Unsolved Physics Problems

Chakrit Pongkitivanichkul
Khon Kaen University

โครงการอบรมฟิสิกส์อนุภาคพื้นฐาน
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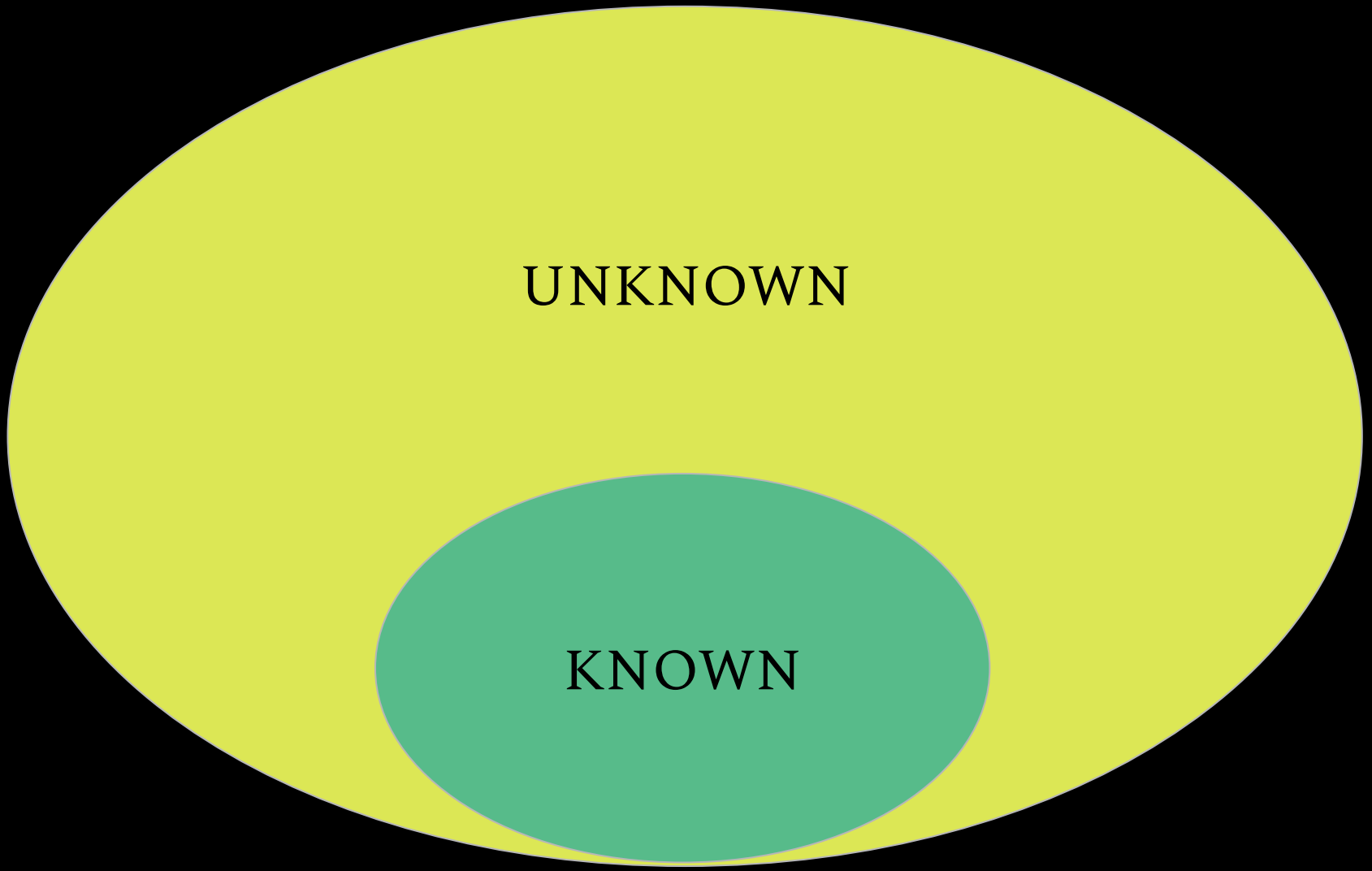
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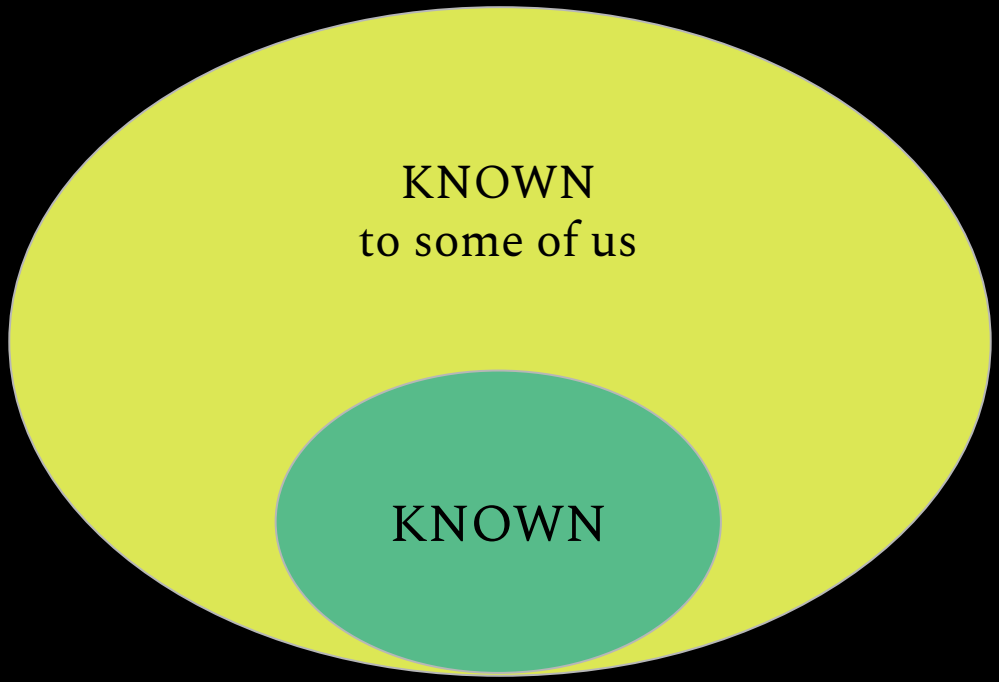
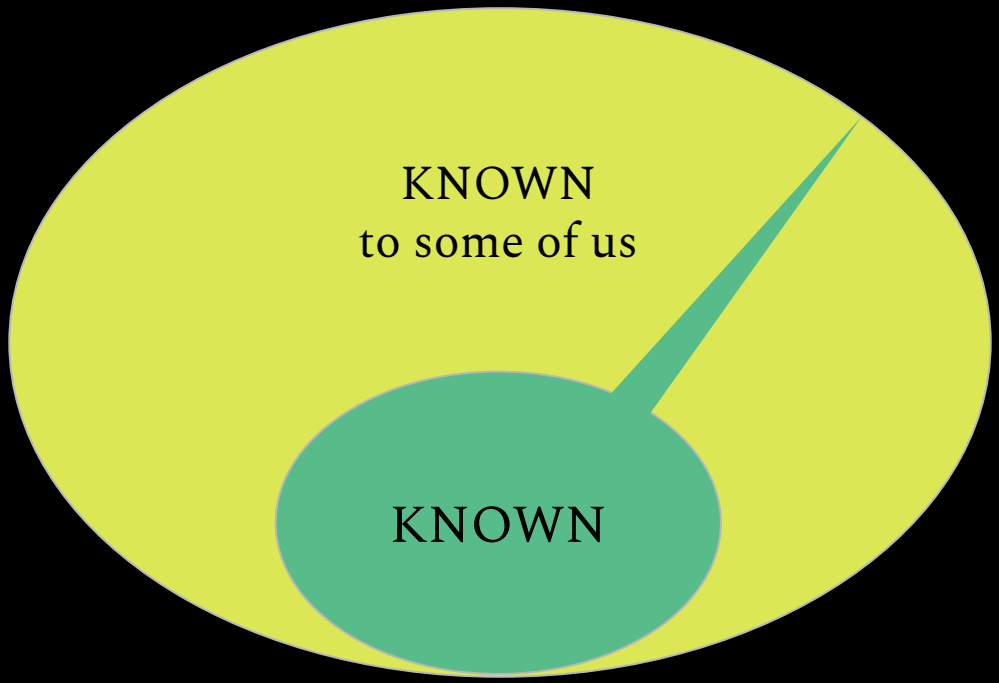
UNKNOWN to humankind



UNKNOWN to humankind

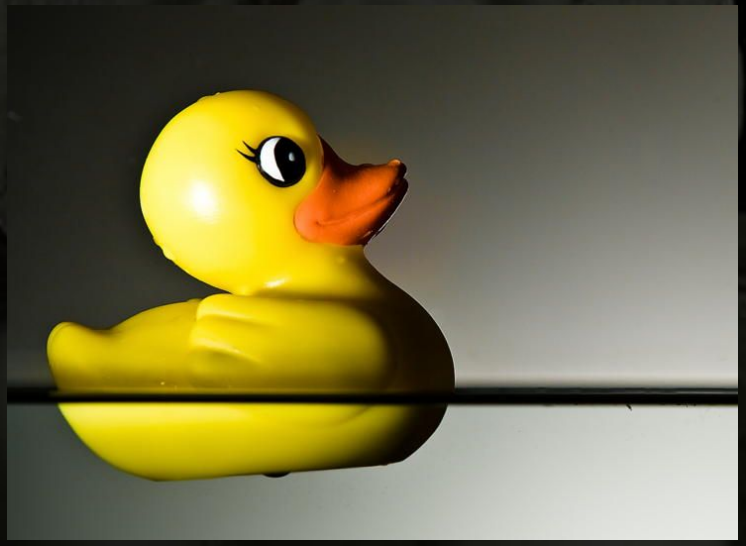


What does being “solved” mean?

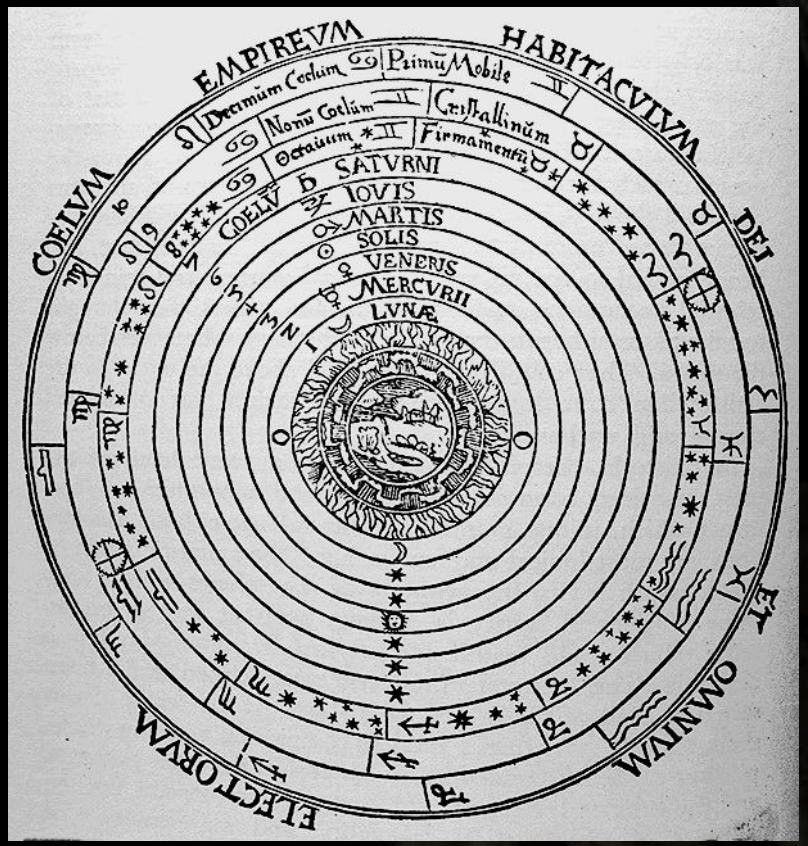
Greek Philosophers

An early attempt to understand nature

Objects rise and fall to their **natural places**



Natural motion vs Forced motion



Objects in a void (vacuum) move in the **natural direction**

Objects in **unnatural motion** will return to their **natural courses** when the force is removed

Philosophy vs Science

There were so many thinkers in the past whose came very close to our current understanding

Deduction from logic and observation sounds reasonable

But **this is not good enough for science!!!**

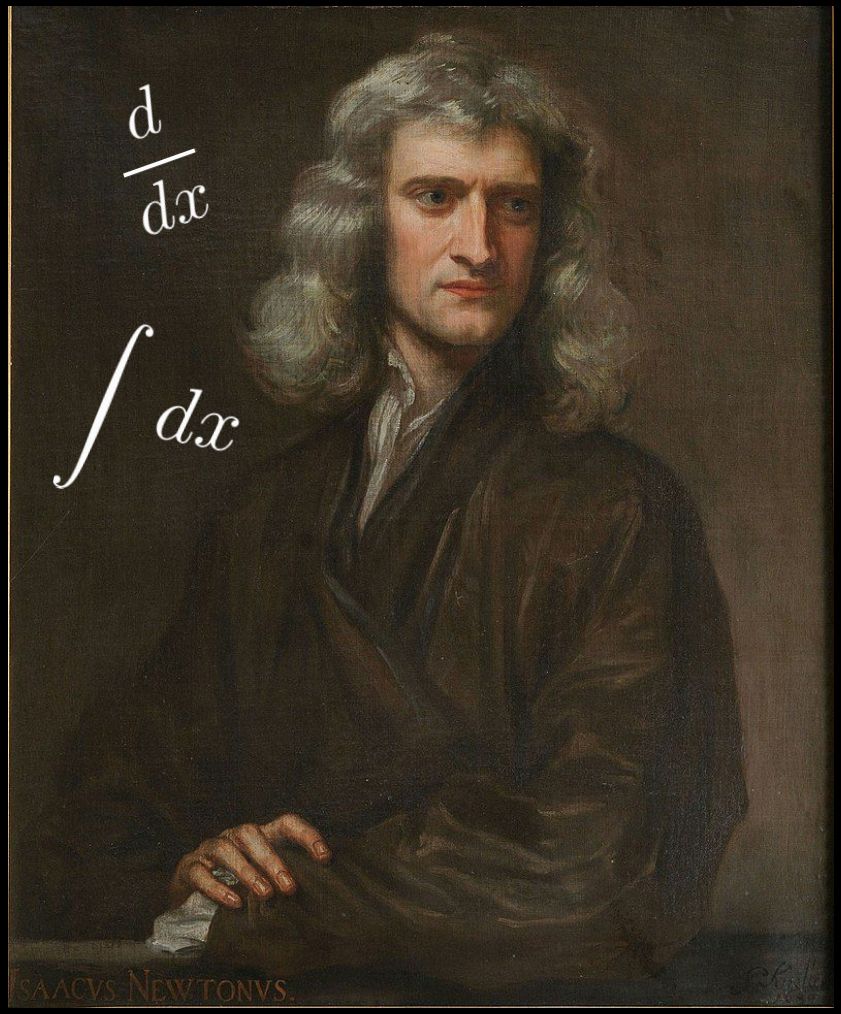
The birth of modern scientific theory

What made Newton's idea different was the invention of calculus!

Theoretical questions can be answered by measurement

Experiments and measurement leads to informative evidence → confirm theory and give predictions

Scientific theory is universal and testable



Scientific theory

Theory with no way to test it → ❌ not a scientific theory

Theory from logic and observations but no quantitative measurement and prediction → ❌ better but still not a scientific theory

Theory with solid mathematical model which gives prediction that can be tested by experiments and measurements → ✔️ Scientific theory

A solid mathematical model which gives prediction that can be tested by experiments and measurements but no good interpretation → ✔️ Still scientific theory

Solved vs Unsolved

If the scientific theory gives predictions that agree with all measurements at the moment → solved problem

New evidence that does not agree with known scientific theory → unsolved problem

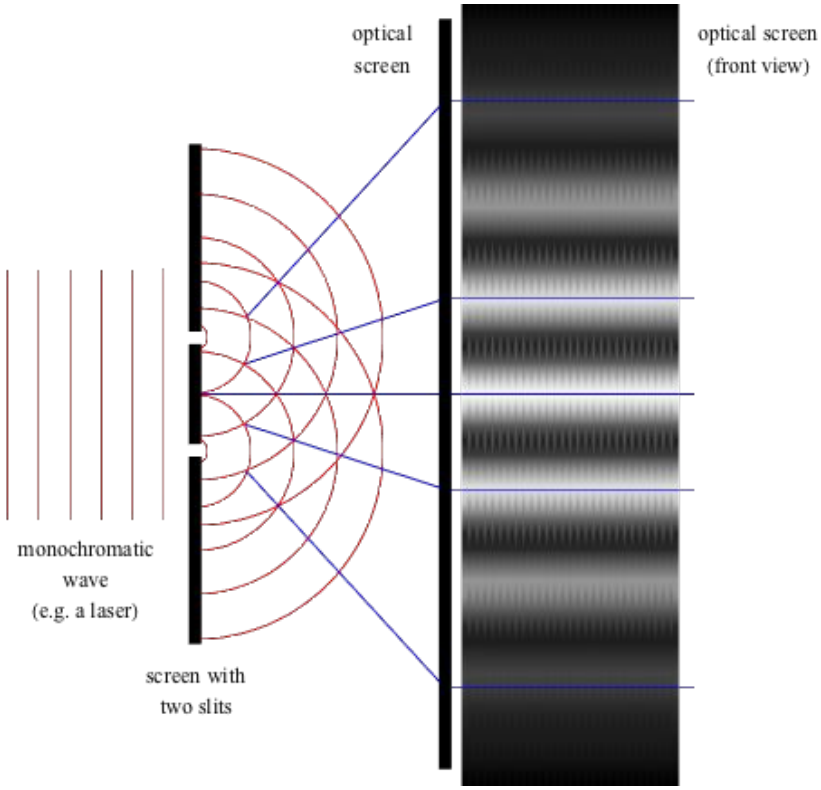
We cannot prove scientific theory right

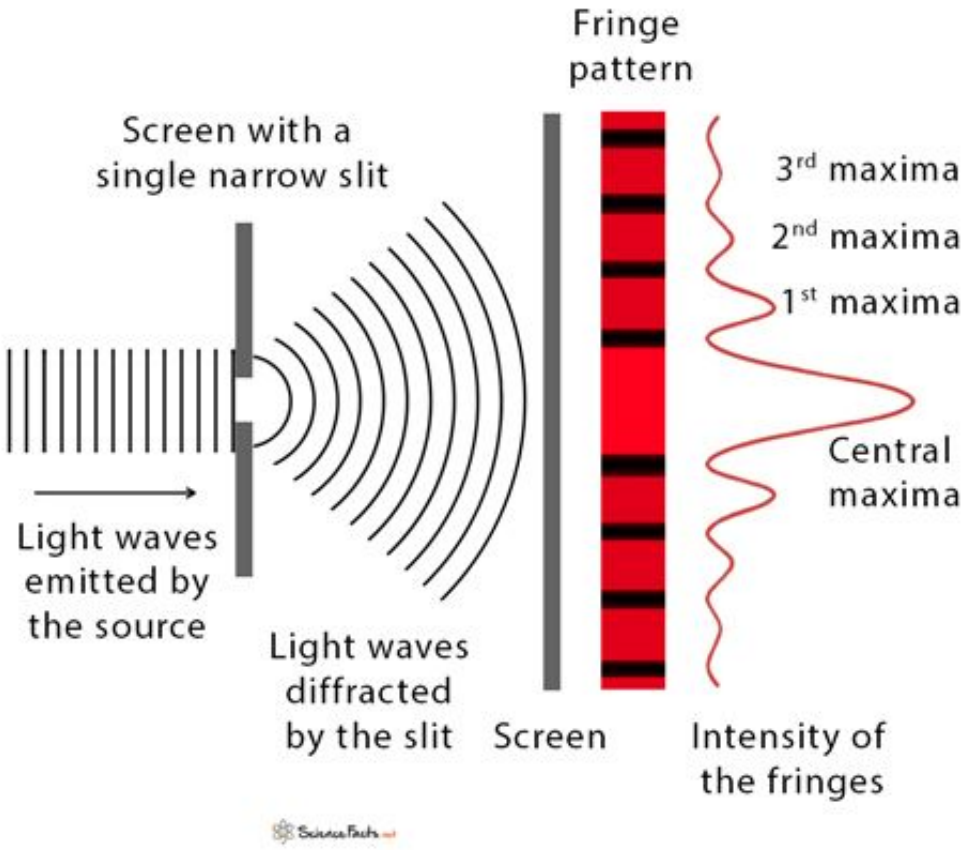
We can only prove scientific theory wrong

Let's go to the frontier

Nature at a small scale

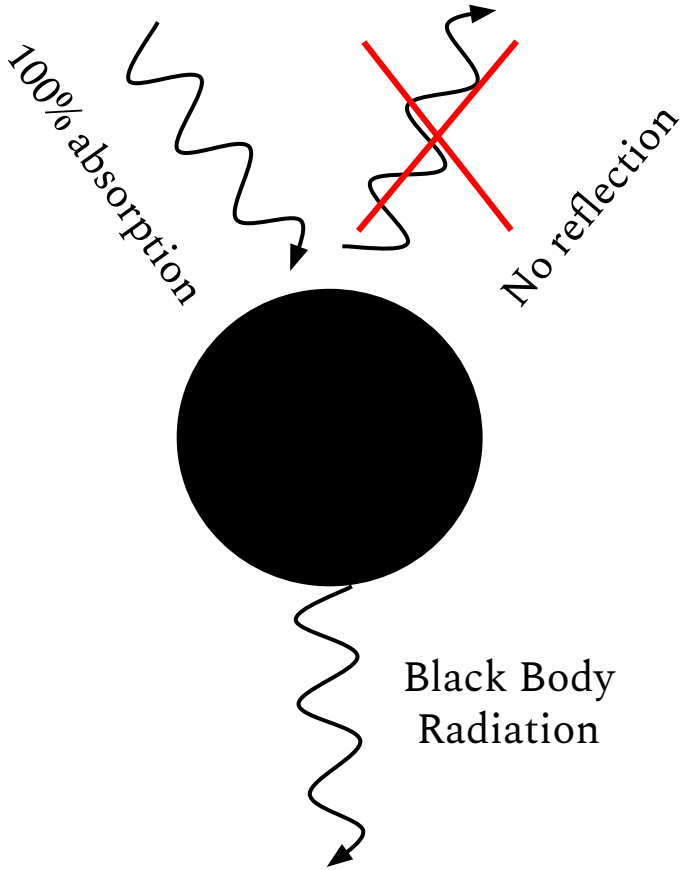
Light is a <u>wave</u> → interference, diffraction, reflection



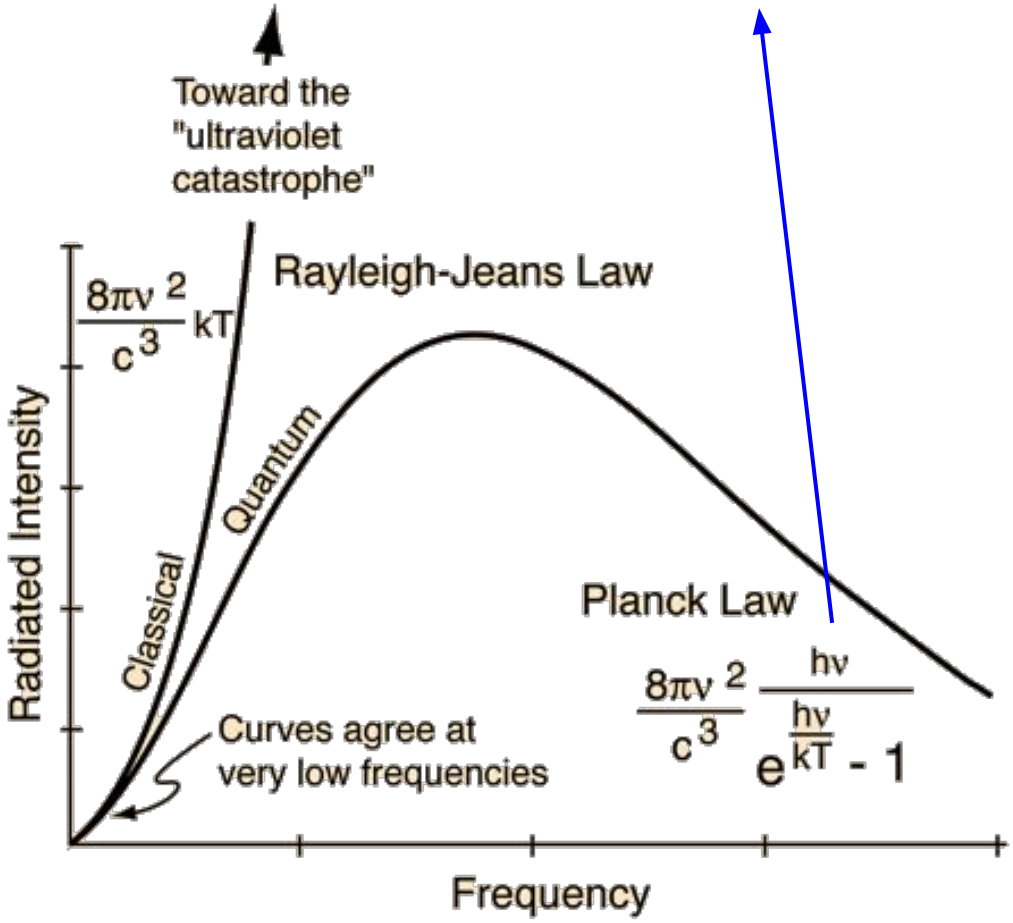


Nature at a small scale

Light can also be <u>particle</u> sometimes

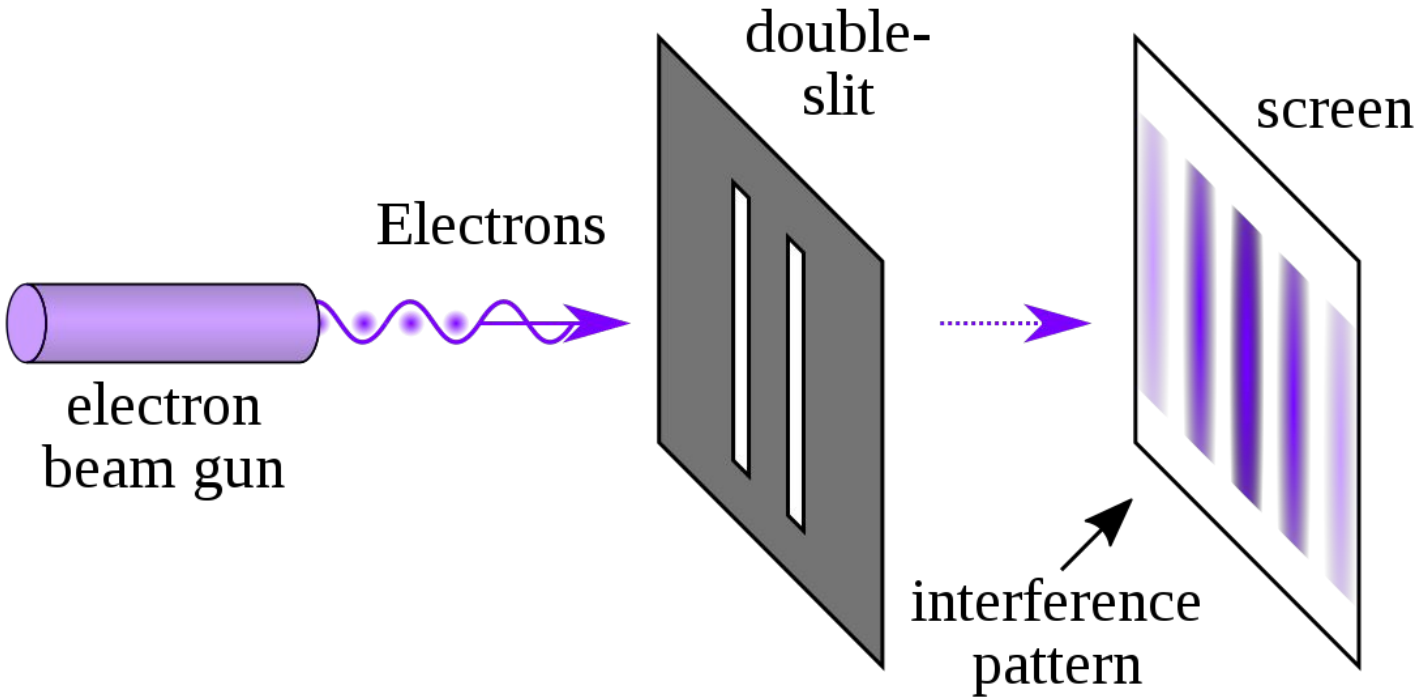


Light comes in "**quanta**" or photon with energy hν



Nature at a small scale

Particles can also be wave

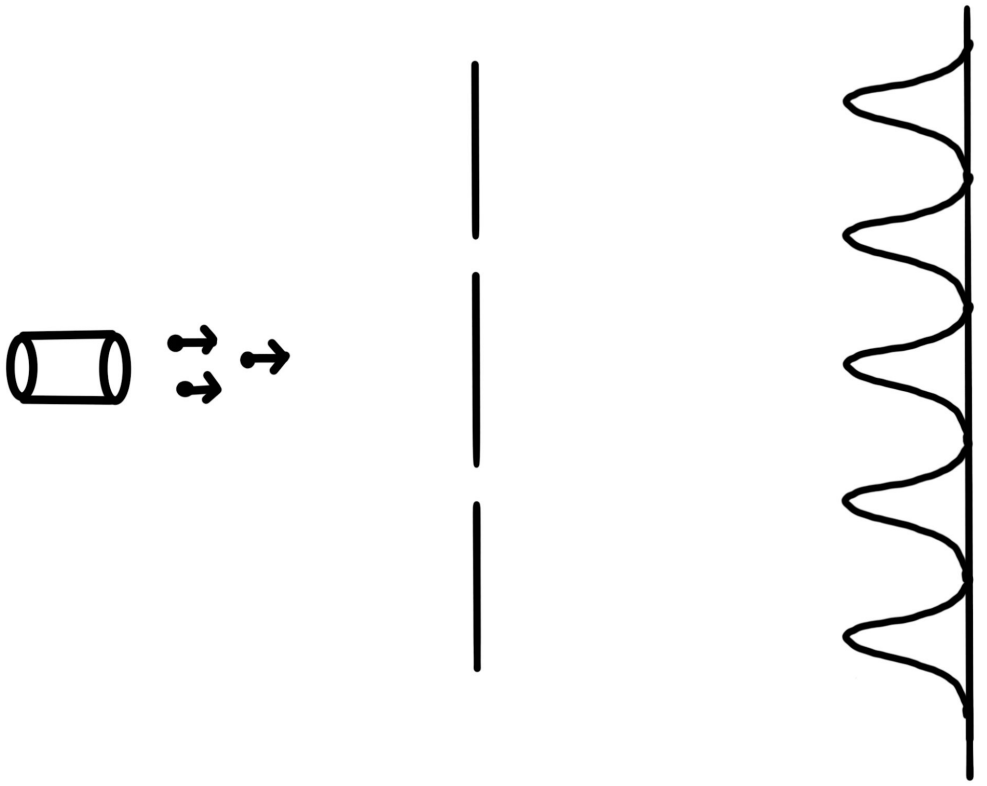


Nature at a small scale

Which ***path*** does electron take?

Left path?

Right path?

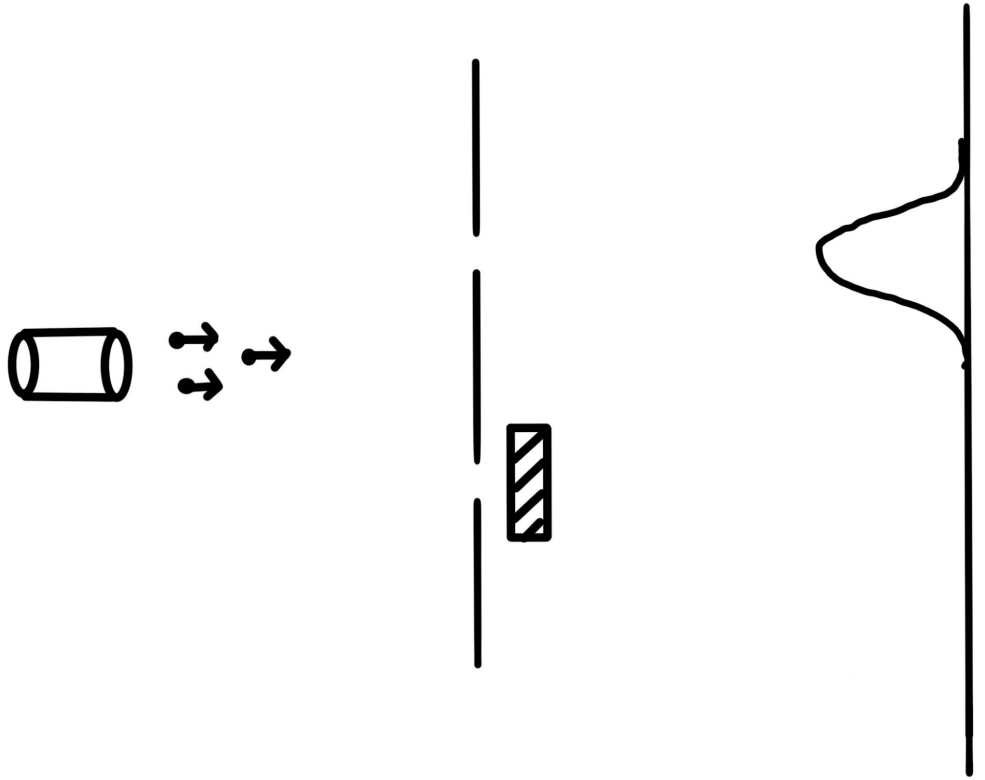


Nature at a small scale

Which ***path*** does electron take?

Left path? ❌

Right path? ❌



Nature at a small scale

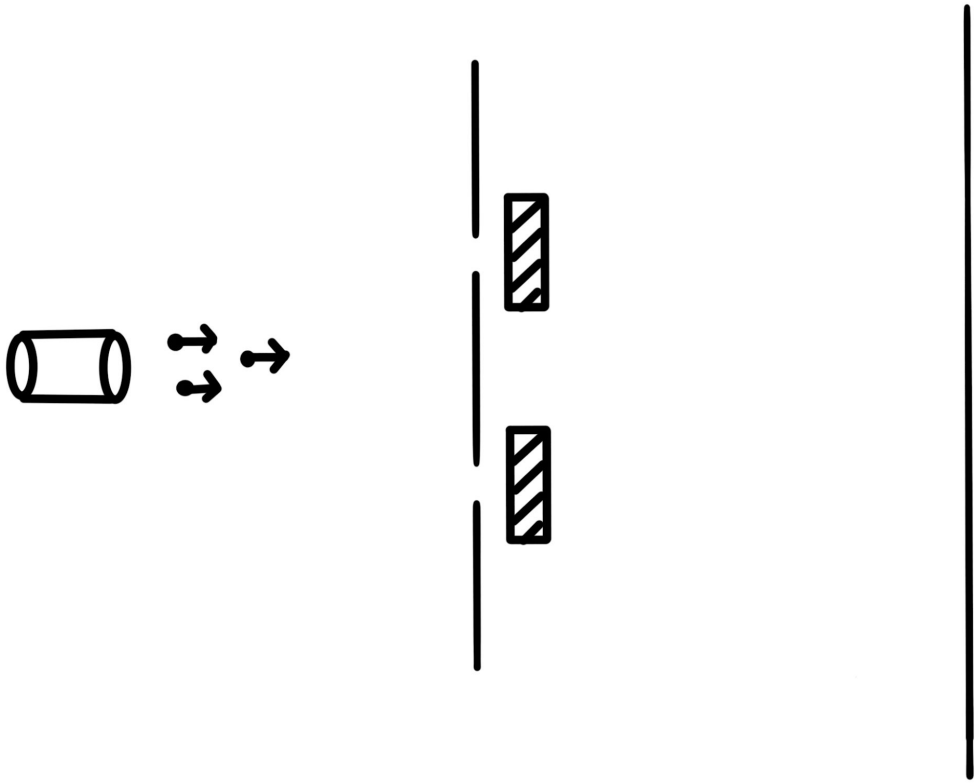
Which ***path*** does electron take?

Left path? ❌

Right path? ❌

No path? ❌

Both paths?



Nature at a small scale

Electron takes **both paths** (quantum state) → **superposition principle**

The state collapses when measured → **uncertainty principle**

The theory is <u>open for interpretation before measurement</u>

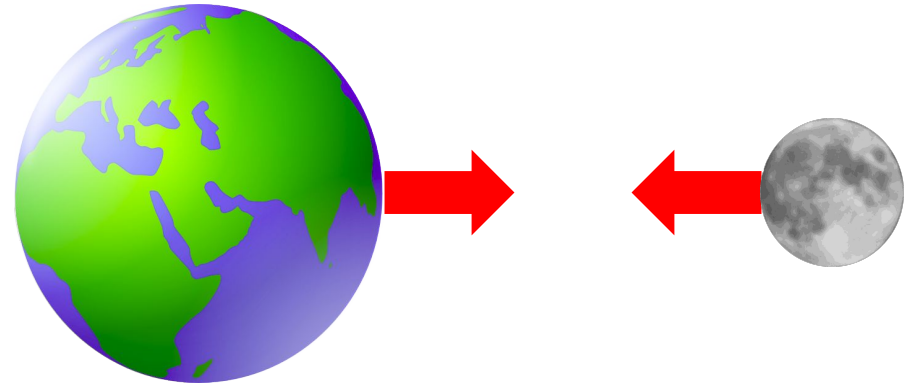
As long as the theory gives predictions and testable → scientific theory!!

There is no experiment yet that contradicts with quantum theory

Long distance force

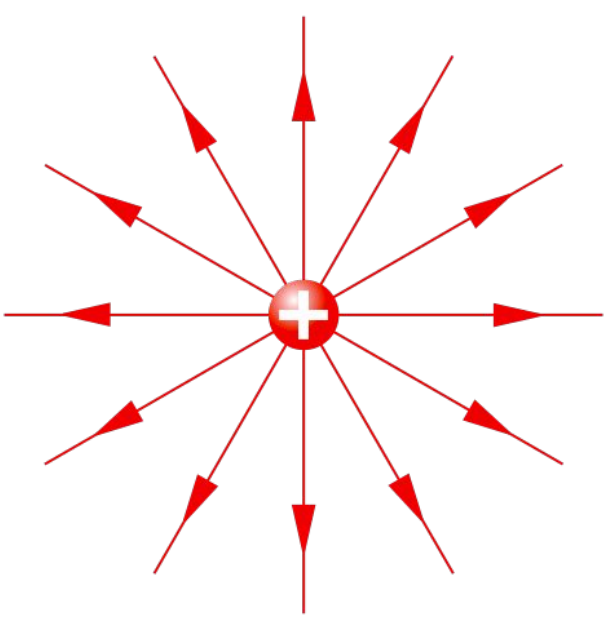
Action at a distance is strange

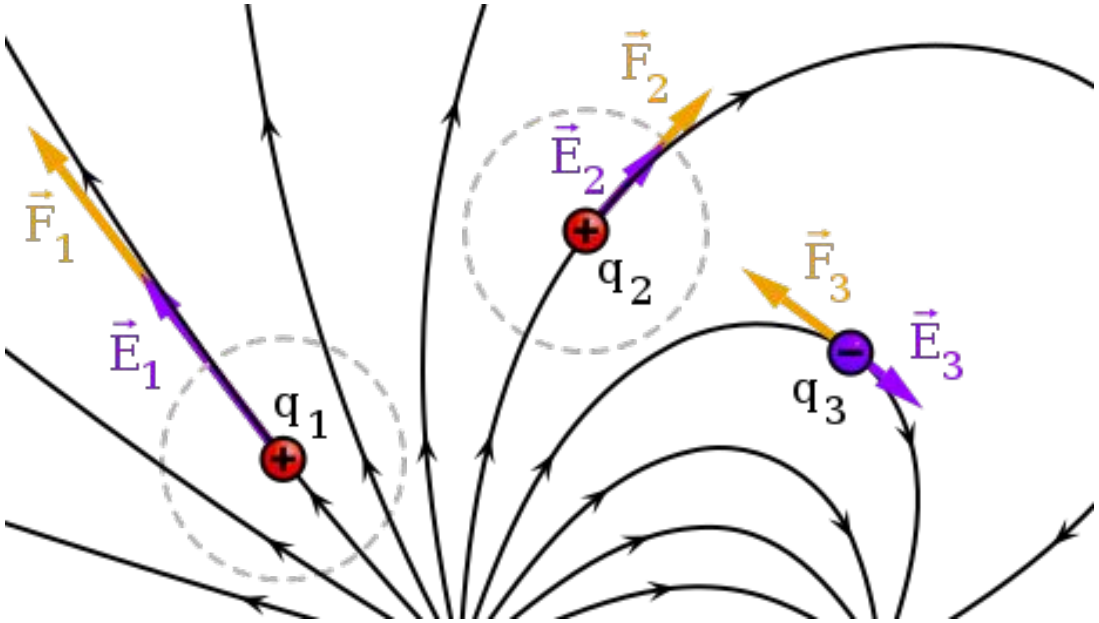
What exactly **communicates** between two objects



Electromagnetic Field

We use **"field"** to describe force





Field = an entity that has value **everywhere** and can change in **time**

Is electromagnetic field even real?

Is electromagnetic field even real?

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

Equations for wave → speed of light

Oscillation of field → light

Yes!! → The electromagnetic field is real

What about gravitational field?

Classical Mechanics is based on the definition of **an inertial frame**

Free from gravitational force? ❌

Einstein's happiest thought

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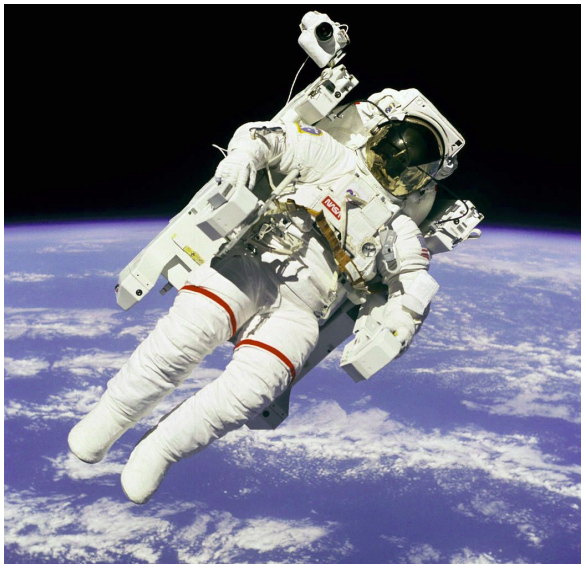
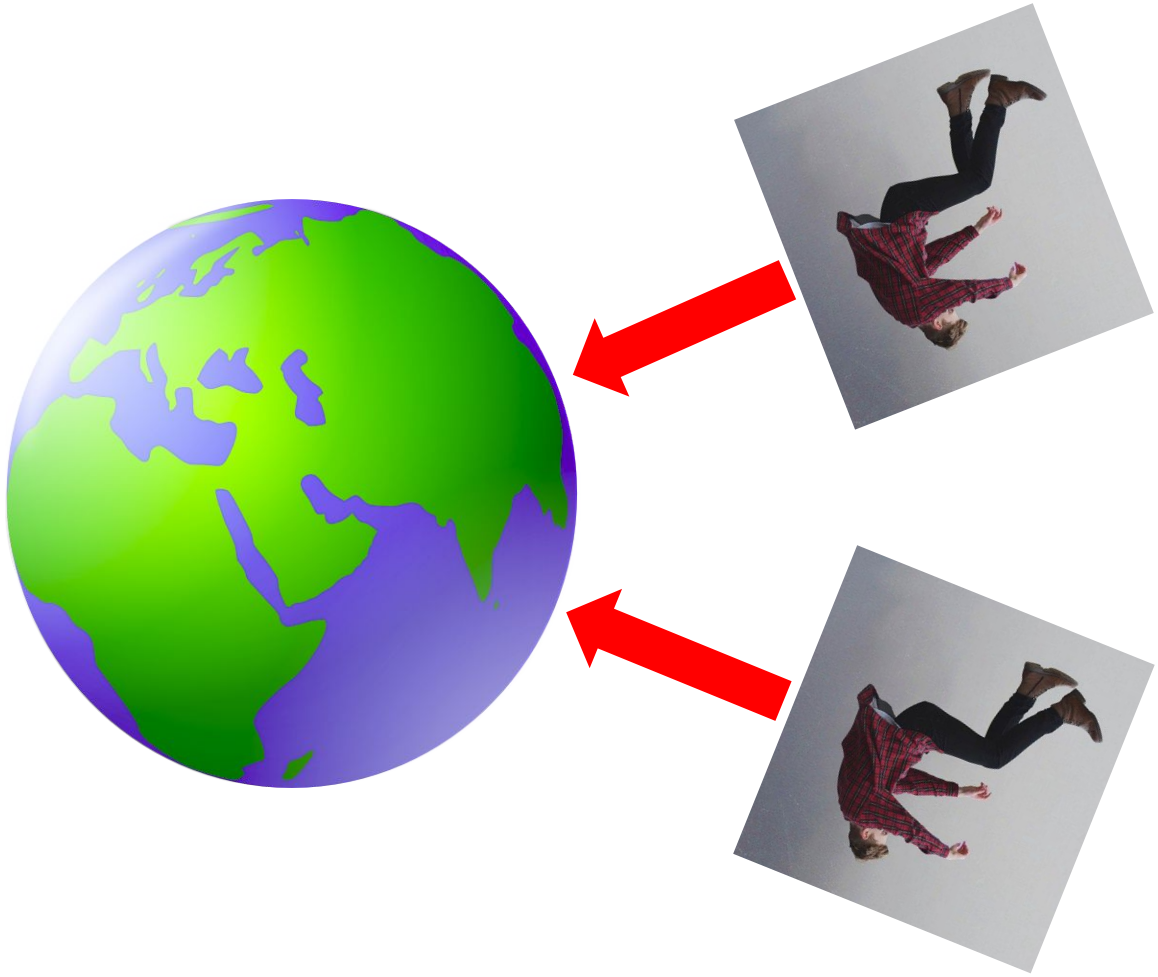


Free fall = inertial frame

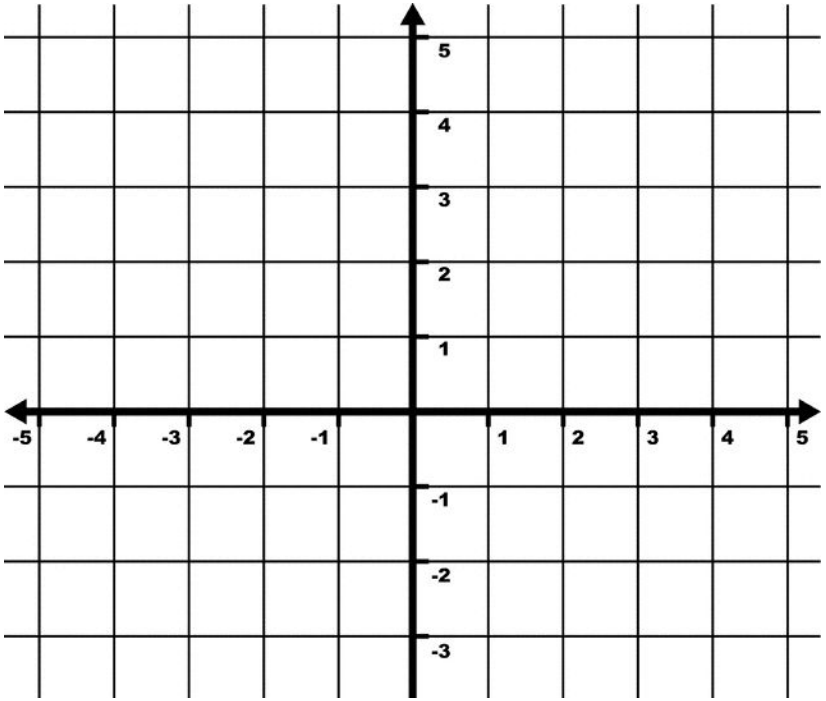
What about gravitational field?

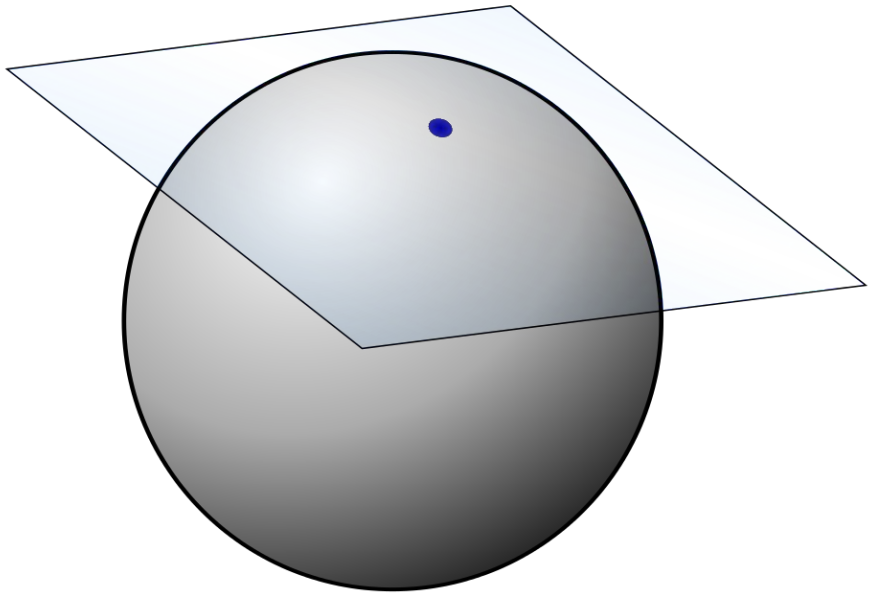


Free fall = **local** inertial frame

General Relativity

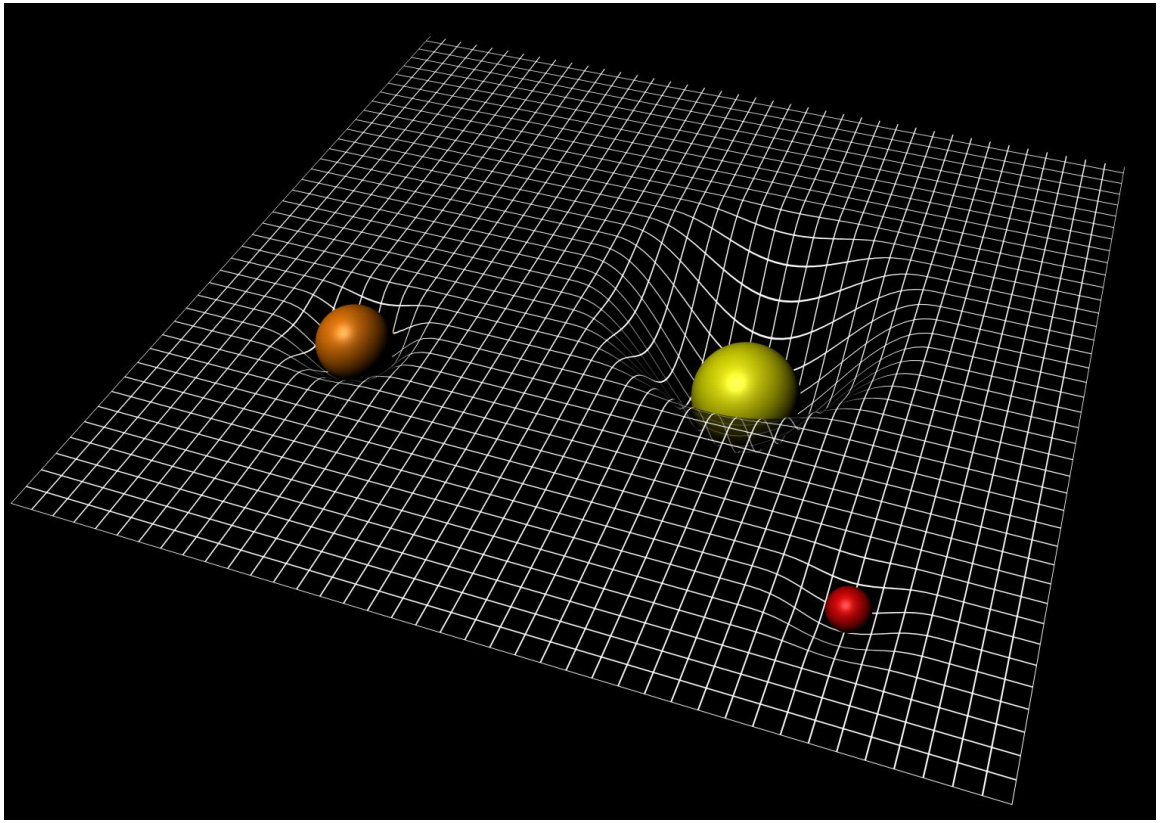
Inertial frame = flat space → **curve space** = locally flat space





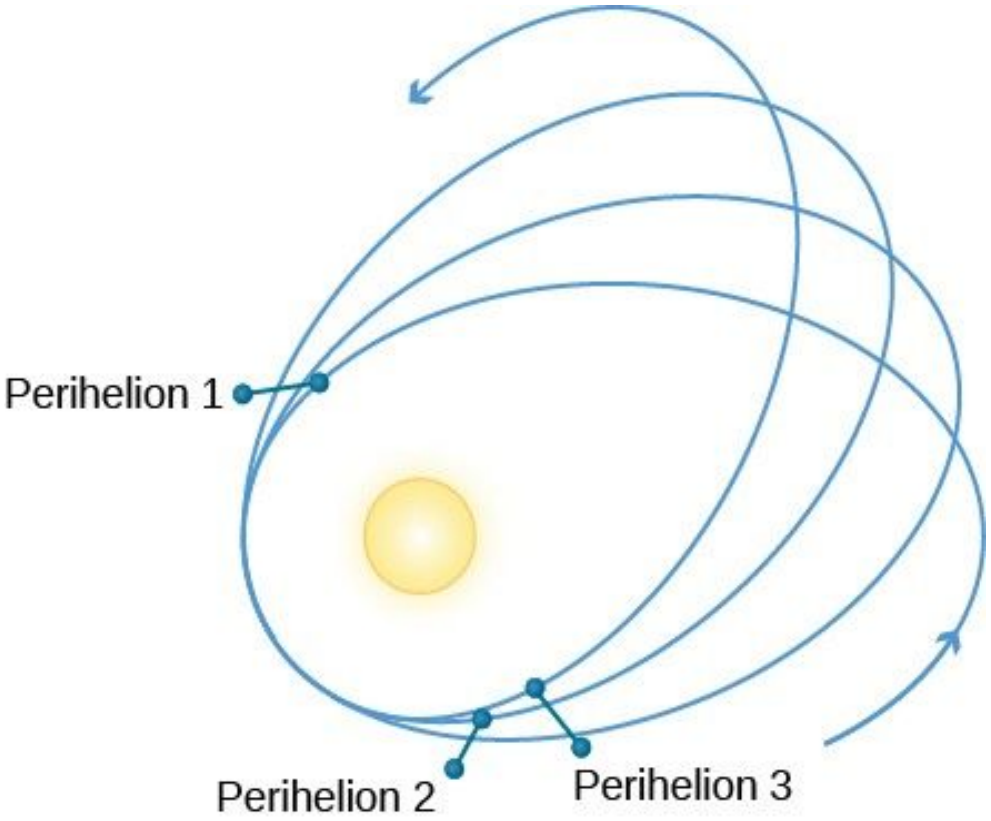
General Relativity

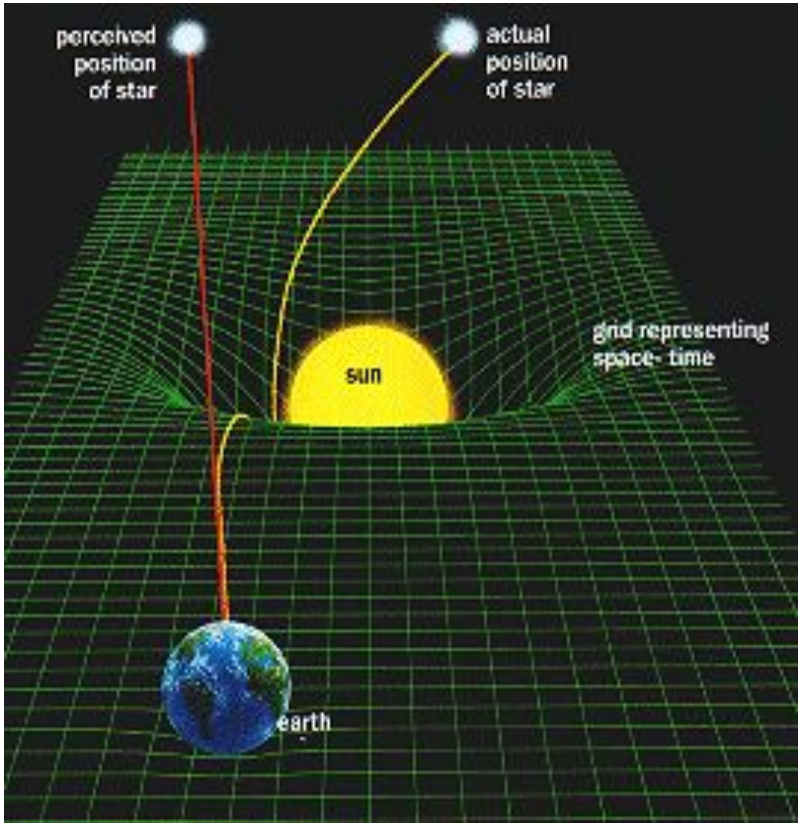
Spacetime is not a coordinate → It is a **field** (fabric of the universe)



GR tests

Is this idea testable?





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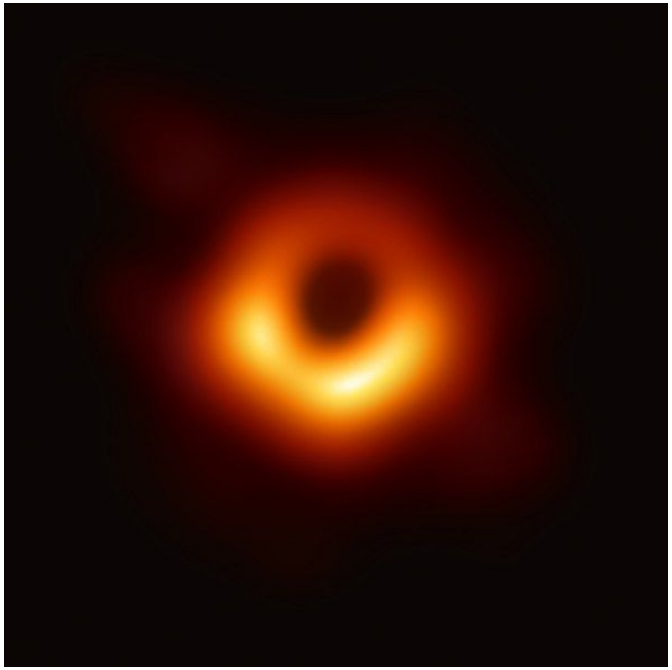
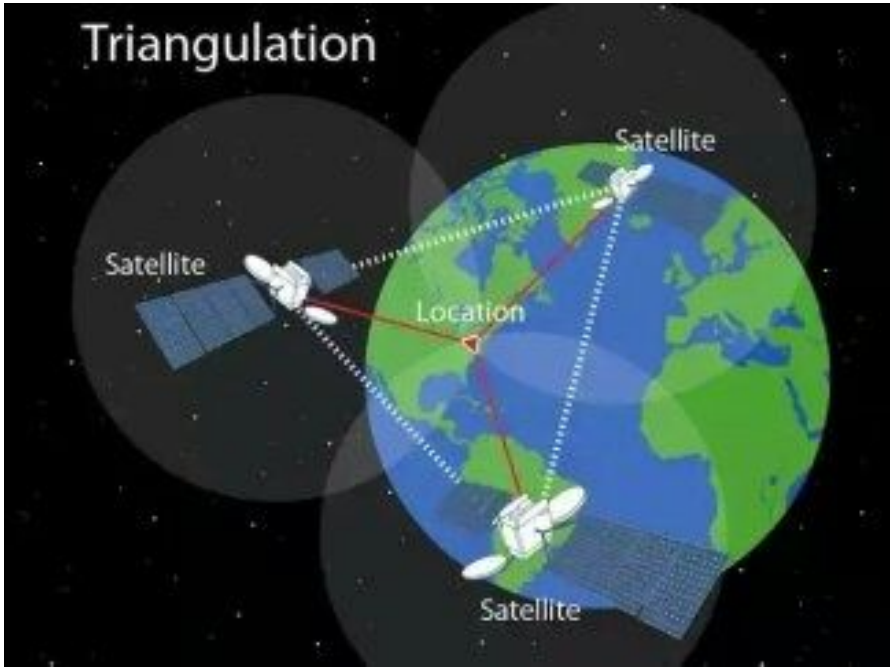
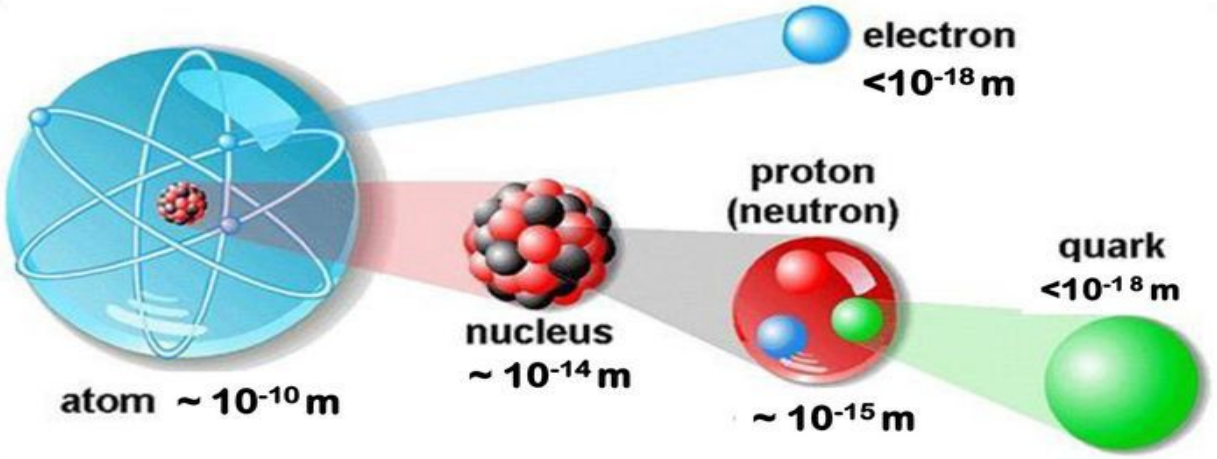




What is the universe made of?

Everything is made of atom → electrons, neutrons, protons → quarks

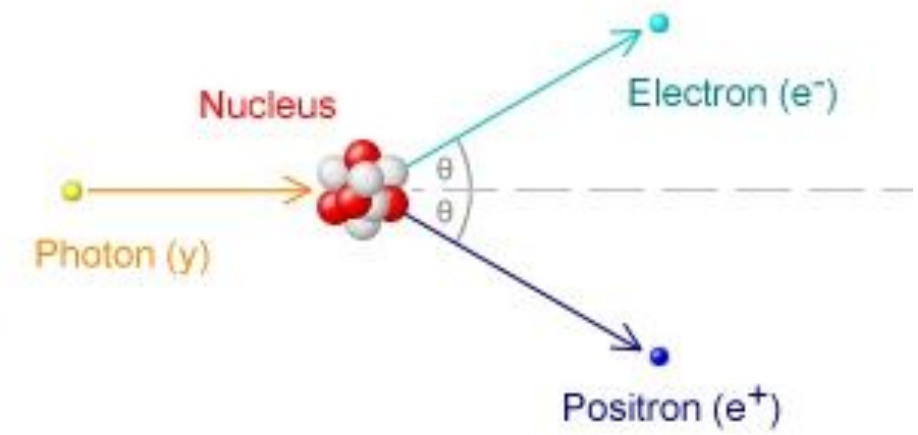


But ***a particle is not a good concept!!***

Energy ⇄ Matter

Einstein's Theory of Relativity (Special Relativity)

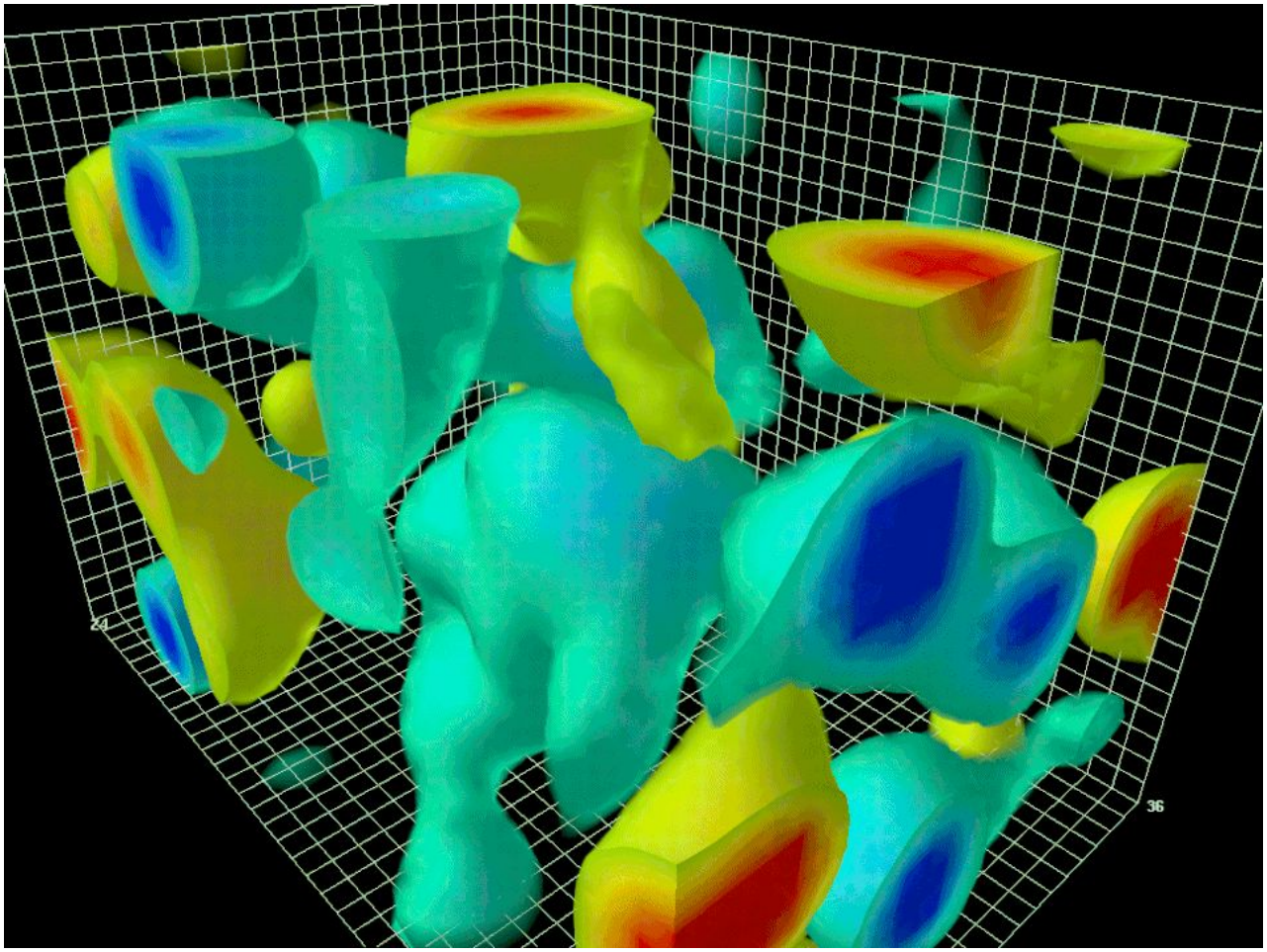
$$E = mc^2$$



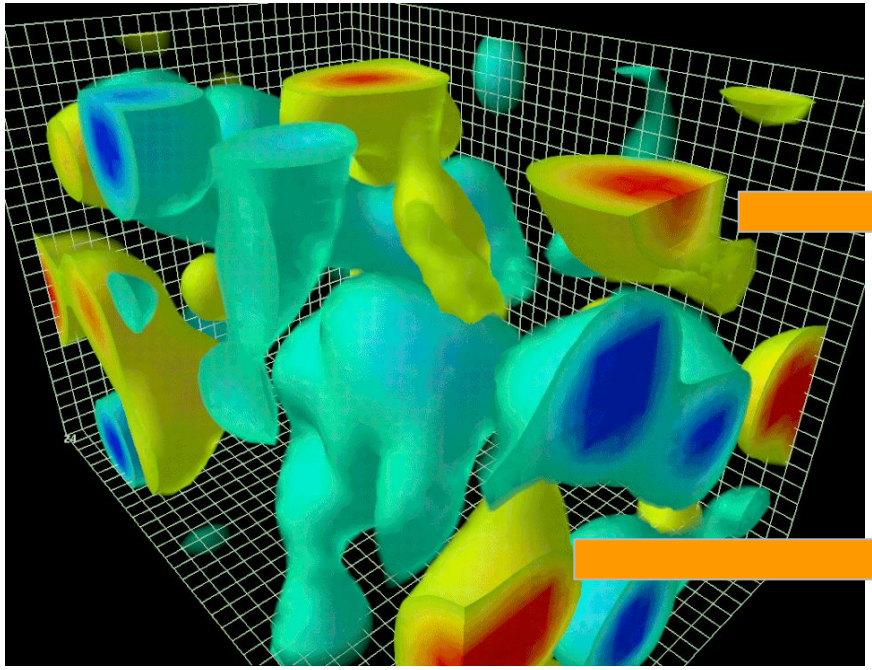
The number of **particles** is not conserved

High Energy Physics needs a **new concept**...

Quantum Field Theory

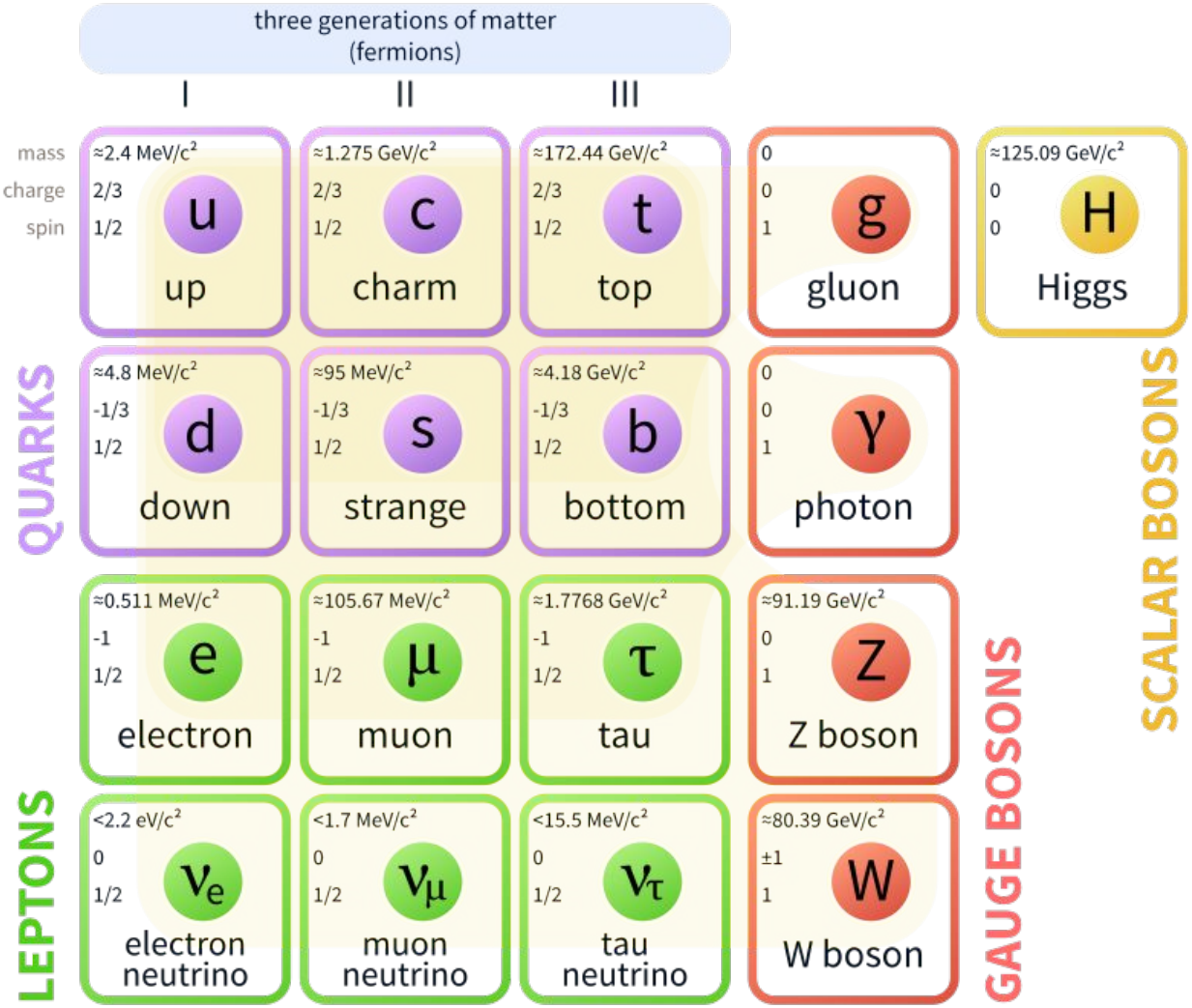


Quantum Field Theory

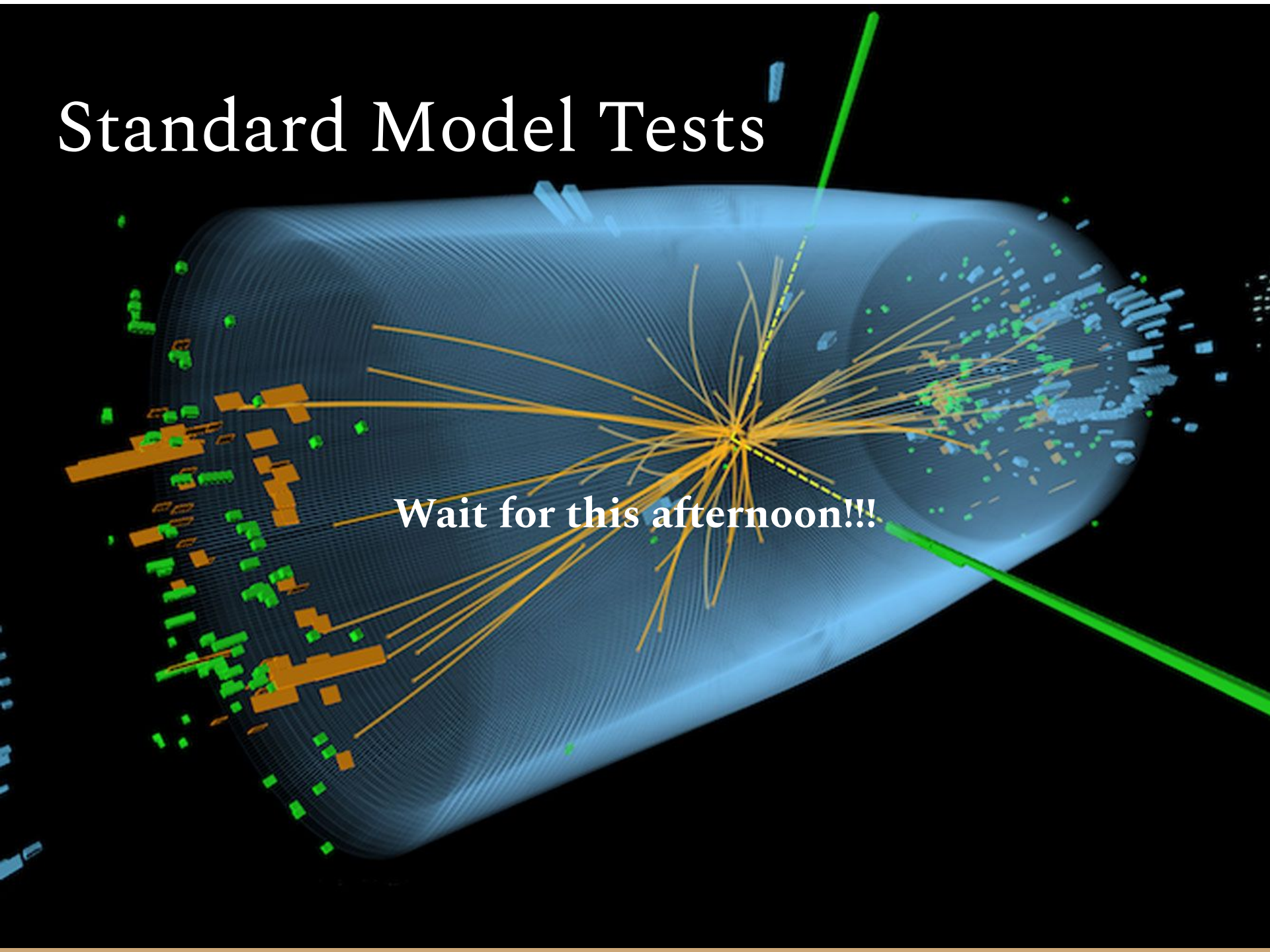


Energy

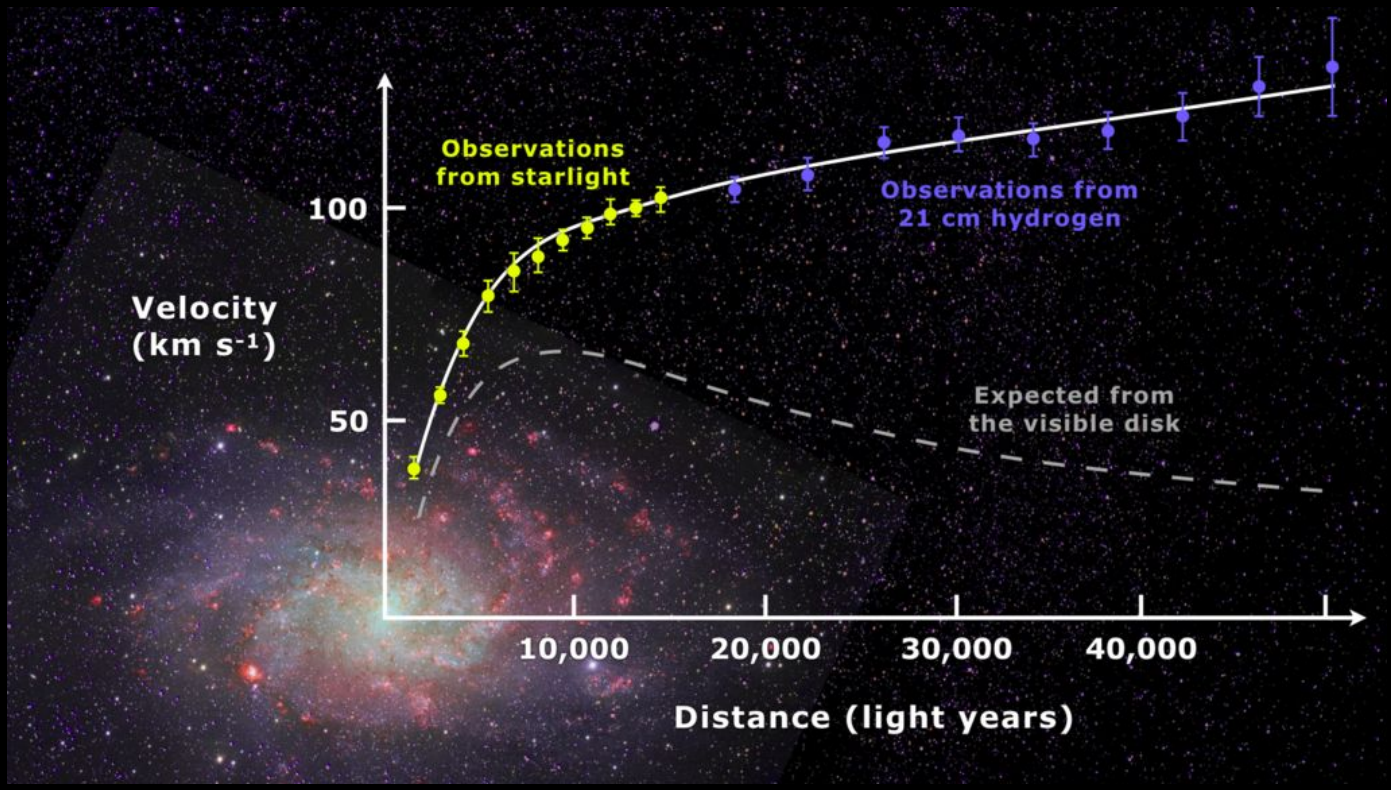
Standard Model of Particle Physics



Standard Model Tests



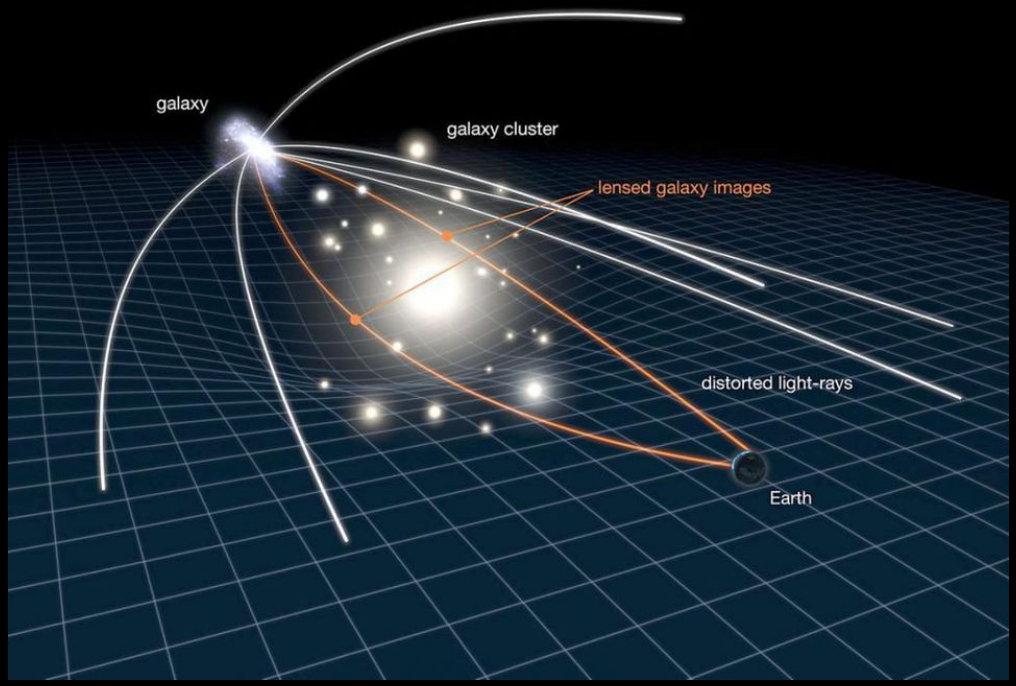
Dark Matter

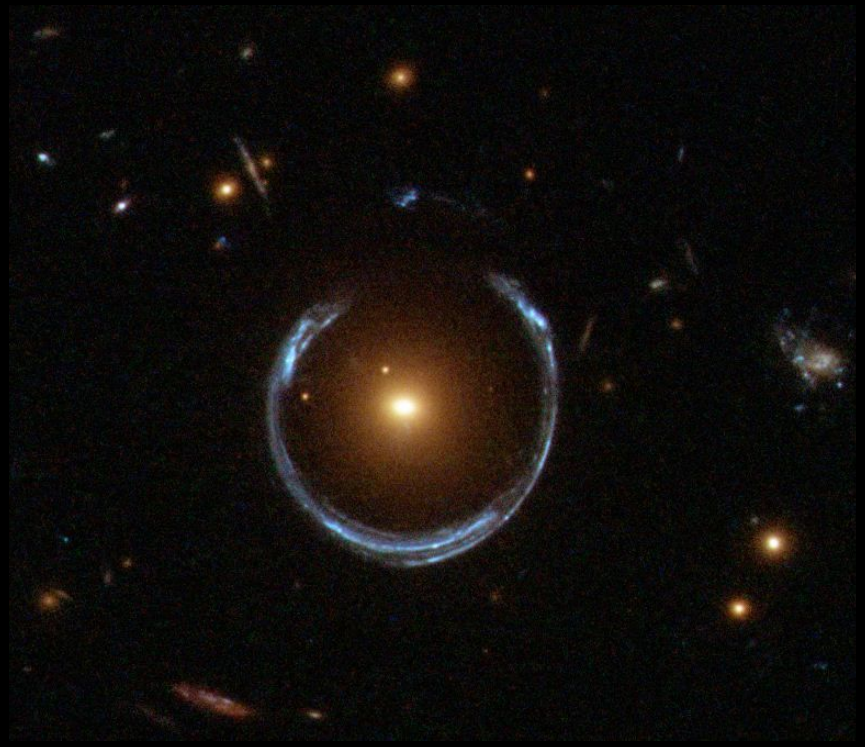


$$\frac{mv^2}{r} = \frac{GM(r)m}{r^2}$$

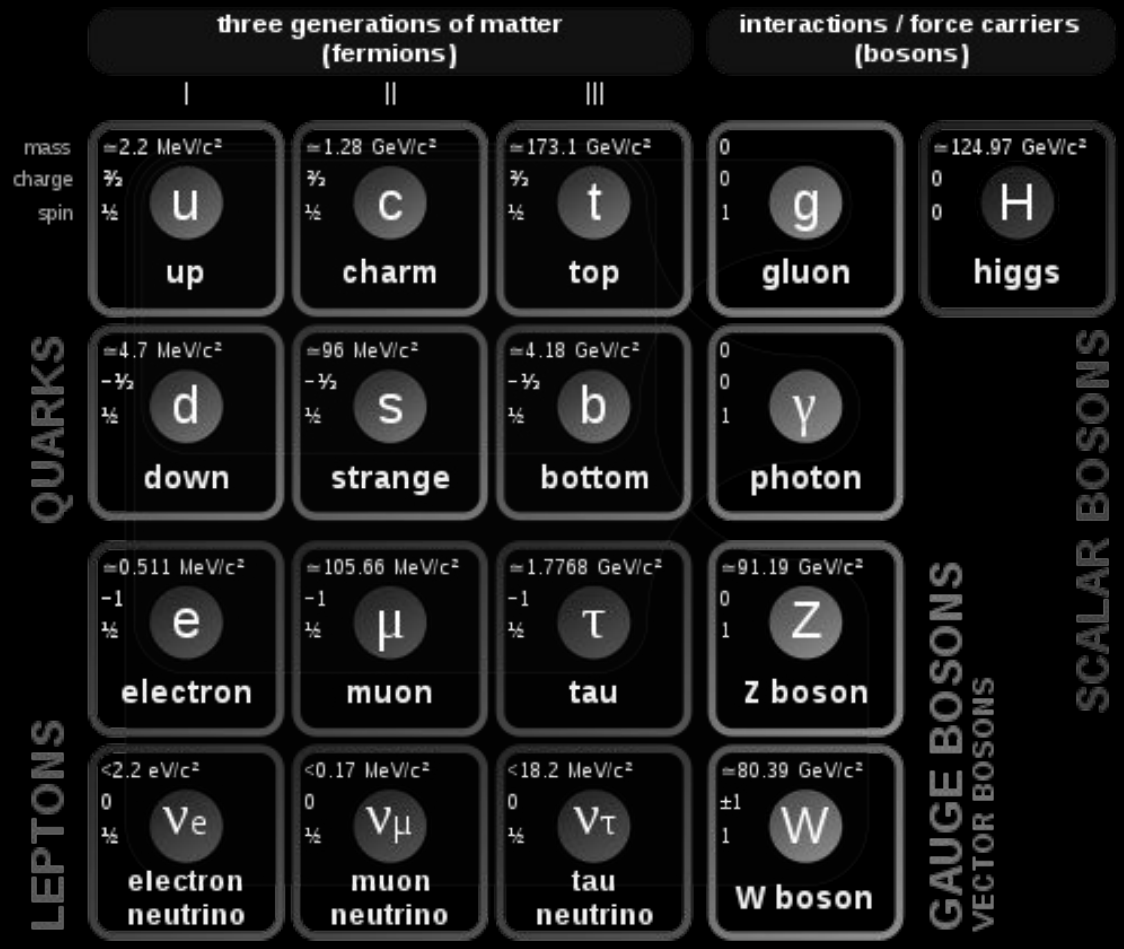
$$v = \sqrt{\frac{GM(r)}{r}}$$

Dark Matter


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth



What is dark matter particle?



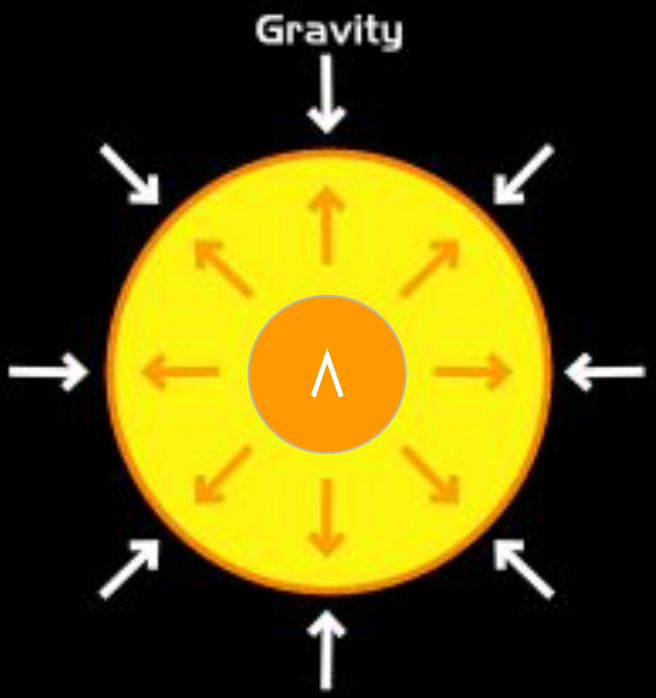
Where is the dark matter?

Only gravitational effect has been observed

No standard model particle is a good fit

Not yet solved!

Einstein's biggest blunder



We chose to believe that our universe is always static

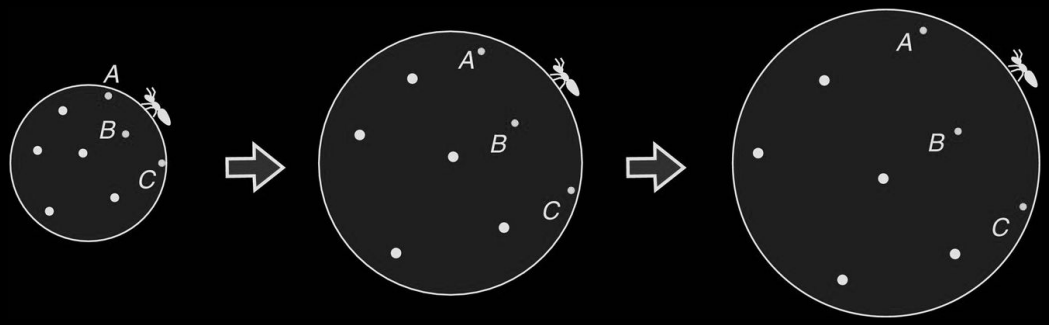
But the gravity is pulling stuff together

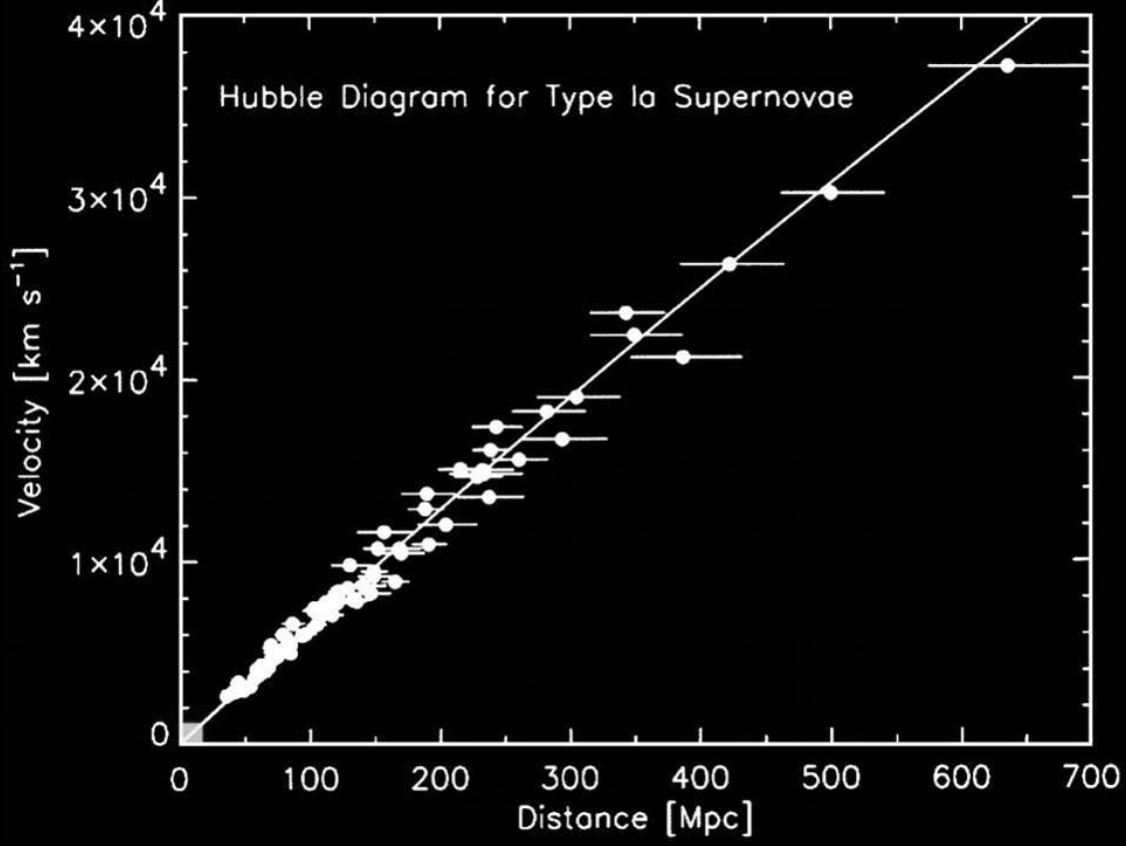
Einstein introduce the "push" → Cosmological constant

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

The universe is expanding → Big Bang

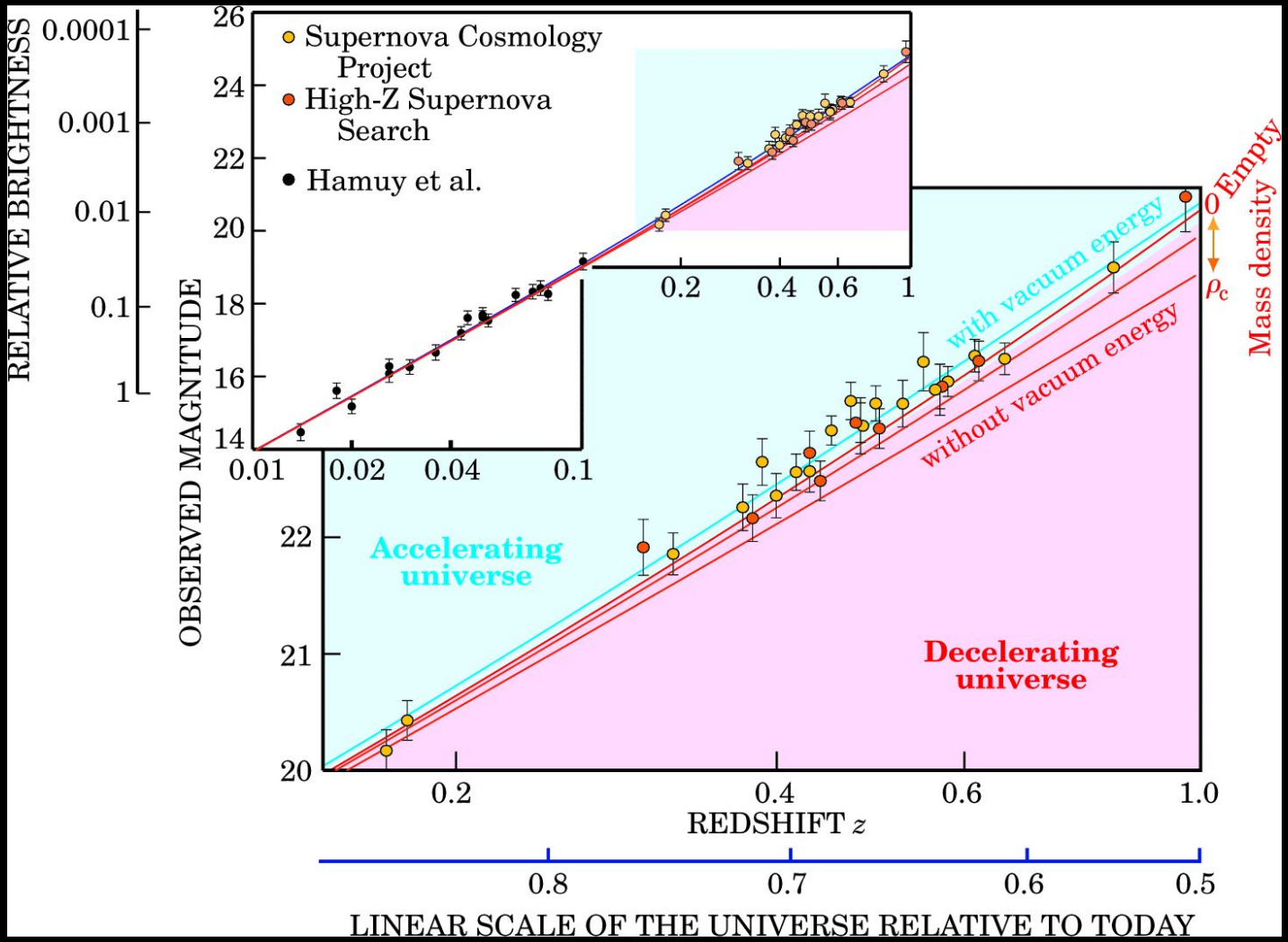
We can measure the speed and distance of galaxies



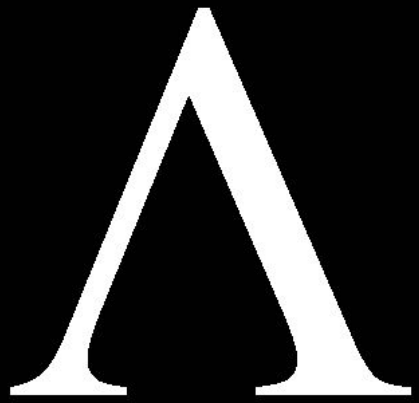


There is no need for a force (Λ) that pushing out

Universe is accelerating



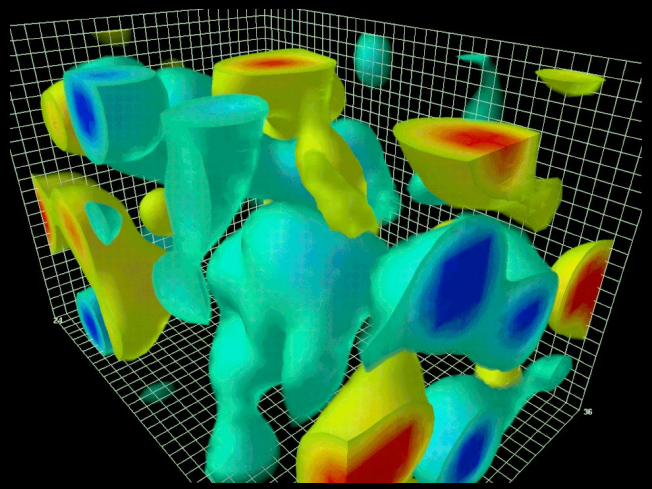
Cosmological constant coming back!



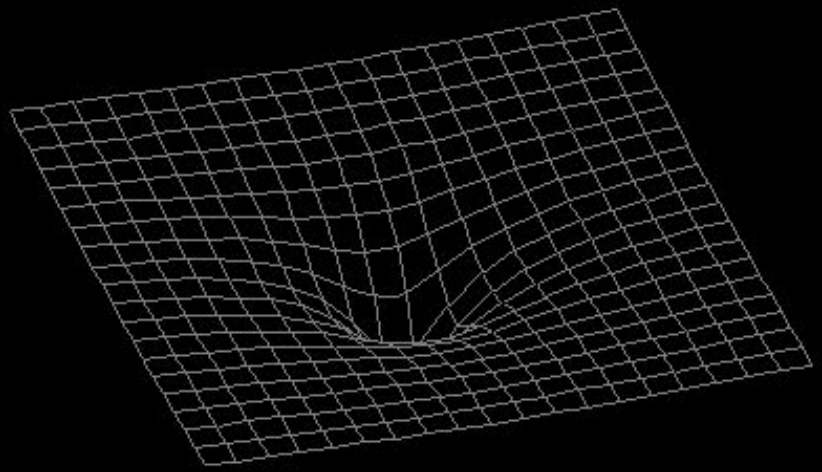
Where does this come from? Quantum field theory?

Vacuum is not empty

vacuum energy from quantum field =
100,000,000,000,000,000,000,000,000,000,000,000,000,000,000,00
0,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,
000,000,000,000,000,000 ❌ cosmological constant



$\approx 10^{120} \times$



Not yet solved!

Unification dream?

Different phenomena described by different theories tend to unified under the same theory

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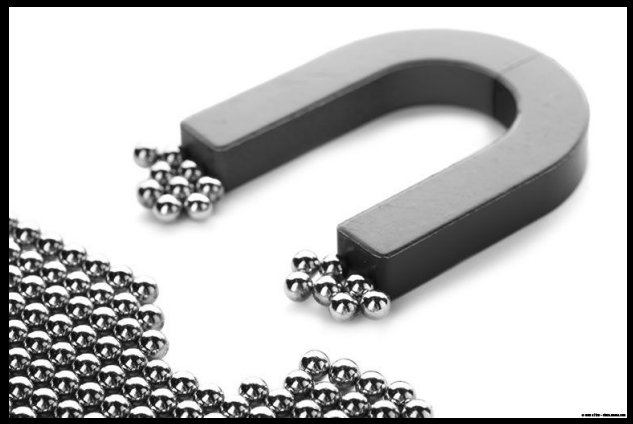

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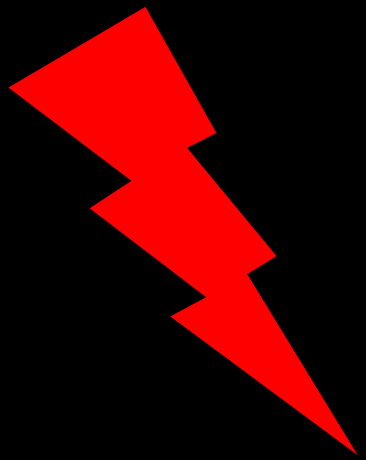
Electromagnetic force (mediated by light)

Unification dream?

Electromagnetic + Weak nuclear interaction

(Quantum Electrodynamics + weak interaction)



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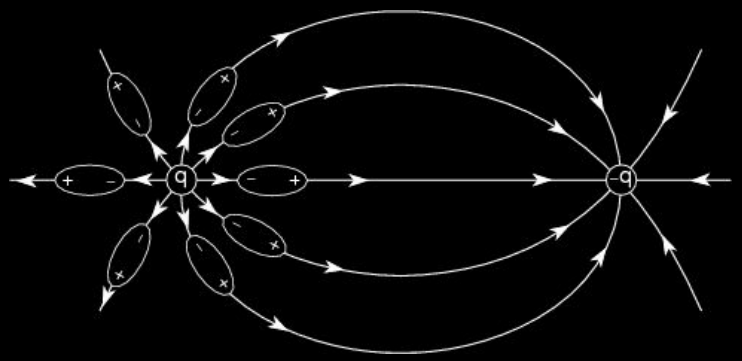
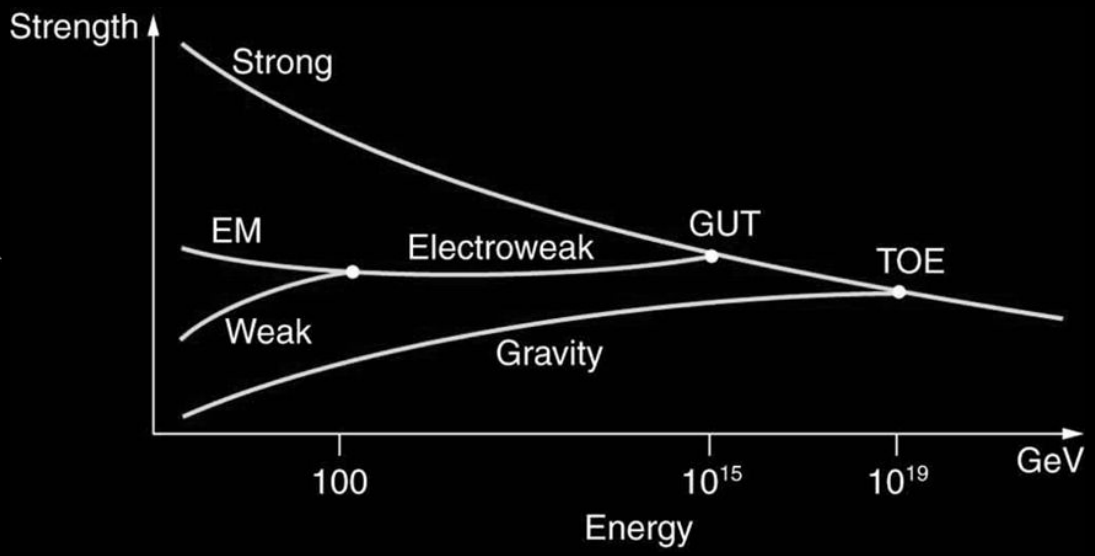
Electroweak theory

Grand Unified Theory?

Can electroweak combine with strong nuclear force?

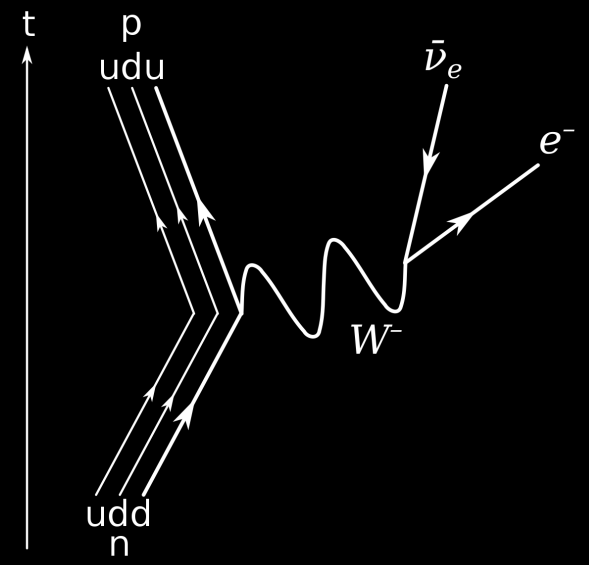


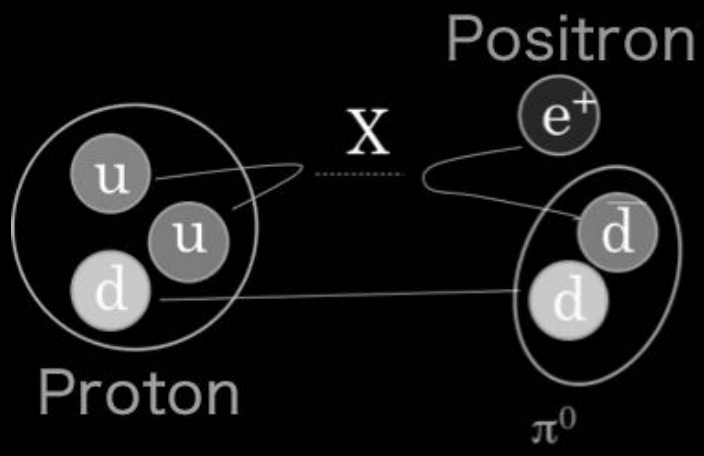


Not yet solved!

Can proton decays?

Neutron is heavier than proton $n \to p + e^- + \overline{\nu}_e$

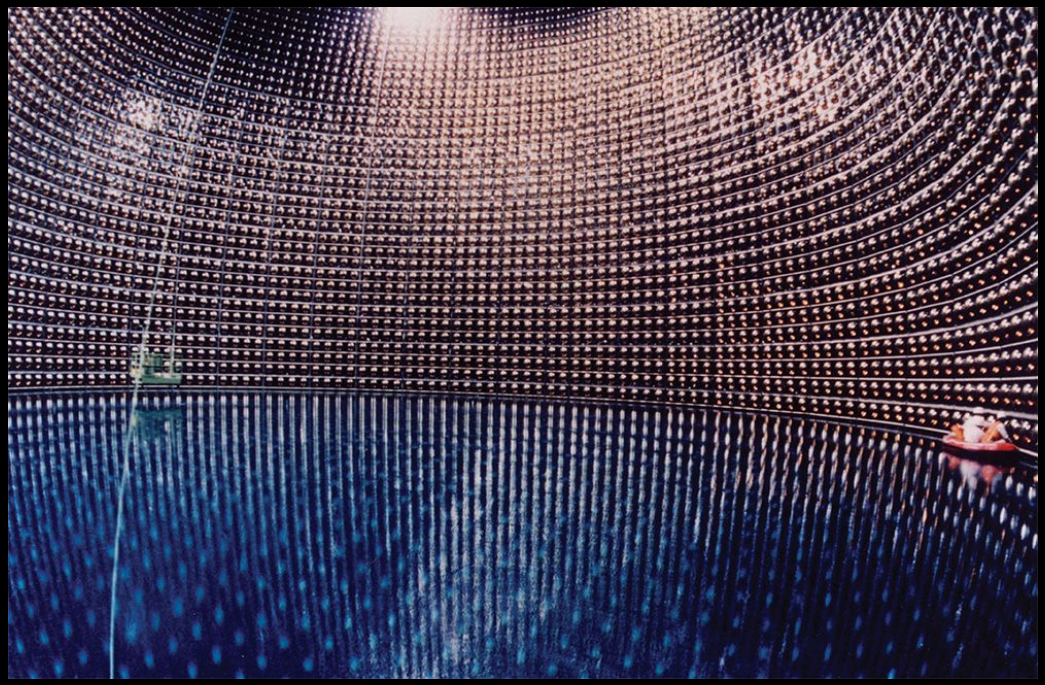




If a new force exists then proton can decay $p \to \pi^0 + e^+$

Can proton decays?

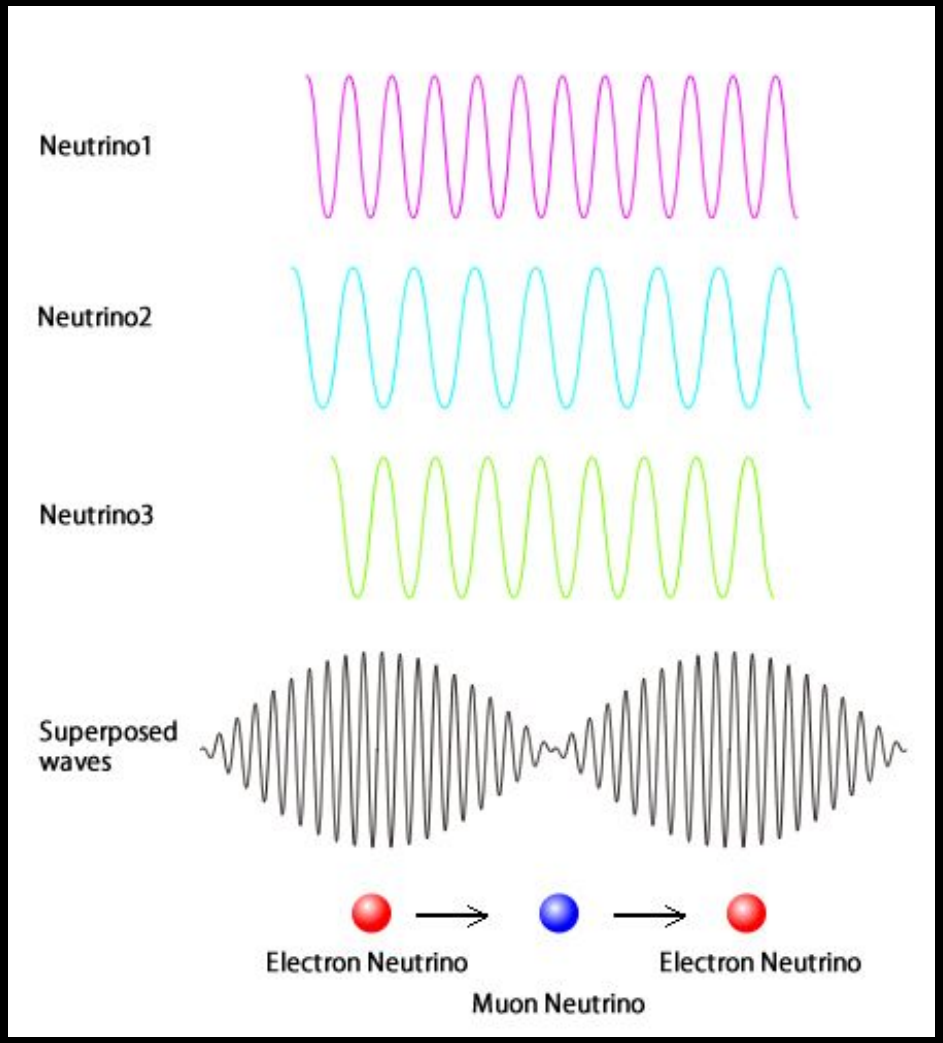
Experiments put the lifetime $\gtrsim 10^{34}$ years

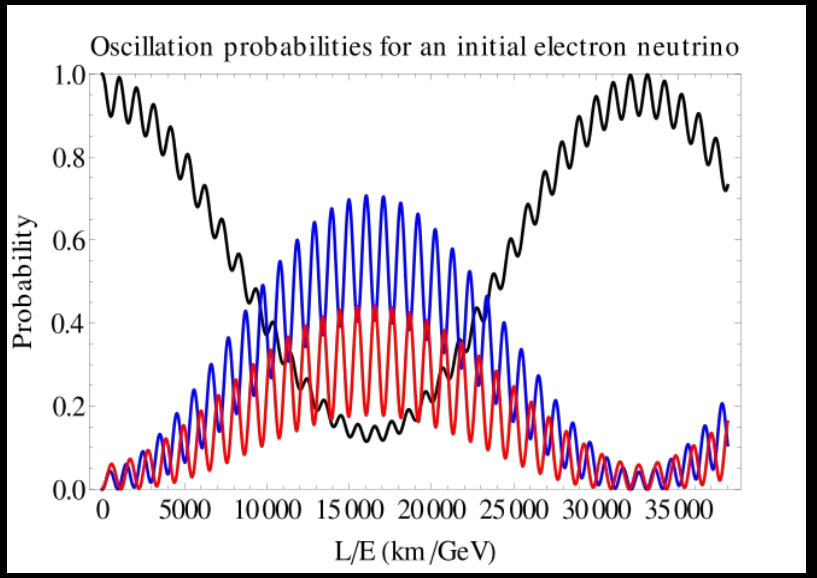


Lifetime of our universe $\sim 10^{10}$ years

Not yet solved!

Neutrino oscillation





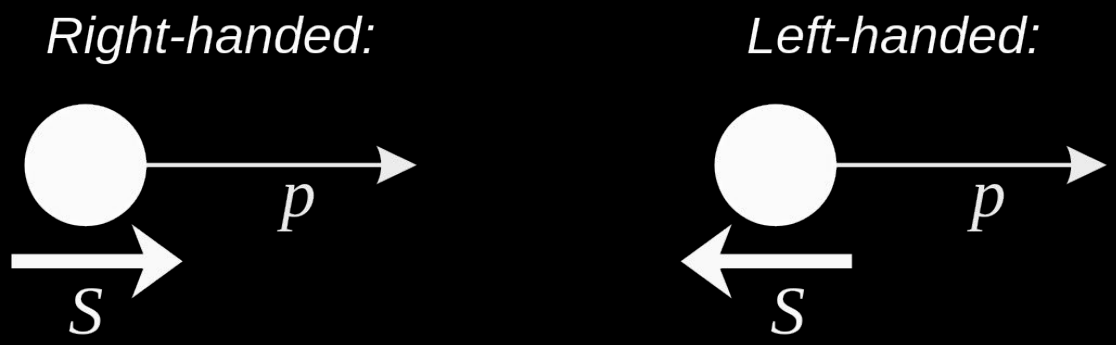
Producing electron neutrino → changing type as it travels

Electron neutrino is composed of 3 different neutrinos which travels with different speed

Neutrino oscillation

Neutrinos have no mass in the standard model

Massive spin ½ particle has 2 components



Standard model has only left-handed neutrinos

New component of neutrino must be there

Not yet solved!

There are many more

Naturalness problem, black hole information paradox, muon g-2 anomaly, lepton flavour anomaly, ...

KKPaCT

Khon Kaen Particle Physics and Cosmology Theory Group









Our Research Topics:

Theoretical Physics, High Energy Physics, Particle Physics, Cosmology, Hadron Physics

We need more hands -- please don’t hesitate to contact us

Thank you