The two infinities and their connections

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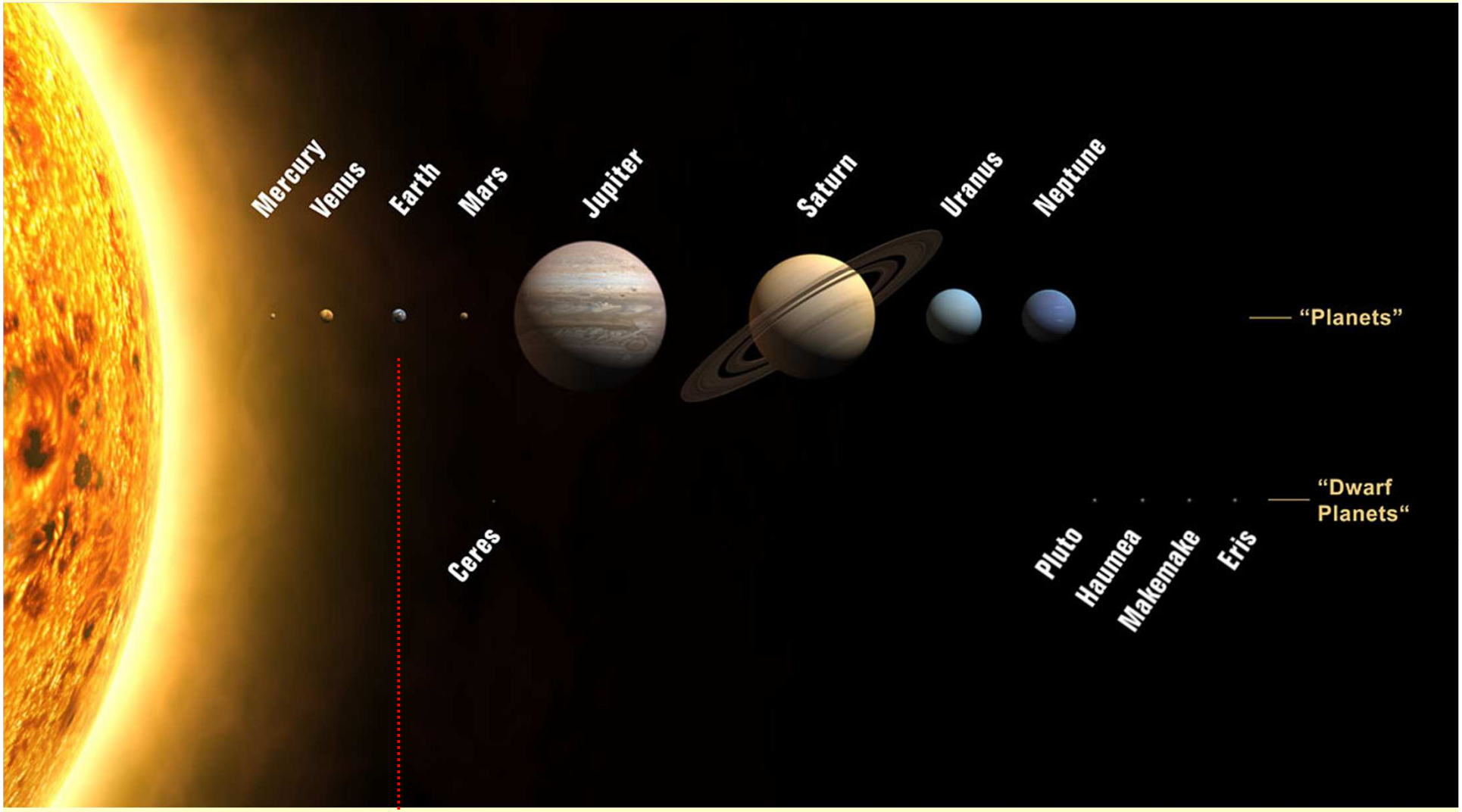
1) Elementary particles and fundamental interactions
2) **Content of the Universe and evolution**

Content of the Universe and evolution

The known universe: the solar system



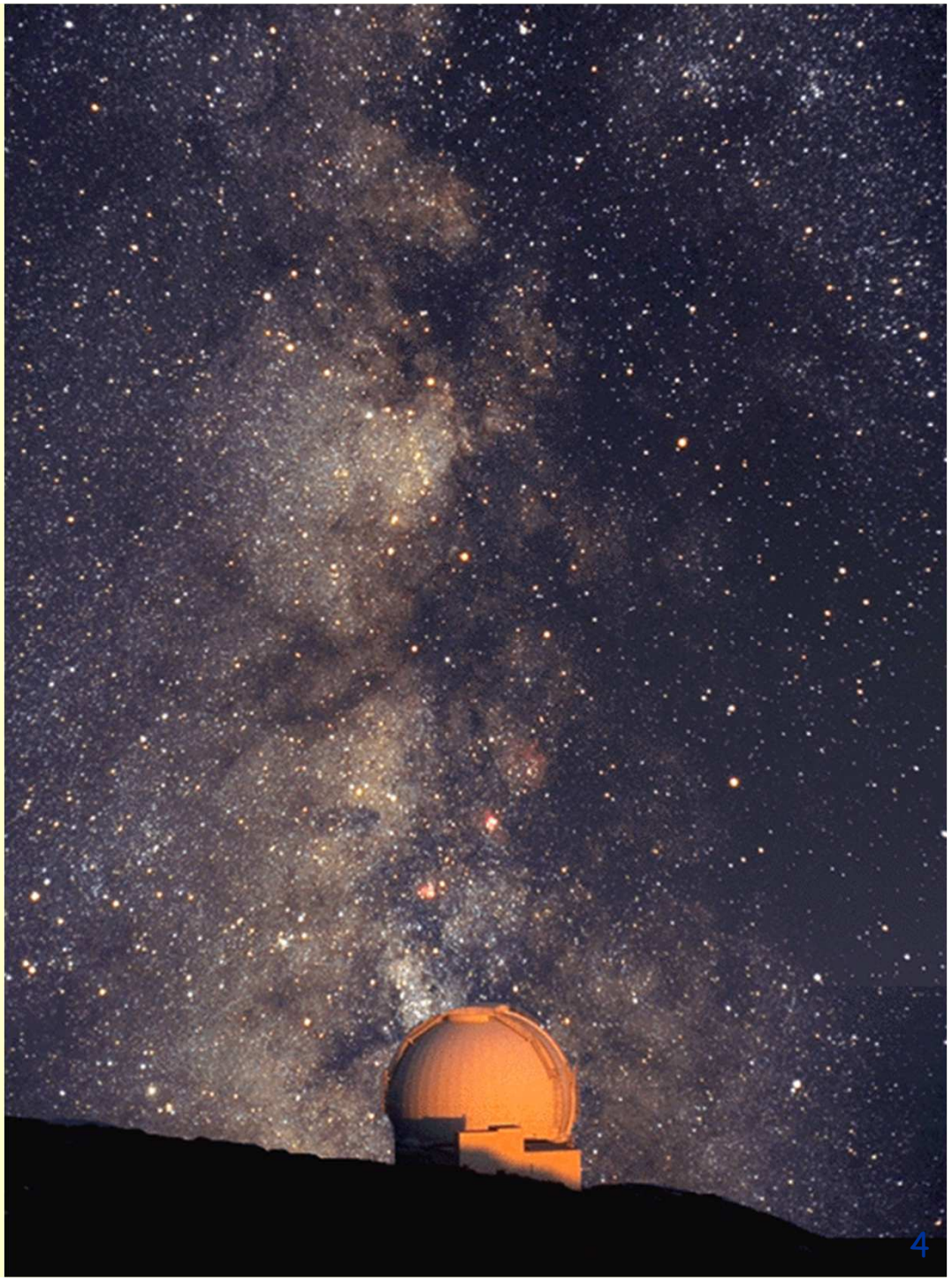
Earth-Sun distance ~ 150 10^6 km ~ 1 AU

The known universe: the Milky Way

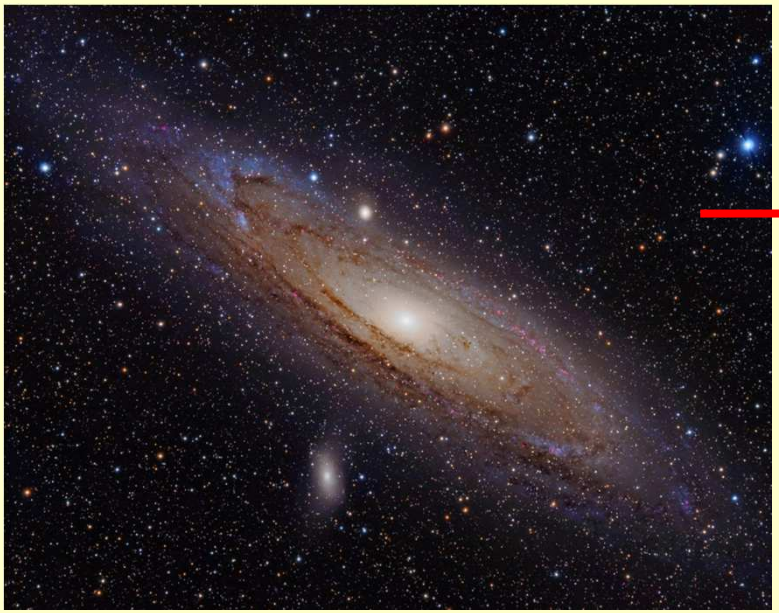
- Barred spiral galaxy (200-400 billion stars)

- Distances:
  ∅ ~100,000 ly ~ 30kpc
  Sun-Gal. center ~ 10kpc

note:
1ly=63,240 AU 1pc=3.26 ly

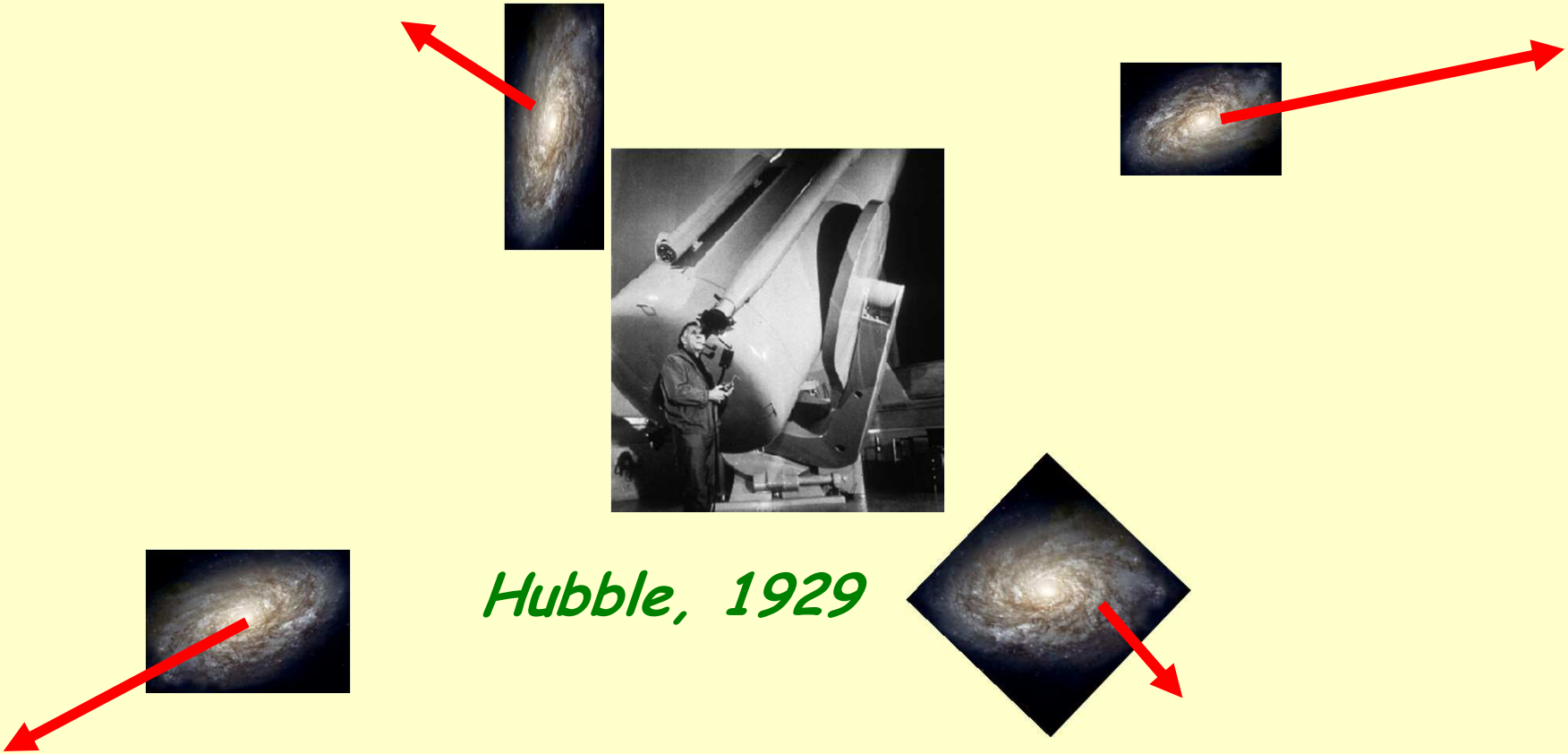


The known universe: galaxies



- Andromeda Galaxy (spiral)
- distance from Earth:
  2.5 10^6 ly or 778 kpc

The rise of modern cosmology

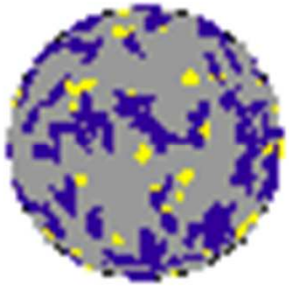


Hubble, 1929

distant galaxies are receding : the Universe is in expansion

(as predicted in General Relativity by A.Friedmann 1922 and G.Lemaître 1927)

The expanding Universe



note: 1Mpc=3,3 10^6 ly

Hubble's law

Velocity = H(t) x distance

$$H_0 \equiv H(t_{today}) = 74 km/s/Mpc$$

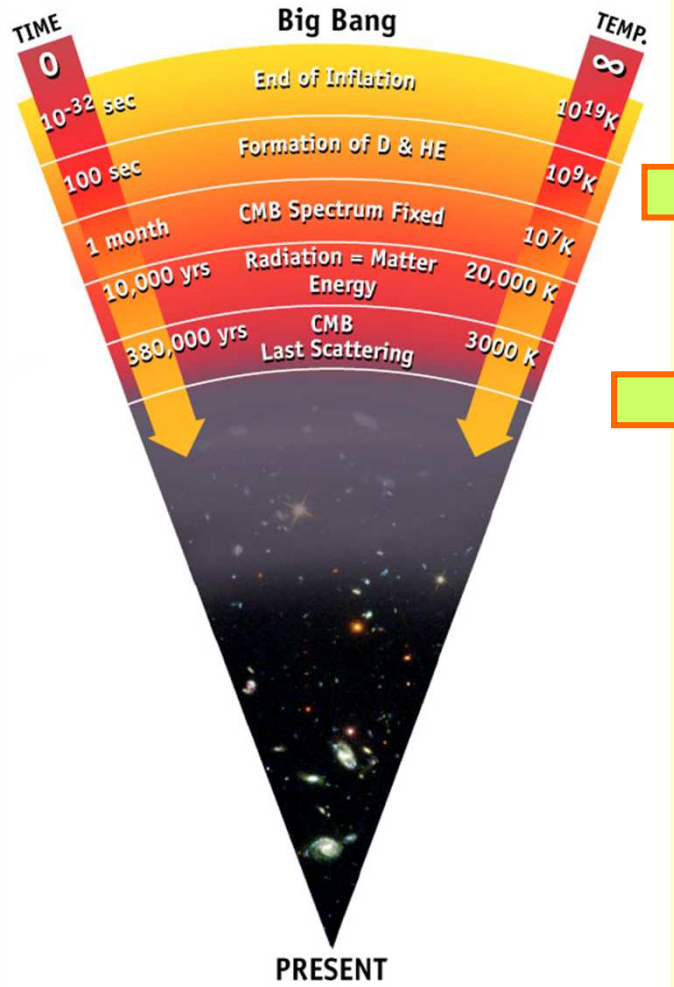
light is redshifted (increased in λ)

$$\frac{\lambda_{observed}}{\lambda_{emitted}} \equiv 1+z = \frac{a(t_{observation})}{a(t_{emission})}$$

a(t) Universe scale factor

More confirmations of the Big Bang model

Initial dense and hot phase followed by expansion



13,7 billions of years after Big Bang

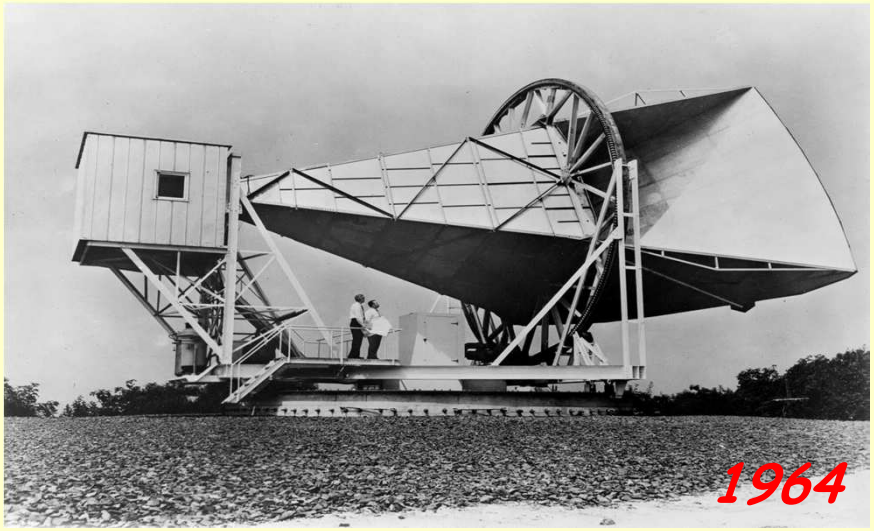
Primordial nucleosynthesis (He, D): T~1MeV
predicted light element abundances = data

$$\frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 10^{-10}$$

1948: G.Gamow, R.Alpher

Matter-radiation decoupling: z~1100 T~3000K
Cosmic Microwave Background, relic radiation
predicted and observed (T~2.725K 1992)

1948: G.Gamow, R.Alpher, R.Herman
1964: A.Penzias, R.Wilson

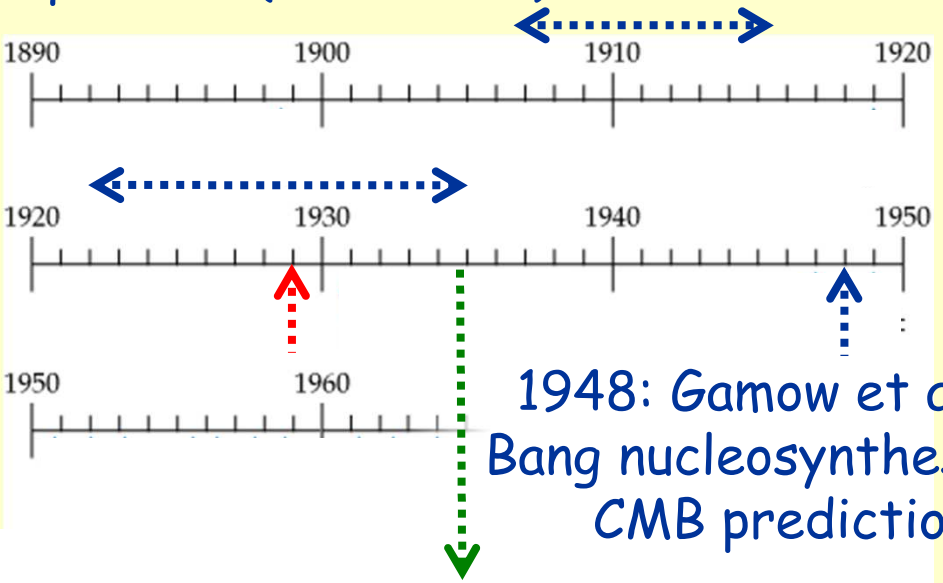


The rise of the Big Bang cosmology model

General Relativity, Einstein's equations (1907-1915)

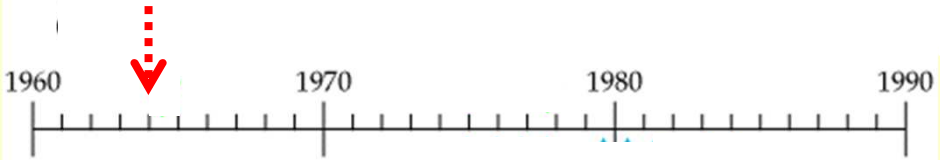
1922-1935 FLRW solutions
(expanding, homogeneous and isotropic Universe)

1929 Hubble's law

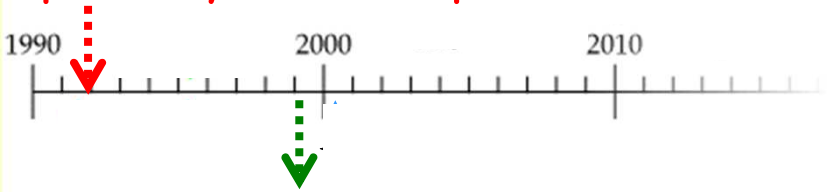


1948: Gamow et al: Big Bang nucleosynthesis and CMB predictions

CMB detection



CMB primary anisotropies



1934: 'missing mass' in galaxy rotation curves→ dark matter postulated (F.Zwicky)

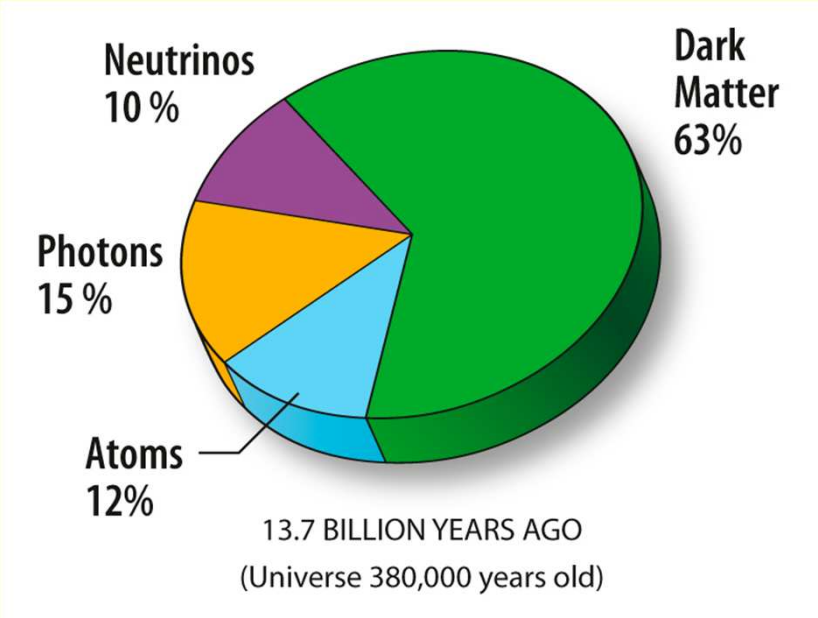
Accelerated expansion: dark energy ?

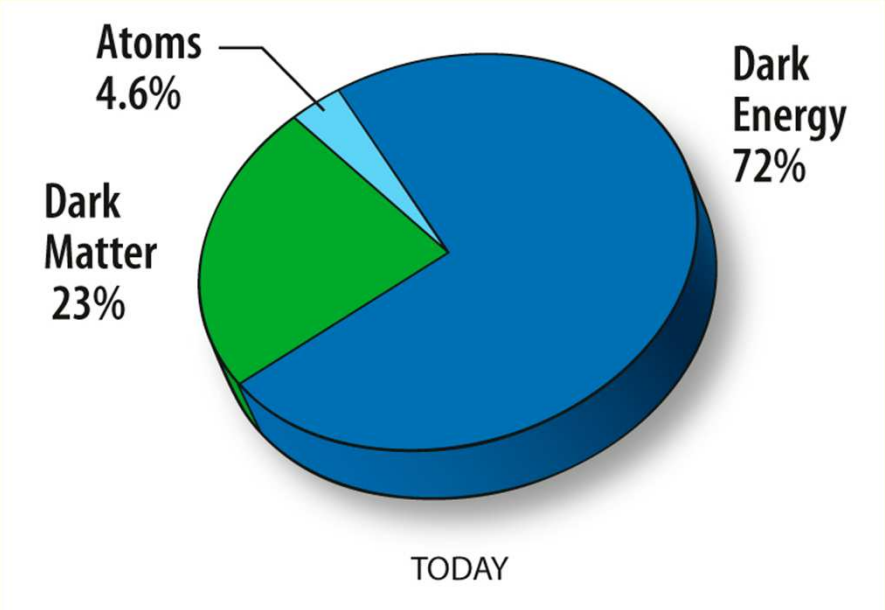
The ingredients of the Big Bang cosmology model

- initial phase: dense and hot, then expansion
- isotropic and homogeneous Universe
- general relativity

Big Bang cosmology model+ **many** cosmological data

⇒ energy balance of the Universe





Particle astrophysics

- Measured HE cosmic particle fluxes
- Composition of the Universe ?
- Origin of cosmic particles ?

messengers: charged cosmic rays, γ-rays, ν's, gravitational waves

Dark matter search

- Evidence for missing mass
- Particles ? Compact objects ? Modified Newtonian dynamics ?

indirect search: γ-ray & ν astronomy
direct search: dedicated specific exp.

Main topics in cosmology and particle astrophysics

Energy balance of the Universe

- Evidence for accelerated expansion
- Modified gravity ? Dark energy ?

probes: CMB, SNe Ia, baryonic acoustic oscillations, clusters

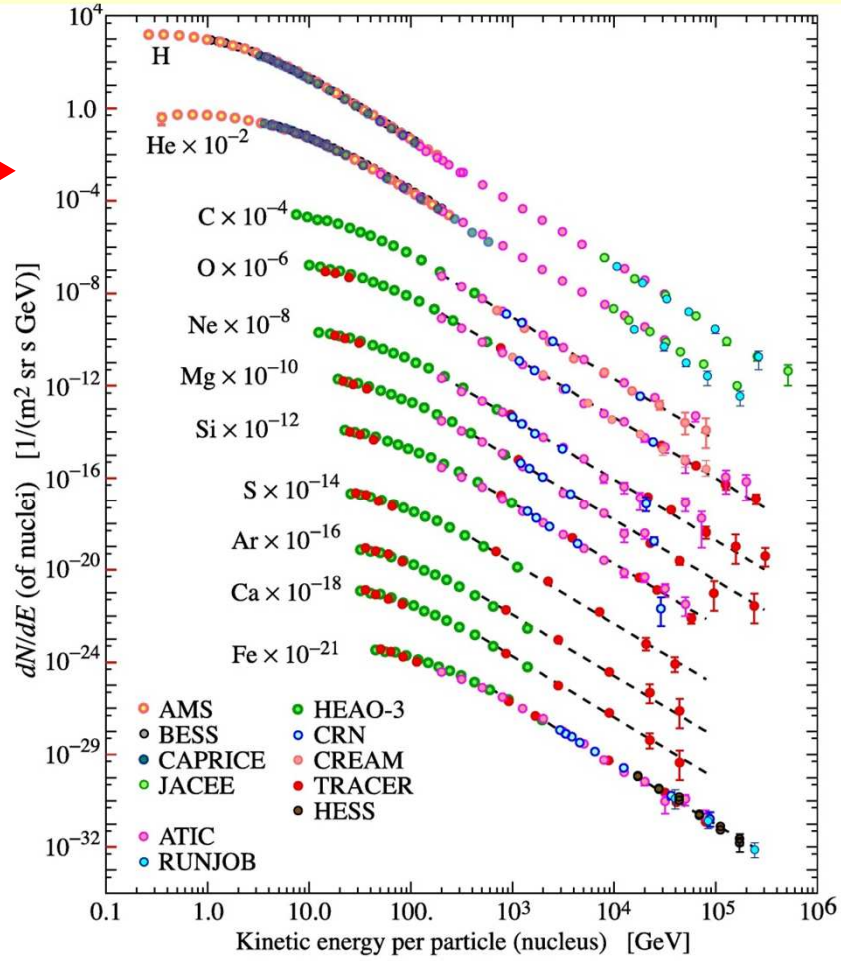
Large scale structures

- Measured galaxy distributions
- Formation of large structures ?

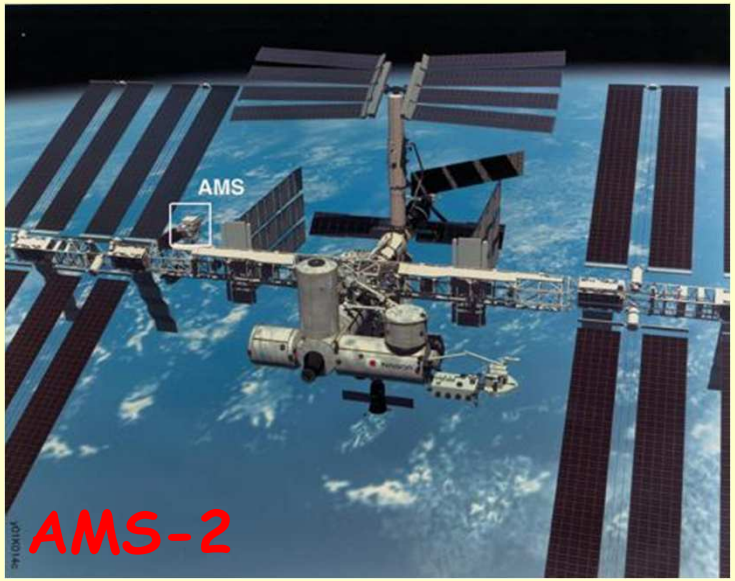
Galaxy surveys, weak lensing, numerical simulations

Particle content of the Universe

- Primary particles:
  - cosmic rays = stable charged particles
  - neutrons, neutrinos & γ rays
- Detectors:
  - satellites, high-flying balloons
  - ground and underground detectors
- Interest:
  - composition of the Universe
  - multi-messenger studies of astrophysical sources
  - production, acceleration and propagation processes

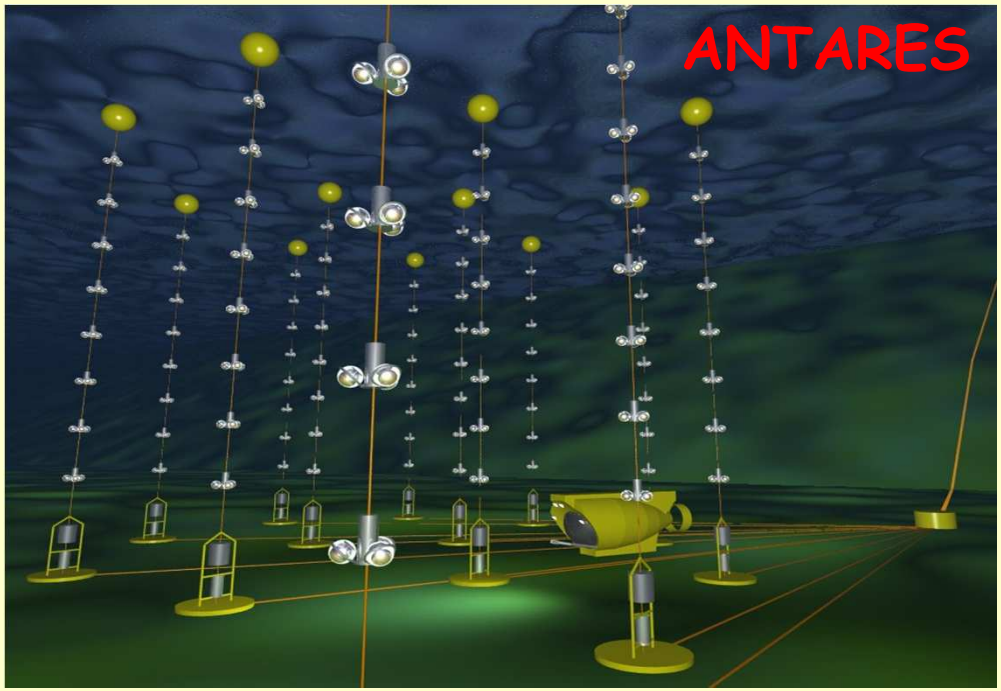


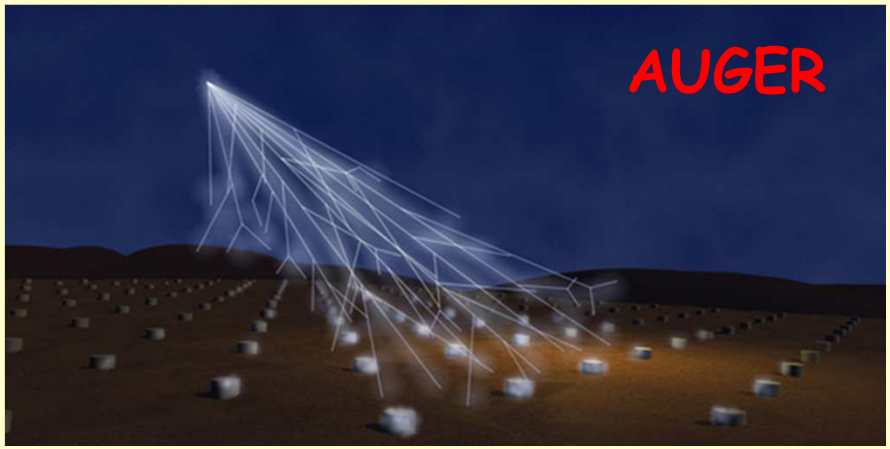
- Link with particle physics: matter-antimatter asymmetry, neutrino oscillations, new exotic particles & detection technics

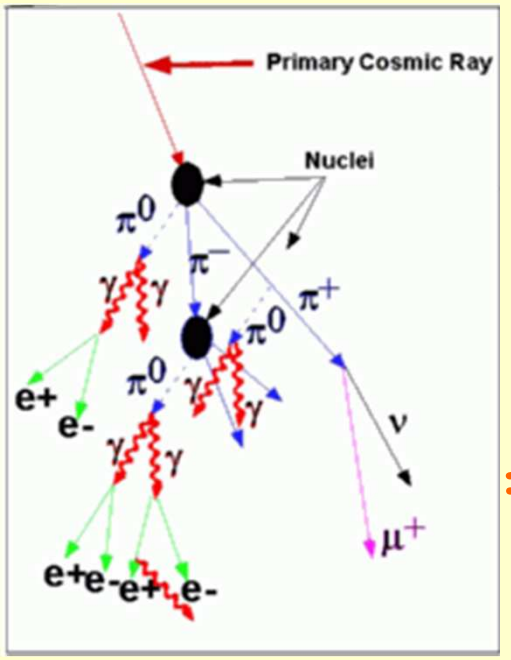


- **Anti Matter Spectrometer**
  - a particle physics detector in space
  - search for primary anti-matter
  - sensitive to exotic particles and dark matter
  - launched may 2011

- **ANTARES (ν)**
  - an underwater Cherenkov detector
  - search for neutrinos from astrophysical sources
  - neutrino oscillations, dark matter
  - taking data since 2007

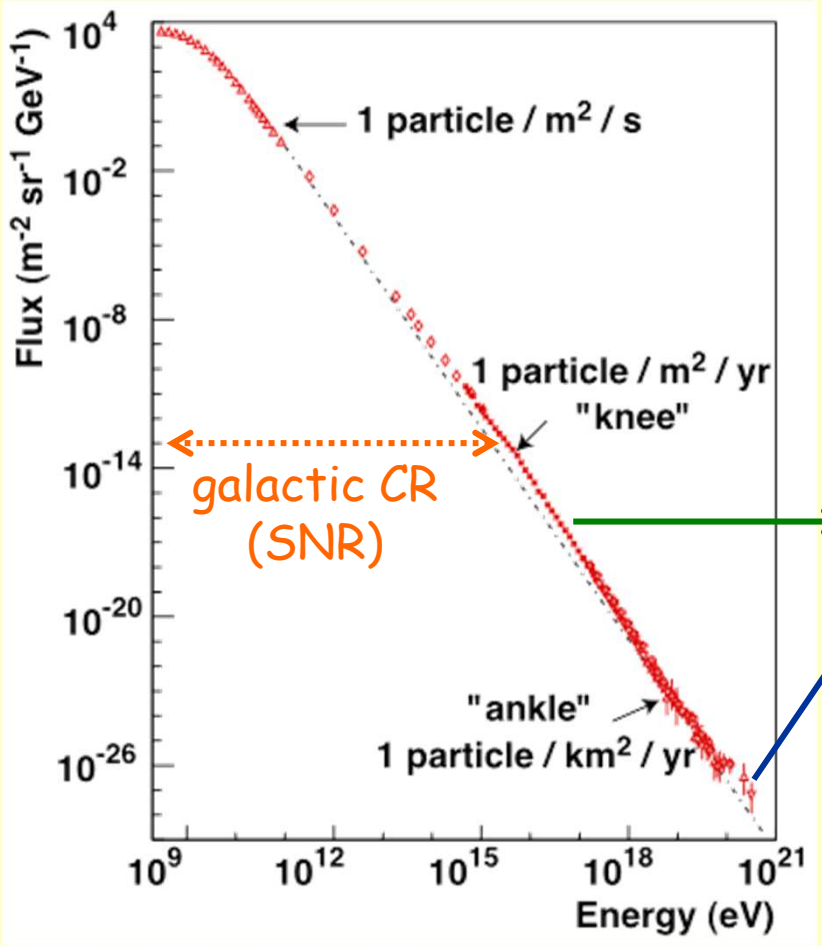






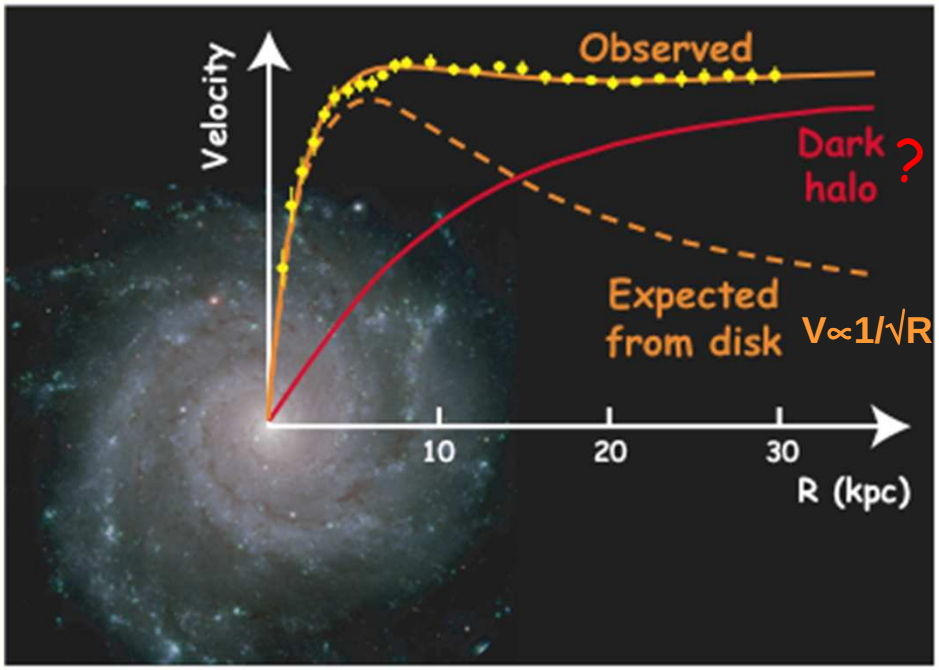
cascade of secondary particles

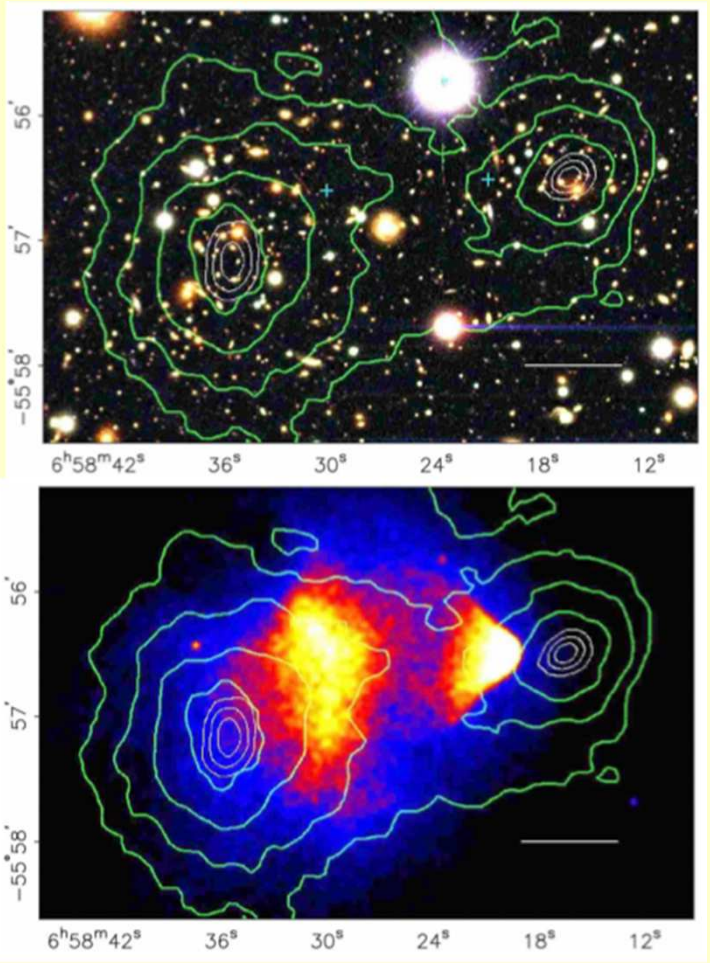
= air shower



- **Pierre Auger observatory (CR)**
  - hybrid detector
  - study high energy cosmic rays
  - cosmological origin of VHE events ?
  - taking data since 2004

Observational evidence





- Examples (beside cosmology):
  - Rotation curves of spiral galaxies (1959..)
  - Colliding clusters (2006)

dark matter (baryonic or new particles)
or modified Newtonian dynamics ?

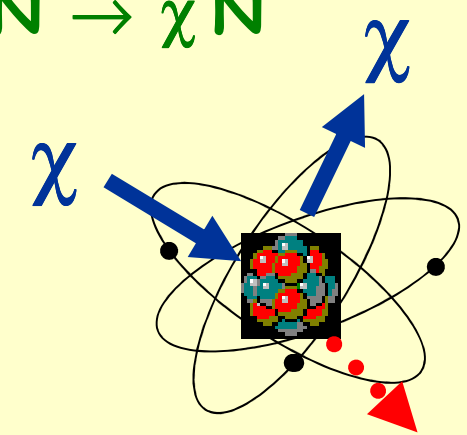
still an open question !

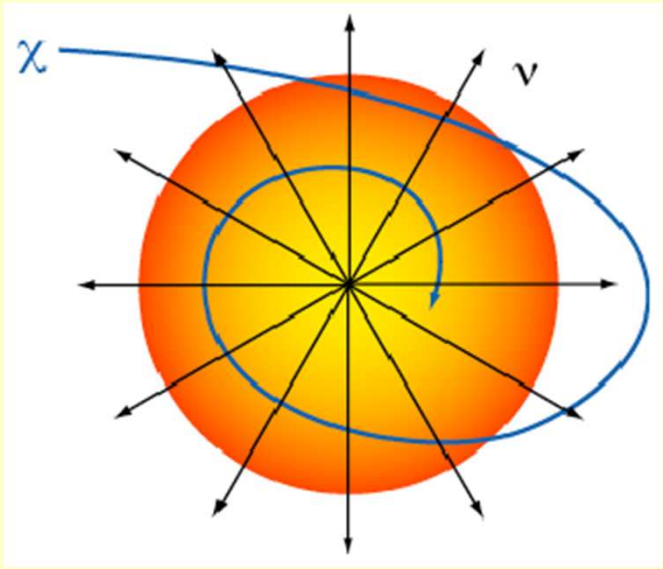
Search for non-baryonic dark matter

- **Direct search**: detect nuclear recoil in cryogenic detectors

  $10\text{GeV} < m_\chi < 1\text{TeV}$

$\chi N \rightarrow \chi N$





- **Indirect search**: gravitational capture and co-annihilation

$\chi\chi \rightarrow \gamma\gamma$ γ–ray astronomy

$100\text{GeV} < m_\chi < 10\text{TeV}$

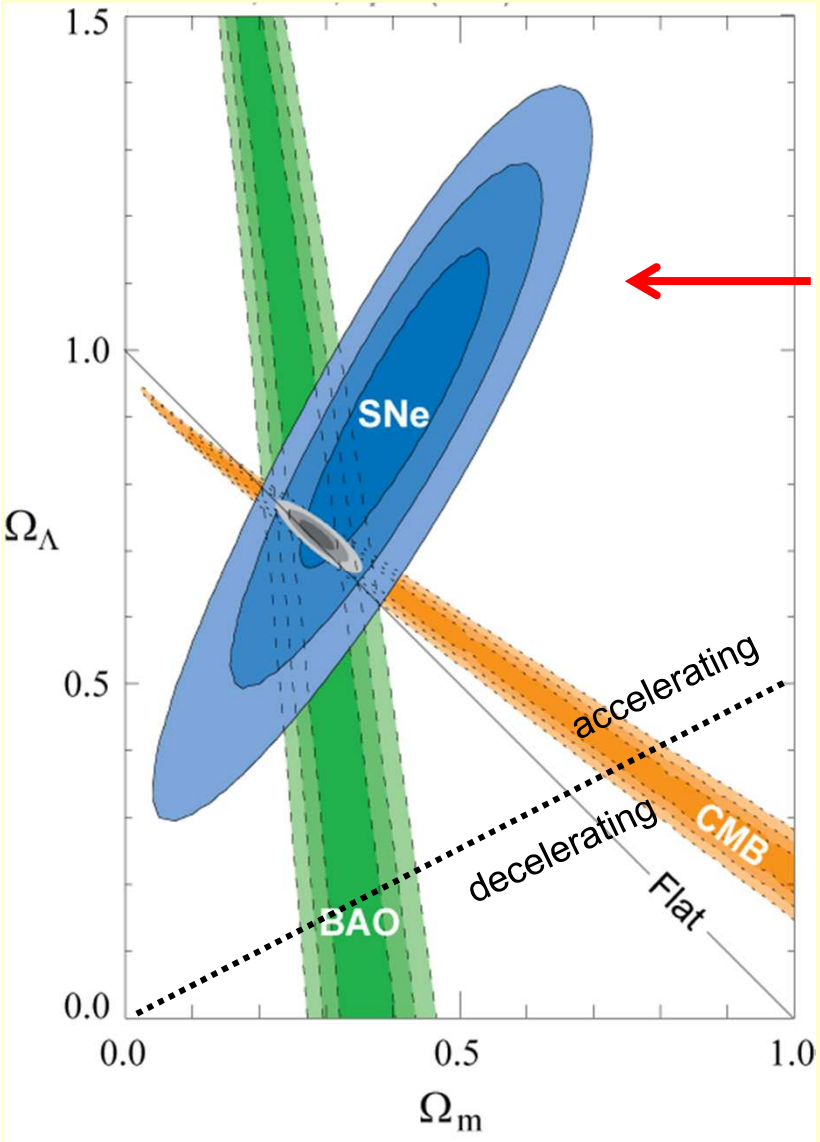
$\chi\chi \rightarrow \nu + X$ ν telescopes

$100\text{GeV} < m_\chi < 3\text{TeV}$

- Complementary to exotic particle searches **at the LHC** ($100\text{GeV} < m_\chi < 3\text{TeV}$)

No undisputed signal so far, stay tuned !

Cosmological data



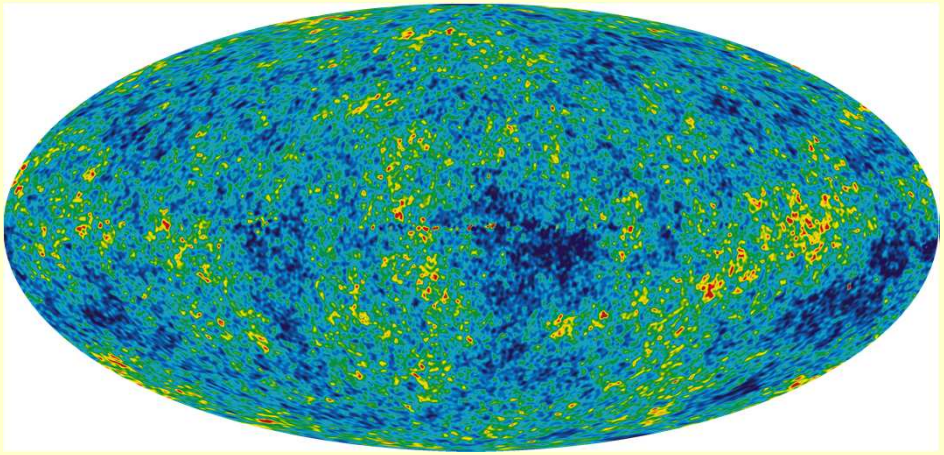
- 1999: SNe Ia dimmer than expected ⇒ more distant ?
- Since then: accelerated expansion confirmed

$$\Omega_m = 0.27 \quad \Omega_\Lambda = 0.73$$

a new fundamental constant
(cosmological constant ↔ vacuum energy)
or dark energy ?
or modified general relativity ?

- Link with particle physics: scalar field theories

Observational facts



WMAP (2008), all foregrounds subtracted

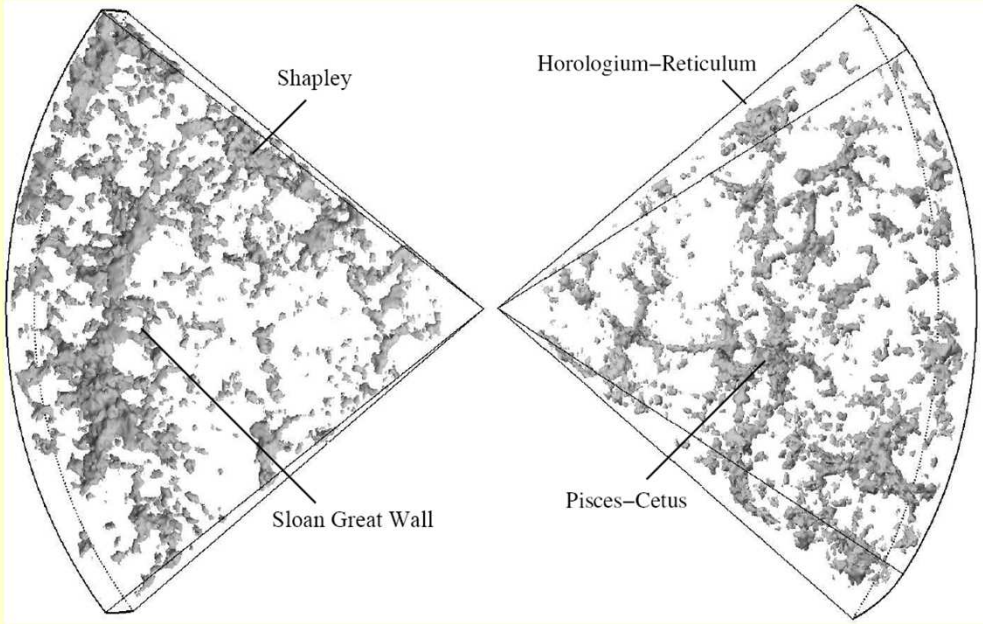
- CMB: very small anisotropies

$$\Delta T/T = 10^{-5}$$

- matter density inhomogeneities,

amplified by gravitation after decoupling → structures

- Large scale structures today: galaxies, clusters, superclusters, voids and filaments
- Formation of structures: cold dark matter mandatory !

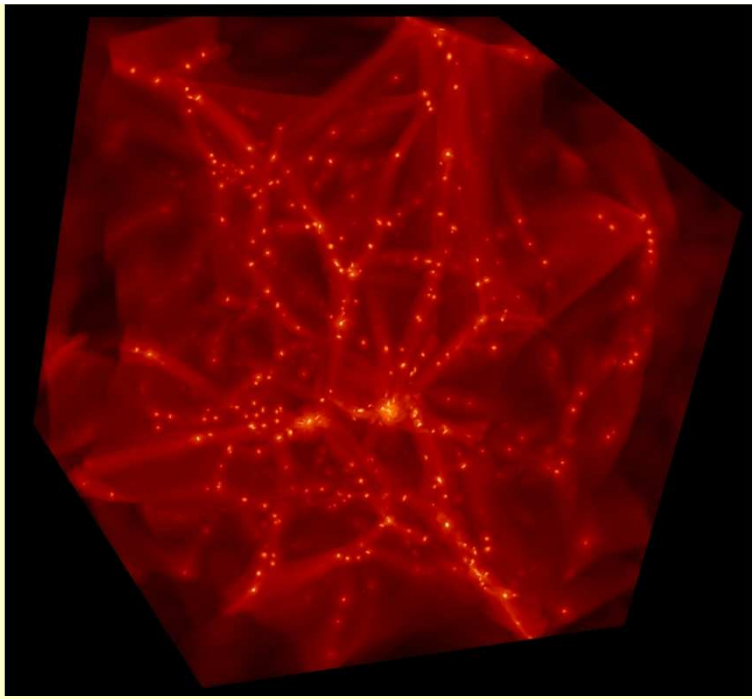


2dF Galaxy Redshift Survey, (2007)

Structure formation ?

- Numerical simulations of large scale structure formation (down to galaxy dense haloes) from cold dark matter :

  voids and filaments (the cosmic web) well reproduced



Present dark matter distribution from simulation

- Interest :
  - better understanding of structure formation (dark matter models)
  - data from galaxy surveys: energy balance of the Universe, tests of general relativity
  - link with particle physics: constraints on neutrinos from cosmology (N_ν, Σm_ν)

Particle astrophysics

Lectures

- Introduction, perspectives and challenges in astroparticle physics
- High energy cosmic ray physics
- Introduction to γ-ray astronomy

Dark matter search

Lecture

- Direct search for cosmological dark matter

Main topics in cosmology and particle astrophysics

Energy balance of the Universe

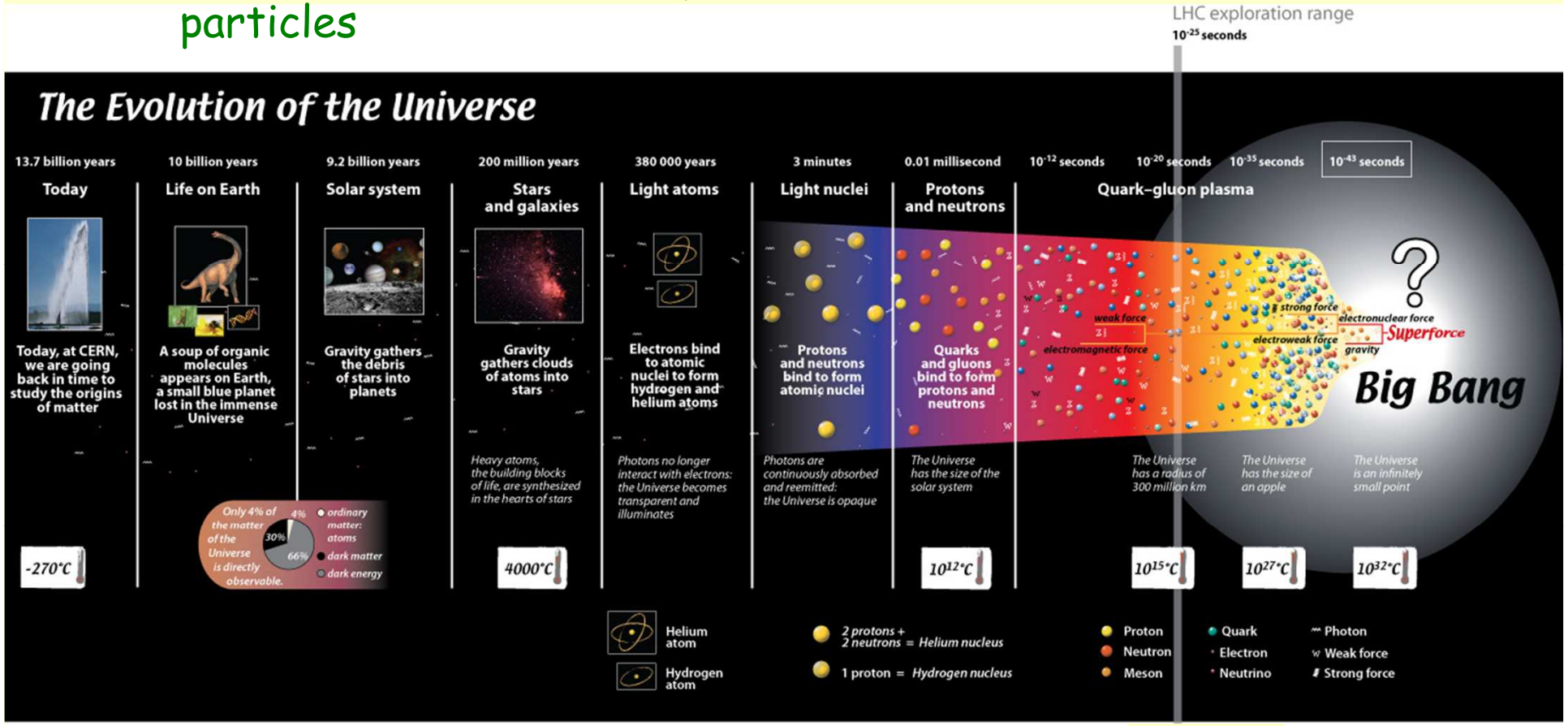
Large scale structures

Lectures

- Dynamics of the Universe and the rise of large scale structures, the cosmological sky
- Alternative to the standard cosmological model

today | 3.10^5 yrs | 3mn | 0.01ms | 10^{-43}s

galaxies, stars, planets, cosmic particles | atoms CMB | nuclei | p, n, mesons… antiparticles ⇓ | particles & antiparticles



Astrophysics, Particle astrophysics & Cosmology

Particle physics

Nuclear physics