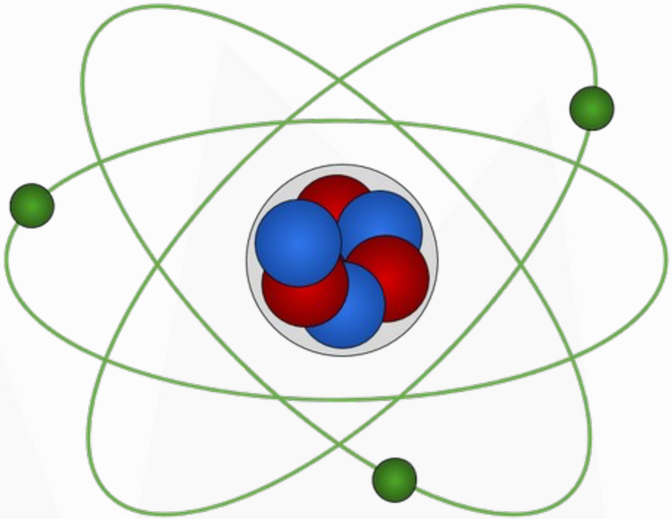


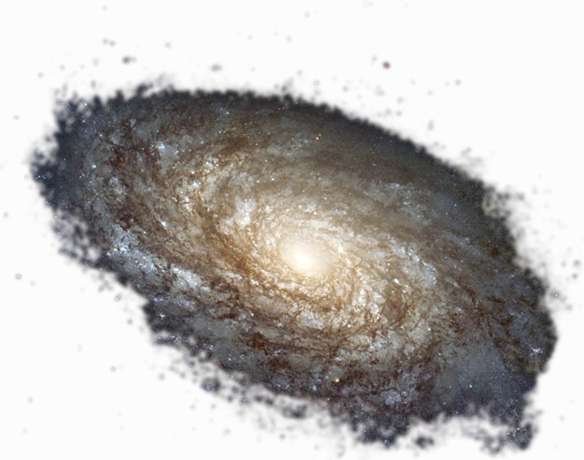
The Universe under a microscope:

Zooming in on particle physics

Anca Preda

Division of Particle and Nuclear Physics
Lund University

Have you ever wondered what we're really made of?



The journey

Biology

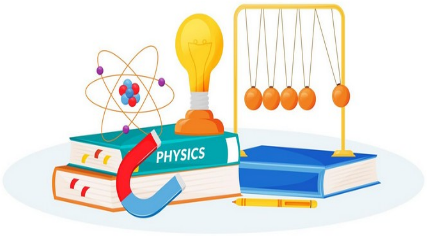
(large)

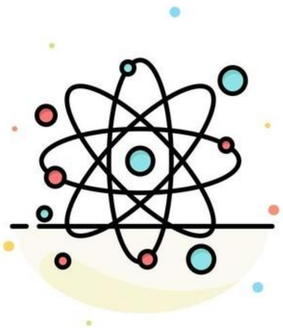
Chemistry

(small)

Physics

(smaller)





Particle Physics

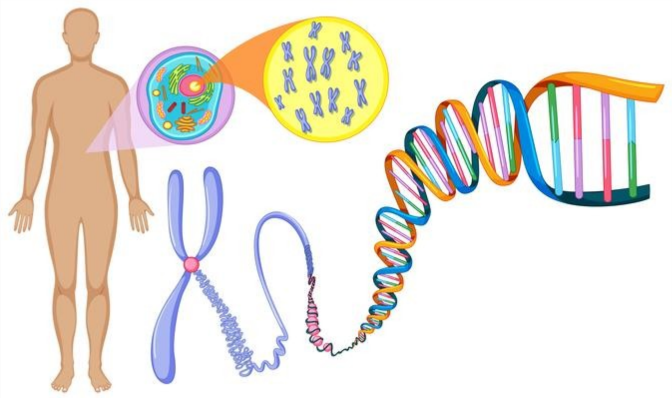
(smallest)

Step 1: Biology

Life starts with **cells**, the smallest units of living organisms.

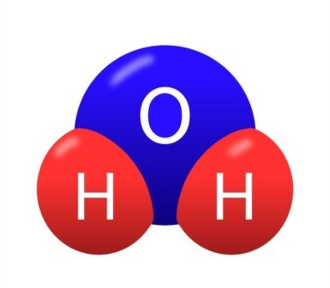
biological functions: growth, repair, reproduction, energy production.

But what are cells made of?

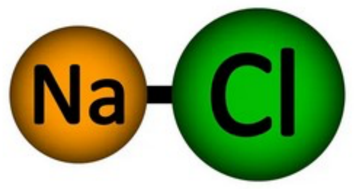


Step 2: Chemistry

- **Zooming in further**: cells are made out of **molecules**, which form the chemistry of life and matter.



H_2O water



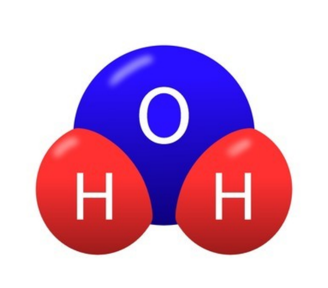
NaCl salt

- Molecules are made of **atoms**, the ingredients of matter.

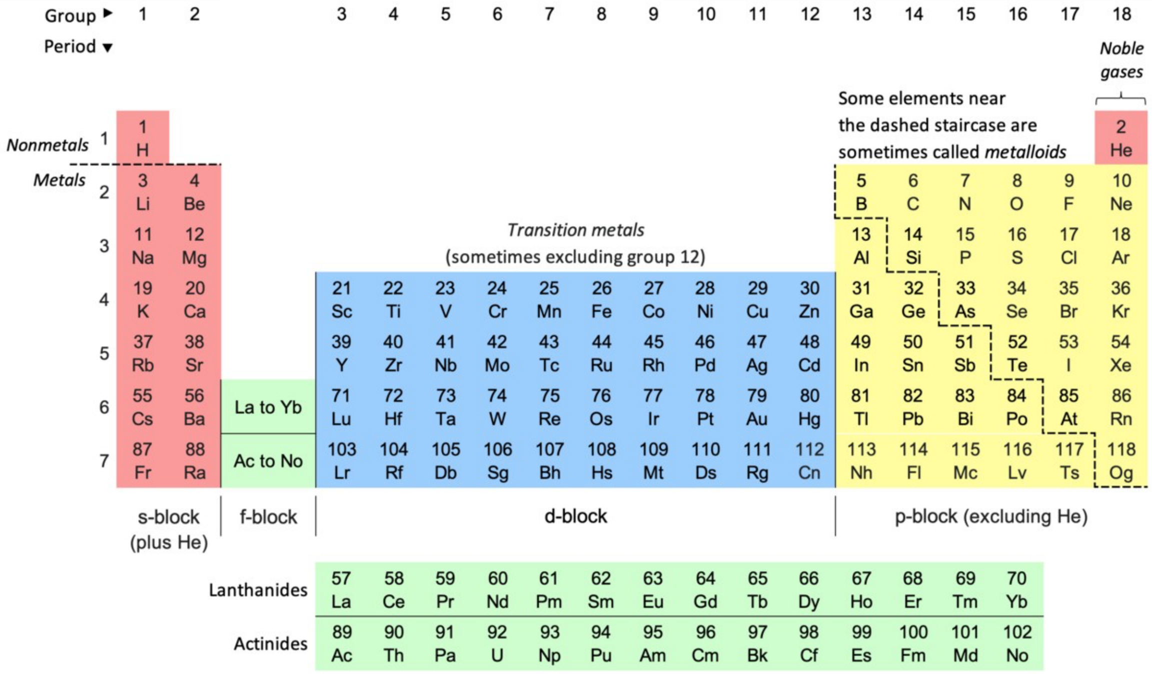
At this level, Nature is therefore described by atoms!

Step 2: Chemistry

- **Zooming in further**: cells are made out of **molecules**, which form the chemistry of life and matter.



H2O water



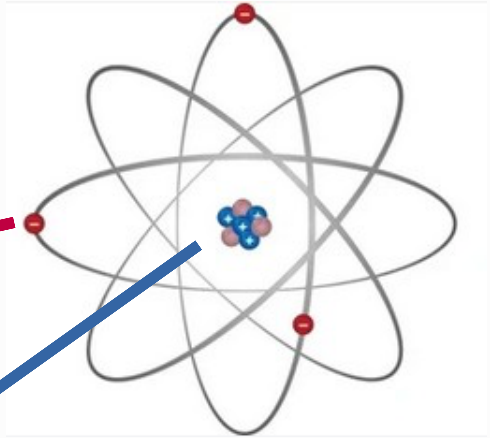
Periodic Table of Elements
Source: Wikipedia

- Molecules are made of **atoms**, which are ingredients of matter.

Step 3: Physics

Atoms can be further divided!

- **Zooming in even more**: atoms have a dense nucleus made of **protons** and **neutrons** [E. Rutherford], which are surrounded by **electrons** [J.J. Thomson].
- The nucleus contains nearly all the atom's mass.



!! If we were to stop here, then Nature would be described in terms of these three ingredients: **electrons, protons, neutrons**

electrons
(orbiting around the nucleus)

protons and neutrons
(forming the nucleus)

Step 3: Physics

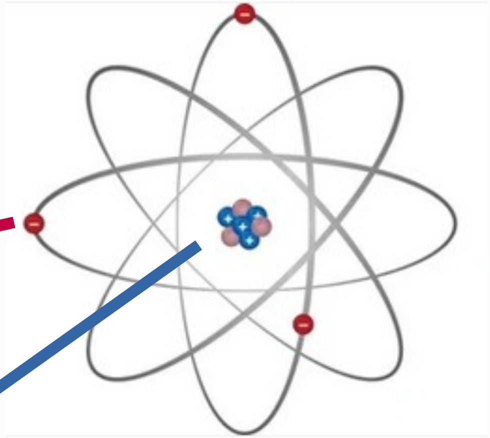
The journey continues...

- **Electrons**: can not be divided further ⟶ **fundamental particles** of Nature
- **Protons** and **neutrons**: different story altogether

↓

Not fundamental particles

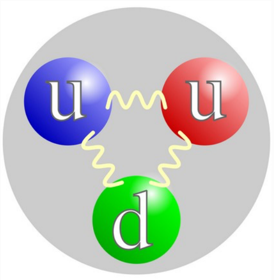
So what are they made of?



Step 4: Particle Physics

As far as we can go

- We have arrived at the smallest scale, where our description of Nature is the most fundamental (yet!).
- **Protons** and **neutrons**: made out of **quarks**
- There are many different types of quarks: up (u), down (d), strange (s), bottom (b), top (t), charm (c).
- Together with the **electron**, **quarks** are **fundamental particles**!



That's a proton!

proton structure:
two up-quarks and
one down-quark

Step 4: Particle Physics

As far as we can go

Let's summarize…

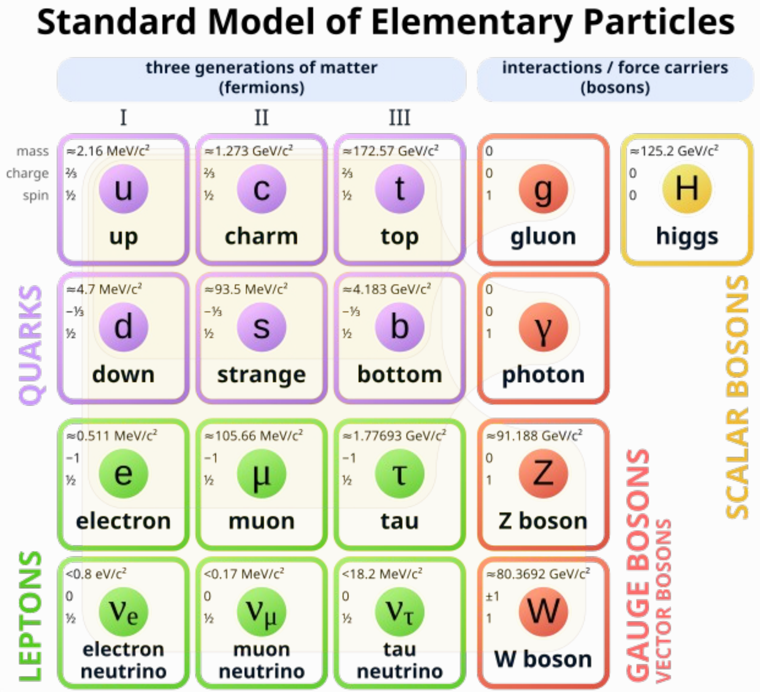
- fundamental particles

quarks
(u, c, t, d, s, b)

leptons
$(e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau)$

cousins of electrons

all matter in Nature!



source: Wikipedia

Step 4: Particle Physics

As far as we can go

Let's summarize…

- fundamental particles

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leptons
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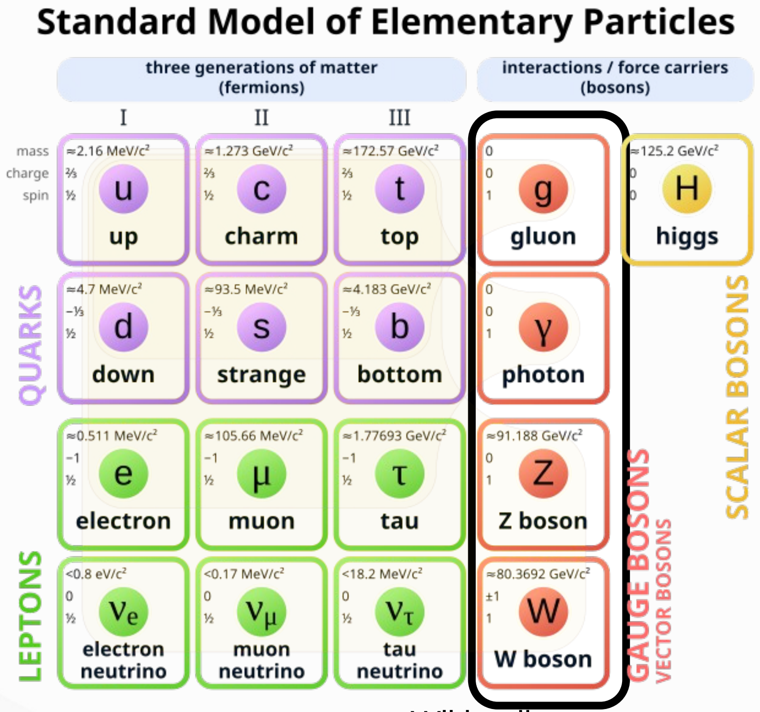
cousins of electrons

all matter in Nature!

- gauge bosons: help particles interact

↓ "carry" the fundamental forces



source: Wikipedia

Step 4: Particle Physics

As far as we can go

gives particles mass!

Let's summarize…

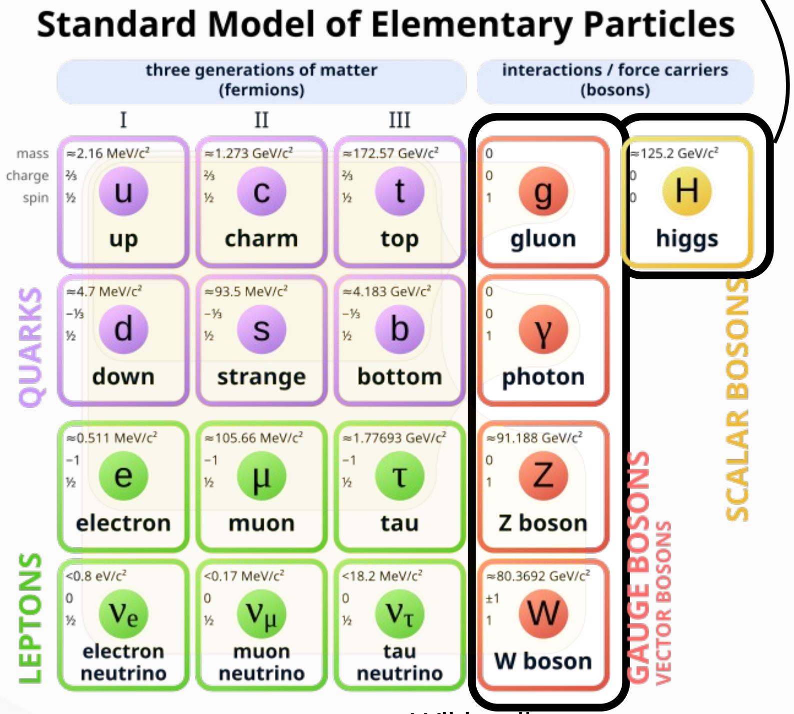
- fundamental particles

quarks
(u, c, t, d, s, b)

leptons
(e, μ, τ, ν_e, ν_μ, ν_τ)

cousins of electrons

all matter in Nature!



source: Wikipedia

- gauge bosons: help particles interact

“carry” the fundamental forces

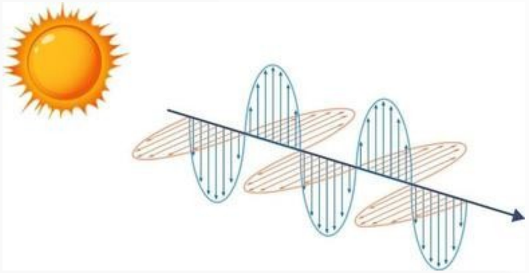
How do these particles interact and shape the Universe around us?

Forces and interactions

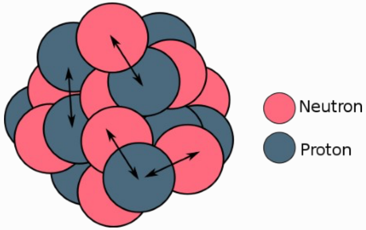
The universe operates under four fundamental forces, each with a unique role!

“invisible rules of the game”

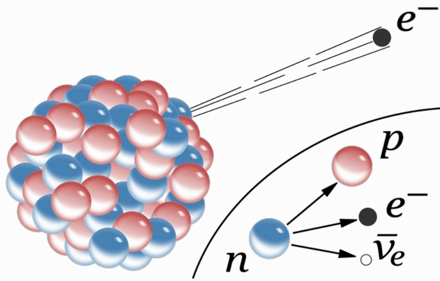
Gravity



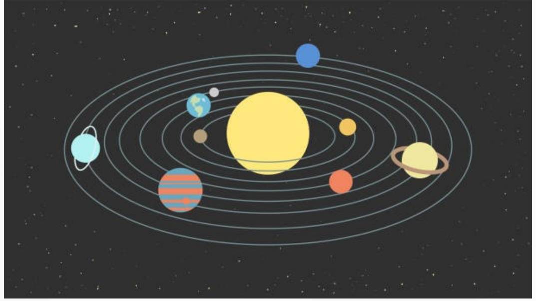
Electromagnetism



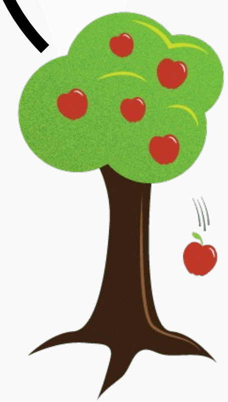
Strong force



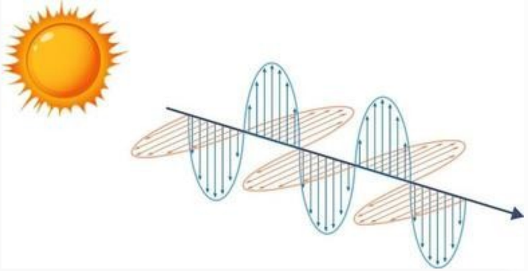
Weak force



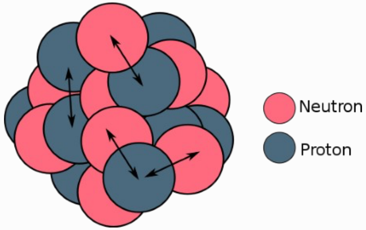
Large scale
Shapes galaxies and planets



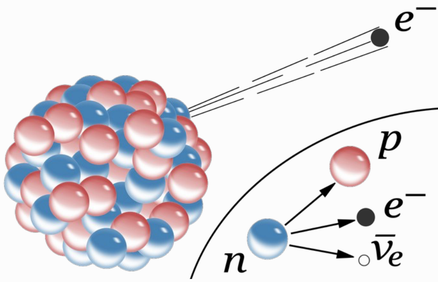
Gravity



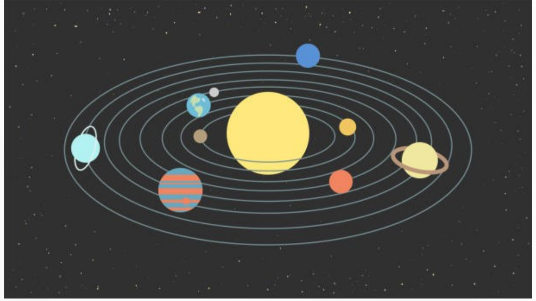
Electromagnetism



Strong force

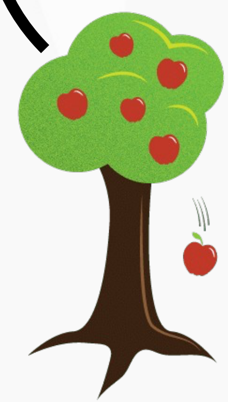


Weak force

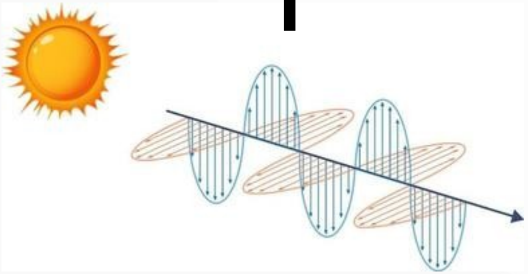


Large scale
Shapes galaxies and planets

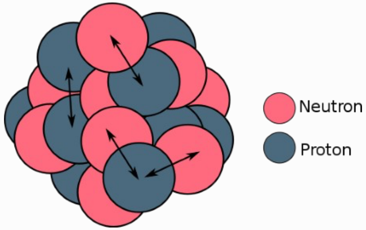
Describes light, electronics, magnetism..



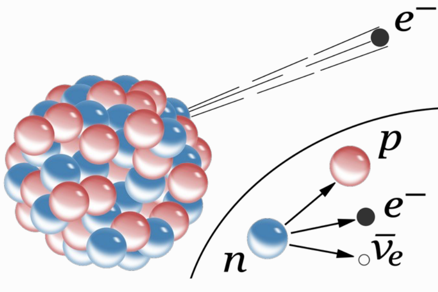
Gravity



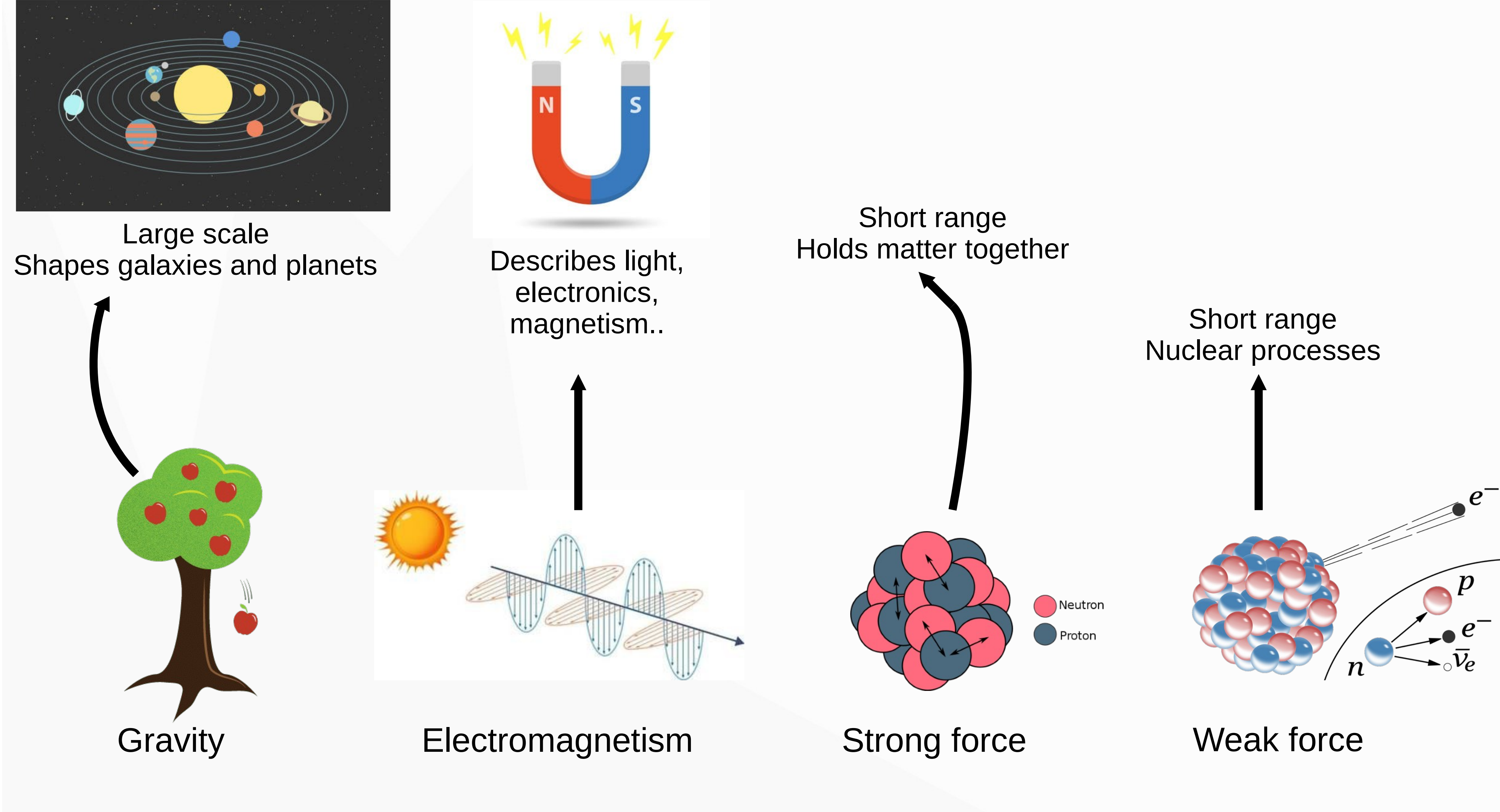
Electromagnetism



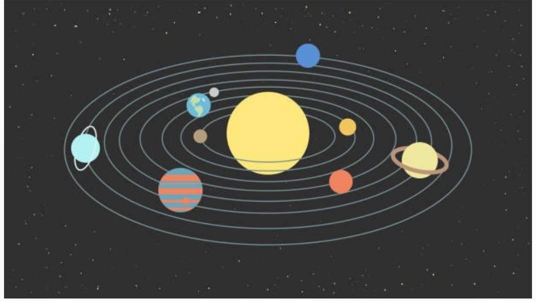
Strong force



Weak force


Large scale
Shapes galaxies and planets
Describes light,
electronics,
magnetism..
Short range
Holds matter together
Short range
Nuclear processes
N
S
Neutron
Proton
e^-
p
e^-
$\bar{\nu}_e$
n
Gravity
Electromagnetism
Strong force
Weak force

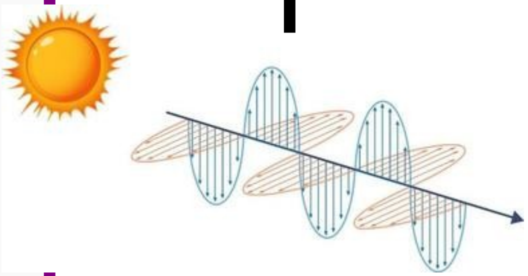
Vital at very small distances!
Described by the Standard Model



Large scale
Shapes galaxies and planets

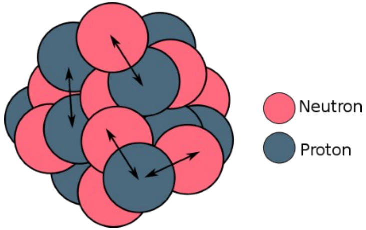
Gravity

Describes light,
electronics,
magnetism..



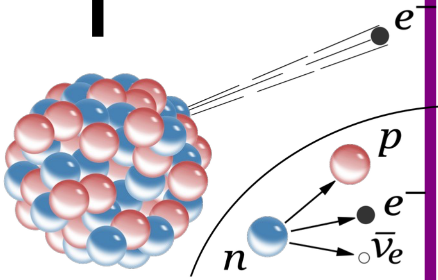
Electromagnetism

Short range
Holds matter together



Strong force

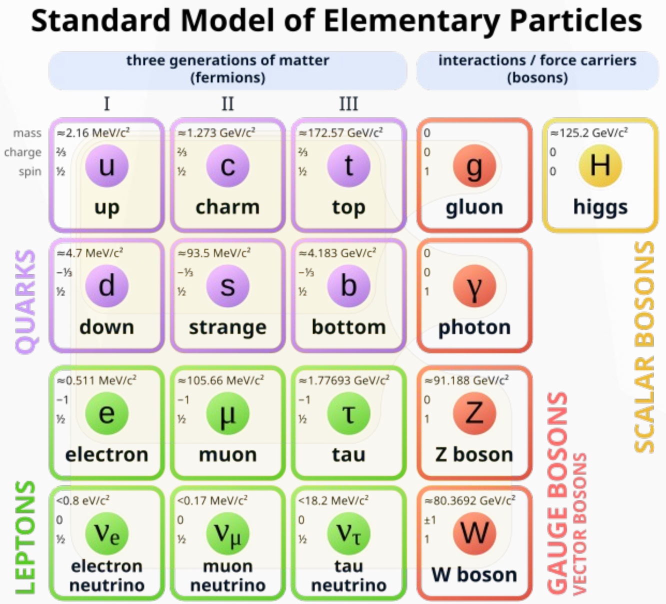
Short range
Nuclear processes



Weak force

Let's summarize
Theoretical side

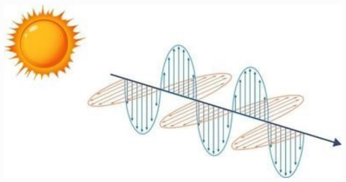
Particles



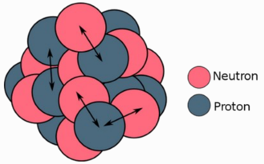
source: Wikipedia

Forces

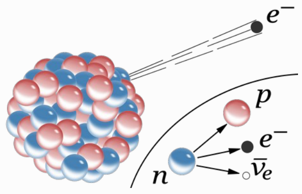
Gravity



Electromagnetism



Strong force

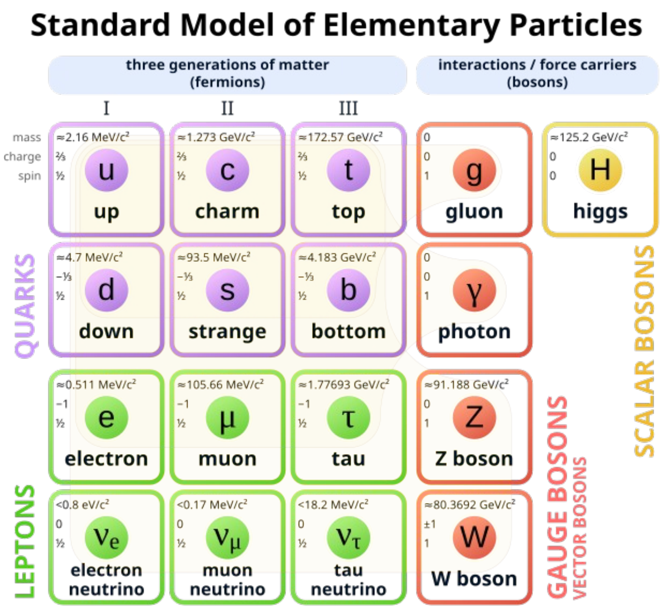


Weak force

Let’s summarize

Theoretical side

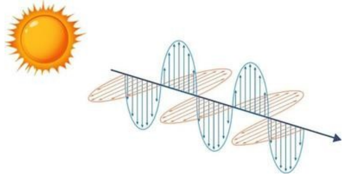
Particles



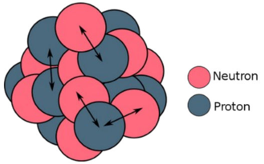
source: Wikipedia

Forces

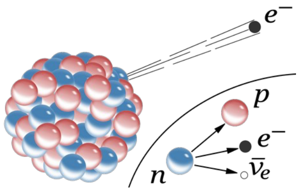
Gravity



Electromagnetism



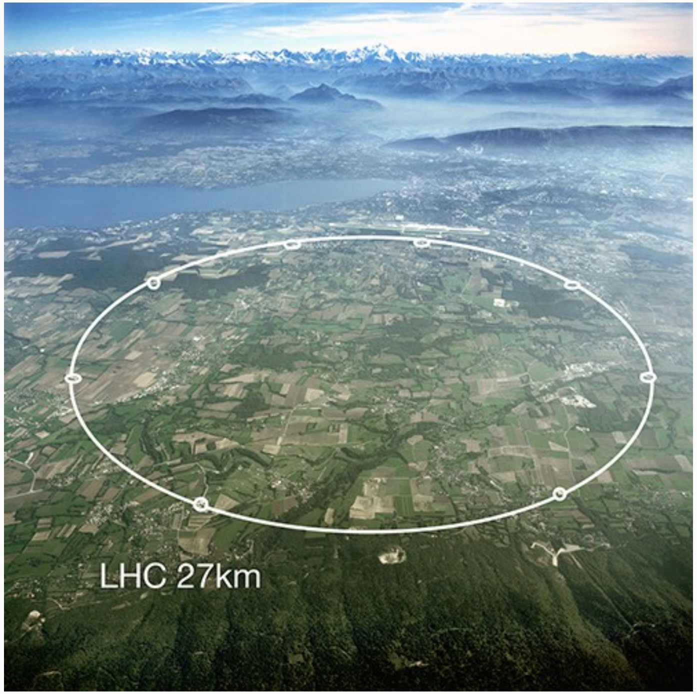
Strong force



Weak force

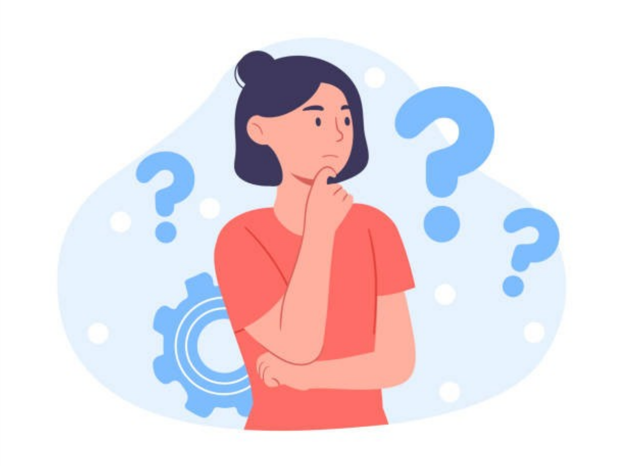
Let’s summarize
Experimental side

- Standard Model has been tested successfully in high-energy experiments at CERN and beyond.
- LHC played a crucial role in these tests (Higgs discovery)
- Collide protons at large speeds and form new particles and processes.
- Physicists compare experimental data with Standard Model predictions to look for differences.
- So far...no (major) difference from theory!



The Large Hadron Collider (LHC) at CERN

Do we know everything?



Do we know everything?

It seems not!

The Standard Model of Particle Physics

The Standard Model of Particle Physics

Beyond the Standard Model

What are the missing pieces of the puzzle?

Dark matter and Dark energy

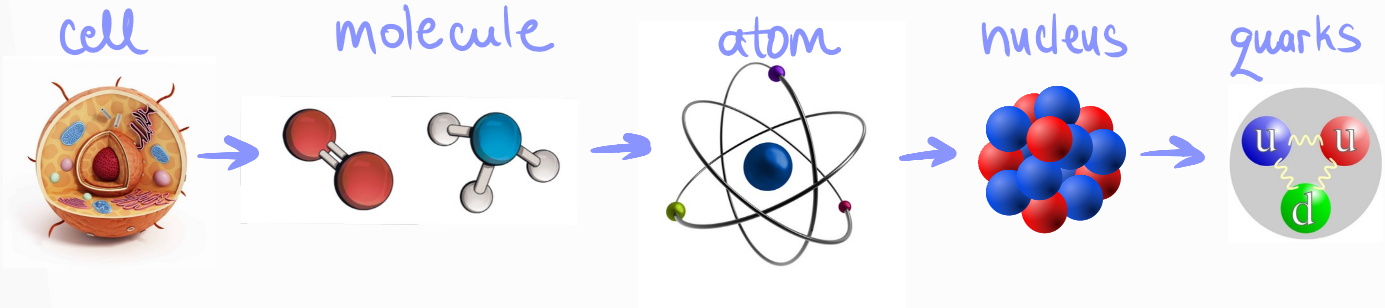
mass of neutrinos

matter-antimatter asymmetry

does not include gravity

Final thoughts...

1. Nature is layered



Final thoughts...

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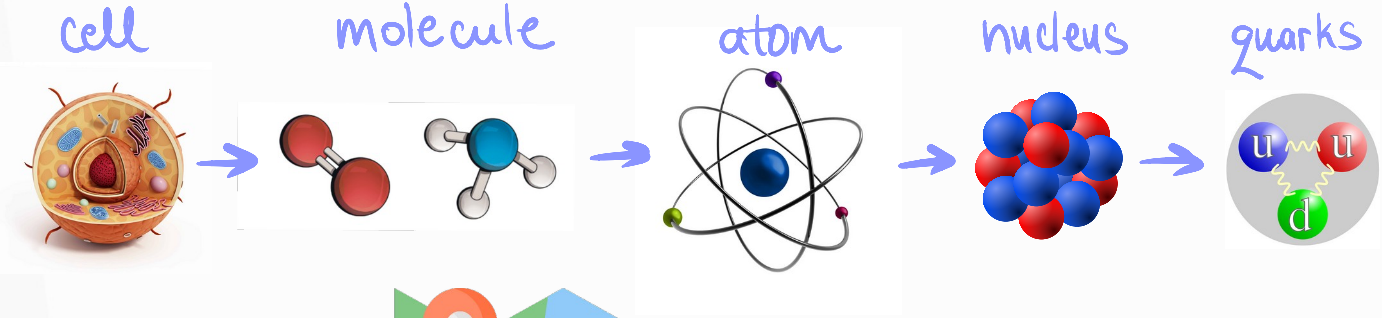
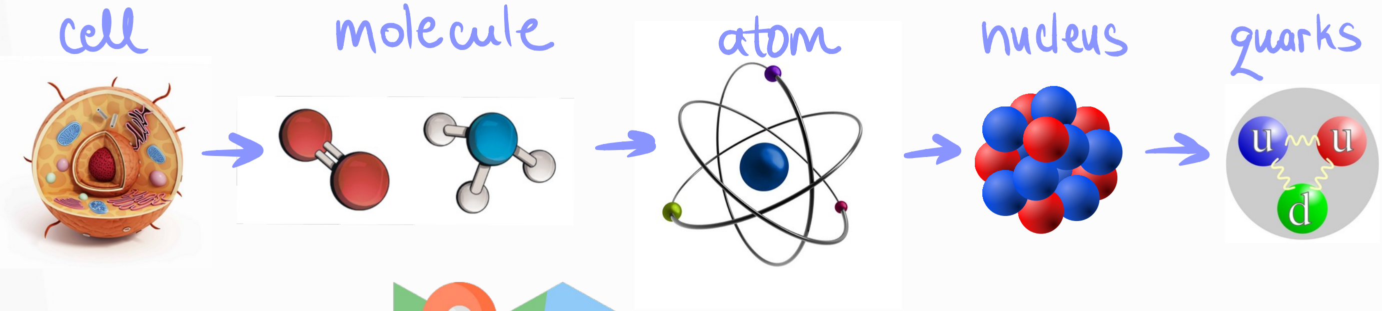


2. The Standard Model is our best map

Final thoughts...

1. Nature is layered



2. The Standard Model is our best map

3. The map is incomplete

- dark matter, neutrino masses, matter-antimatter asymmetry, and gravity still point beyond it.