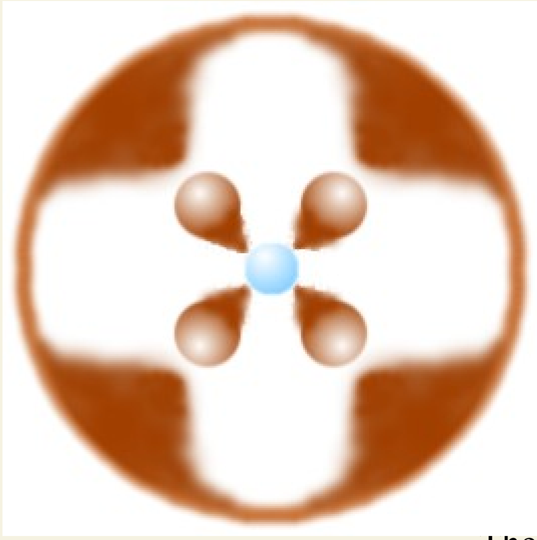
http://www.space.com/scienceastronomy/map_mission_basics_030211.html

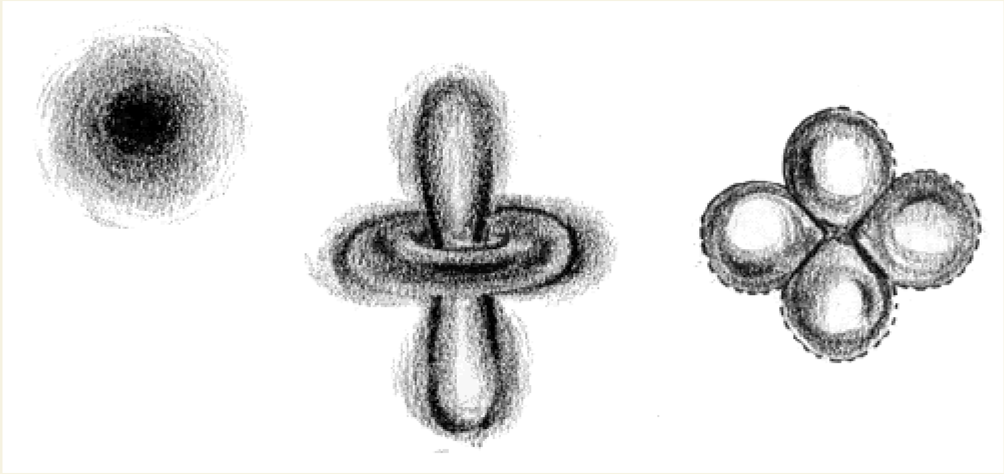
What is the Universe Made Of?

- Atoms -
- Electrons
- Nucleus - Nucleons
- Antiparticles
- And ... quarks?





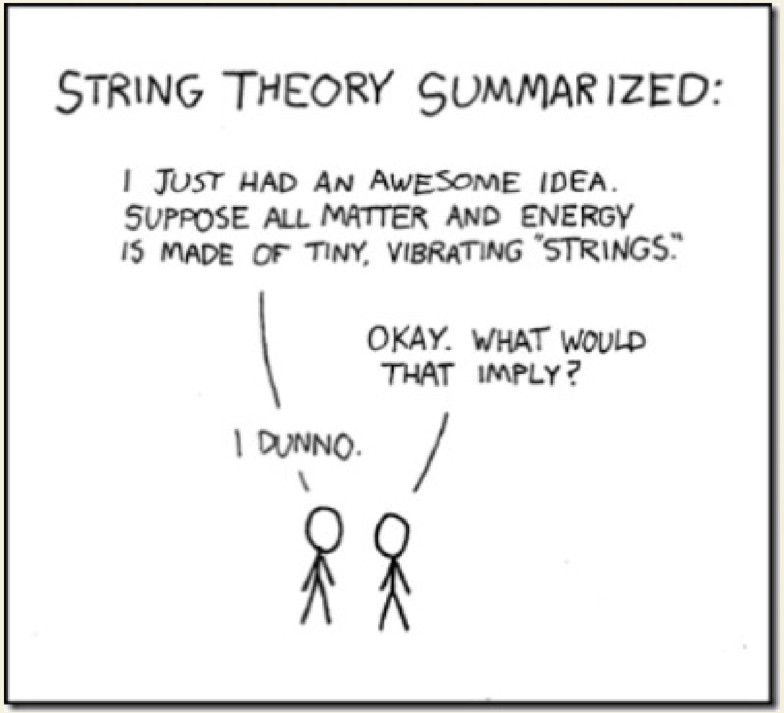


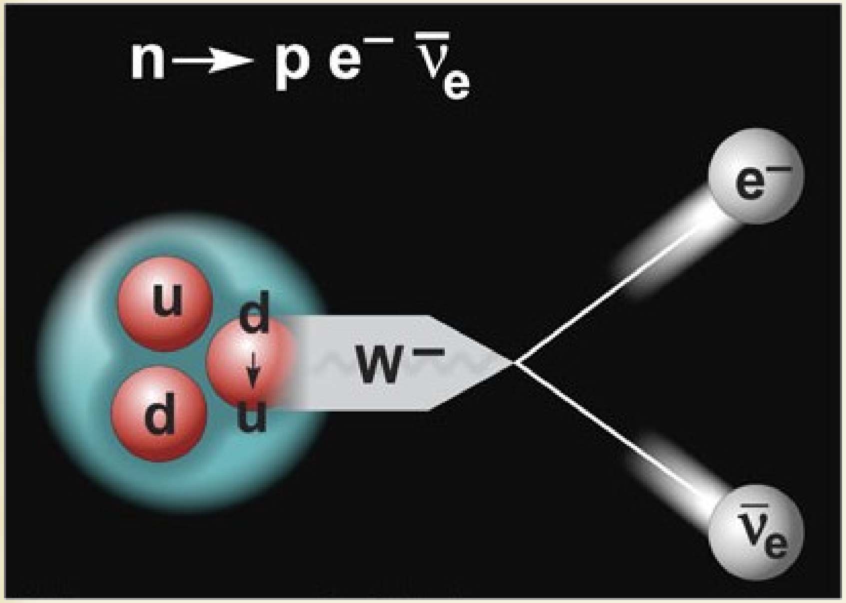


http://www.parentcompany.com/creation_explanation/cx6a.htm

What Holds it Together?

- Gravitational Force
- Electromagnetic Force
- Strong Force
- Weak Force





Unification of Forces –

Electricity/Magnetism = EM

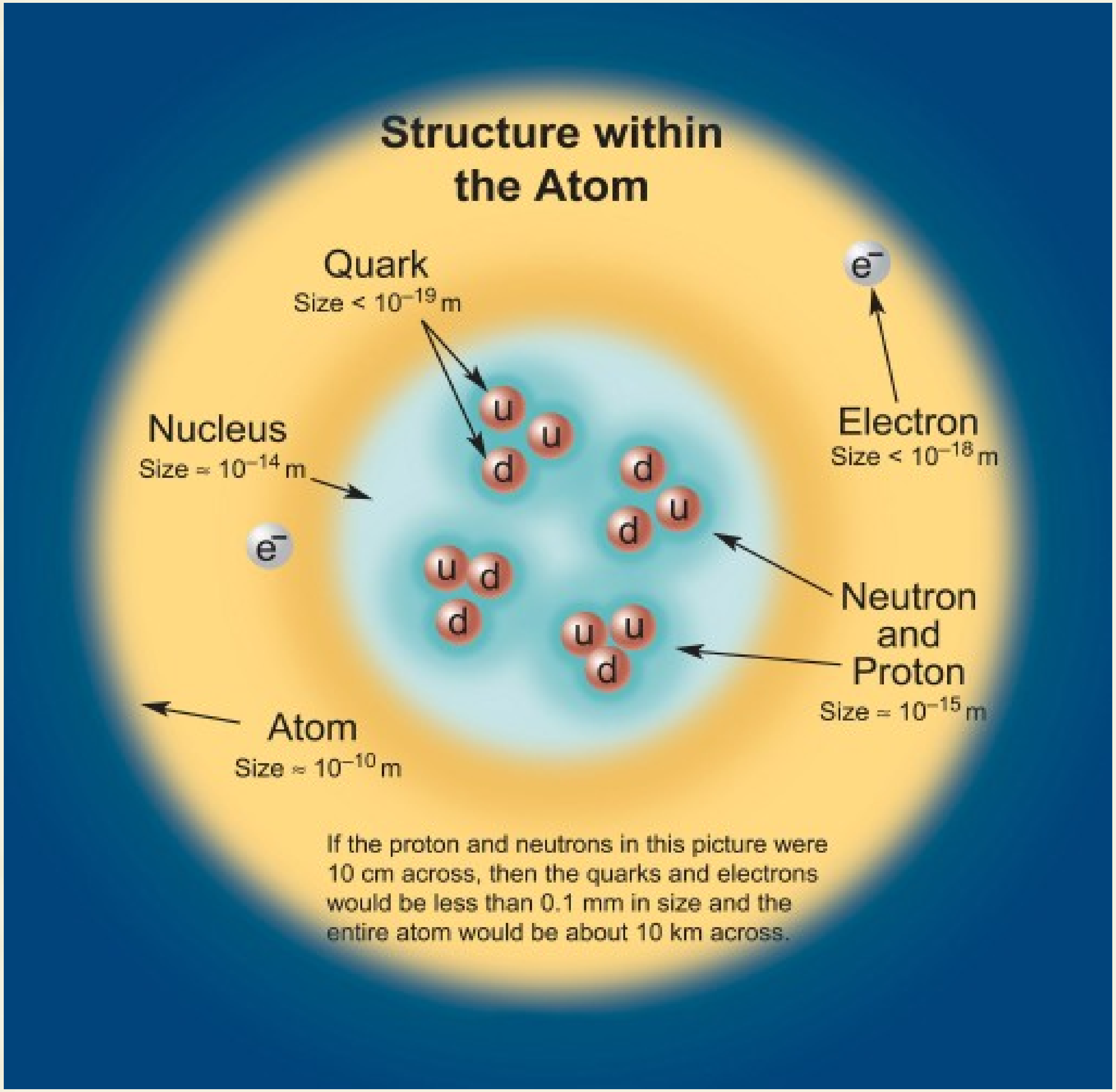
Quantum and EM = QED

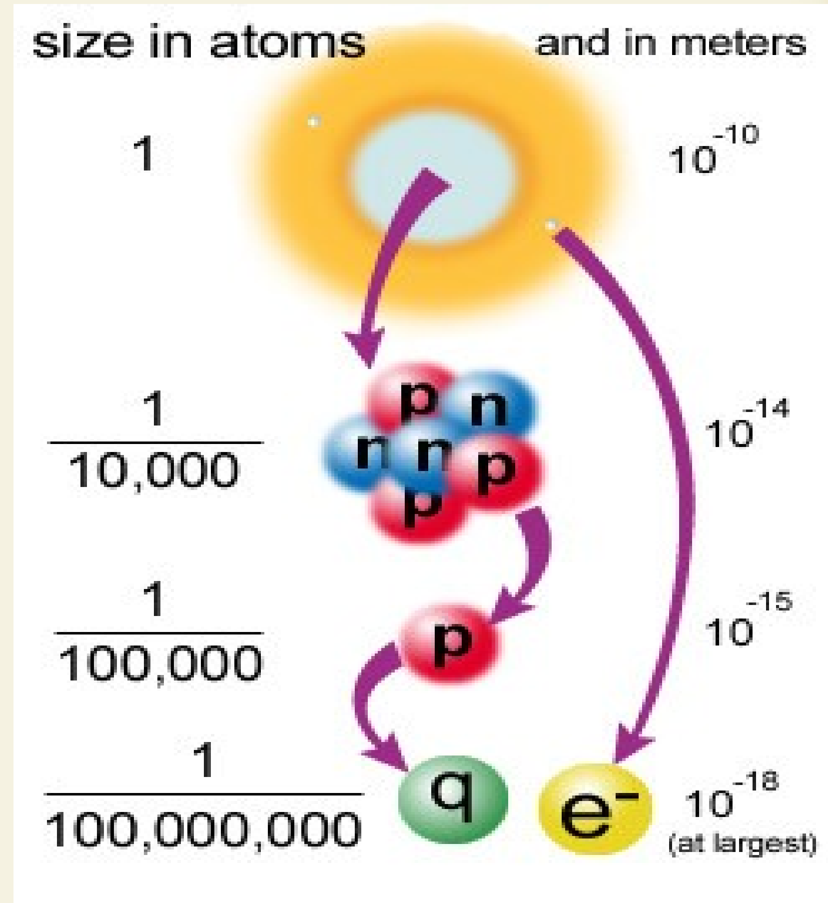
QED and Weak = Electroweak

Quantum & Strong = QCD

QCD & Electroweak = **Standard Model**

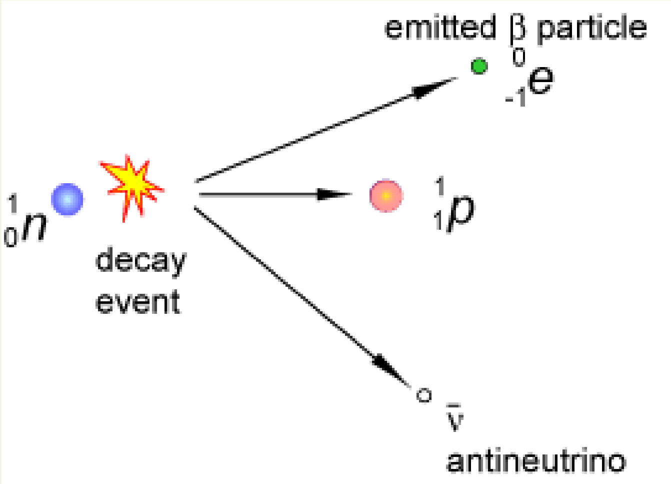
The Standard Model



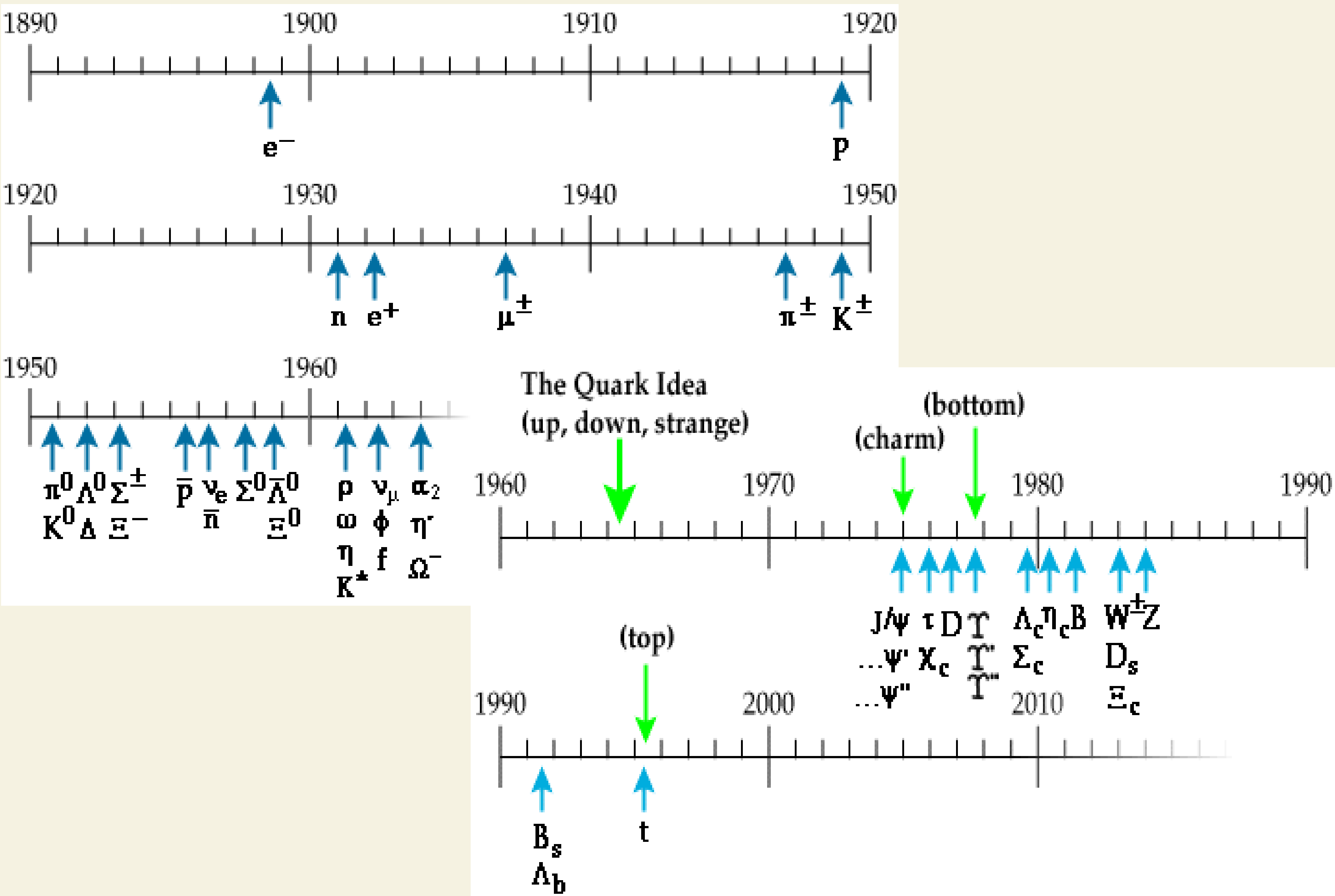


Particle Discoveries

1930 **Wolfgang Pauli** "**neutrino**"
1931 **Paul Dirac** **positrons/antiparticles**
1931 **James Chadwick** **neutron**.
1933-34 **Enrico Fermi** - theory of beta decay
1933-34 **Hideki Yukawa** "**pions**" between protons and neutrons.
1937 **Muon** is discovered in cosmic rays.
1946-47 "**lepton**" is introduced
1947 Pion found in cosmic rays.
1949 Discovery of $\mathbf{K^+}$ via its decay.
1950 The neutral pion is discovered.
1951 lambda^0 and the K^0.
1952 **delta** particle: (delta^{++}, delta^{+}, delta^0, and delta$^-$.)
1953 The beginning of a "**particle explosion**"
1953-57 **internal structure** for protons and neutrons
1957 **Julian Schwinger** **unification of weak and electromagnetic interactions**.
1957-59 **Julian Schwinger**, **Sidney Bludman**, and **Sheldon Glashow**, weak interactions are mediated $\mathbf{W^+}$ and $\mathbf{W^-}$
1962 Experiments verify two distinct types of **neutrinos** (electron and muon neutrinos).



The Particle Explosion



http://www.particleadventure.org/other/history

Timeline -Quarks

1964 **Murray Gell-Mann** and **George Zweig** tentatively put forth **quarks**.
mesons and baryons are composites of three quarks or antiquarks:
up, down, strange

1964 Leptons suggest fourth quark, **charm** - **Sheldon Glashow** and **James Bjorken**

1965 **O.W. Greenberg**, **M.Y. Han**, and **Yoichiro Nambu** introduce **color charge**.

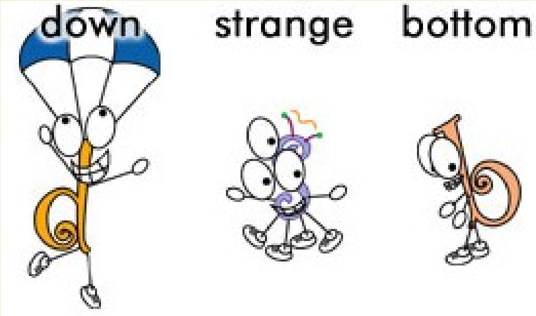
1967 **Steven Weinberg** and **Abdus Salam**
Unified electromagnetic and weak interactions, predict Higgs Boson
Theory needs neutral, weakly interacting boson that mediates weak interaction

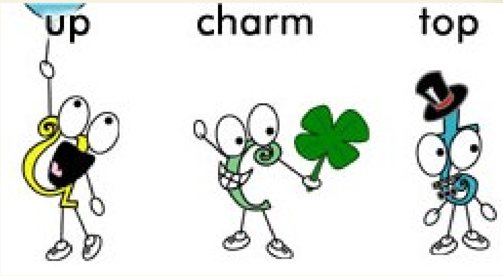
1968-69 Stanford Linear Accelerator - electrons are scattered off protons,
Electrons appeared to be bouncing off small hard cores inside proton.
James Bjorken and **Richard Feynman** analyzed as particles inside proton

1970 **Sheldon Glashow, John Iliopoulos,** and **Luciano Maiani**
recognize the importance of a fourth type of quark in **Standard Model**.

1973 **Donald Perkins**, re-analyzes old CERN data,finds indications of Z^0 exchange.

1973 A quantum field theory of strong interaction - **quantum chromodynamics (QCD)**.

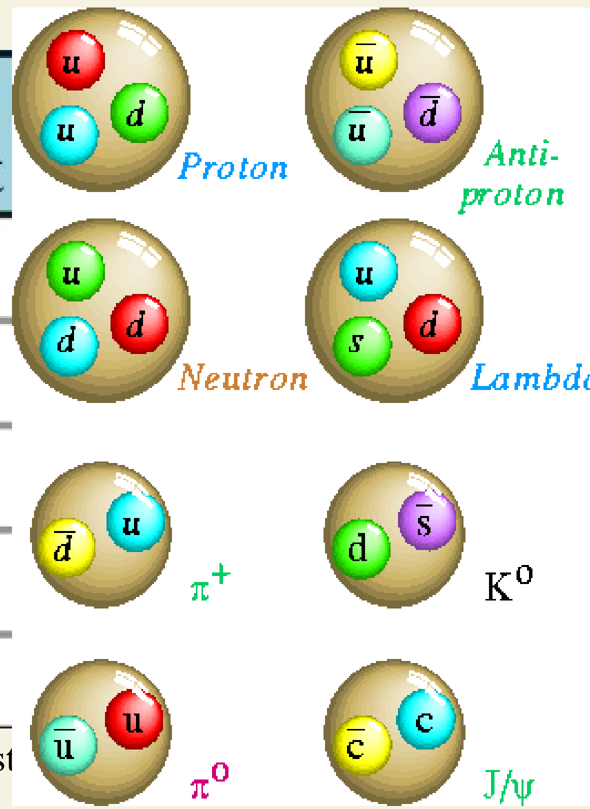




Timeline - Standard Model

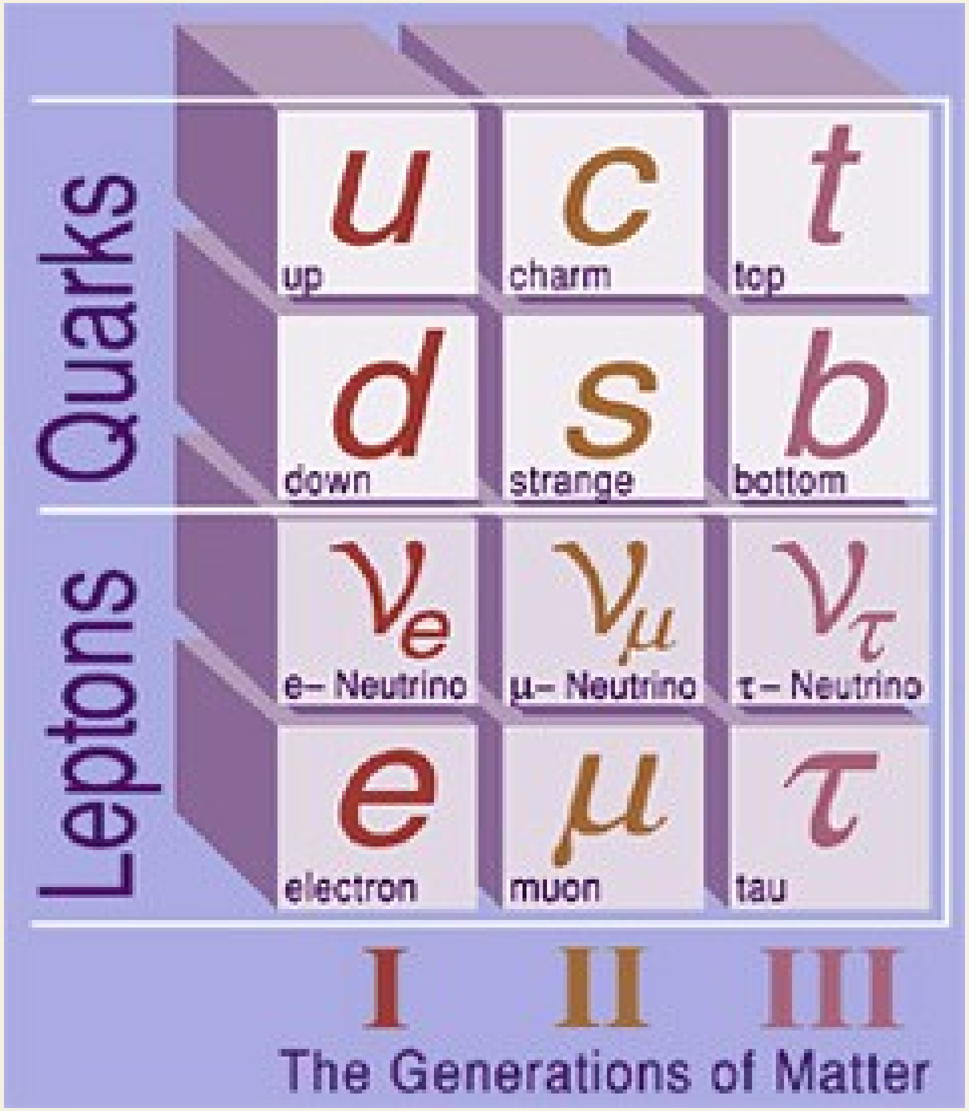
1974 **Burton Richter** and **Samuel Ting**, - "**J/psi**" particle, a charm-anticharm meson.
1976 **Gerson Goldhaber** and **Francois Pierre** find the $\mathbf{D^0}$ meson (anti-up and charm).
1976 The **tau** lepton is discovered by **Martin Perl** and collaborators at SLAC.
1977 **Leon Lederman** and his collaborators at Fermilab discover the **bottom** quark.
1978 **Charles Prescott** and **Richard Taylor** observe a $\mathbf{Z^0}$ mediated weak interaction
1983 Find $\mathbf{W^{\pm}}$ and $\mathbf{Z^0}$ intermediate bosons using the CERN synchrotron
using p and anti-p techniques of **Carlo Rubbia** and **Simon Van der Meer**
1995 The **top** quark found at the unexpected mass of 175 GeV

Symbol	Name	Quark content
p	proton	**uud**
$\bar{p}$	antiproton	$\bar{u}\bar{u}\bar{d}$
n	neutron	**udd**
Λ	lambda	**uds**
Ω^-	omega	**sss**



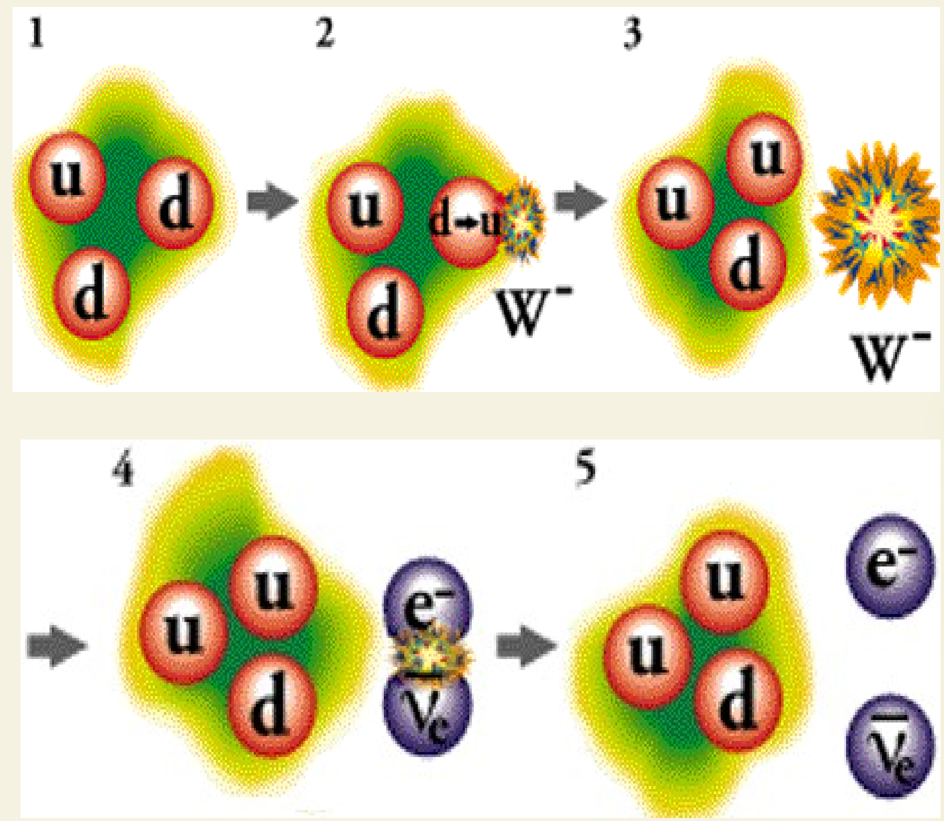
Symbol	Name	Quark content
π^+	pion	$u\bar{d}$
K^-	kaon	$s\bar{u}$
ρ^+	rho	$u\bar{d}$
B^0	B-zero	$d\bar{b}$
η_c	eta-c	$c\bar{c}$

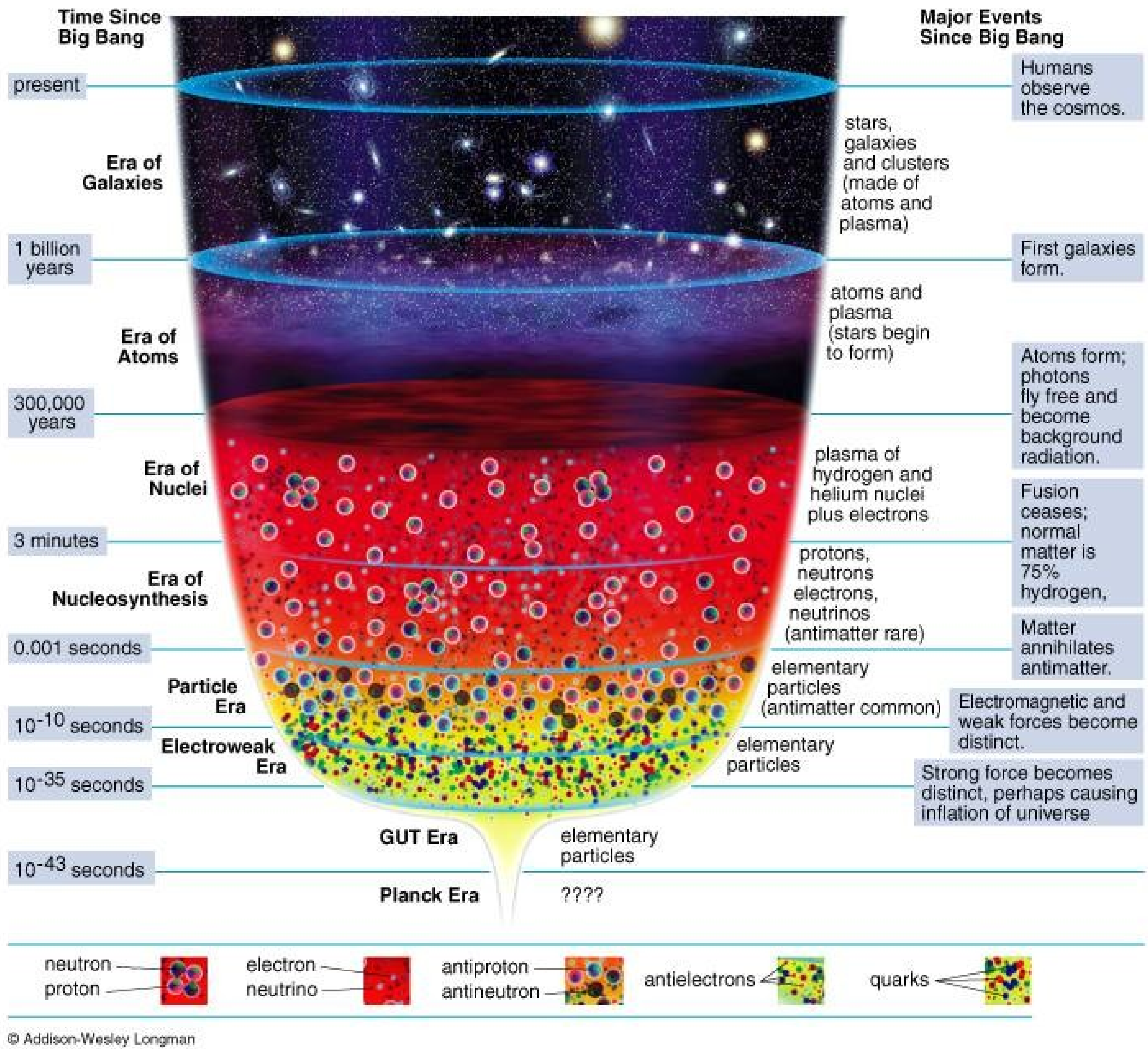
Quarks and Leptons



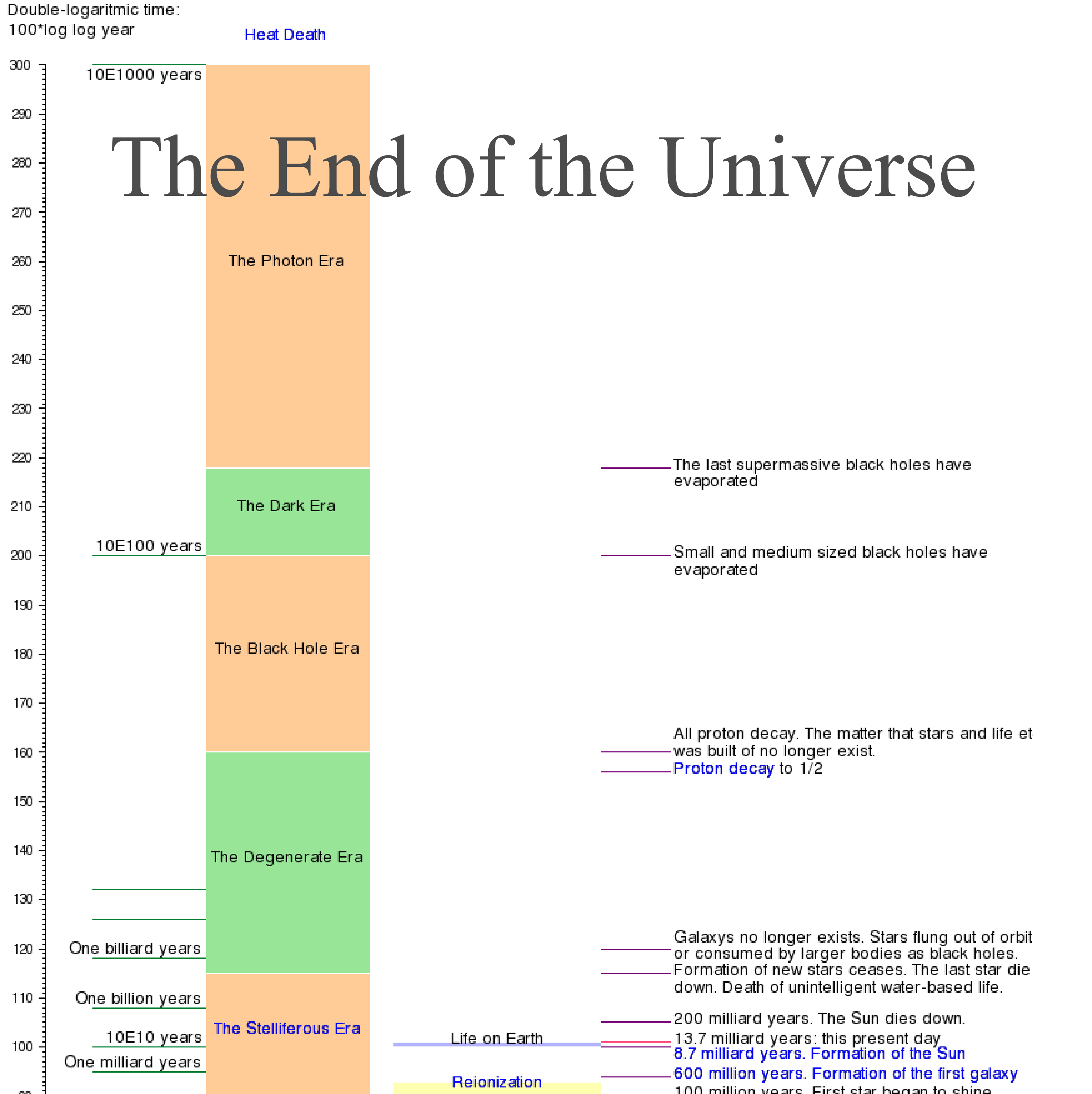
Neutron - udd
Proton - uud

$n \Rightarrow p + e^- + \underline{v}_e$



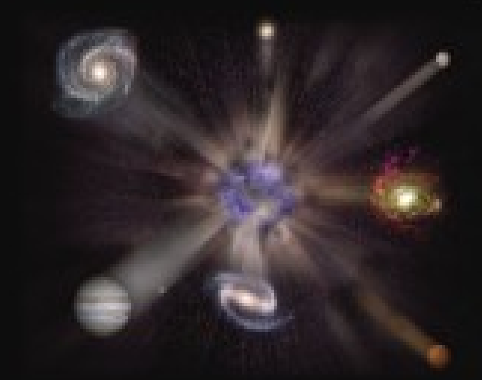

Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
stars, galaxies and clusters (made of atoms and plasma)
Era of Galaxies
1 billion years
First galaxies form.
atoms and plasma (stars begin to form)
Era of Atoms
300,000 years
Atoms form; photons fly free and become background radiation.
Era of Nuclei
plasma of hydrogen and helium nuclei plus electrons
3 minutes
Fusion ceases; normal matter is 75% hydrogen.
Era of Nucleosynthesis
protons, neutrons electrons, neutrinos (antimatter rare)
0.001 seconds
Matter annihilates antimatter.
Particle Era
elementary particles (antimatter common)
10^{-10} seconds
Electromagnetic and weak forces become distinct.
Electroweak Era
elementary particles
10^{-35} seconds
Strong force becomes distinct, perhaps causing inflation of universe
GUT Era
elementary particles
10^{-43} seconds
Planck Era
????
neutron
proton
electron
neutrino
antiproton
antineutron
antielectrons
quarks
© Addison-Wesley Longman

The End of the Universe



More Mysteries

Universe Accelerating?



The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?

Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Origin of Mass?

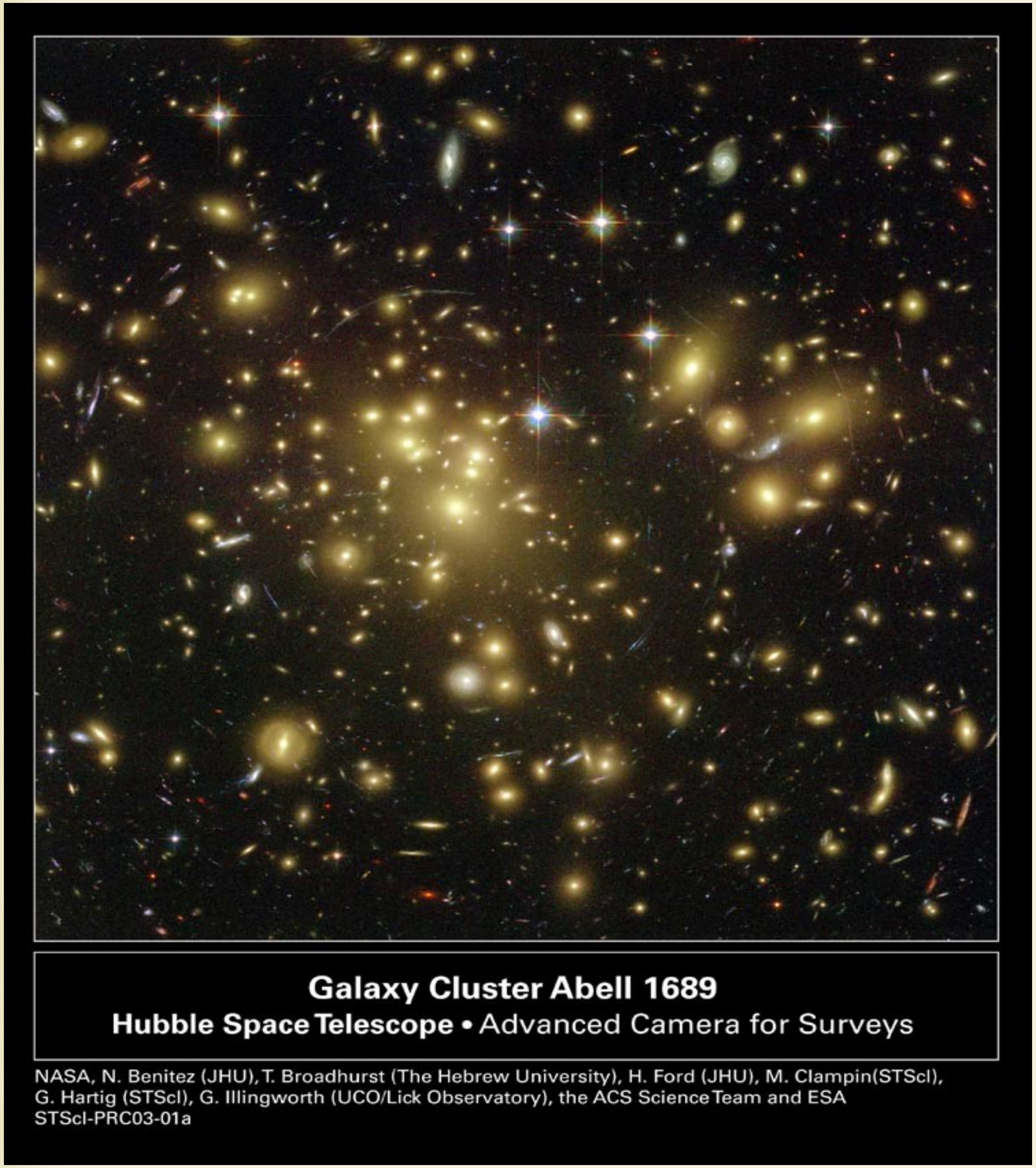
In the Standard Model, for fundamental particles to have masses, there must exist a particle called the Higgs boson. Will it be discovered soon? Is supersymmetry theory correct in predicting more than one type of Higgs?

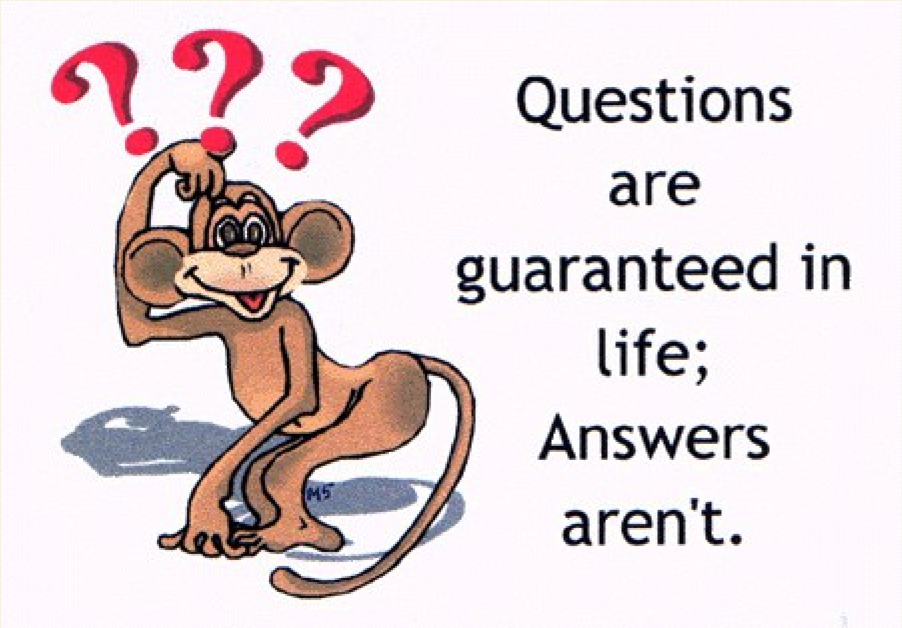
N

Further Reading

The First Three Minutes, S. Weinberg
A Briefer History of Time, S. Hawking and L. Mlodinow
Many Worlds in One, A. Vilenkin
Endless Universe: Beyond the Big Bang, P. J. Steinhardt and N. Turok
Big Bang: The Origin of the Universe (P.S.), S. Singh
Dark Side of the Universe: Dark Matter, Dark Energy, and the Fate of the Cosmos, I. Nicolson
The Elegant Universe or The Fabric of the Cosmos, B. Greene
Parallel Worlds: A Journey Through Creation, Higher Dimensions, and the Future of the Cosmos, M. Kaku
Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions, L. Randall
The Trouble with Physics, L. Smolin
A Brief History of Time, S. Hawking

What Don't We Know?



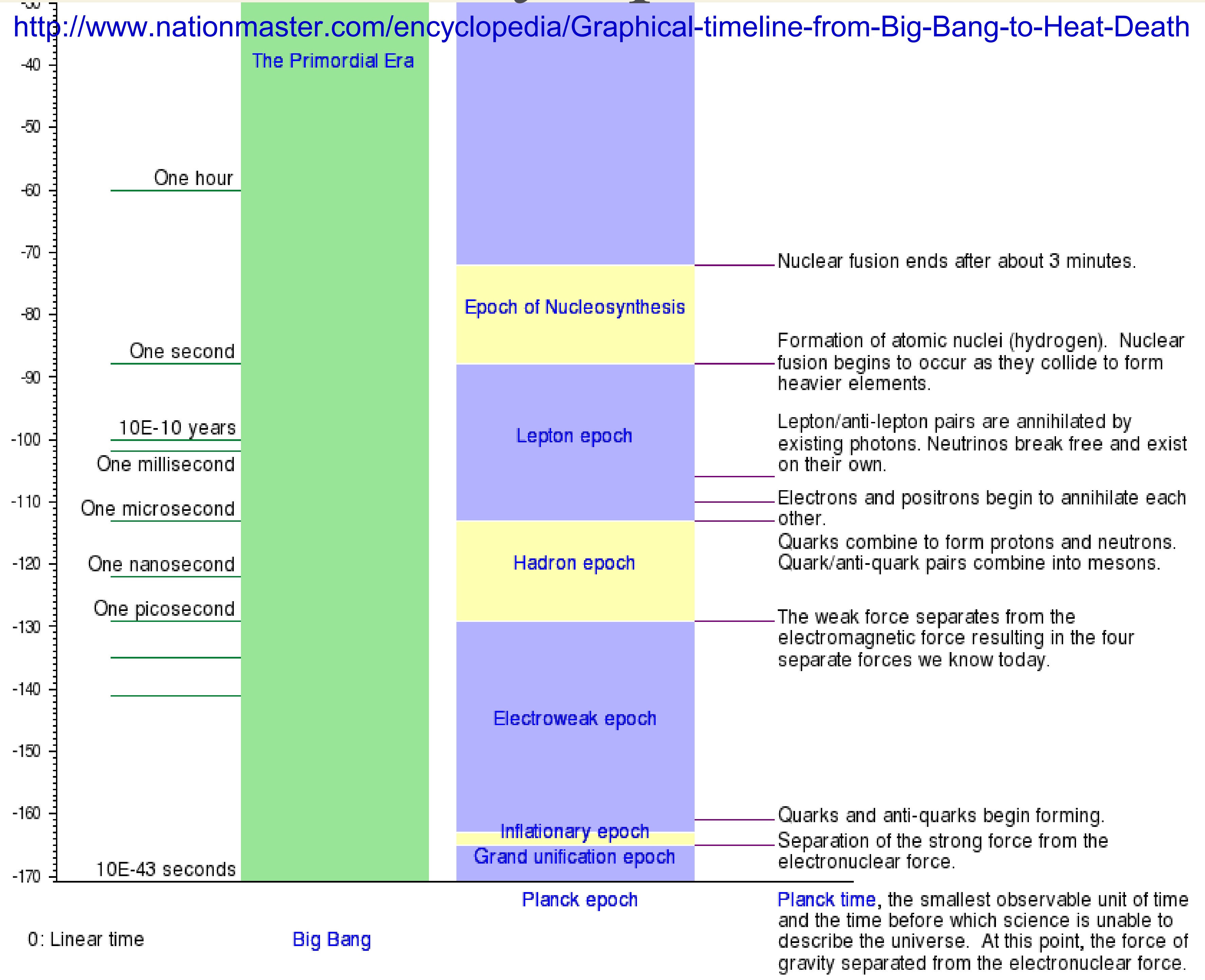


More information:
http://people.uncw.edu/hermanr/

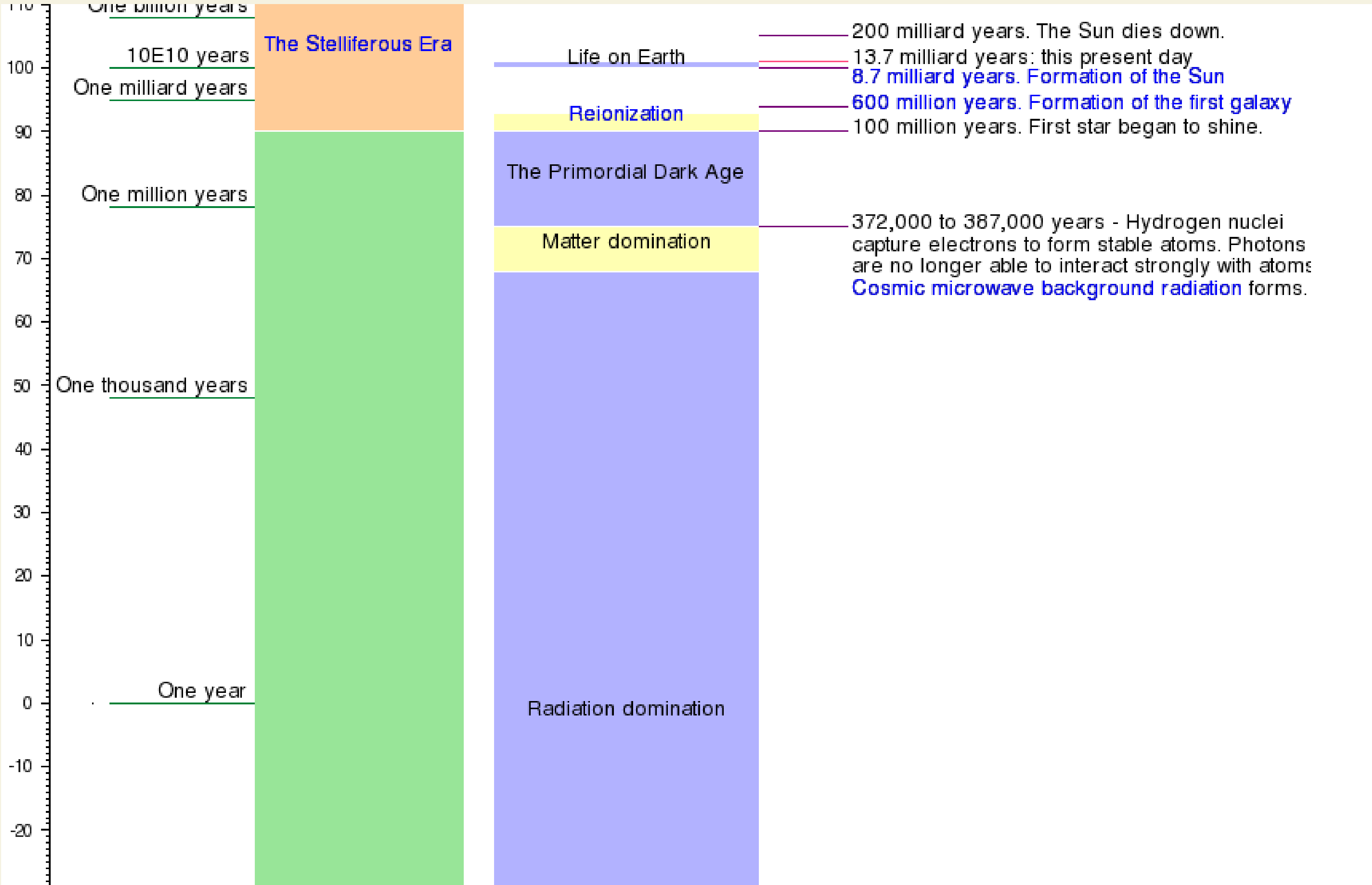
The History of the Universe in 200 Words or Less

Quantum fluctuation. Inflation. Expansion. Strong nuclear interaction. Particle-antiparticle annihilation. Deuterium and helium production. Density perturbations. Recombination. Blackbody radiation. Local contraction. Cluster formation. Reionization? Violent relaxation. Virialization. Biased galaxy formation? Turbulent fragmentation. Contraction. Ionization. Compression. Opaque hydrogen. Massive star formation. Deuterium ignition. Hydrogen fusion. Hydrogen depletion. Core contraction. Envelope expansion. Helium fusion. Carbon, oxygen, and silicon fusion. Iron production. Implosion. Supernova explosion. Metals injection. Star formation. Supernova explosions. Star formation. Condensation. Planetesimal accretion. Planetary differentiation. Crust solidification. Volatile gas expulsion. Water condensation. Water dissociation. Ozone production. Ultraviolet absorption. Photosynthetic unicellular organisms. Oxidation. Mutation. Natural selection and evolution. Respiration. Cell differentiation. Sexual reproduction. Fossilization. Land exploration. Dinosaur extinction. Mammal expansion. Glaciation. Homo sapiens manifestation. Animal domestication. Food surplus production. Civilization! Innovation. Exploration. Religion. Warring nations. Empire creation and destruction. Exploration. Colonization. Taxation without representation. Revolution. Constitution. Election. Expansion. Industrialization. Rebellion. Emancipation Proclamation. Invention. Mass production. Urbanization. Immigration. World conflagration. League of Nations. Suffrage extension. Depression. World conflagration. Fission explosions. United Nations. Space exploration. Assassinations. Lunar excursions. Resignation. Computerization. World Trade Organization. Terrorism. Internet expansion. Reunification. Dissolution. World-Wide Web creation. Composition. Extrapolation?

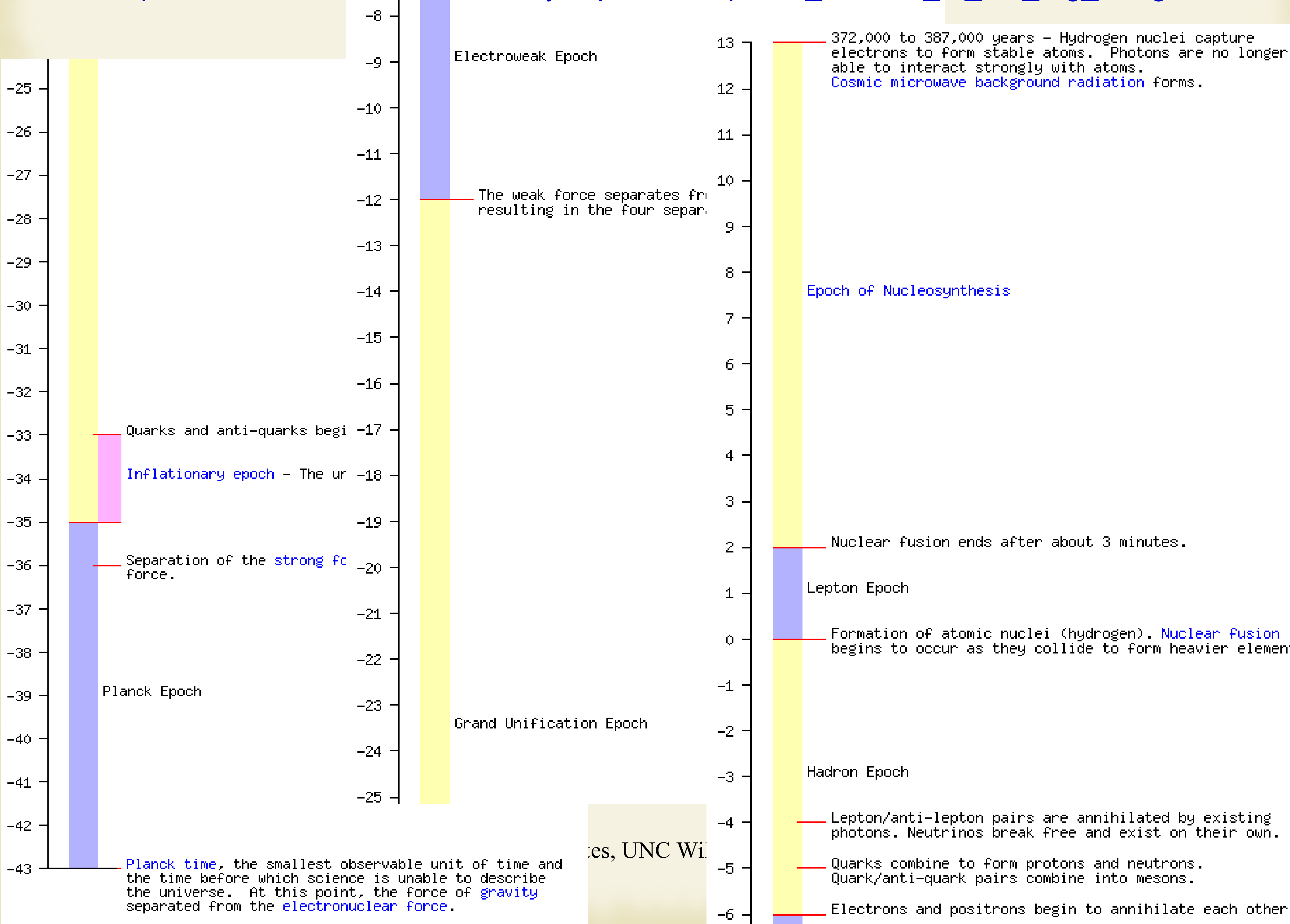
Early Epochs



Later Epochs



http://www.nationmaster.com/encyclopedia/Graphical_timeline_of_the_Big_Bang



es, UNC Wi

Supernova 1987A

http://www.oberlin.edu/physics/dstyer/Astronomy/S

http://science.nationalgeographic.com/staticfile