Physics 51 LECTURE 3 October 10, 2011

Newton's Laws

1. inertia — inertial reference frames
2. F/a = mass — is a property of matter
3. $F_{ab} = - F_{ba}$ — momentum conservation

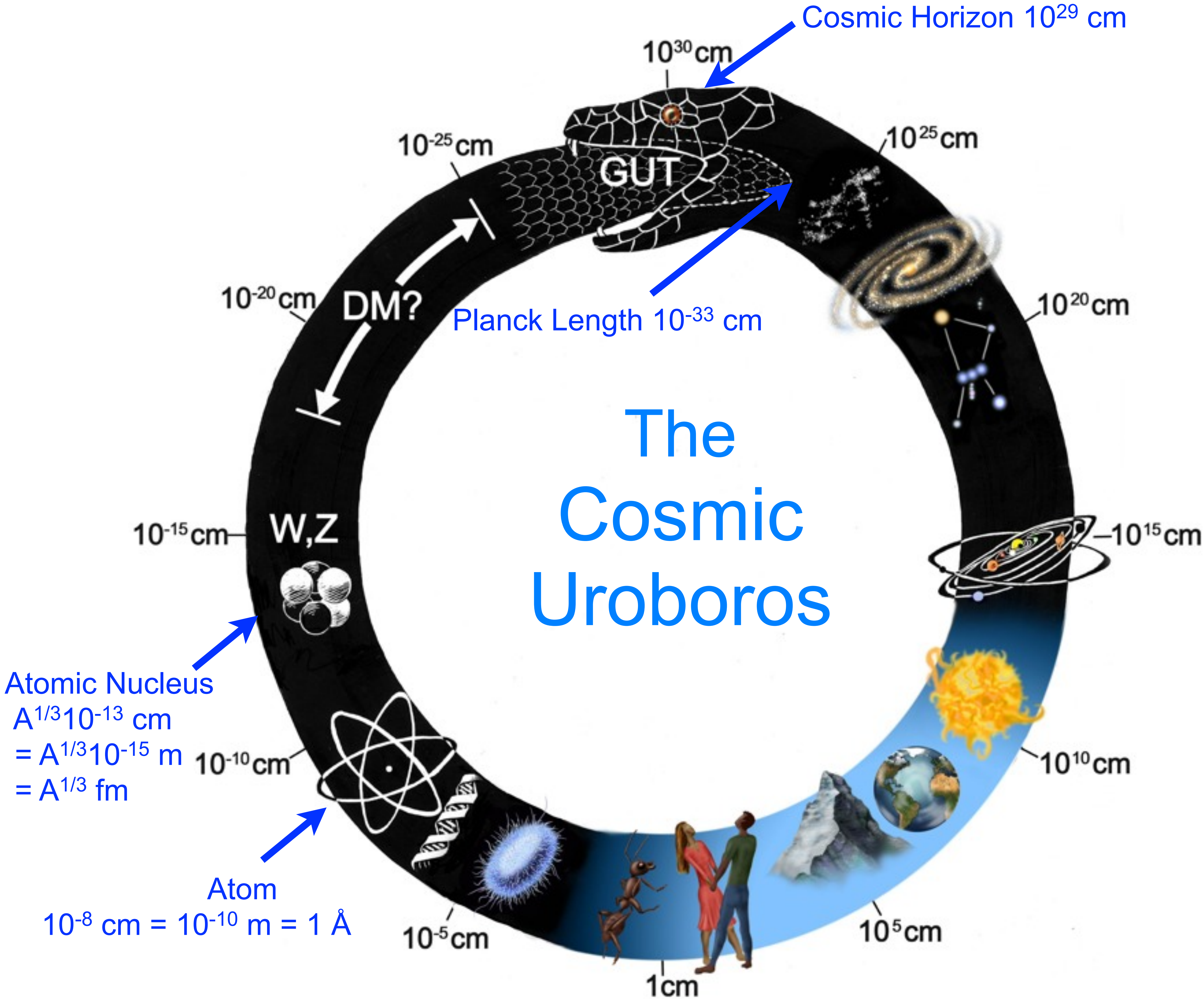
Forces need to be specified: approximate vs. fundamental

Friction and Drag forces formulas are approximate:

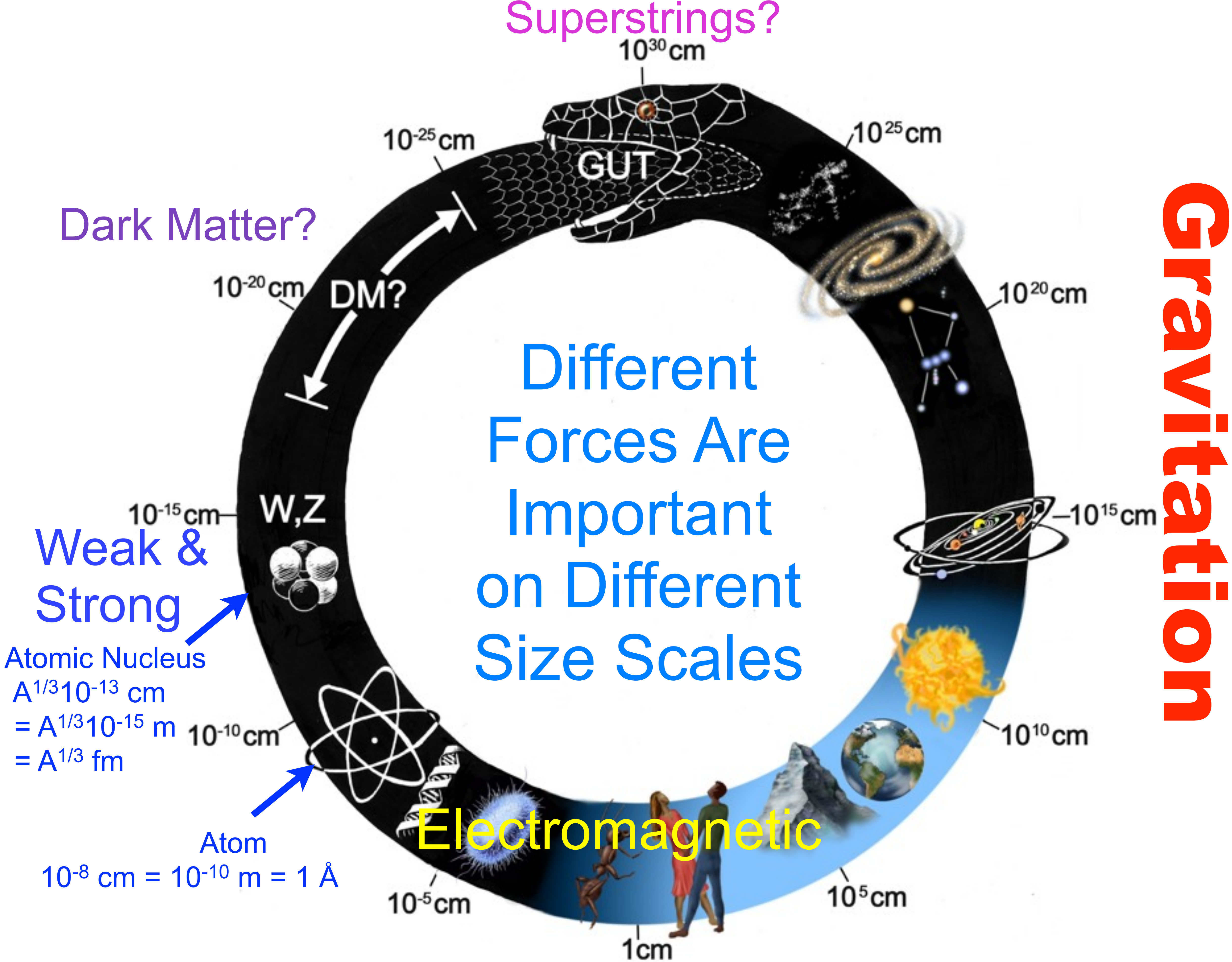
$F_{friction} = \mu N$, $F_{drag} = -bv$ (low speed)

$= -kv^2$ (high speed), $k=\rho A C_d/2$

Fundamental Forces (Gravity, Electromagnetism, Weak and Strong Interactions) on the Cosmic Uroboros: different forces are important at different size scales. Other forces may be discovered on smaller size scales.

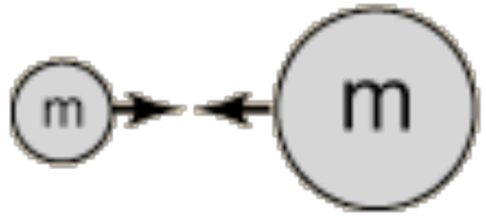


Cosmic Horizon 10^{29} cm
10^{30} cm
10^{-25} cm
GUT
10^{25} cm
10^{-20} cm
DM?
Planck Length 10^{-33} cm
10^{20} cm
The Cosmic Uroboros
10^{-15} cm
W,Z
10^{15} cm
Atomic Nucleus
$A^{1/3}10^{-13}$ cm
$= A^{1/3}10^{-15}$ m
$= A^{1/3}$ fm
10^{-10} cm
10^{10} cm
Atom
10^{-8} cm = 10^{-10} m = 1 Å
10^{-5} cm
10^{5} cm
1cm


Superstrings?
10^30 cm
10^-25 cm
GUT
10^25 cm
Dark Matter?
10^-20 cm
DM?
10^20 cm
Different Forces Are Important on Different Size Scales
Gravitation
10^-15 cm
W,Z
10^15 cm
Weak & Strong
Atomic Nucleus
A^1/3 10^-13 cm
= A^1/3 10^-15 m
= A^1/3 fm
10^-10 cm
10^10 cm
Electromagnetic
Atom
10^-8 cm = 10^-10 m = 1 Å
10^-5 cm
10^5 cm
1cm

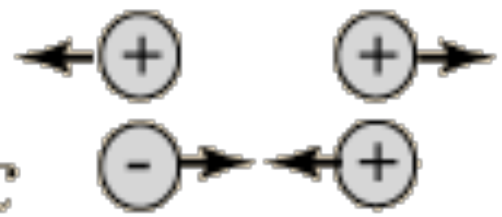
Fundamental Forces

Gravity



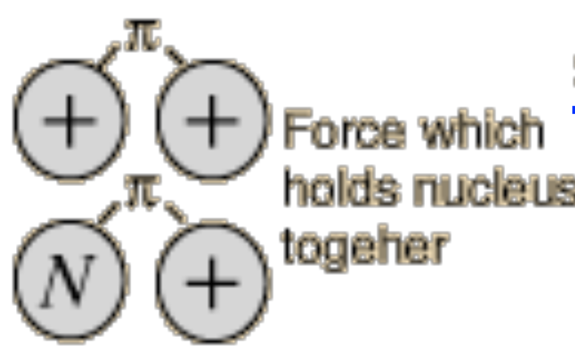
Strength	Range (m)	Particle
6×10^{-39}	Infinite	graviton mass = 0 spin = 2

Electro-magnetic



Strength	Range (m)	Particle
$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1

Strong



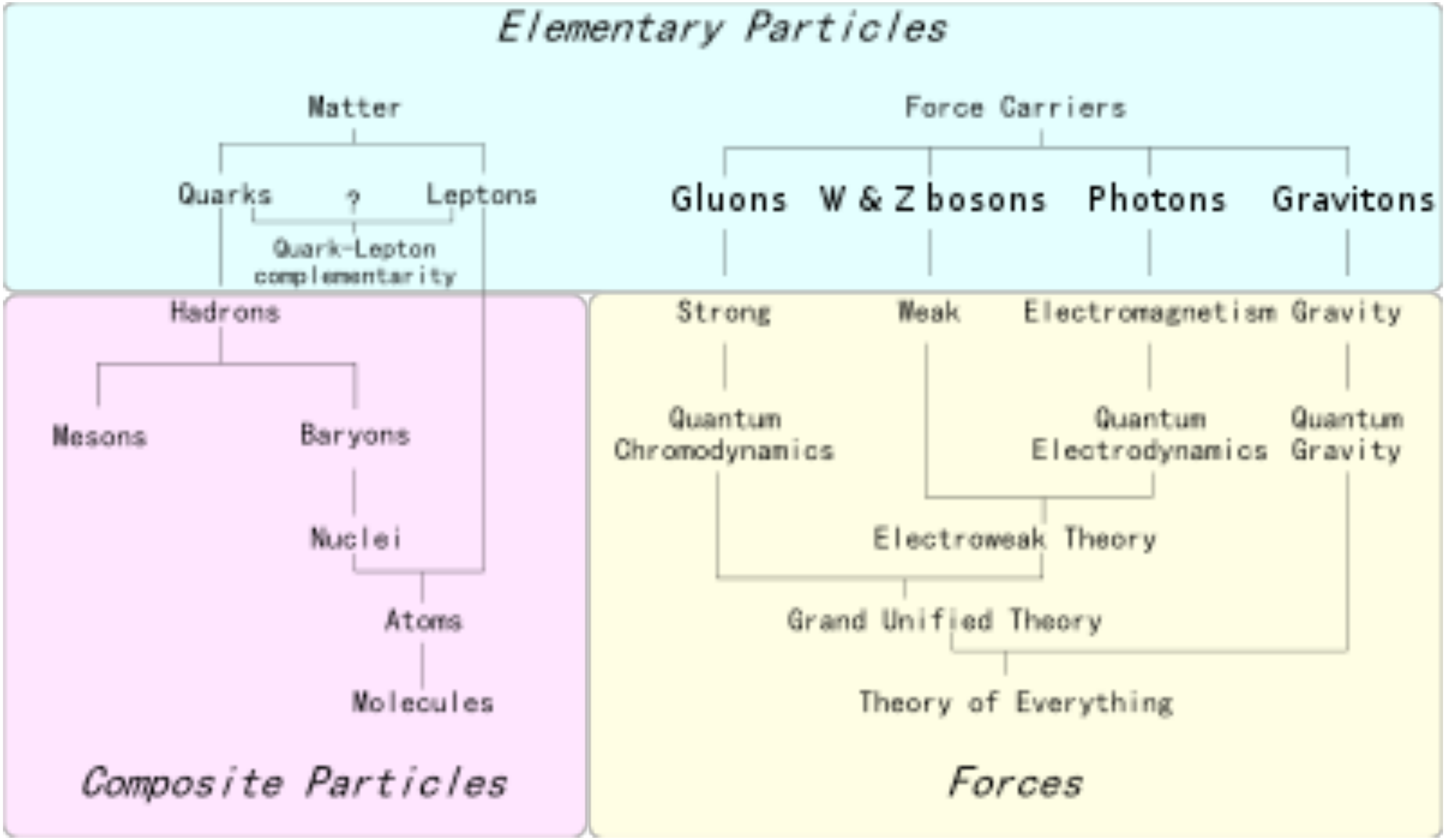
Strength	Range (m)	Particle
1	$\sim 10^{-15}$ (diameter of a medium sized nucleus)	gluons, π(nucleons)

Weak

Strength	Range (m)	Particle
10^{-6}	$\sim 10^{-18}$ (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1

http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html

Elementary Particles and Forces



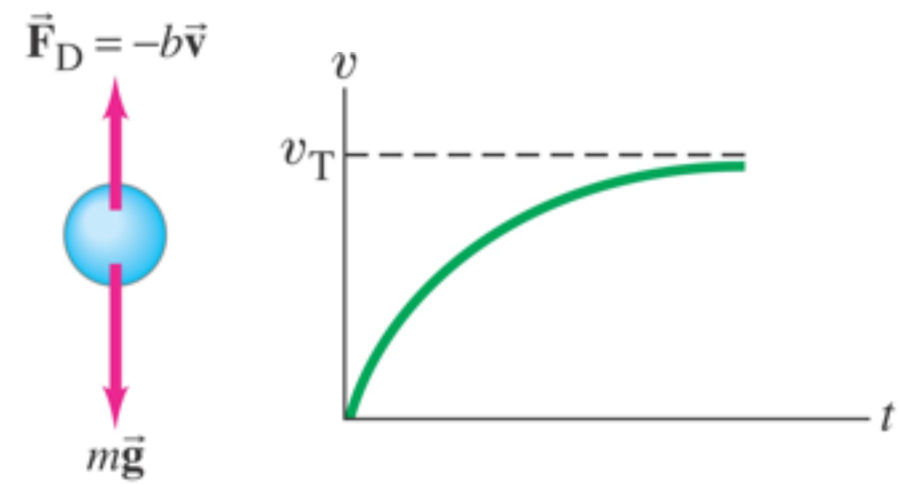
http://en.wikipedia.org/wiki/Fundamental_interaction

Drag at Low and High Speeds

$F_{drag} = -bv$ (low speed)

$F_{grav} + F_{drag} = mg - bv_{terminal} = 0$

$\Rightarrow$ low speed $v_{terminal} = mg/b$



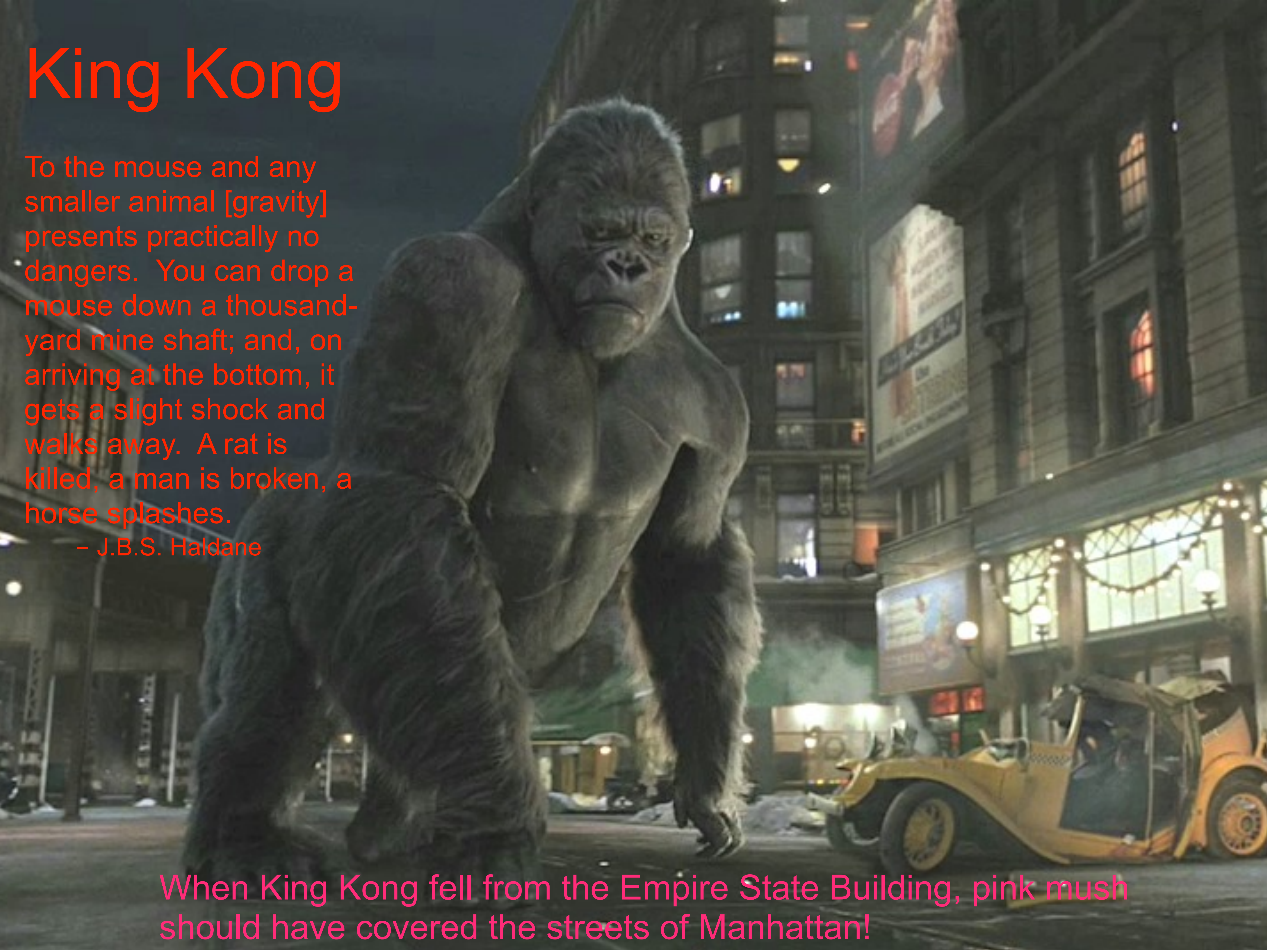
$F_{drag} = -kv^2$ (high speed), $k=\rho AC_d/2$

where ρ=density of air, A=area of object,

and C_d=drag coefficient, ~1

$F_{grav} + F_{drag} = mg - k(v_{terminal})^2 = 0$

$\Rightarrow$ high speed $v_{terminal} = [mg/k]^{1/2} = [2mg/\rho AC_d]^{1/2}$



King Kong

To the mouse and any smaller animal [gravity] presents practically no dangers. You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away. A rat is killed, a man is broken, a horse splashes.

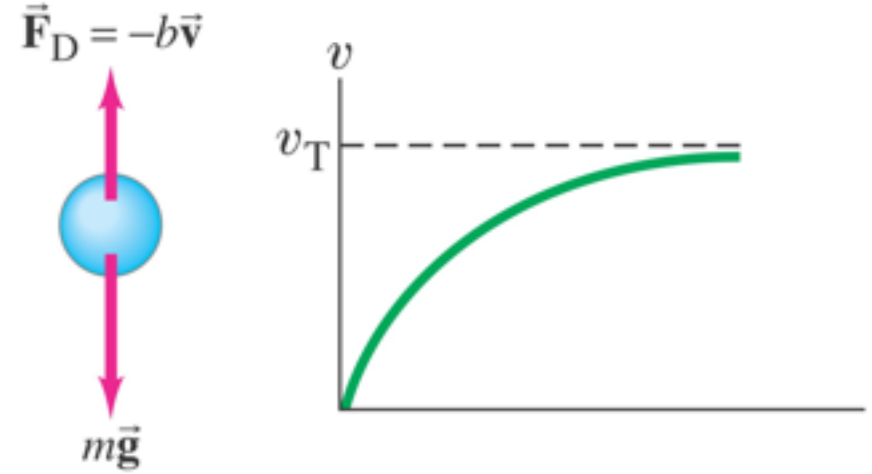
– J.B.S. Haldane

When King Kong fell from the Empire State Building, pink mush should have covered the streets of Manhattan!

Drag at Low and High Speeds

F_{drag} = -bv (low speed)

low speed $v_{terminal}$ = mg/b



$F_{drag} = -kv^2$ (high speed), $k=\rho AC_d/2$

where ρ=density of air, A=area of object,

and C_d=drag coefficient ~1, g=10 m/s^2

high speed $v_{terminal} = [2mg/\rho AC_d]^{1/2}$

Animals all have density about the same as water, ~1 g/cm^3. Suppose an animal has linear dimension L. Then $m \sim L^3$ while $A \sim L^2$, so $v_{terminal} \sim L^{1/2}$. A mouse has L~5 cm and a human has L~1 m. The ratio of their A's is ~400, so the ratio of their terminal velocities is ~20. For a skydiver, $v_{terminal}$ ~ 55 m/s ~ 200 km/hr. But a parachute (A --> 100 A) can slow $v_{terminal}$ to ~ 5 m/s.

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- Fundamental Forces (Gravity, Electromagnetism, Weak and Strong Interactions) on the Cosmic Uroboros: different forces are important at different size scales. Other forces may be discovered on small size scales.

- $F_{friction} = \mu N$ and Drag forces formulas are approximate:
  $F_{drag} = -bv$ (low speed), $v_{terminal} = mg/b$
  $= -kv^2$ (high speed), $k=\rho AC_d/2$, $v_{terminal} = [2mg/\rho AC_d]^{1/2}$

- In accelerating reference frames there are "pseudoforces" $F_{pseudo} = ma$, where a is the acceleration of the frame. Einstein: gravity is a pseudoforce which is eliminated in inertial (freely falling) reference frames

- Introduction to Special Relativity

Galilean–Newtonian Relativity

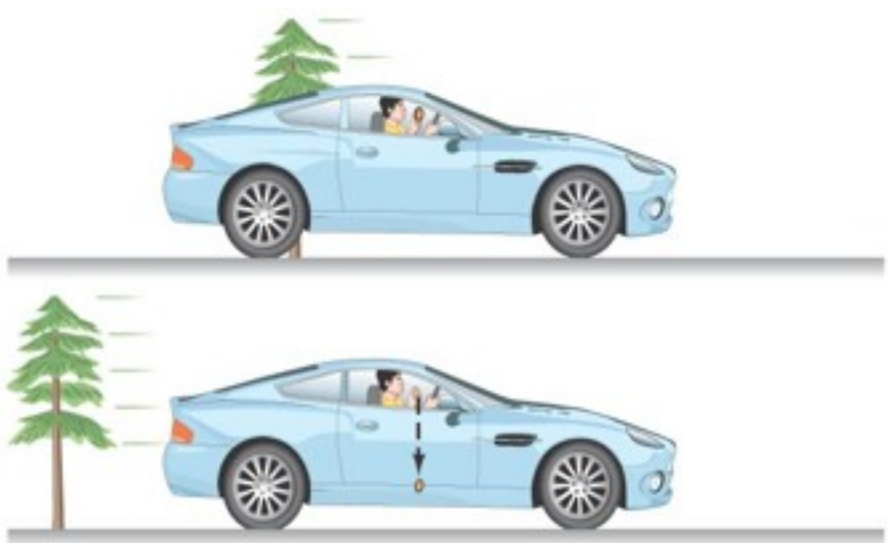
Definition of an inertial reference frame: One in which Newton's first law is valid.

A frame moving with a constant velocity with respect to an inertial reference frame is itself inertial.

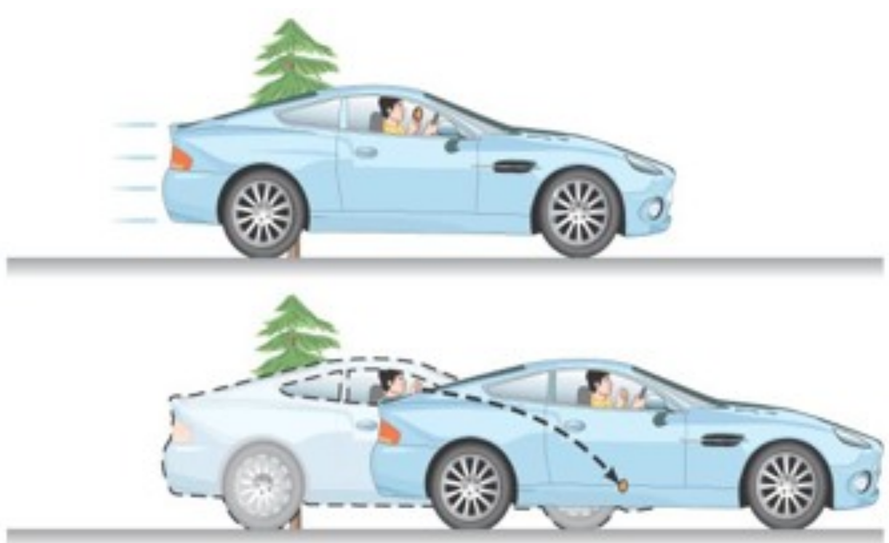
Earth is rotating and has gravity, and therefore is not an inertial reference frame -- but we can treat it as one for many purposes.

Relativity principle:

The basic laws of physics are the same in all inertial reference frames.



(a)
Reference frame = car



(b)
Reference frame = Earth

Galilean–Newtonian Relativity

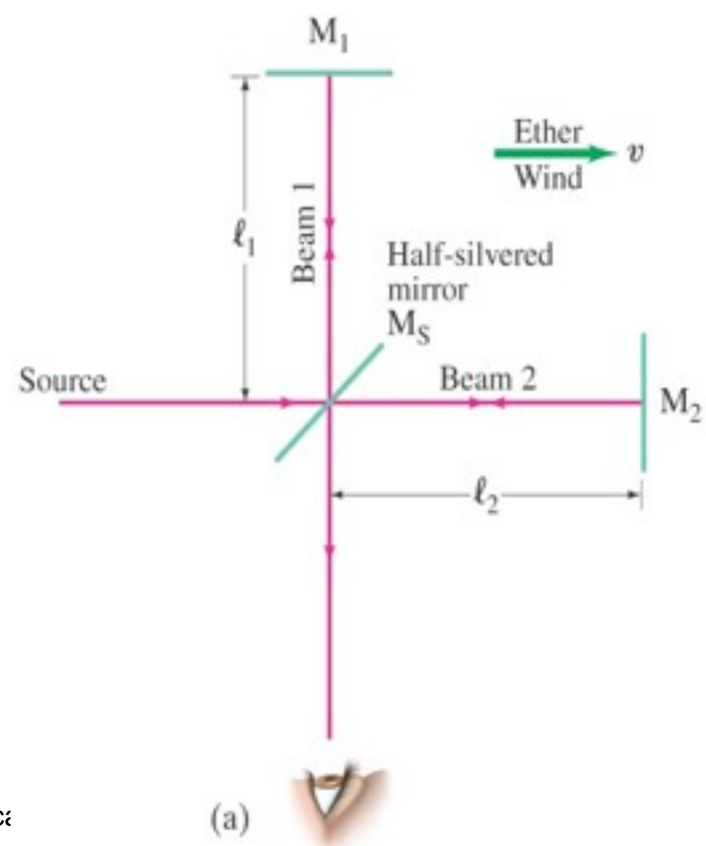
This principle works well for mechanical phenomena.

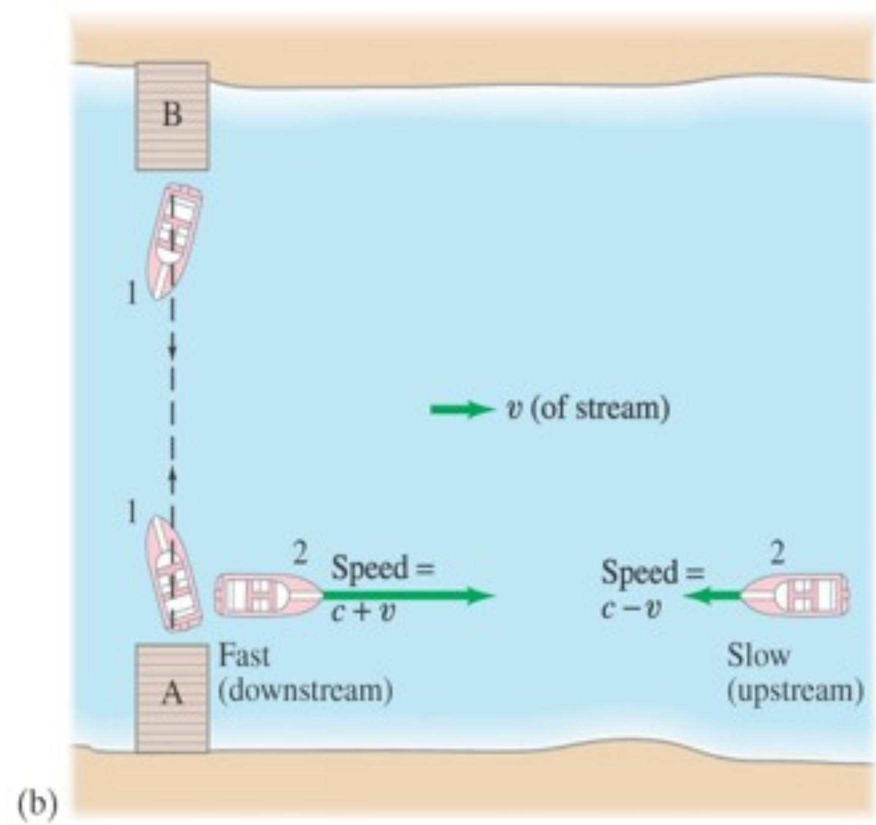
However, Maxwell's equations yield the velocity of light *c*; it is 3.0×10^8 m/s.

So, which is the ether reference frame in which light travels at that speed?

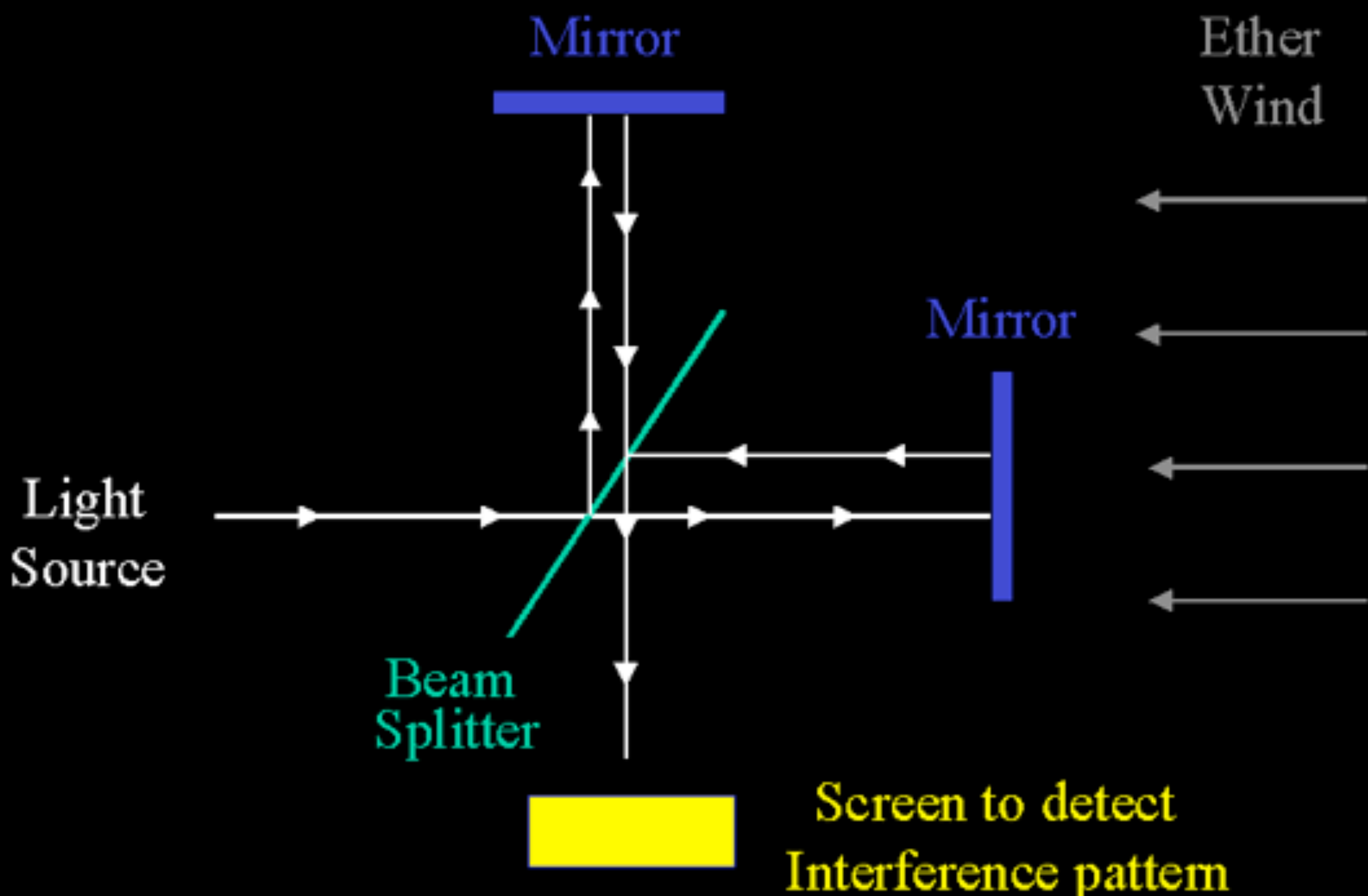
The 1887 Michelson-Morley experiment was designed to measure the speed of the Earth with respect to the ether.

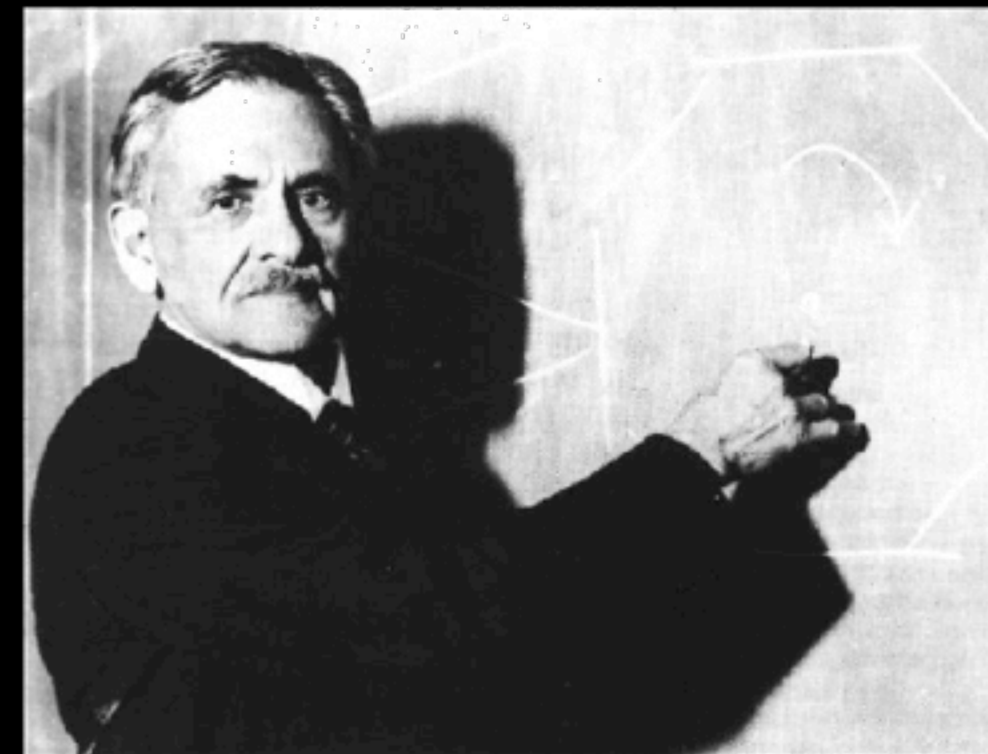
The Earth's motion around the Sun should produce small changes in the speed of light, which would be detectable through interference when the split beam is recombined.





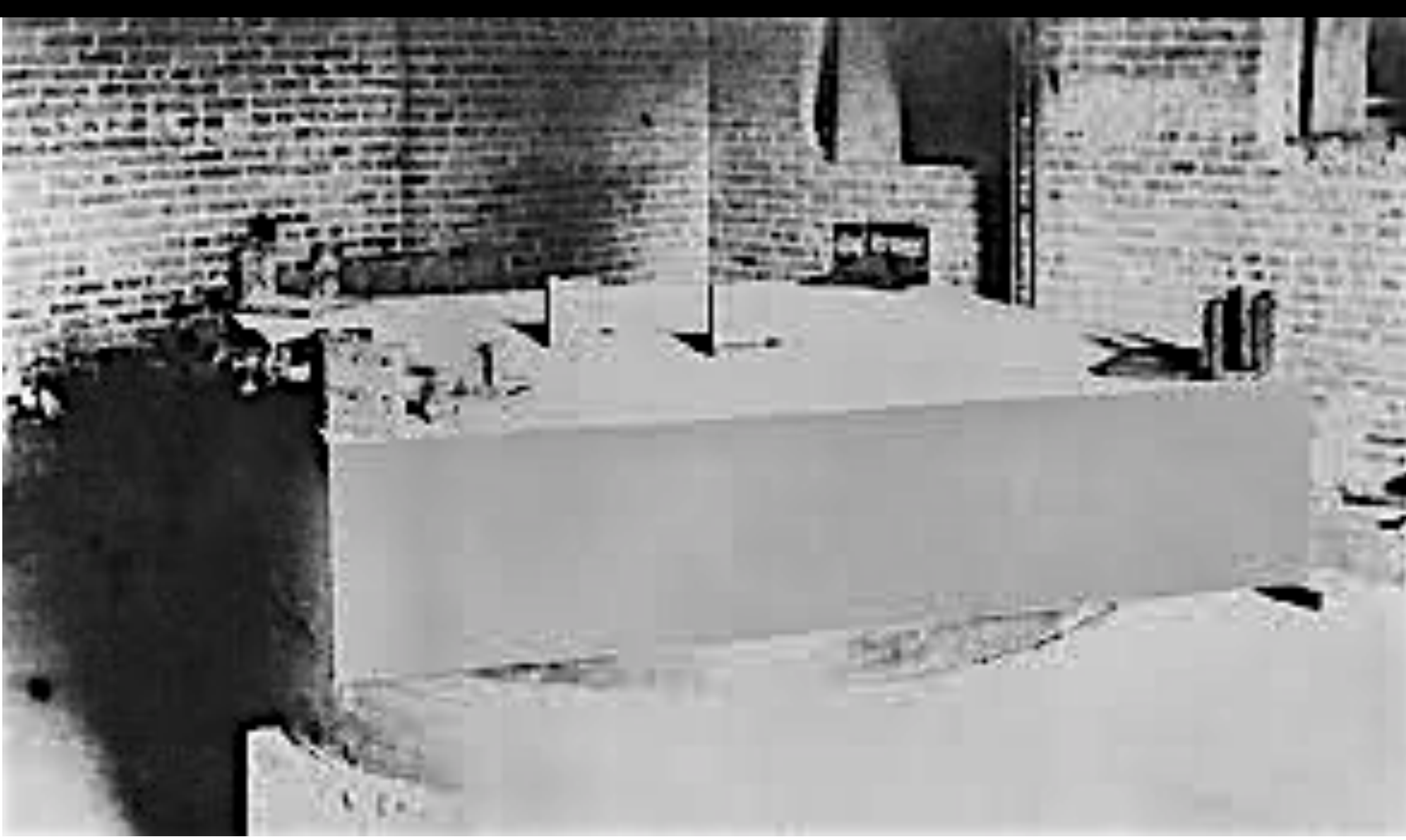
Michelson-Morley Experiment

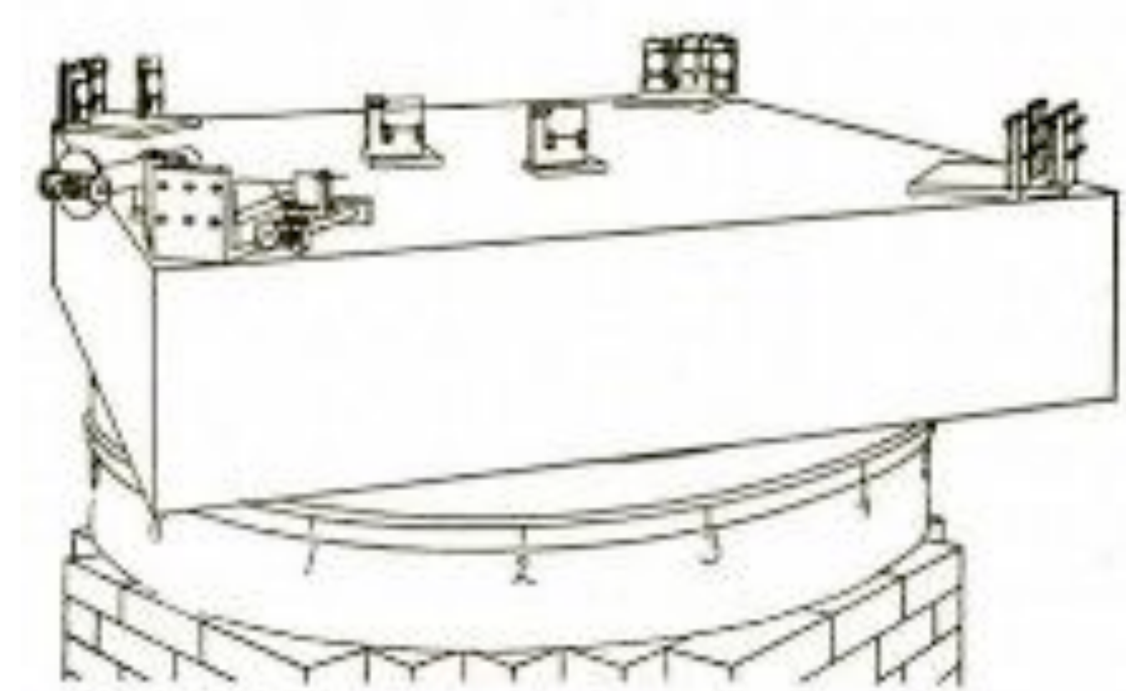




Albert Michelson, 1852-1931

(the first American to win a Nobel Prize)





Einstein's Special Theory of Relativity

Special Relativity is based on two postulates:

1. The Principle of Relativity: If a system of coordinates K is chosen so that, in relation to it, physical laws hold good in their simplest form [i.e., K is an inertial reference system], the same laws hold good in relation to any other system of coordinates K' moving in uniform translation relatively to K.

2. Invariance of the speed of light: Light in vacuum propagates with the speed *c* in terms of any system of inertial coordinates, regardless of the state of motion of the light source.

Einstein's Rocket - Thought Experiments and Games

use
Safari ⟶ http://physics.ucsc.edu/~snof/er.html