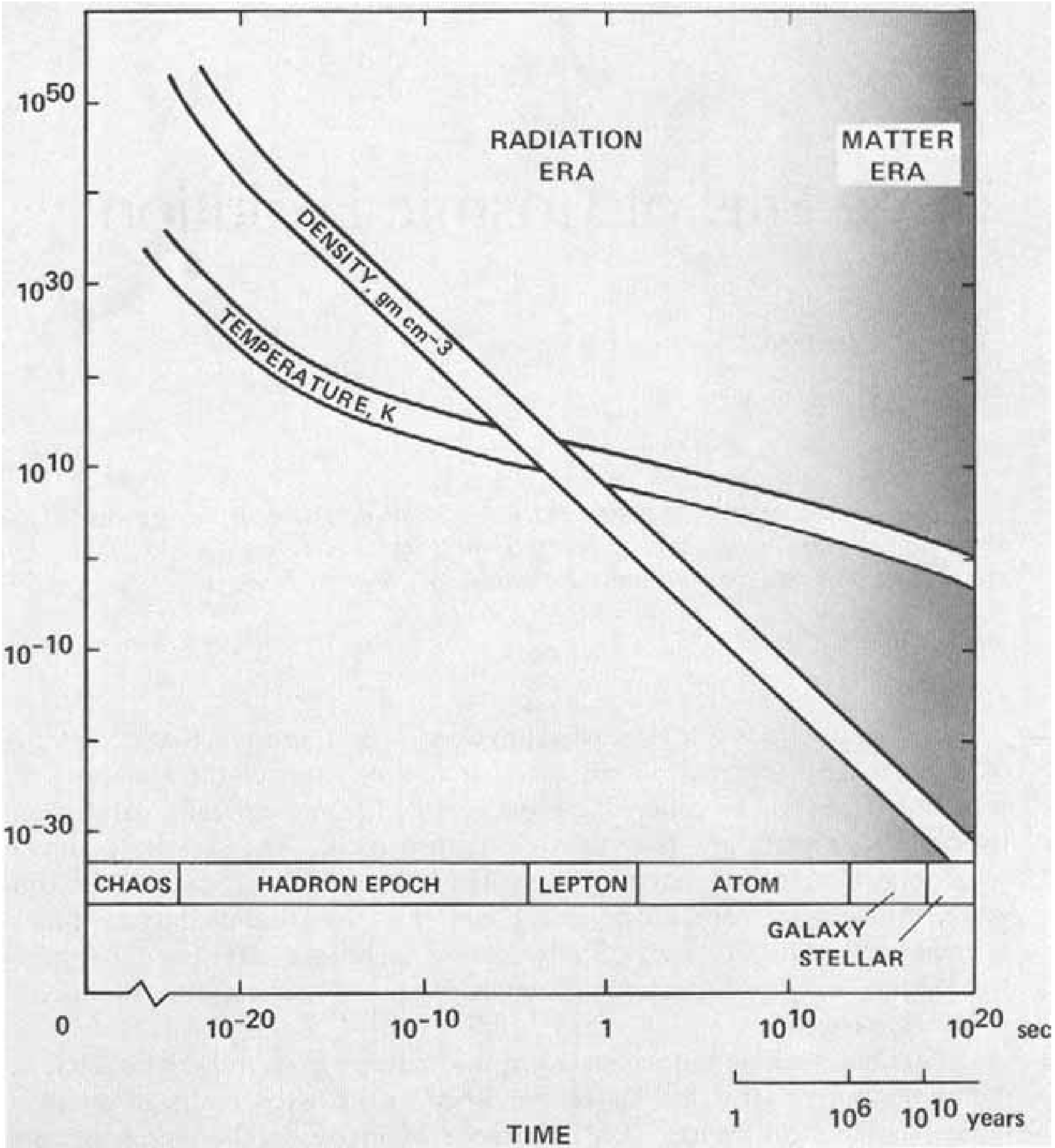
Big Bang

universe began at some point in time

→ based on extrapolating back
the observed Hubble expansion
of galaxies

Is there any other evidence?



smaller in the past

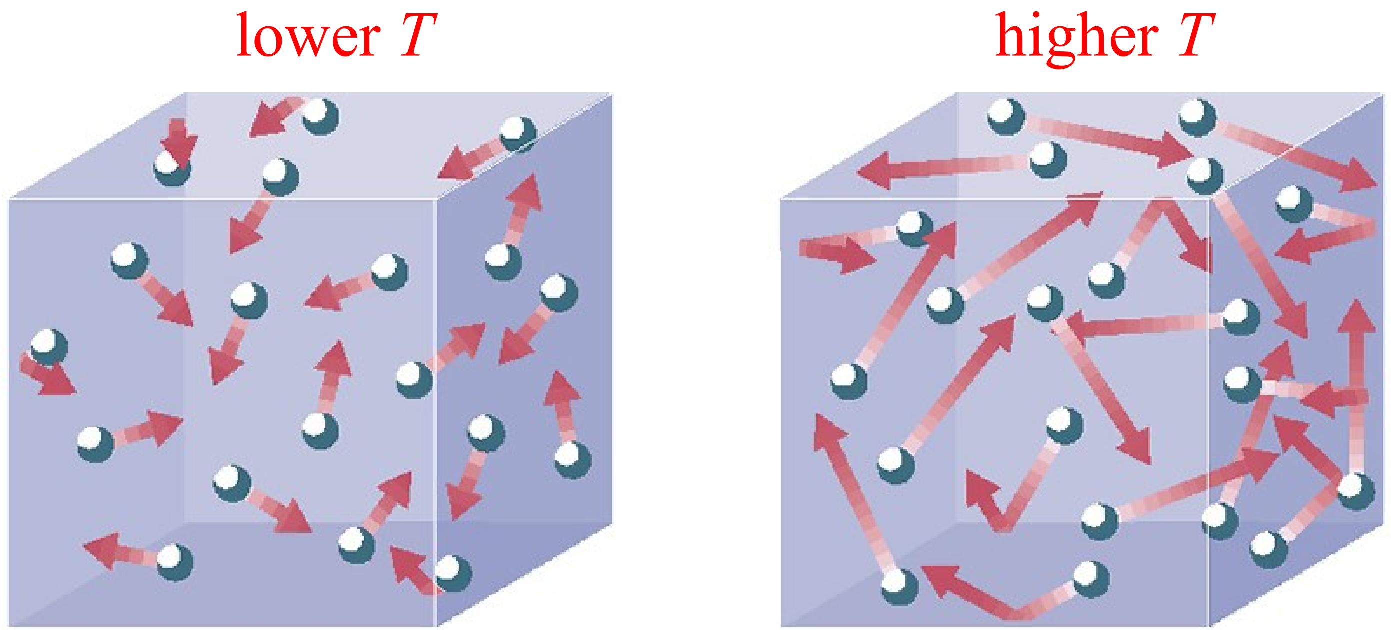
+

roughly the same amount of matter and energy

=

the density of matter and energy must have been higher in the past

universe was hotter in the past



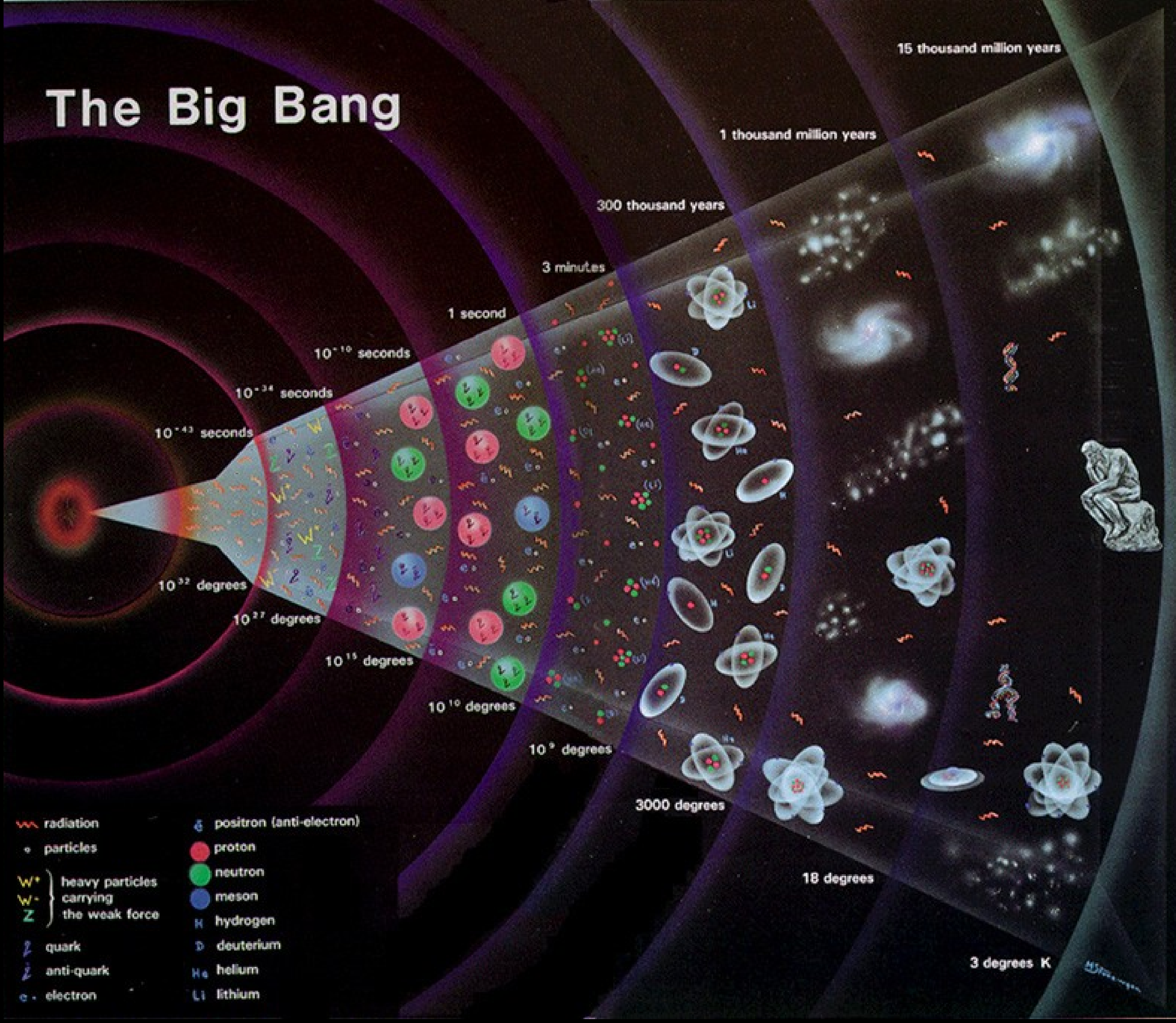
Longer arrows mean higher average speed.

- temperature is proportional to the average kinetic energy per molecule

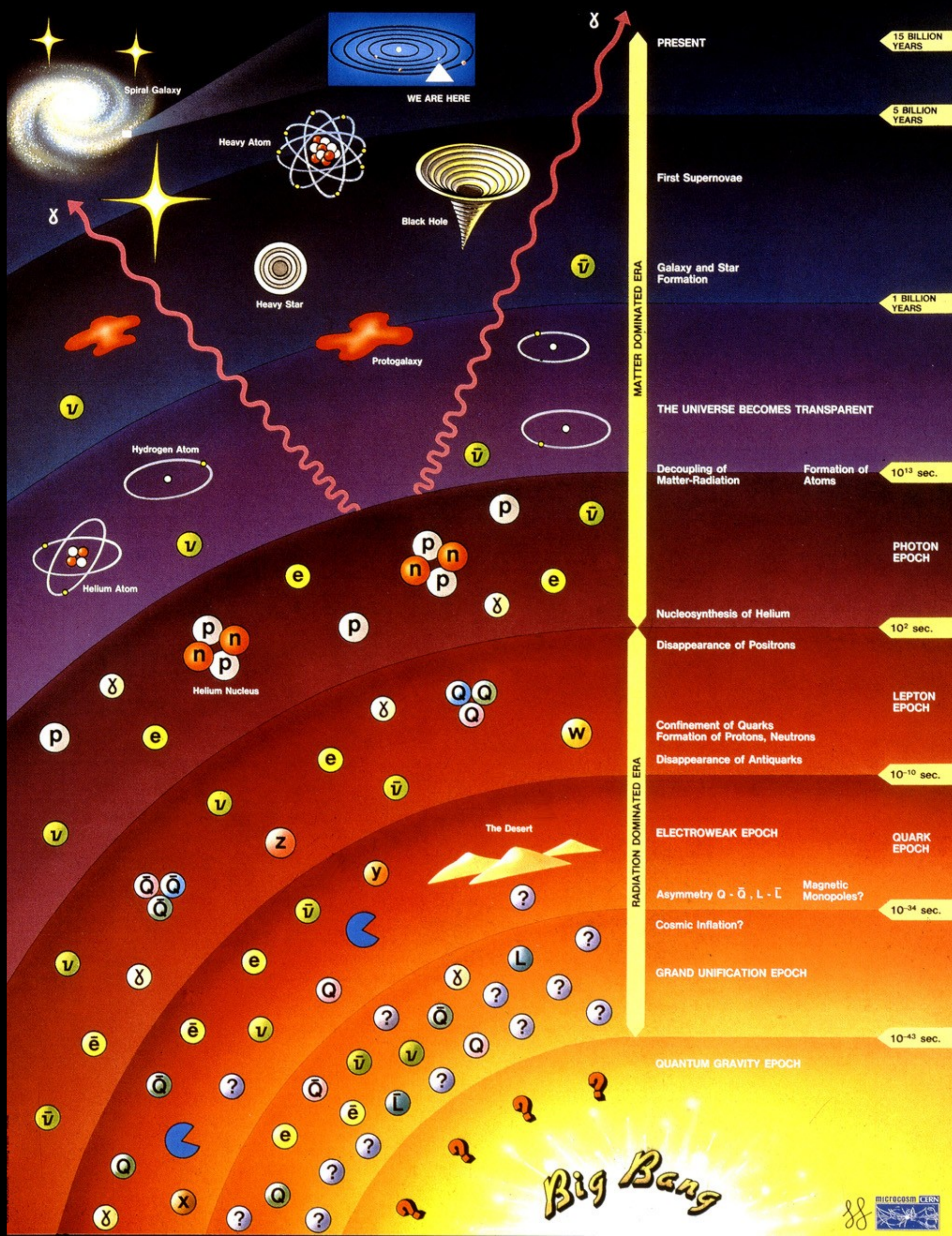
$$E_K = \frac{1}{2}mv^2 = \frac{3}{2}kT$$

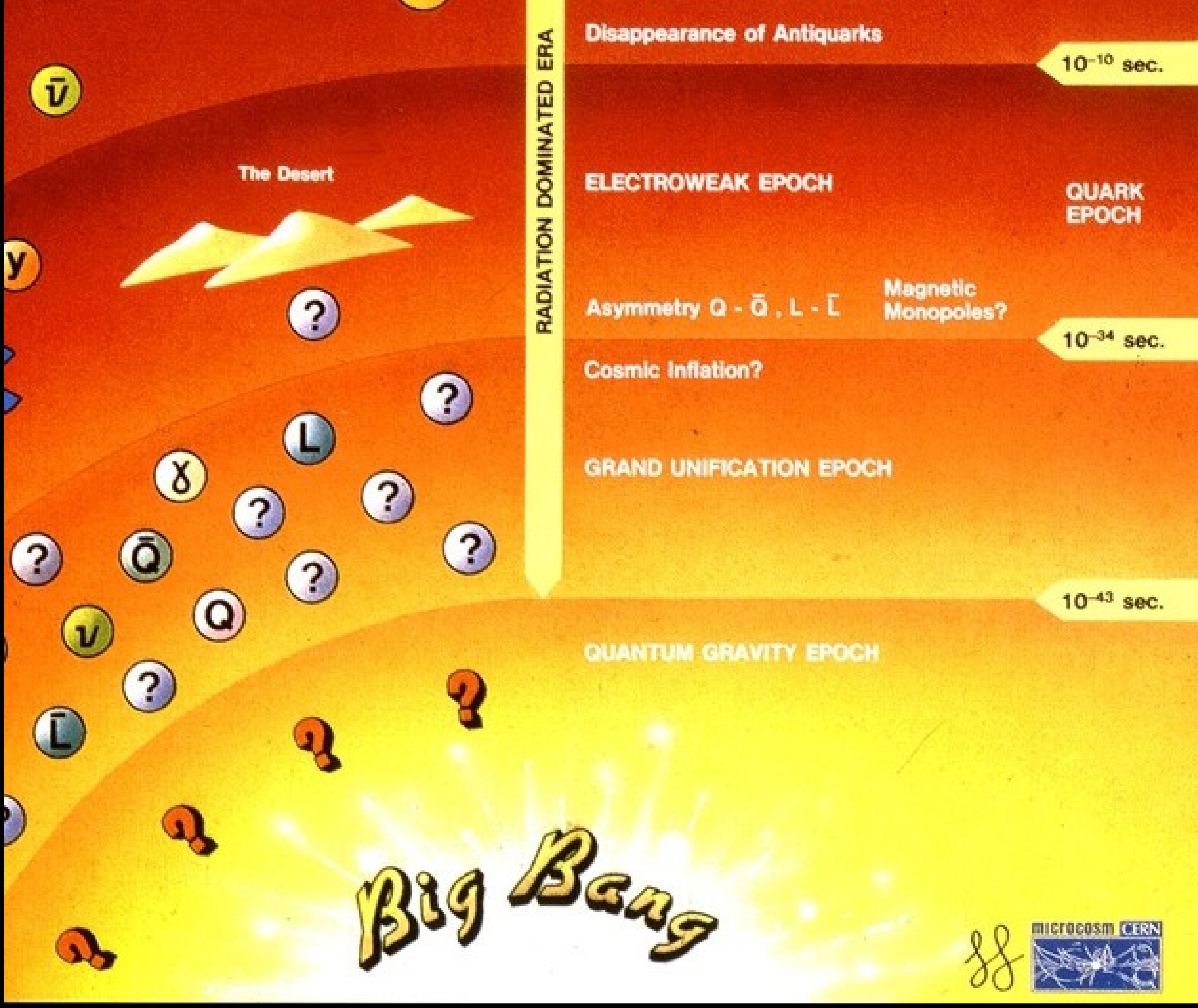
Boltzmann constant

k = 1,4.10^{-23} J/K = 8,6.10^{-5} eV/K

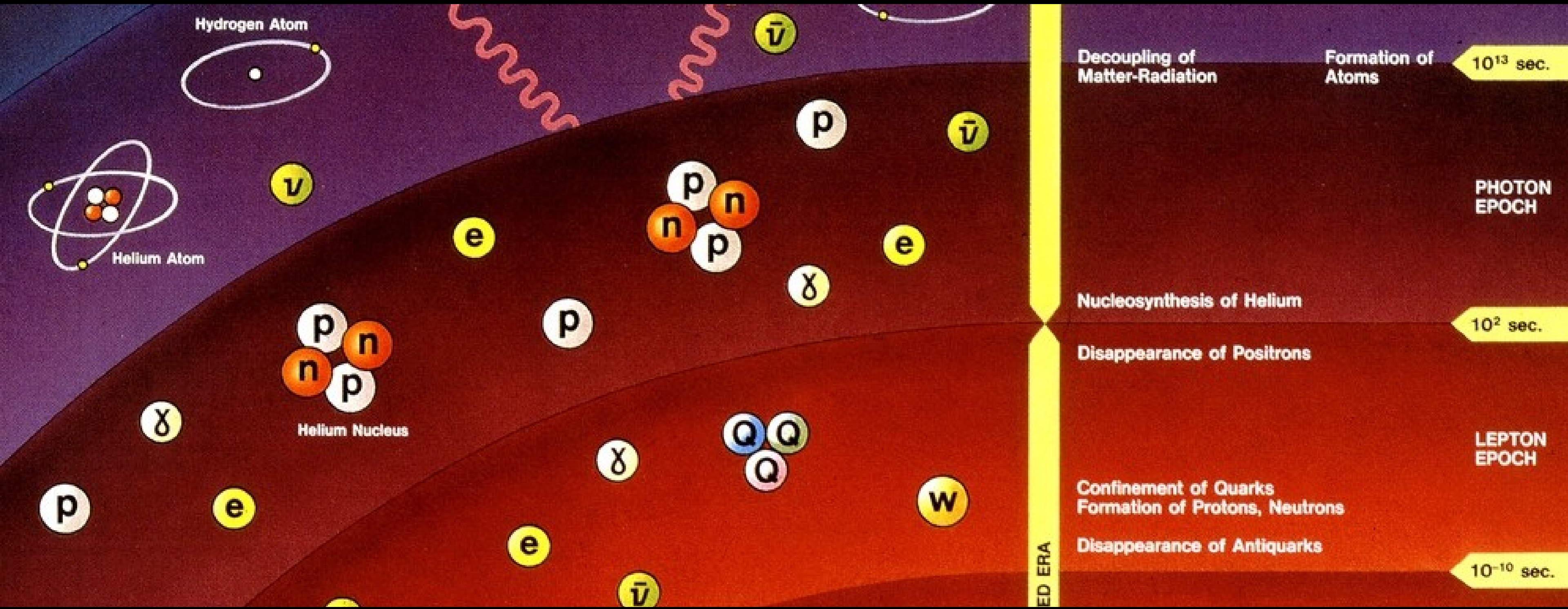

The Big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
3000 degrees
18 degrees
3 degrees K
radiation
particles
W^+ W^- Z heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
H hydrogen
D deuterium
He helium
Li lithium

History of the Universe

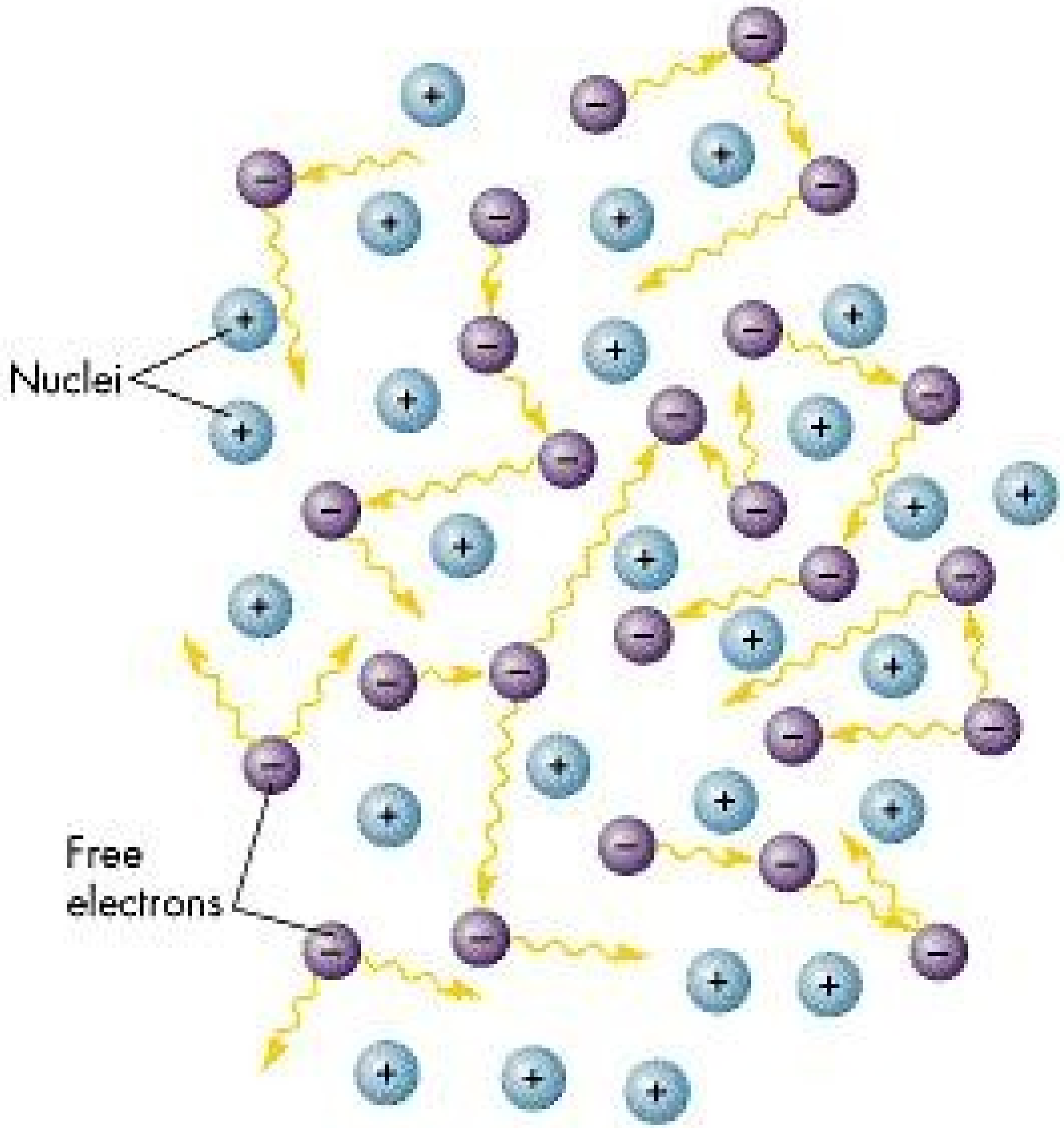


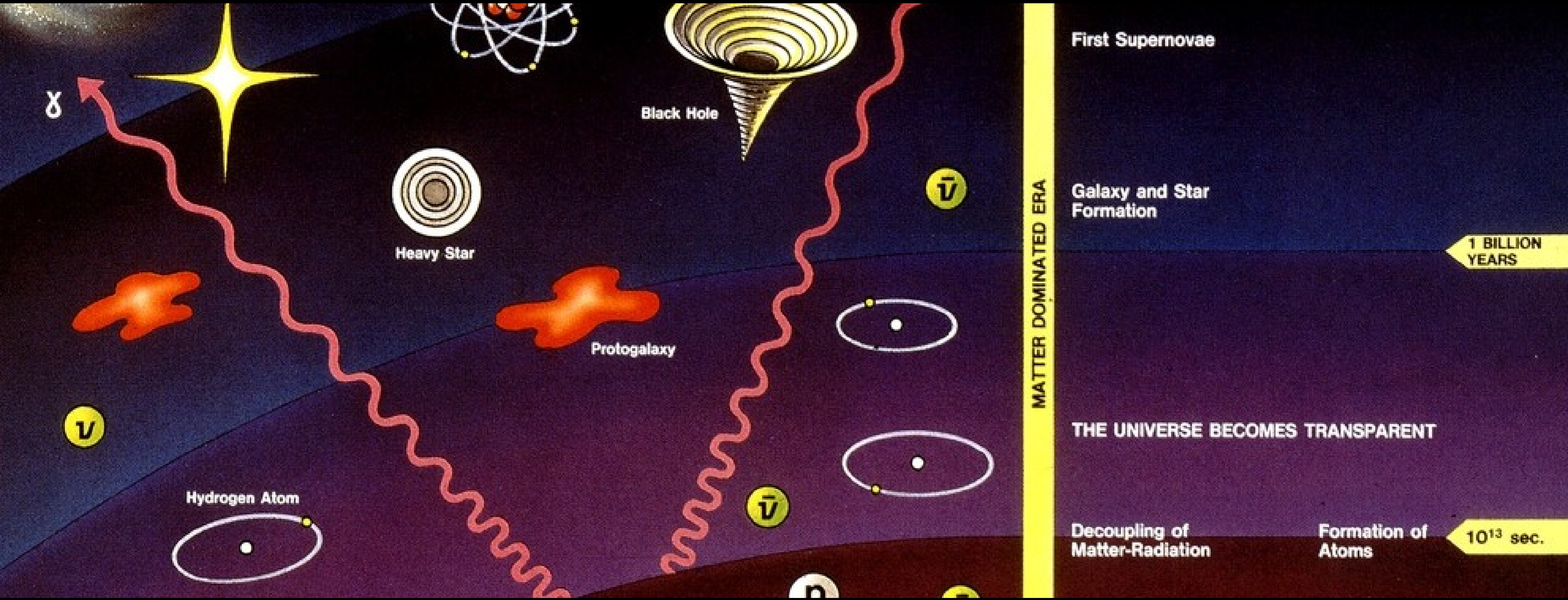


Disappearance of Antiquarks
10⁻¹⁰ sec.
RADIATION DOMINATED ERA
The Desert
ELECTROWEAK EPOCH
QUARK EPOCH
Asymmetry Q - Q̄ , L - L̄
Magnetic Monopoles?
10⁻³⁴ sec.
Cosmic Inflation?
GRAND UNIFICATION EPOCH
10⁻⁴³ sec.
QUANTUM GRAVITY EPOCH
Big Bang
microcosm CERN

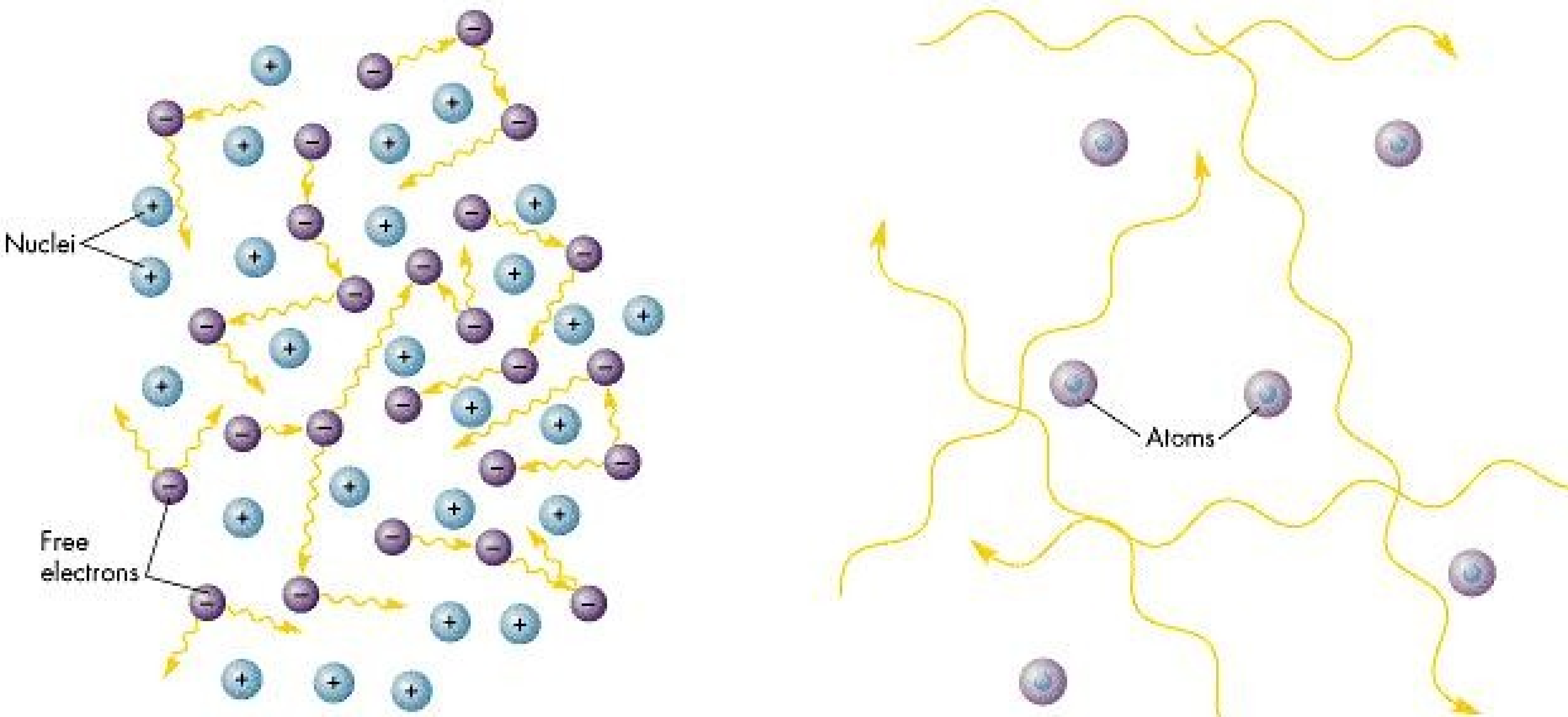


- first protons and neutrons at about 1 sec
- helium nuclei formed at about 100 sec
- observed ratio of helium/hydrogen matches Big Bang prediction
- universe is opaque


Nuclei
Free electrons



- at one million years, electrons combine with nuclei and atoms form
- universe becomes transparent

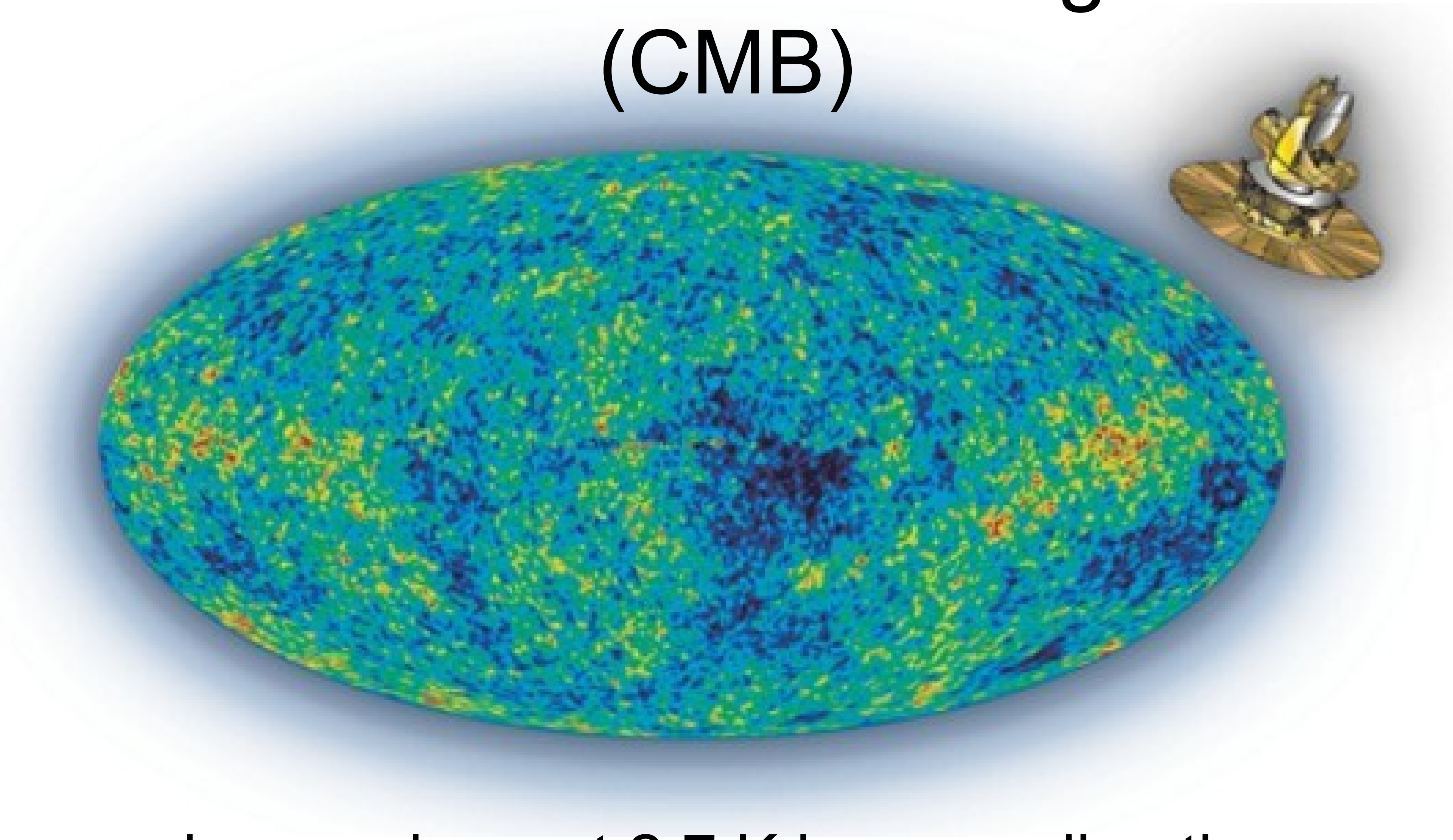


A Before recombination: The universe was opaque

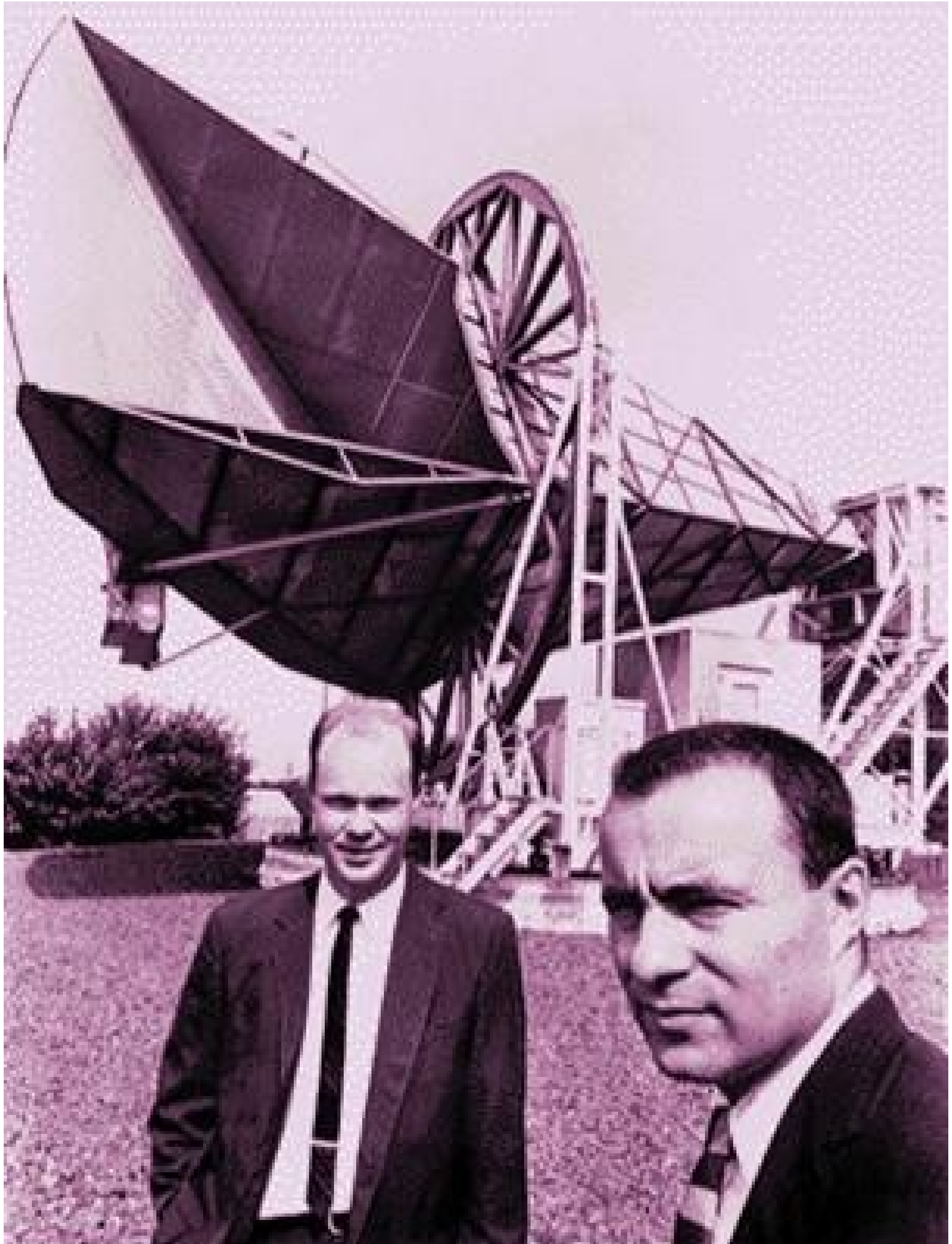
B After recombination: The universe was transparent

transition occurs at around T = 3740 K

cosmic microwave background (CMB)



universe glows at 2,7 K in every direction

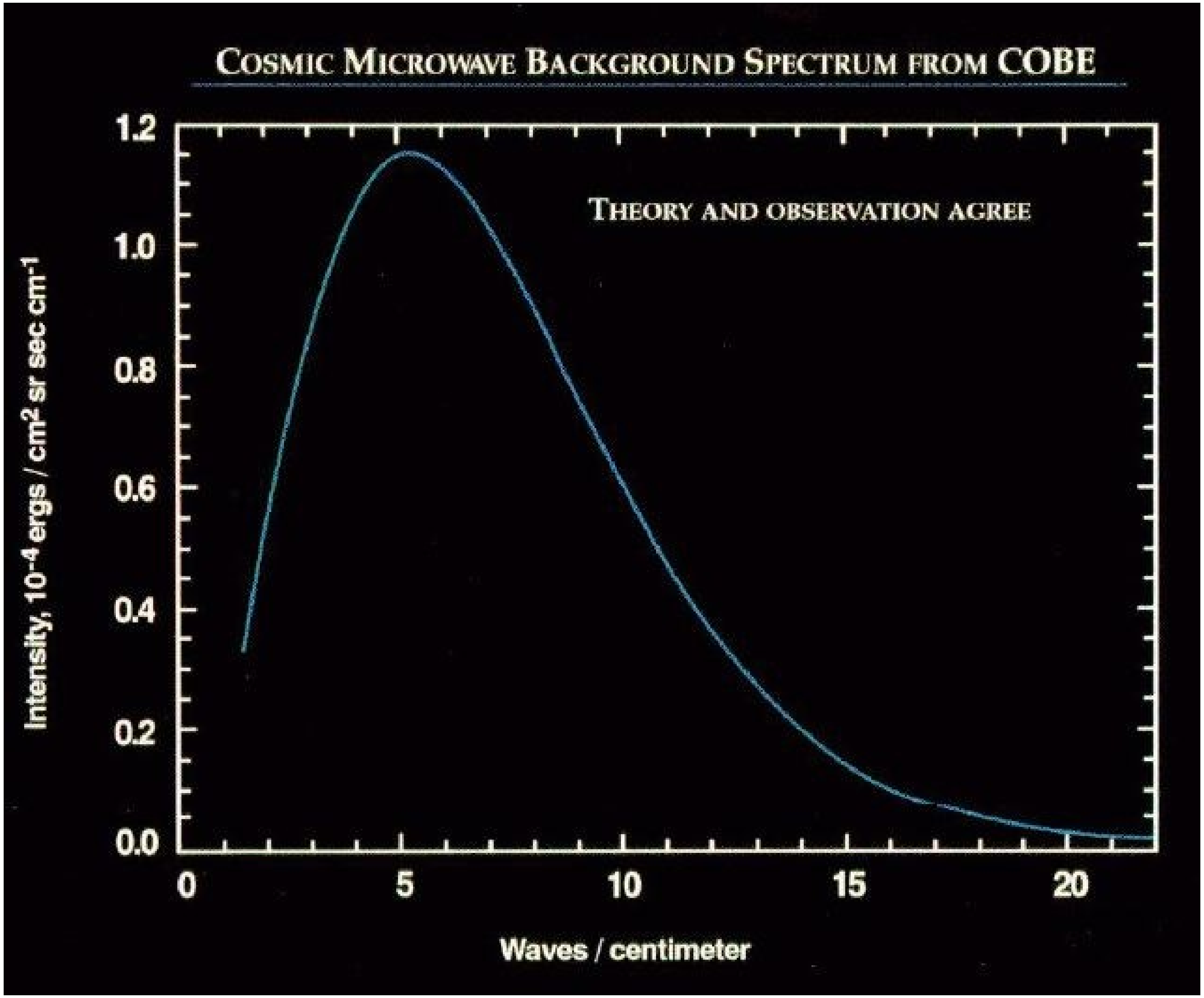


discovered by
Arno Penzias
and Robert Wilson

(1960-65)
AT&T's Bell Labs

finding the source of noise in an antenna used to bounce telephone signals bounced off metallic balloons high in the atmosphere

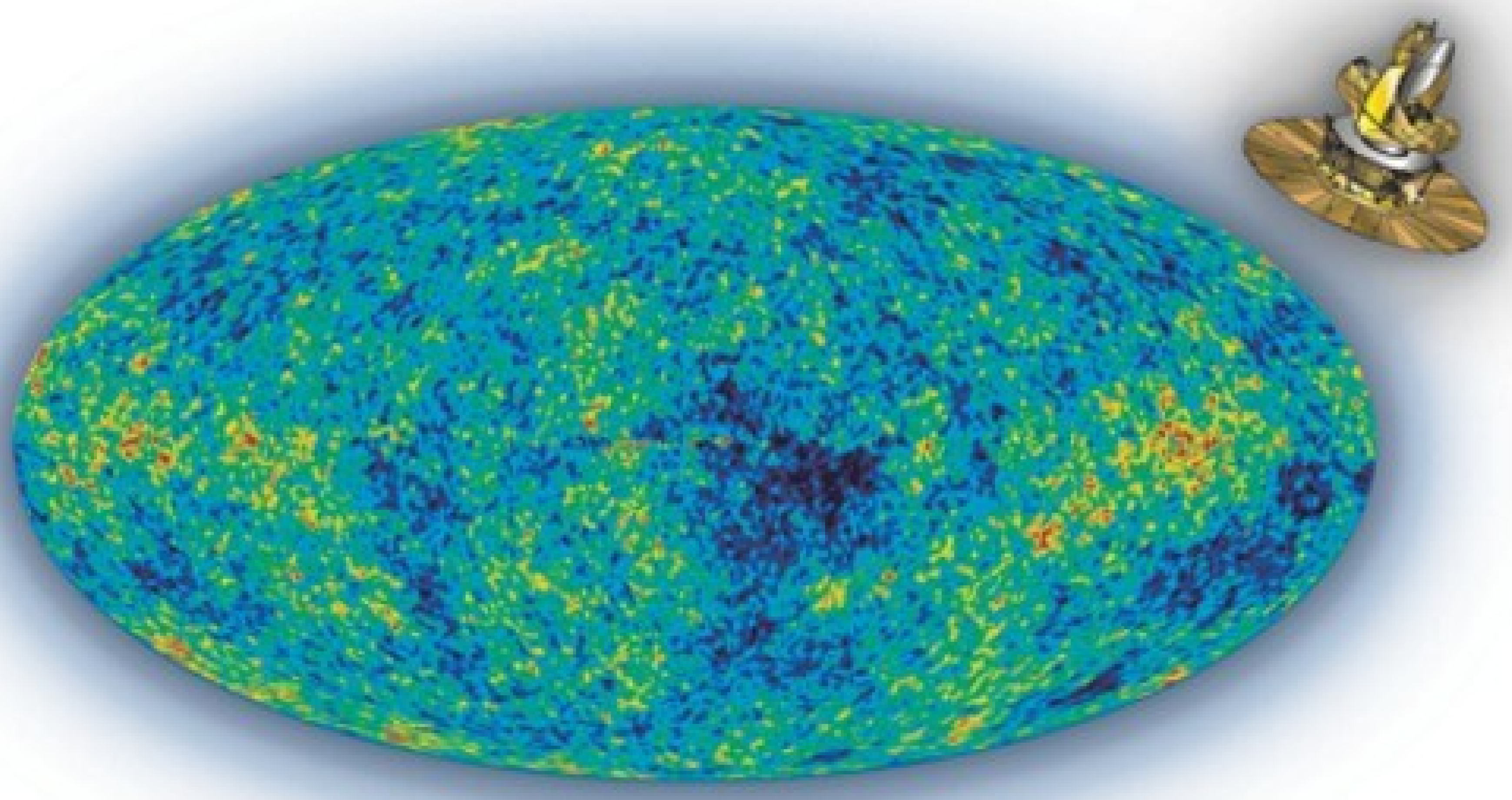
Nobel prize in 1978



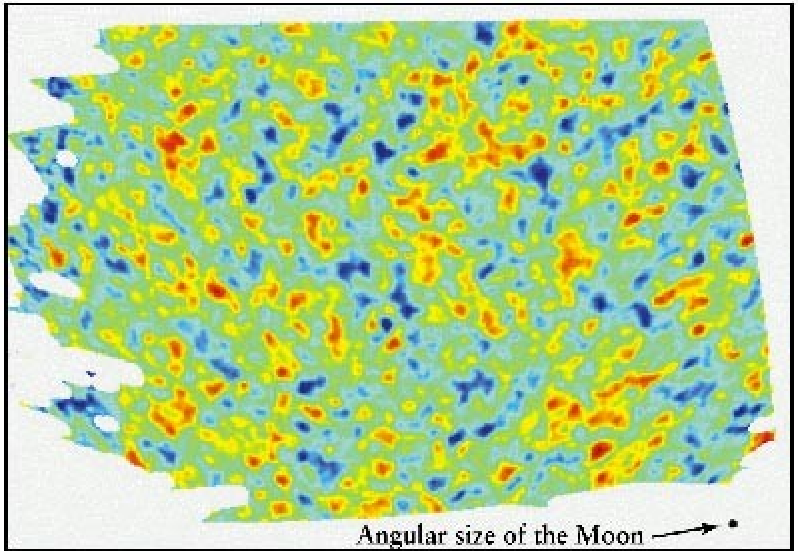
radiation is a blackbody spectrum emitted at 3000 K, red shifted by a factor of 1000

3 parts of evidence for the Big Bang model

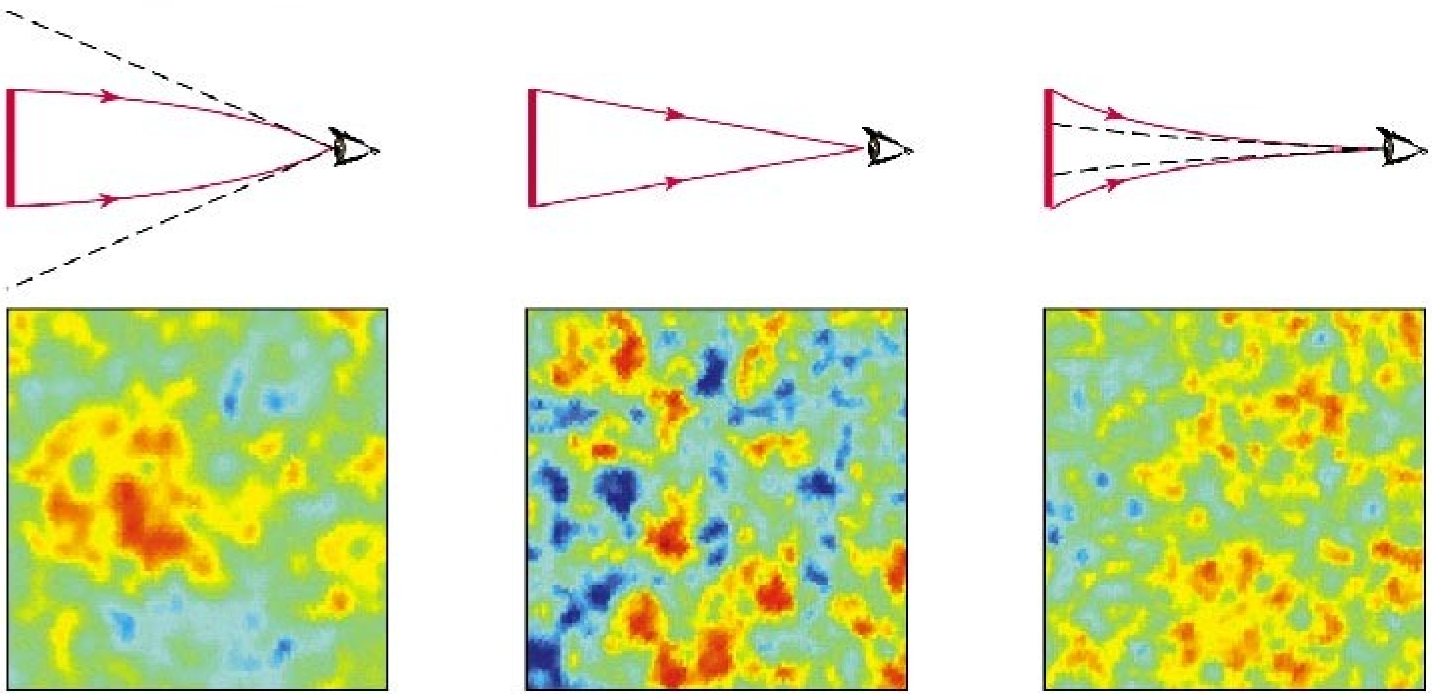
- Hubble expansion: galaxies are moving away from us with speed proportional to distance
- Ratio of Helium vs. Hydrogen in gas clouds unaffected by stars
- CMB:
  a 2.7 K glow seen in all directions



small fluctuations are due to sound waves at recombination



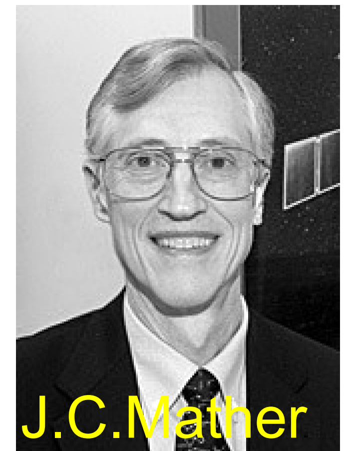
- temperature variations in the CMB are observed to be about 0.0003 K
- expected physical size of the hot/cold regions can be calculated

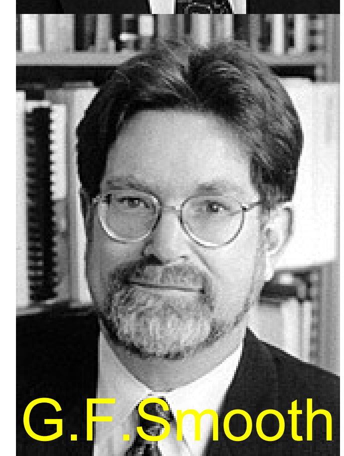


a If universe is closed, "hot spots" appear larger than actual size

b If universe is flat, "hot spots" appear actual size

c If universe is open, "hot spots" appear smaller than actual size





curvature of the universe

determined by the density parameter Ω_0

$$\Omega_0 = \frac{\rho}{\rho_C}$$

$\Omega_0 < 1 \Rightarrow$ negative curvature

$\Omega_0 > 1 \Rightarrow$ positive curvature

measurement of CMB fluctuations gives

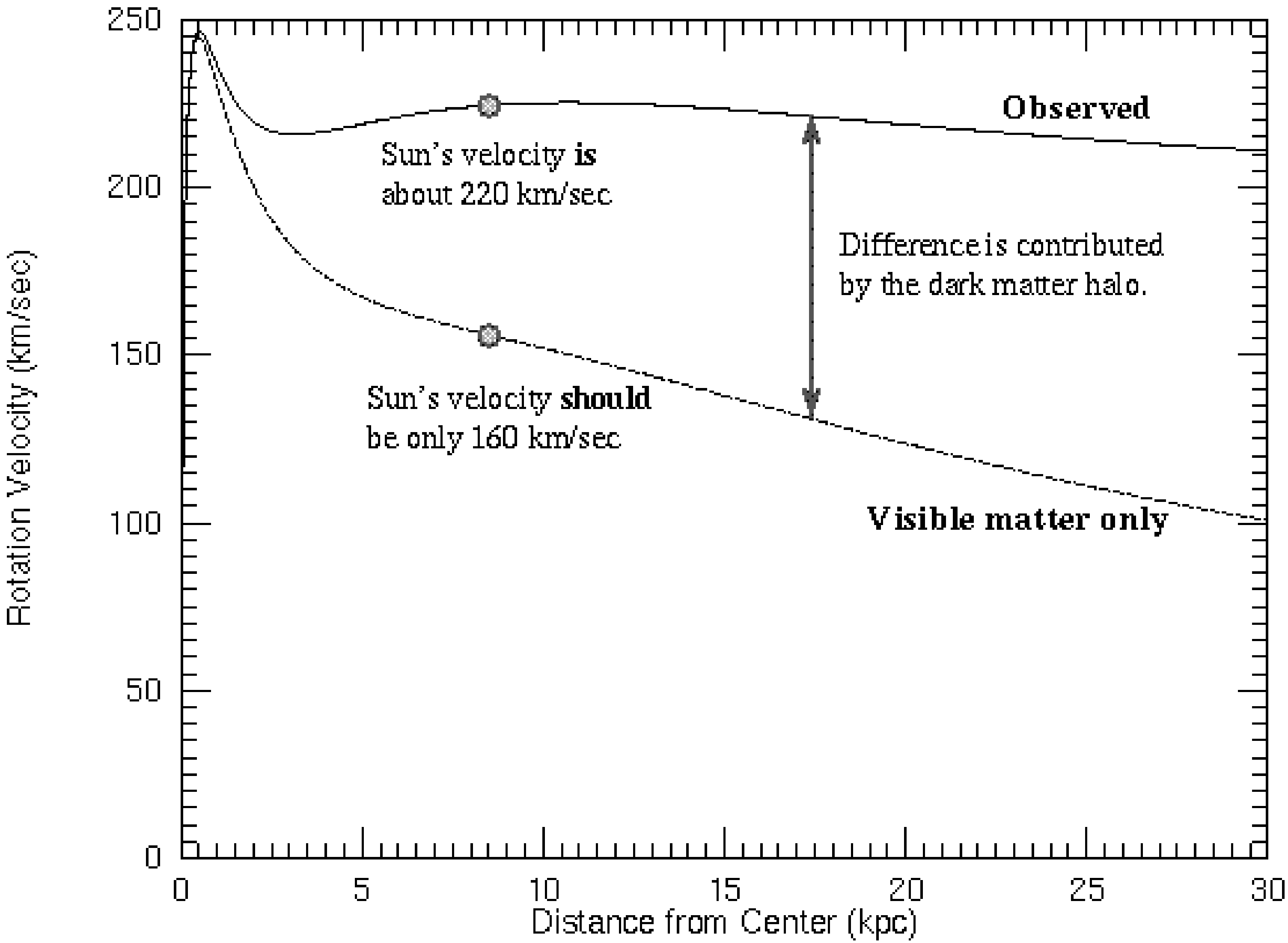
$$\Omega_0 = 1.02 \pm 0.02$$

contents of the Universe

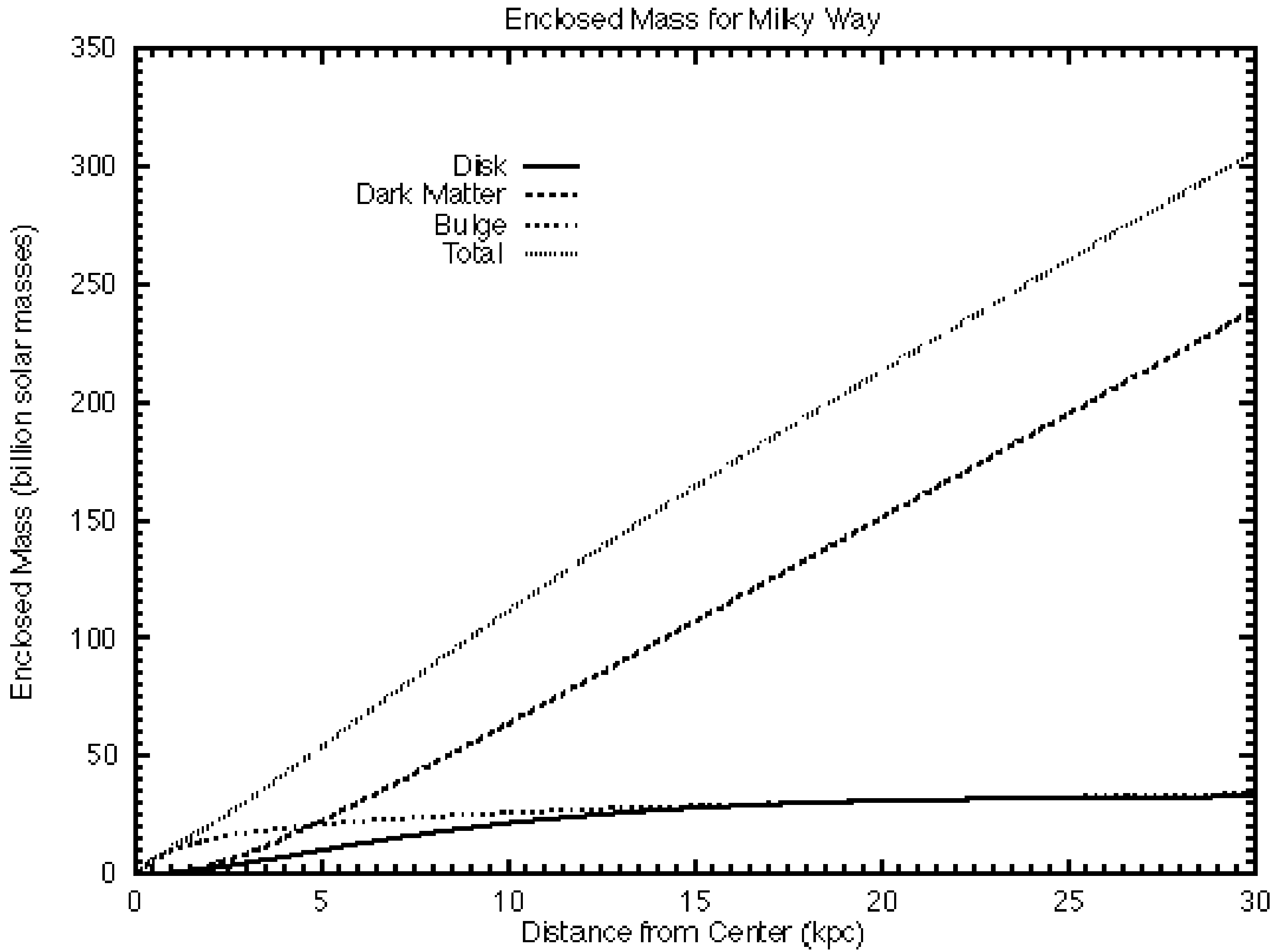
- normal matter
  - Stars
  - hot gas
  - anything made of atoms

- total is 4% of ρ_c

rotation curve of our Galaxy



mass of our Galaxy



dark matter

- dark – it doesn’t produce light (of any kind)
- it does have mass, produces gravity
- nature is unknown

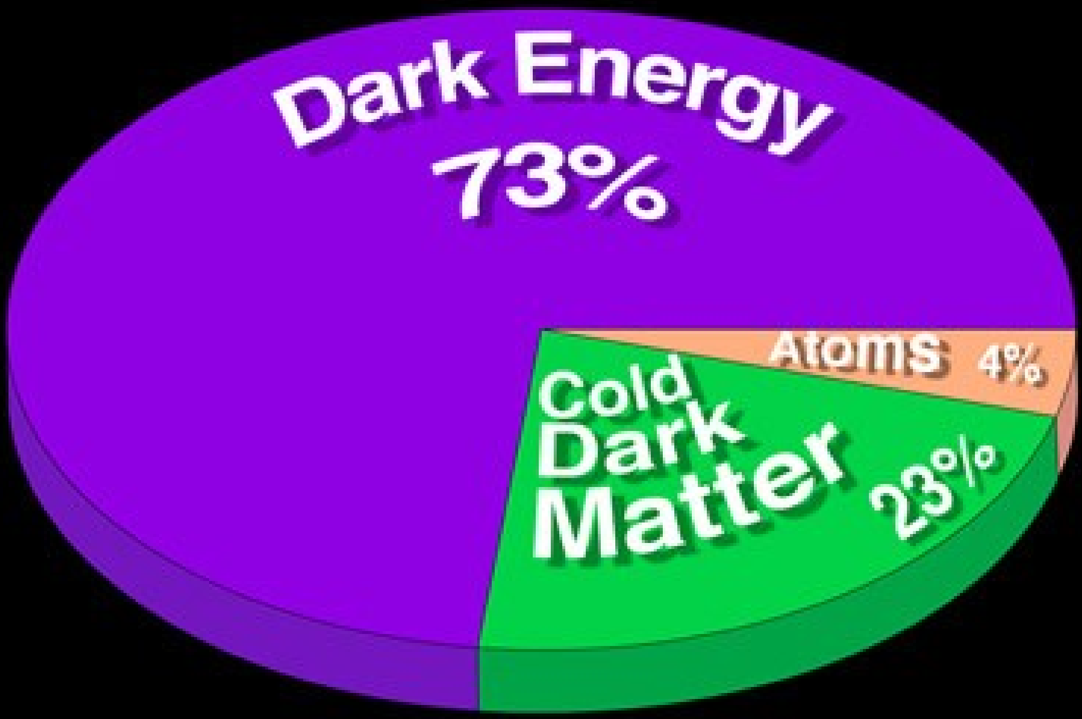
- most likely that's elementary particles

contents of the universe

- normal matter is 4% of ρ_C
- dark matter is 23% of ρ_C
- total of normal and dark matter is $\Omega_M = 0.3$

- but, we need 100% of ρ_C
- other 73% that is dark energy $\Omega_\Lambda = 0.7$

contents of the universe



cosmology

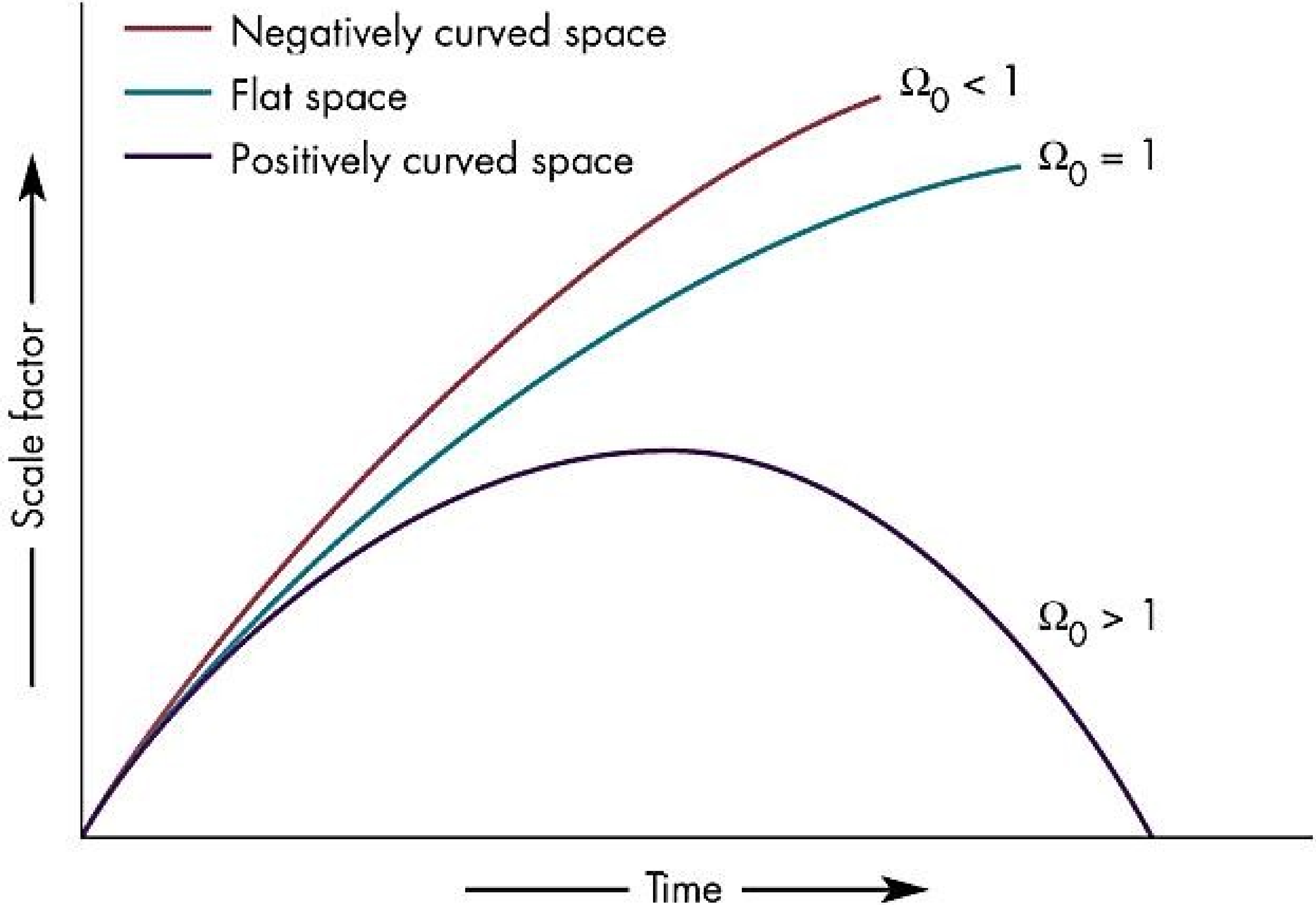
Einstein and cosmology

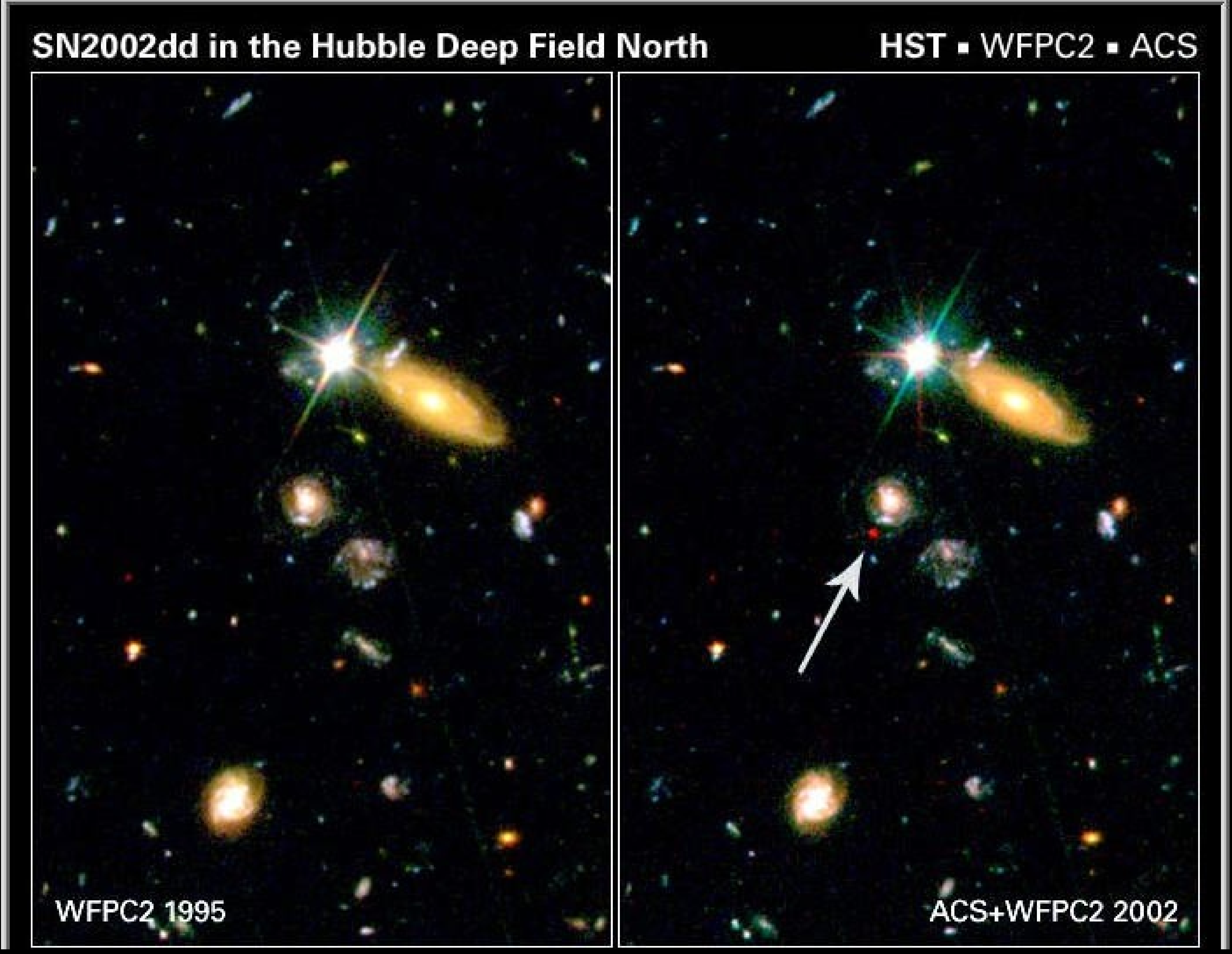
- Einstein:
  - wrote down the equations for GR
  - made a model of the universe
  - found that universe had to be either expanding or contracting
- new term (cosmological constant, Λ):
  – representing a energy field which could create antigravity to allow a static model
- after Hubble, Einstein called Λ his greatest blunder

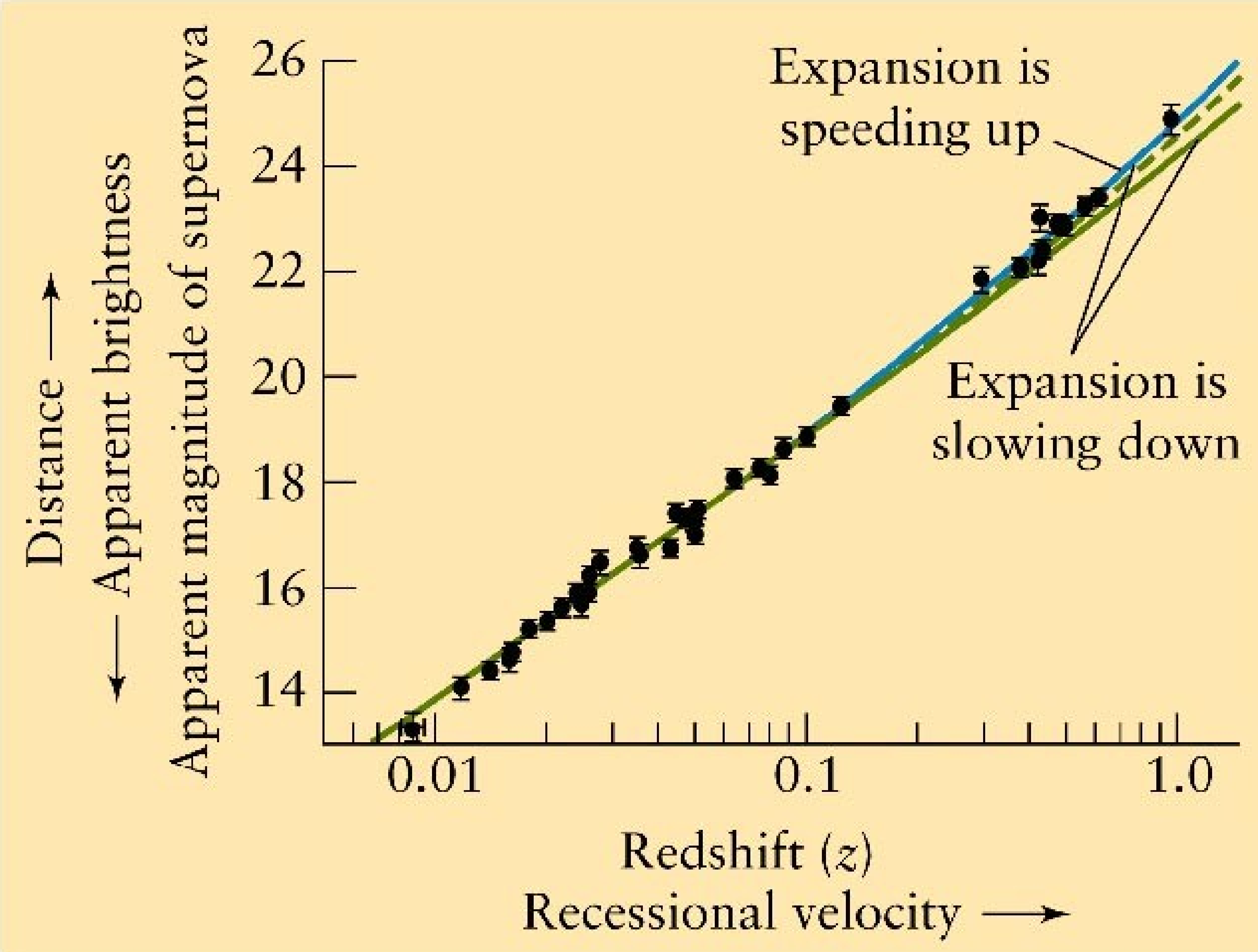
cosmological constant

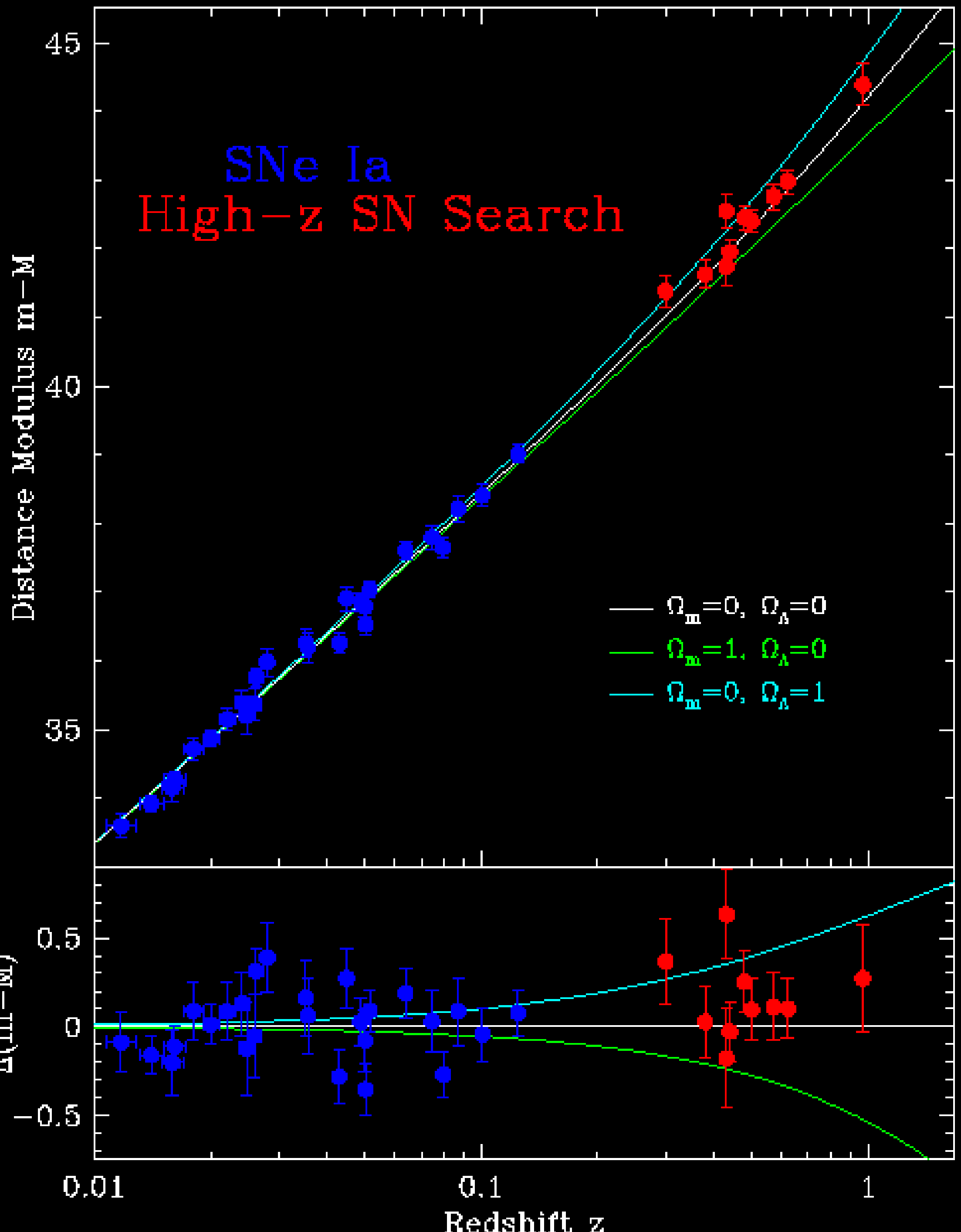
- quantum physics predicts that some energy fields that act like Λ
- one such field is the one thought to cause the rapid expansion of the Universe during inflation
- another such field appears to be operating today

matter slows down expansion




SN2002dd in the Hubble Deep Field North
HST ▪ WFPC2 ▪ ACS
WFPC2 1995
ACS+WFPC2 2002


Expansion is speeding up
Expansion is slowing down
Distance →
← Apparent brightness
Apparent magnitude of supernova
26
24
22
20
18
16
14
0.01
0.1
1.0
Redshift (z)
Recessional velocity →

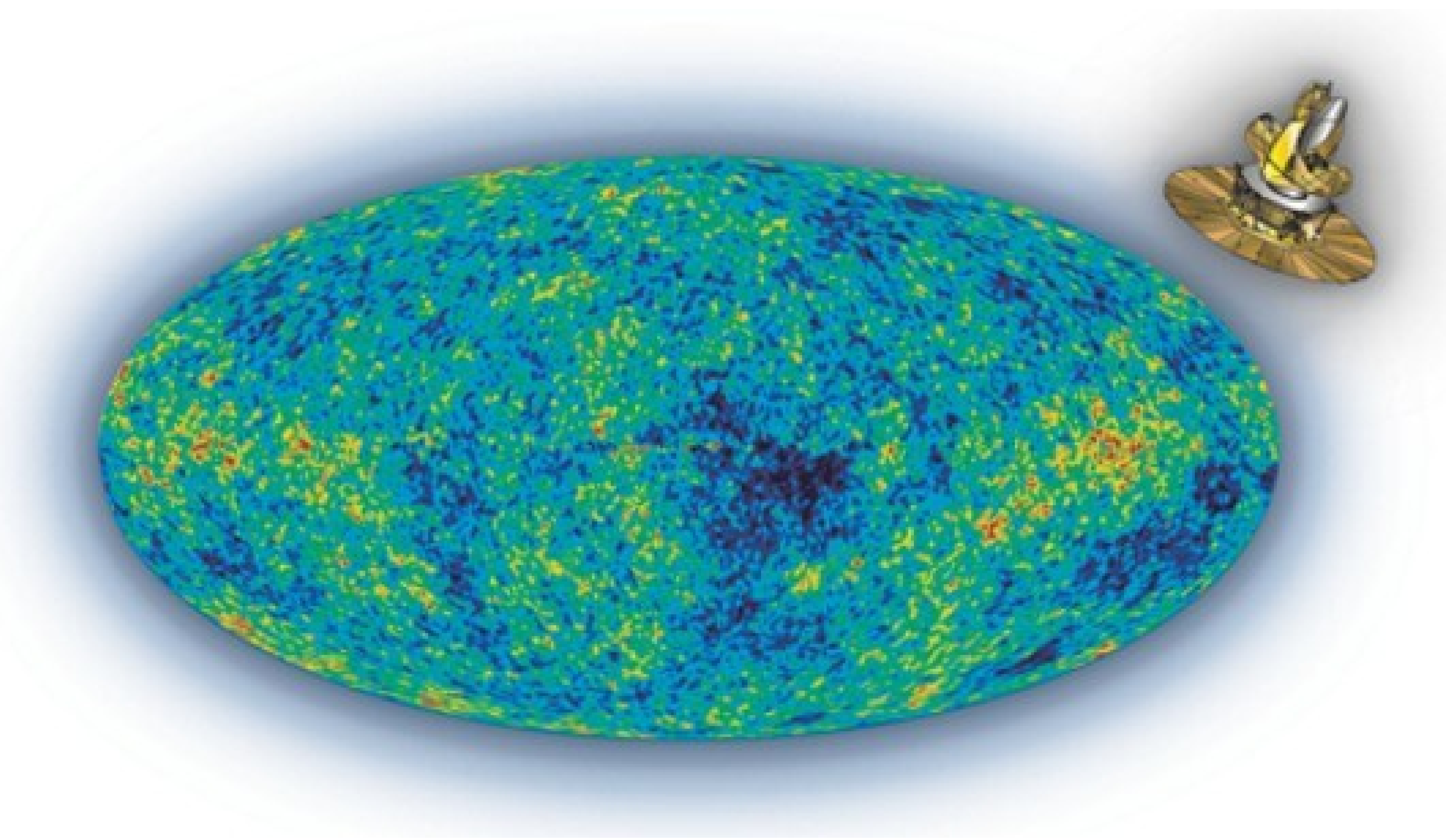


SNe Ia
High-z SN Search
Distance Modulus m−M
45
40
35
Ω_m=0, Ω_Λ=0
Ω_m=1, Ω_Λ=0
Ω_m=0, Ω_Λ=1
Δ(m−M)
0.5
0
−0.5
0.01
0.1
1
Redshift z

accelerating universe

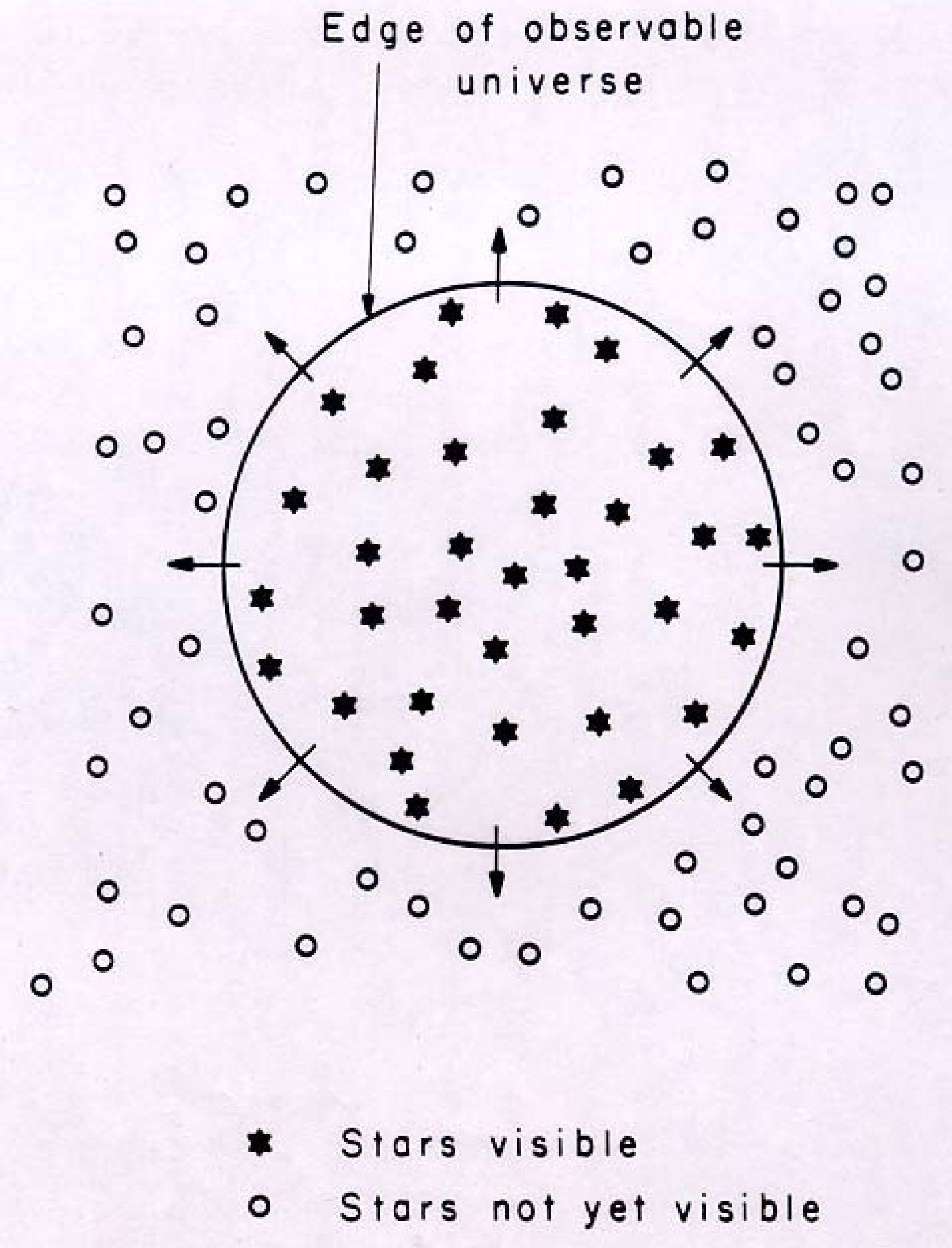
- Hubble expansion appears to be accelerating
- normal matter cannot cause acceleration, only deceleration of expansion
- dark energy is required
  - may be cosmological constant
  - may be something else
  - major current problem in astronomy

Problems with the Big Bang



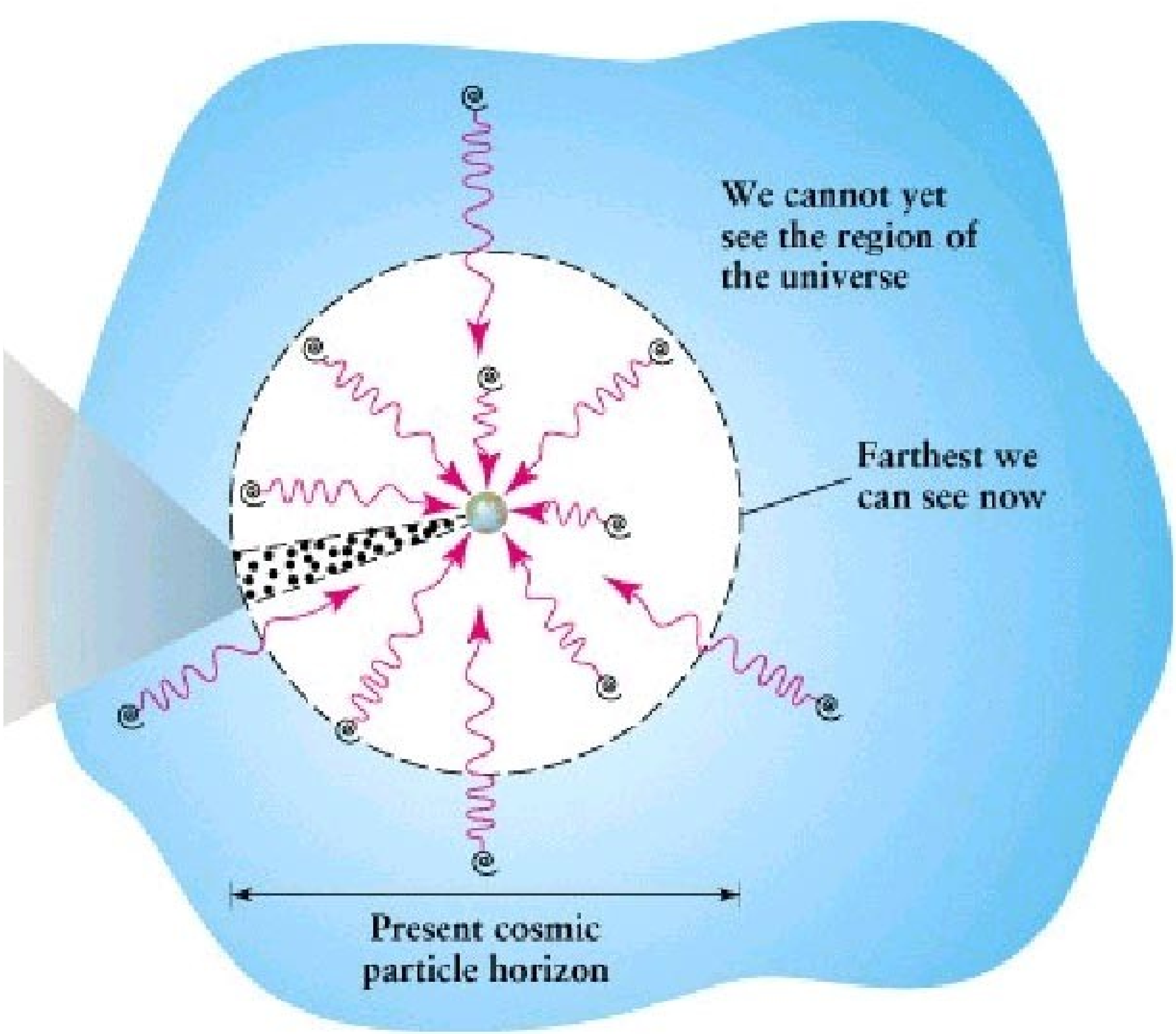
universe glows at 2,7 K in every direction

temperature is the same to < 0,1 %



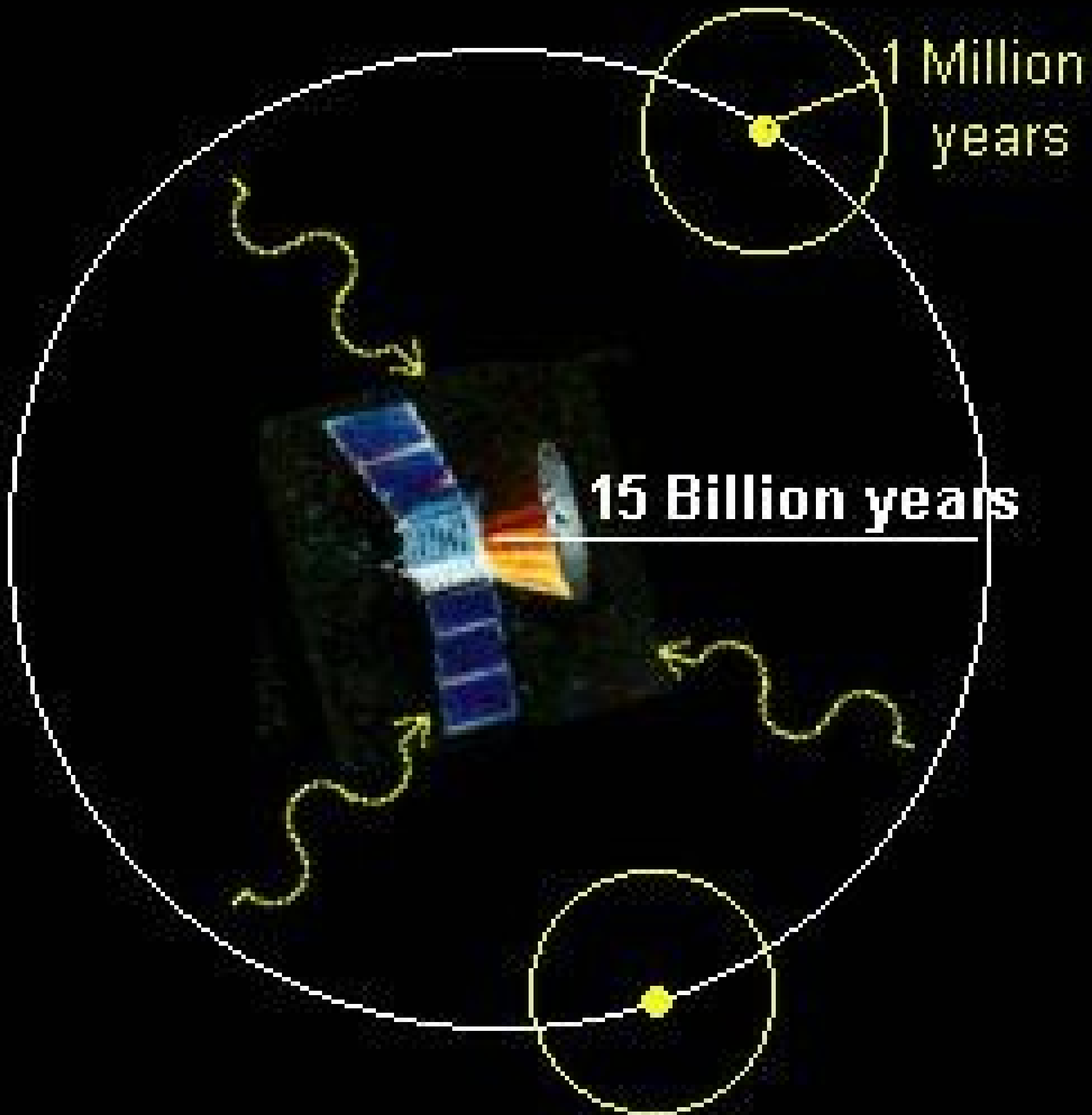
observable universe

We can only see the parts of the Universe from which light has had time to travel to us!

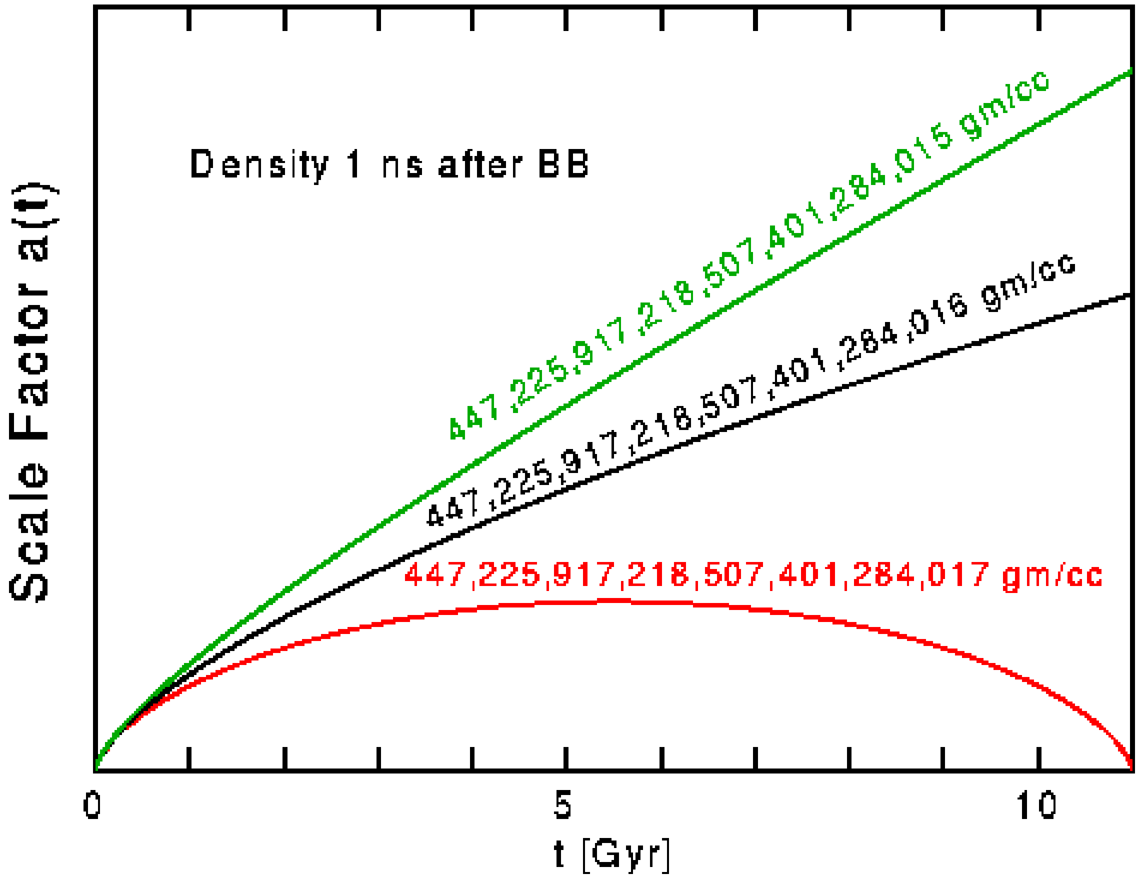


We cannot yet
see the region of
the universe
Farthest we
can see now
Present cosmic
particle horizon

horizon problem



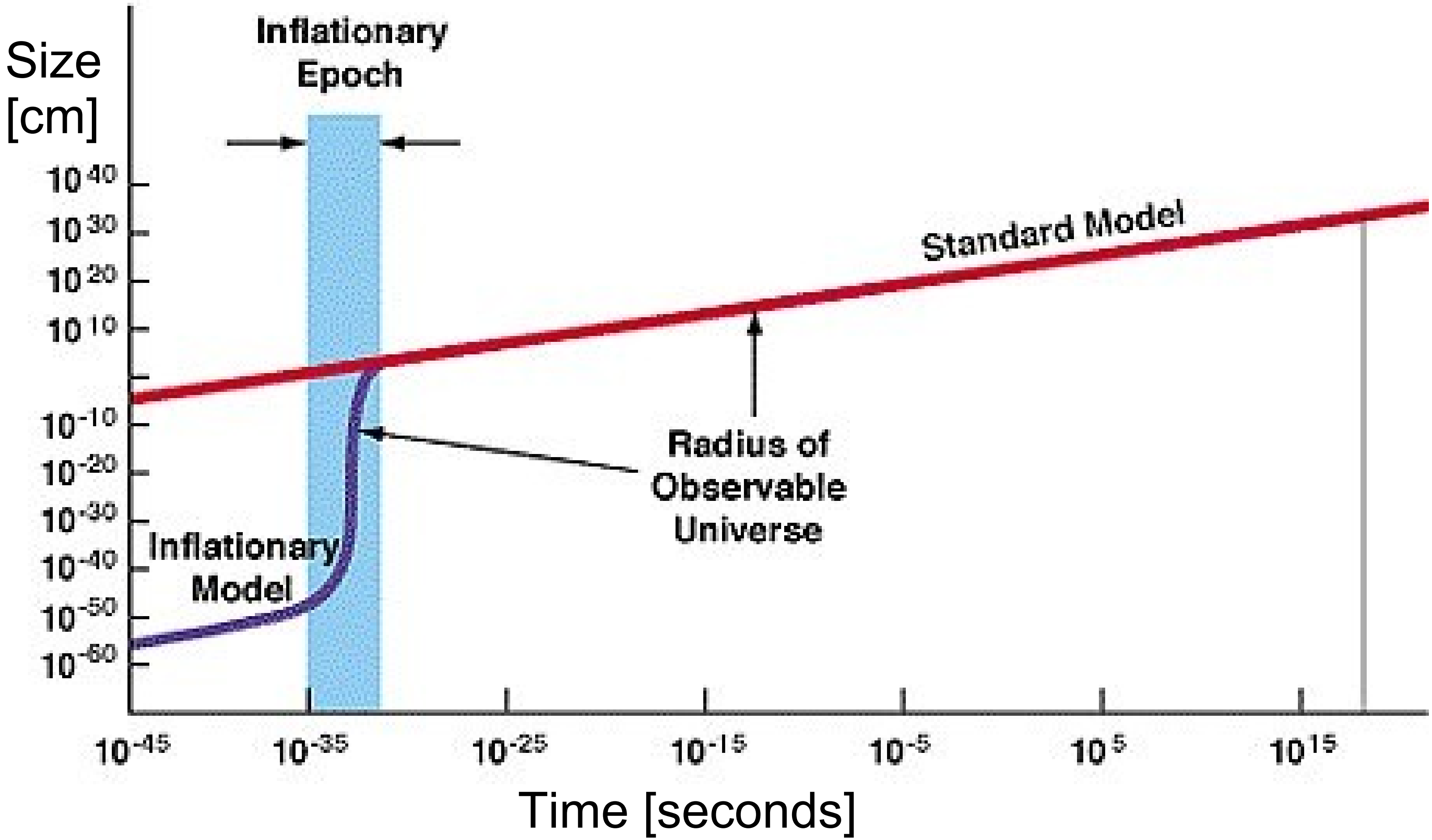
flatness problem



any tiny deviation from the critical density is amplified over time

inflation makes the Universe flat

inflation



whole observable universe came from a tiny region

inflation and cosmology

- universe is very uniformity and very close to flat
- new theoretical idea – inflation - gives an explanation for the uniformity and flatness of the universe
- inflation still needs to be tested
- NASA plans to fly a satellite to measure the polarization of the cosmic microwave background in order to test inflation