the PARTICLES and the UNIVERSE

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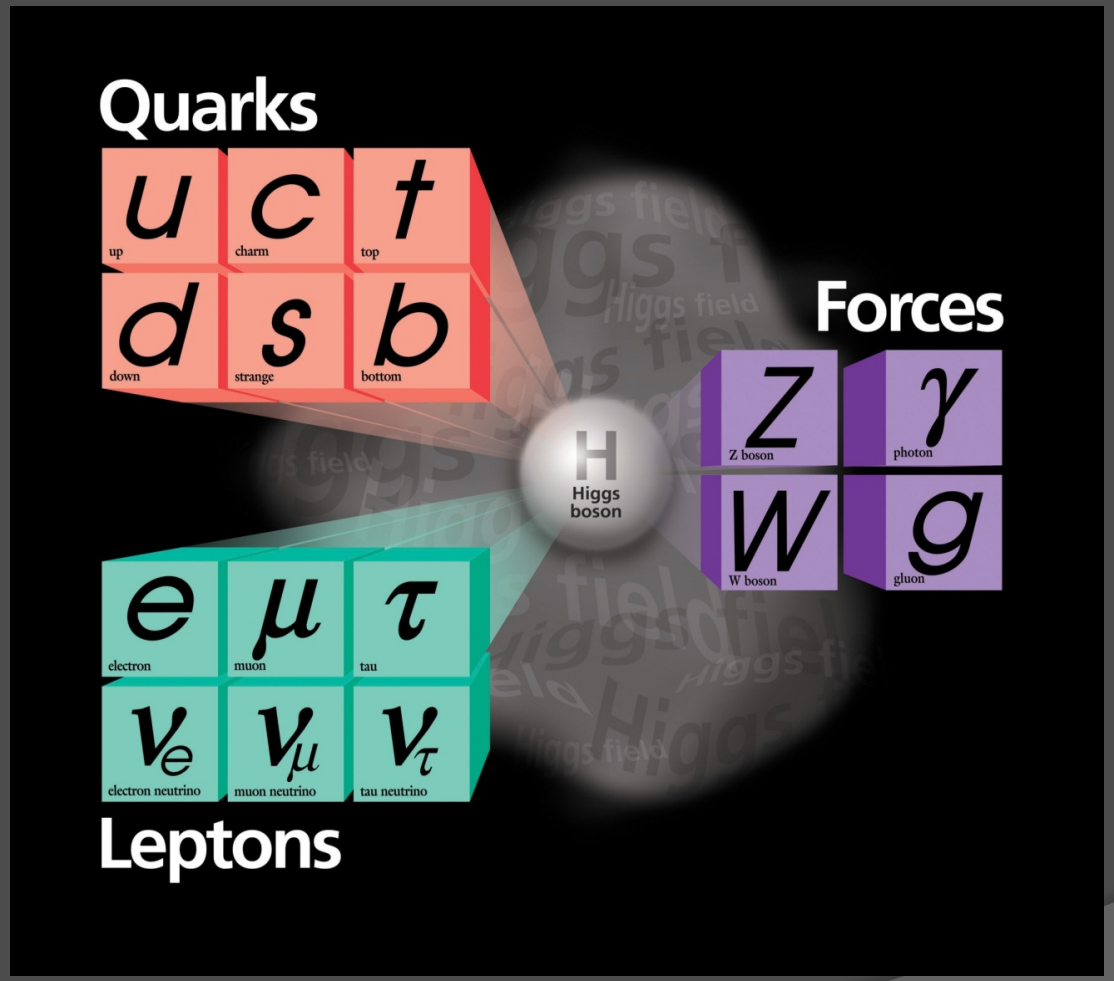
Particle Standard Model



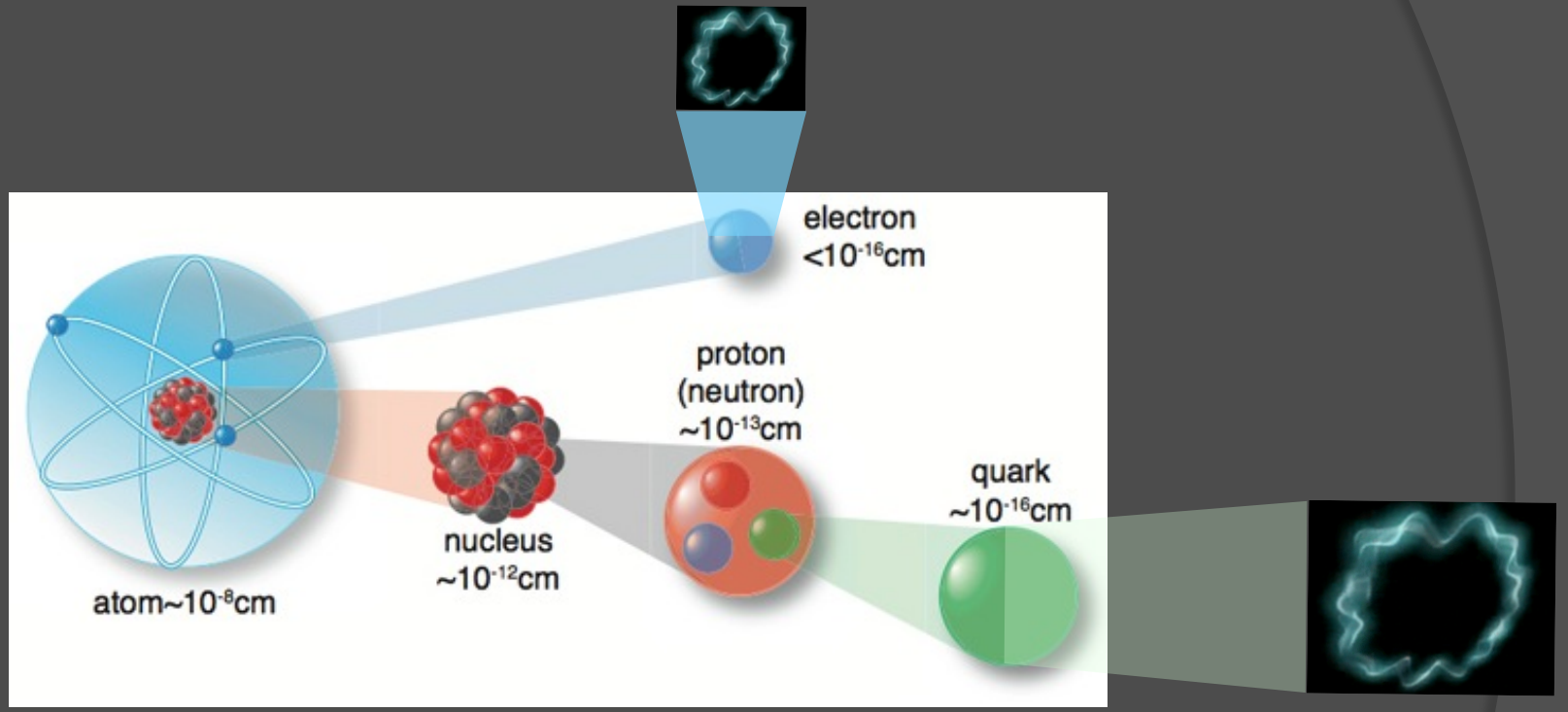
the final theory? NO

Particle Standard Model

- ✓ esplicative limits
  - in SM neutrinos have no mass, while in fact their masses are merely very small (< a millionth of electron mass) but not zero
  - SM doesn't include gravity; this force is described by a theory - General Relativity (GR) - that cannot made quantistic

- ✓ aesthetic limits
  - why so many parameters (19: masses of quarks, leptons, Higgs, …)? values from the experiments without understanding why they are what they are
  - why 3 families?
  - why matter e interactions? → supersymmetry?
  - …

String Theory



further layer at distances of the order of 10^{-33} cm: fundamental ingredients are tiny strings → the particles that we observe correspond to different vibration modes of the string

String Theory

one of these modes corresponds to the graviton (the "quantum" of the gravitational field) → SM e General Relativity are just be demoted to "effective theories", approximations that holds at the low energy scale that we have been to explore

actractive theory:

- incorporates gravity
- tightly constrained by the request of mathematical consistency: apparently there is only one string theory

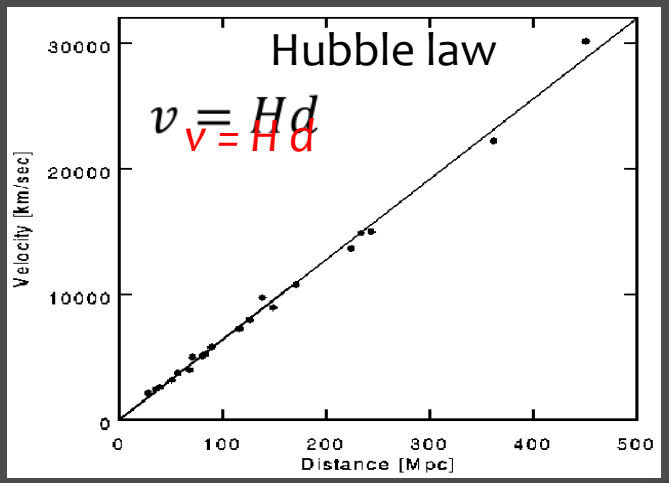
… but:

- no maths → equations of the theory unknown
- reasons to believe whatever these equations are, they have a vast number (10^{500}) of solutions → no one so far has succeeded in finding a solution that corresponds to the world we observe

Cosmology

- 300 B.C. - geocentric model (Aristotle)
- 16th century - eliocentric model with elliptic ordbits (Copernicus, Kepler)
- 17th century - newtonian static universe (Newton, Cartesio, Kant)
- 1917 - uniform & static universe of GR (Einstein)

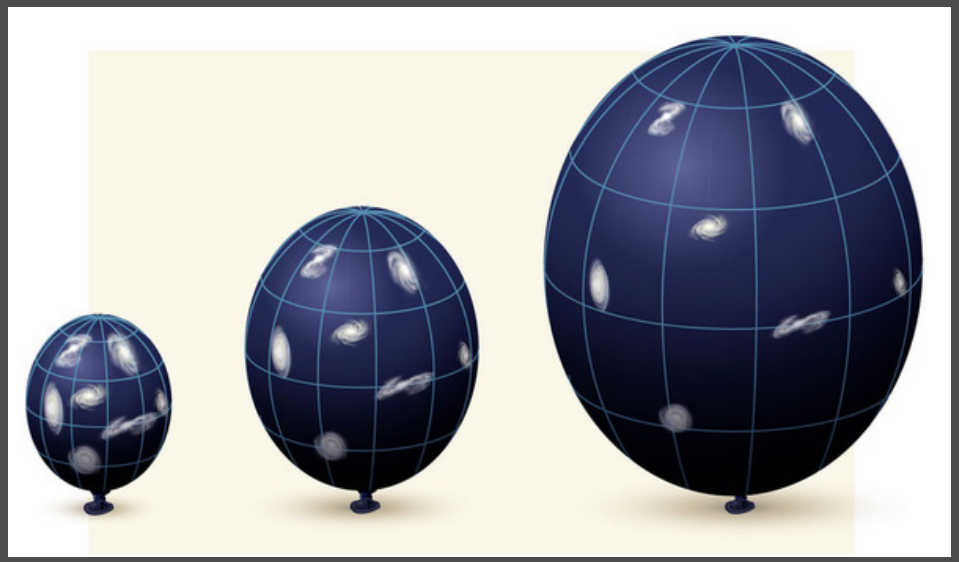
1929 - universe espansion discovered



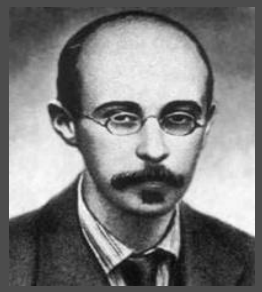
Einstein & Hubble

NB – oddly, little attention was given to an obvious conclusion: if galaxies are rushing apart, there would be a time in the past when they were all crunched together

Cosmology



1922 - mathematical model of the expanding Universe based on Einstein theory



Fridman

Lemaître

Einstein loved a static Universe → insertion of an "ad hoc" cosmological costant in GR equations: Hubble's discovery puts an end to this attempt

Universe age

$$H = 67\ \frac{km/s}{Mpc} \quad \Rightarrow \quad t = 1/H = 13.7 \times 10^9\ y$$

Hot Big Bang

✓ late 1940s

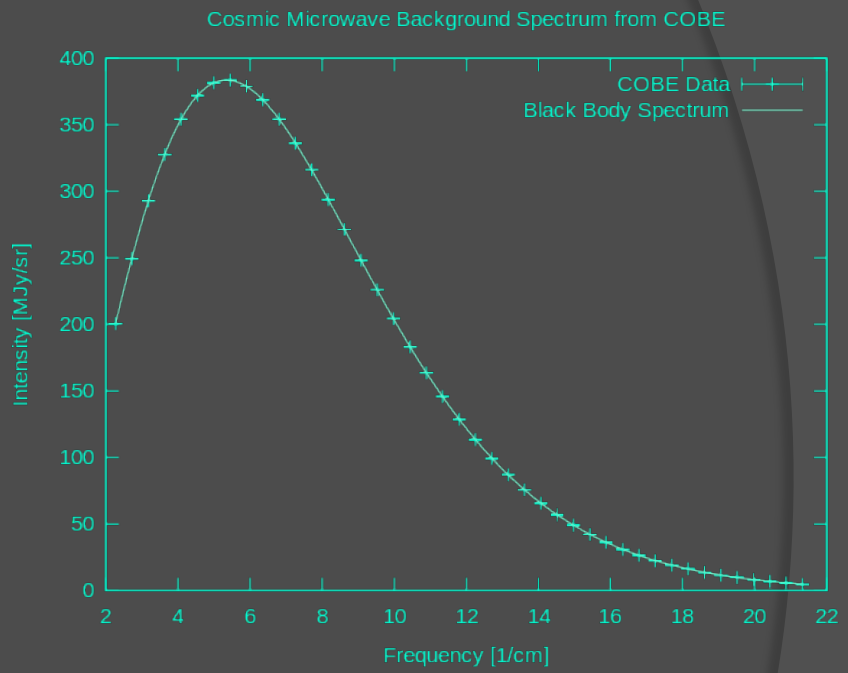
- theoretical calculation (Gamov, Alpher, Herman) → early Universe must have been very hot → due to espansion the radiation emitted by matter should come to us as a microwave, with temperature few degrees above absolute zero (- 273 °C)
- steady state hypothesis (Bondi, Gold e Hoyle): the Universe is eternal, with always the same average aspect and with new matter continously created to fill the empty among the receding galaxies

✓ 1964
(accidental) discovery of cosmic microwave background (CMB)

T = 2.725 K

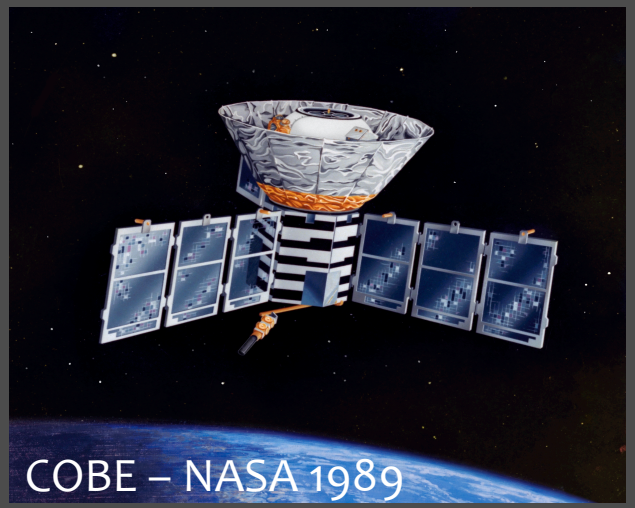
Cosmic Microwave Background

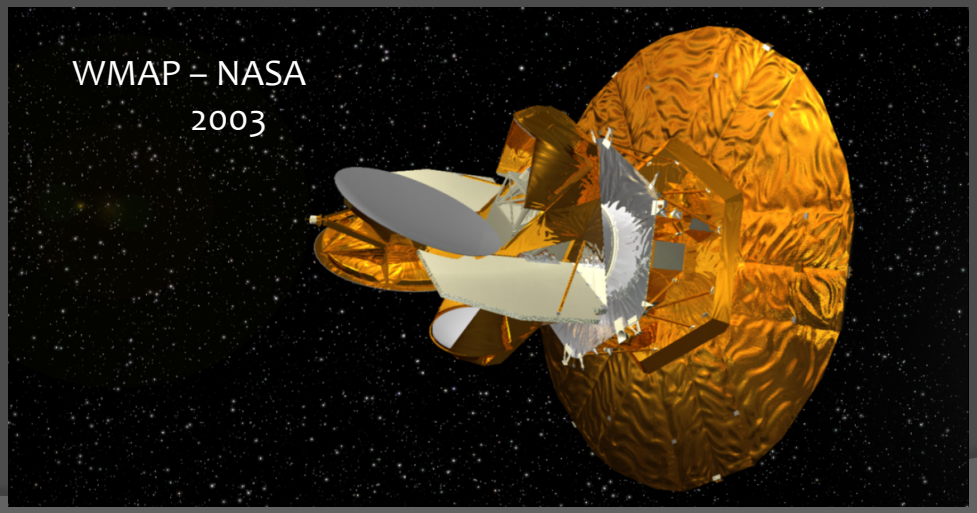
Wilson Penzias



T < 3,000 K (380,000 years after Big Bang): free electrons become locked in hydrogen atoms and Universe becomes trasparent to radiation that no longer interacts with matter (decoupling), cooled by subsequent expansion of the Universe

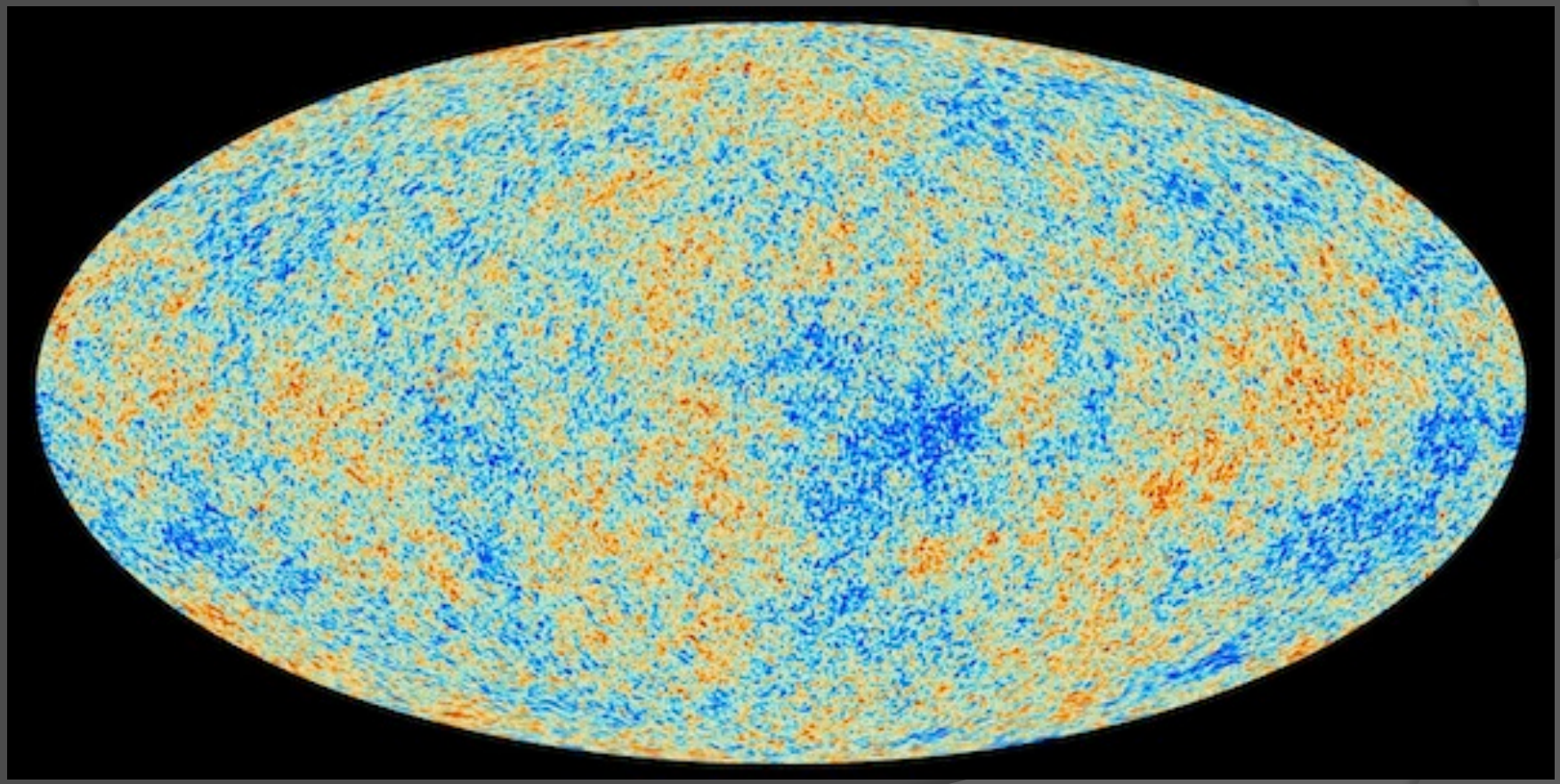
Cosmic Microwave Background


COBE – NASA 1989



Cosmic Microwave Background

temperature map measured by PLANCK (2013)



Cosmic Microwave Background

CMB temperature is not the same throughout the sky: 1/100,000 level of fluctuactions observed

a surprising result? NO

there would have to have been such ripples, caused by small lumps in the matter of the early Universe that are needed to serve as seeds for the later gravitational condensation of matter into galaxies

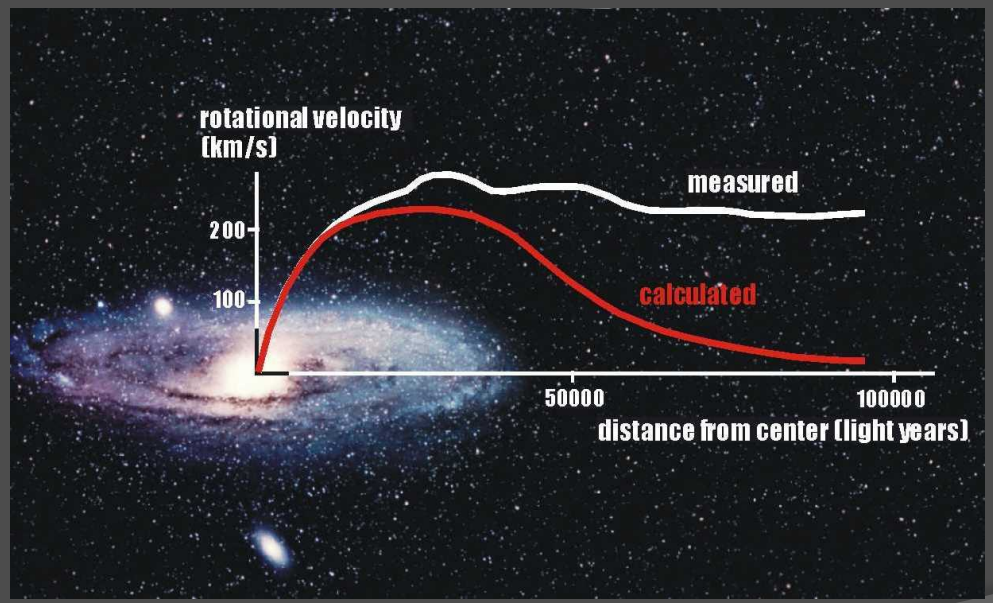
From details of CMB ripples we can calculate the abundance of the various types of particles that must have been before decoupling → surprising result: known particles are not enough to accont for the mass of hot matter

5/6 of matter of the Universe would have to be a some kind of dark matter (no emission/absorption of light)

Dark Matter

other evidence of the existence of dark matter:

- ✓ galaxies clusters held together gravitationally despite individual galaxies components have very high speed
- ✓ rotation curves of the galaxies



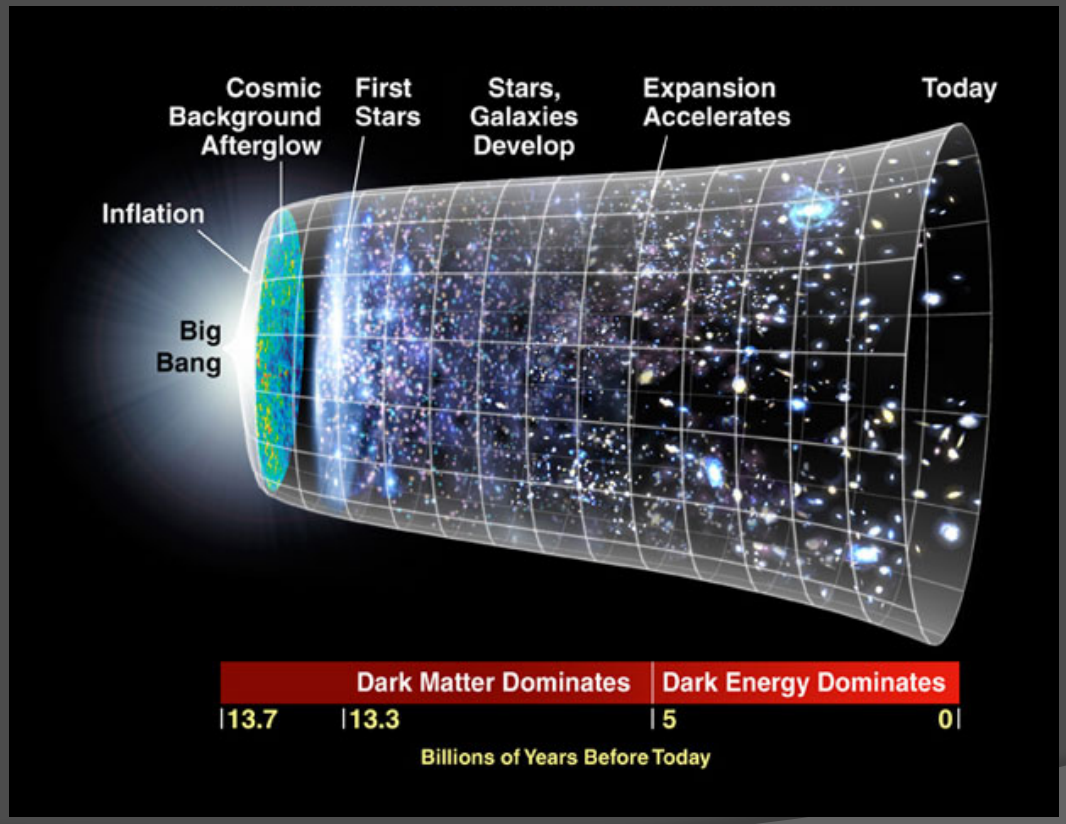
many theories & experiments:
no confirmation

↓

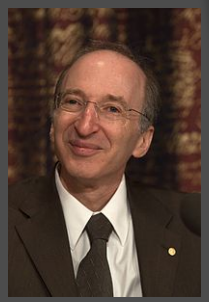
nobody knows what dark matter is

Dark Energy

1998 - measurement of the apparent brightness of supernovae Ia → expansion of the Universe started to speed up around 5 billions of years ago




Riess


Perlmutter

Schmidt

Dark Energy

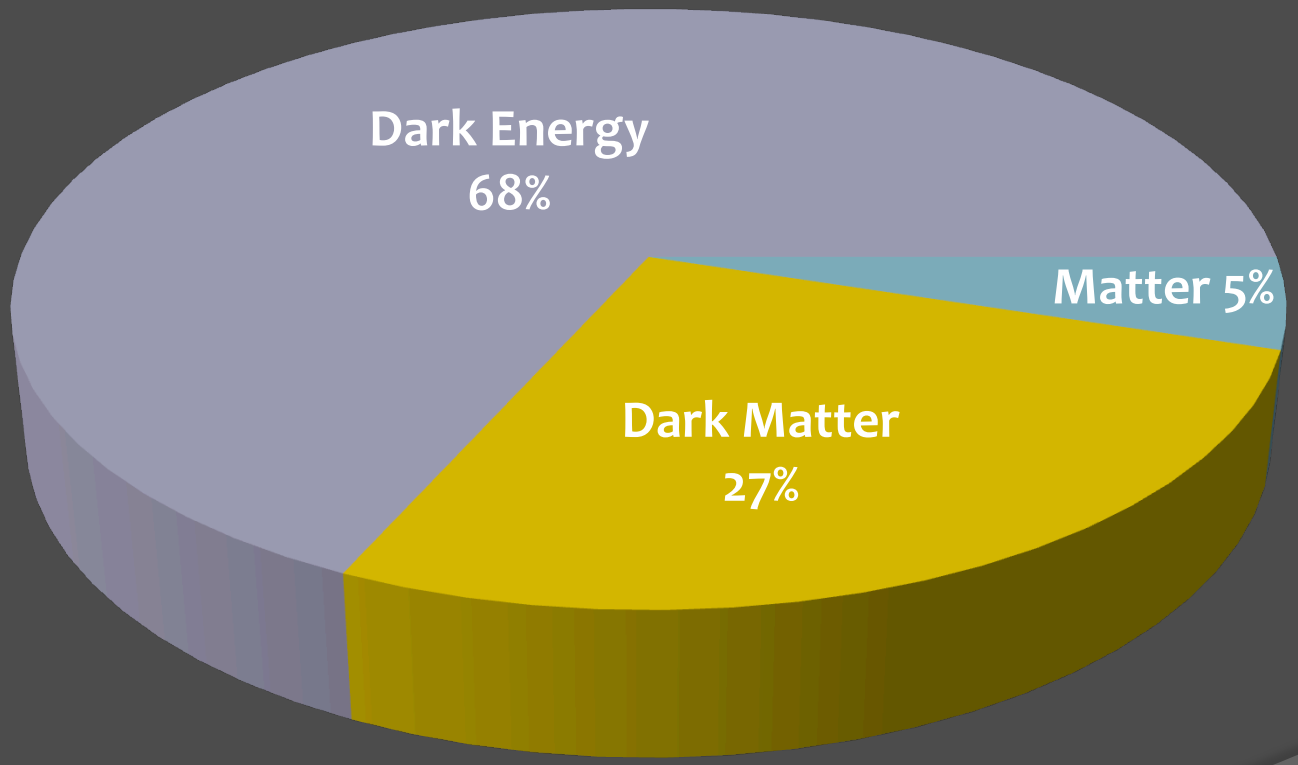
within GR this observation could only be explained by a dark energy producing a repulsive gravity pushing the galaxies apart

what is the origin of dark energy?

- cosmological constant *à la Einstein*?
  due to what? quantum vacuum? theoretical calculations predict a cosmological constant 10^{121} greater than the observed one
- modification of gravitational force?
  could only be effective on large scale: on small scales (solar system) the predictions of GR are in agreement with the experiment
- new forms of matter?
  scalar particles (quintessence) → negative pressure

(perhaps) the greater mistery

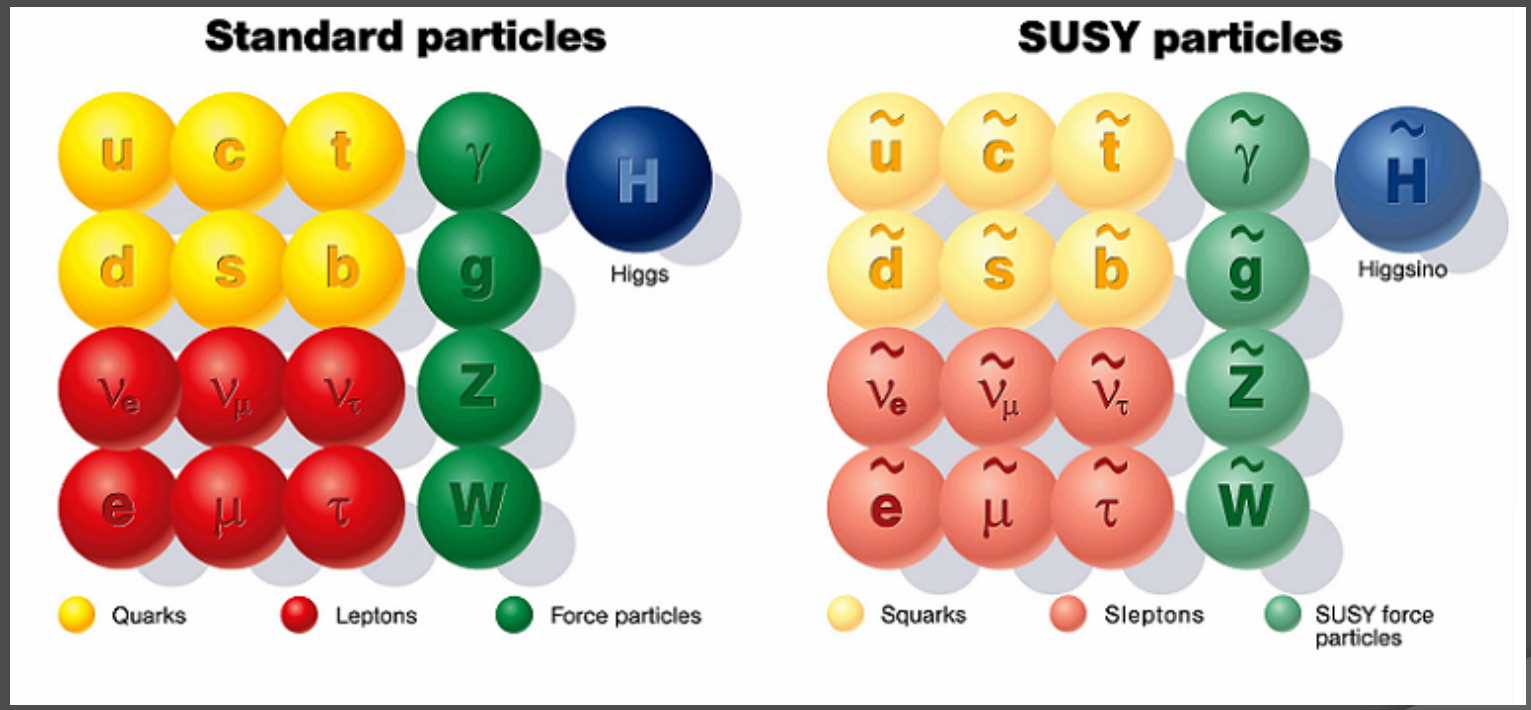
The Universe



we know nothing about the 95% of the Universe

Particle & Cosmology

new simmetry bosons $\Longleftrightarrow$ fermions: supersymmetry

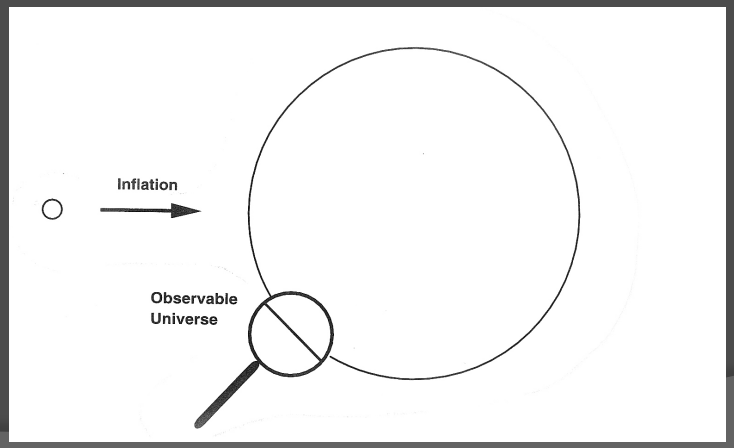


lightest superparticle is neutralino (stable e very heavy) → main candidate for dark matter: no hints from LHC

Particle & Cosmology

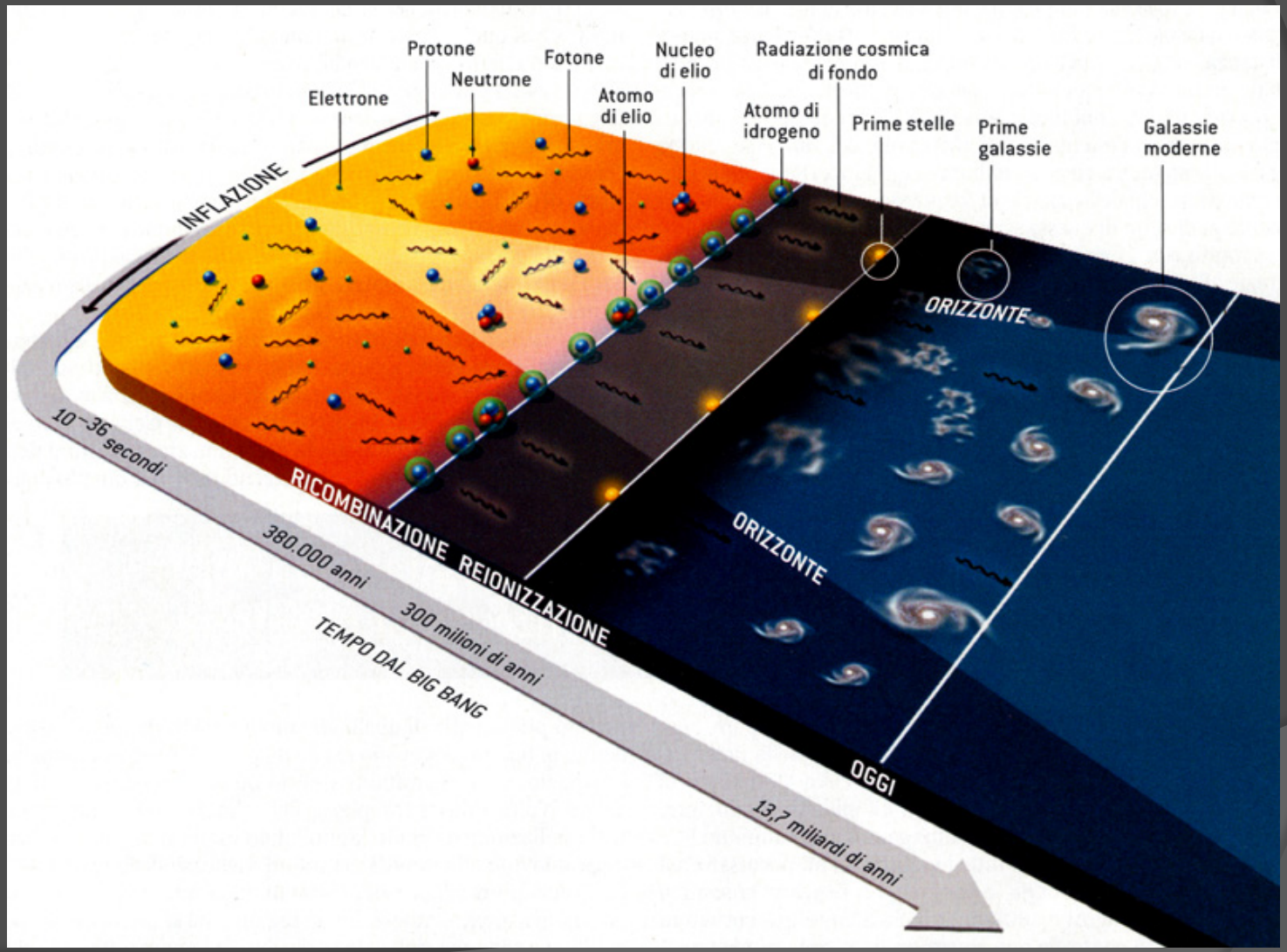
problem: why the Universe is so nearly uniform? how is it possible that cosmic photons coming from opposite directions of the sky have (within 1/100,000) the same temperature?

solution: (80s) QFT of scalar field → exponential espansion of the Universe (inflation) → highly uniform and tiny regions would expand to become, in a very small time (10^{-36} s), larger than the size of the present observed Universe, remaining approximately uniforms



Guth

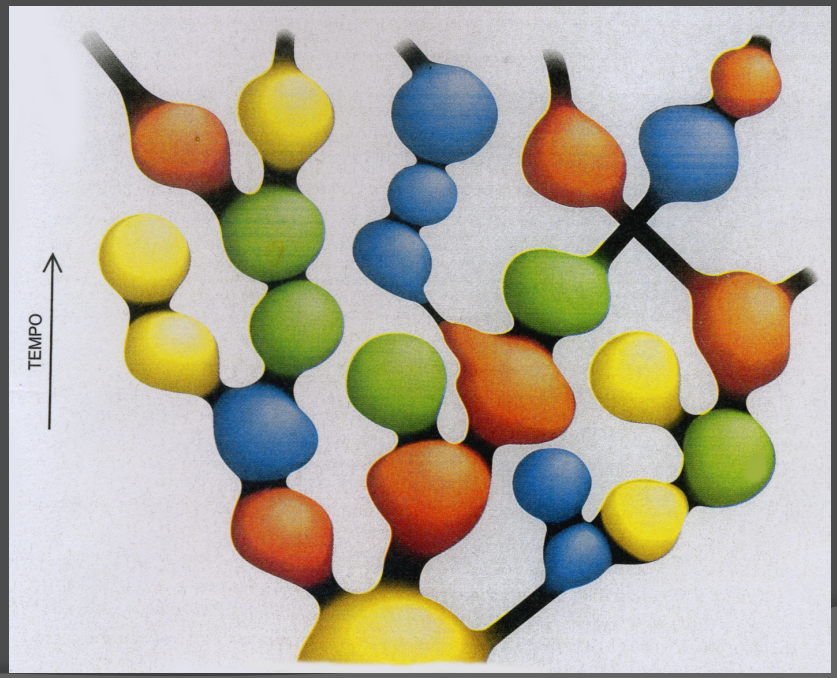
Inflation


Protone
Neutrone
Fotone
Nucleo di elio
Radiazione cosmica di fondo
Elettrone
Atomo di elio
Atomo di idrogeno
Prime stelle
Prime galassie
Galassie moderne
INFLAZIONE
ORIZZONTE
RICOMBINAZIONE
REIONIZZAZIONE
ORIZZONTE
OGGI
10⁻³⁶ secondi
380.000 anni
300 milioni di anni
13,7 miliardi di anni
TEMPO DAL BIG BANG

Inflation

impressive success: calculations show that quantum fluctuactions during inflation would trigger the temperature ripples we now see in CMB

mechanism difficult to stop → eternal inflation: formation of bubbles in an inflating Universe



Linde

Multiverse

bubbles form is an expanding Universe, each developing into a big or small Bang, perhaps with different values for what we usually call the constants of nature; each bubble appears to his inhabitants (if any) like the whole universe

Multiverse

hyphotesis: bubbles realize all the different solutions of the equations of string theory $\rightarrow$ SM parameters have accidental values , characteristic of the part of the Multiverse in which we to live

Anthropic Reasoning: observers must live in a part of the Multiverse where natural constants allow the evolution of life and intelligence; though not quite in the sense intended by Protagora, man may indeed the measure of all things

Anthropic Reasoning

So far, this anthropic speculation seems to provide the only explanation of the observed value of the dark energy

In the SM (and all other known QFTs) dark energy can have any value; Weinberg showed that a value much greater than the measured one would prevent formation of galaxies, stars, planets, i.e. life

is anthropic speculations what we have hoped for in Physics?

Physical sciences has historically progressed not only by finding precise explanations of natural phenomena, but also by discovering what sorts of things can be precisely explained. These may be fewer than we had thought

S. Weinberg