

End of semester announcements

FINAL EXAM: Next Wed. May 13, 7-10pm (A1), Fri. May 15, 1:30-4:30pm (A2)
Three hours & 45-50 questions
Cumulative & covers material evenly (10-13 questions in each area):

Four main areas:

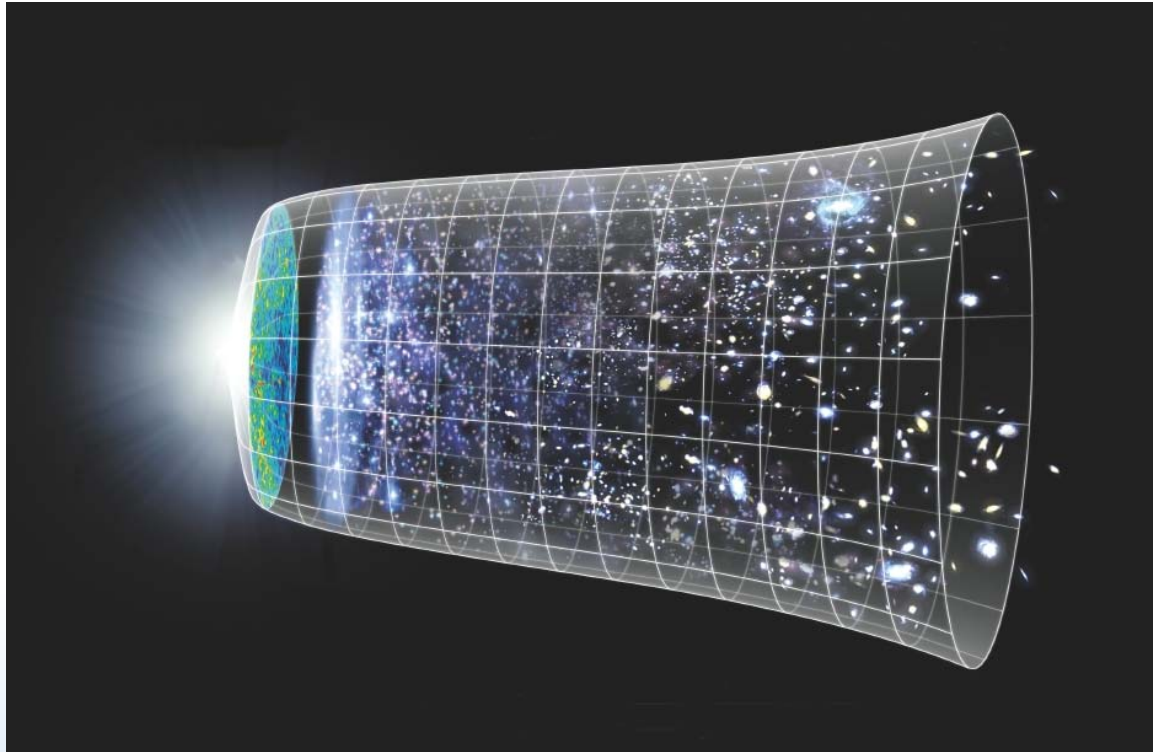
- 1) Electricity (including circuits) – Lect. 1-9
- 2) Magnetism (including EM induction) – Lect. 10-15
- 3) Light and optics – Lect. 16-23
- 4) Modern physics – Lect. 24-28

IN-CLASS REVIEW: Wed. 5/6

OFFICE HOURS: 3-4pm Friday – Tuesday, 161 Loomis

TA office hours this Mon-Wed. Coordinators also available. Check website!

EXTRA PRACTICE: Optional HW on byteshelf, exam-like problems on course website



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

Yes

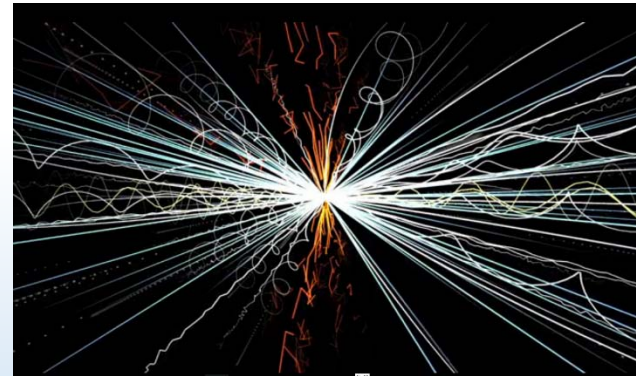
Are the electron, proton, and neutron the fundamental building blocks of matter? Evidence says NO for proton & neutron

Particle “zoo” Hundreds of particles identified in particle accelerator experiments

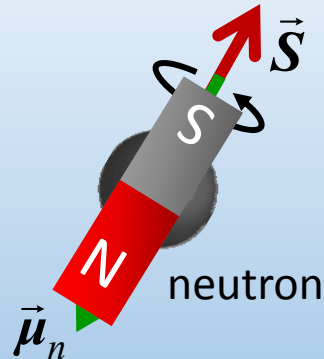
“sigma” $\Sigma^0, \Sigma^+, \Sigma^-$ “xi” Ξ^0, Ξ^-

“pion” π^0, π^+, π^- etc...

“kaon” K^0, K^+



Neutron magnetic dipole moment



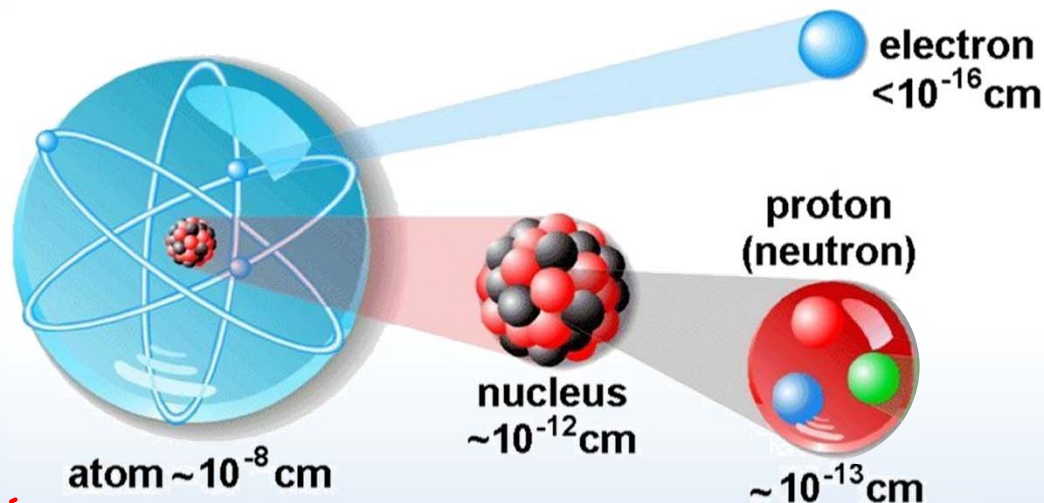
Neutron has spin $\frac{1}{2}$, is electrically neutral, yet has a magnetic dipole moment!

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

Don't confuse
with SPIN!

“Flavors”

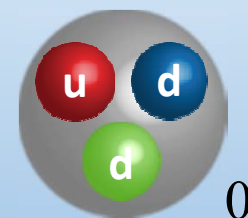
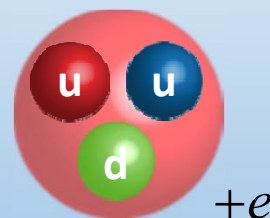
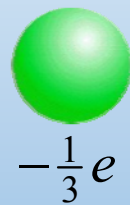
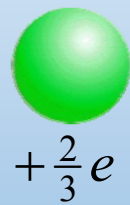
Hadrons are particles composed of quarks

Quark up (u) down (d)

1 proton = uud

1 neutron = udd

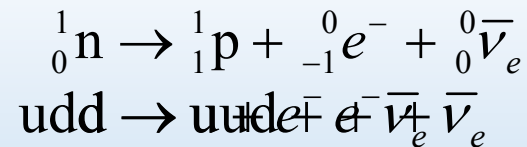
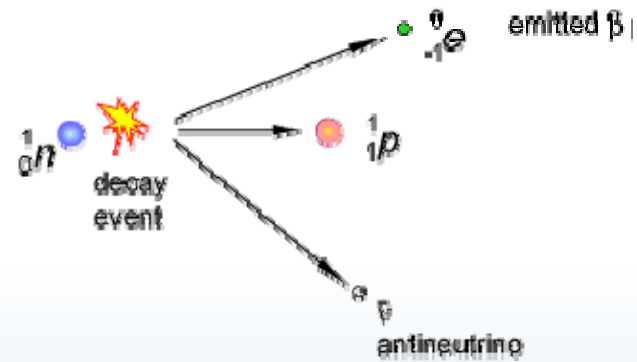
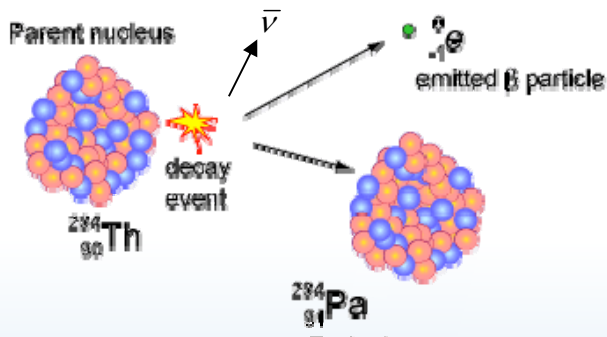
Charge





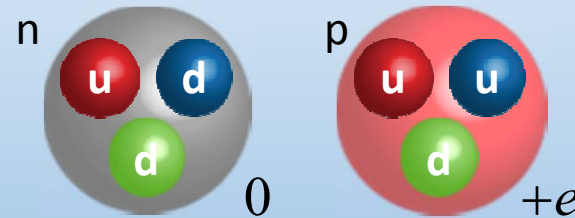
ACT: Beta decay

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



How could this decay be described in terms of quarks?

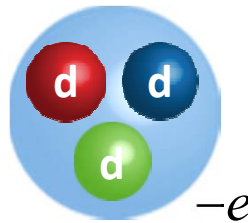
- A. A d converts to a u
- B. A u converts to a d
- C. A d converts to an e^{-}





ACT: Hadrons & quarks

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



What could the quark makeup of this particle be?

A. uuu

$$+\frac{2}{3}e + \frac{2}{3}e + \frac{2}{3}e$$

B. ddd

$$-\frac{1}{3}e - \frac{1}{3}e - \frac{1}{3}e$$

C. an e^- & ν_e Not quarks

Building blocks of matter

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

Generation 1

mass $\rightarrow \approx 2.3 \text{ MeV}/c^2$
charge $\rightarrow 2/3$
spin $\rightarrow 1/2$

u
up

'74

'95

mass $\rightarrow \approx 4.8 \text{ MeV}/c^2$
charge $\rightarrow -1/3$
spin $\rightarrow 1/2$

d
down

'74

'77

QUARKS

mass $\rightarrow 0.511 \text{ MeV}/c^2$
charge $\rightarrow -1$
spin $\rightarrow 1/2$

e
electron

'75

LEPTONS

mass $\rightarrow < 2.2 \text{ eV}/c^2$
charge $\rightarrow 0$
spin $\rightarrow 1/2$

ν_e
electron neutrino

'00

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

Mass



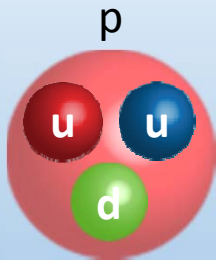
ACT: Quarks

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



Quarks are spin $\frac{1}{2}$ particles, so they obey the Pauli Exclusion Principle like electrons!

What about 2 u quarks in proton (or 2 d in neutron)?

Quarks have a quantum number known as *color charge* (analogous to electric charge, but for strong force), which must be different for each quark in proton.

4 Fundamental forces of Nature

Gravitational force (solar system, galaxies)

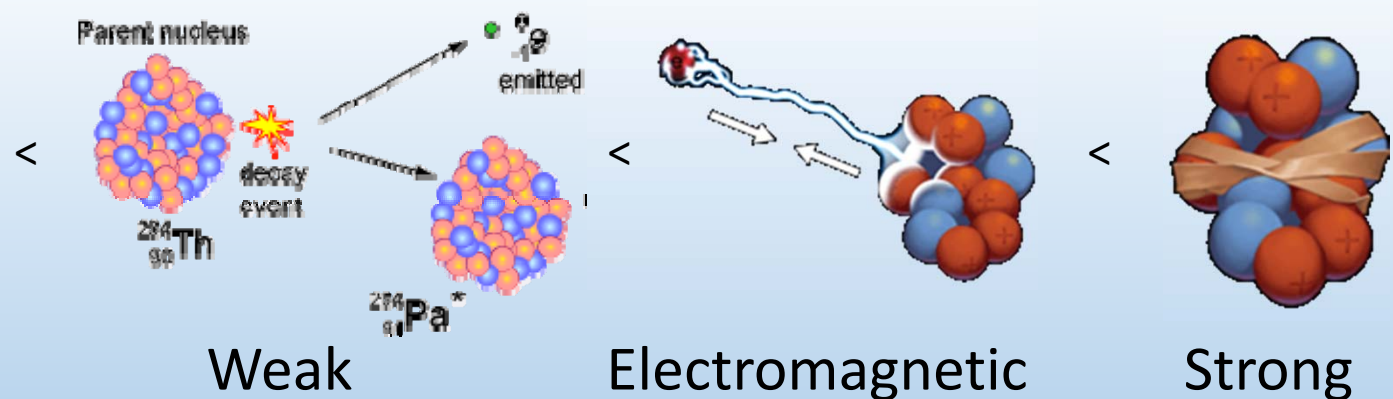
Electromagnetic force (atoms, molecules)

Strong force (atomic nuclei)

Weak force (radioactive decay)



Gravitational



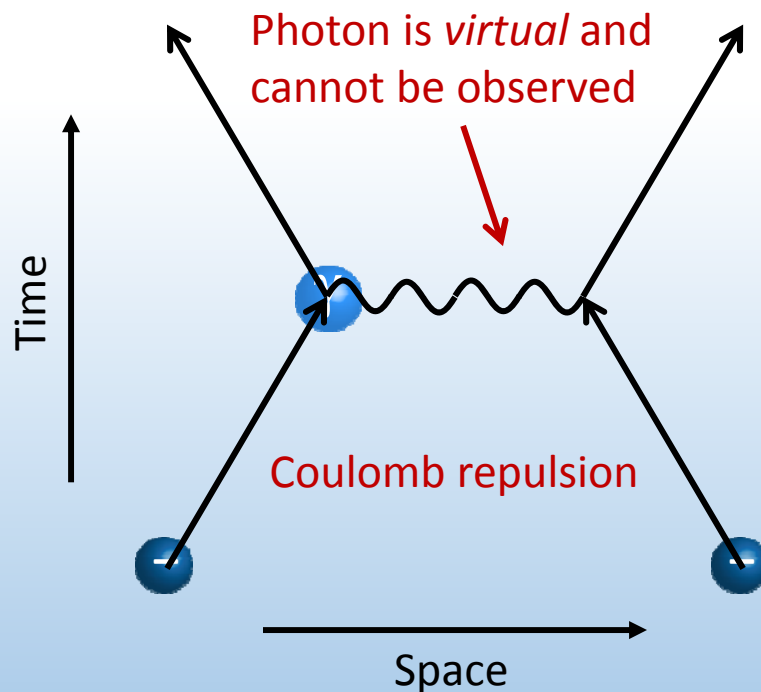
weakest

strongest

Particle physics view of forces

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

Ex: electromagnetic exchange particle is the *photon*!



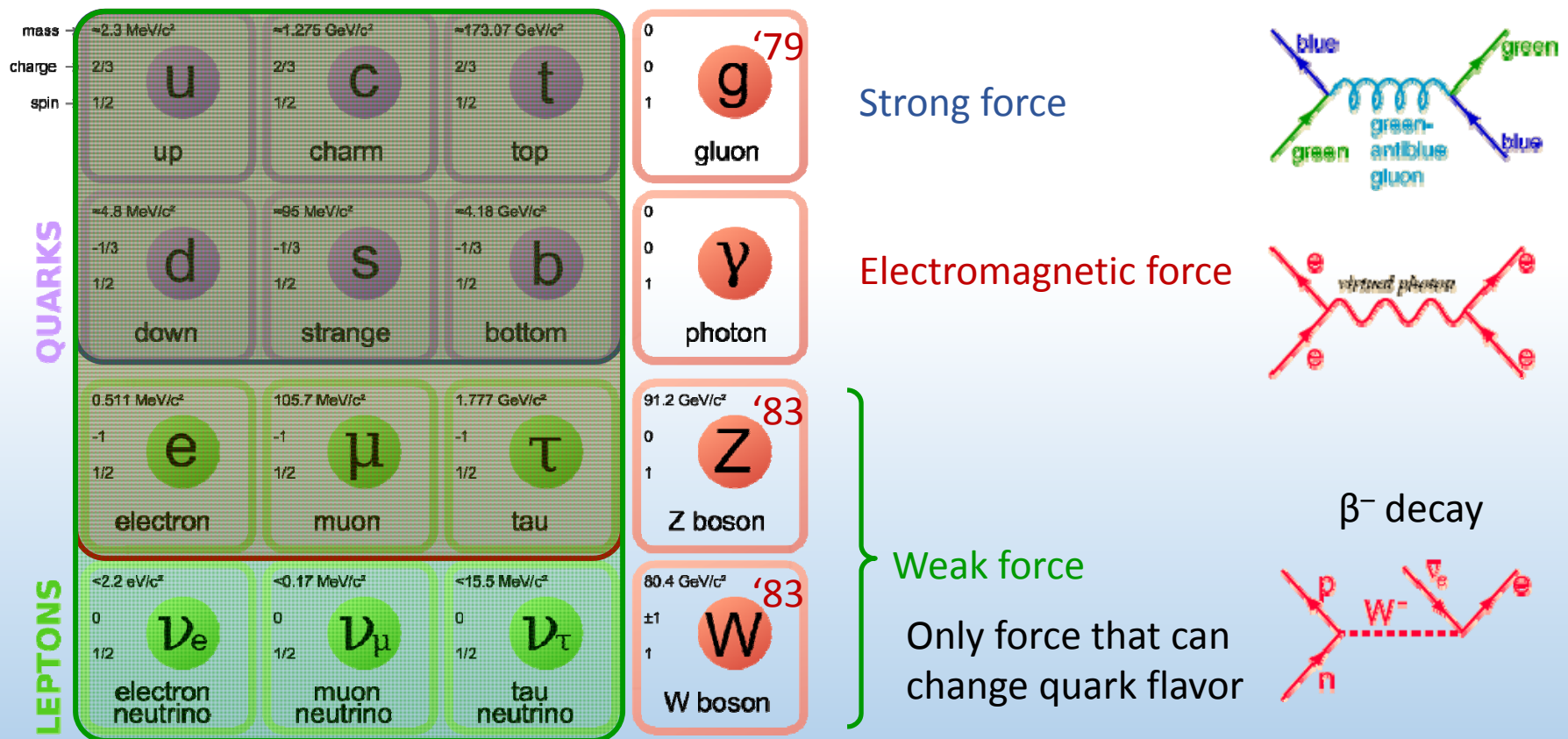
“Feynman diagram”



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*



What about gravity?

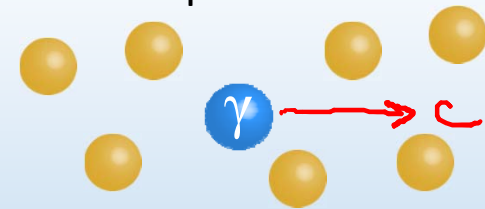
The Higgs boson

Higgs boson gives elementary particles their masses

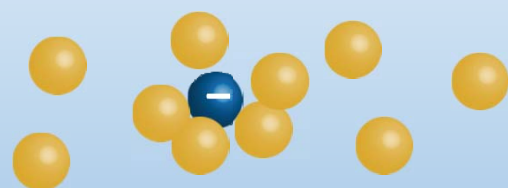
QUARKS	mass → $\approx 2.3 \text{ MeV}/c^2$ charge → $2/3$ spin → $1/2$  up	mass → $\approx 1.275 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$  charm	mass → $\approx 173.07 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$  top	mass → 0 charge → 0 spin → 1  gluon
	mass → $\approx 4.8 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$  down	mass → $\approx 95 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$  strange	mass → $\approx 4.18 \text{ GeV}/c^2$ charge → $-1/3$ spin → $1/2$  bottom	mass → 0 charge → 0 spin → 1  photon
	mass → $0.511 \text{ MeV}/c^2$ charge → -1 spin → $1/2$  electron	mass → $105.7 \text{ MeV}/c^2$ charge → -1 spin → $1/2$  muon	mass → $1.777 \text{ GeV}/c^2$ charge → -1 spin → $1/2$  tau	mass → $91.2 \text{ GeV}/c^2$ charge → 0 spin → 1  Z boson
LEPTONS	mass → $< 2.2 \text{ eV}/c^2$ charge → 0 spin → $1/2$  electron neutrino	mass → $< 0.17 \text{ MeV}/c^2$ charge → 0 spin → $1/2$  muon neutrino	mass → $< 15.5 \text{ MeV}/c^2$ charge → 0 spin → $1/2$  tau neutrino	mass → $80.4 \text{ GeV}/c^2$ charge → ± 1 spin → 1  W boson
GAUGE BOSONS				

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

Massless photon



Massive electron





ACT: Fundamental forces

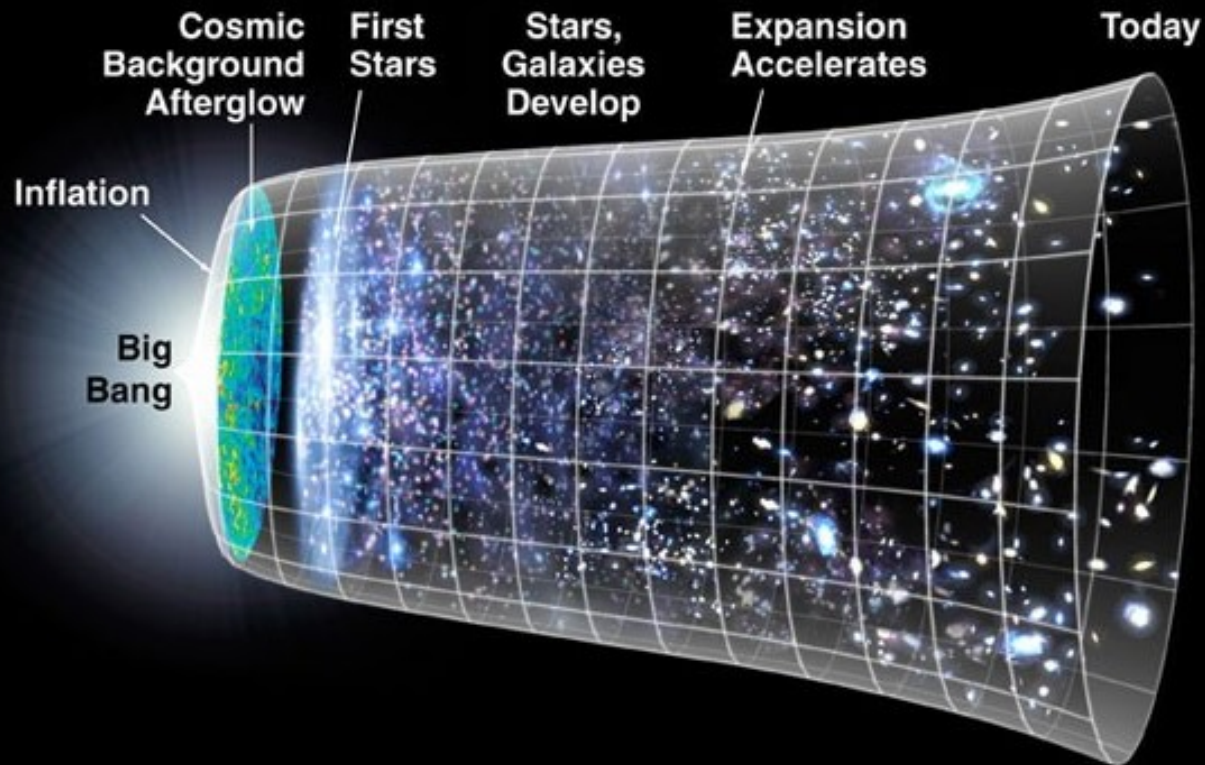
Which of the following particles can interact via the electromagnetic force?

- A. A muon $-e$
- B. An up quark $+\frac{2}{3}e$
- C. A strange quark $-\frac{1}{3}e$
- D. All of the above
- E. None of the above

All three particles have electric charge!

The expansion of the universe

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

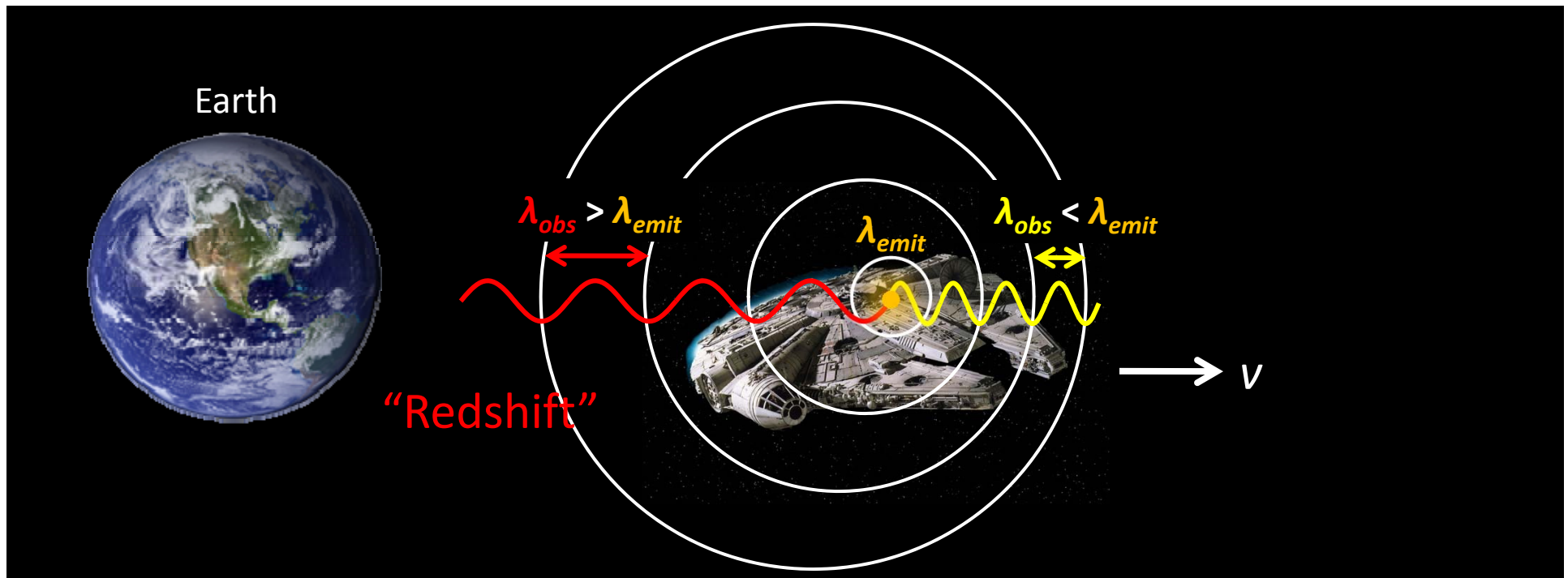




ACT: Doppler effect

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}

$$\frac{\lambda_{emit}}{\lambda_{obs}} = \frac{f_{obs}}{f_{emit}} = \sqrt{\frac{1 + v_{rel}/c}{1 - v_{rel}/c}} < 1$$

Emitter moving away: $v_{rel} < 0$

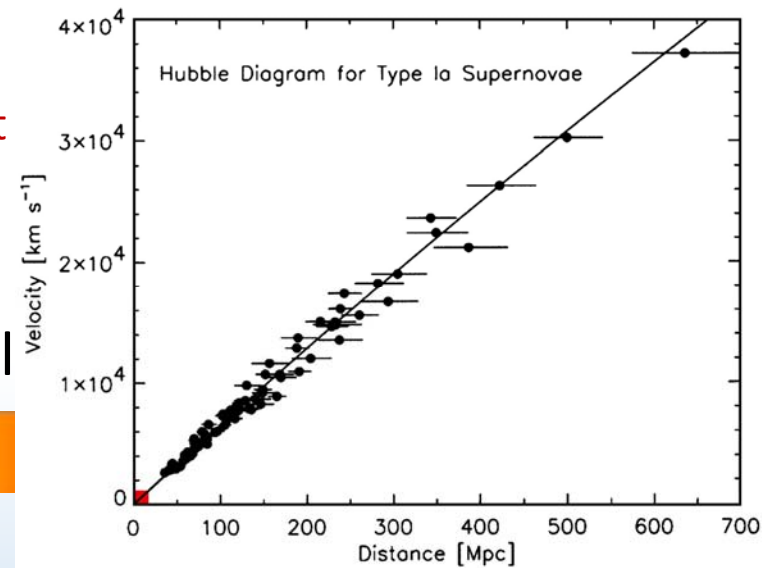


ACT: Hubble law

More distant celestial objects recede from us *faster*

Recessional velocity \rightarrow $v = H_0 d$ \leftarrow Distance to object

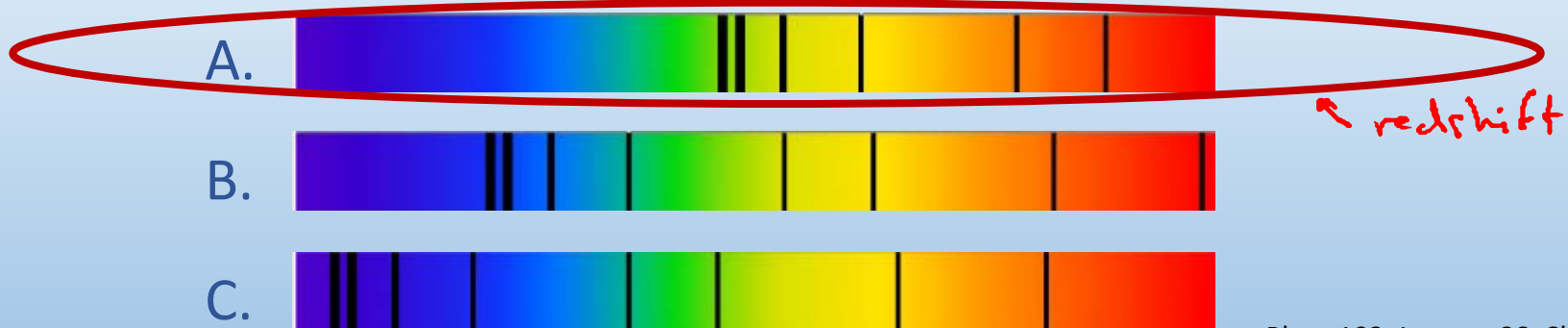
\uparrow
"Hubble" constant 70 km/s Mpc



The light spectrum of a stationary gal



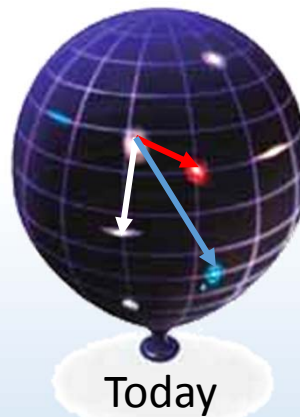
Which of the following belongs to the most distant galaxy?



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: $v = \frac{d}{t} = H_0 d$

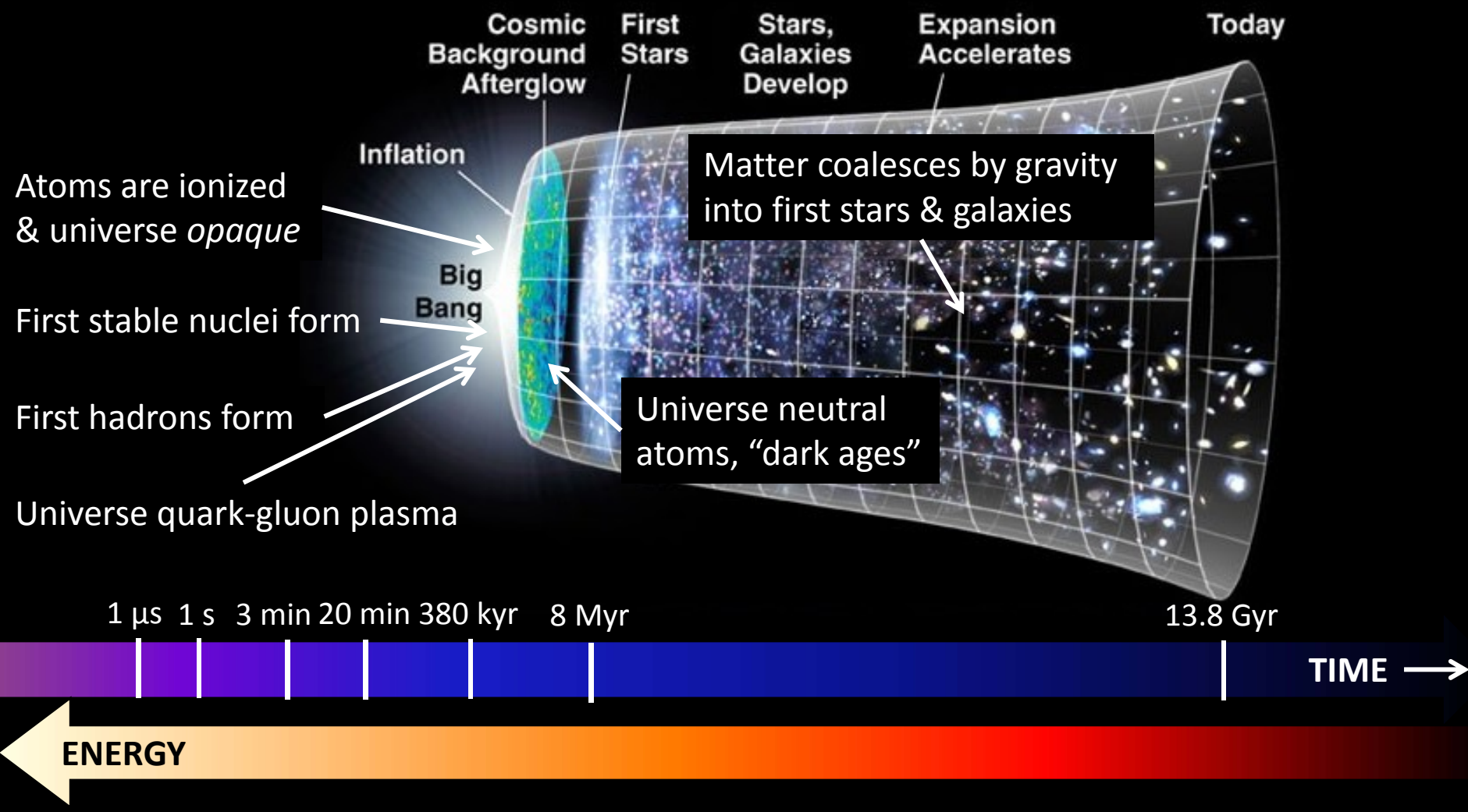
$$t_{universe} = \frac{1}{H_0} = \frac{1}{70} \frac{\text{s} \cdot \text{Mpc}}{\text{km}} 3 \times 10^{19} \frac{\text{km}}{\text{Mpc}} \frac{1}{60 \cdot 60 \cdot 24 \cdot 365} \frac{\text{yr}}{\text{s}} \approx 14 \text{ Gyr}$$

1 "Megaparsec" = 1 Mpc = 3×10^{19} km

Best estimate is 13.8 Gyr

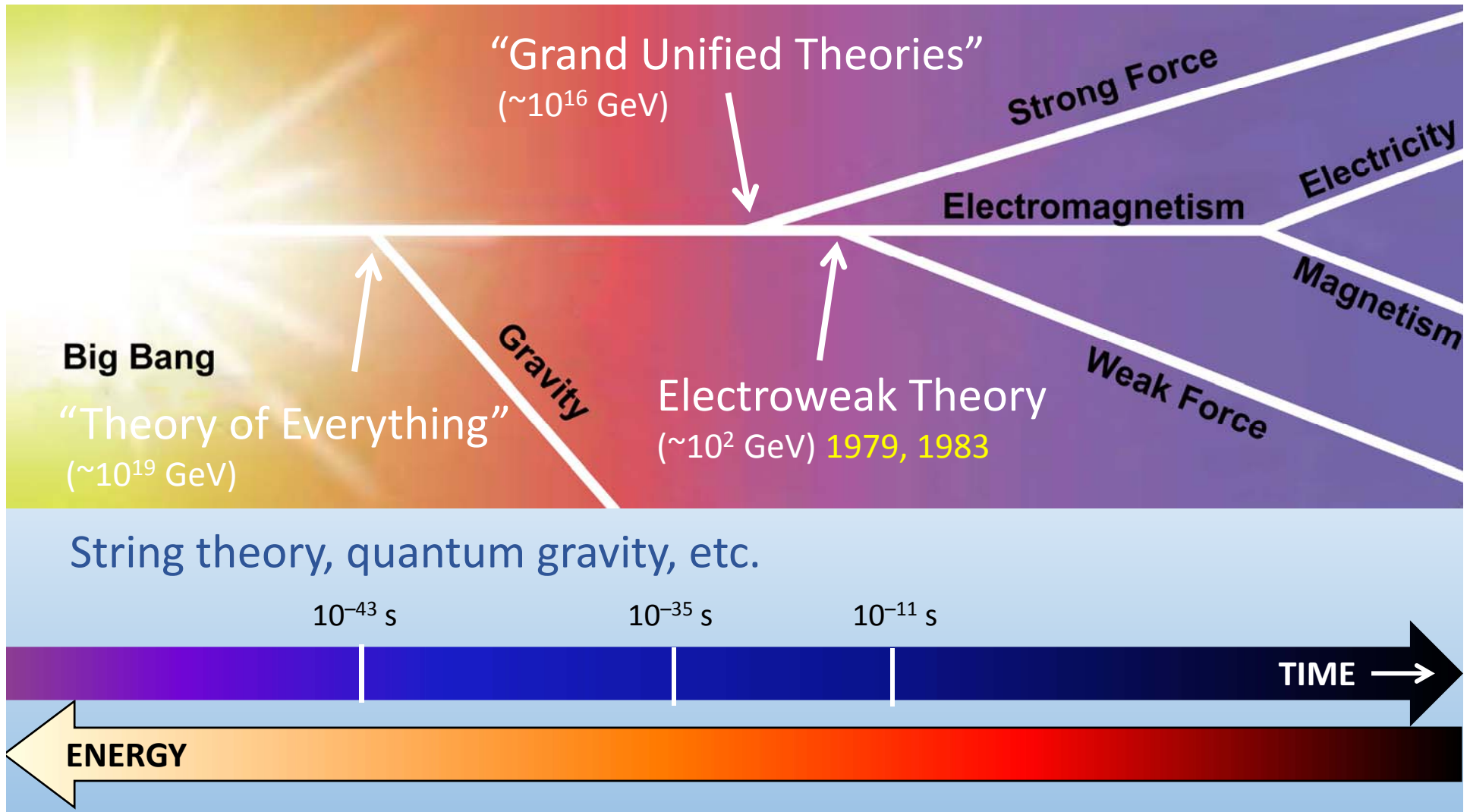
A journey back in time...

Early universe was smaller, more dense, & hotter



Unification

At high energies, fundamental forces begin to look the same



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

