Properties of the substance and field. Interactions: gravitational, electromagnetic, weak and strong. Standard model: fermions and bosons.

Sven Lange 07.09.2020

Standard model

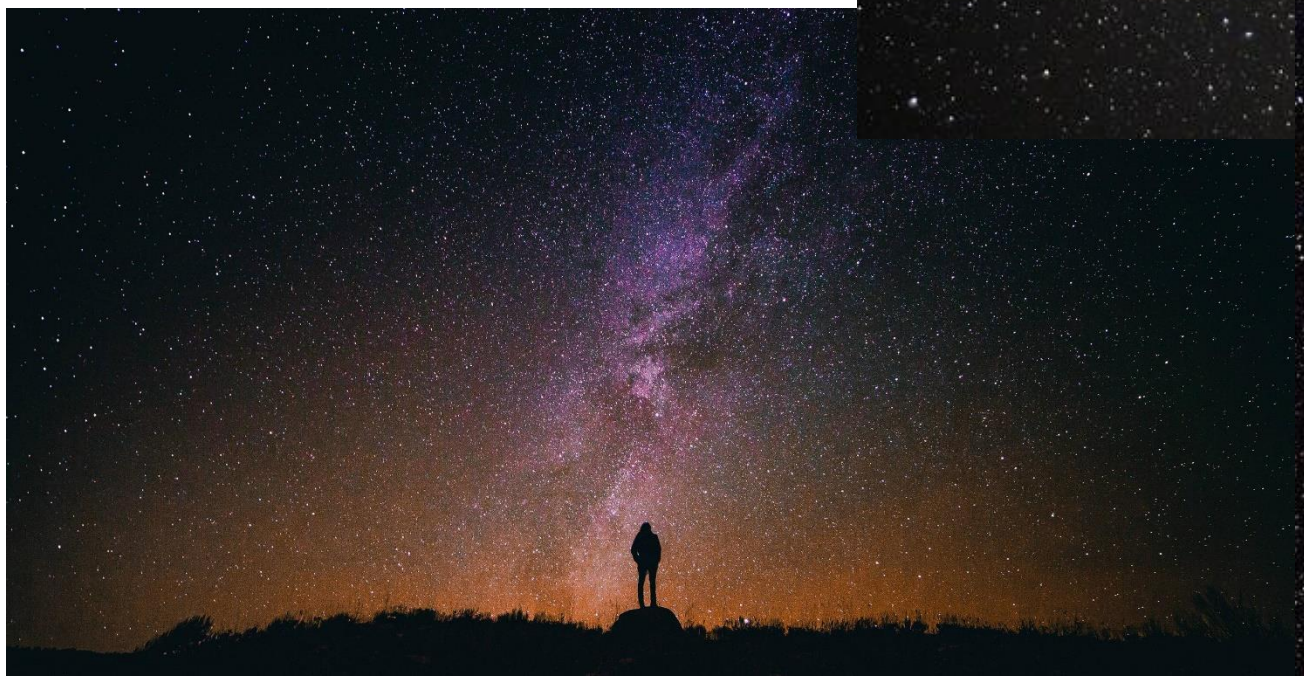
The night sky

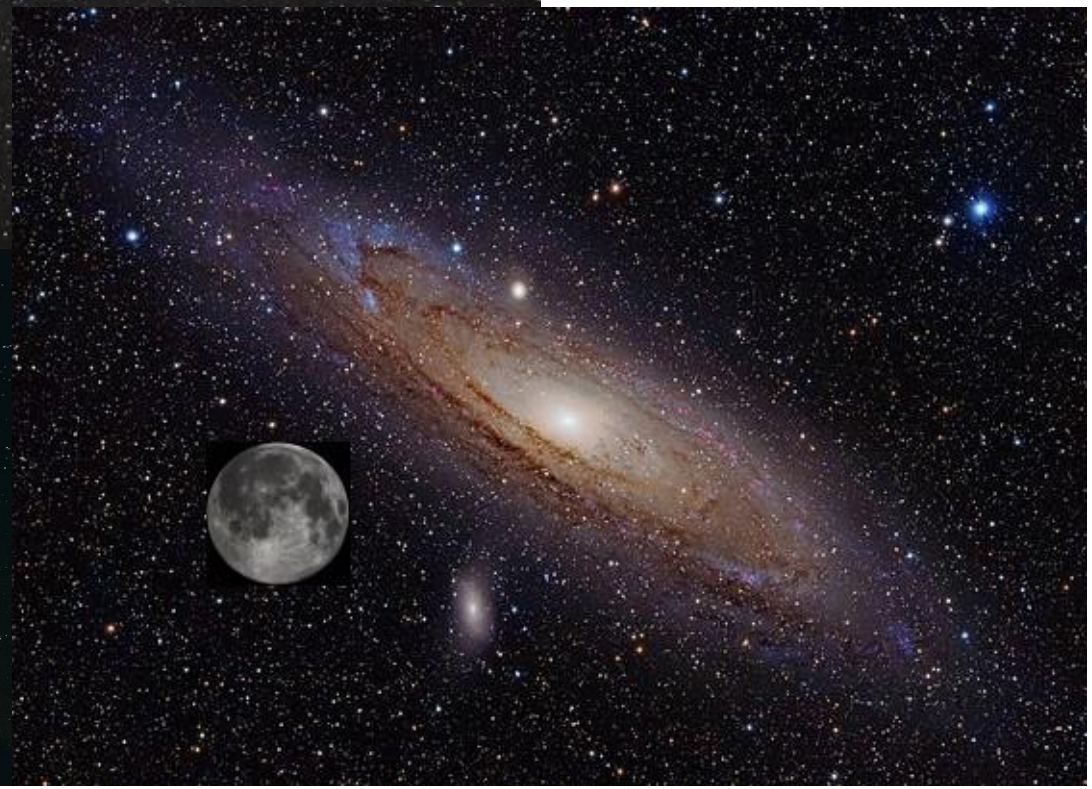
Milky way (edge on, ~200 k light years in diameter)

Large Magellanic Cloud (160 k light years away)

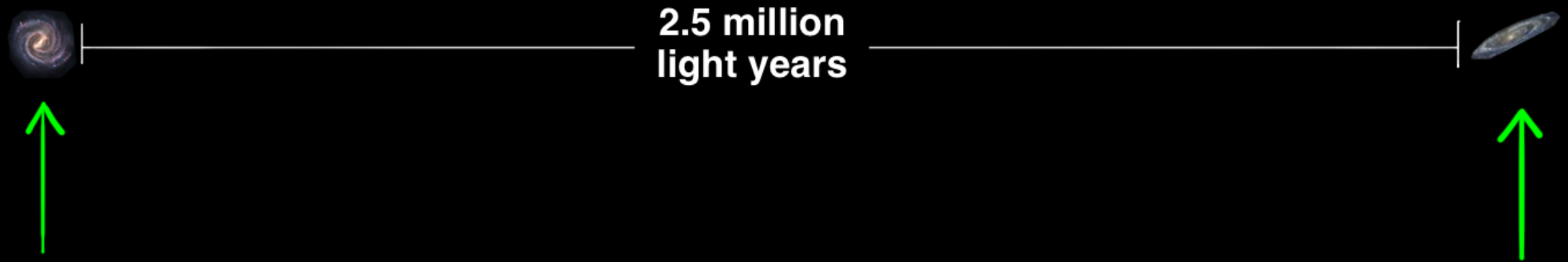
Andromeda in the night
2.5 M light years away

Milky way in the night



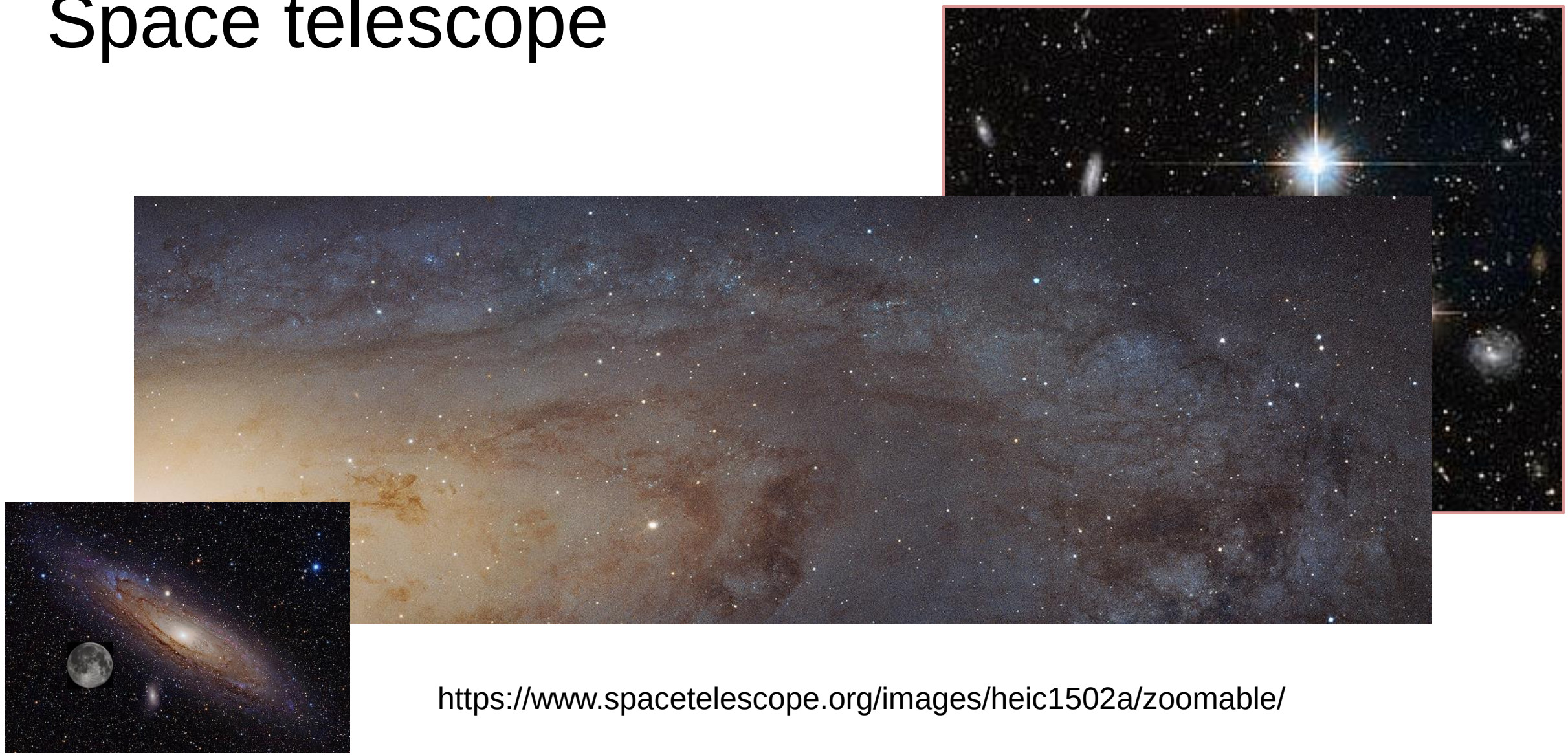


Andromeda's Distance From Us (to Scale)



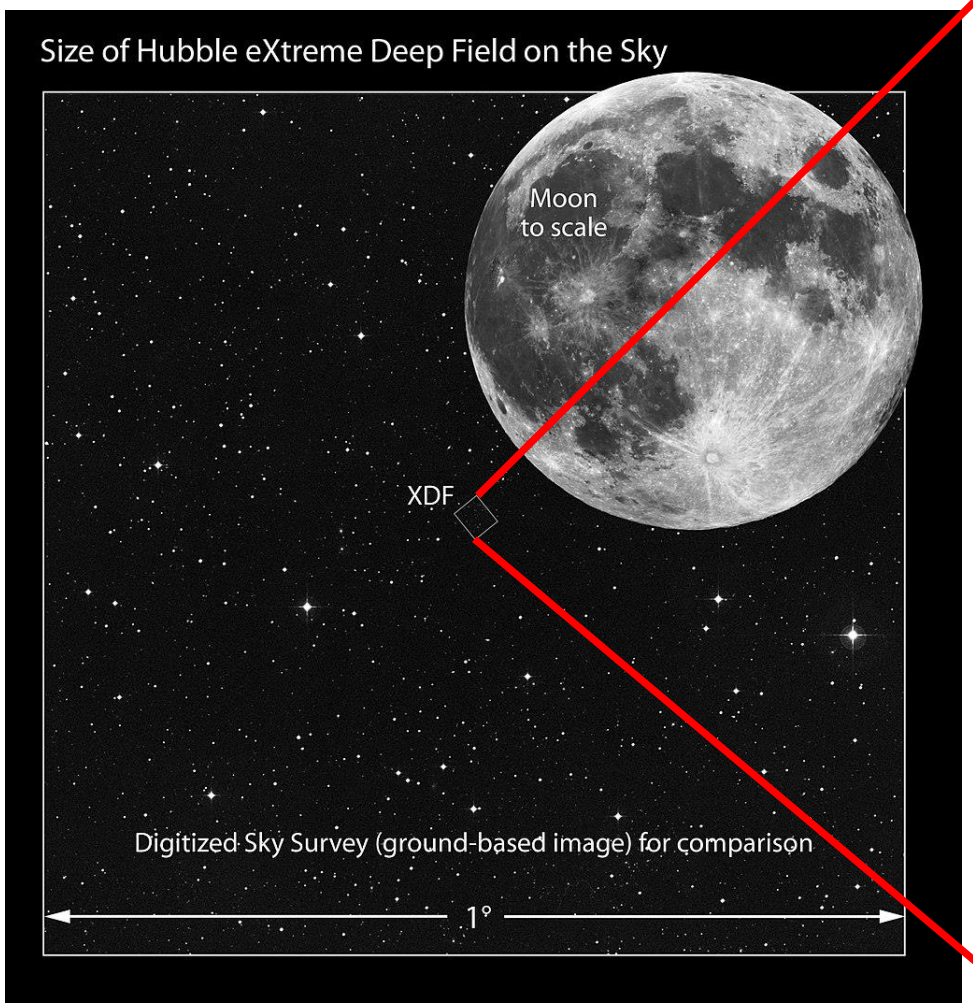
www.waitbutwhy.com

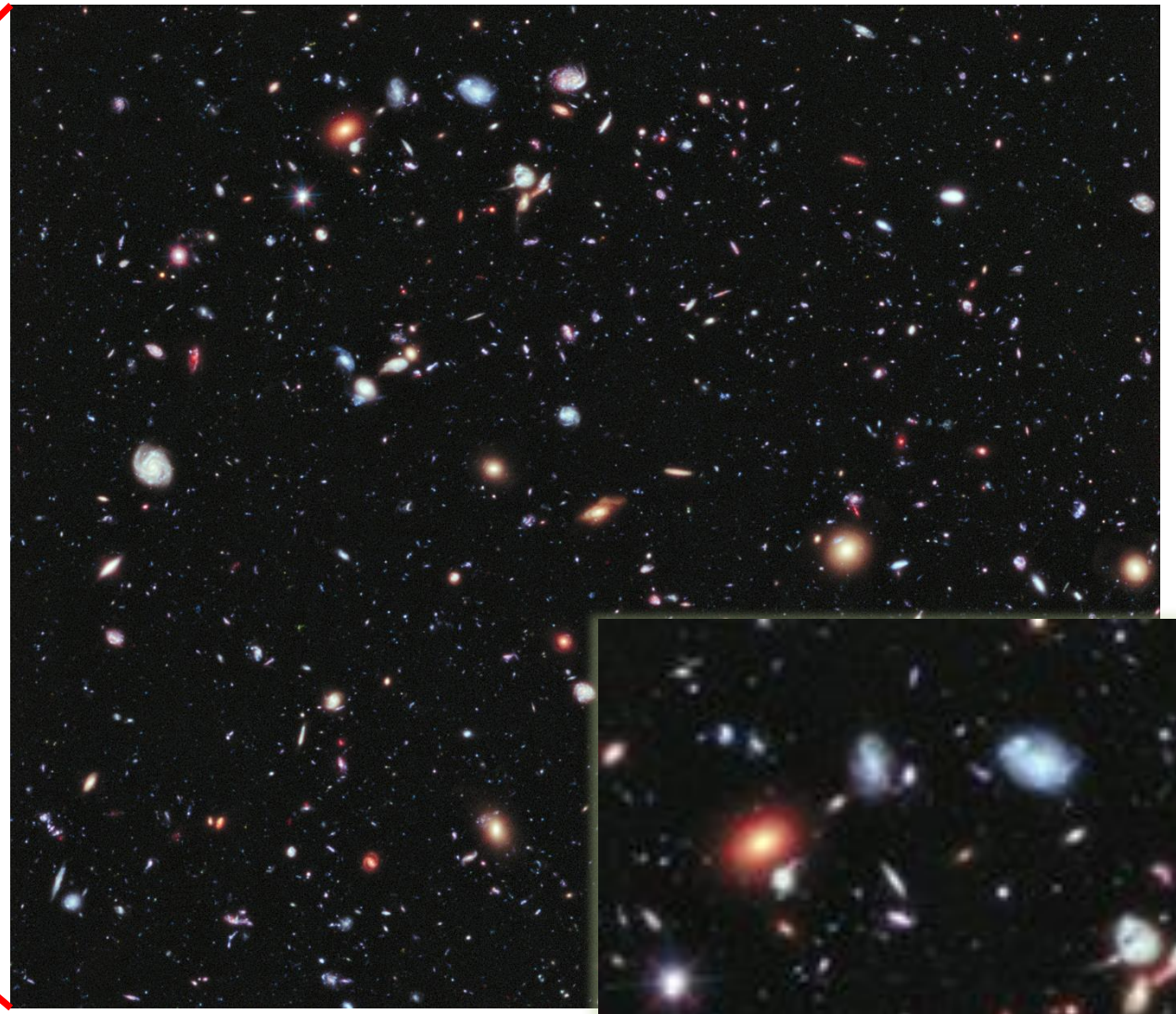
Andromeda and beyond as seen by Hubble Space telescope



https://www.spacetelescope.org/images/heic1502a/zoomable/

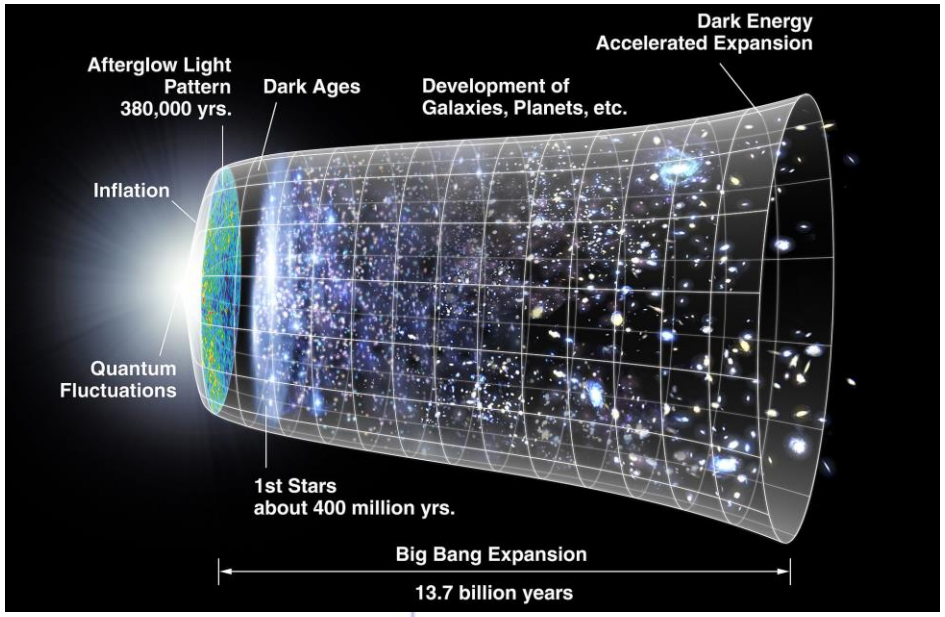
Hubble Extreme Deep field image



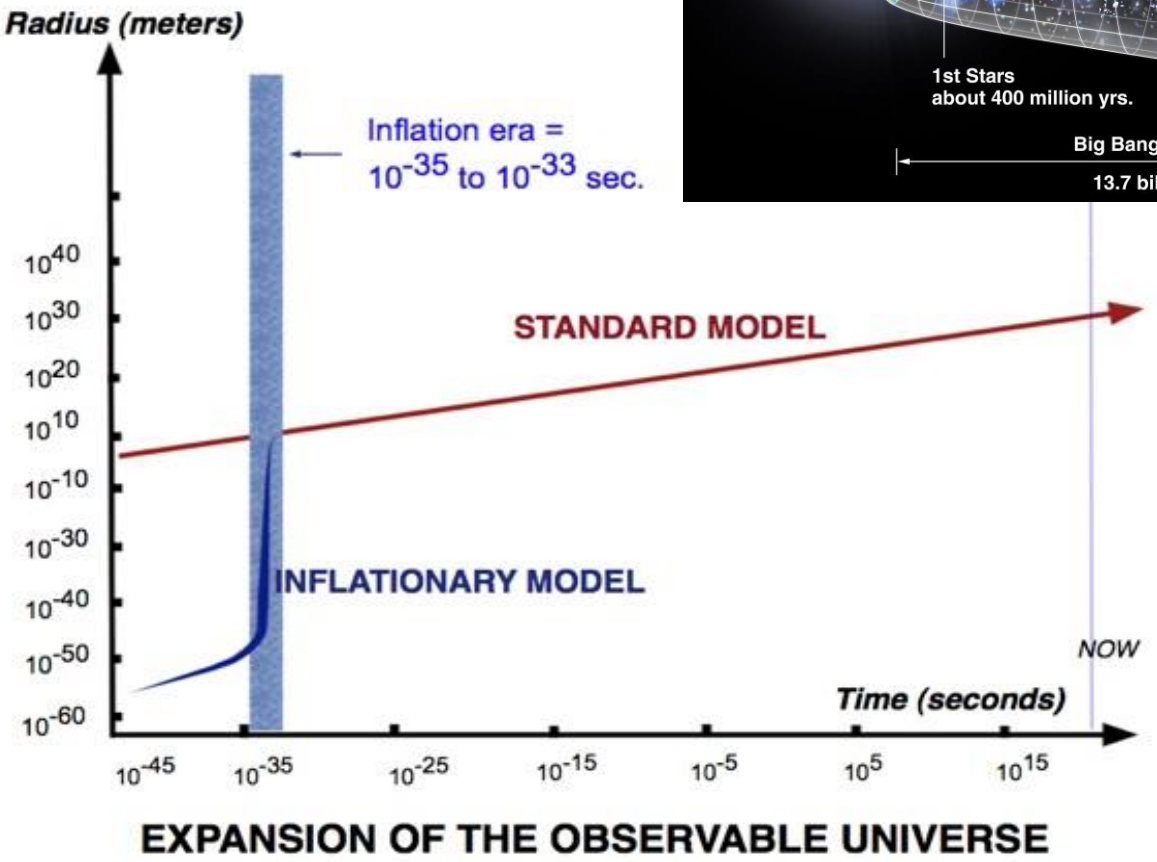


It all started with a Big Bang...

Beginning: 10^{-43}s:
At this point, the universe a diameters of only 10^{-35} metres (1 Planck Length), and has a temperature of over 10^{32}°K (the Planck Temperature).



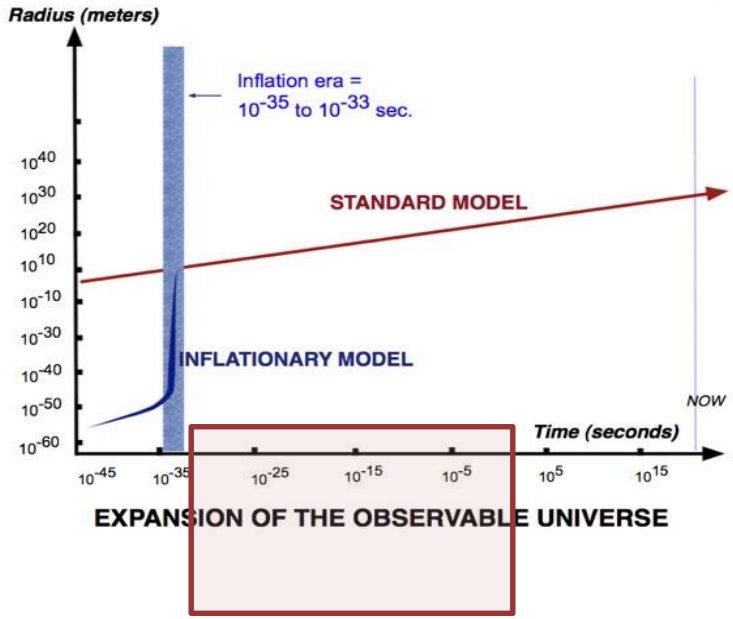
http://www.physicsoftheuniverse.com/topics_bigbang_timeline.html

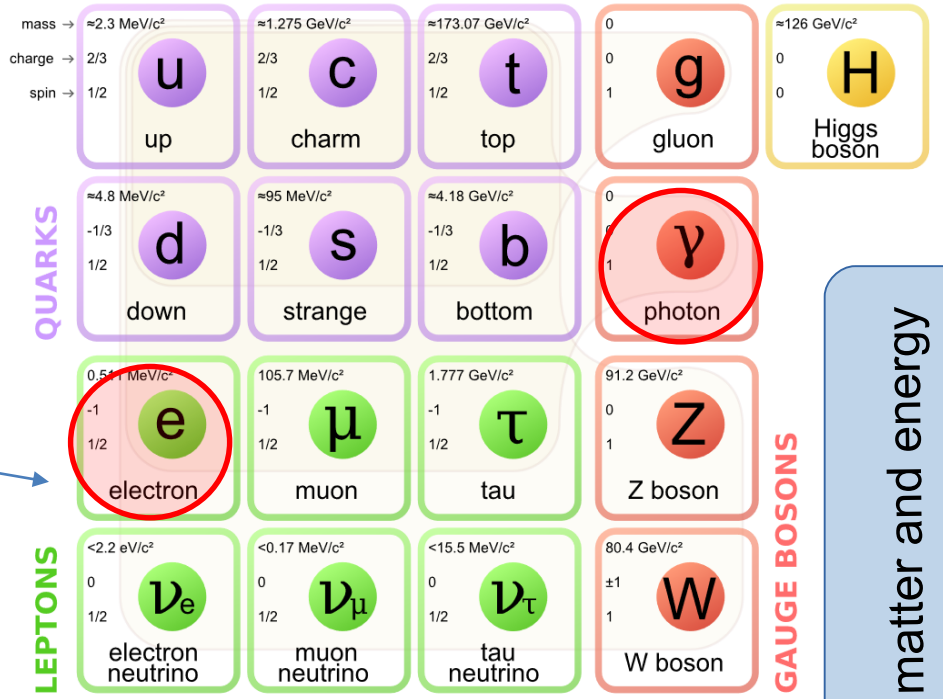


Inflation (10^{-35} seconds to 10^{-33} seconds): The linear dimensions of the early universe increases during this period by a factor of at least 10^{26} (100 000 000 000 000 000 000 000 000x) to around **10 centimeters (about the size of a grapefruit/Apple….very speculative!).**

Next -> Basic building blocks of our universe formed. Nucleosynthesis

Elementary particles as basic buildingblocks of nature





Higgs creates mass for quarks and heavy bosons

Electron diameter 2.8×10^{-15}m!

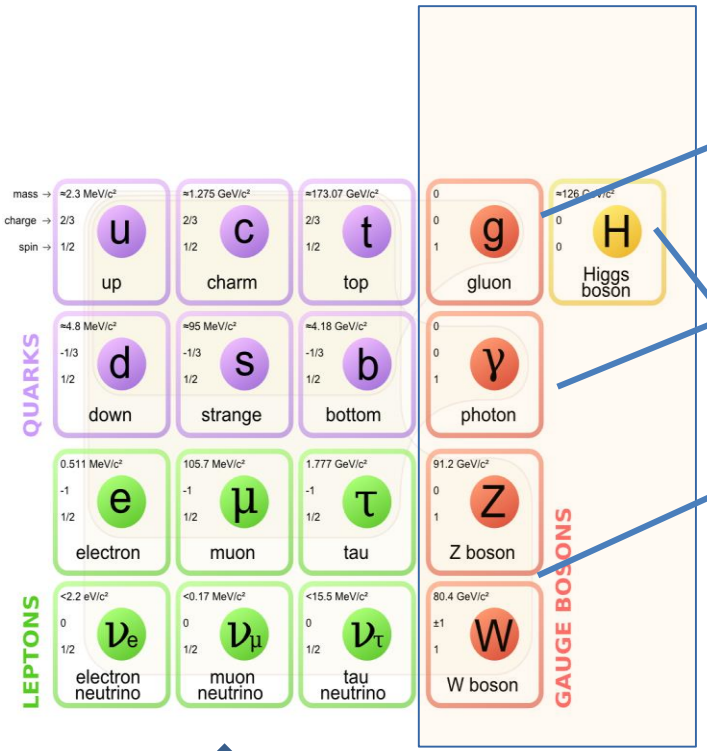
Dark matter and energy

Some say it accounts for ~85% of the matter and energy in universe

Bosons – force field particles

$$V_{\text{Yukawa}}(r) = -g^2 \frac{e^{-\mu r}}{r}$$

Spin 1



Spin ½

Fundamental Forces

		Strength	Range (m)	Particle
Strong	Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

$$F = k\frac{q_1 q_2}{r^2}$$

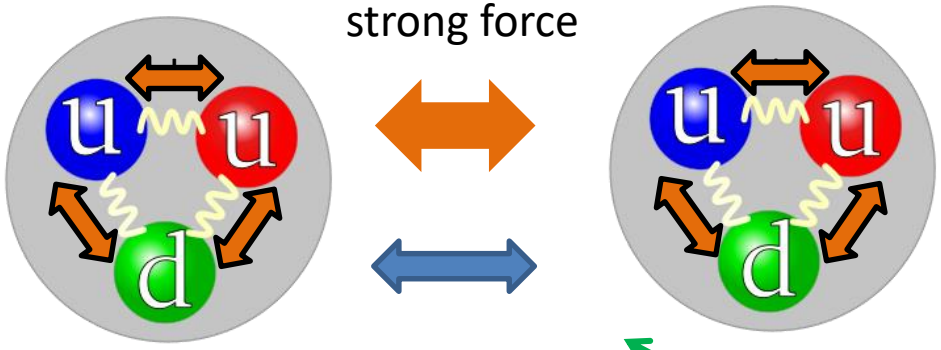
$$F = G\frac{m_1 m_2}{r^2}$$

Nuclear fusion inside the sun won't work without weak and strong force !

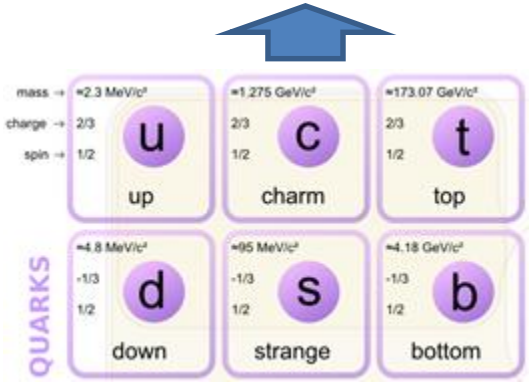
Formation of atomic nucleus

Strong force

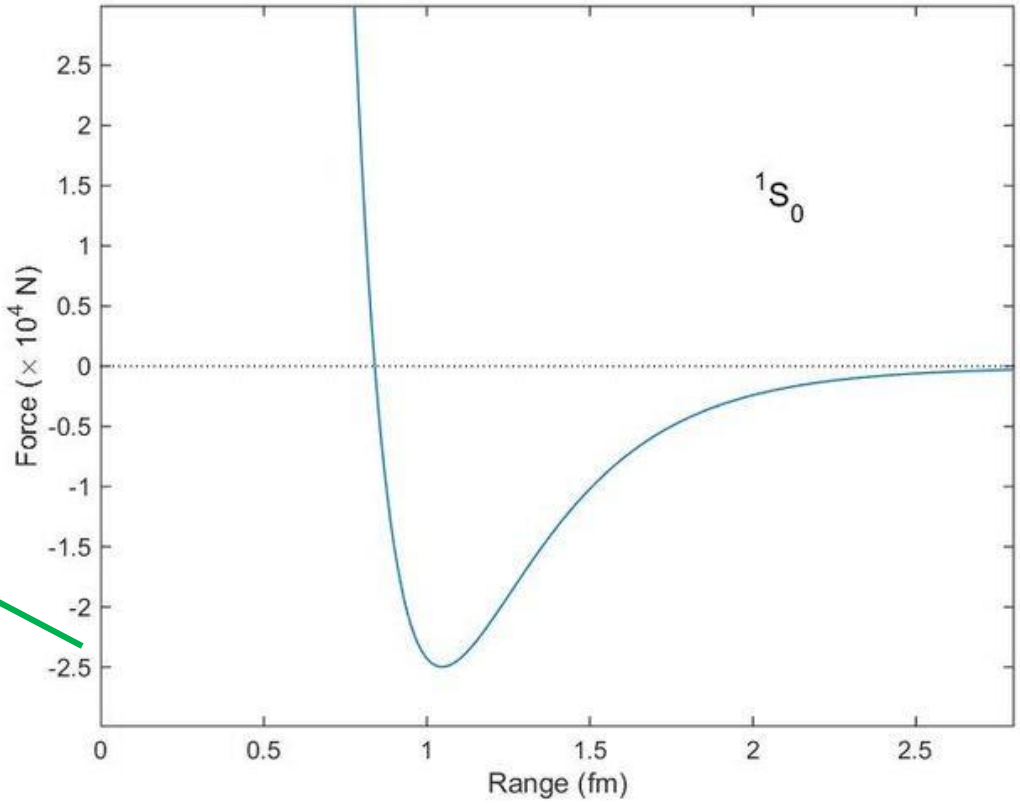
Residual strong force



Electromagnetic force

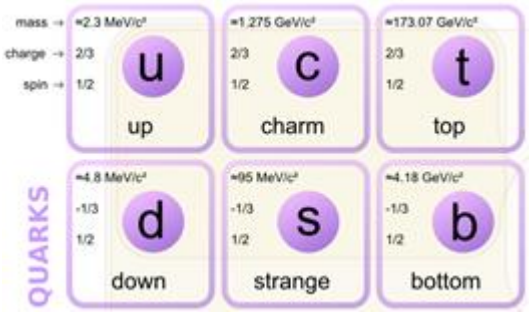


Nuclear potential

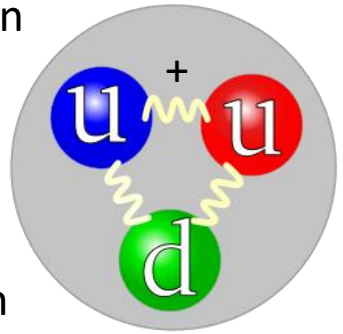


Fermions - ordinary matter

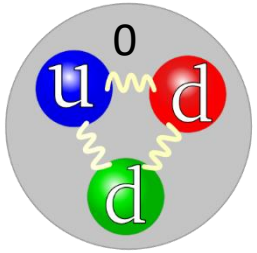
Atom diameter
~ 10^{-11}m (10 picometer)
Nucleus diameter
~ 10^{-15}m (femtometer)



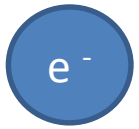
Proton

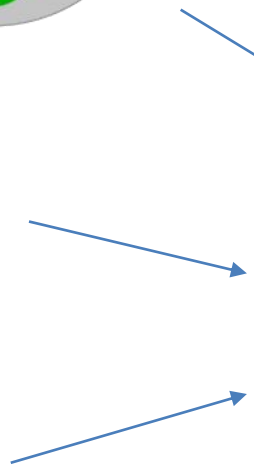


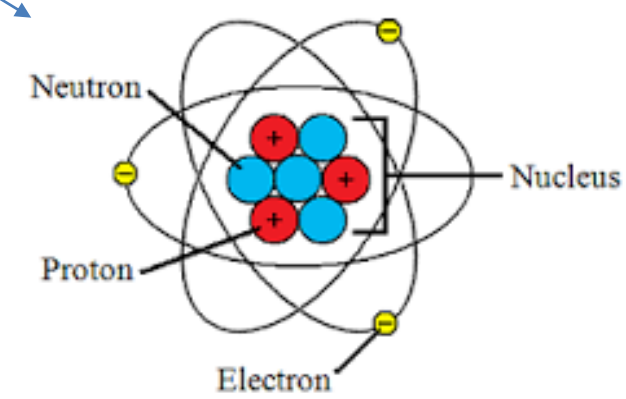
Neutron



Electron



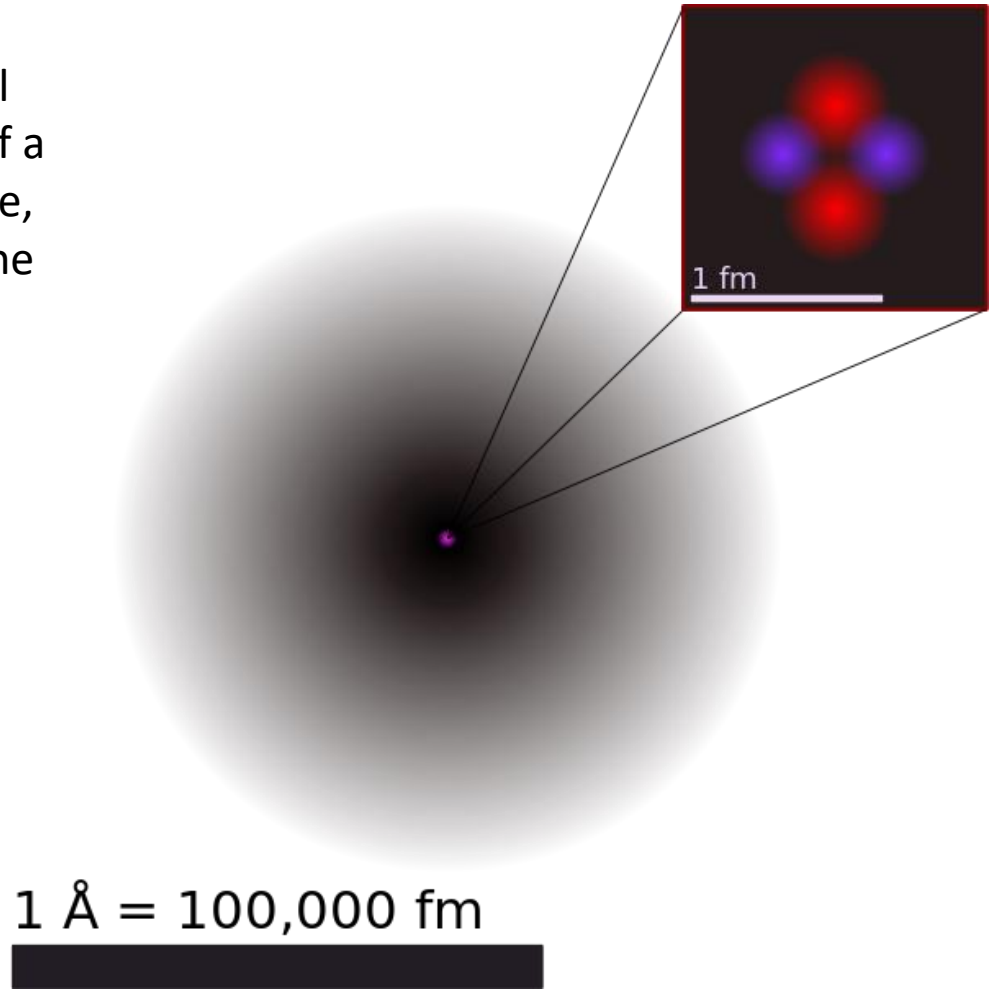




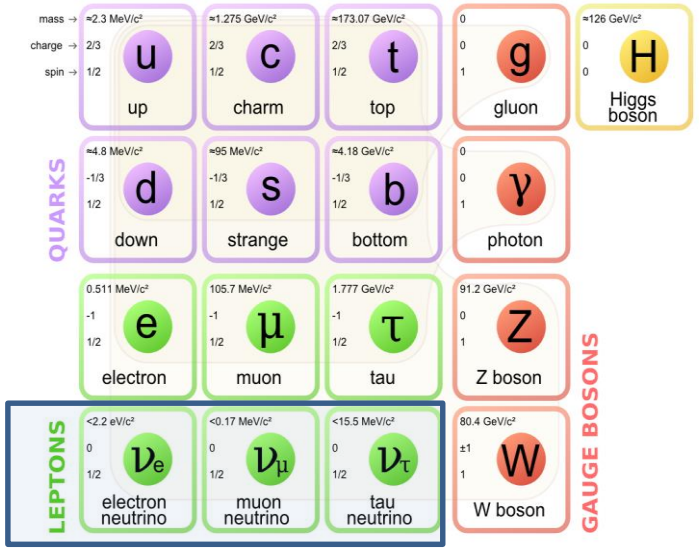
First and still the most abundant atom in the universe is hydrogen: one proton, orbited by one electron

Realistic model of an atom

Under most definitions the radii of isolated neutral atoms range between 30 and 300 pm (trillionths of a meter), or between 0.3 and 3 ångströms. Therefore, the radius of an atom is more than 10,000 times the radius of its nucleus (1–10 fm),



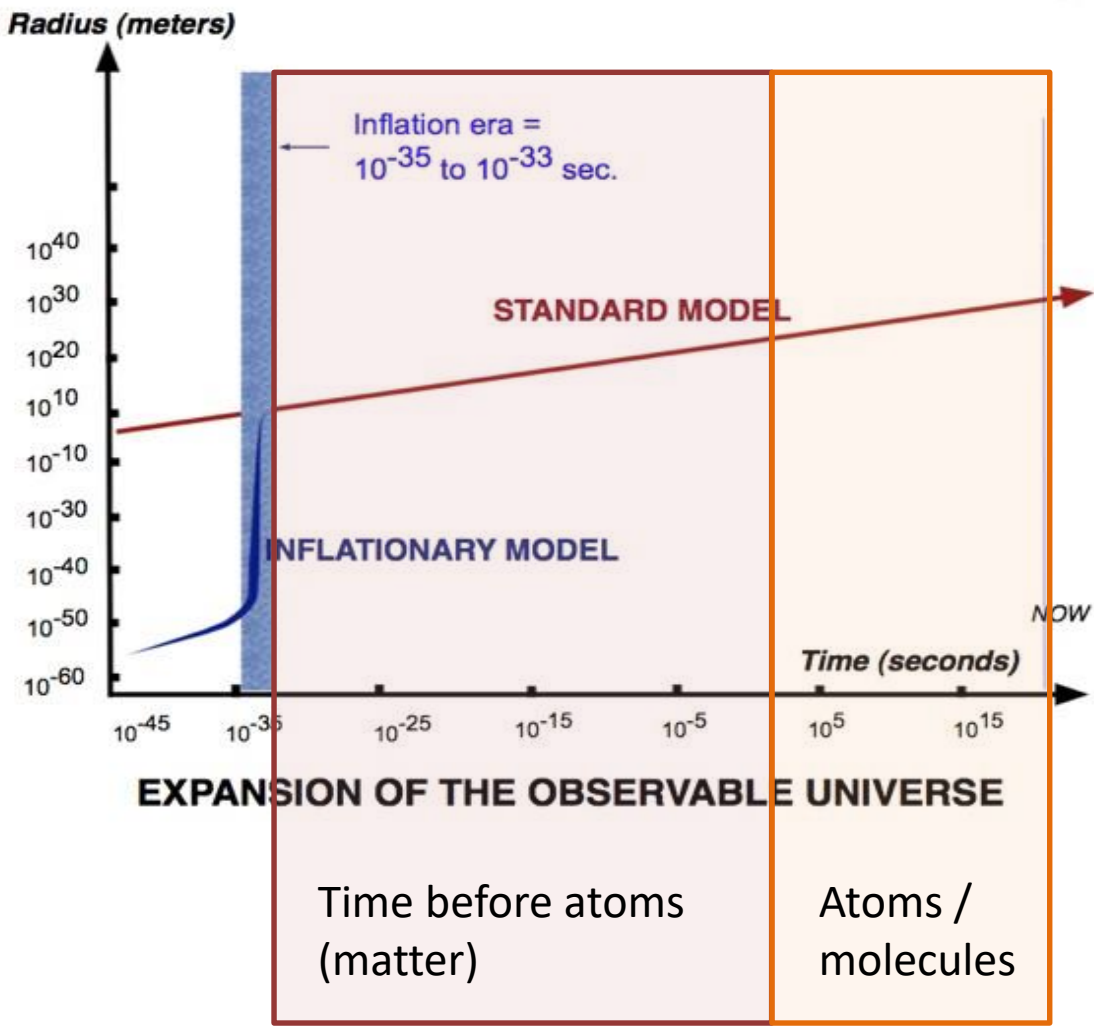
Neutrinos



- Created in nuclear reactions (inside the Sun)
- Have no charge
- Do not interact via Strong force but only via Weak force

- Do not combine or interact with almost anything in the universe!
- In the vicinity of the Earth, about 65 billion (6.5×10^{10}) solar neutrinos per second pass through every square centimeter perpendicular to the direction of the Sun

The creation of elementary particles



T ~ 10^{32} K

1. Creation, inflation of space – not much is known before ~10^{-35}..10^{-33}s.
2. Electroweak epoch (fundamental forces separate)
3. Quark epoch (**quarks** and exotic particles exist alone and rejoin with **antiparticles**)
4. -------(1 microsecond (1*10^{-6}) has passed)----------
5. Hadron epoch (protons, neutrons are formed and destroyed in matter-antimatter annihilation)
6. ----------(1 second has passed !)----------
7. Lepton epoch (**electrons** and antielectrons annihilate each ohter)
8. ----------(10 minutes !)----------
9. Photon epoch (universe filled with **photons** (light) and atomic nuclei and **electrons**)
10. ----------(380k years)----------
11. Ordinary matter forms and light is set free to travel in the universe

Temperature

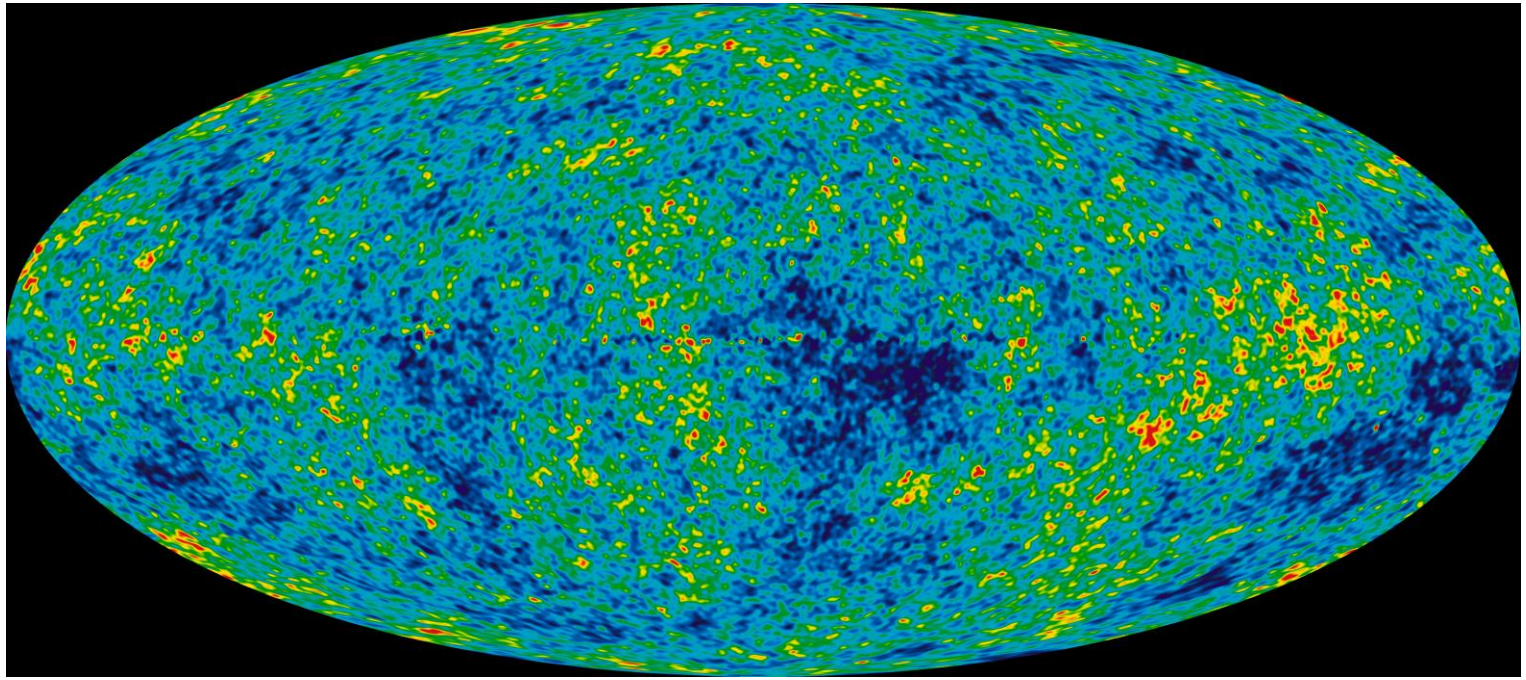
T ~ 10^4 K

12. 13.8 B years later = Today !

T ~ 2 K

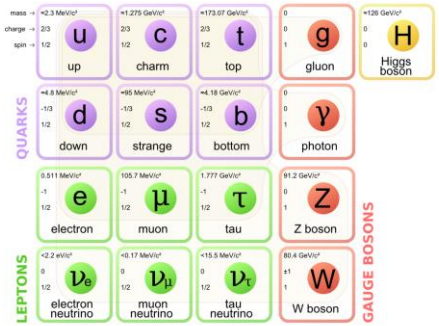
380 000 years later atoms (hydrogene) formed and light was free to traver throughout the universe.
Background radiation was born

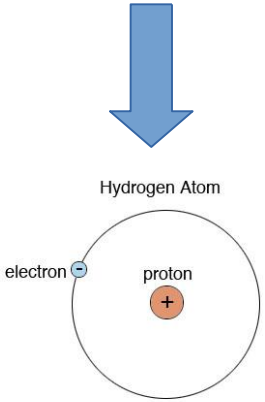
Universe contained H atoms only!



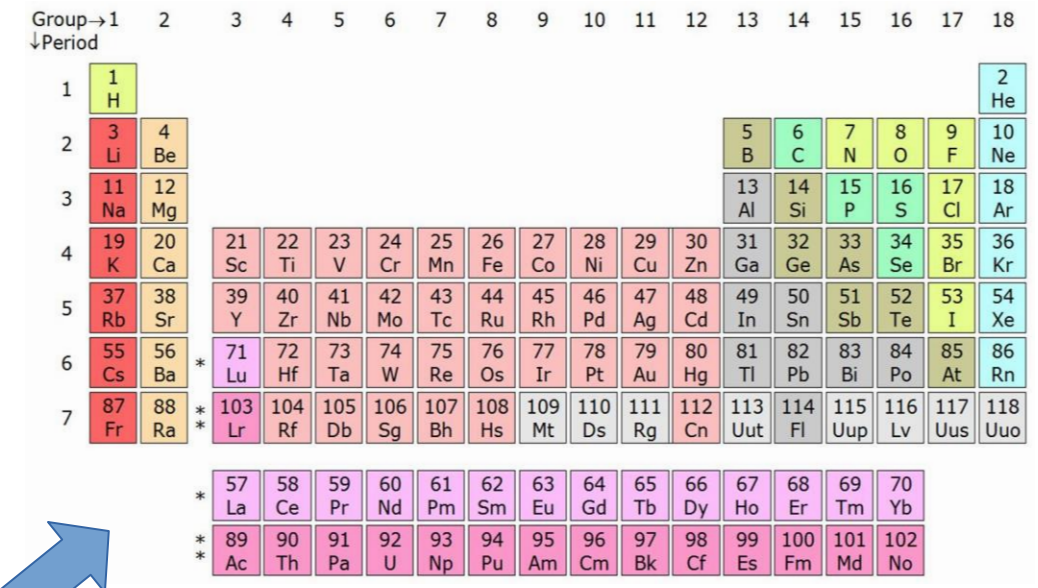
Wilkinson Microwave Anisotropy Probe (observations 2001-2010) (first photo of the universe)

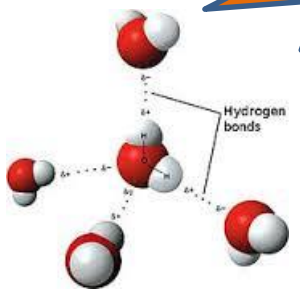
ALL MATTER



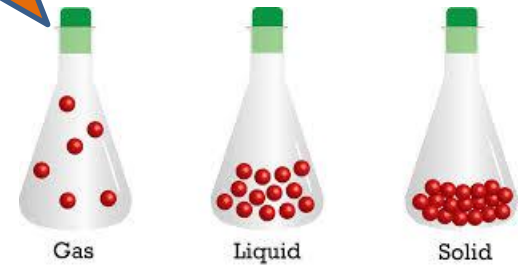


Fusion in stars !

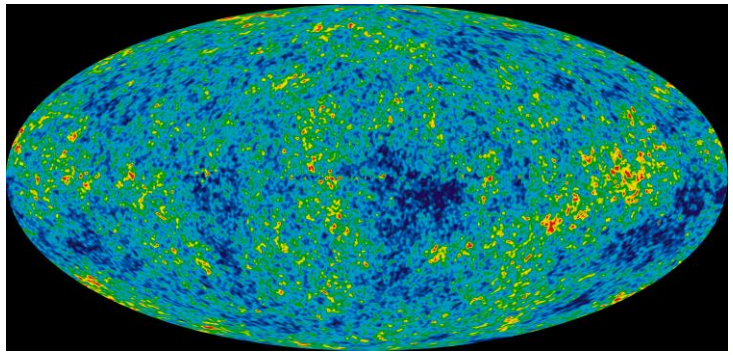


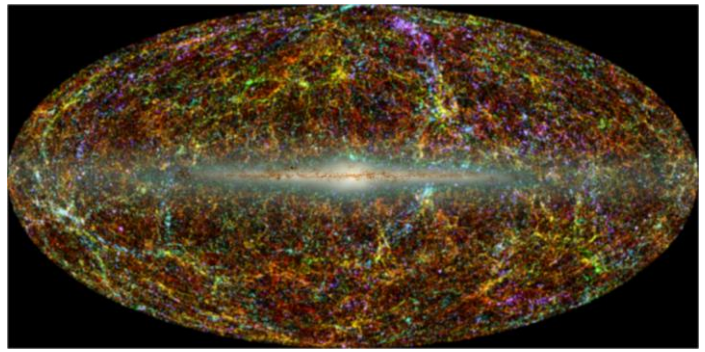


Chemistry

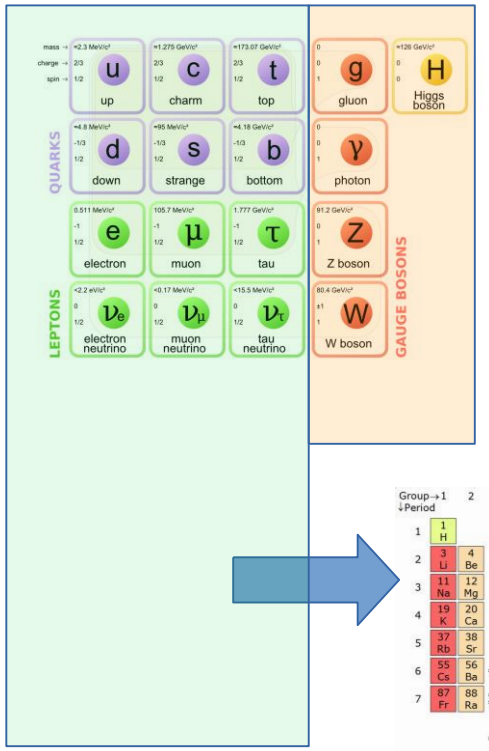


Big Bang





bosons



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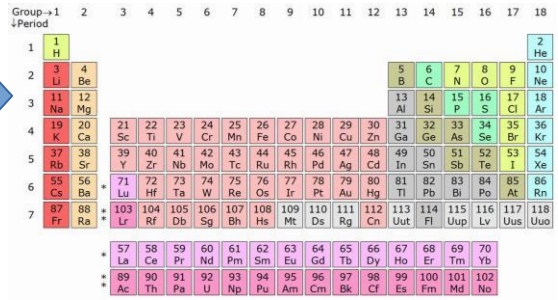
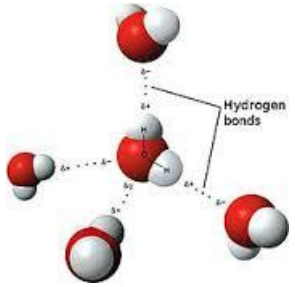
ALL MATTER

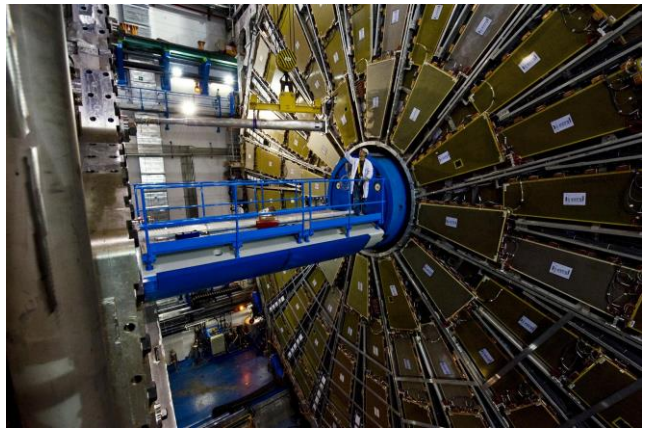


fermions

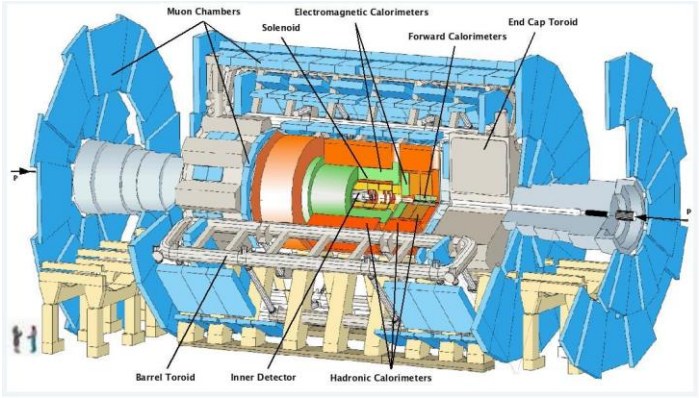


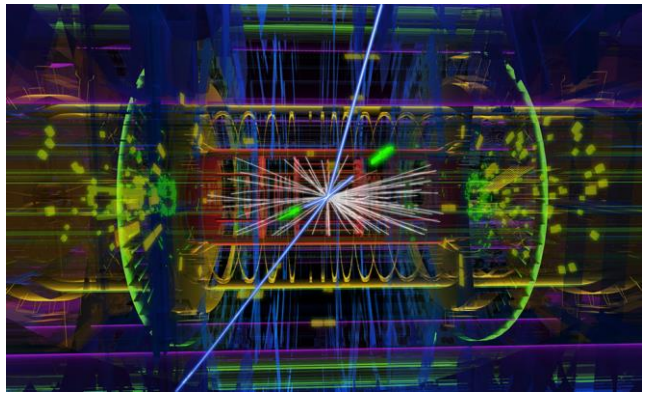
How do we know any of this ?
The Large Hadron Collaider (LHC) experiment

In order to study the basic building blocks of universe we need to simulate the conditions of pre-matter/nuclear universe. In order to do so, extreme energy is needed (LHC ~14 GeV).



30 km diameeter accelerator with superconducting magnets cooled down to a few Kelvins (1K = -273.14^{o}C)





Universe today ~13.8 * 10^9 years old, 90 billion light years across