Physics 100 – March 28, 2007

Note Change!

Exam 2 time → April 11

Presentation Schedule

16 17, Solar System formation
18 2, nucl. bombs – 6, GPS – 18, Football
23 24A, Feynman – Nucl. Terrorism
25 26, music
30 24, Galileo – ~~23~~ 25, comets mass ext.

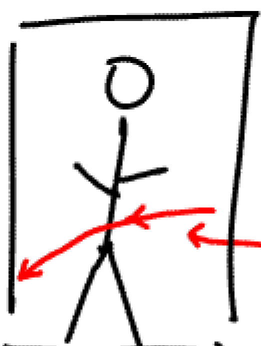
Last Time

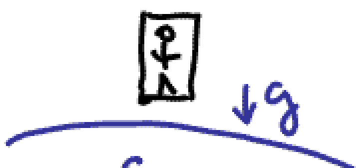
Planetary Motion / gravitation ⇒ Moving Beyond Newton

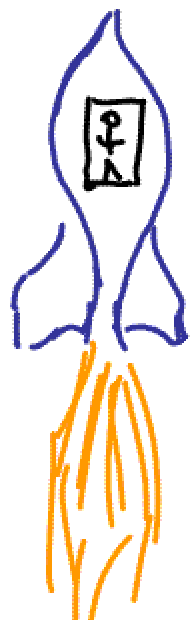
General Relativity – 1916

Equivalence Principle

gravitational fields are indistinguishable from accelerated reference frames

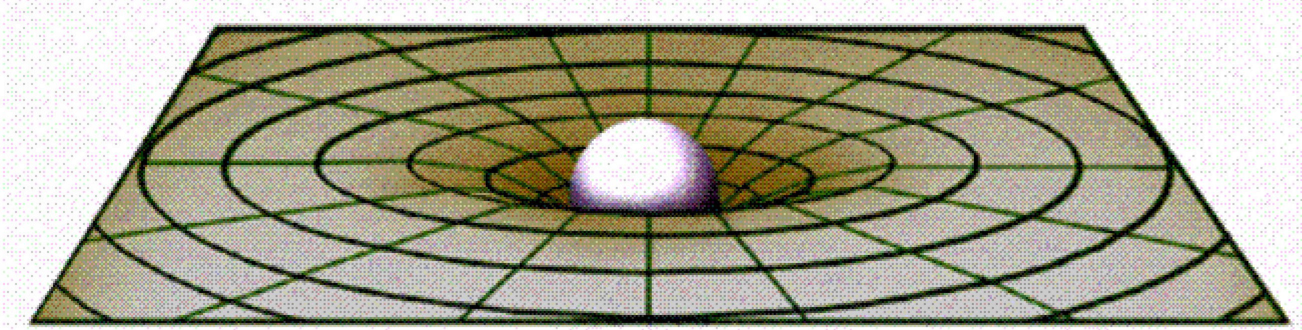






Interpret gravitation as a bending of spacetime

→ very different from Newton



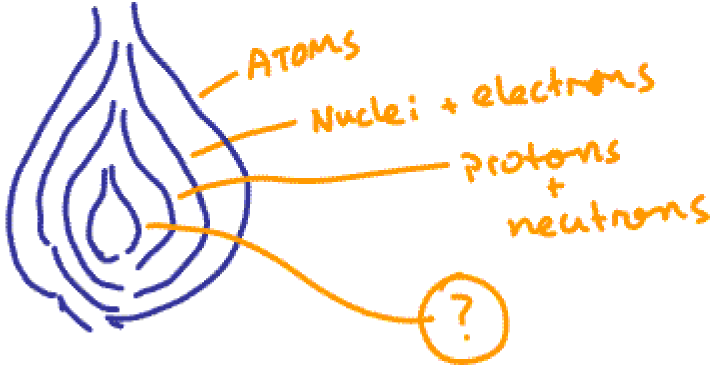
Mass causes a distortion/bending of spacetime

Remember: in Science observation is King

Evidence supporting GR:

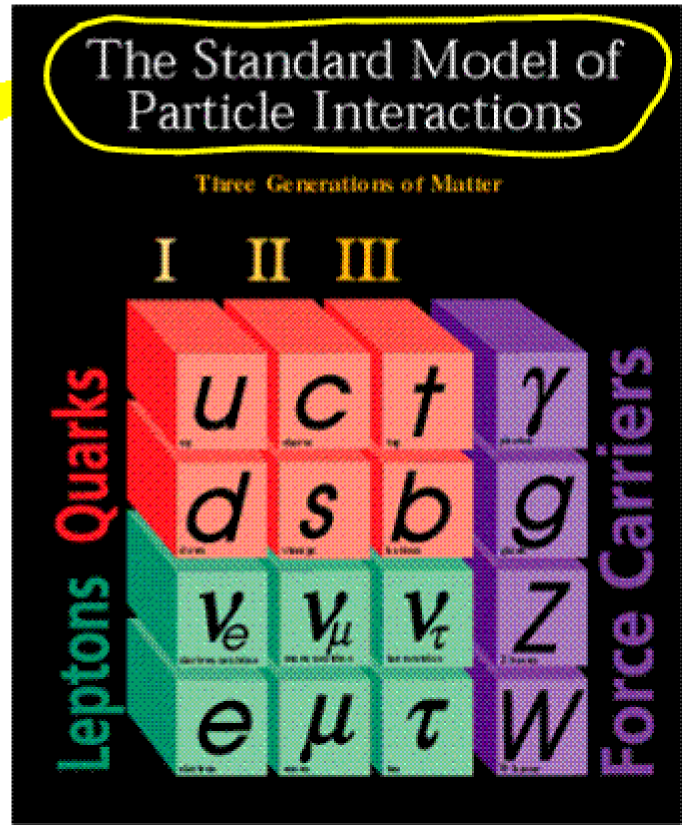
- Bending of light passing near sun or near massive astrophysical objects
- Redshifting of light
- Perihelion advance of Mercury's orbit

Perhaps someday we will even detect predicted gravitational waves
→ LIGO experiment



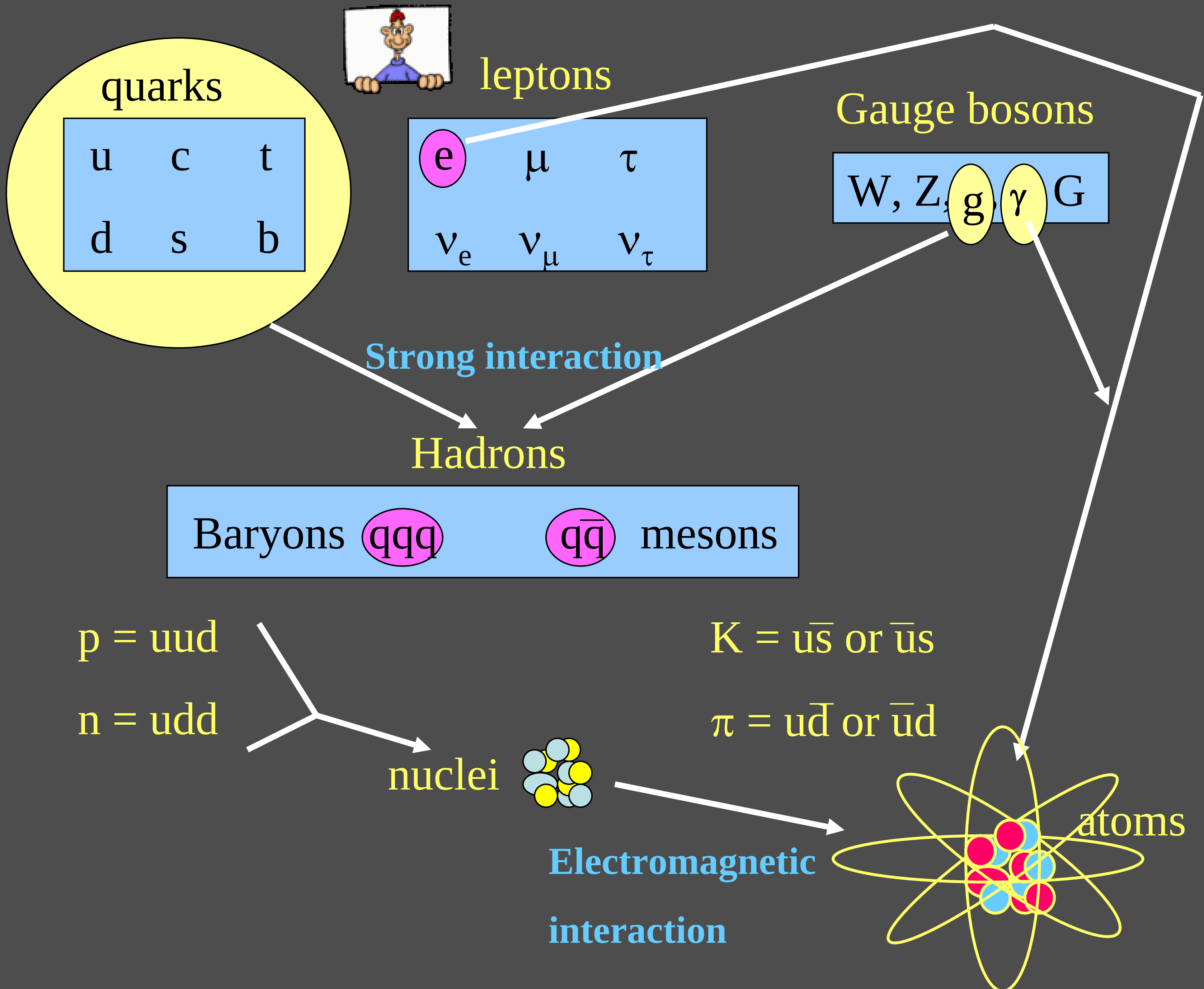
Let's continue our peeling of Nature's onion

- What forces exist in nature?
- Interactions between what particles?
- What is the nature of a force?



Force	Source	Range	Strength
Gravitation	mass	infinite	10^{-39}
Electromagnetism	Electric charge	infinite	10^{-2}
Strong nuclear	Color charge	10^{-15} m	1
Weak nuclear	Weak charge	10^{-18} m	10^{-5}

May seem very STRANGE at FIRST – hang in there!


quarks
u c t
d s b
leptons
e μ τ
ν_e ν_μ ν_τ
Gauge bosons
W, Z, g, γ, G
Strong interaction
Hadrons
Baryons qqq
$q\bar{q}$ mesons
p = uud
n = udd
K = $u\bar{s}$ or $\bar{u}s$
π = $u\bar{d}$ or $\bar{u}d$
nuclei
atoms
Electromagnetic
interaction

Anti Matter

e^- ~ e^+ positron

Anti-electron

$$e^- \; e^+ \longrightarrow \gamma\gamma$$

All particles have antiparticles

Why is universe made of matter rather than antimatter?
we don't know why this is true ... yet.
Active area of study ... believe it is probably due to a basic matter-antimatter asymmetry in one of the forces of nature.

Gauge Bosons - force carriers

Quantum Field Theory

	Q	Mass	Mediates
γ ≡ photon	0	0	Electromagnetic
W^+, W^- ≡ "W"	+ or - 1	80000 MeV	Weak
Z^0 = "Z"	0	91000 MeV	Weak
g ≡ gluon	0	0	Strong

$\Delta E \Delta T \leq h$

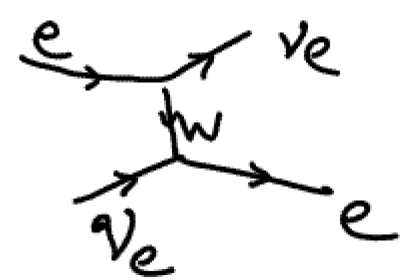
Force comes from exchange of "virtual" particle

Feynman diagrams

Electromagnetism

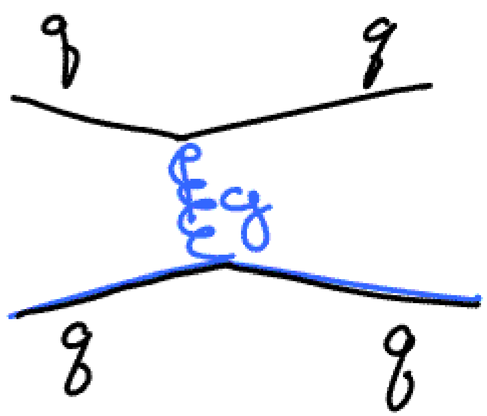
Quantum Electrodynamics (QED)

particles must have electric charge



Weak Nuclear Force

very short range



Similar to electromagnetism ... but 3 charges (called color charges)

Strong Nuclear force

Quantum Chromodynamics
QCD

No bare quarks

Nature of Force in quantum field theory is determined by the characteristics of the virtual particle that mediates the force

Virtual particles only exist for briefest of moments as allowed by Heisenberg's uncertainty principle $\Delta E \Delta t < h$

Can Break Energy conservation for Δt satisfying

Leptons

Leptons	Q	Mass	Fermions spin
e^- ≡ electron	-1	.5 meV	1/2
μ^- ≡ Muon	-1	105 MeV	"
τ^- ≡ Tau	-1	1777 MeV	"
ν_e ≡ electron neutrino	0	Tiny but nonzero	"
ν_μ ≡ muon neutrino	0	" " "	"
ν_τ ≡ tau neutrino	0	" " "	"

leptons experience these forces:
- Electromagnetic (if $q \neq 0$)
- Weak

Quarks	Q	Mass	Spin (fermions)
u ≡ up	$+2/3$	~ 5 MeV	$1/2$
d ≡ down	$-1/3$	~ 8 MeV	"
c ≡ charm	$+2/3$	~ 1300 MeV	"
s ≡ strange	$-1/3$	~ 150 MeV	"
t ≡ top	$+2/3$	~ 175000 MeV	"
b ≡ bottom	$-1/3$	~ 4300 MeV	"

Quarks experience these forces:
- Electromagnetic
- Weak
- Strong

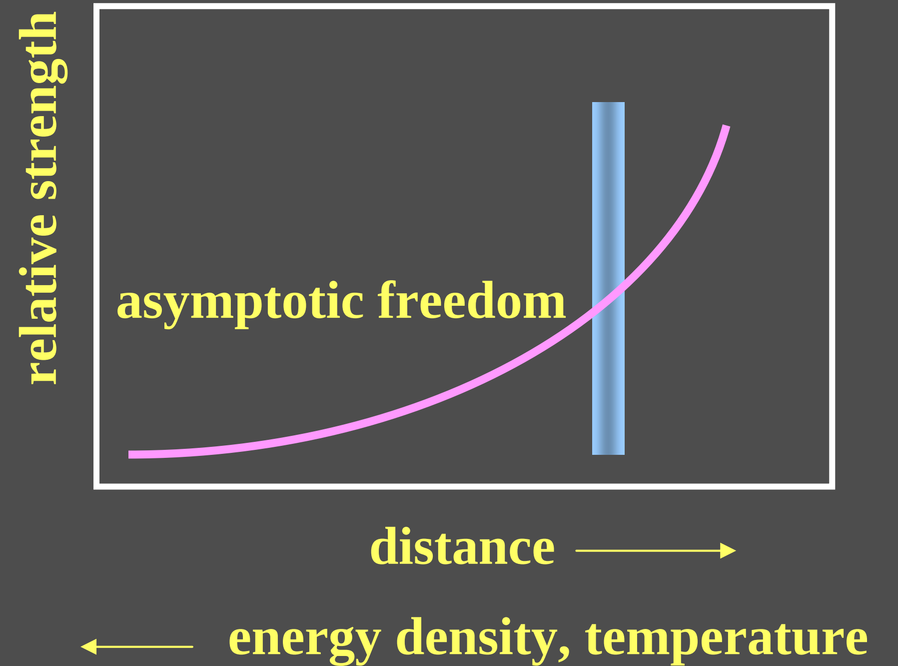
qqq Baryon → Examples: protons, neutrons

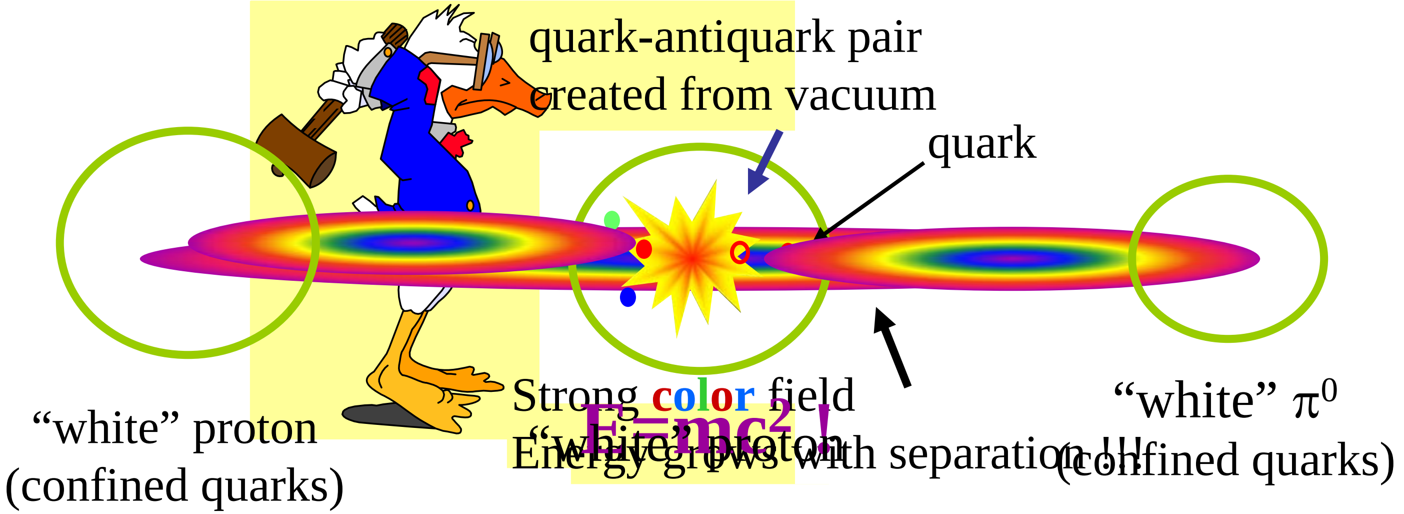
$q\bar{q}$ Mesons: kaons, K; pions, π

colorless STATES

Quantum Chromodynamics
QCD

Why bare quarks have never been observed.





Thanks to Mike Lisa (OSU)
for parts of this animation

The Vacuum

-R. Kolb

Much ado about NOTHING:

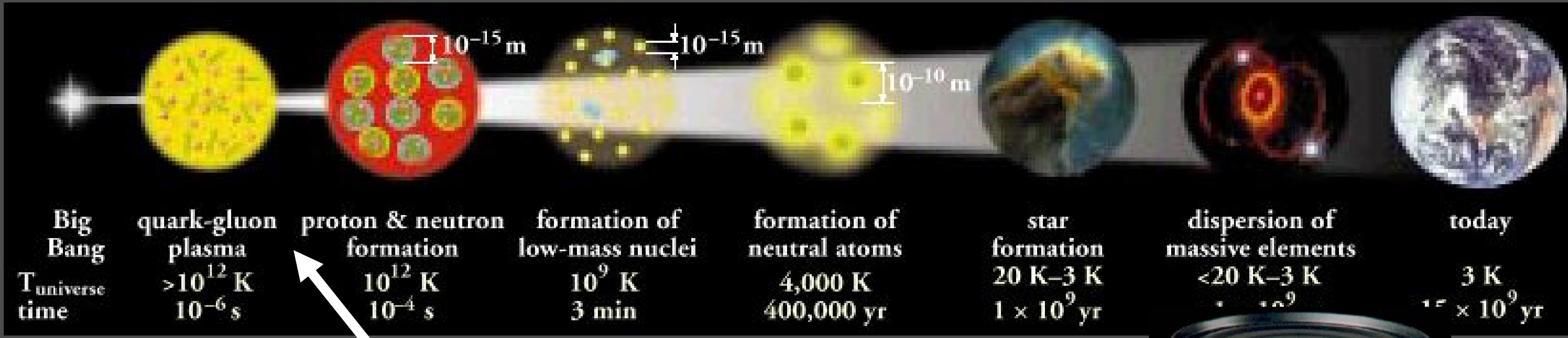
Nothing is something

Nothing has energy

Nothing interacts with something

Modern accelerators study processes at energies that existed VERY early in the universe

Another form of time travel !

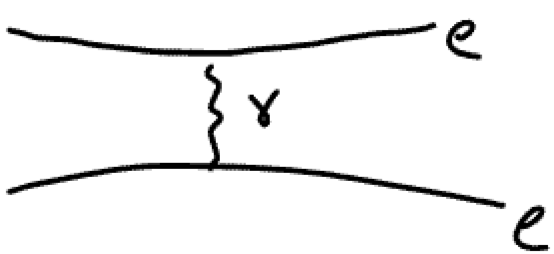


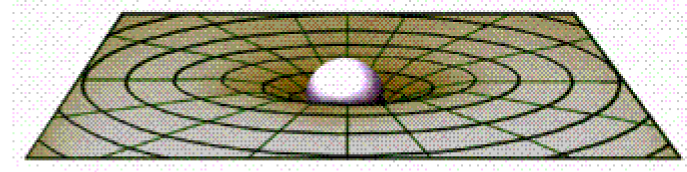
What were forces like at those temperatures?

What types of particles existed?

Electromagnetism
Weak interaction
Strong Nuclear force

understood through quantum field theory as exchange of virtual particles





Gravitation

understood thru General Relativity as a bending of space time.

many of us believe someday we will discover a quantum field theory of gravity ... where gravity will be understood as exchange of virtual "gravitons"