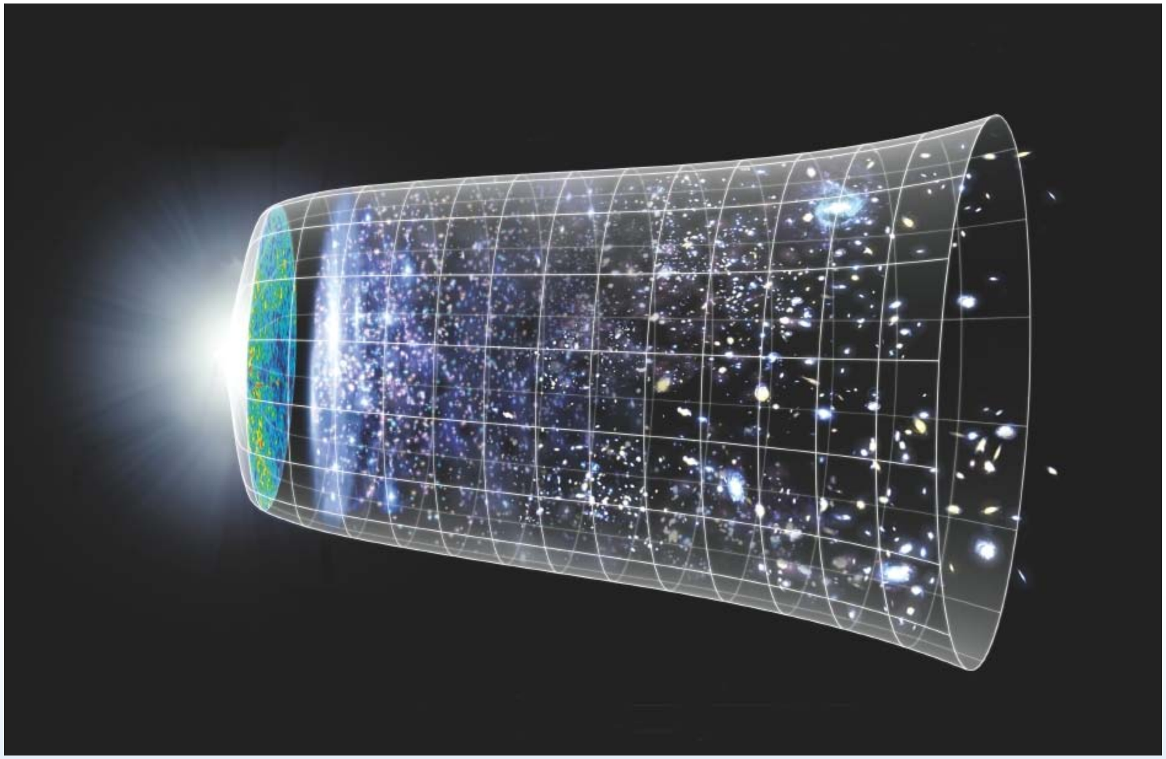


Phys 102 – Lecture 28

Life, the universe, and everything

Today we will...

- Learn about the building blocks of matter & fundamental forces
  - Quarks and leptons
  - Exchange particle (“gauge bosons”)
- Learn about the Big Bang theory
  - Hubble law & the expansion of the universe
  - The early universe
  - Unification of forces

Fundamental particles

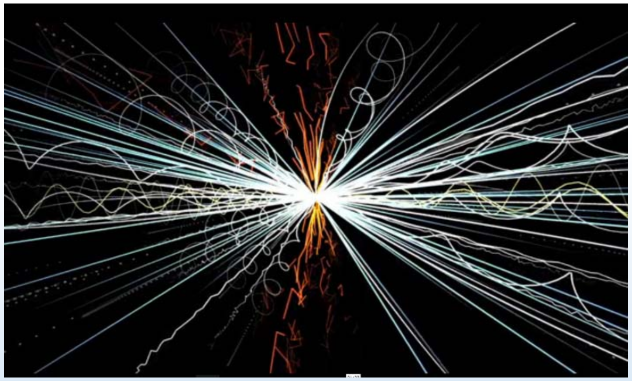
Are the electron, proton, and neutron the fundamental building blocks of matter? Evidence says NO for proton & neutron

Particle "zoo" Hundreds of particles identified in particle accelerator experiments

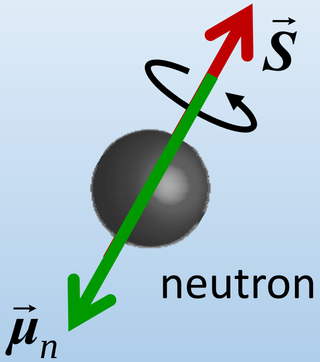
"sigma" Σ^0, Σ^+, Σ^- "xi" Ξ^0, Ξ^-

"pion" π^0, π^+, π^- etc...

"kaon" κ^0, κ^+



Neutron magnetic dipole moment



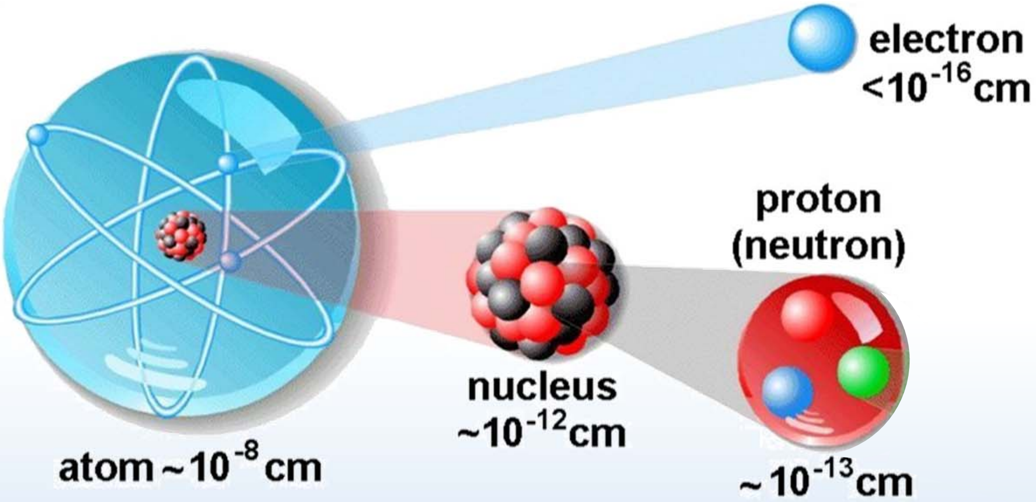
Neutron has spin ½, is electrically neutral, yet has a magnetic dipole moment!

Indicates these are *composite* particles

Quarks

“Three quarks for Muster Mark”
Finnegan’s Wake, James Joyce

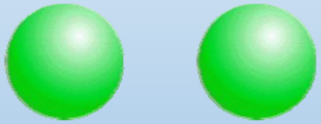
Neutrons and protons are composite particles



Discovered
in 1968

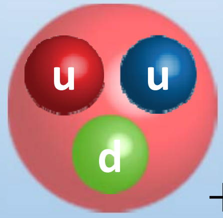
“Flavors”

Quark	up (u)	down (d)
Charge	$+\frac{2}{3}e$	$-\frac{1}{3}e$



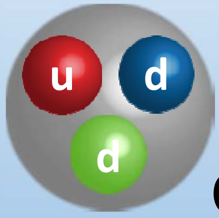
Hadrons are particles composed of quarks

1 proton = uud



$+e$

1 neutron = udd



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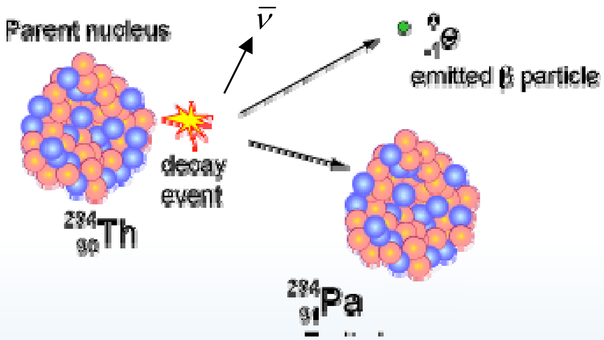
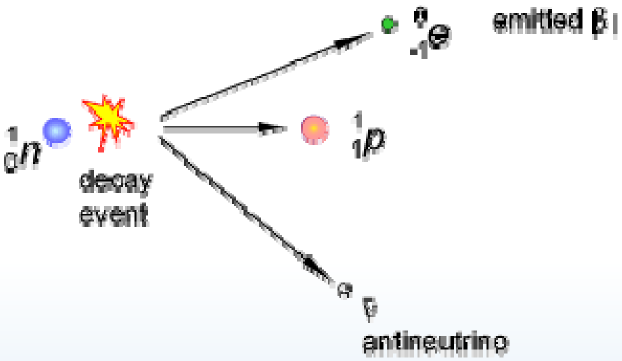
ACT: Beta decay

Last lecture, we saw that β⁻ decay involves converting a neutron into a proton.





$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}e^{-} + {}^{0}_{0}\overline{\nu}_e$$

$$^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}e^{-} + {}^{0}_{0}\overline{\nu}_e$$

How could this decay be described in terms of quarks?

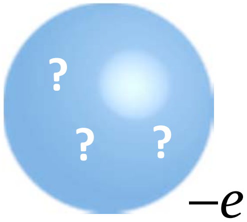
A. A *d* converts to a *u*

B. A *u* converts to a *d*

C. A *d* converts to an e⁻

ACT: Hadrons & quarks

The Δ^- is an exotic hadron with charge –e.

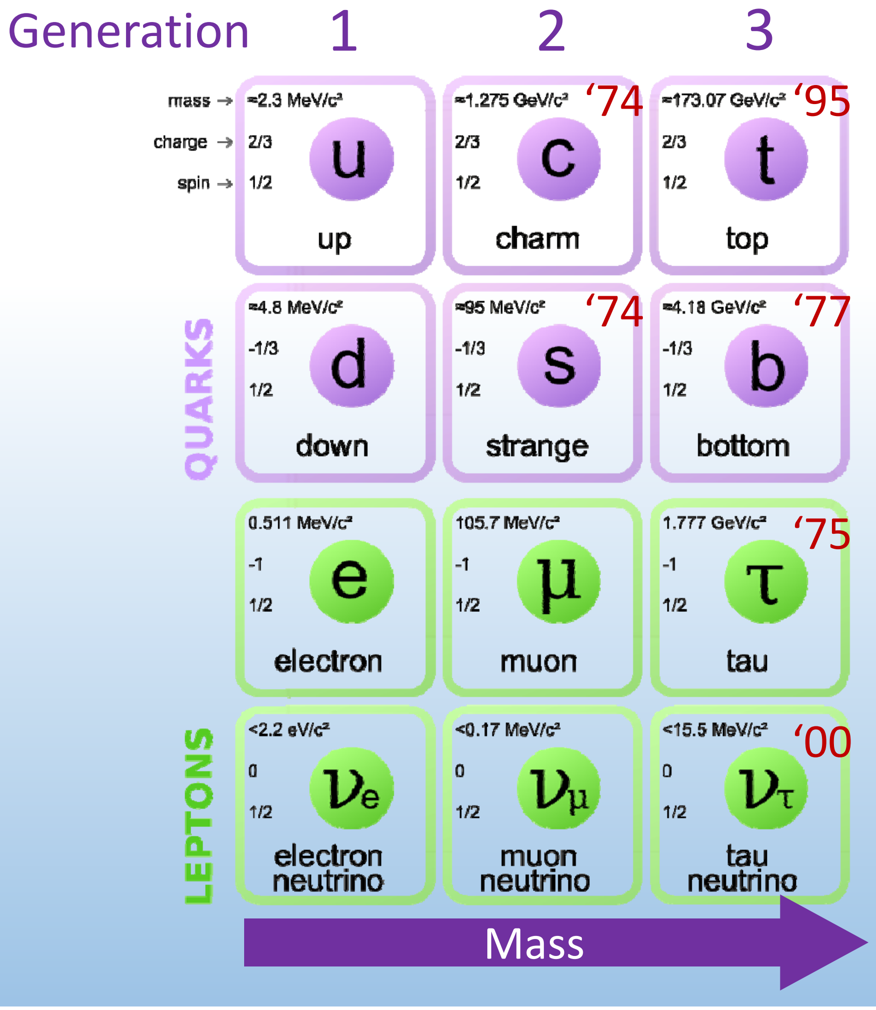


What could the quark makeup of this particle be?

A. uuu
B. ddd
C. an e^- & ν_e

Building blocks of matter

Ordinary matter is made of u, d (quarks), e and ν_e (leptons)



Hadrons (ex: n, p) are composite particles made of quarks

Quarks and *leptons* (ex: e^-) are believed to be the elementary particles

There is a corresponding *anti-particles* for each elementary particles! Same *m*, opposite *q*

ACT: Quarks

In Lect. 26 we saw that two electrons cannot be in the same state (i.e. have the same quantum numbers).

Can two quarks be in the same state?

A. Yes
B. No

4 Fundamental forces of Nature

Gravitational force (solar system, galaxies)

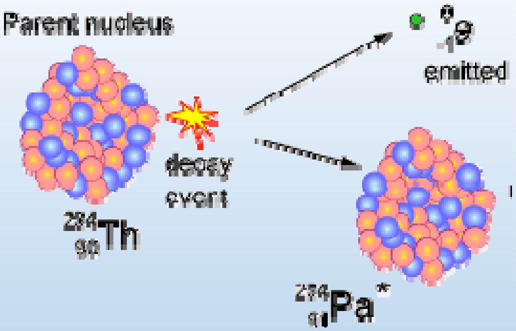
Electromagnetic force (atoms, molecules)

Strong force (atomic nuclei)

Weak force (radioactive decay)

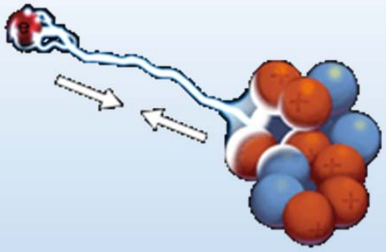
Gravitational

<



Weak

<



Electromagnetic

<

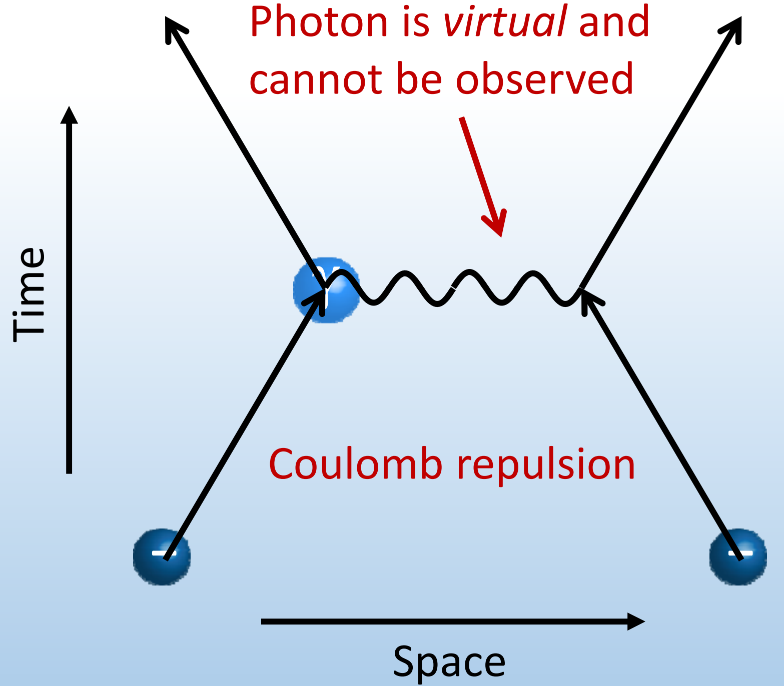
Strong

weakest strongest

Particle physics view of forces

Matter interacts through exchange of *mediator* or *exchange* particles

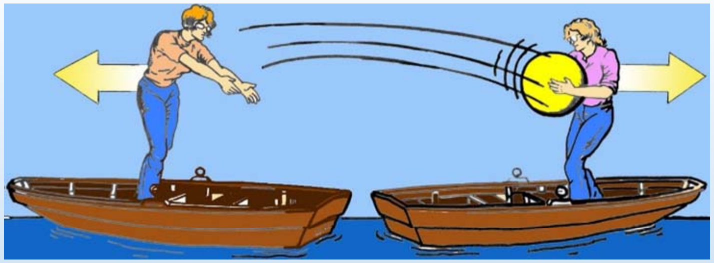
Ex: electromagnetic exchange particle is the *photon*!



Photon is *virtual* and cannot be observed

Coulomb repulsion

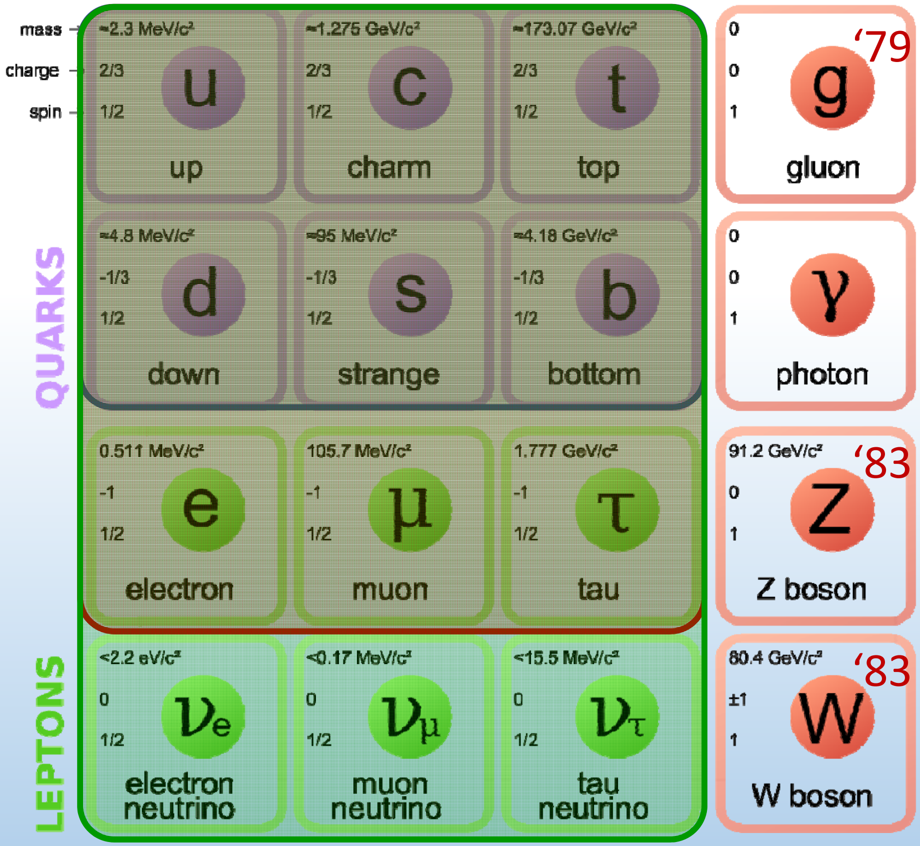
"Feynman diagram"



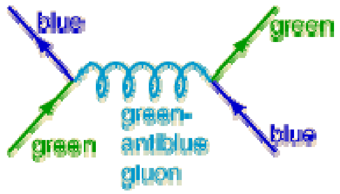
Summing over all the possible ways photon can be exchanged leads to Coulomb's law

The “Standard Model”

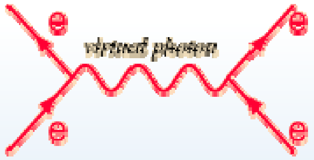
Exchange particles for are known as *gauge bosons*



Strong force



Electromagnetic force



Weak force

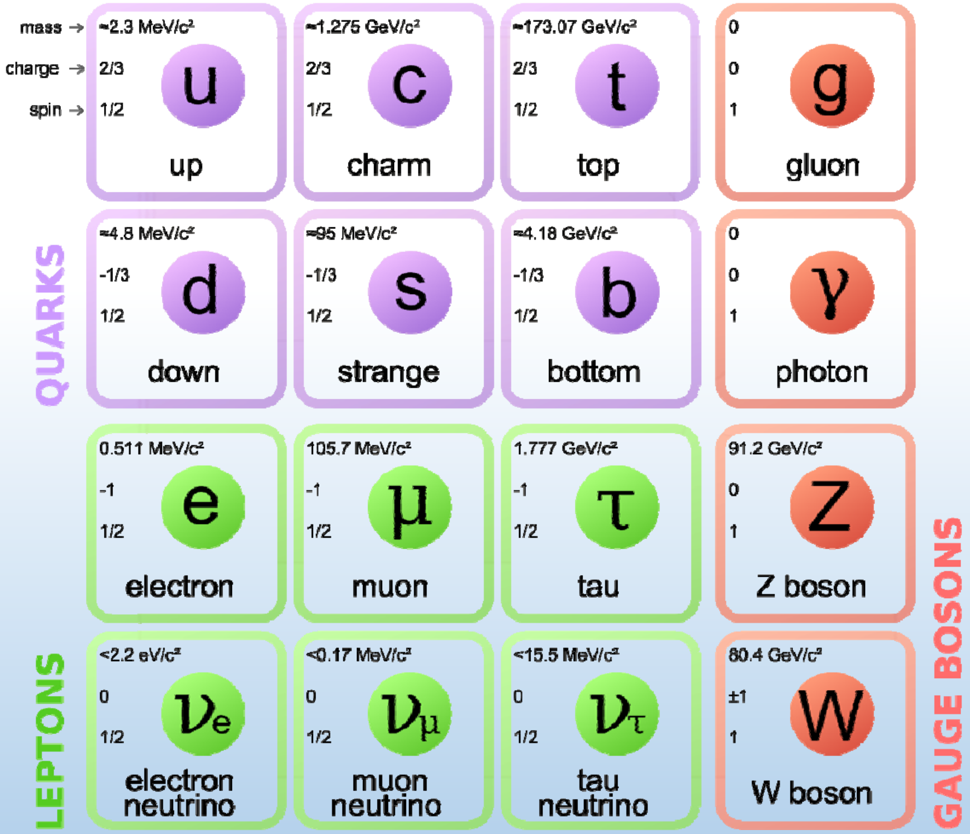
Only force that can change quark flavor

β⁻ decay

What about gravity?

The Higgs boson

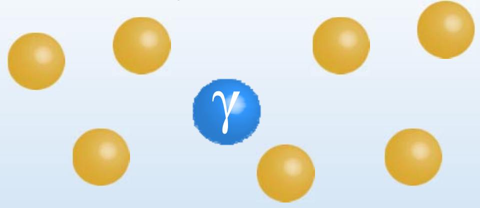
Higgs boson gives elementary particles their masses



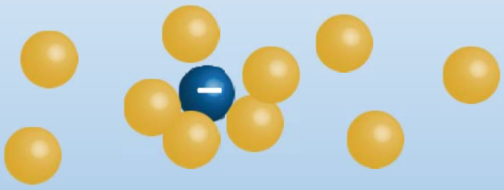
mass → charge → spin →	≈2.3 MeV/c^2 2/3 1/2 u up	≈1.275 GeV/c^2 2/3 1/2 c charm	≈173.07 GeV/c^2 2/3 1/2 t top	0 0 1 g gluon	
QUARKS	≈4.8 MeV/c^2 -1/3 1/2 d down	≈95 MeV/c^2 -1/3 1/2 s strange	≈4.18 GeV/c^2 -1/3 1/2 b bottom	0 0 1 γ photon	
	0.511 MeV/c^2 -1 1/2 e electron	105.7 MeV/c^2 -1 1/2 μ muon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

The more massive the particle, the more it interacts with the Higgs boson

Massless photon



Massive electron



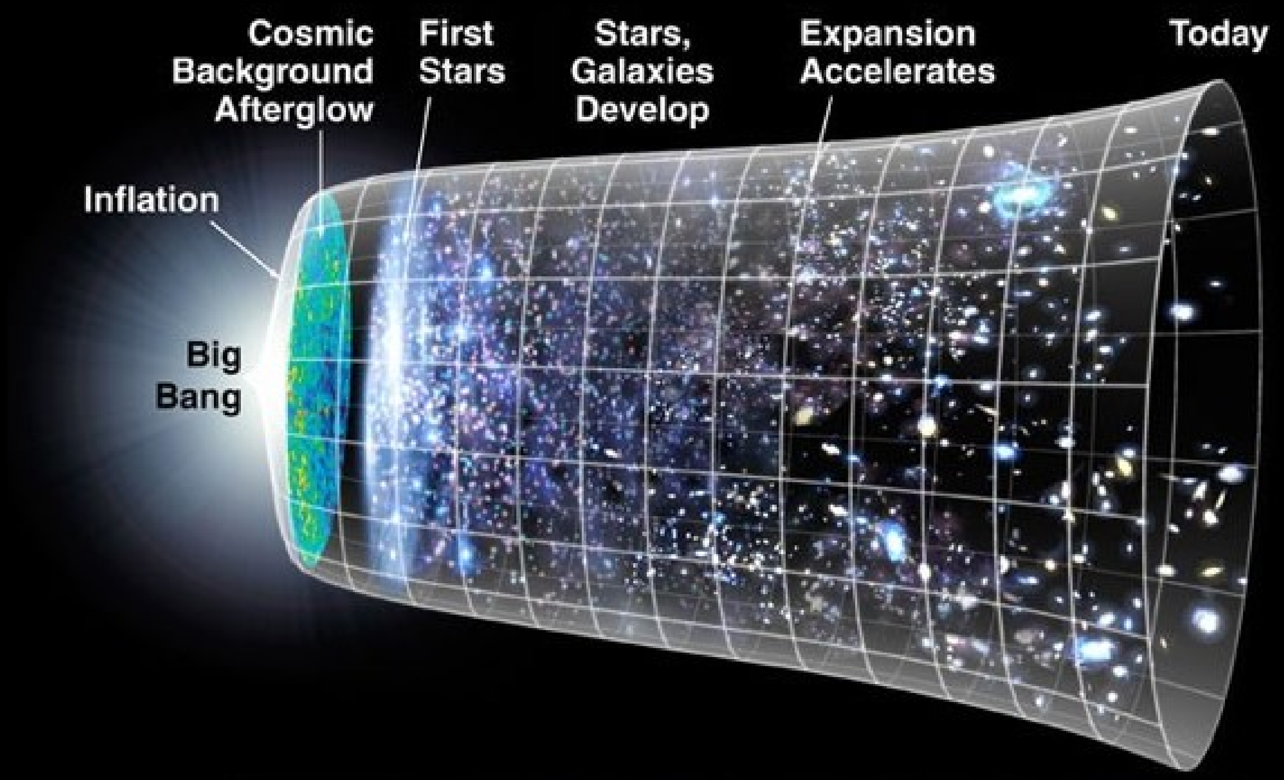
ACT: Fundamental forces

Which of the following particles can interact via the electromagnetic force?

A. A muon
B. An up quark
C. A strange quark
D. All of the above
E. None of the above

The expansion of the universe

Astronomers observed that all celestial bodies are *receding* from us. Therefore, the universe is expanding!



ACT: Doppler effect

Recall Lect. 15

The wavelength λ_{obs} observed on earth from the spaceship is

A. Larger than λ_{emit}
B. The same as λ_{emit}
C. Smaller than λ_{emit}

ACT: Hubble law

More distant celestial objects recede from us *faster*

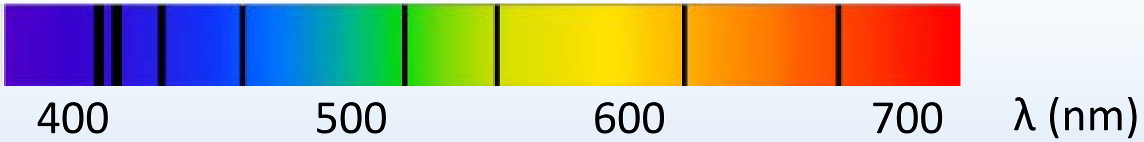
Recessional velocity

$$\boxed{v = H_0 d}$$

Distance to object

“Hubble” constant

The light spectrum of a stationary galaxy is given by:

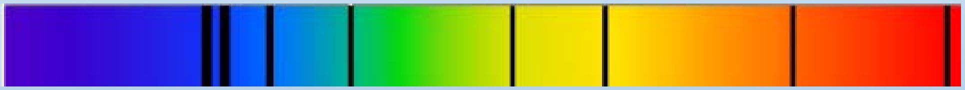


Recall Lect. 25

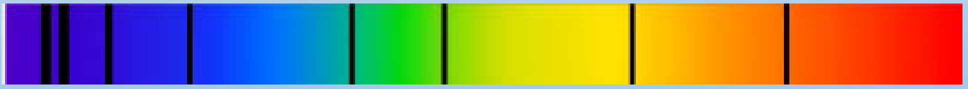
Which of the following belongs to the most distant galaxy?

A.

B.

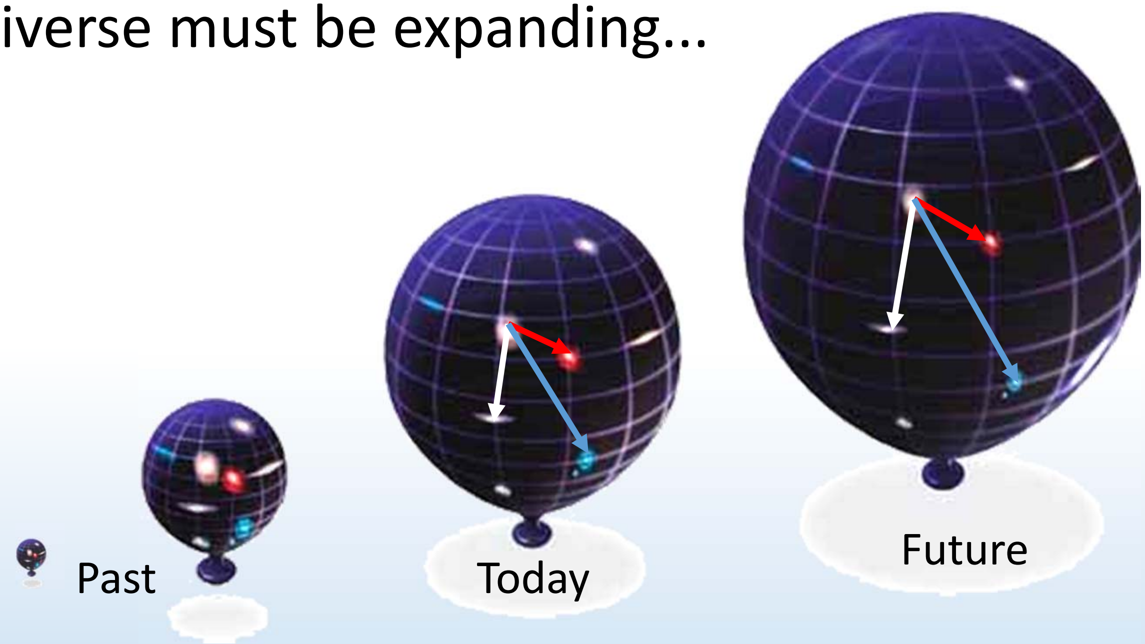


C.



The Big Bang

All celestial bodies are receding from us *and* each other, so universe must be expanding...



DEMO

Distances increase in every direction

Assuming a constant rate of expansion: $v = \frac{d}{t} = H_0 d$

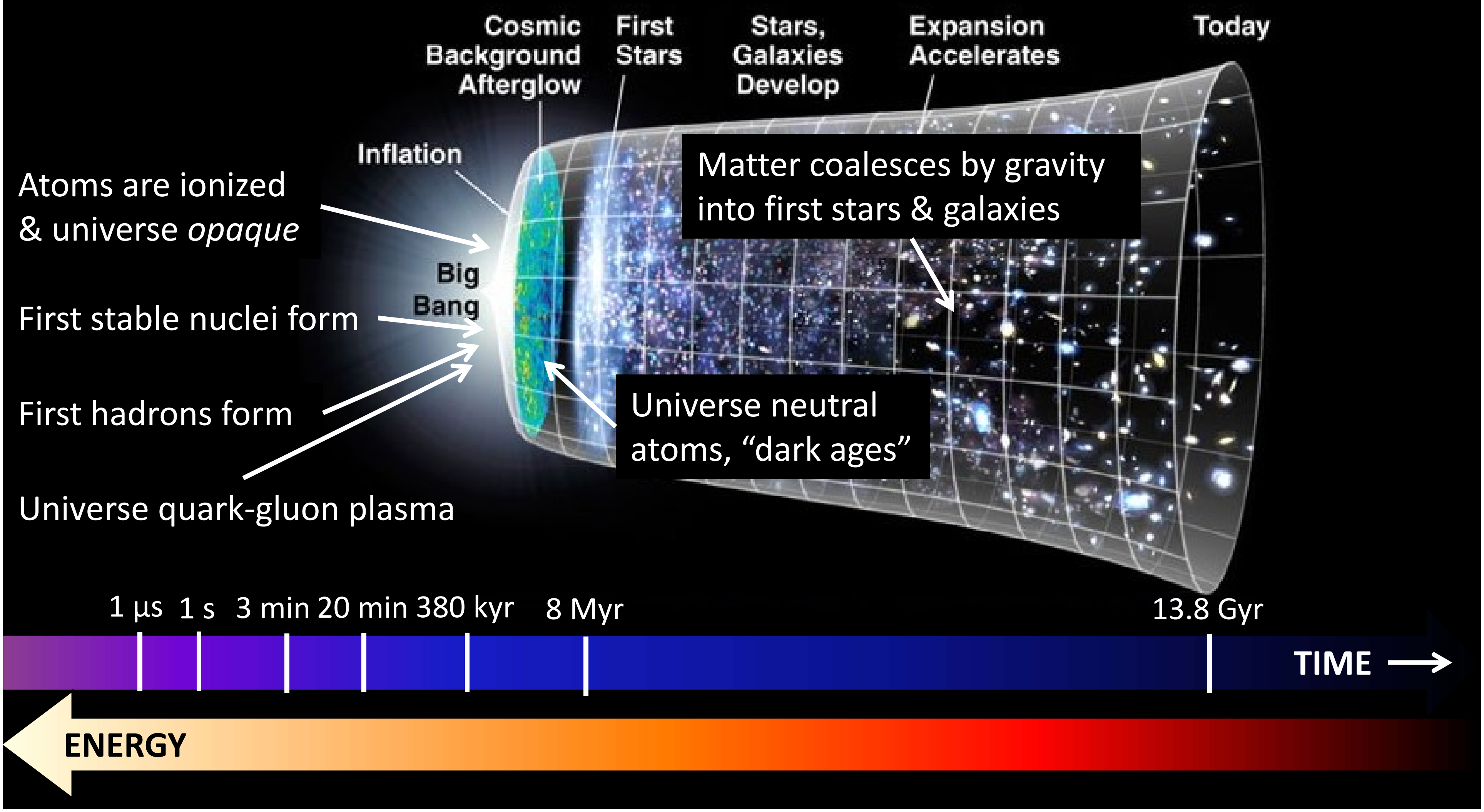
$$t_{universe} = \frac{1}{H_0} = \frac{1}{70}\frac{\text{s}\cdot\text{Mpc}}{\text{km}}\, 3\times10^{19}\frac{\text{km}}{\text{Mpc}}\frac{1}{60\cdot60\cdot24\cdot365}\frac{\text{yr}}{\text{s}} \approx 14\,\text{Gyr}$$

1 “Megaparsec”= 1 Mpc = 3×10^{19} km

Best estimate is 13.8 Gyr

A journey back in time…

Early universe was smaller, more dense, & hotter



Atoms are ionized & universe *opaque*

First stable nuclei form

First hadrons form

Universe quark-gluon plasma

Matter coalesces by gravity into first stars & galaxies

Universe neutral atoms, “dark ages”

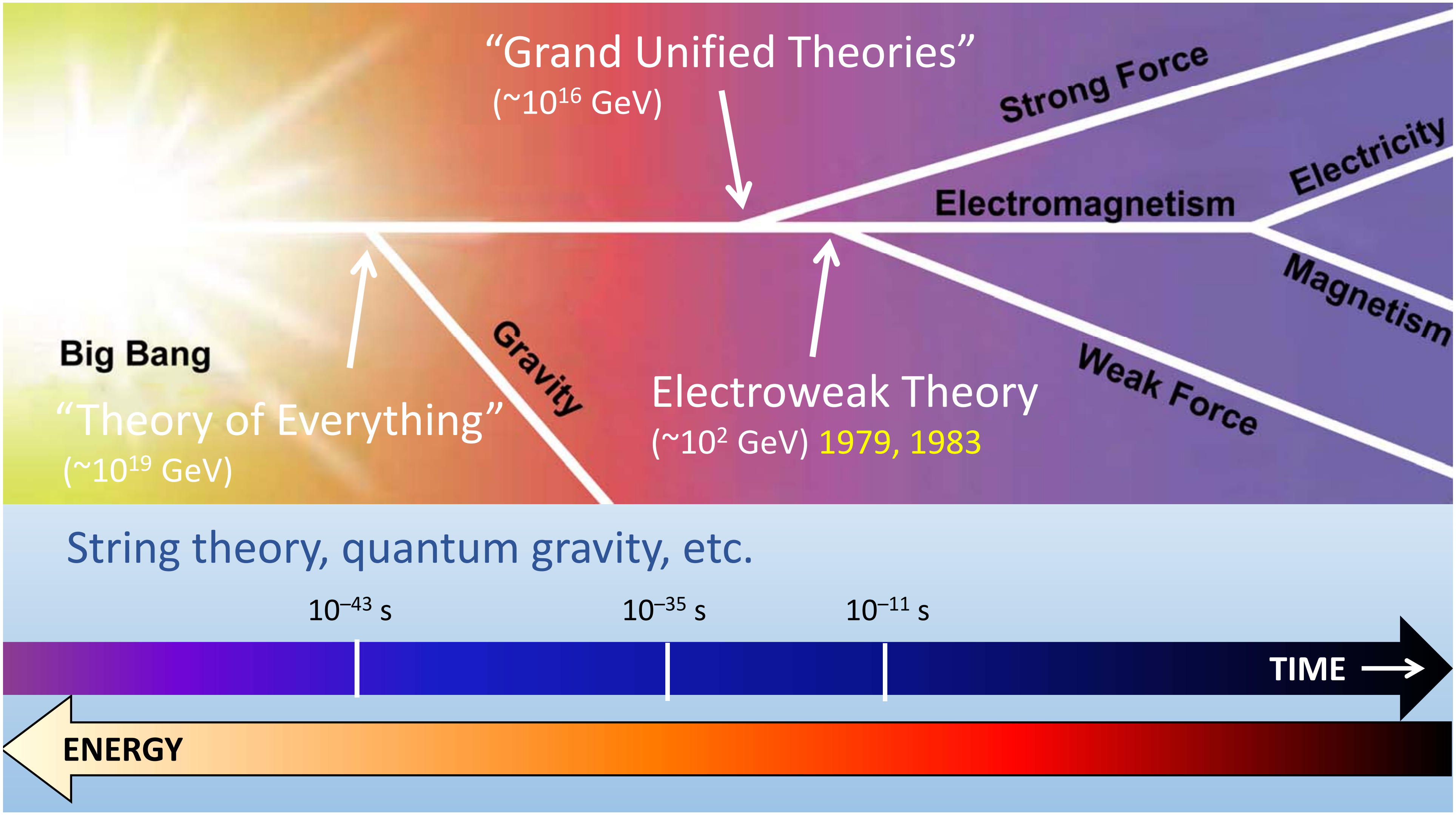
1 μs 1 s 3 min 20 min 380 kyr 8 Myr 13.8 Gyr

TIME →

ENERGY

Unification

At high energies, fundamental forces begin to look the same



“Grand Unified Theories”
(~10^{16} GeV)

Big Bang

“Theory of Everything”
(~10^{19} GeV)

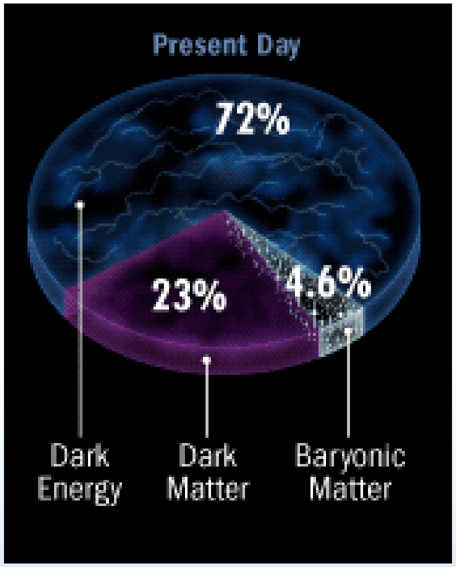
Electroweak Theory
(~10^{2} GeV) 1979, 1983

String theory, quantum gravity, etc.

Some unsolved problems

What is dark matter?

We cannot detect most of the matter in the universe.
It is "dark".



What is the nature of dark energy?

The expansion of the universe is *accelerating*.
A "dark energy" is driving this acceleration

Why is there more matter than antimatter?

The universe is made up mostly of matter

Can the fundamental forces be unified?

There is no unified model of electroweak & strong force, nor a quantum theory of gravity