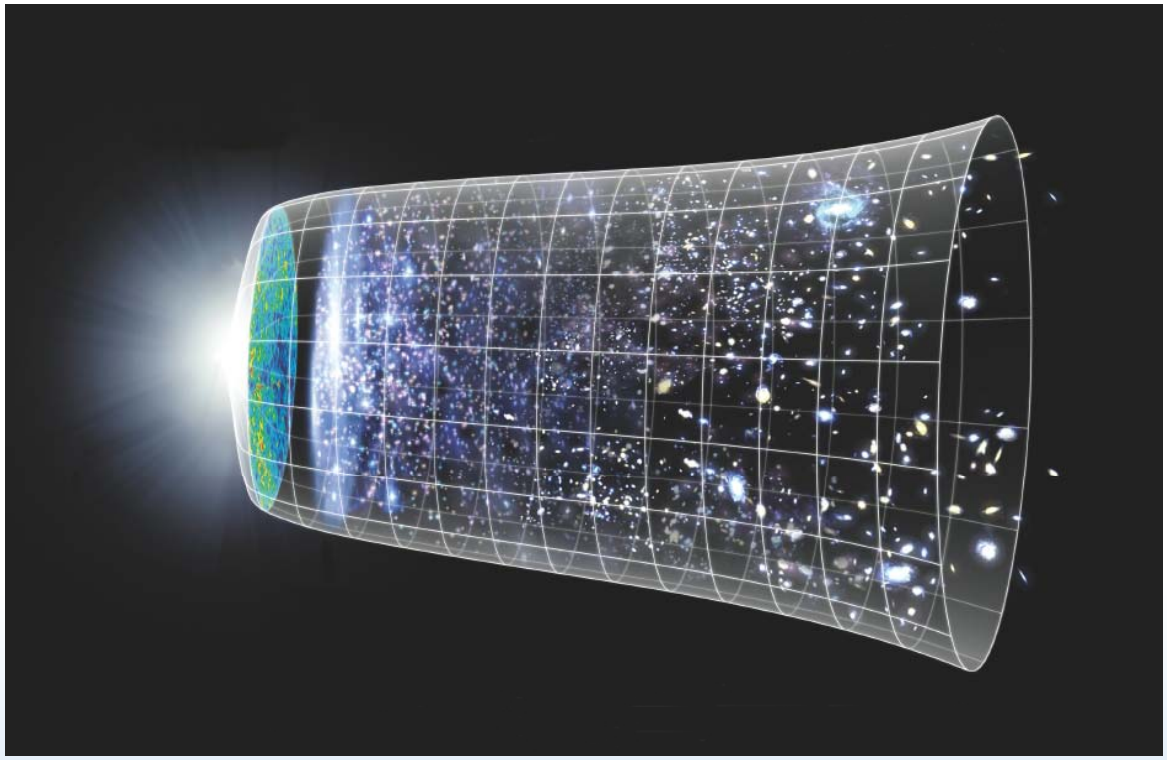


Phys 102 – Lecture 28

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

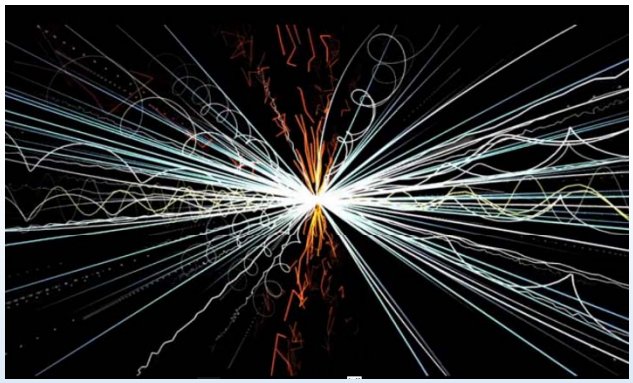
Are the electron, proton, and neutron the fundamental building blocks of matter?

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

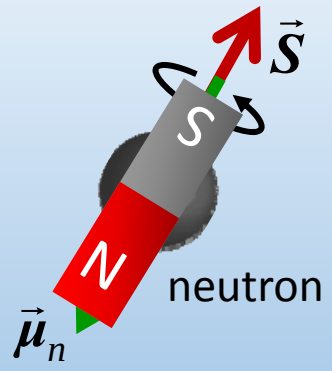
"sigma" Σ^0, Σ^+, Σ^- "xi" Ξ^0, Ξ^-

"pion" π^0, π^+, π^- etc...

"kaon" κ^0, κ^+



Neutron magnetic dipole moment

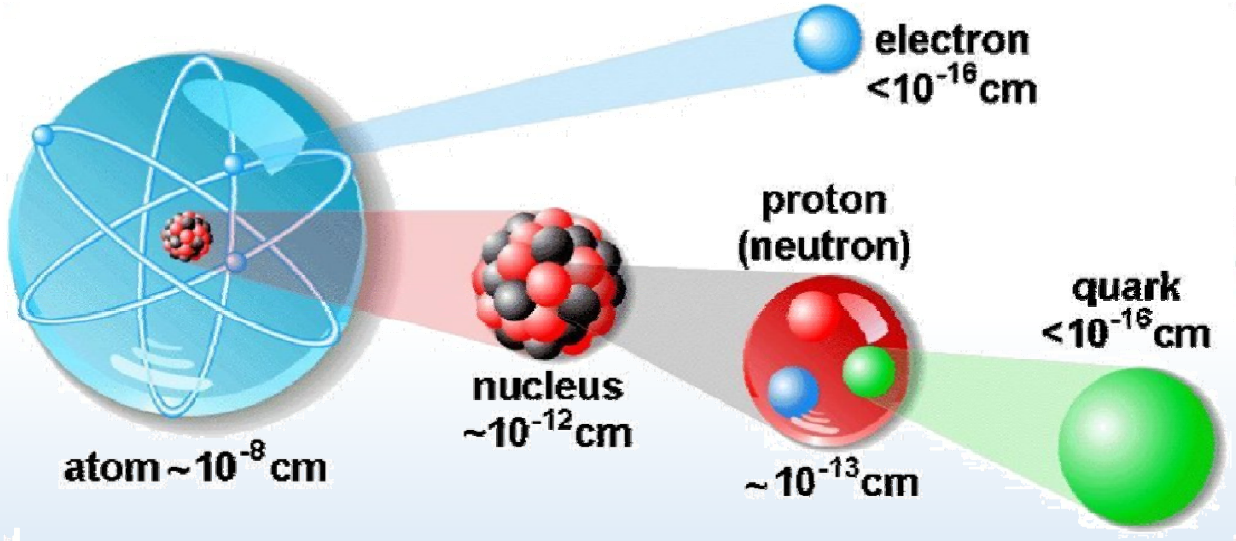


Neutron has spin ½, is electrically neutral, yet has a magnetic dipole moment!

Indicates these are *composite* particles

Quarks

Neutrons and protons are composite particles



Discovered in 1968

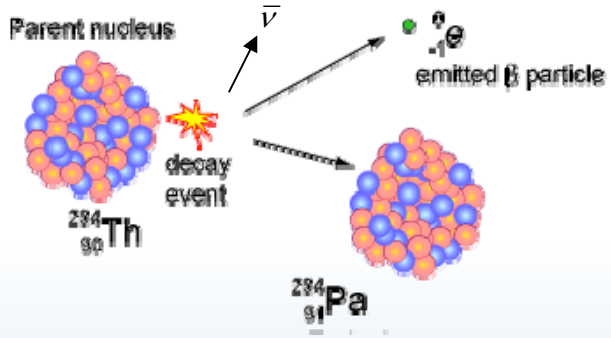
"Flavors"

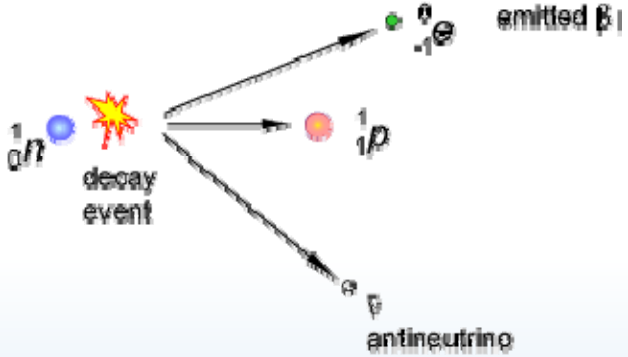
Hadrons are particles composed of quarks

Quark	up (u)	down (d)	1 proton = uud	1 neutron = udd
Charge	$+\frac{2}{3}e$	$-\frac{1}{3}e$	$+e$	0

ACT: Beta decay

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





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

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

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

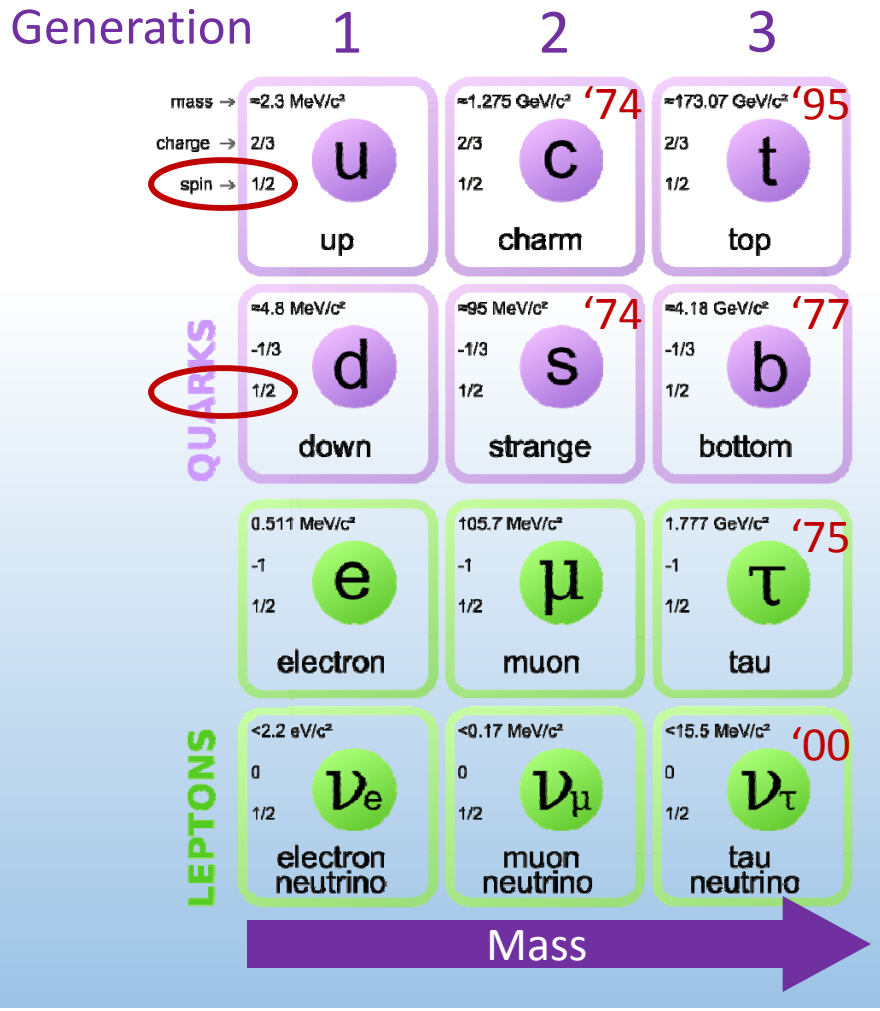
The Δ^- is an exotic hadron with charge –e.

What could the quark makeup of this particle be?

A. uuu
B. ddd
C. an e^- & ν_e

Building blocks of matter

Most of matter is made of u, d, e and ν_e



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

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

ACT: Quark spin

The quark has spin ½, so how is it that the proton and neutron, which have 3 quarks, can have spin ½?

A. One spin points opposite the other two
B. The spin of the proton is independent of the quark spin

4 Fundamental forces of Nature

Gravitational force (solar system, galaxies)

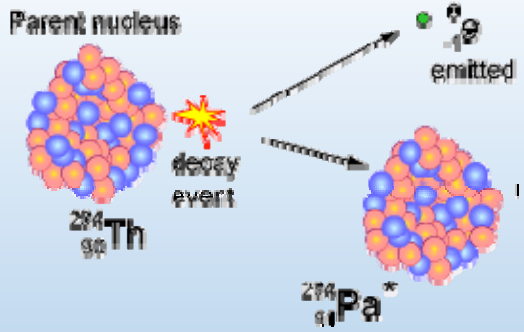
Electromagnetic force (atoms, molecules)

Strong force (atomic nuclei)

Weak force (radioactive decay)

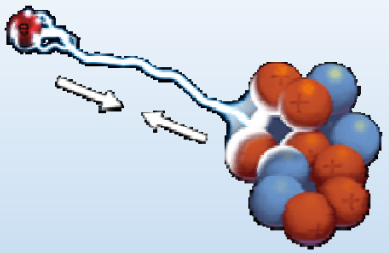
Gravitational

<



Weak

<



Electromagnetic

<

Strong

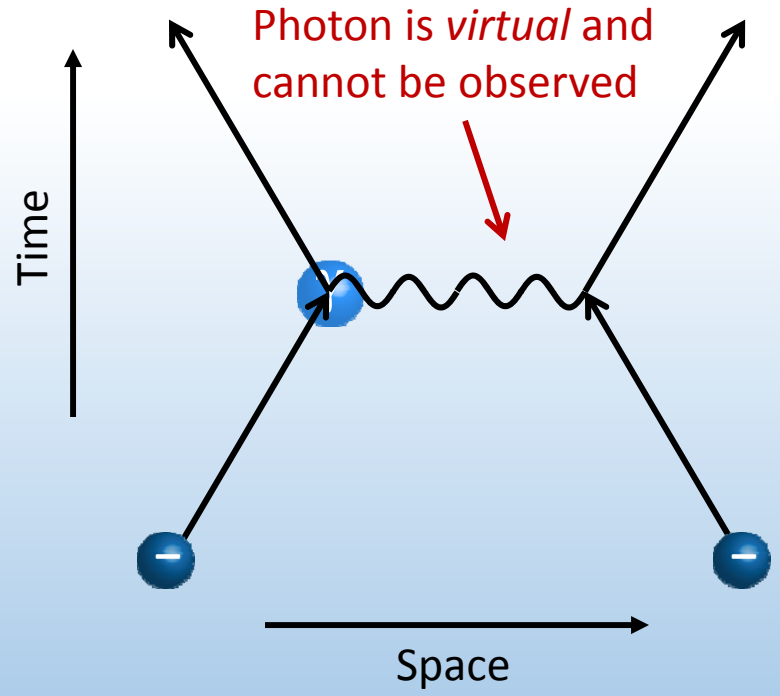
weakest

strongest

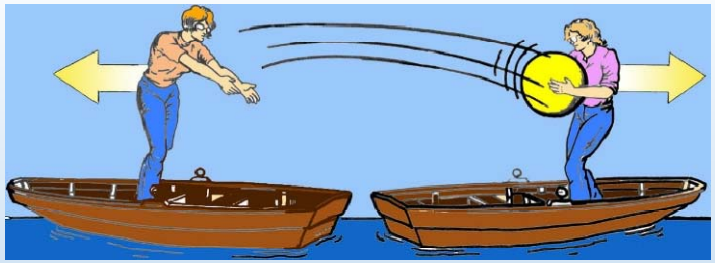
Particle physics view of forces

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

Ex: electromagnetic exchange particle is the *photon*!



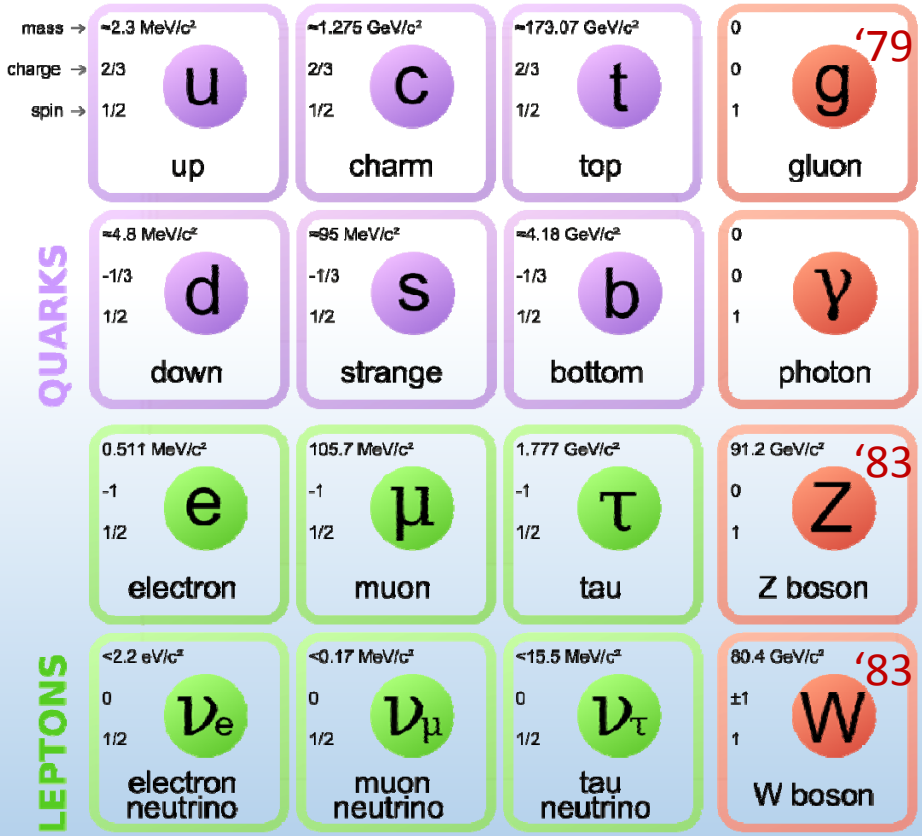
"Feynman diagram"



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

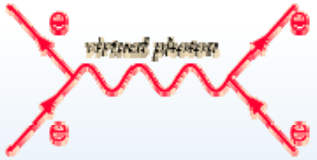
The "Standard Model"

Exchange particles for are known as *gauge bosons*



Strong force

Electromagnetic force



Weak force

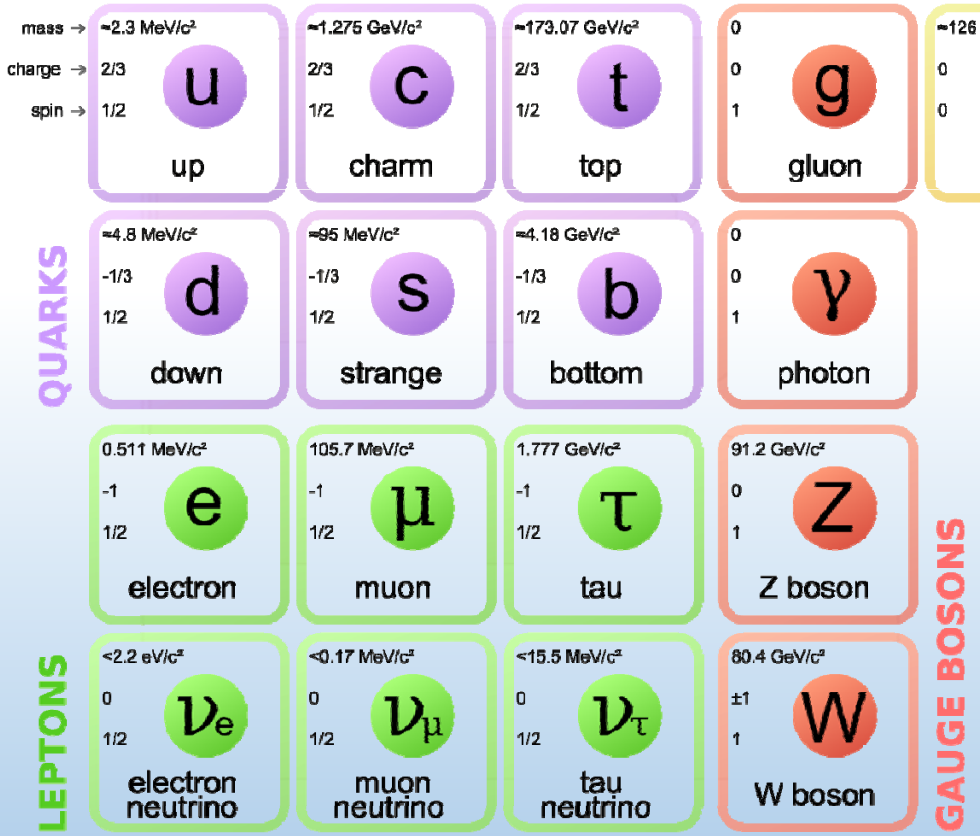
Only force that can change quark flavor

β^- decay

What about gravity?

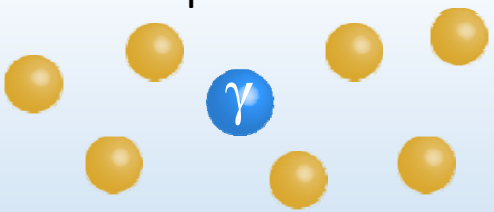
The Higgs boson

Higgs boson gives elementary particles their masses

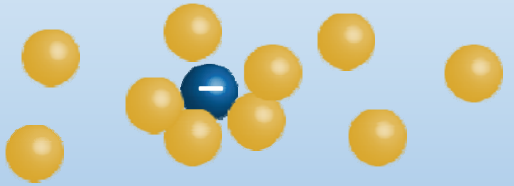


The more massive the particle, the more it interacts with the Higgs boson

Massless photon

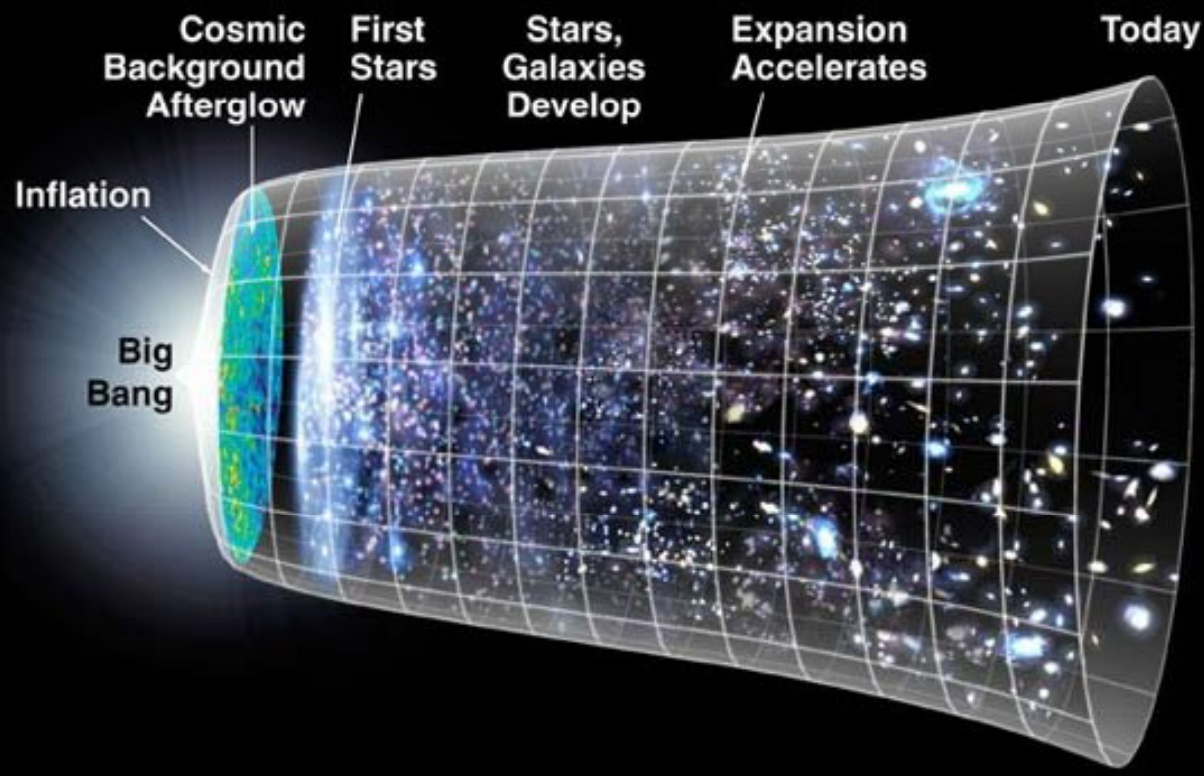


Massive electron



The expansion of the universe

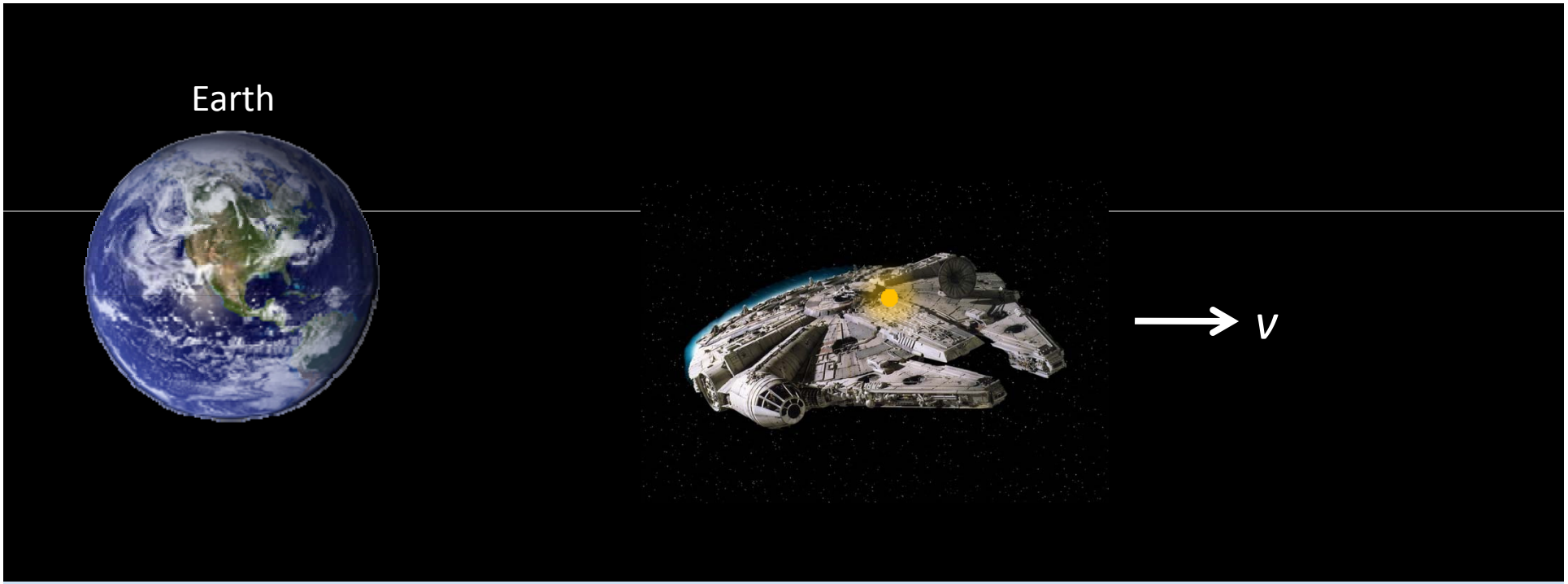
Astronomers observed that all celestial bodies are *receding* from us. Therefore, the universe is expanding!



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 → $v = H_0 d$ ← Distance to object

"Hubble" constant

The absorption spectrum of a stationary galaxy is given by:

Recall Lect. 25

Which of the following belongs to the most distant galaxy?

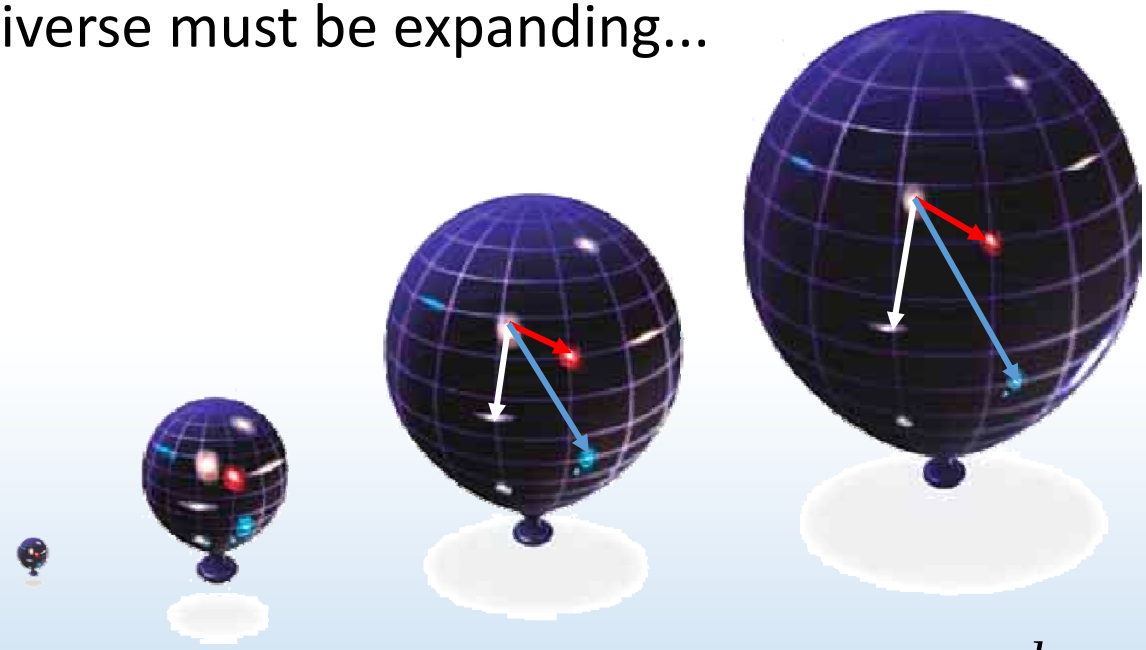
A.

B.

C.

The Big Bang

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



Distances increased in every direction

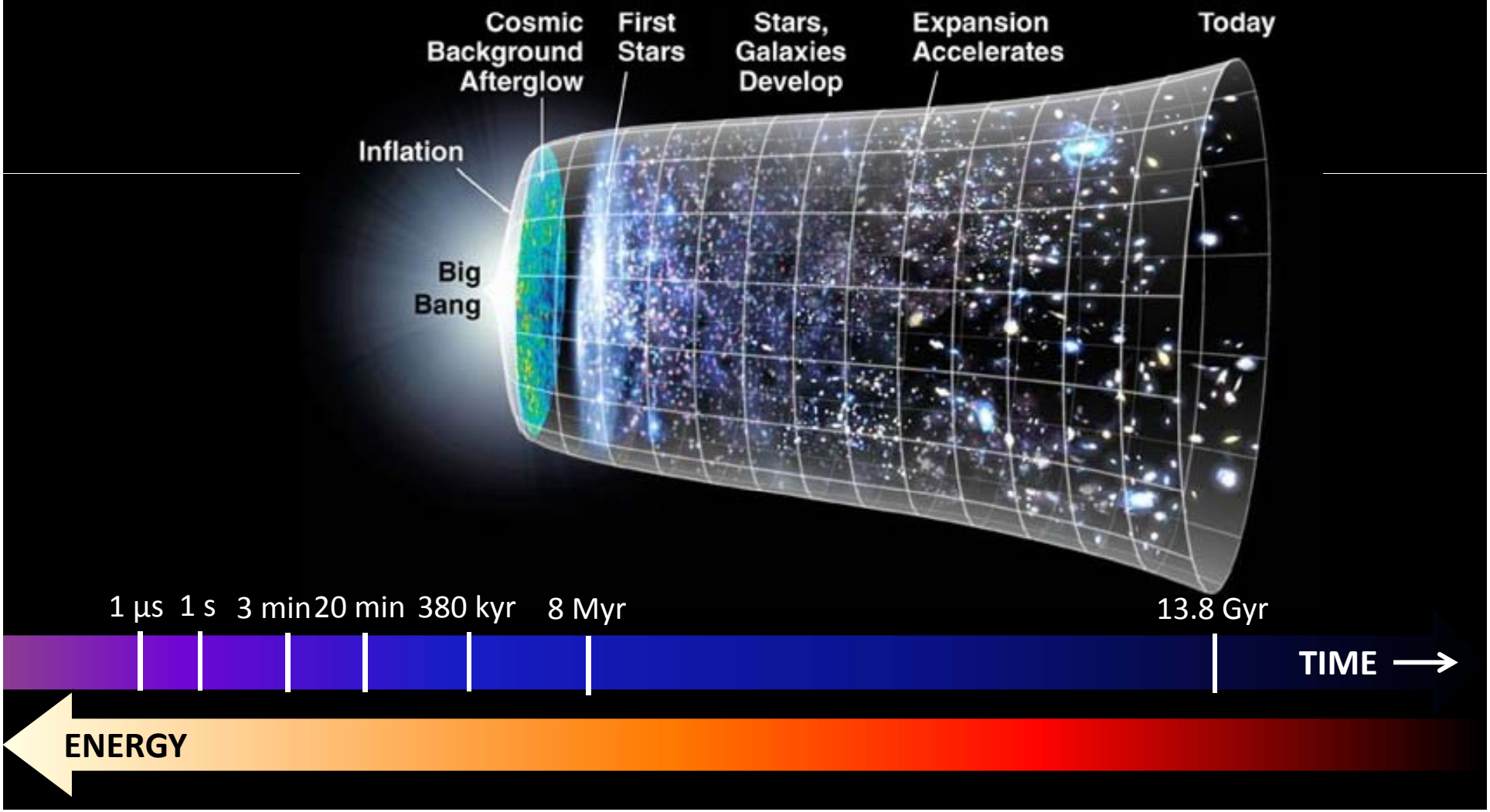
DEMO

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

$$t_{universe} = \frac{1}{H_0}$$

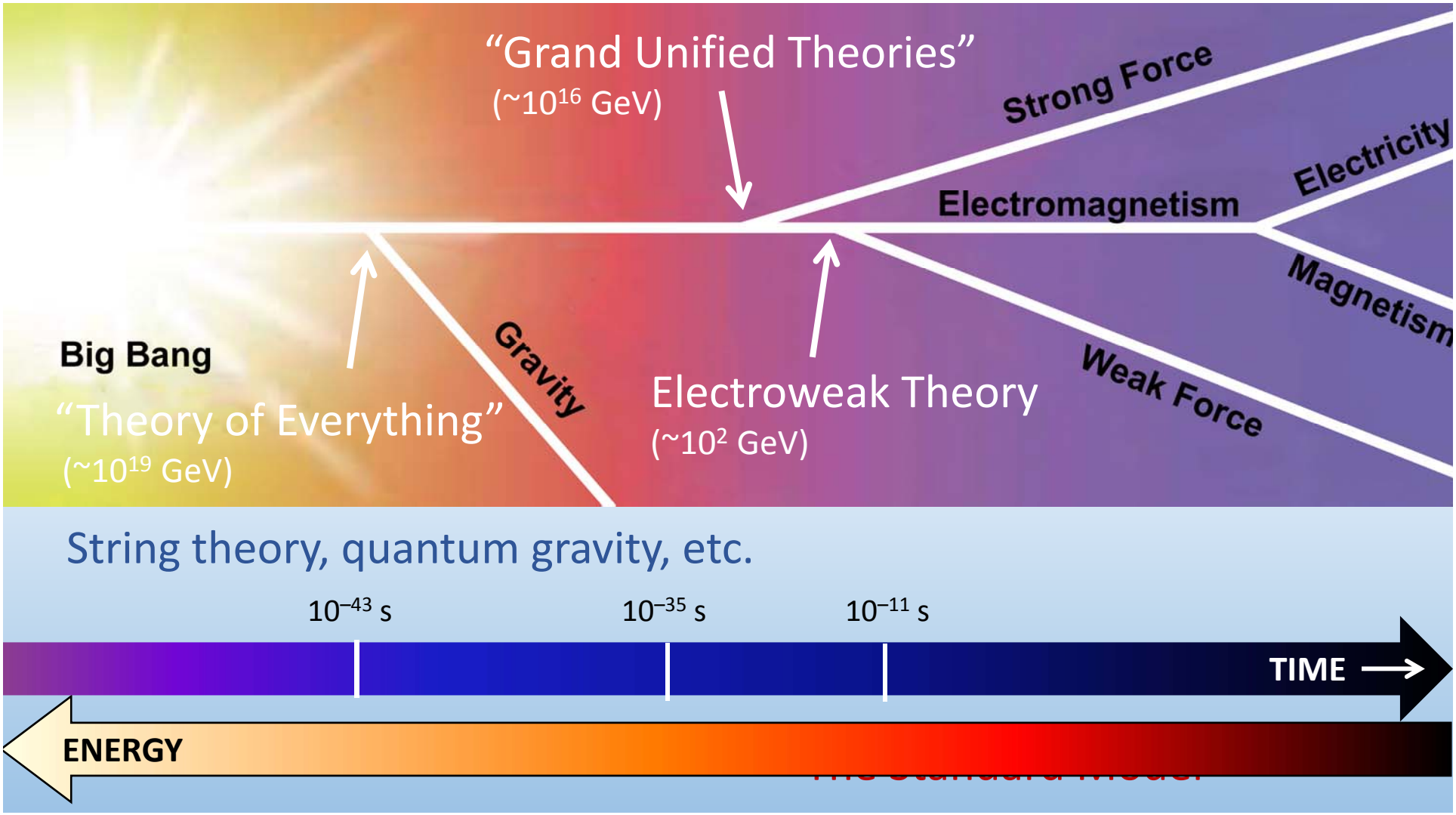
A journey back in time...

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?

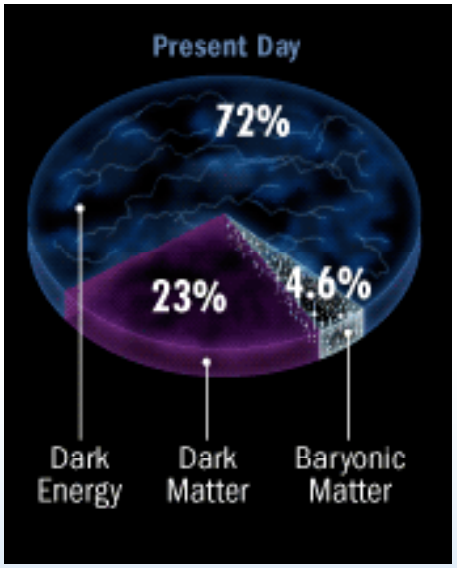
We cannot detect most of the matter in the universe.
It is “dark”.

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