

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)



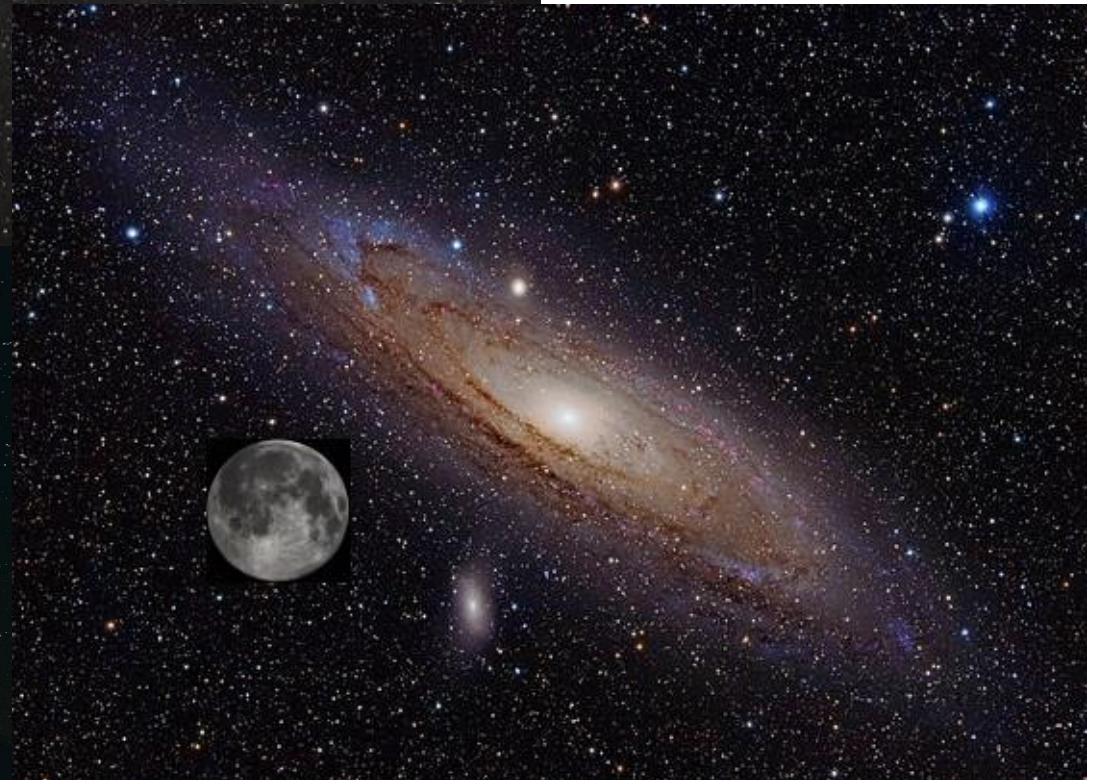
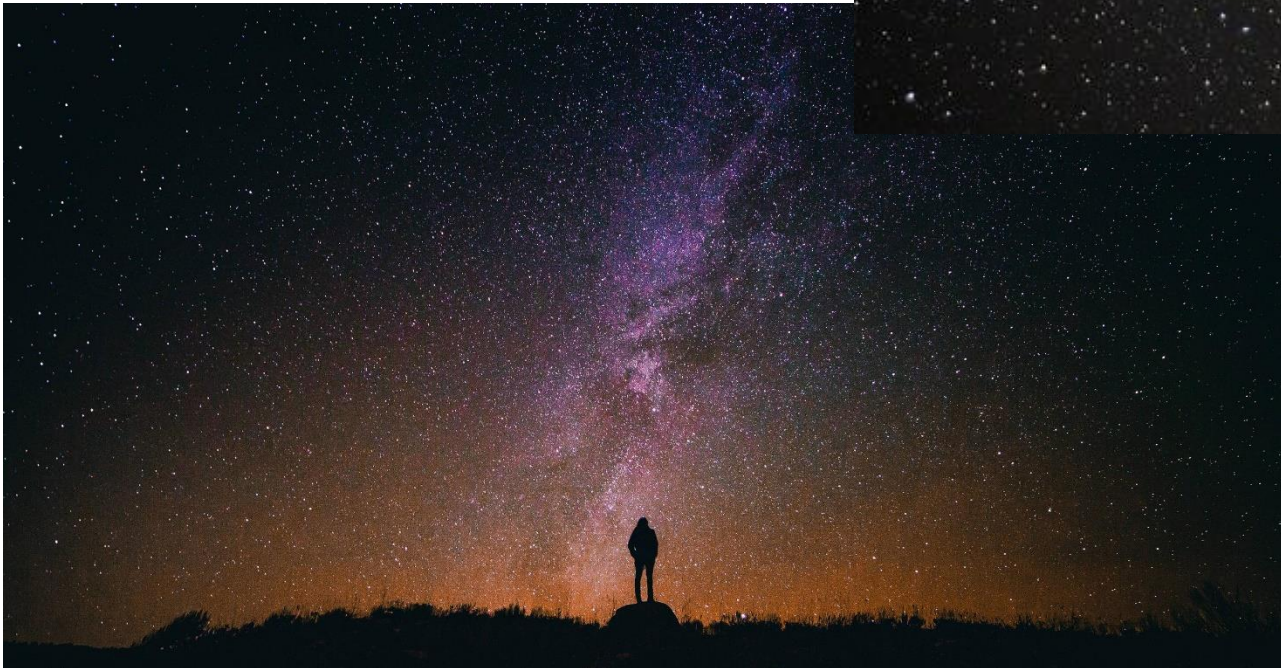
Large Magellanic Cloud (160 k light years away)



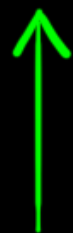
Andromeda in the night
2.5 M light years away



Milky way in the night



Andromeda's Distance From Us (to Scale)



Milky Way

2.5 million
light years



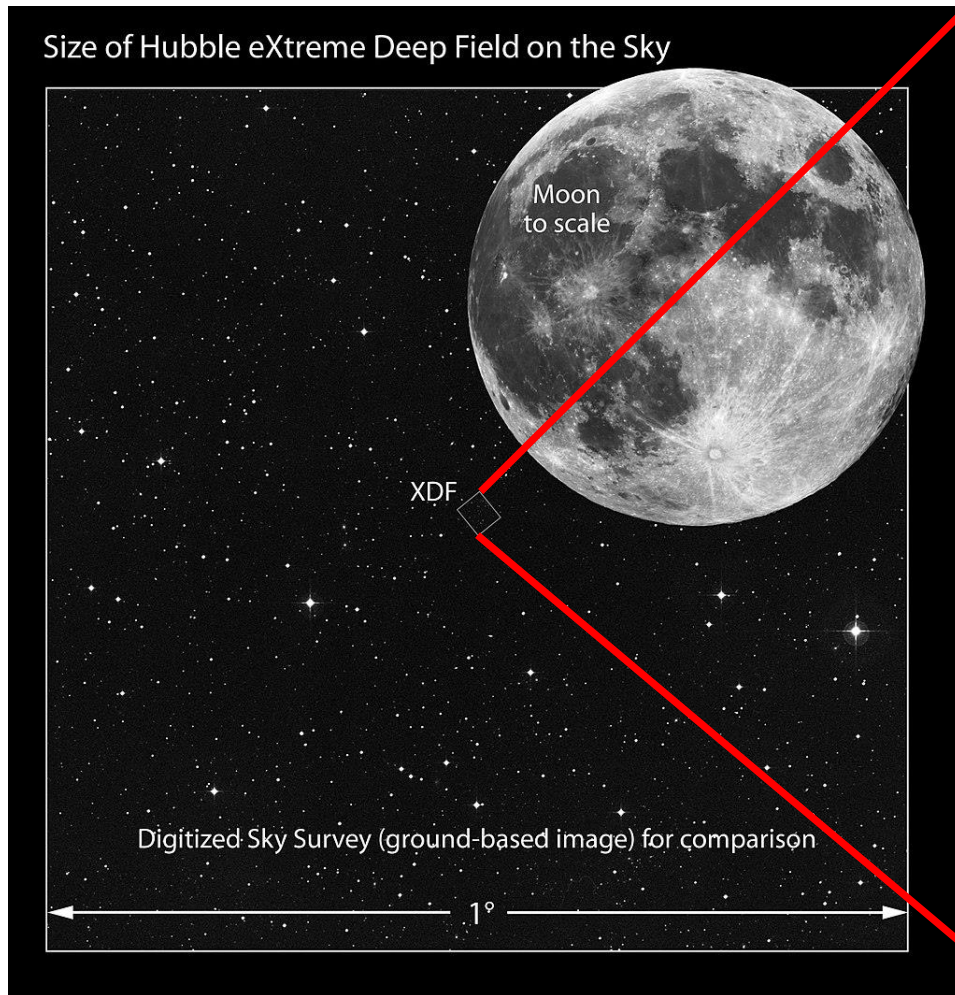
Andromeda

Andromeda and beyond as seen by Hubble Space telescope



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

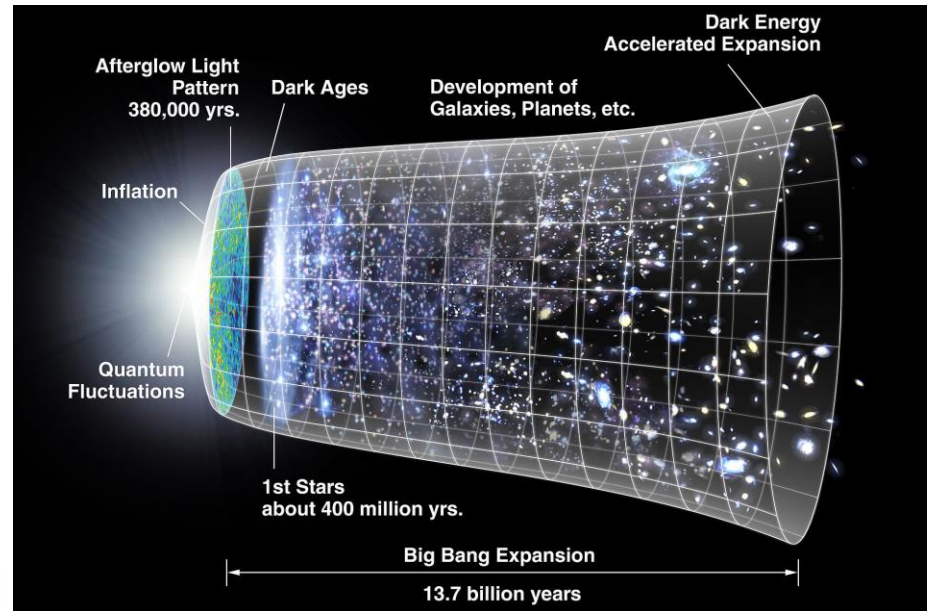
Hubble Extreme Deep field image



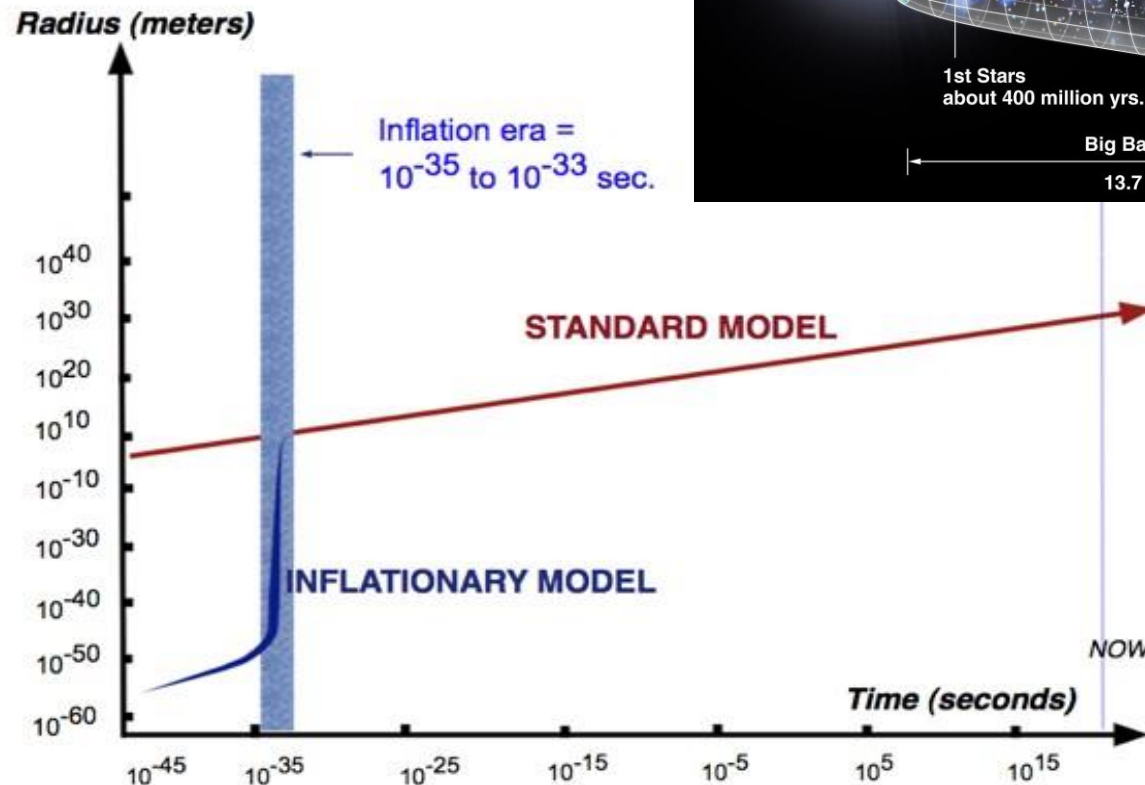
It all started with a Big Bang...

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

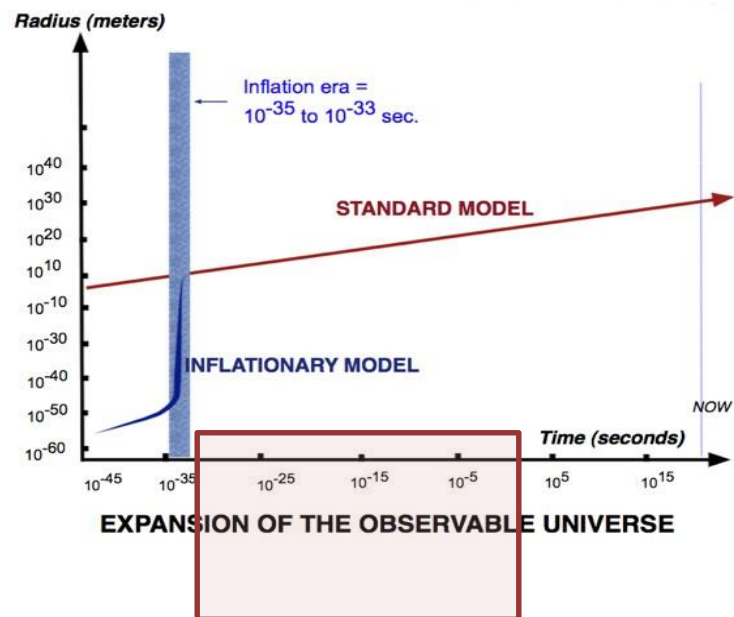


EXPANSION OF THE OBSERVABLE UNIVERSE

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



Electron diameter
 $2.8 \times 10^{-15} \text{m}$

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H Higgs boson
	d down	s strange	b bottom	γ photon	
	e electron	μ muon	τ tau	Z Z boson	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

Higgs creates mass for quarks and heavy bosons

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

Dark matter and energy

Bosons – force field particles

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

Spin 1



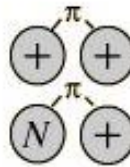
QUARKS	mass → charge → spin →	$\approx 2.3 \text{ MeV}/c^2$ 2/3 1/2	$\approx 1.275 \text{ GeV}/c^2$ 2/3 1/2	$\approx 173.07 \text{ GeV}/c^2$ 2/3 1/2
		u up	c charm	t top
		$\approx 4.8 \text{ MeV}/c^2$ -1/3 1/2	$\approx 95 \text{ MeV}/c^2$ -1/3 1/2	$\approx 4.18 \text{ GeV}/c^2$ -1/3 1/2
LEPTONS		$0.511 \text{ MeV}/c^2$ -1 1/2	$105.7 \text{ MeV}/c^2$ -1 1/2	$1.777 \text{ GeV}/c^2$ -1 1/2
		e electron	μ muon	τ tau
		$< 2.2 \text{ eV}/c^2$ 0 1/2	$< 0.17 \text{ MeV}/c^2$ 0 1/2	$< 15.5 \text{ MeV}/c^2$ 0 1/2
GAUGE BOSONS		0 0 1	0 0 1	$91.2 \text{ GeV}/c^2$ 0 1
		g gluon	γ photon	Z Z boson
		0 0 0	0 0 0	$80.4 \text{ GeV}/c^2$ ±1 1
		H Higgs boson		W W boson
		$\approx 126 \text{ GeV}/c^2$ 0 0		

Spin 1/2



Fundamental Forces

Strong



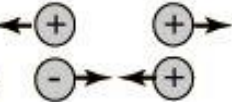
Force which holds nucleus together

Strength
1

Range (m)
 10^{-15}
(diameter of a medium sized nucleus)

Particle
gluons,
π(nucleons)

Electro-magnetic

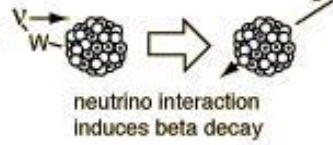


Strength
 $\frac{1}{137}$

Range (m)
Infinite

Particle
photon
mass = 0
spin = 1

Weak

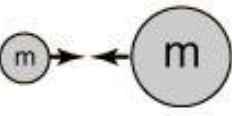


Strength
 10^{-6}

Range (m)
 10^{-18}
(0.1% of the diameter of a proton)

Particle
Intermediate vector bosons
 W^+, W^-, Z_0 ,
mass > 80 GeV
spin = 1

Gravity



Strength
 6×10^{-39}

Range (m)
Infinite

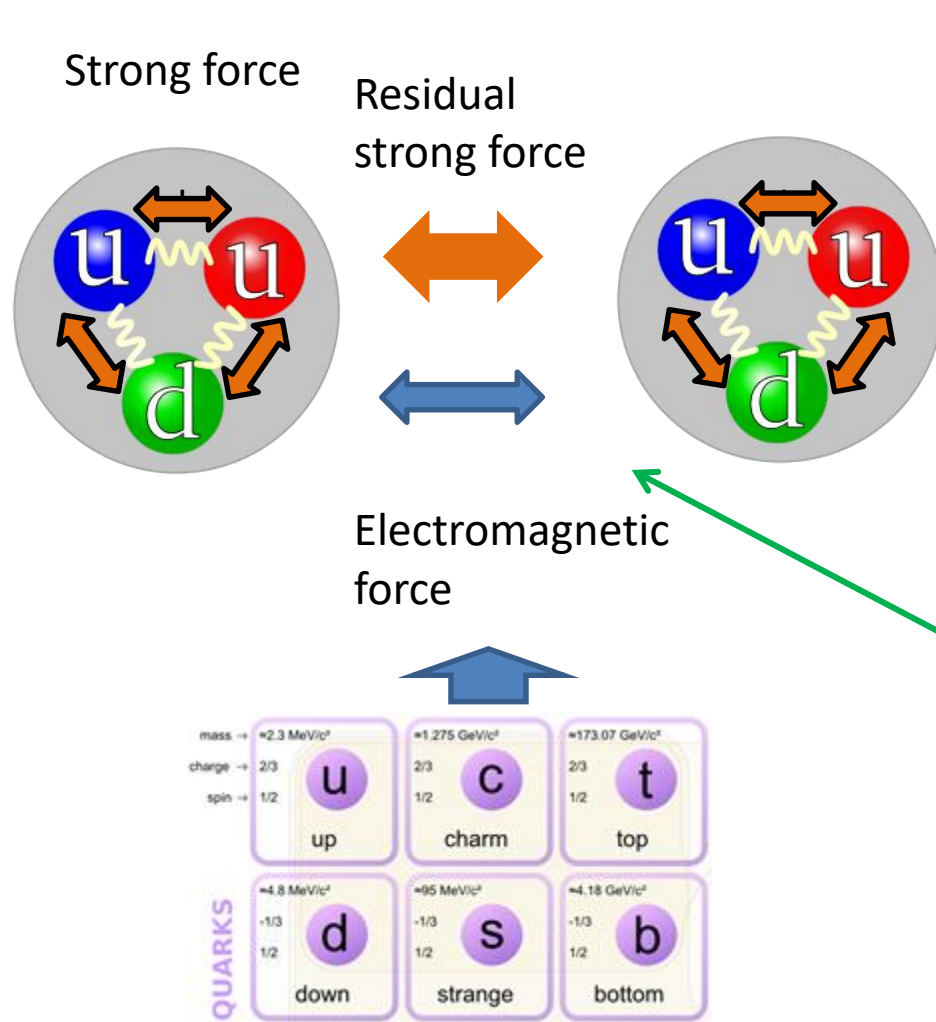
Particle
graviton ?
mass = 0
spin = 2

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

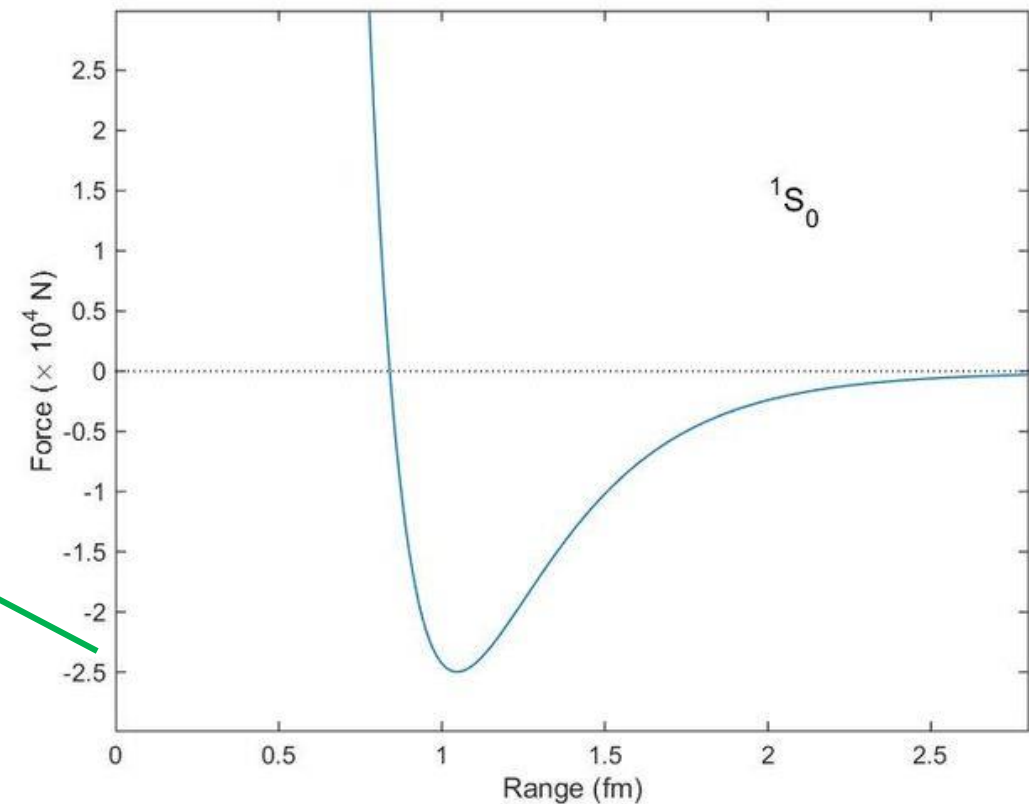
Nuclear fusion inside the sun won't work without weak and strong force !

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

Formation of atomic nucleus



Nuclear potential



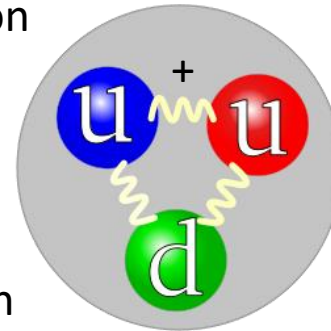
Fermions - ordinary matter

mass →	≈2.3 MeV/c ²	≈1.275 GeV/c ²	≈173.07 GeV/c ²
charge →	2/3	2/3	2/3
spin →	1/2	1/2	1/2
	u	c	t
	up	charm	top
QUARKS	≈4.8 MeV/c ²	≈95 MeV/c ²	≈4.18 GeV/c ²
	-1/3	-1/3	-1/3
	1/2	1/2	1/2
	d	s	b
	down	strange	bottom

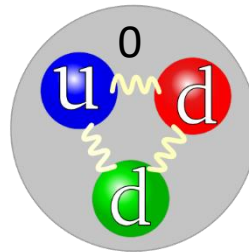
0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²
-1	-1	-1
1/2	1/2	1/2
e	μ	τ
electron	muon	tau
<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²
0	0	0
1/2	1/2	1/2
ν_e	ν_μ	ν_τ
electron neutrino	muon neutrino	tau neutrino



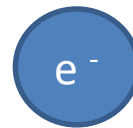
Proton



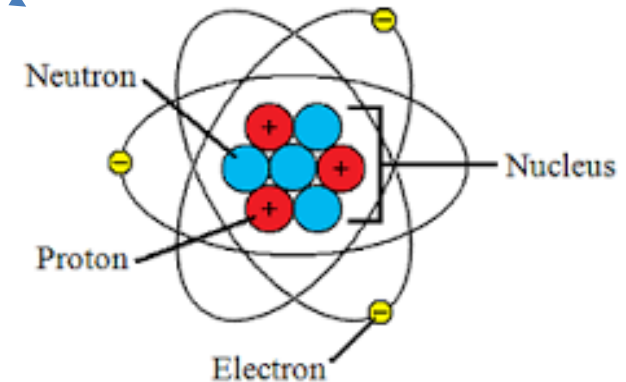
Neutron



Electron



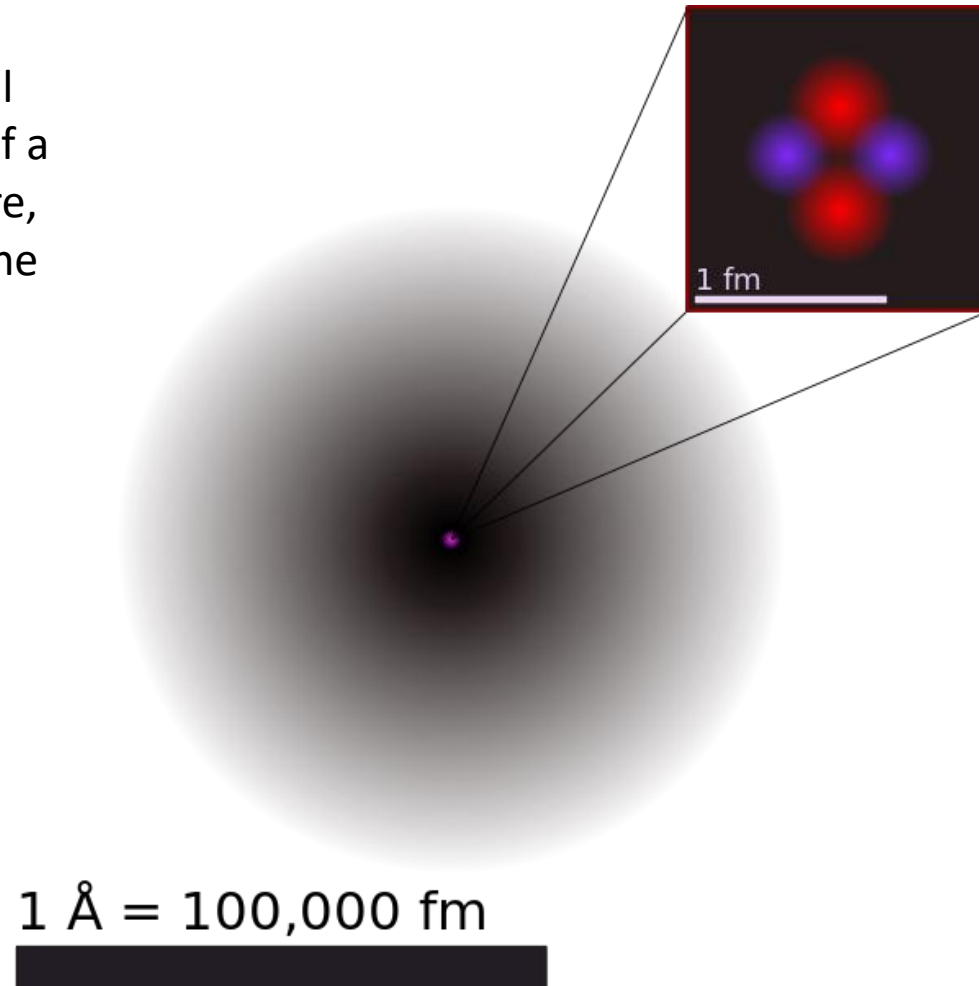
Atom diameter
~ 10⁻¹¹m (10 picometer)
Nucleus diameter
~ 10⁻¹⁵m (femtometer)



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),

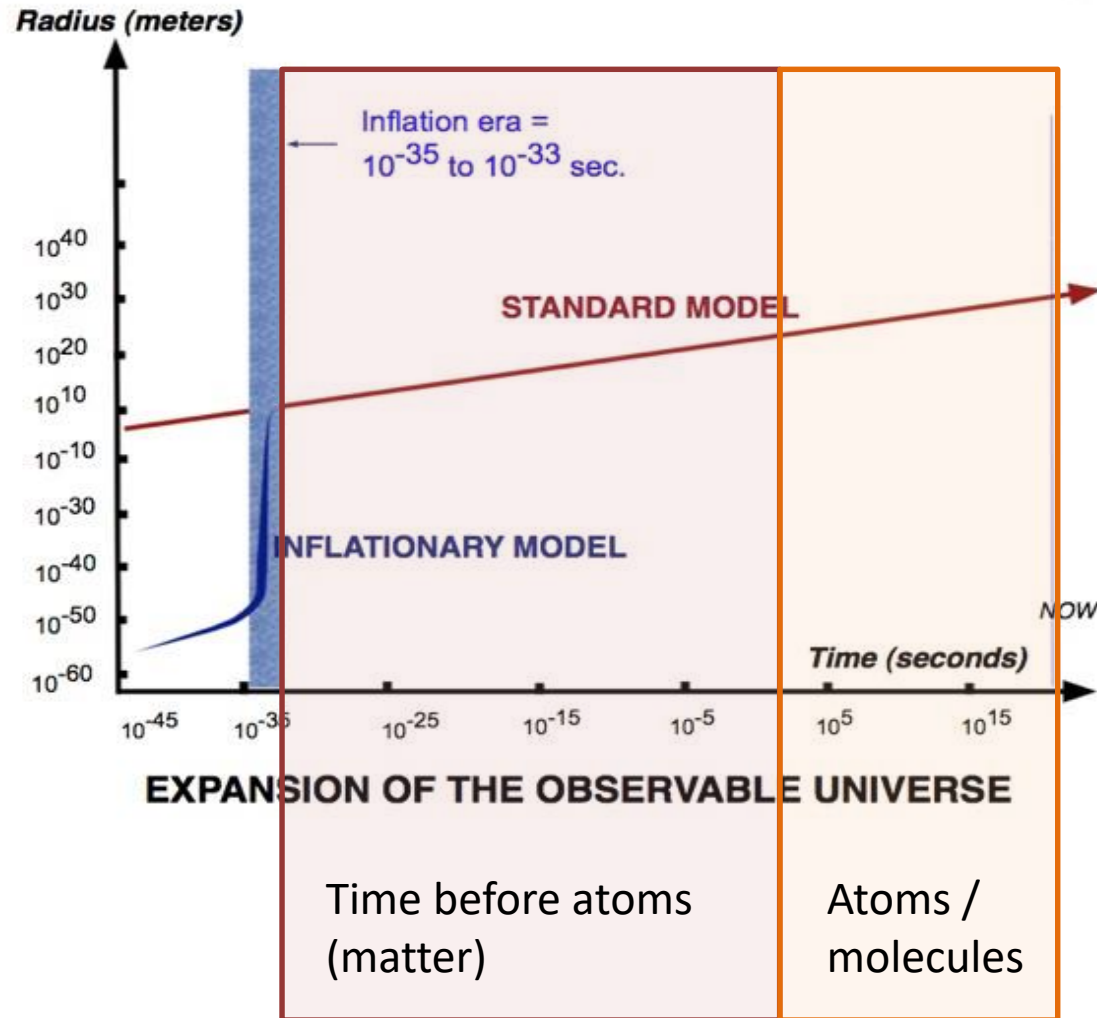


Neutrinos

mass →	$\approx 2.3 \text{ MeV/c}^2$	$\approx 1.275 \text{ GeV/c}^2$	$\approx 173.07 \text{ GeV/c}^2$	0	$\approx 126 \text{ GeV/c}^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H Higgs boson
QUARKS	$\approx 4.8 \text{ MeV/c}^2$	$\approx 95 \text{ MeV/c}^2$	$\approx 4.18 \text{ GeV/c}^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	d down	s strange	b bottom	γ photon	
	0.511 MeV/c^2	105.7 MeV/c^2	1.777 GeV/c^2	91.2 GeV/c^2	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	$< 2.2 \text{ eV/c}^2$	$< 0.17 \text{ MeV/c}^2$	$< 15.5 \text{ MeV/c}^2$	80.4 GeV/c^2	
	0	0	0	± 1	
	$1/2$	$1/2$	$1/2$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
				GAUGE BOSONS	

- 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



1. Creation, inflation of space – not much is known before $\sim 10^{-35}..10^{-33}$ s.
2. Electroweak epoch (fundamental forces separate)
3. Quark epoch (**quarks** and exotic particles exist alone and rejoin with **antiparticles**)
4. -----(1 microsecond ($1 \cdot 10^{-6}$) 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 other)
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
12. 13.8 B years later = Today !

$T \sim 10^{32}$ K

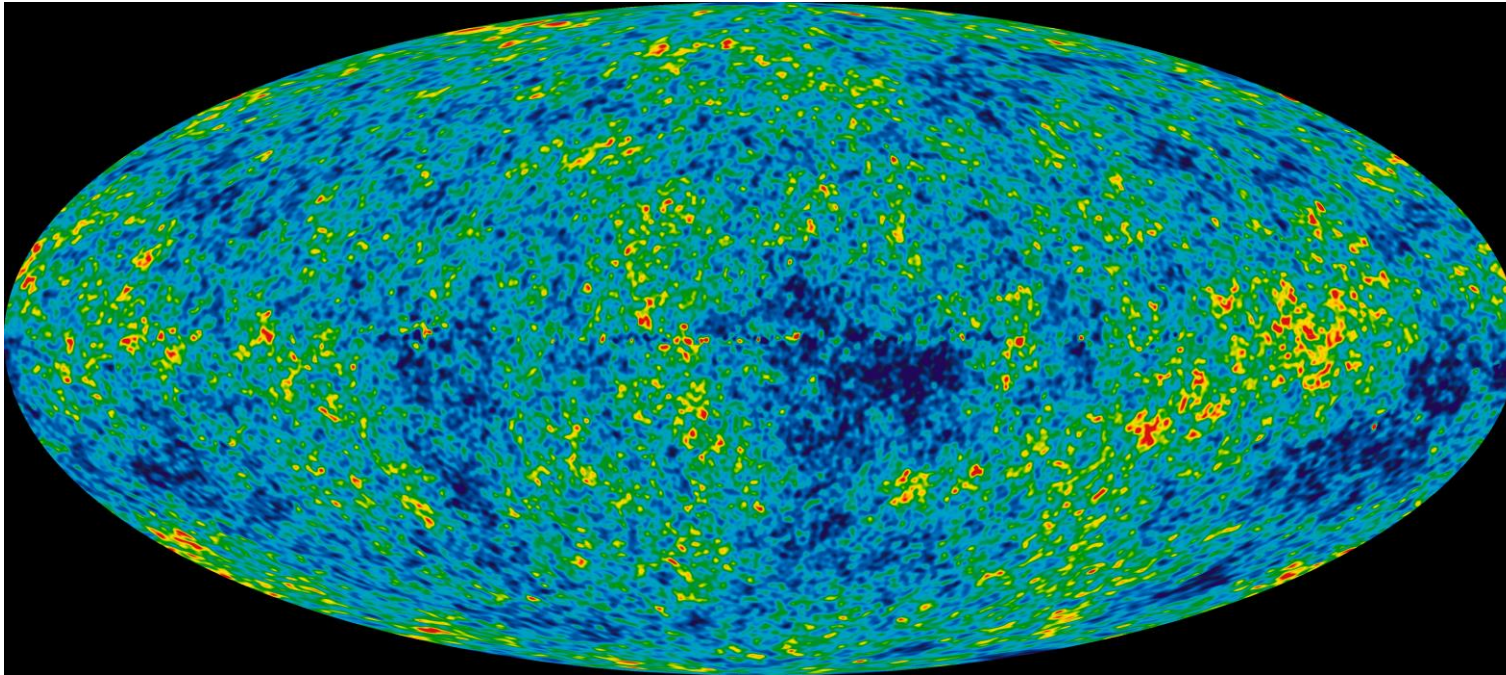


$T \sim 10^4$ K

$T \sim 2$ K

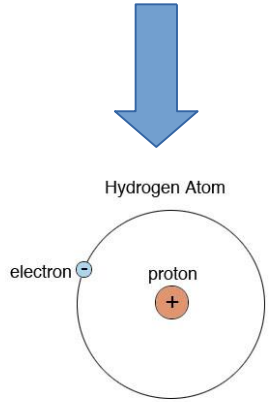
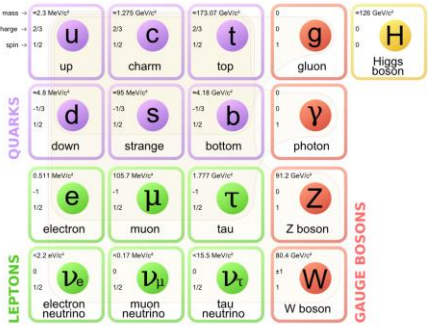
380 000 years later atoms (hydrogene)
formed and light was free to traver
throughout the universe.
Background radiation was born

Universe contained H atoms only!




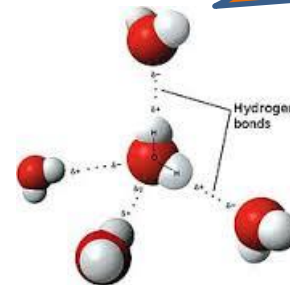
Wilkinson Microwave Anisotropy Probe (observations 2001-2010) (first photo of the universe)

ALL MATTER



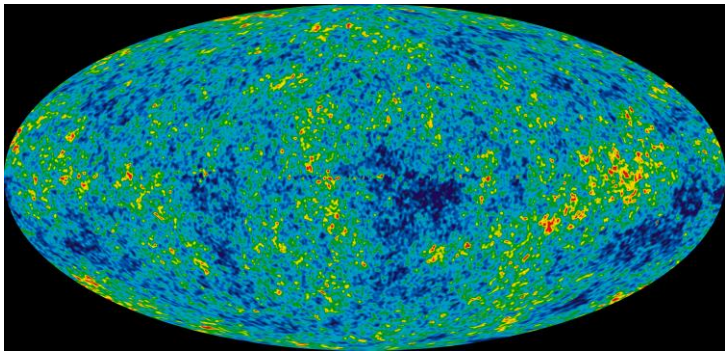
Fusion in stars !

Group→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
↓Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	* 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
			* 57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
			* 89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		



Chemistry





bosons

QUARKS			GAUGE BOSONS		
mass $\approx 2.3 \text{ MeV}/c^2$ charge $\rightarrow \frac{2}{3}$ spin $\rightarrow \frac{1}{2}$	$\approx 1.275 \text{ GeV}/c^2$ 2/3 $\frac{1}{2}$	$\approx 173.07 \text{ GeV}/c^2$ 2/3 $\frac{1}{2}$	0 0 1	$\approx 126 \text{ GeV}/c^2$ 0 0	
u up	c charm	t top	g gluon	H Higgs boson	
$\approx 4.8 \text{ MeV}/c^2$ -1/3 $\frac{1}{2}$	$\approx 95 \text{ MeV}/c^2$ -1/3 $\frac{1}{2}$	$\approx 4.18 \text{ GeV}/c^2$ -1/3 $\frac{1}{2}$	0 0 1		
d down	s strange	b bottom	γ photon		
LEPTONS					
0.511 MeV/c ² -1 $\frac{1}{2}$	105.7 MeV/c ² -1 $\frac{1}{2}$	1.777 GeV/c ² -1 $\frac{1}{2}$	91.2 GeV/c ² 0 1	Z boson	
e electron	μ muon	τ tau			
$<2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$	$<0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	$<15.5 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	80.4 GeV/c ² ± 1 1	W boson	
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino			



Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	1 H																	2 He	
2	3 Li	4 Be																	10 Ne
3	11 Na	12 Mg																	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo	
	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb					
	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No					

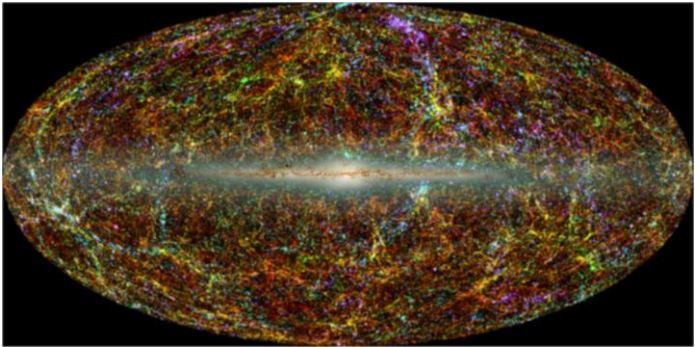
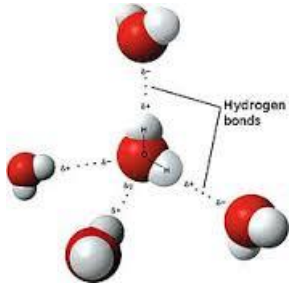
fermions

Fundamental Forces

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



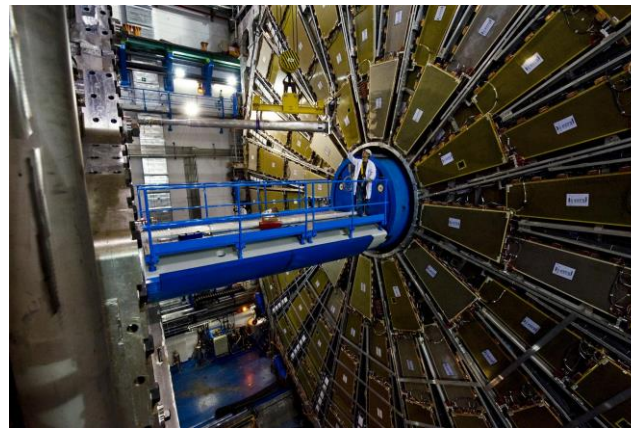
ALL MATTER



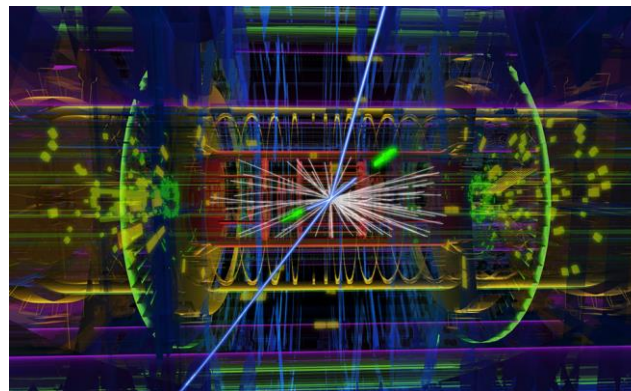
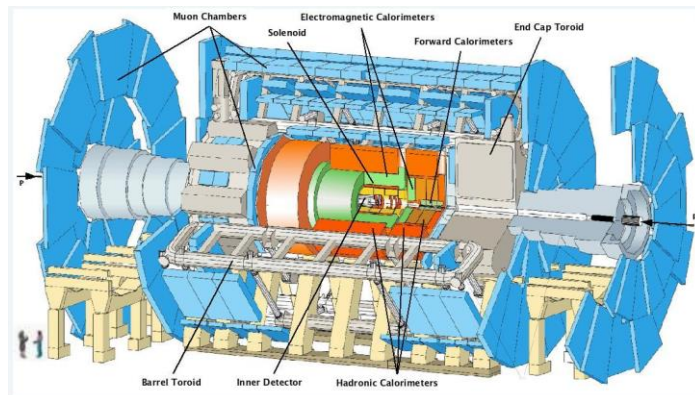
How do we know any of this ?

The Large Hadron Collider (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 diameter accelerator with
superconducting magnets cooled
down to a few Kelvins ($1\text{K} = -273.14^{\circ}\text{C}$)



Universe today $\sim 13.8 \times 10^9$ years old, 90 billion light years across

