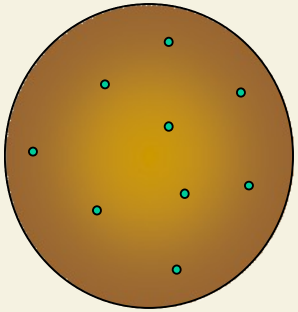
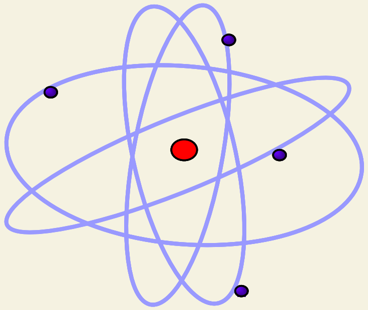
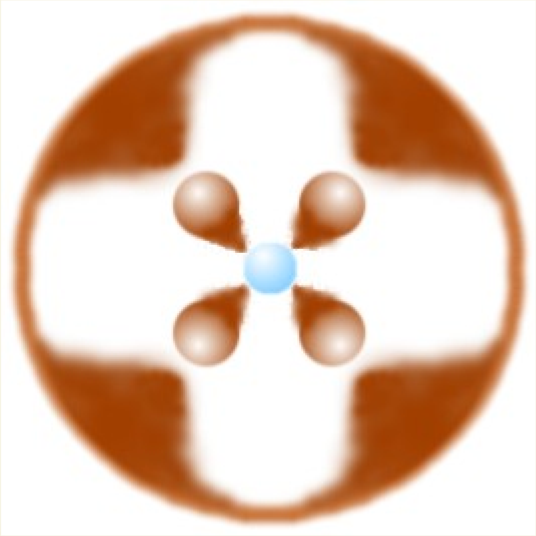
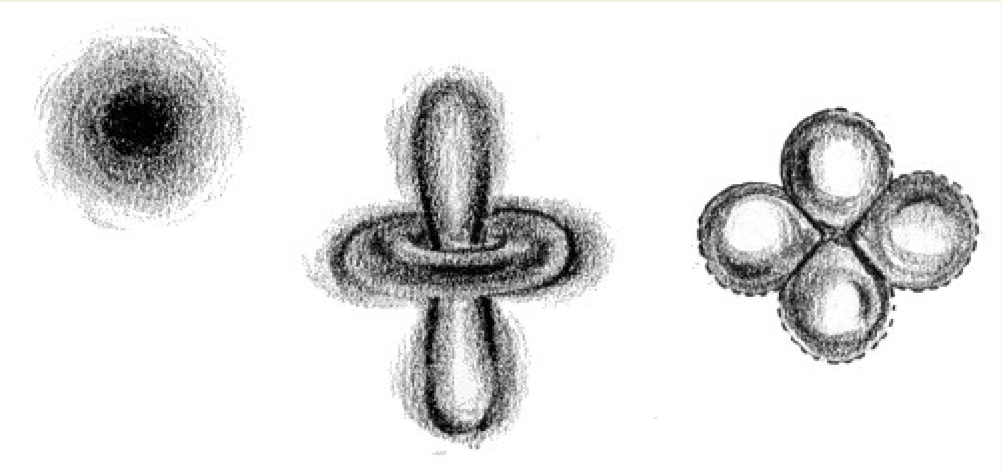
What is the Universe Made Of?

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





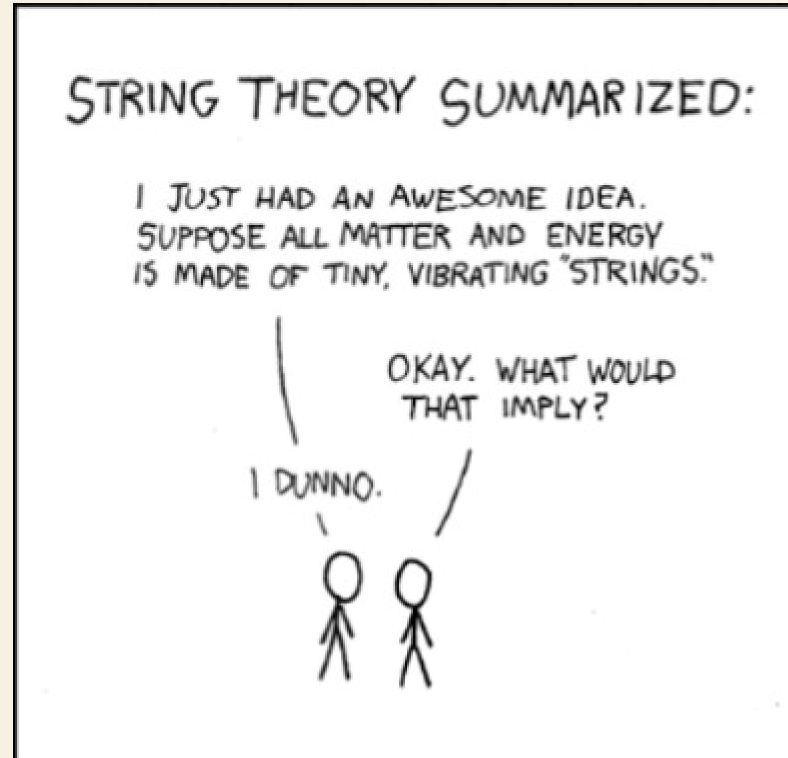


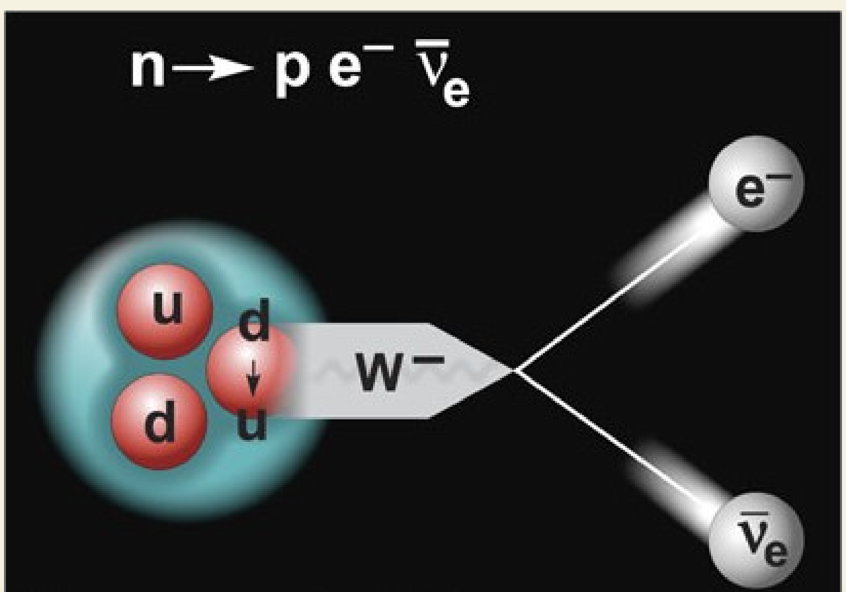


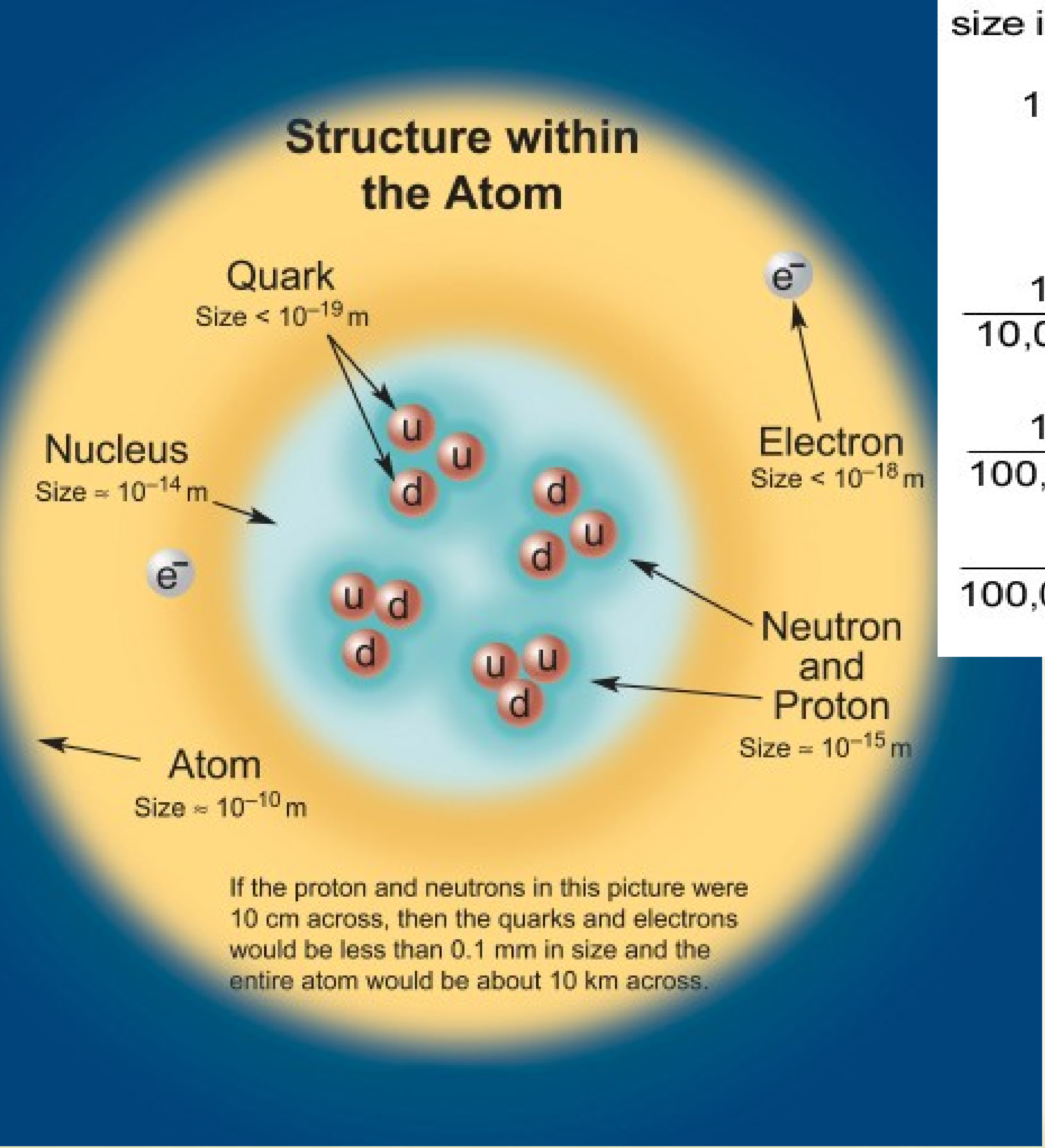
http://www.parentcompany.com/creation_explanation/cx6a.htm

What Holds it Together?

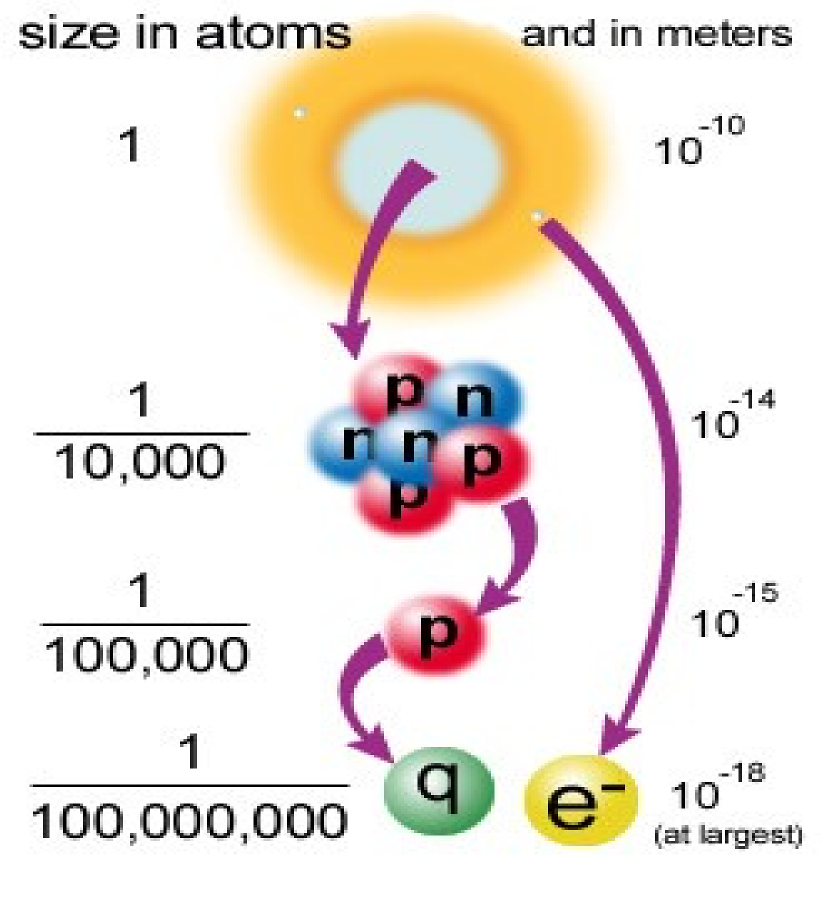
- Gravitational Force
- Electromagnetic Force
- Strong Force
- Weak Force







Structure within the Atom
Quark
Size < 10^{-19} m
e⁻
Electron
Size < 10^{-18} m
Nucleus
Size ≈ 10^{-14} m
u
d
e⁻
Neutron and Proton
Size ≈ 10^{-15} m
Atom
Size ≈ 10^{-10} m
If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.



size in atoms
and in meters
1
10^{-10}
1/10,000
p n n n p p
10^{-14}
1/100,000
p
10^{-15}
1/100,000,000
q
e⁻
10^{-18}
(at largest)

Timeline - Ancient

624-547 B.C. **Thales of Miletus** - water is the basic substance,
knew attractive power of **magnets** and **rubbed amber**.
580-500 B.C. **Pythagoras -** Earth spherical,
sought mathematical understanding of universe.
500-428 B.C. **Anaxagoras** changes in matter due to different orderings of indivisible particles (**law of the conservation of matter**)
484-424 B.C. **Empedocles** reduced indivisible particles into four elements:
earth, air, fire, and water.
460-370 B.C. **Democritus** All matter is made of indivisible particles called **atoms**.
384-322 B.C. **Aristotle** formalized the gathering of scientific knowledge.
310-230 B.C. **Aristarchus** describes a cosmology identical to that of Copernicus.
287-212 B.C. **Archimedes** provided the foundations of hydrostatics.
70-147 AD **Ptolemy of Alexandria** collected the optical knowledge,
theory of planetary motion.
1214-1294 AD **Roger Bacon** To learn the secrets of nature we must first observe.
1473-1543 AD **Nicholaus Copernicus** **The earth revolves around the sun**

Timeline – Classical Physics

1564-1642 **Galileo Galilei** - scientifically deduced theories.
1546-1601, **Tycho Brahe** accurate celestial data to support Copernican system.
1571-1630, **Johannes Kepler**. theory of **elliptical planetary motion**
1642-1727 **Sir Isaac Newton** **laws of mechanics** explain motion, **gravity** .
1773-1829 **Thomas Young** - the **wave theory of light** and light interference.
1791-1867 **Michael Faraday** - the electric motor, and **electromagnetic induction**, electricity and magnetism are related. electrolysis, conservation of energy.
1799-1878 **Joseph Henry** - electromagnetic induction, the first motor; telegraph.
1873 **James Clerk Maxwell** - molecular theory, **electromagnetic theory** the **propagation of light waves** in a vacuum.
1874 **George Stoney** theory of the electron and estimate of mass.
1895 **Wilhelm Röntgen** discovers x rays.
1898 **Marie and Pierre Curie** separate radioactive elements.
1898 **Joseph Thompson** measures electron, **"plum-pudding" model of the atom** - a slightly positive sphere with small, raisin-like negative electrons.

Classical Physics

- Gravitation
- Optics
- Electromagnetism
- Electromagnetic Waves
- Fluid Dynamics
- Spectroscopy
- Radioactive Decay
- Thermodynamics
- Blackbody Radiation

Timeline – Quantum Theory

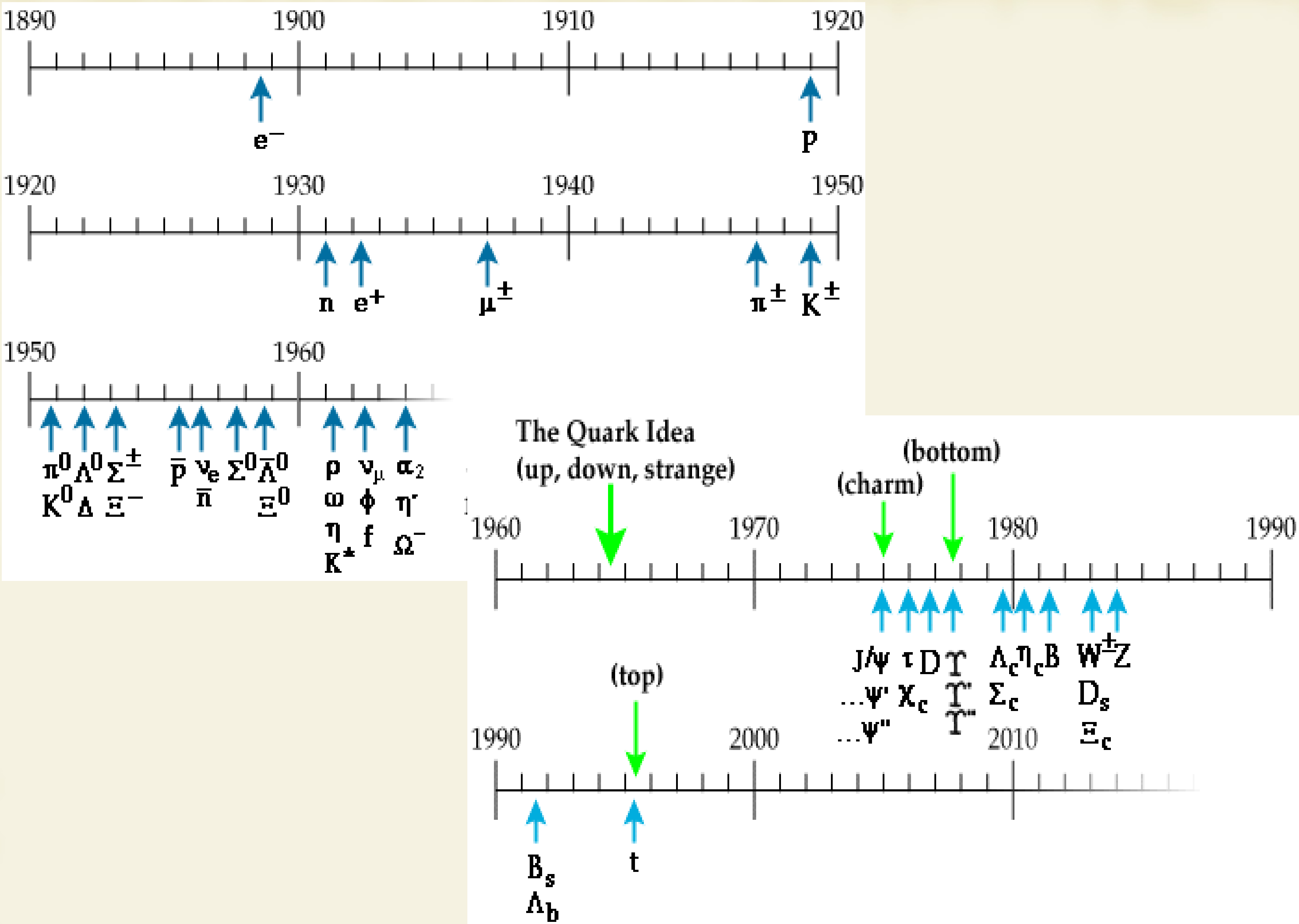
1900 **Max Planck** suggests **radiation is quantized**.
1905 **Albert Einstein**, a **quantum of light** which behaves like a particle.
Other: Brownian motion, equivalence of mass and energy, special relativity.
1909 **Hans Geiger** and **Ernest Marsden**, (under **Ernest Rutherford)**
scattered alpha particles off gold foil
atoms have a small, dense, positively charged **nucleus**.
1911 **Ernest Rutherford** infers the nucleus
1912 **Albert Einstein** explains the **curvature of space-time**.
1913 **Niels Bohr** - a **theory of atomic structure** based on quantum ideas.
1919 **Ernest Rutherford** first evidence for a **proton**.
1921 **James Chadwick** and **E.S. Bieler** - strong force holds the nucleus together.
1923 **Arthur Compton** - quantum nature of x rays, confirming **photons as particles**.
1924 **Louis de Broglie** proposes **matter has wave properties**.
1925 **Wolfgang Pauli -** the exclusion principle for electrons.
1925 **Walther Bothe** and **Hans Geiger** energy/mass conserved in atomic processes.

Timeline – Wave Mechanics

1926 **Erwin Schroedinger** develops wave mechanics,
Max Born - **probability** interpretation of quantum mechanics.
G.N. Lewis named "**photon**" for a light quantum.
1927 **Beta decay** observed
1927 **Werner Heisenberg** - **the uncertainty principle**.
1928 **Paul Dirac** combines quantum mechanics and relativity to describe the electron.
1930 **Max Born**, "Physics as we know it will be over in six months."
1930 **Wolfgang Pauli** "**neutrino**" to explain continuous electron spectrum for beta decay.
1931 **Paul Dirac** introduces **positrons/antiparticles**
1931 **James Chadwick** discovers the **neutron**.
1933-34 **Enrico Fermi** - theory of beta decay
introduces the weak interaction uses neutrinos.
1933-34 **Hideki Yukawa** nuclear interaction – meson exchange ("**pions**")
between protons and neutrons.
1937 **Muon** is discovered in cosmic rays., at first considered Yukawa's pion.
1941 **C. Moller** and **Abraham Pais** introduce the term "**nucleon**".
1946-47 "**lepton**" is introduced to describe objects that do not interact too strongly.
1947 A meson that does interact strongly is found in cosmic rays, the pion.

Timeline – More Particles

1947 Introduction of Feynman diagrams.
1948 The Berkeley synchro-cyclotron produces the first artificial pions.
1949 **Enrico Fermi** and **C.N. Yang** - a pion is a nucleon and an anti- nucleon.
1949 Discovery of **K^+** via its decay.
1950 The neutral pion is discovered.
1951 Two new types of particles are discovered in cosmic rays. lambda^0 and the K^0.
1952 Discovery of **delta** particle: (delta^{++}, delta$^+$, delta^0, and delta$^-$.)
1952 **Donald Glaser** invents **bubble chamber**.
The Brookhaven Cosmotron, starts operation.
1953 The beginning of a "**particle explosion**"
1953-57 Scattering of electrons off nuclei - **internal structure** for protons and neutrons
1954 **C.N. Yang** and **Robert Mills** "gauge theories" - the basis of the Standard Model.
1957 **Julian Schwinger** **unification of weak and electromagnetic interactions**.
1957-59 **Julian Schwinger**, **Sidney Bludman**, and **Sheldon Glashow**,
weak interactions are mediated by charged heavy bosons, later called **W^+** and **W^-**
1961 Mathematical classification scheme to organize large number of particles
- leads to patterns.
1962 Experiments verify two distinct types of **neutrinos** (electron and muon neutrinos).



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)**.
Quarks are real particles, carrying a color charge.
Gluons are massless quanta of the strong-interaction field.
First suggested by **Harald Fritzsch** and **Murray Gell-Mann**.

Interactions

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

Timeline - Standard Model

1973 **David Politzer**, **David Gross**, and **Frank Wilczek**
strong interaction has "asymptotic freedom."
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
1979 Strong evidence for a gluon radiated by the initial quark or antiquark if found
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**
1989 SLAC and CERN strongly suggest only three generations of fundamental particles.
1995 The **top** quark found at the unexpected mass of 175 GeV

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.

These are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathbf{p}}$	antiproton	$\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$	–1	0.938	1/2
n	neutron	**udd**	0	0.940	1/2
Λ	lambda	**uds**	0	1.116	1/2
Ω^-	omega	**sss**	–1	1.672	3/2

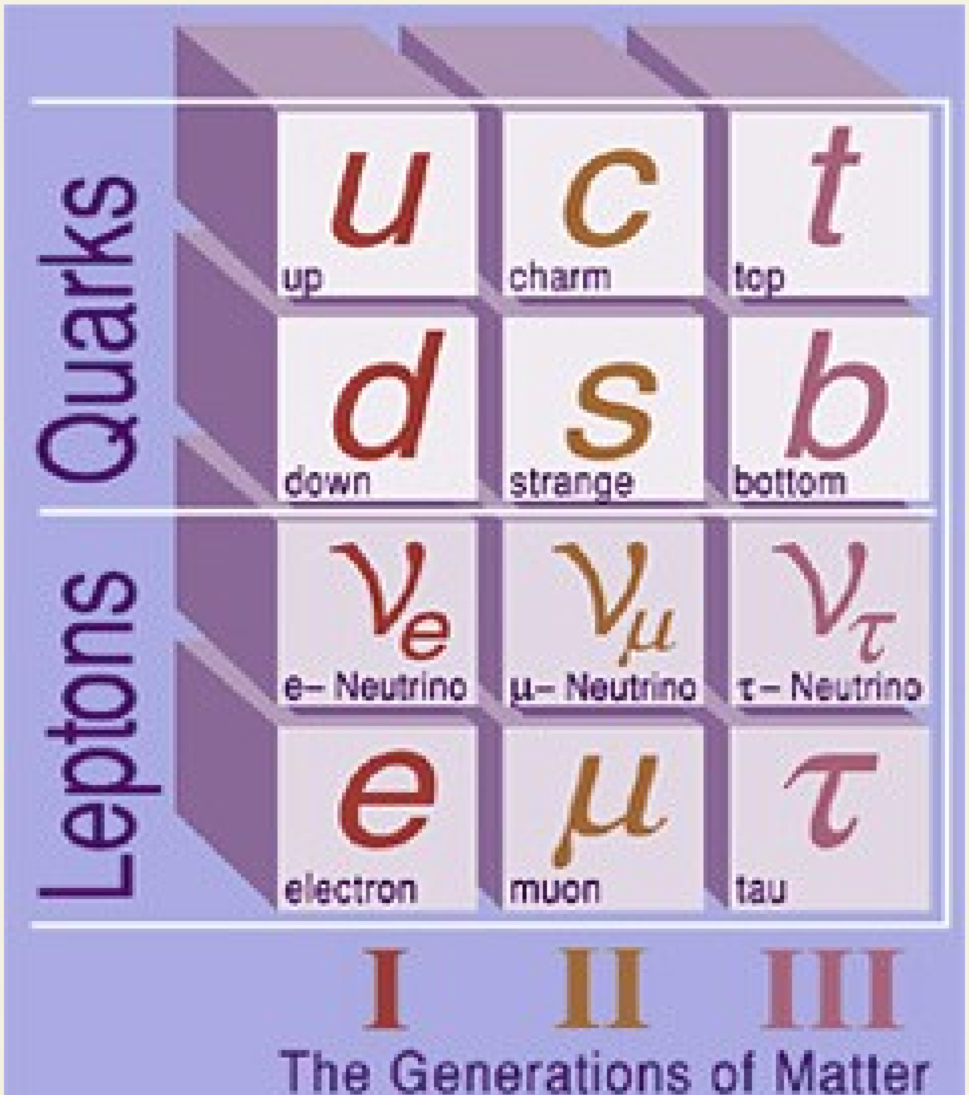
Mesons $q\bar{q}$

Mesons are bosonic hadrons

These are a few of the many types of mesons.

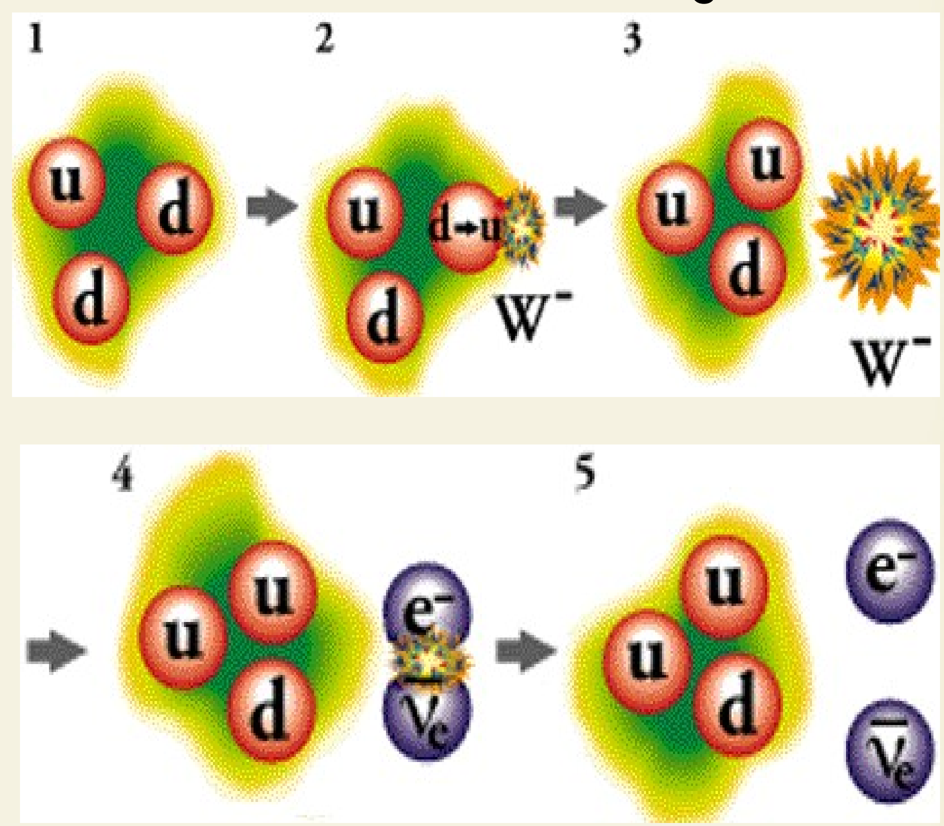
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$\mathbf{u\bar{d}}$	+1	0.140	0
$\mathbf{K^-}$	kaon	$\mathbf{s\bar{u}}$	–1	0.494	0
ρ^+	rho	$\mathbf{u\bar{d}}$	+1	0.776	1
B^0	B-zero	$\mathbf{d\bar{b}}$	0	5.279	0
η_c	eta-c	$\mathbf{c\bar{c}}$	0	2.980	0

Quarks and Leptons



Neutron - udd
Proton - uud

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



Bosons

BOSONS force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Fermions

FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...

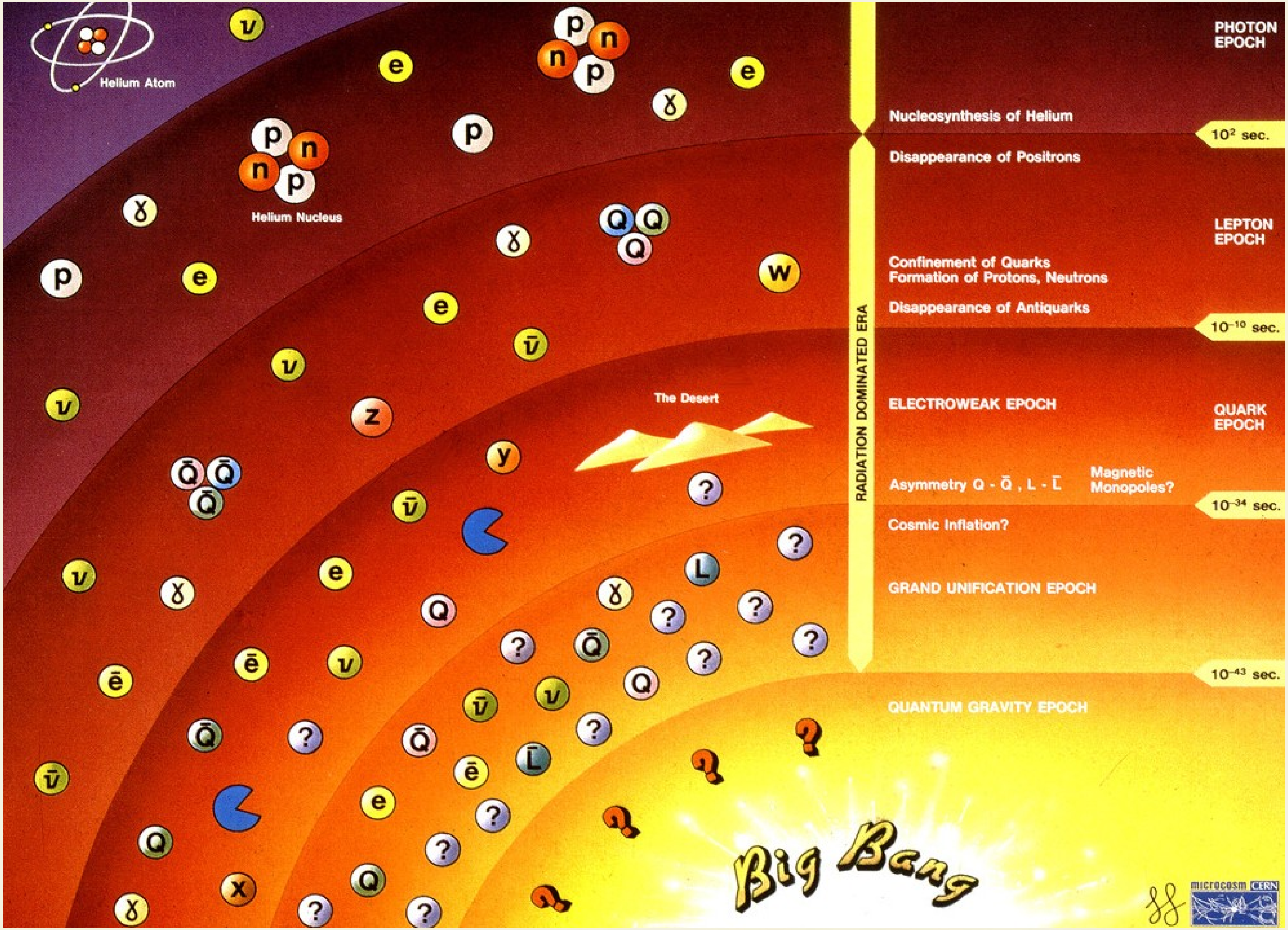
Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

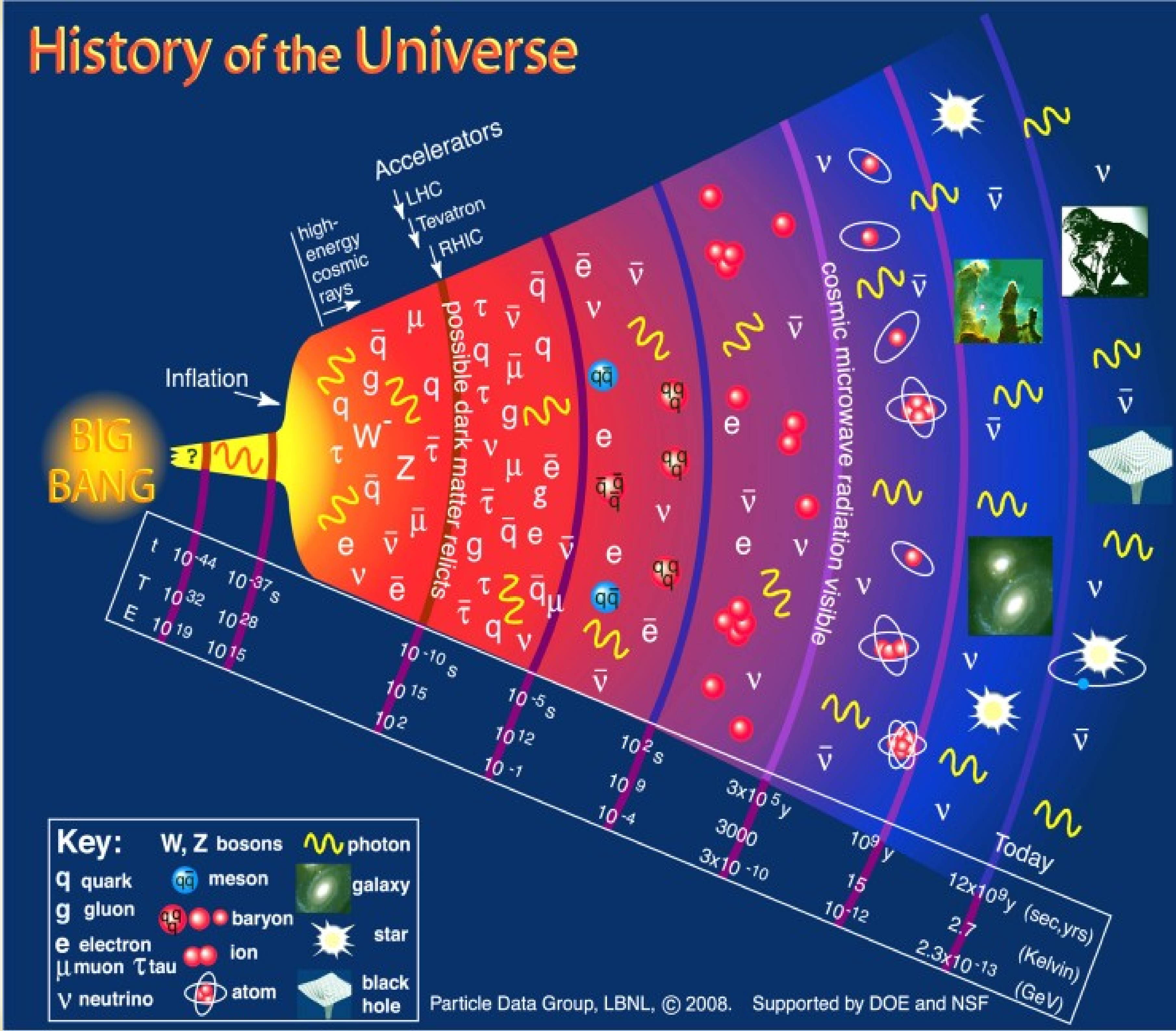
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

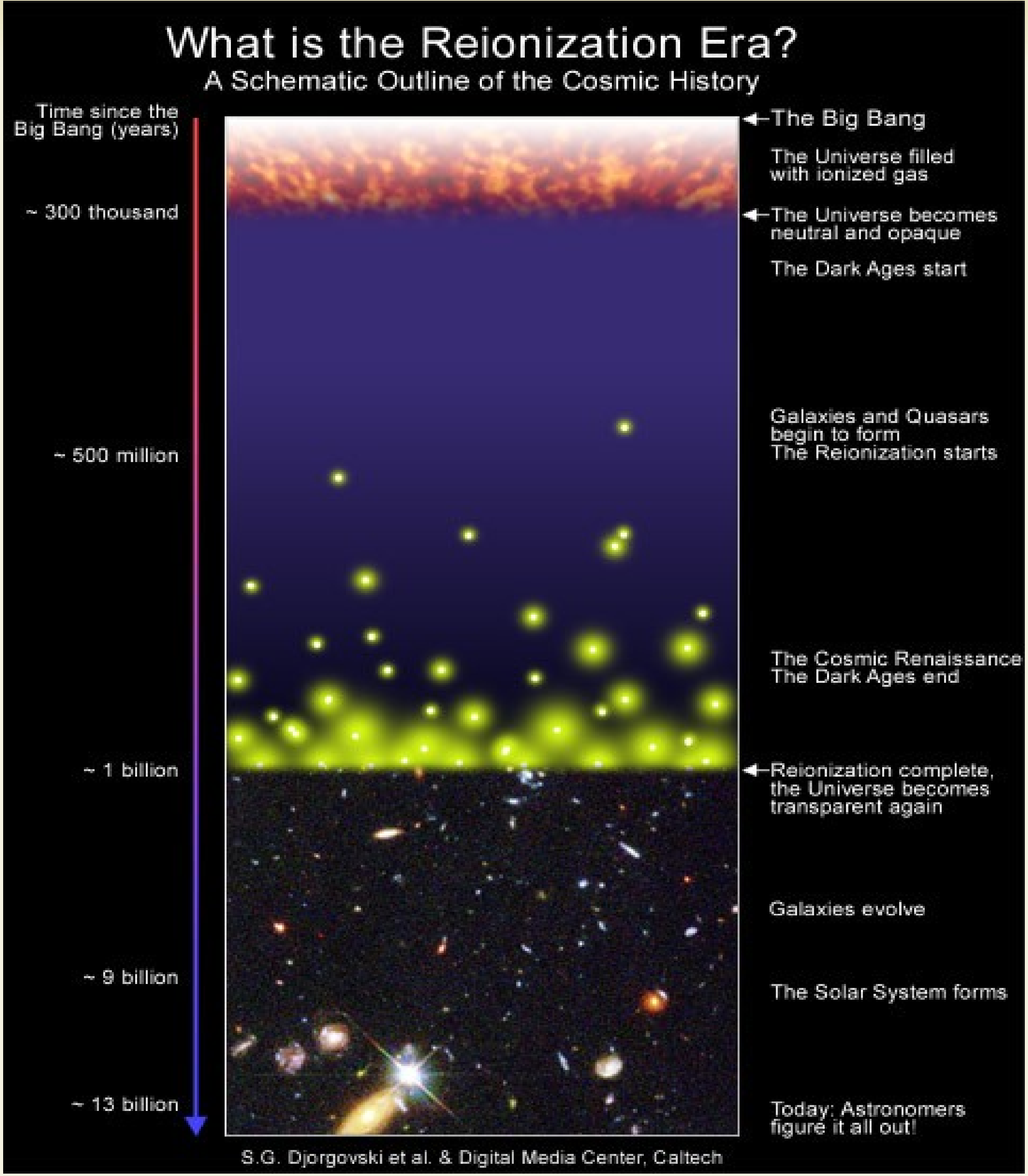
The History of the Universe



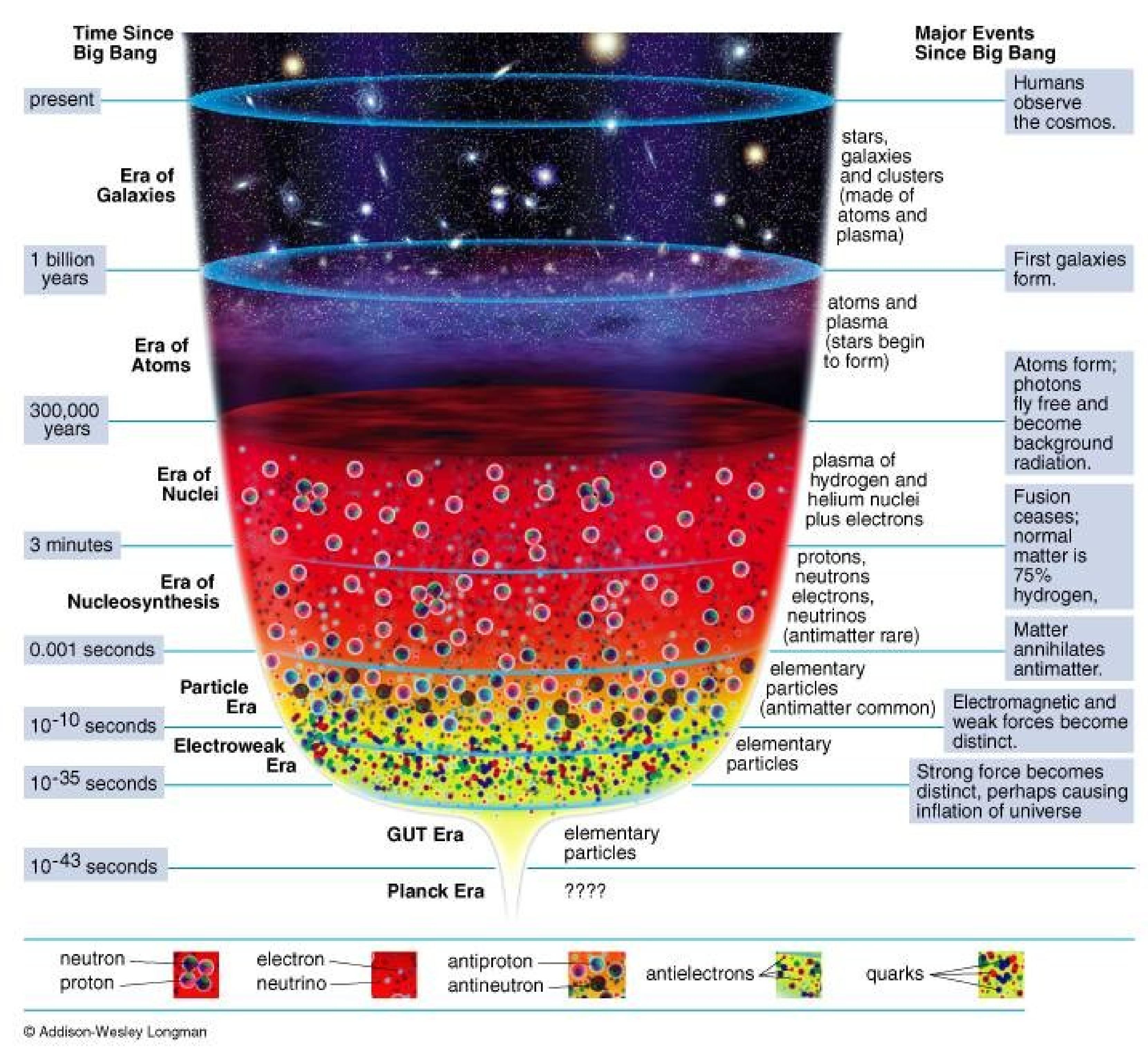
The History of the Universe in 200 Words or Less

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?


History of the Universe
BIG BANG
Inflation
high-energy cosmic rays
Accelerators
LHC
Tevatron
RHIC
possible dark matter relicts
cosmic microwave radiation visible
Today
t 10^-44 10^-37 s 10^-10 s 10^-5 s 10^2 s 3x10^5 y 10^9 y 12x10^9 y (sec,yrs)
T 10^32 10^28 10^15 10^12 10^9 3000 15 2.7 (Kelvin)
E 10^19 10^15 10^2 10^-1 10^-4 3x10^-10 10^-12 2.3x10^-13 (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF



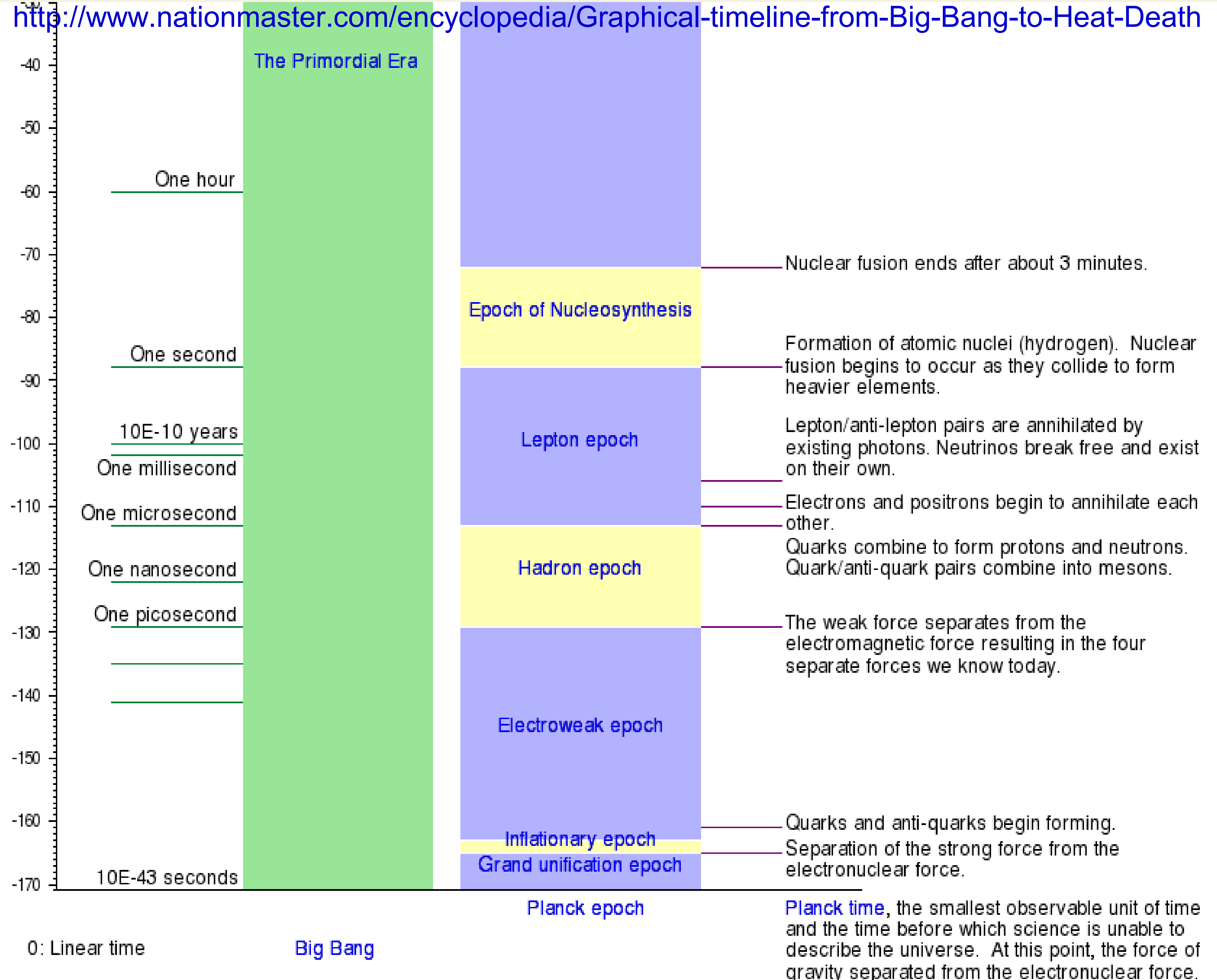
http://www.haystack.mit.edu/mwa/Science%20Goal/EOR/EOR.html



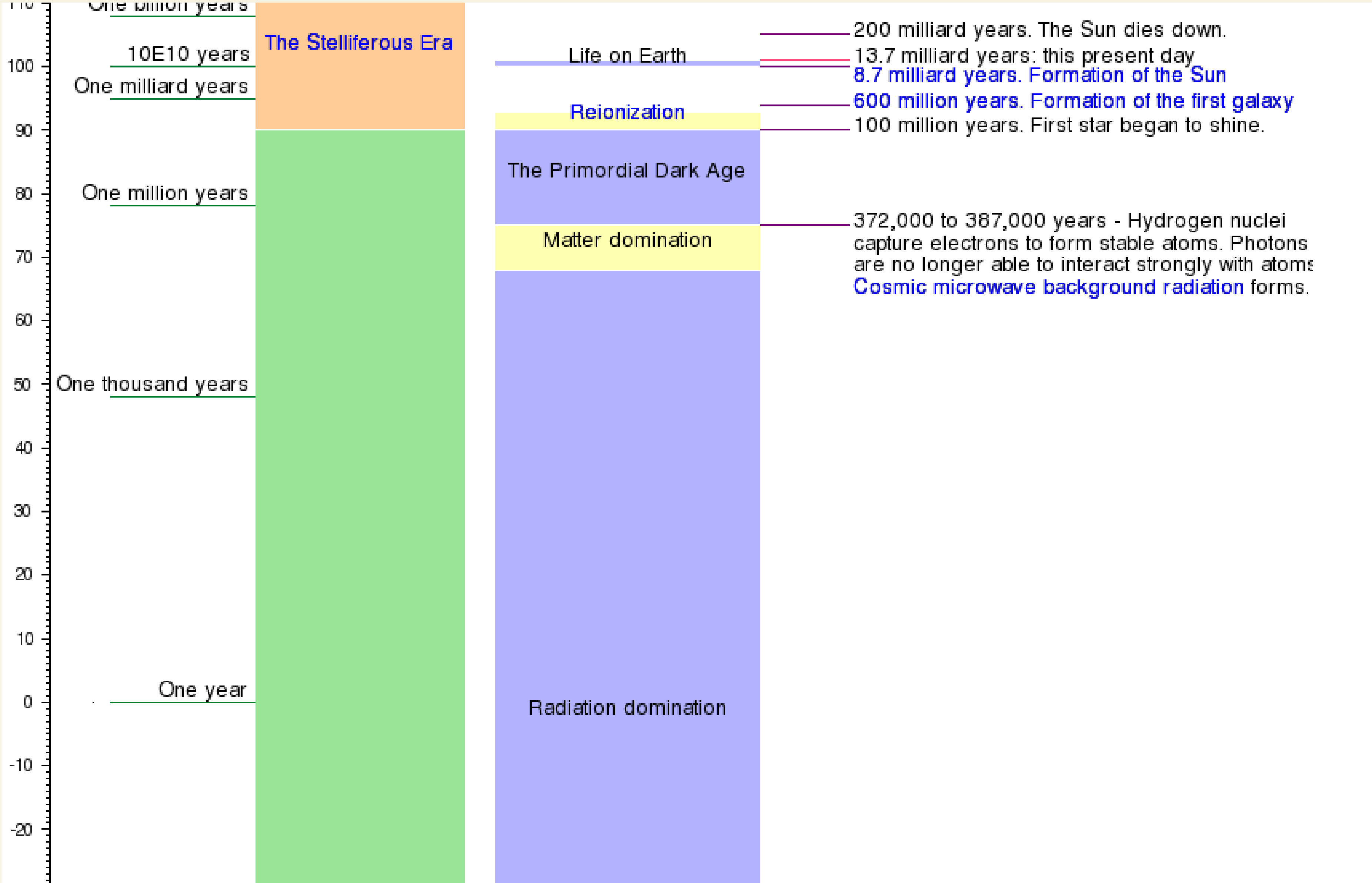
Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies and clusters (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
300,000 years
Atoms form; photons fly free and become background 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

Early Epochs

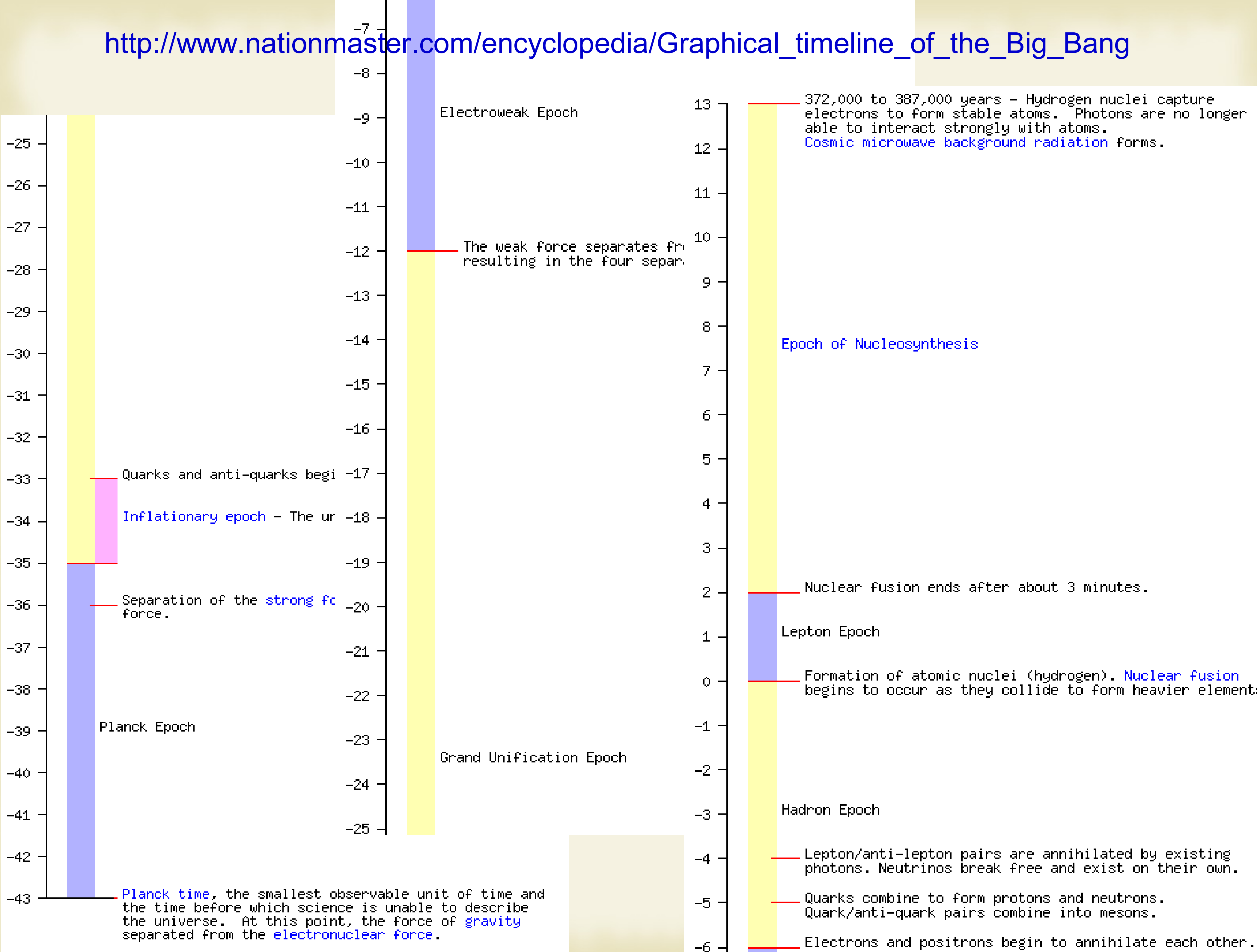
http://www.nationmaster.com/encyclopedia/Graphical-timeline-from-Big-Bang-to-Heat-Death



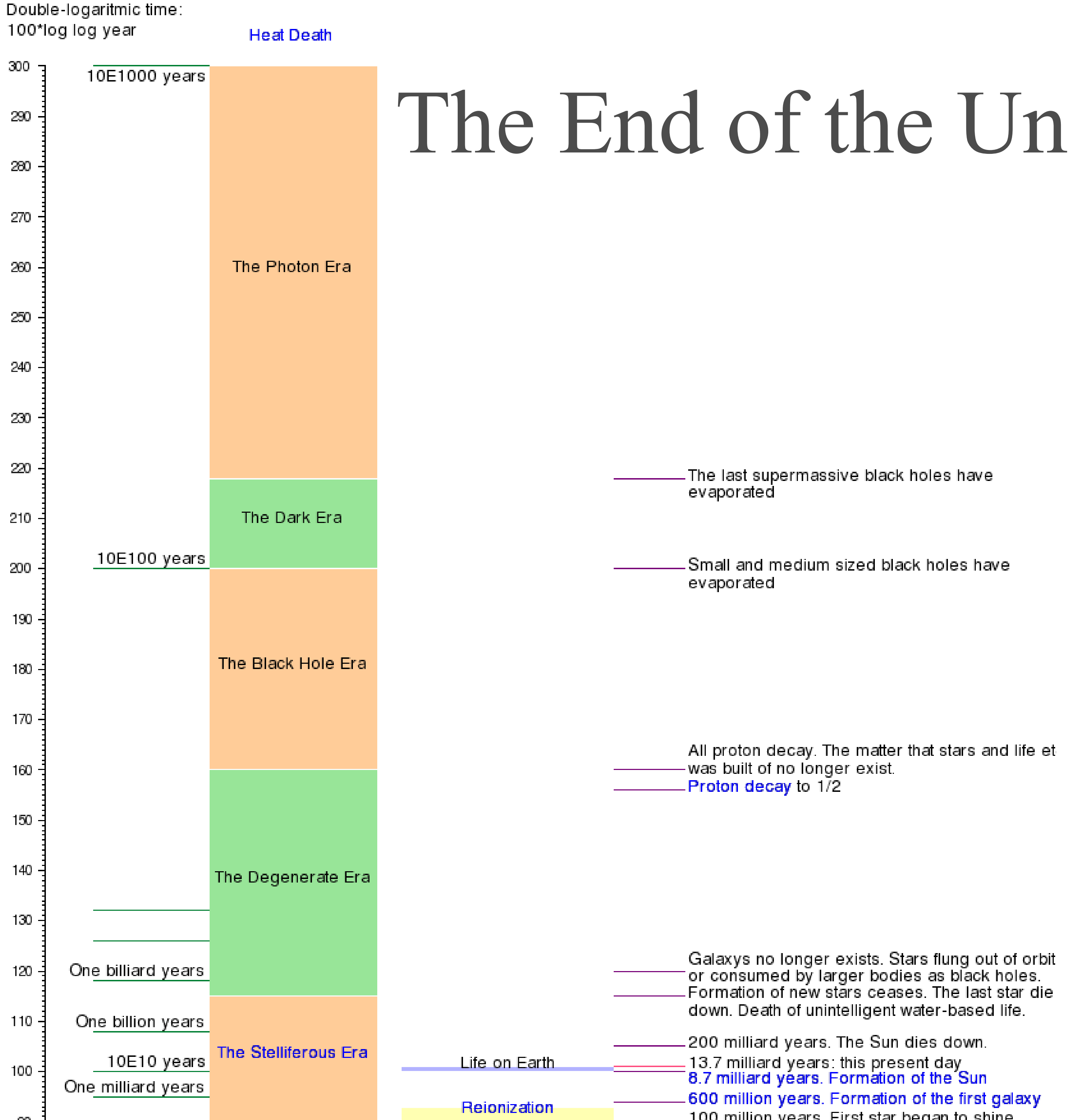
Later Epochs



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



The End of the Universe



History of Universe - Epochs

- Planck <10^{-43}s
- Grand Unification 10^{-43}-10^{-36}s
- Electroweak 10^{-36}s-10^{-12}s
  - Inflationary 10^{-36}s-10^{-32}s
  - Reheating
  - Baryogenesis
- Quark 10^{-12}s-10^{-6}s
- Hadron 10^{-6}s-1s
- Lepton 1s-3 min
- Photon 3 min-380,000 yr
  - Nucleosynthesis 3-20 min
  - Matter Domination 70,000 yr
  - Recombination 240,000-310,000 yr
- Dark Ages
- Structure Formation 150 million- 1 billion
- Solar system 8 billion yr
- Today 13.7 billion yr

Temperatures After Big Bang

- 13.7 billion years – now. 2.726 K
- 400 million years - "reionization": first stars heat and ionize hydrogen gas. 30 K.
- 380 thousand years - "recombination": hydrogen gas cools down to form molecules. 3000 K.
- 10 thousand years - end of the radiation-dominated era. 12,000K
- 1000 seconds - decay of lone neutrons. 500 million K.
- 180 seconds - beginning of "nucleosynthesis": formation of helium and other elements from hydrogen 1 billion K.
- 10 seconds - annihilation of electron-positron pairs.5 billion K
- 1 second - decoupling of neutrinos. 10 billion K
- 100 microseconds - annihilation of pions. 1 trillion K
- 50 microseconds - quarks bound into neutrons and protons. 1.7-2.1 trillion K
- 10 picoseconds - electromagnetic and weak force become different. 1-2 quadrillion K

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?