The Changing Universe

DLDK U3A

Dún Laoghaire

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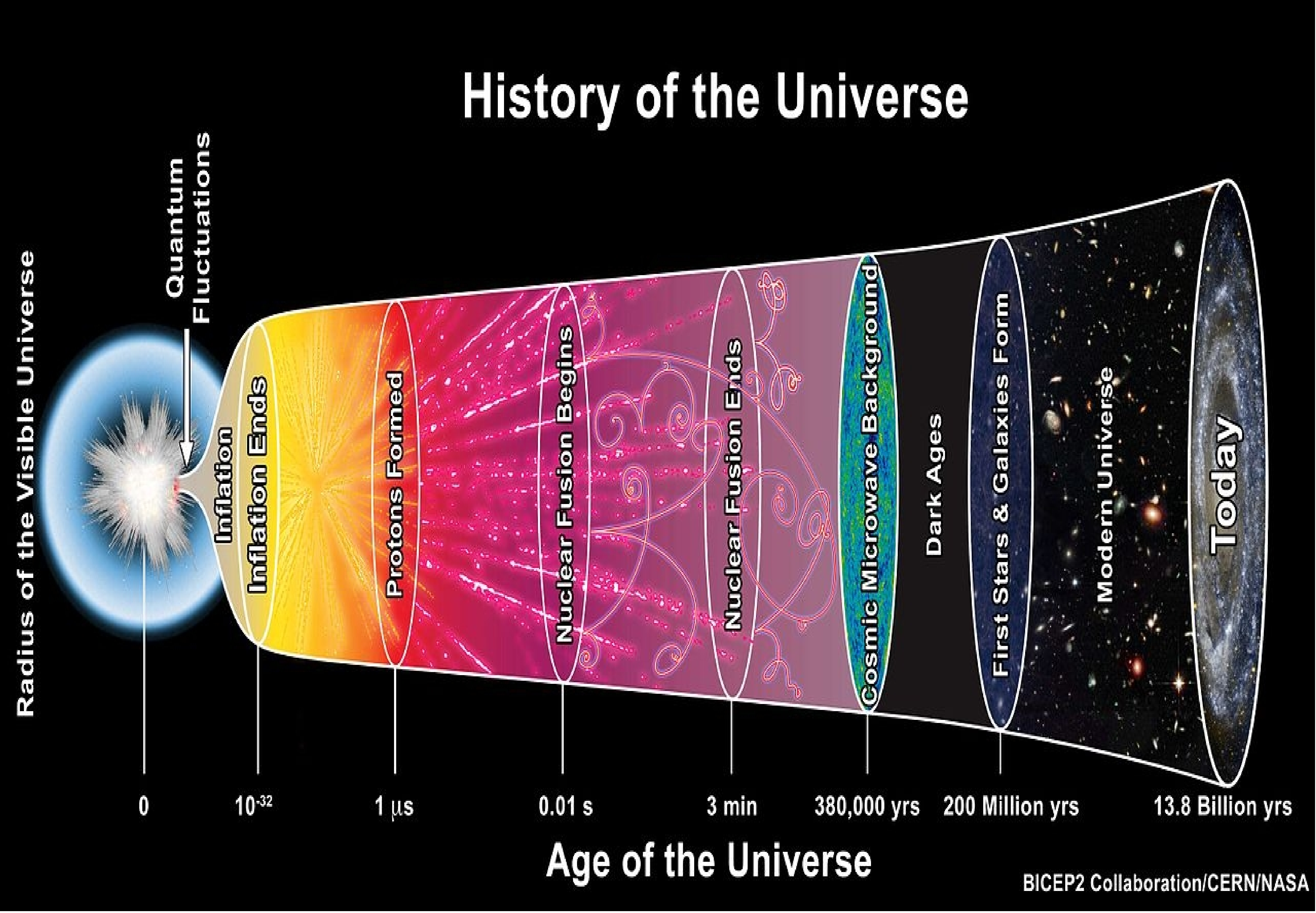
Nigel Buttimore



History of the Universe
Radius of the Visible Universe
Quantum Fluctuations
Inflation
Inflation Ends
Protons Formed
Nuclear Fusion Begins
Nuclear Fusion Ends
Cosmic Microwave Background
Dark Ages
First Stars & Galaxies Form
Modern Universe
Today
0
10-32
1 μs
0.01 s
3 min
380,000 yrs
200 Million yrs
13.8 Billion yrs
Age of the Universe
BICEP2 Collaboration/CERN/NASA

Outline

- The electron was found in 1897 by J J Thomson
- Ernest Rutherford named the proton in 1920
- The fundamental constituents of the universe
- Chemical elements made in the heat of stars
- Six episodes in the evolution of the universe
- Emergence of plant and animal life on Earth
- Dark energy and the future of the universe

G. J. Stoney (1826 – 1911)

looked for a formula for the hydrogen lines
which was found by Johann Balmer in 1885

$$b\,/\,\mathit{wavelength} \;=\; 1 - 4\,/\,n^2, \quad (n = 3, 4, 5, 6)$$

Margaret and Wm Huggins confirmed $n = 7$

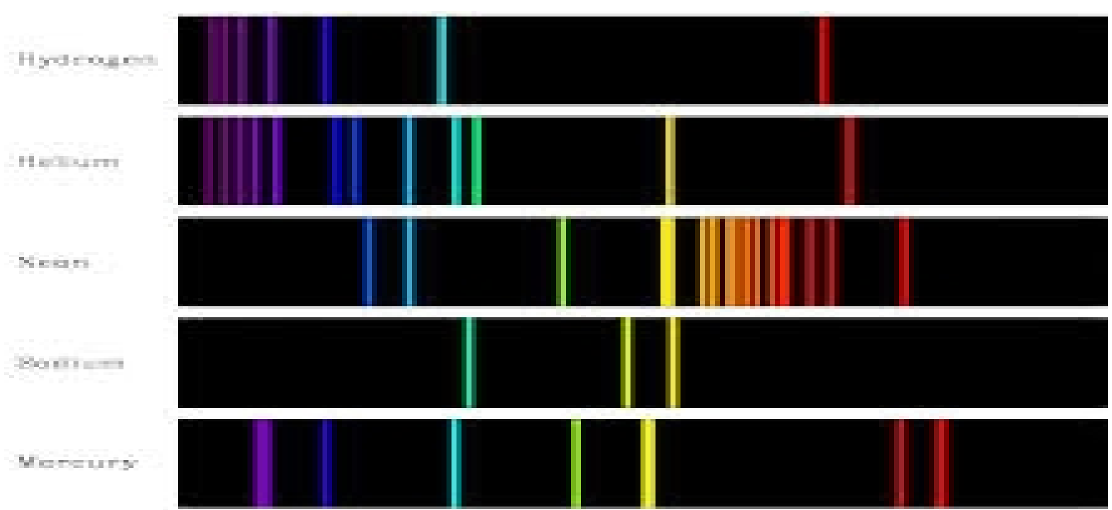
In 1891 Stoney coined “electron” as the
"fundamental unit quantity of electricity"

Cecilia Payne (1900-1979)

Chose astronomy on hearing Eddington talk

Sun has the same composition of chemical elements as the Earth except for hydrogen

H is a million times more plentiful in the Sun when the equation of Meghnad Saha is used to adjust the spectrum for temperature effects

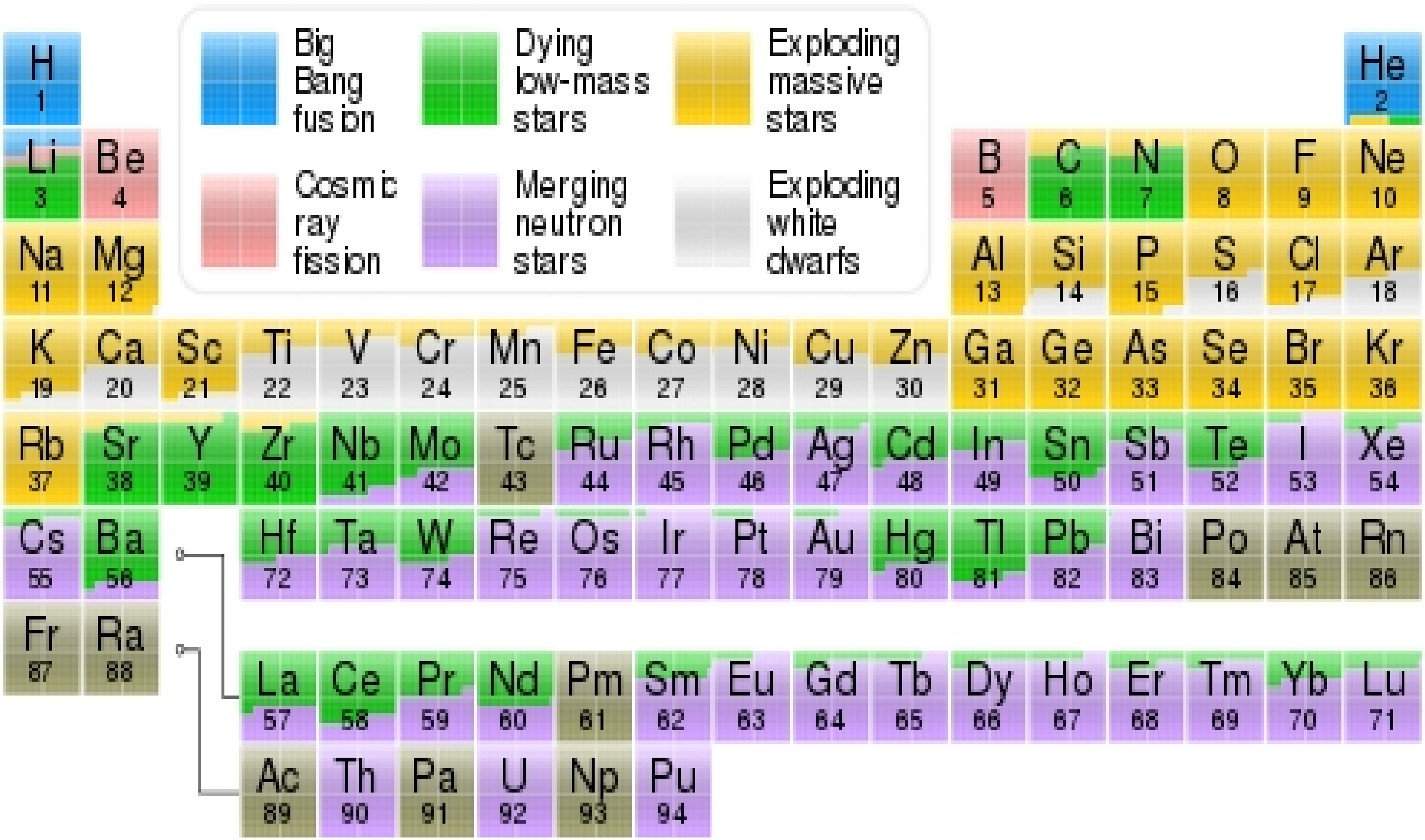


George Gamov (1904 – 1968)

- explained the alpha decay of a nucleus in 1928 using the quantum theory of 1926 and talked to Cockcroft and Walton about proton beams
- employed the Friedmann solution of gravity and assumed the early universe was mostly radiation to predict, in 1953, a cosmic back-ground temperature of 7 degrees Kelvin today

WALTON, RUTHERFORD, AND COCKCROFT

Chemical Elements



European laboratory for particle physics

CERN employs just over 3,000 people. Around 12,000 scientists from over 70 countries with 120 different nationalities come to Geneva & Prévessin for research.

CERN uses complex scientific instruments to study the basic constituents of matter. The particles are made to collide together to study how they interact and to provide insights into fundamental laws of nature.

The twenty two Member States of CERN

Member States (date of accession)

- Austria (1959)
- Belgium (1953)
- Bulgaria (1999)
- Czech Republic (1993)
- Denmark (1953)
- Finland (1991)
- France (1953)
- Germany (1953)
- Greece (1953)
- Hungary (1992)
- Israel (2014)
- Italy (1953)
- Netherlands (1953)
- Norway (1953)
- Poland (1991)
- Portugal (1986)
- Romania (2016)
- Slovakia (1993)
- Spain (1961-1968, 1983-)
- Sweden (1953)
- Switzerland (1953)
- United Kingdom (1953)

Englert and Higgs at CERN in 2012

Many young researchers were involved in the discovery of the Brout Englert Higgs field and its quanta, Higgs Boson (named for S N Bose)

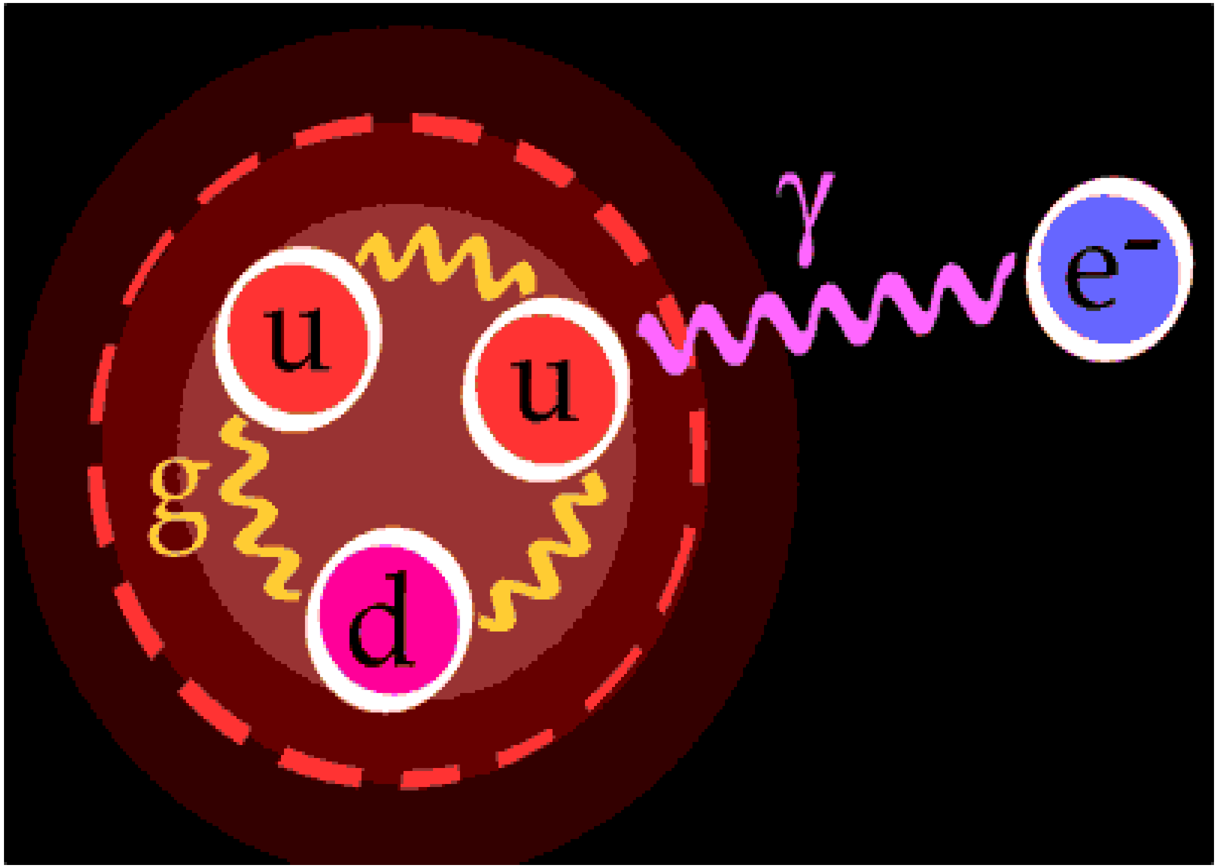
Progress in the Sixties

1963 Murray Gell-Mann introduces 'quark' as "Three quarks for Muster Mark" appears in Finnegans Wake 1939 by James Joyce

1964 Brout & Englert, Higgs, . . . , publish a mechanism for imparting mass to many fundamental particles; Higgs predicts the existence of a Boson of unknown mass

1965 Penzias and Wilson accidentally discover the cosmic microwave background (CMR)

Hydrogen atom: a proton (uud) emits a photon (γ) that is absorbed by an electron (e^-) giving rise to an attractive force between the opposite charges

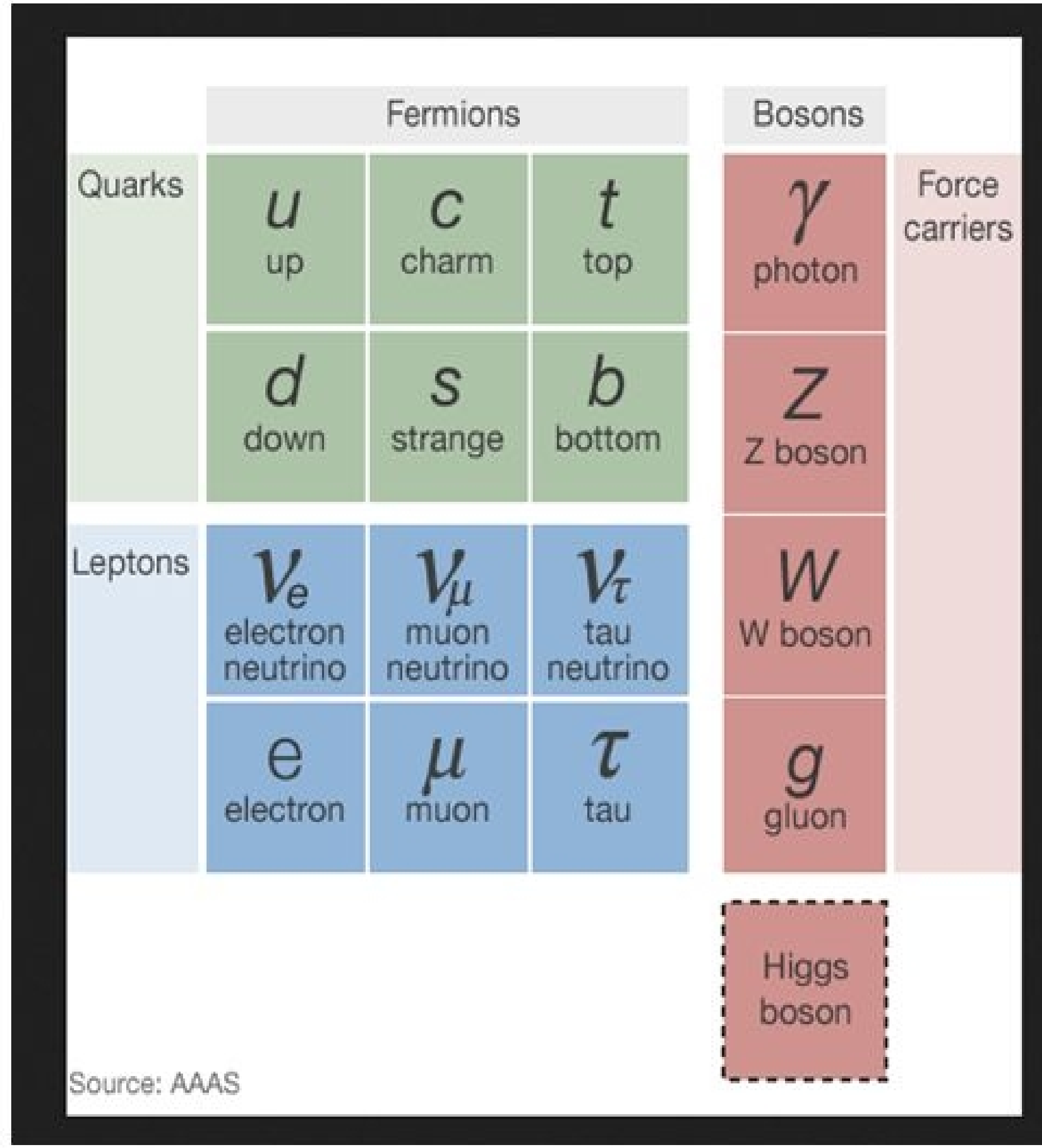


The "Standard Model" (1970s)

- Table shows the basic particles (61)
- 3 leptons and 3 quarks
- We never see free quarks
- Neutrons and protons are 3 quarks
- All particles have now been seen
- The interactions between the particles is mathematically simple but very difficult to "solve" except on big computers
- Almost complete agreement with all experiments. (0.02%)

BUT

- Why so many parameters? (19)
- How to combine with gravity
- Are there more particles such as WIMPS for dark matter?
- Matter/antimatter imbalance.



Evolution of the Universe

1 P°C 1 ps Higgs imparts mass to fermions & weak bosons

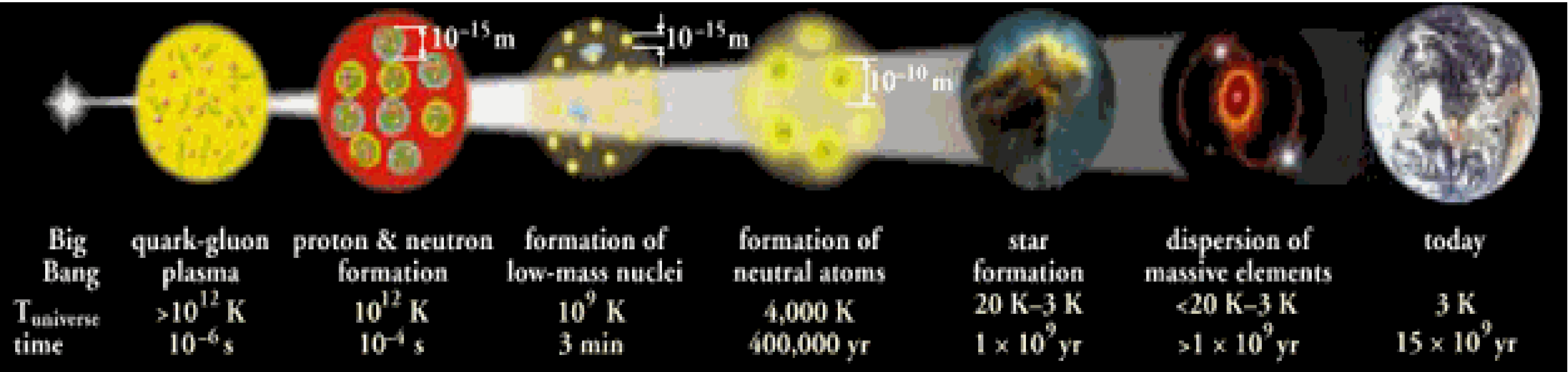
1 T°C 9 μs quarks coalesce to form protons and neutrons

1 G°C 3 min neutrons and some protons form helium nuclei

4 kK 0.4 My hydrogen and helium nuclei attract electrons

30 K 90 My atoms condense to initiate stars and galaxies

10 K 9 Gy sun and earth form out of clouds of star-dust

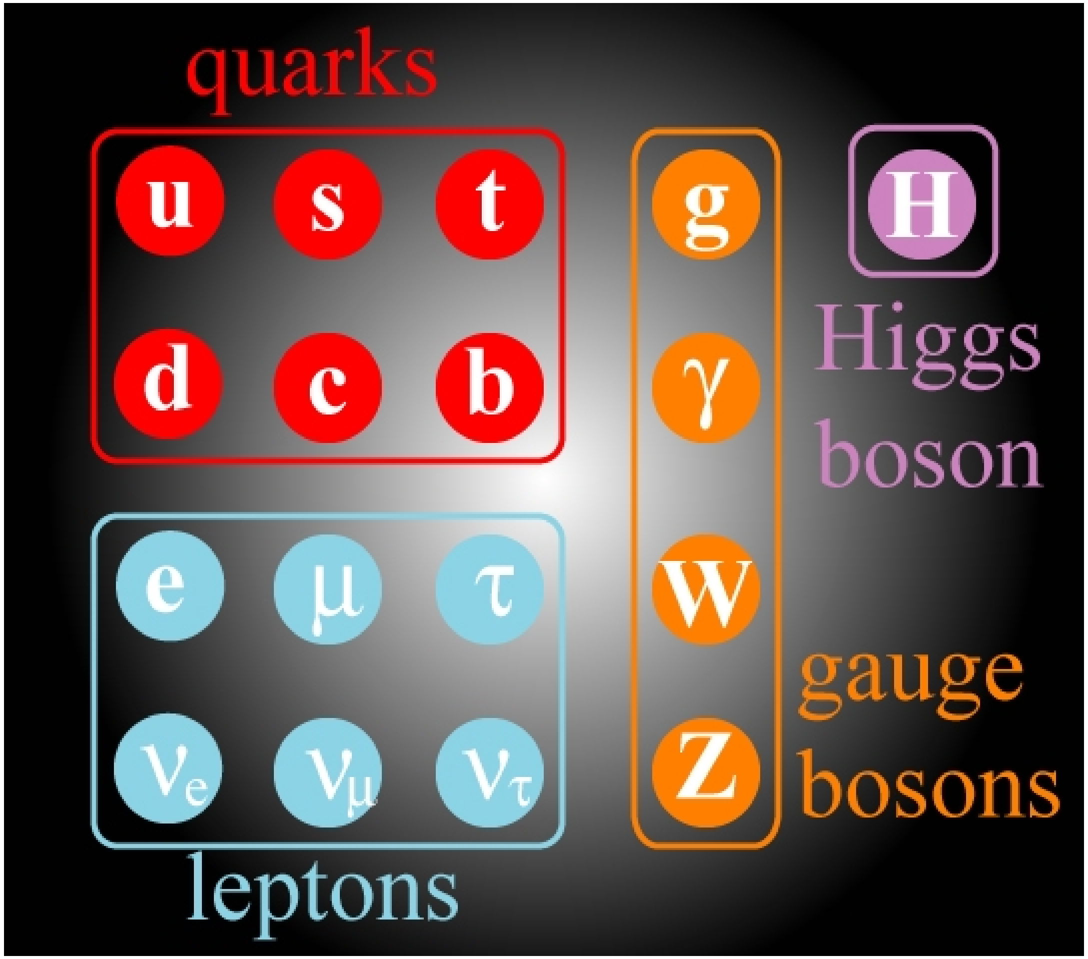


Life in the Universe

9 Gyr	Sun's fire ignites; earth & water appear
10	Life begins with the emergence of DNA
11	Cells and sunlight make oxygen in the air
12	Animals differentiate from static plants
13	Life advances from the sea to the land
13.8	Humankind studies its past and future

Dark Energy (1998)

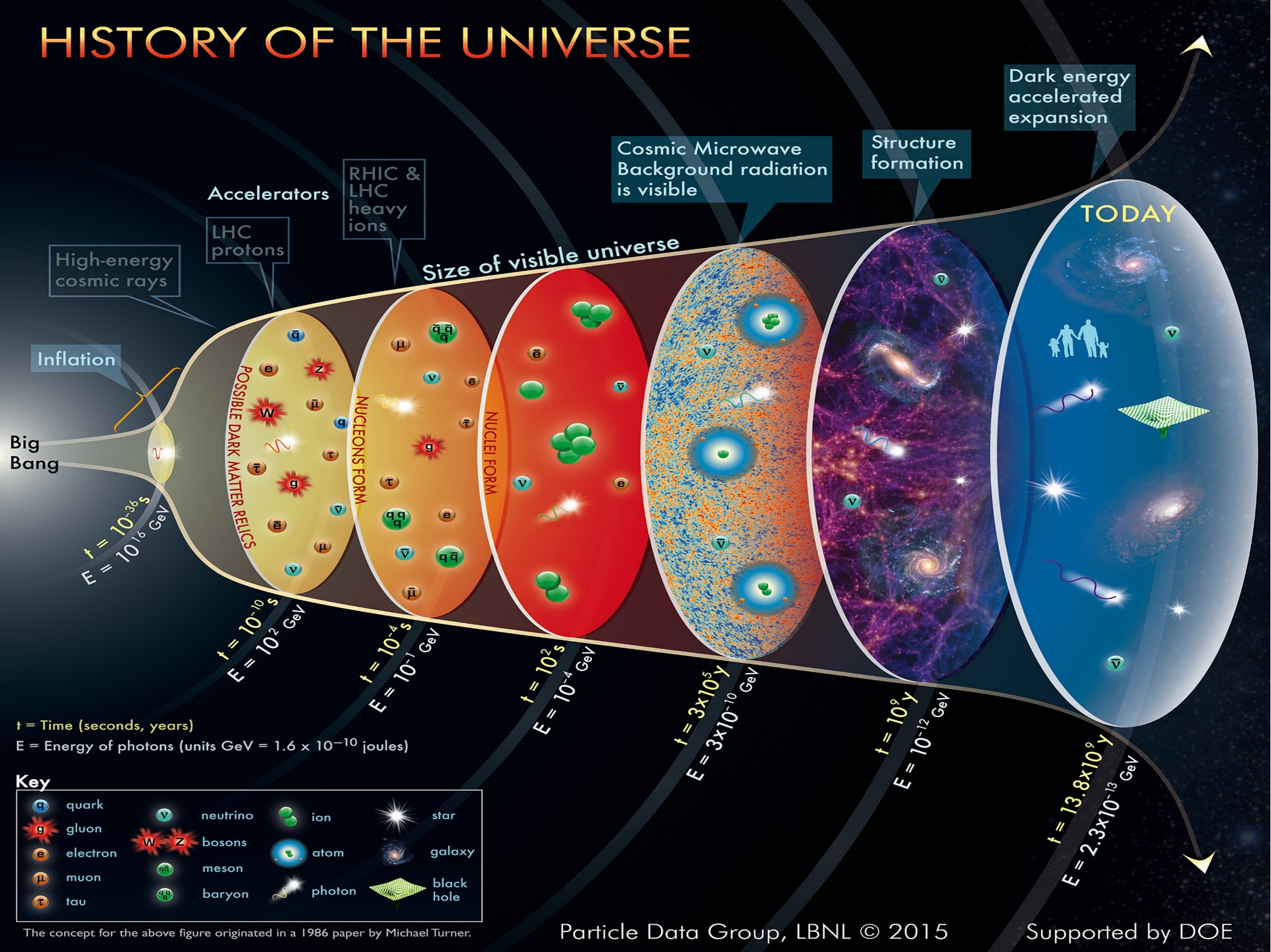
- The expansion of the universe is found to be accelerating (from a study of supernovae)
- An accelerated expansion term in the equations for gravity has been called 'dark energy' in 1998
- The Hubble space telescope indicates that dark energy has been present for over 9 billion years
- Its source is unknown – the universe comprises 68% dark energy, 27% dark & 5% visible matter

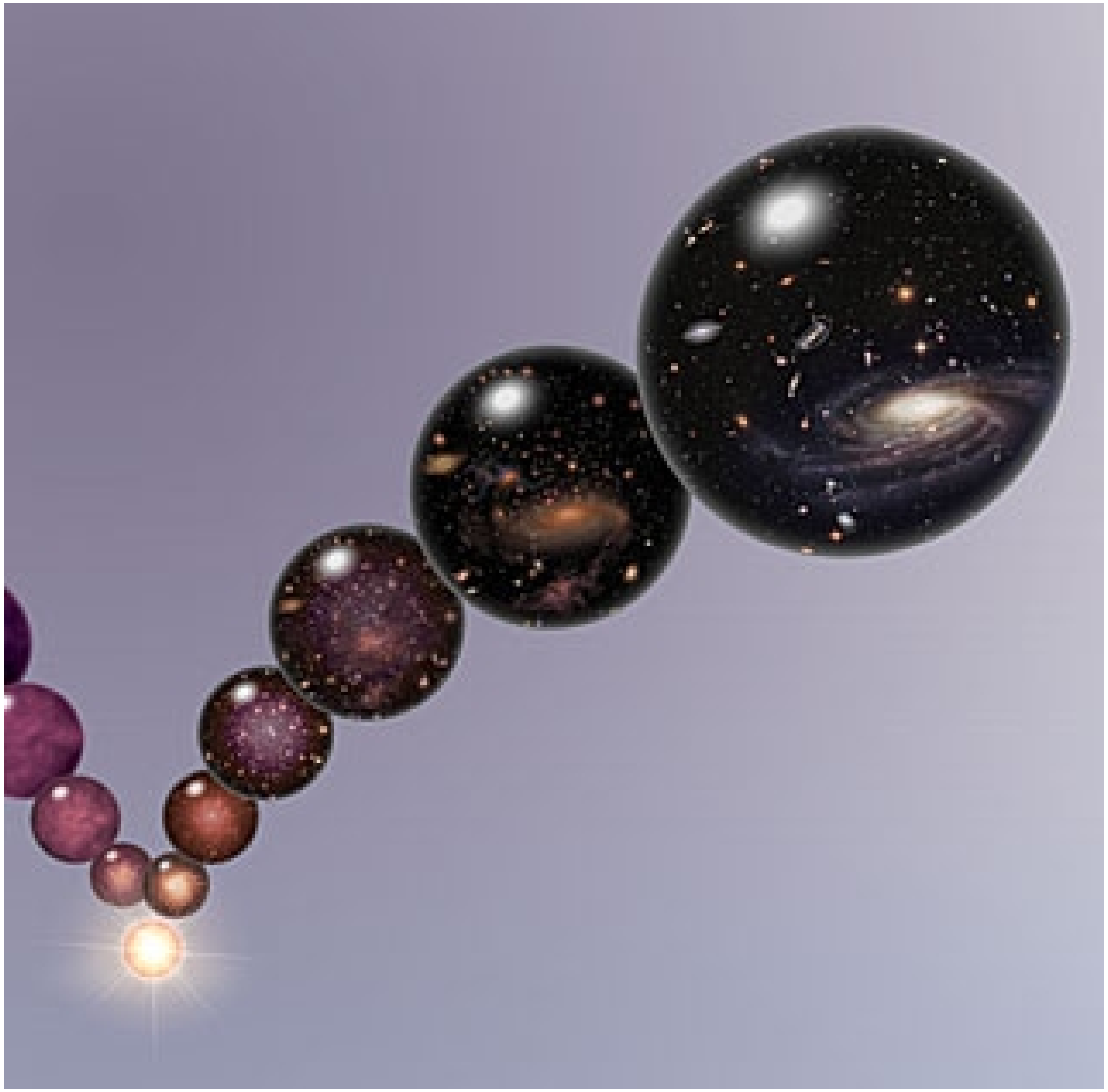

quarks
u
s
t
d
c
b
e
μ
τ
νe
νμ
ντ
leptons
g
γ
W
Z
gauge
bosons
H
Higgs
boson

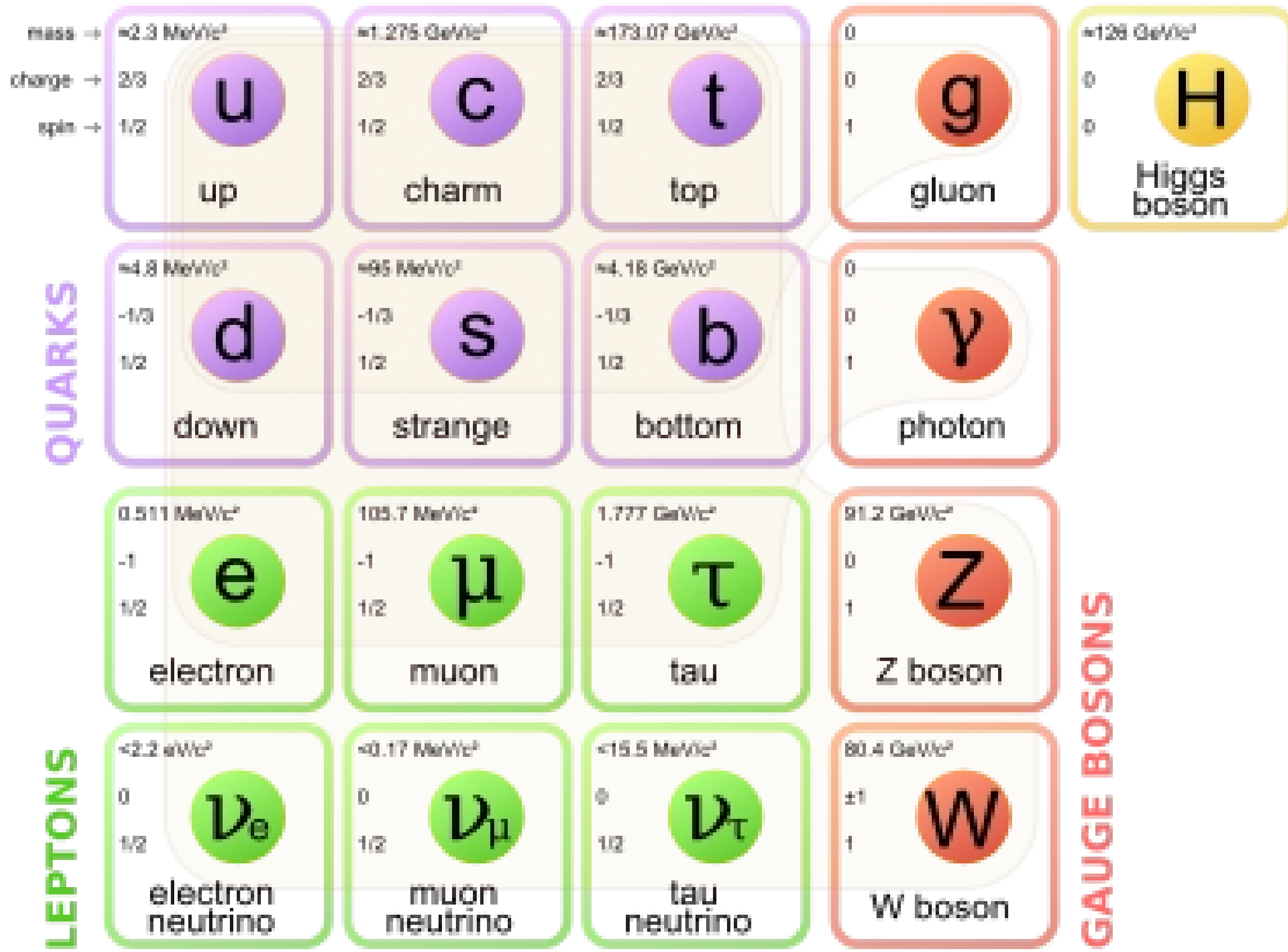
Fine-tuned Universe

If gravity were too strong compared with the expansion, the universe would have collapsed before life could have evolved.

If gravity were too weak, no stars would have formed to generate the heavier chemical elements necessary for life.


HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Size of visible universe
TODAY
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^{-36} s
E = 10^{16} GeV
t = 10^{-10} s
E = 10^{2} GeV
t = 10^{-4} s
E = 10^{-1} GeV
t = 10^{2} s
E = 10^{-4} GeV
t = $3x10^{5}$ y
E = $3x10^{-10}$ GeV
t = 10^{9} y
E = 10^{-12} GeV
t = $13.8x10^{9}$ y
E = $2.3x10^{-13}$ GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^{-10} joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Particle Data Group, LBNL © 2015
Supported by DOE





mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS

"A universe simple enough to be understood is too simple to produce a mind capable of understanding it."

John D. Barrow