

Who am I?

- Studies:
Theoretical physics in Univ. Helsinki MSc
2002–06, PhD 2008
- Career:
 - ETH Zurich 2008–10,
 - McGill University, Montreal 2010–13
 - CERN, Geneve 2013–

Theory division at CERN

- **Collider physics, 19**

Precision prediction in SM...

- **Heavy ions, 5**

Material properties of elementary particle matter, quark-gluon plasma, early universe, neutron stars...

- **Beyond standard model physics, 12**

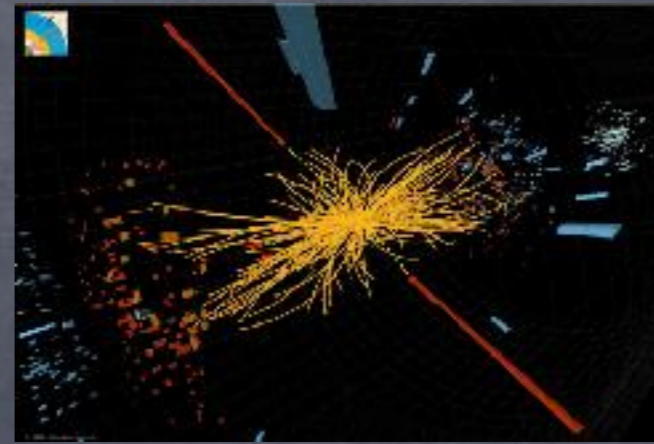
Dark matter, super symmetry, naturalness, hierarchy problem...

- **Cosmology, 6**

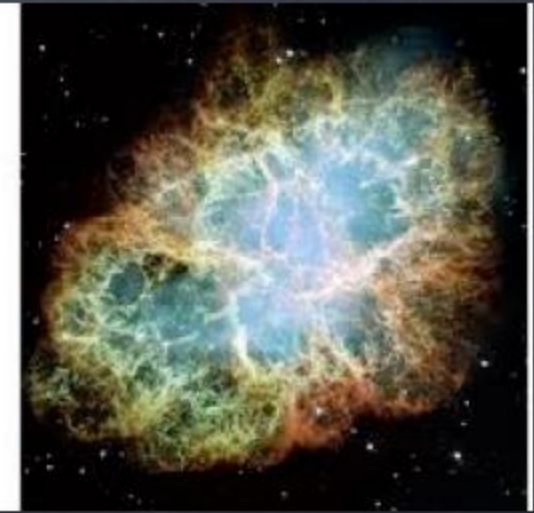
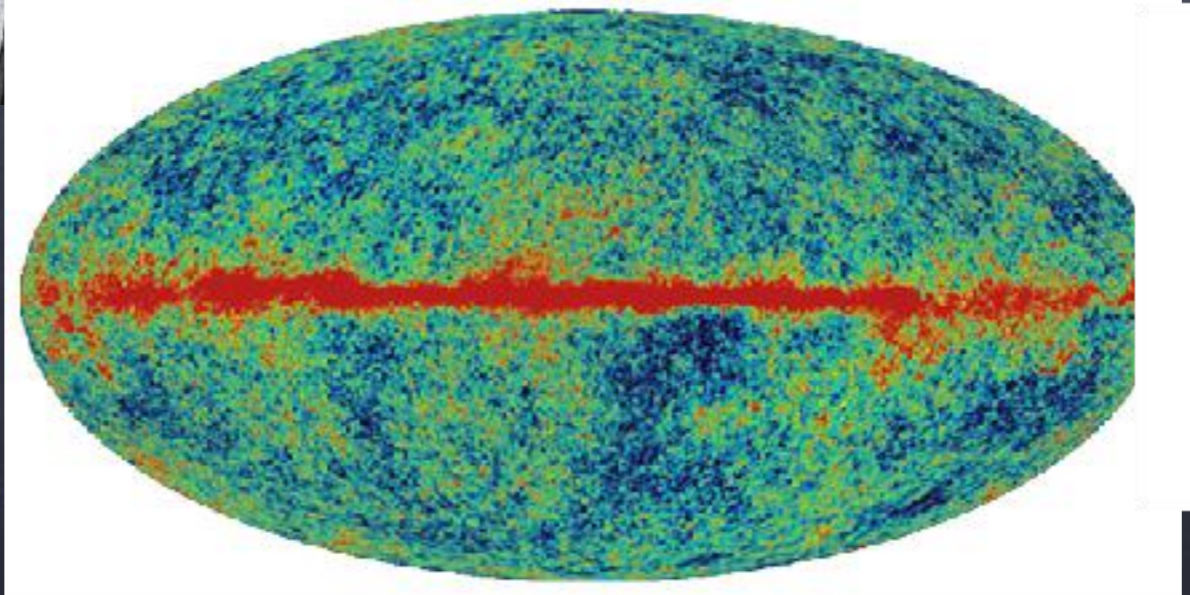
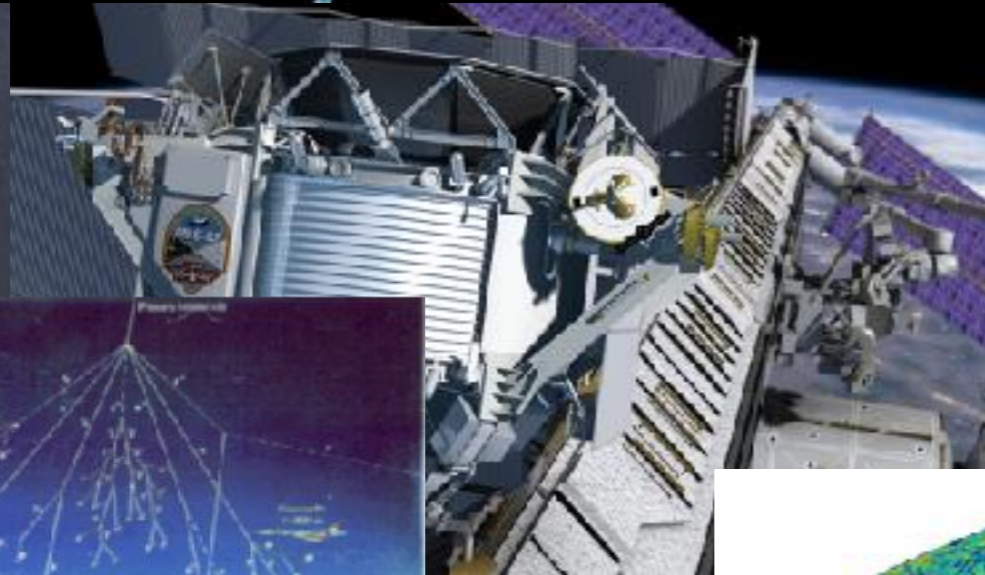
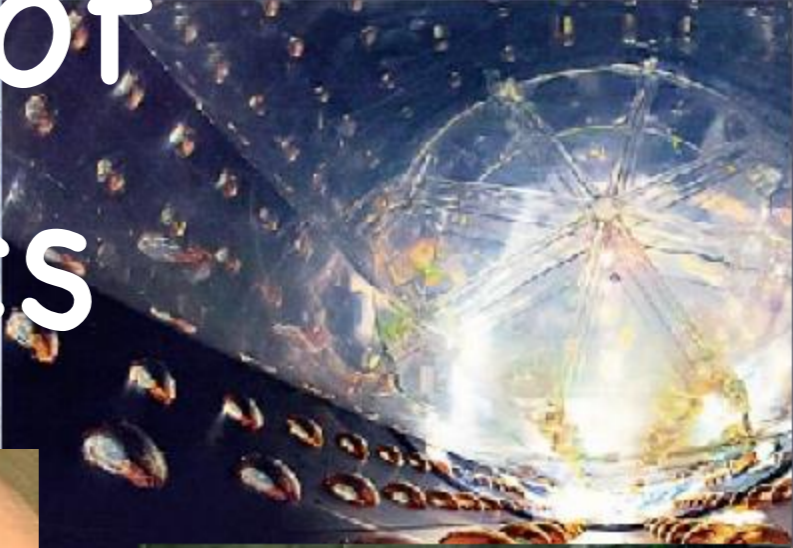
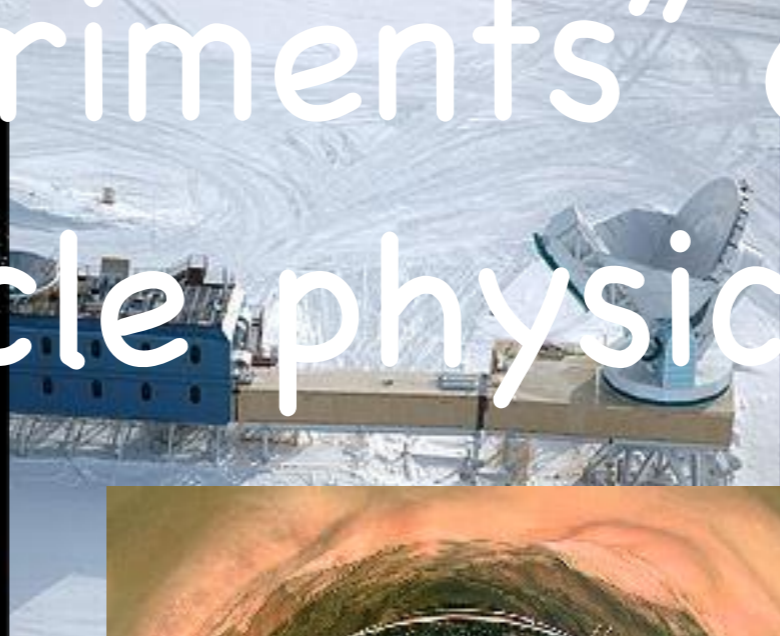
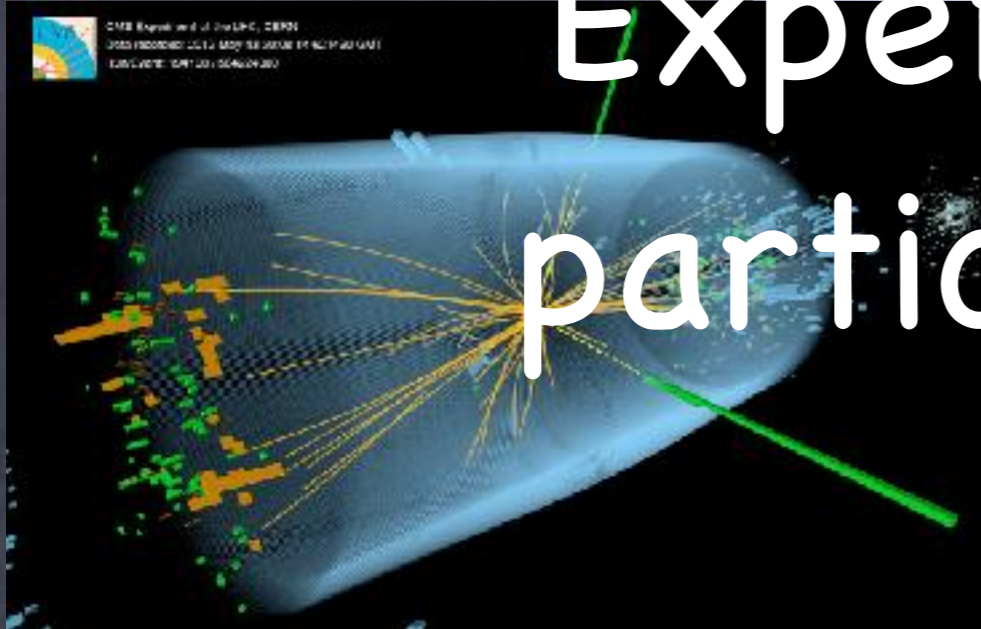
Big bang, large scale structure, inflation, baryogenesis...

- **String theory, 12**

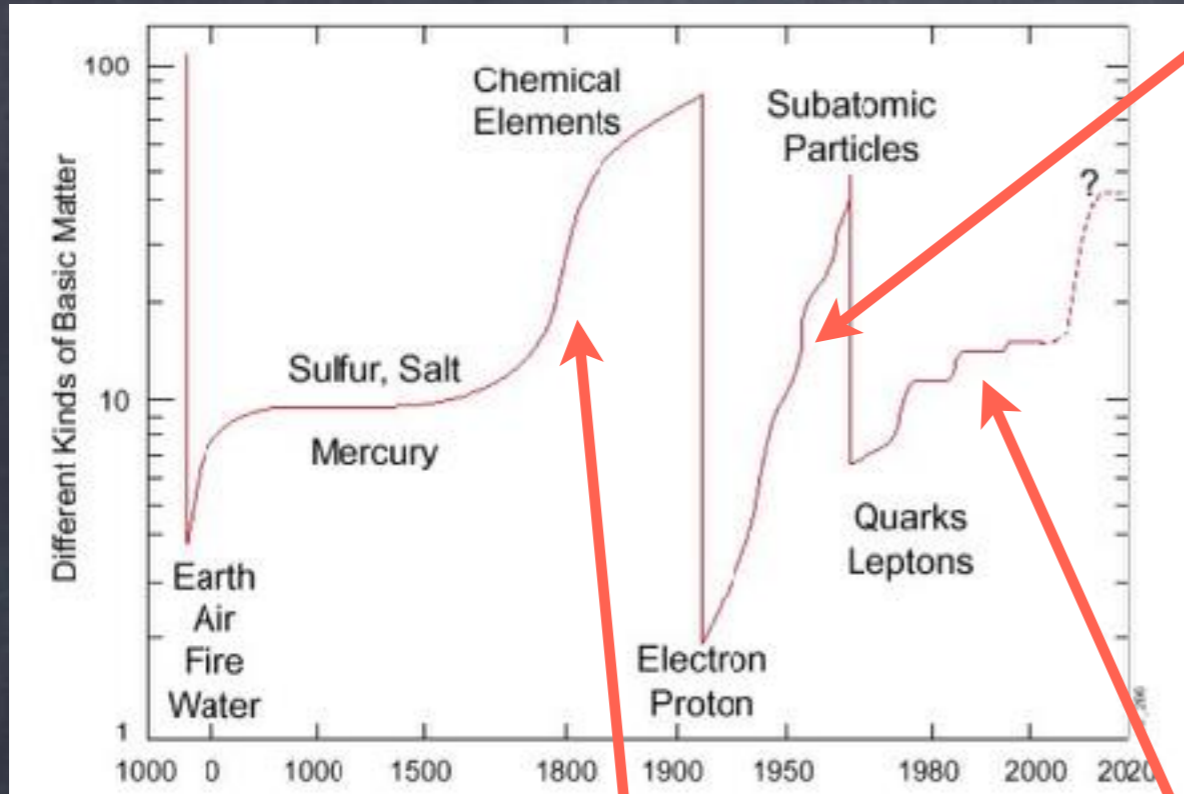
Mathematical physics, condensed matter, AdS/CFT...



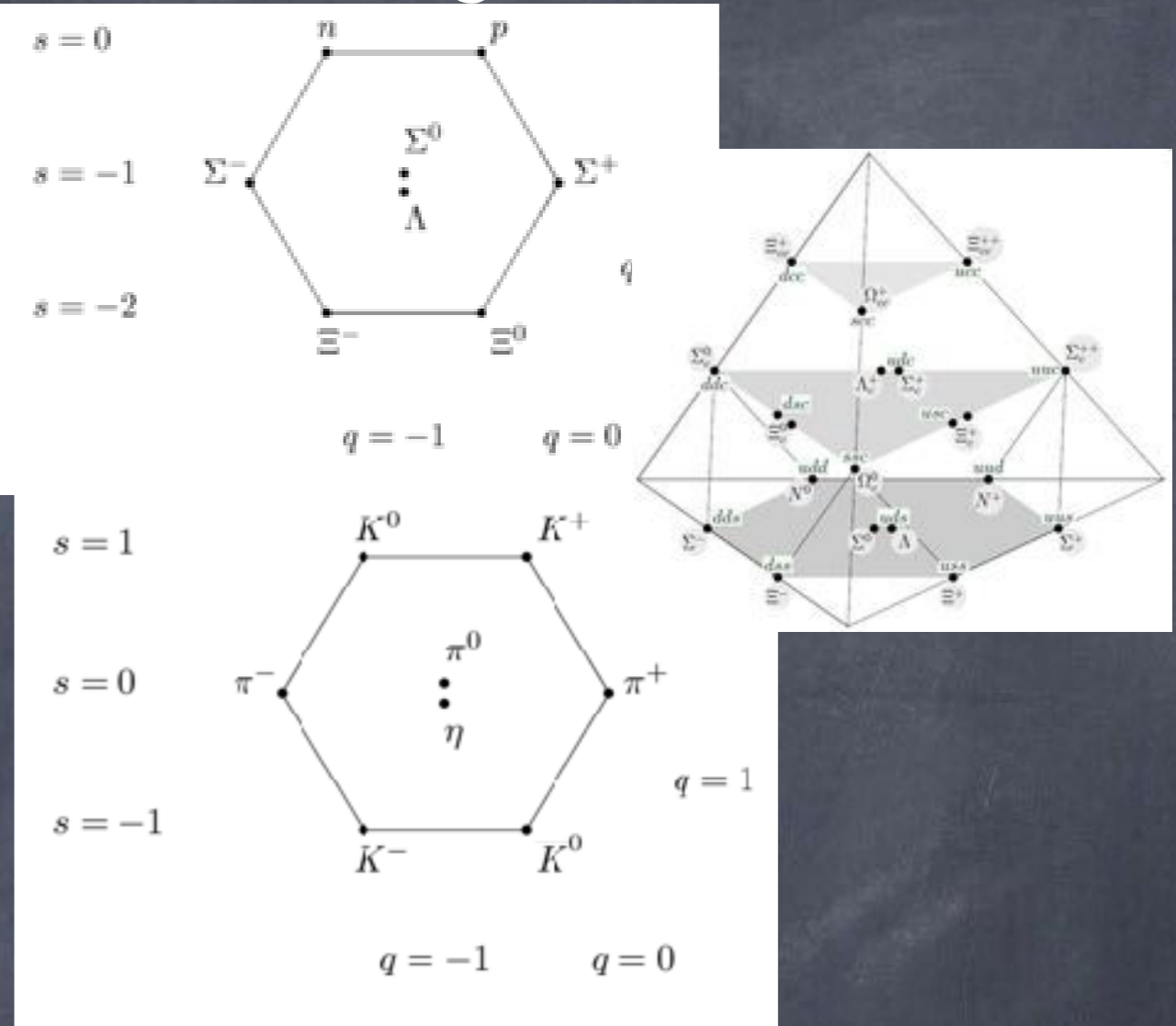
"Experiments" of particle physics



"The eightfold way"



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											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	*	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	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mc	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Uup	116 Lv	117 Ous	118 Ouo
				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	71 Lu
				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	103 Lr



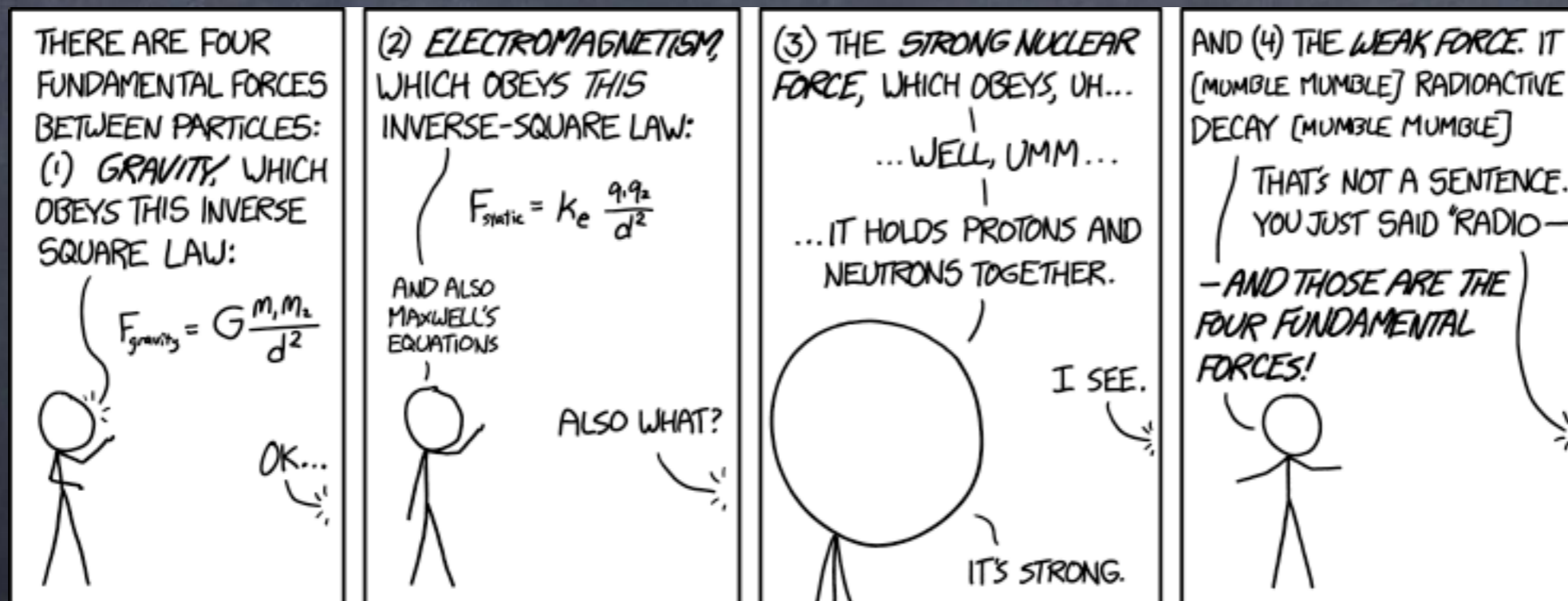
Standard model of particle physics

“Periodic table” of particle physics



+ Higgs, 126 GeV

Elementary forces



Quantum mechanics

Uncertainty principle

$$\Delta x \Delta p > \hbar/2$$

Special relativity

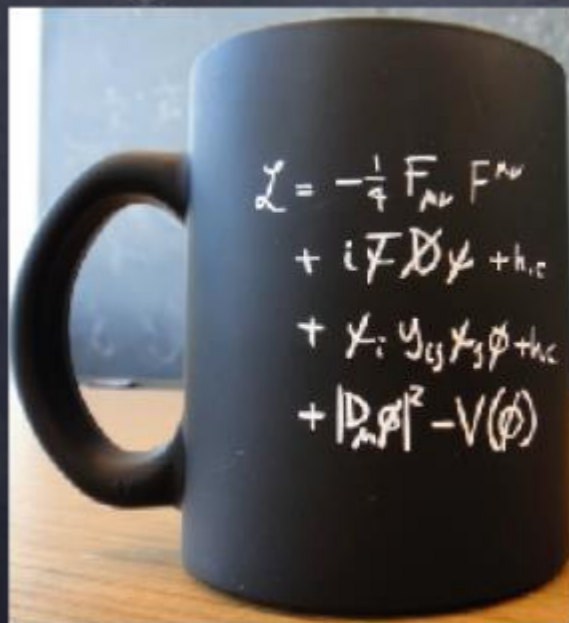
Constant speed of light,
frame independence

Gravity

General relativity

Quantum field theory

Particle-field duality

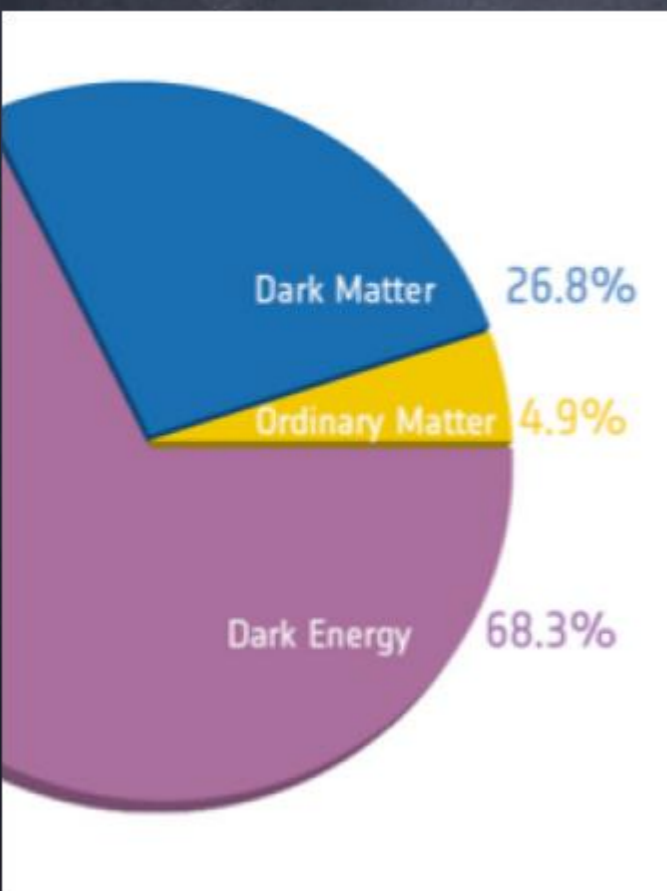


Interactions between particles through fields

- Electro-magnetism: electric- and magnetic fields
Photon
- Strong force: chromo-electric and magnetic
gluon
- weak force: "SU(2)" fields
W,Z bosons
- gravity: gravitational field (metric)
graviton?

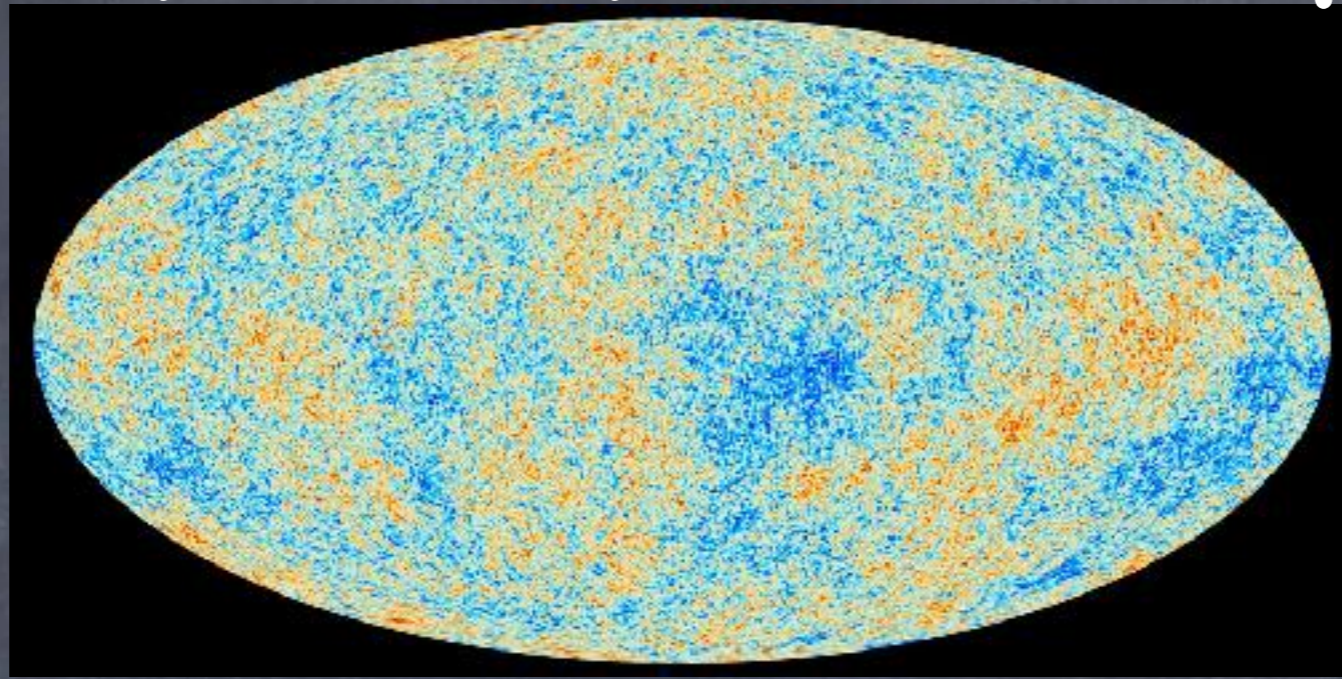
Challenges of SM

- Where does the structure of “periodic” table arise
- How to combine with gravity?
- Cosmo/astro:



- Why more matter than anti-matter?
Baryogenesis
- Most of energy budget “dark”
 - Dark energy 68%, dark matter 27%,
SM particles only 5%!

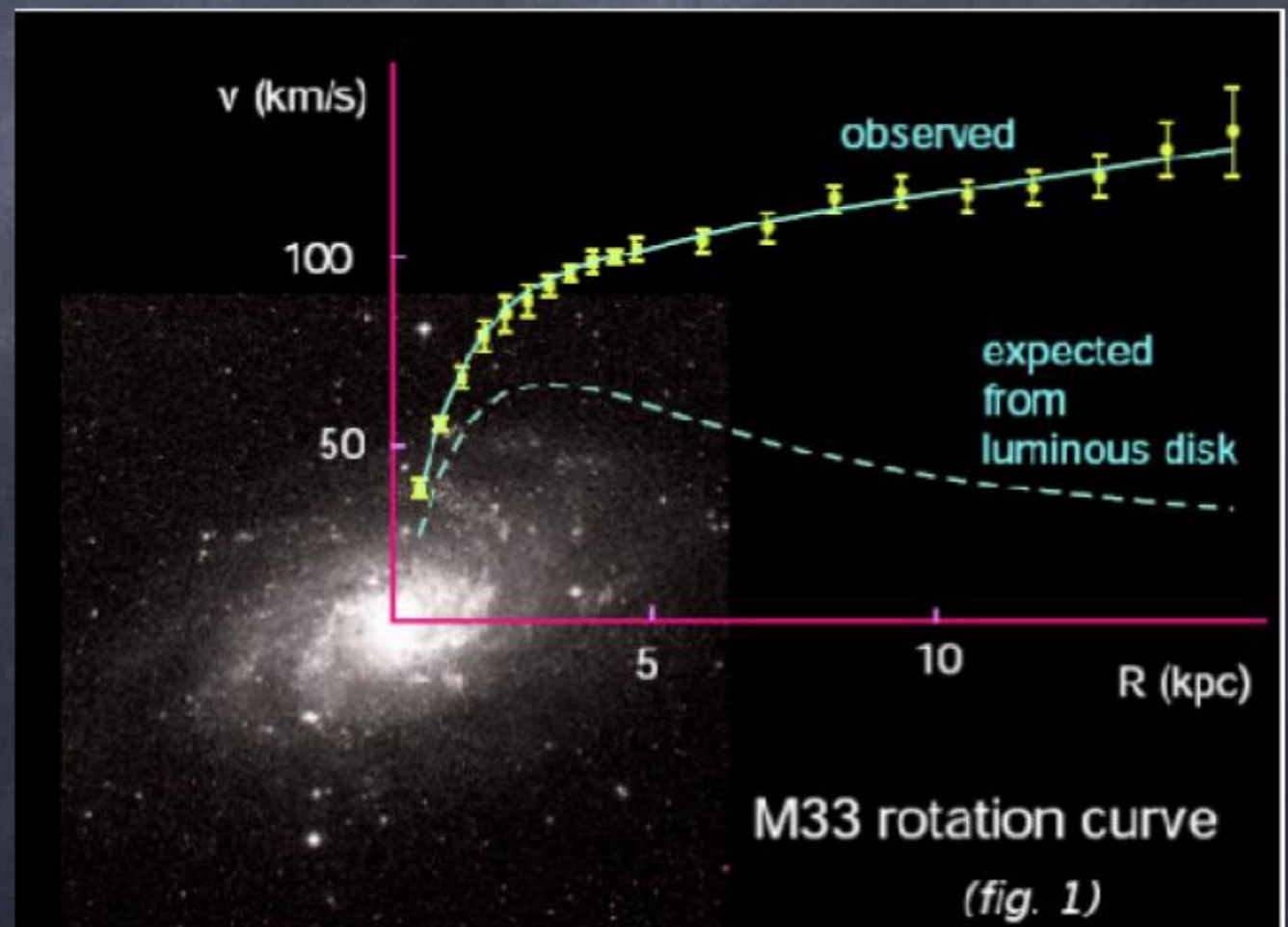
Mystery: isotropy



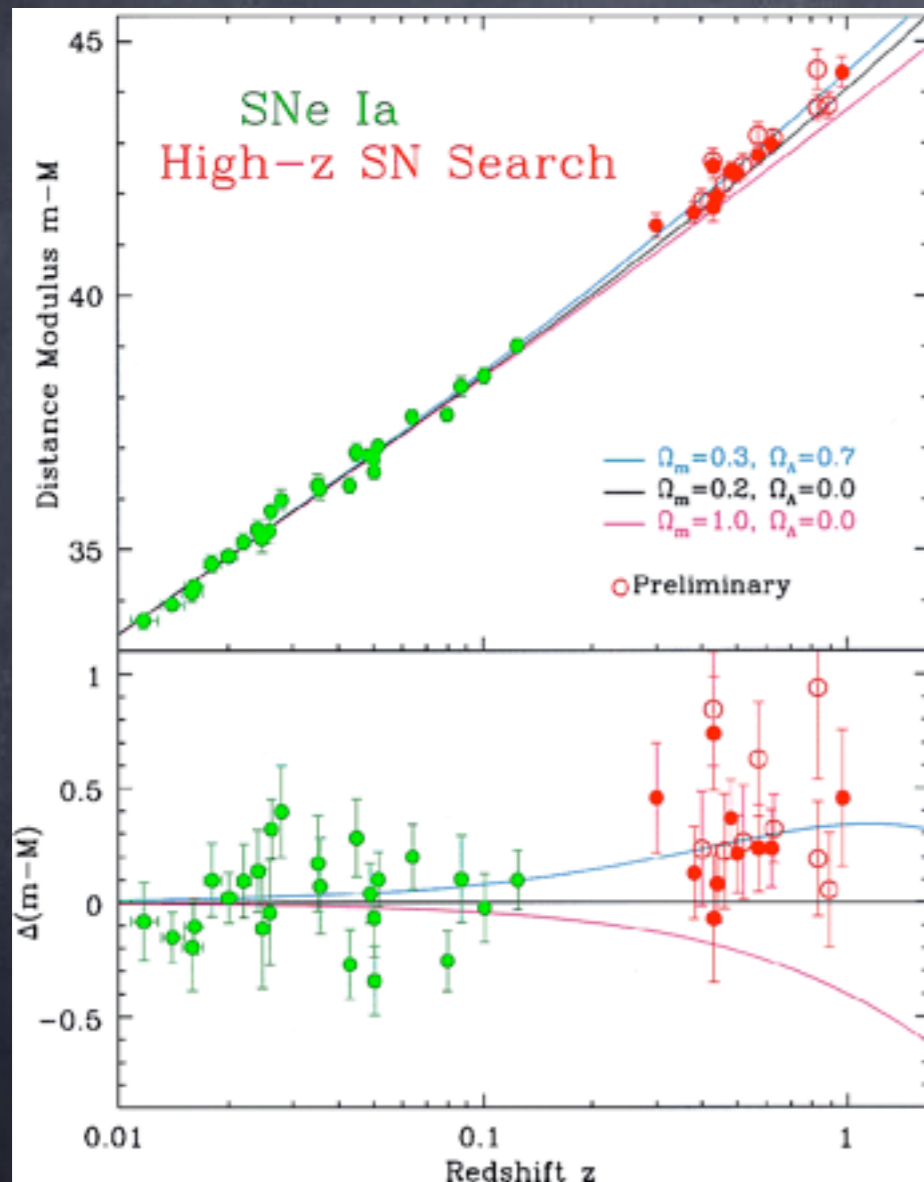
- Temperature of cosmic microwave background very isotropic ($2.7 \pm 0.00001\text{K}$)
- Different directions causally disconnected
- Possible solution: inflation

Mystery: dark matter

- 80% of all matter
- Explanation requires new particle physics
- Weak or no interaction with photons, invisible



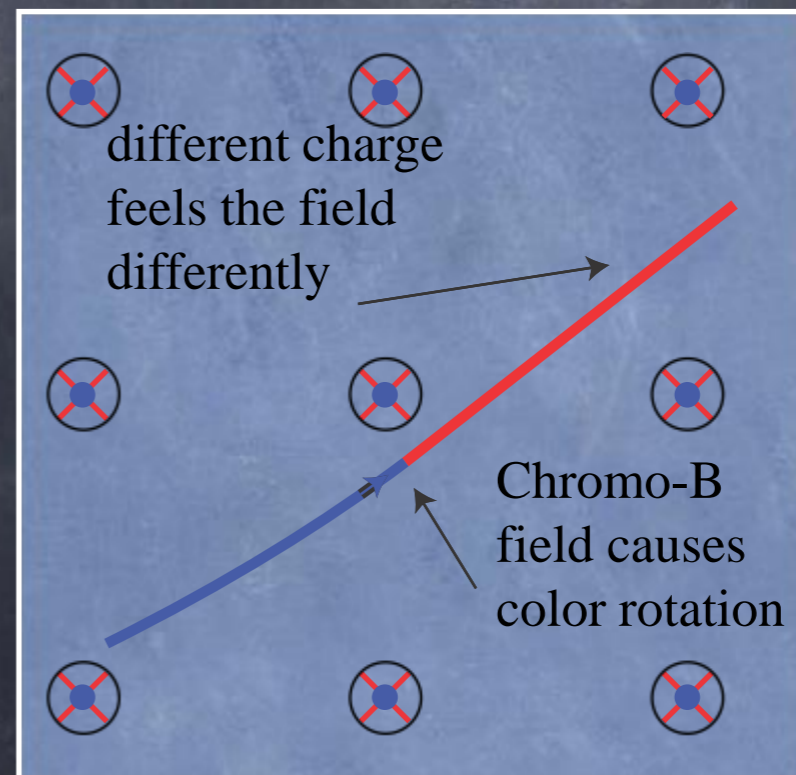
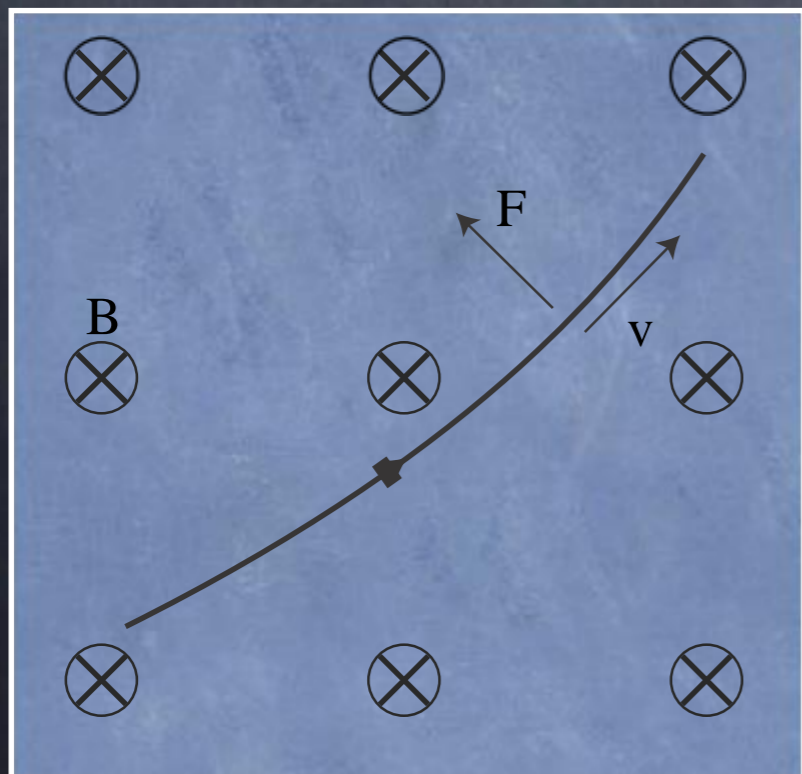
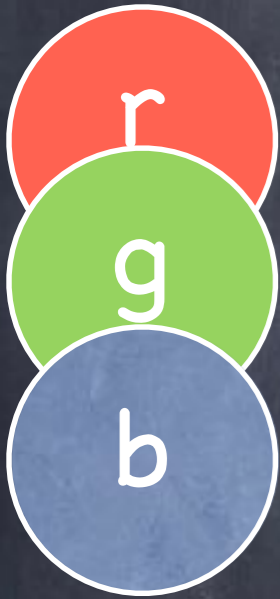
Mystery, dark energy



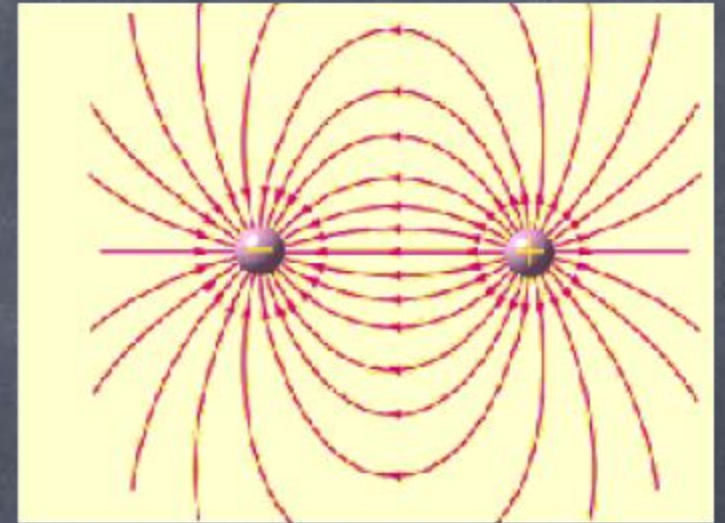
- ..or cosmological constant or vacuum energy...
- The expansion of universe accelerates

Strong force, QCD

- 3 different colors of quarks [rgb]
- Gluons like photons, except couple to color instead of charge
- Chromomagnetic/electric fields not only change momentum but also color: rb, bg,...
- Gluons colored \rightarrow self-interaction!



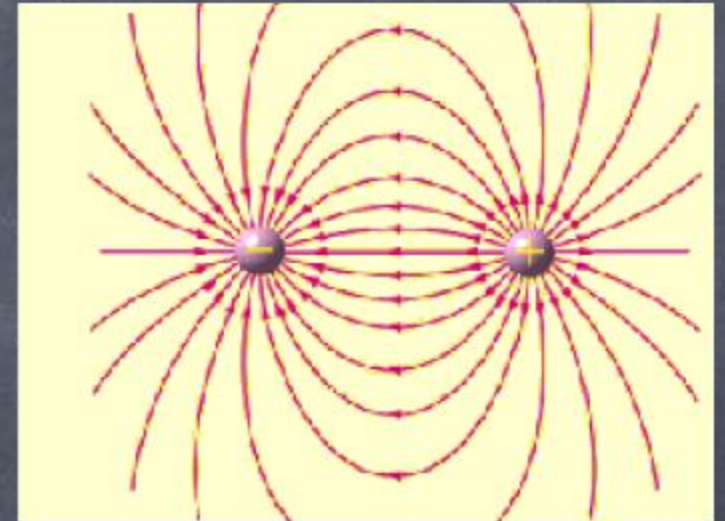
Gluons



Gluons

- The force between two electric charges

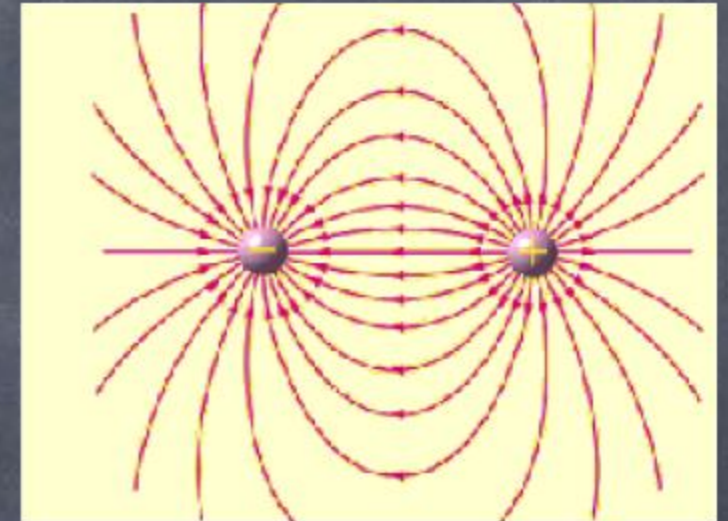
- $F = q_1 q_2 / r^2$



Gluons

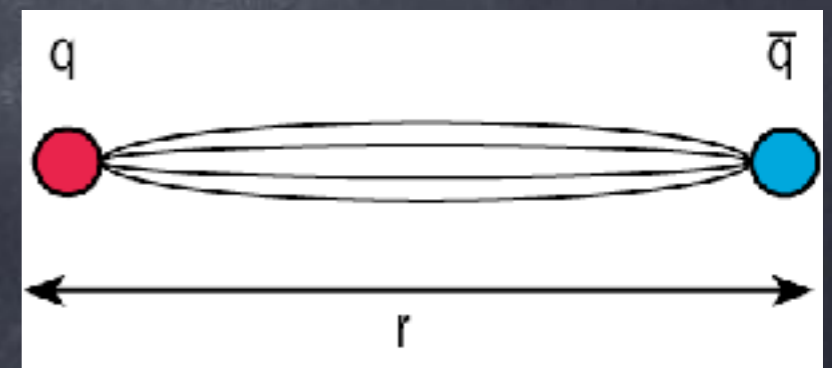
- The force between two electric charges

- $F = q_1 q_2 / r^2$



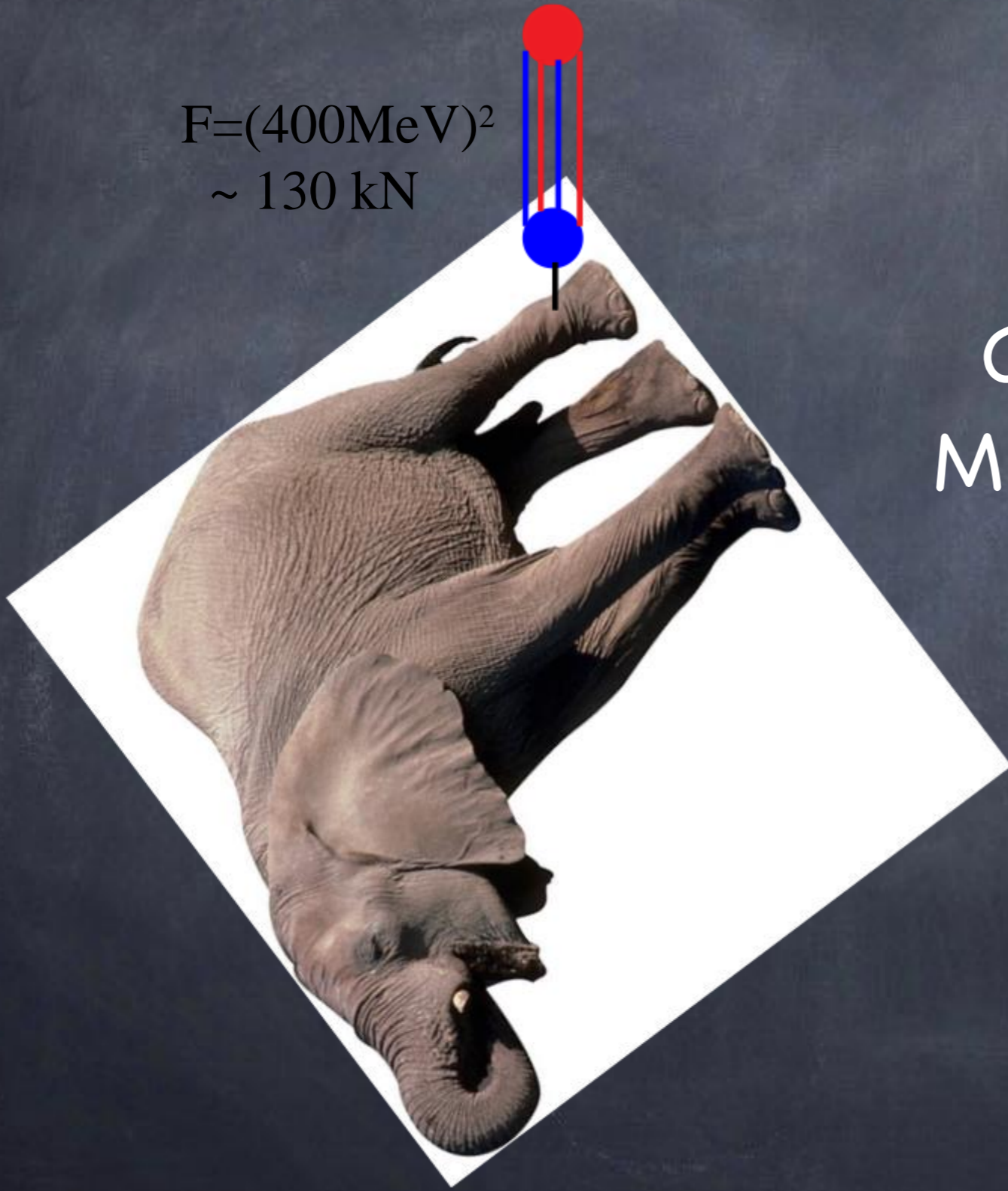
- Force between quarks

- $F = (400 \text{ MeV})^2$



Gluons

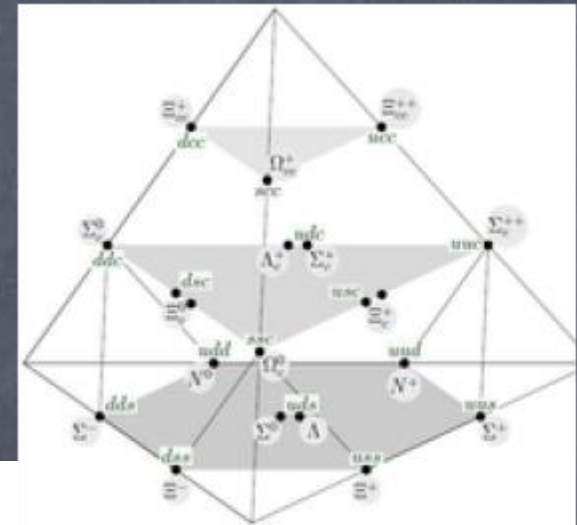
$$F=(400\text{MeV})^2$$
$$\sim 130 \text{ kN}$$



Color confinement
Millenium Prize 1M\$

Standardmodellin gluonit

- Because of confinement, quarks and gluons confined to color neutral lumps. Hardons!



Soft partons
mostly gluons

