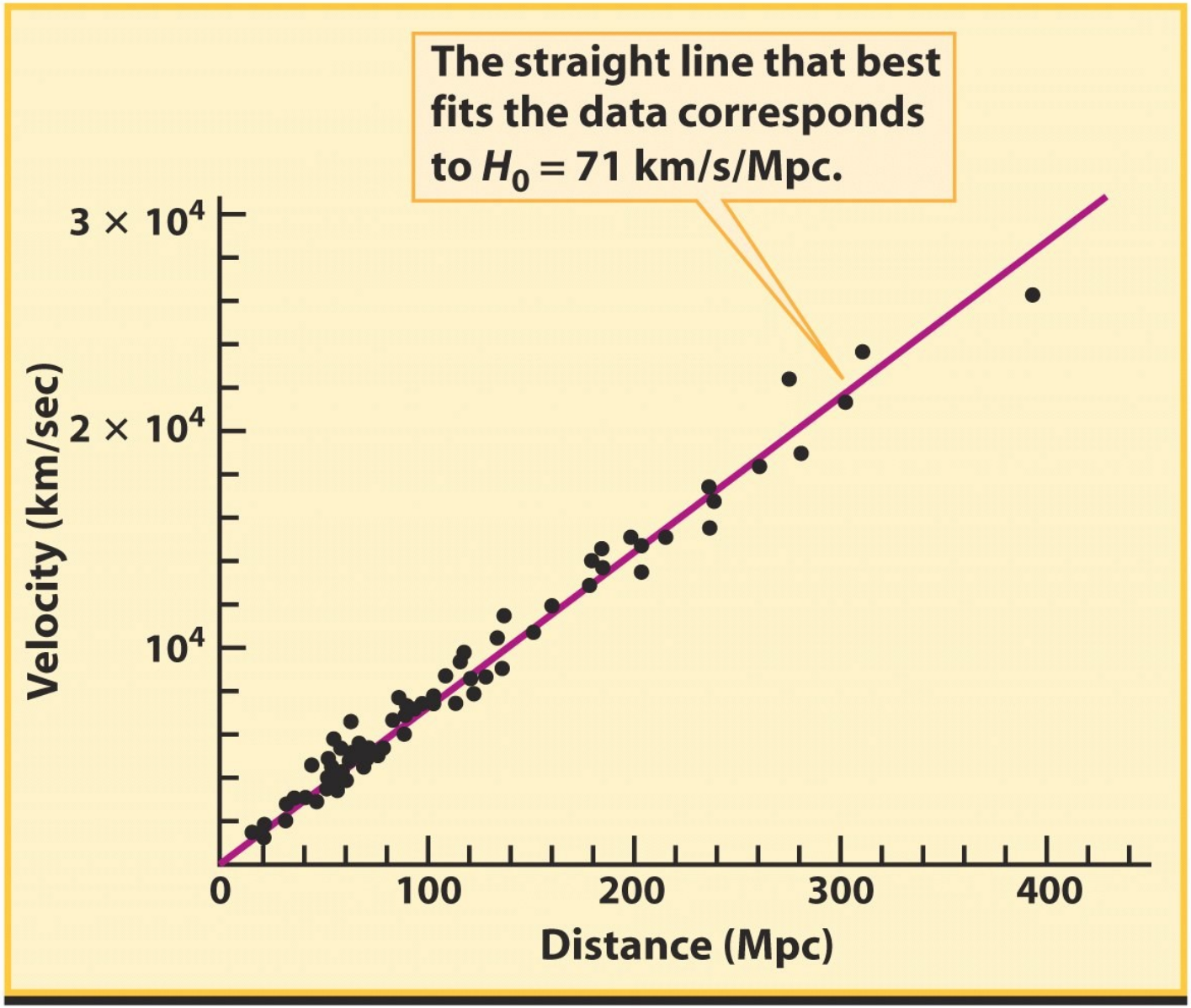
The Big Bang

- Review of Hubble expansion
- Assumptions in cosmology
- The Big Bang
- Cosmic microwave background

Hubble expansion $v = H_0 d$

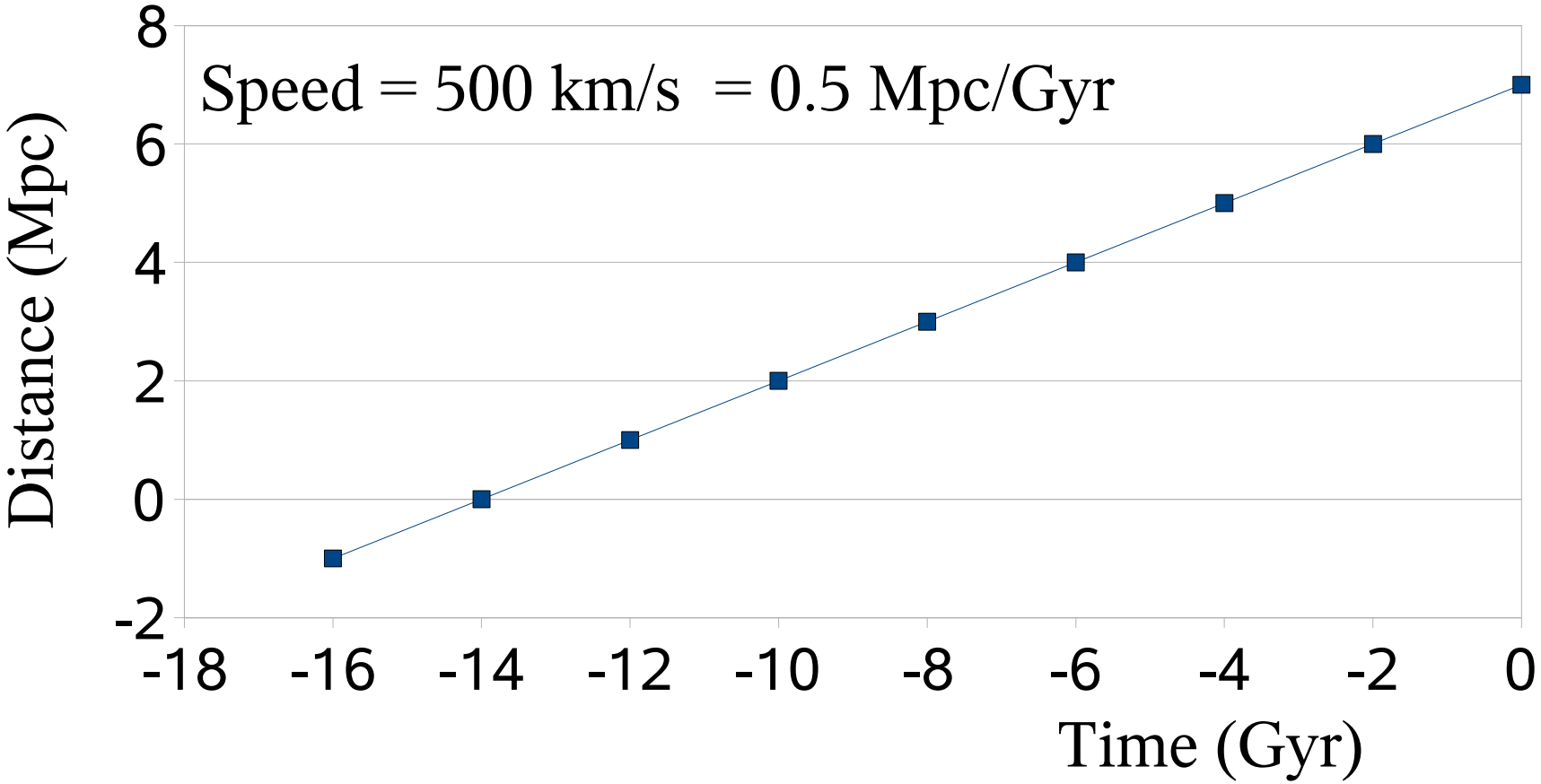


What would be the recession speed of a galaxy at a distance of 7 Mpc?

A) 0.1 km/s
B) 10 km/s
C) 250 km/s
D) 500 km/s
E) 1000 km/s

Speed = $H_0 \times$ distance $H_0 = 71$ km/s/Mpc

Receding galaxy



When was this galaxy in the same place as the Milky Way? time = distance / velocity

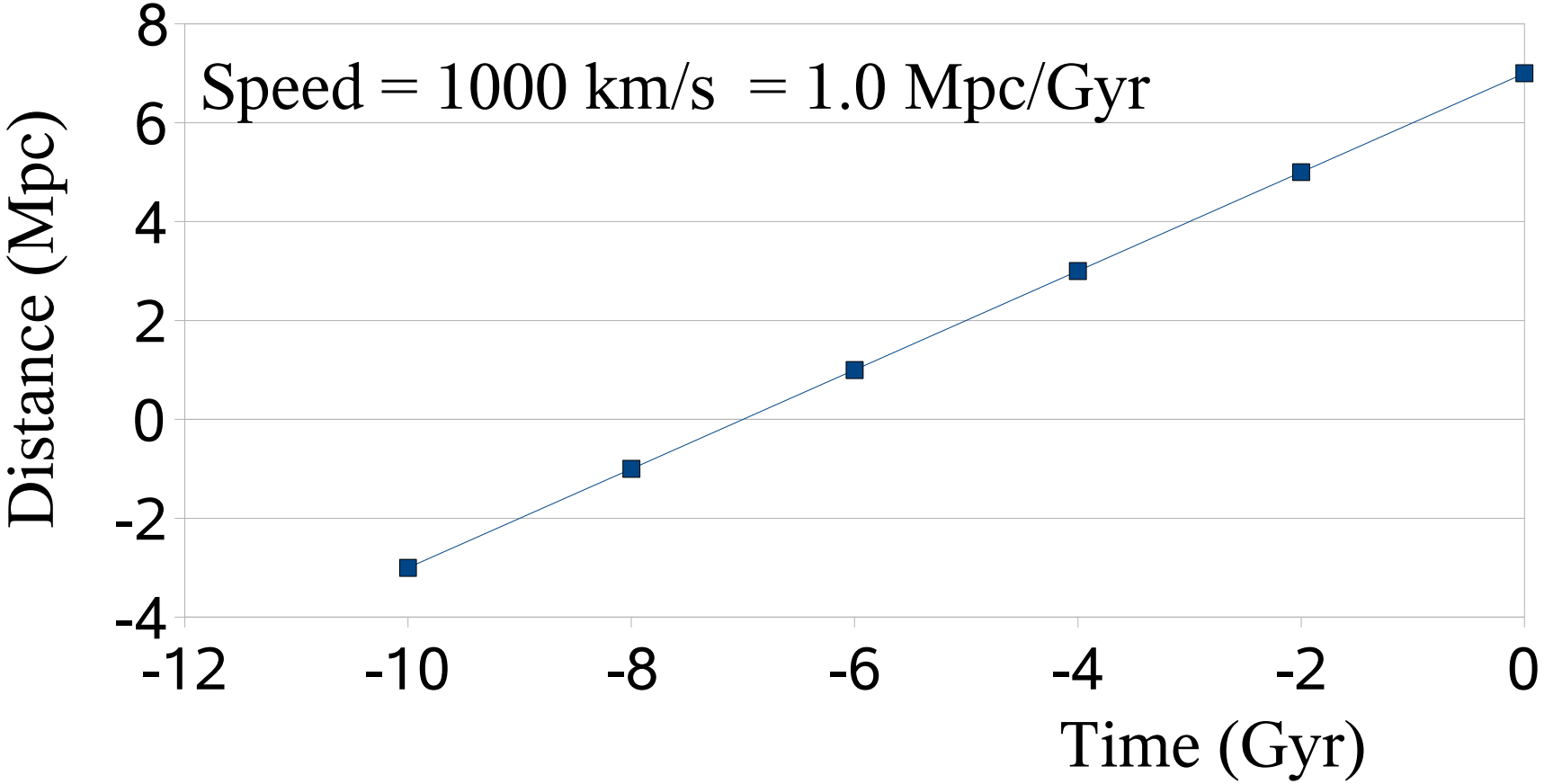
= 7 Mpc/(0.5 Mpc/Gyr) = 14 Gyr ago

If the Hubble constant were doubled, what would be the recession speed of a galaxy at a distance of 7 Mpc?

A) 0.1 km/s
B) 10 km/s
C) 250 km/s
D) 500 km/s
E) 1000 km/s

Speed = $H_0 \times$ distance $H_0 = 2 \times 71$ km/s/Mpc

Receding galaxy



When was this galaxy in the same place as the Milky Way? time = distance / velocity

= 7 Mpc/(1.0 Mpc/Gyr) = 7 Gyr ago

If Hubble's constant were twice as large as we now think it is, our estimate of the age of the universe would

A) be unchanged

B) increase by a factor of 2

C) increase by a factor of 4

D) decrease by a factor of 2

E) decrease by a factor of 4

Quasars are receding from us at high velocities because

A) matter in black hole jets moves at close to the speed of light

B) matter moves rapidly when close to a black hole

C) quasars are at large distances

D) we smell bad

The variety of different active galaxies can be explained as due to

A) different orientations of the accretion disk
B) different forms of matter being accreted
C) different shapes of black holes
D) different velocities of black holes

Assumptions in Cosmology

Copernican principle:

- We do not occupy a special place.
- There are no special places.
- The universe is homogeneous if viewed at sufficently large scales.
- The laws of physics are the same everywhere.

How can we test the Copernican principle?

- Does the Universe look the same in all directions? (Isotropy)
- Are the spectral lines from atoms the same in distant galaxies?
- Do the same laws of gravity apply in other galaxies?

Implications of the Copernican Principle

- The average density of matter and energy is the same throughout the Universe.
- The same Hubble expansion law is seen for all observers anywhere in the Universe.
- The curvature of the Universe is the same everywhere.

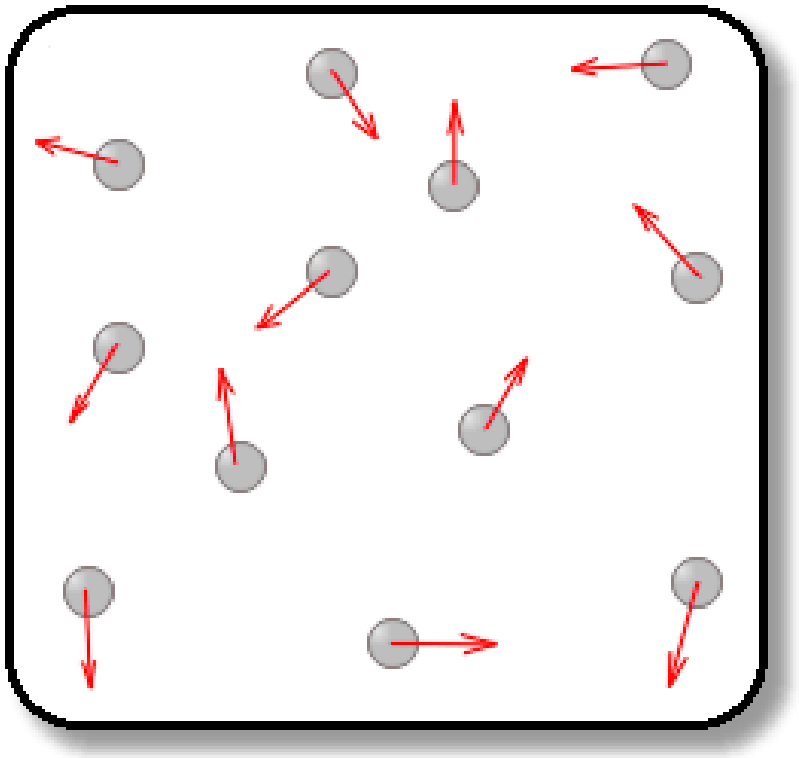
Big Bang

- Our conclusion that the Universe actually began at some point in time is based on extrapolating back the observed Hubble expansion of galaxies

- Is there any other evidence?

Temperature

- Temperature is a measure of how fast the atoms in a gas move



- Hotter

→ atoms move faster

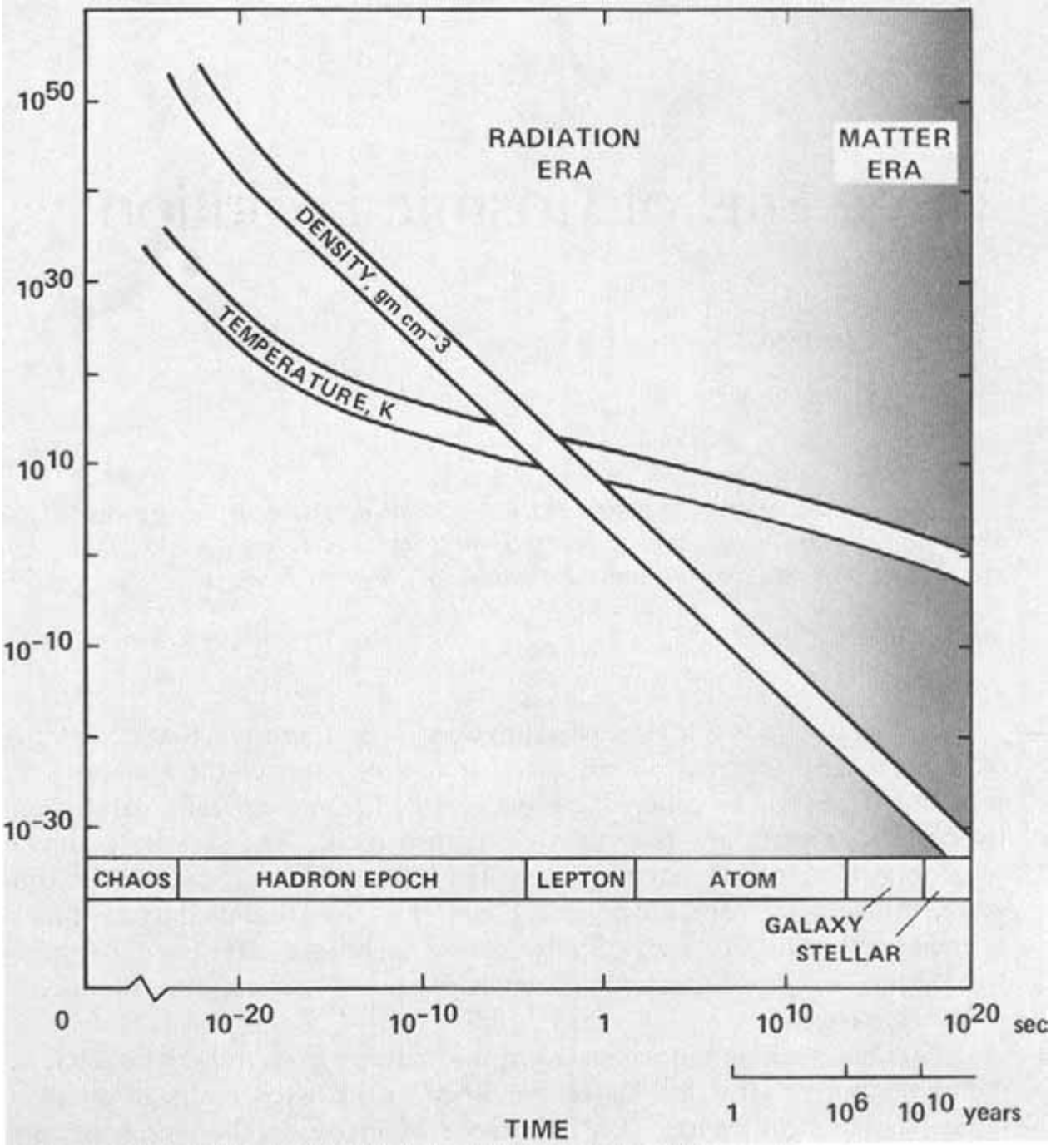
→higher energy density

- Cooler

→atoms move slower

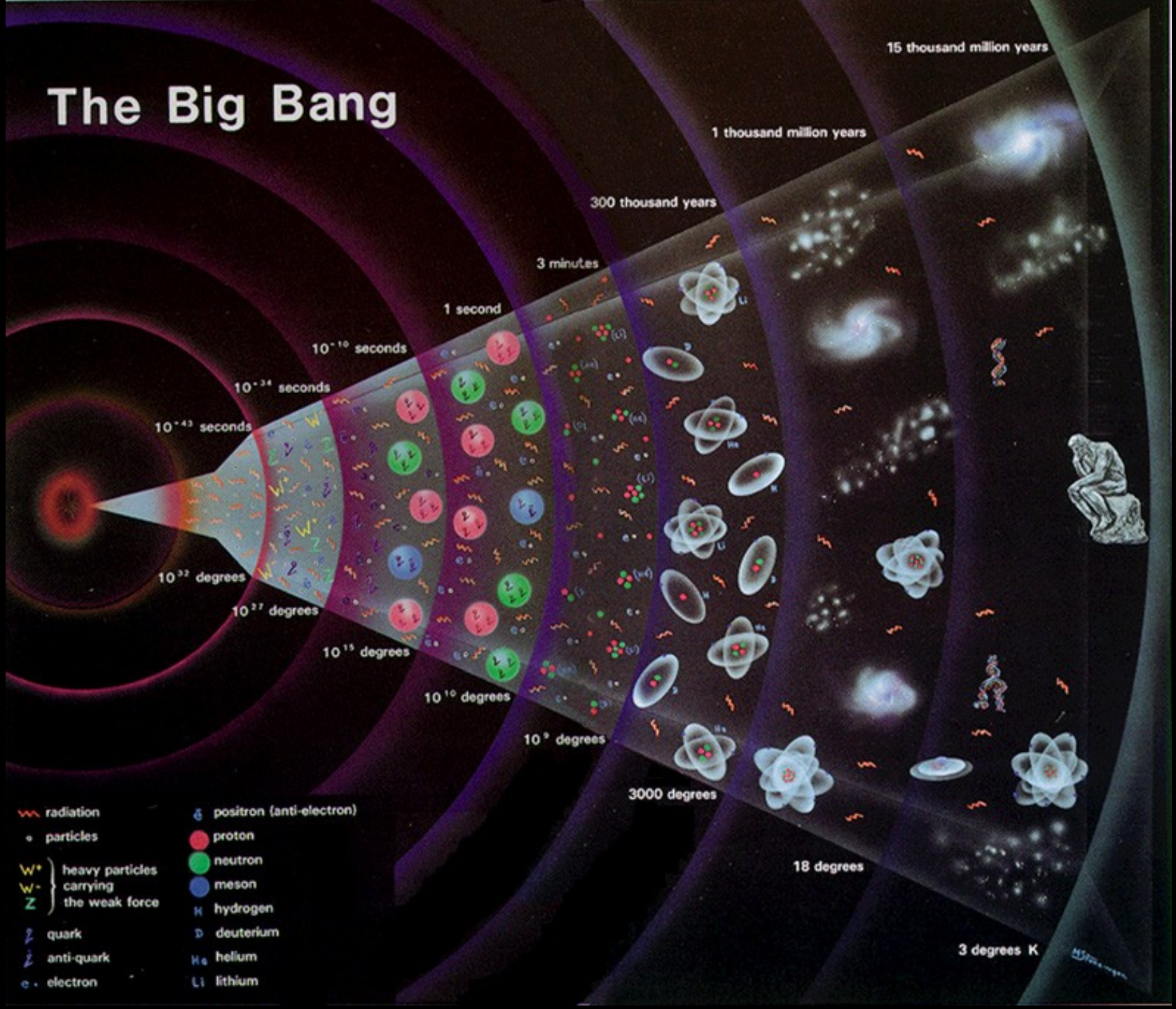
→lower energy density

Anything will melt if the temperature is high enough

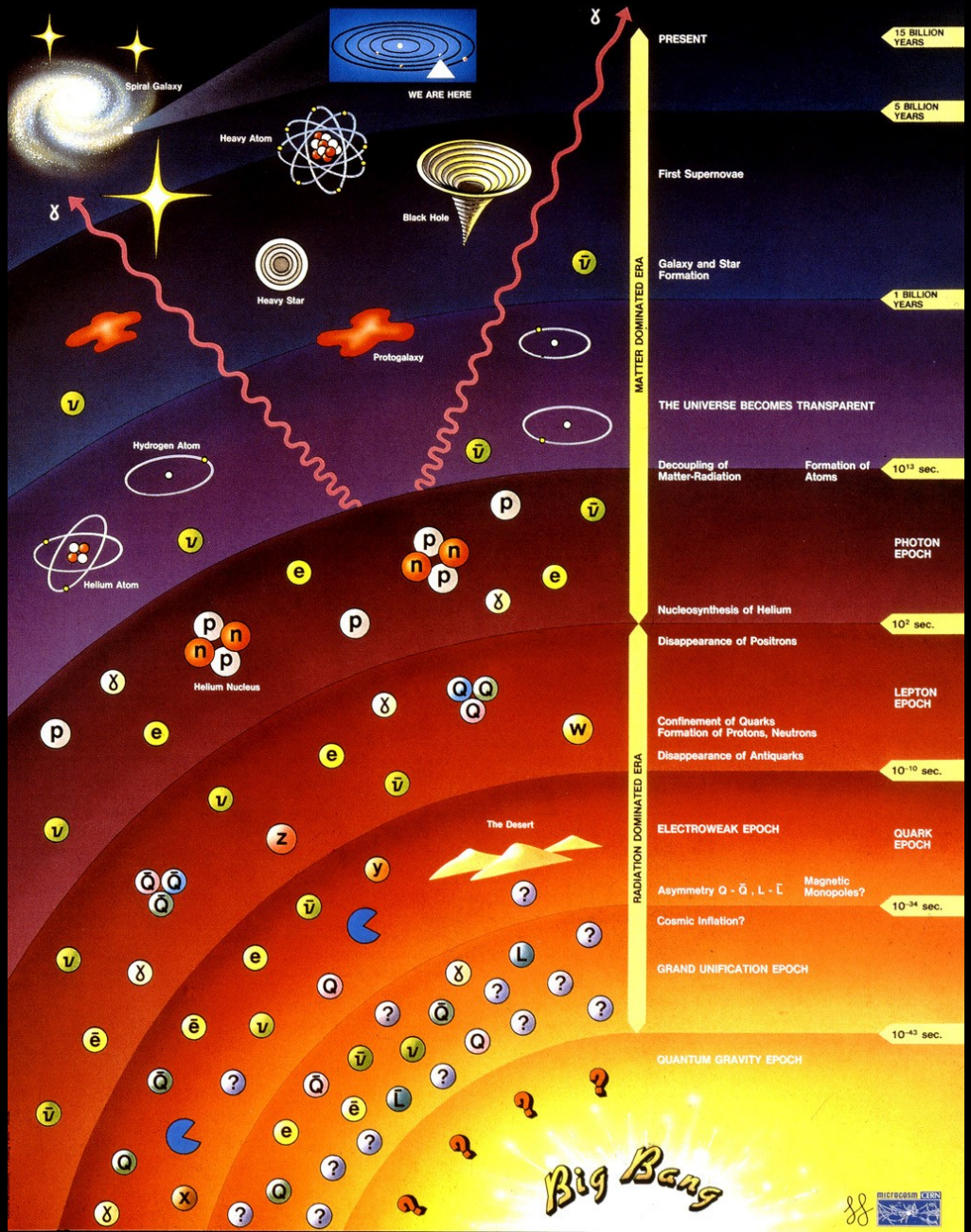


Big Bang

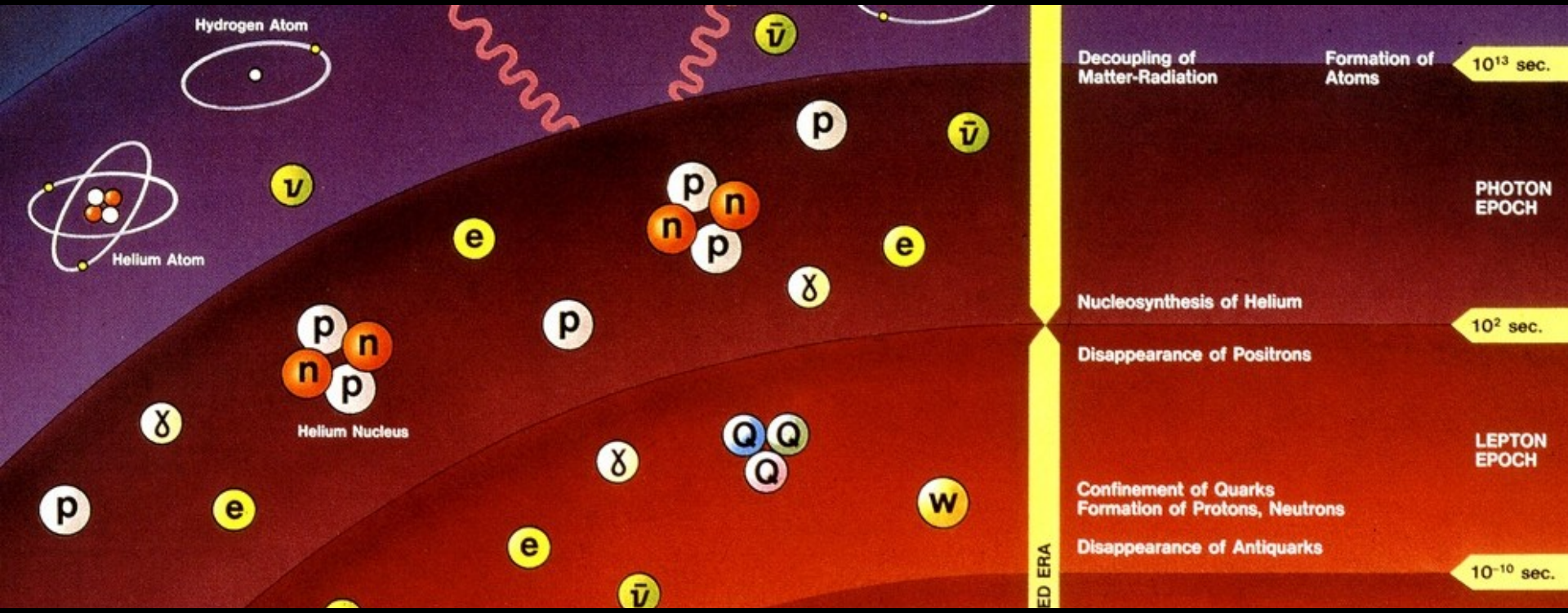
If the Universe was smaller in the past, but had roughly the same amount of matter and energy, then the density of matter and energy must have been higher in the past.


The Big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-24} 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
e- electron
positron (anti-electron)
proton
neutron
meson
H hydrogen
D deuterium
He helium
Li lithium

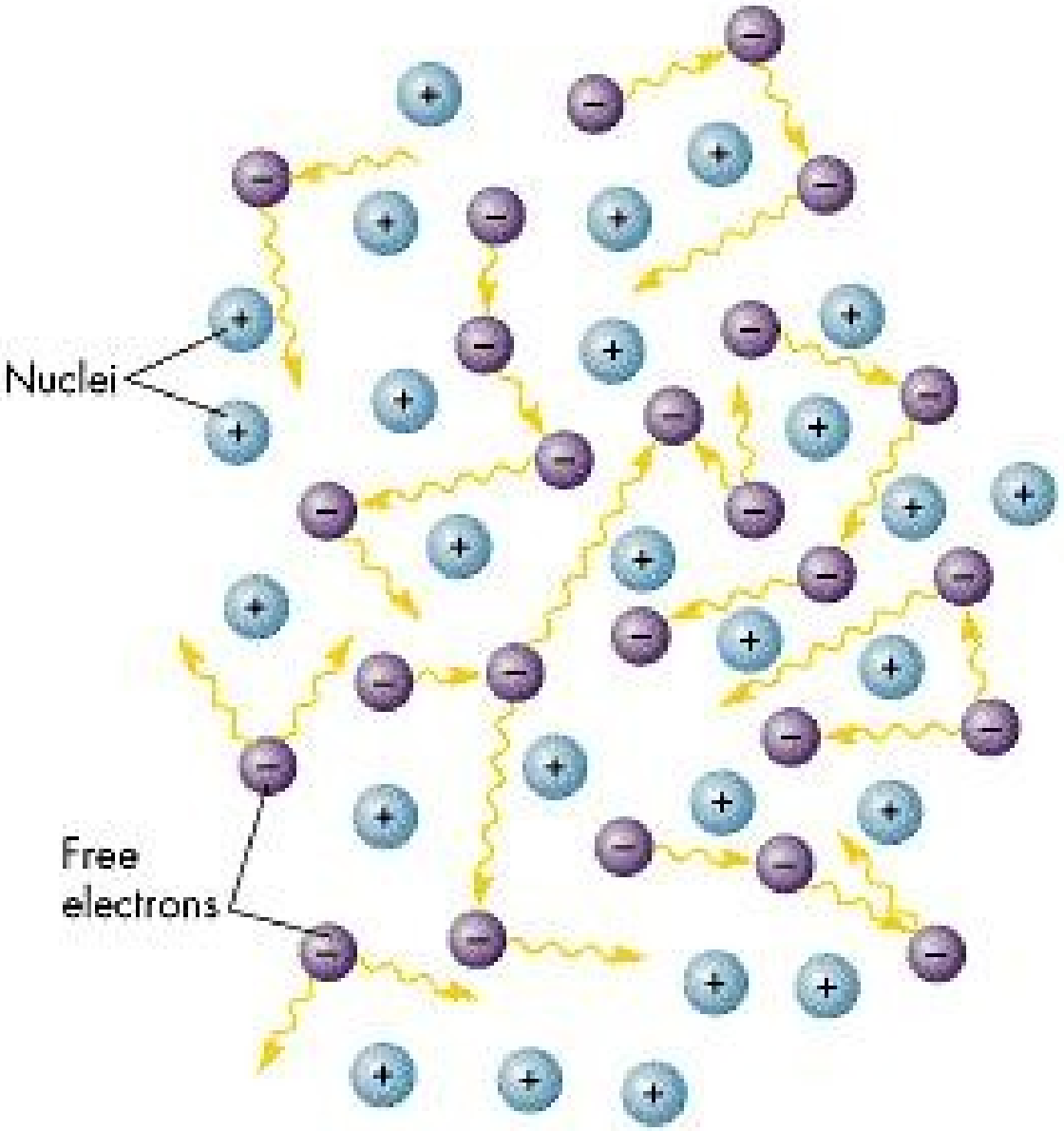
History of the Universe

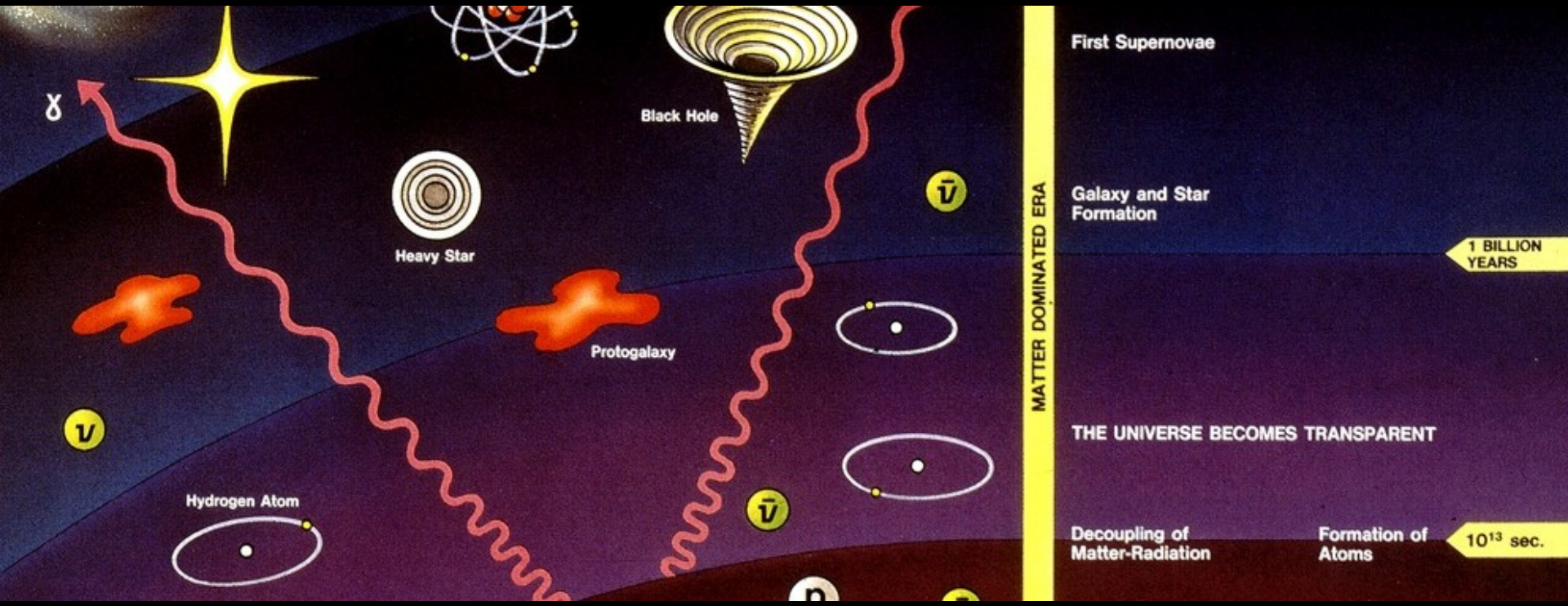



Disappearance of Antiquarks
10^{-10} sec.
RADIATION DOMINATED ERA
The Desert
ELECTROWEAK EPOCH
QUARK EPOCH
Asymmetry Q - $\bar{Q}$, L - $\bar{L}$
Magnetic Monopoles?
10^{-34} sec.
Cosmic Inflation?
GRAND UNIFICATION EPOCH
10^{-43} sec.
QUANTUM GRAVITY EPOCH
Big Bang
microcosm CERN



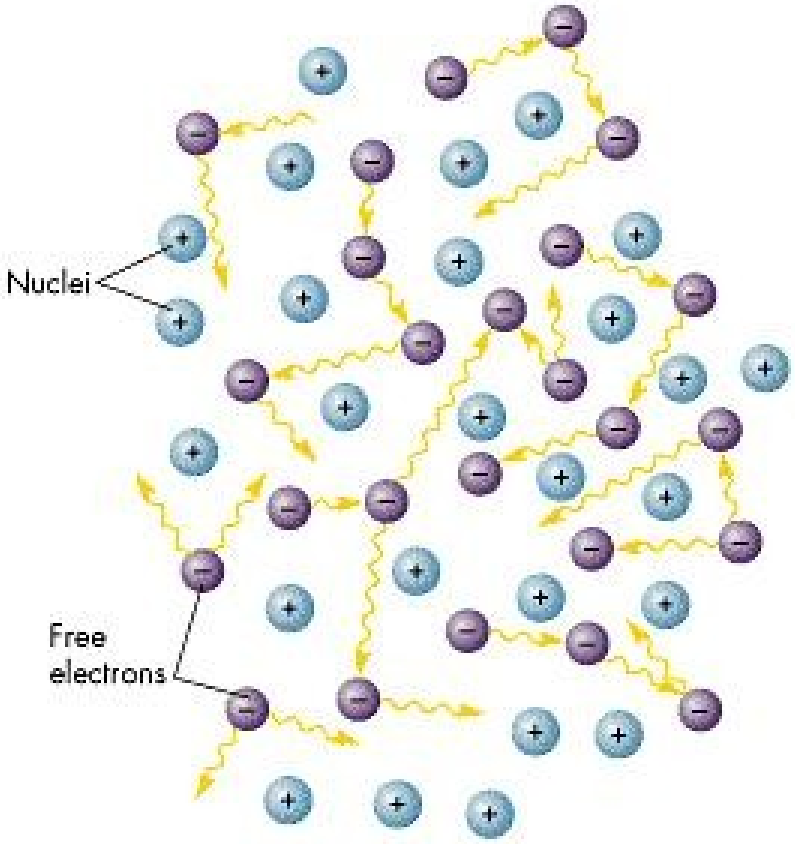
First protons and neutrons at about 1 second.
Helium nuclei formed at about 100 seconds.
Observed ratio of Helium/Hydrogen matches Big Bang prediction.
Universe is opaque.


Nuclei
Free electrons

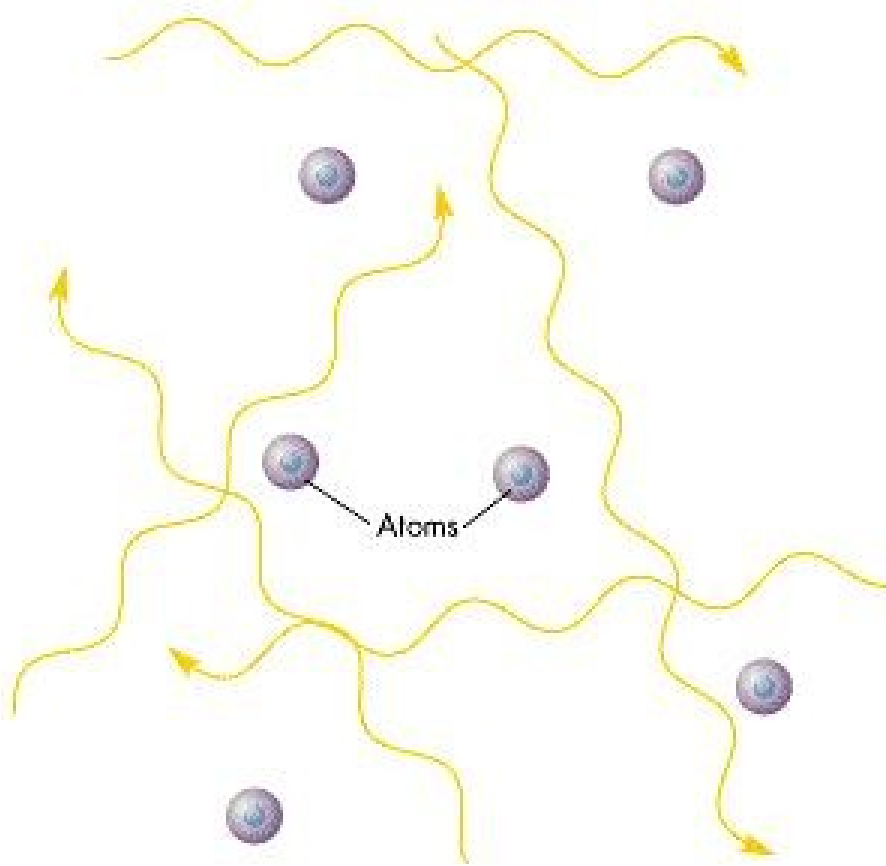


At one million years, electrons combine with nuclei and atoms form.

Universe becomes transparent.

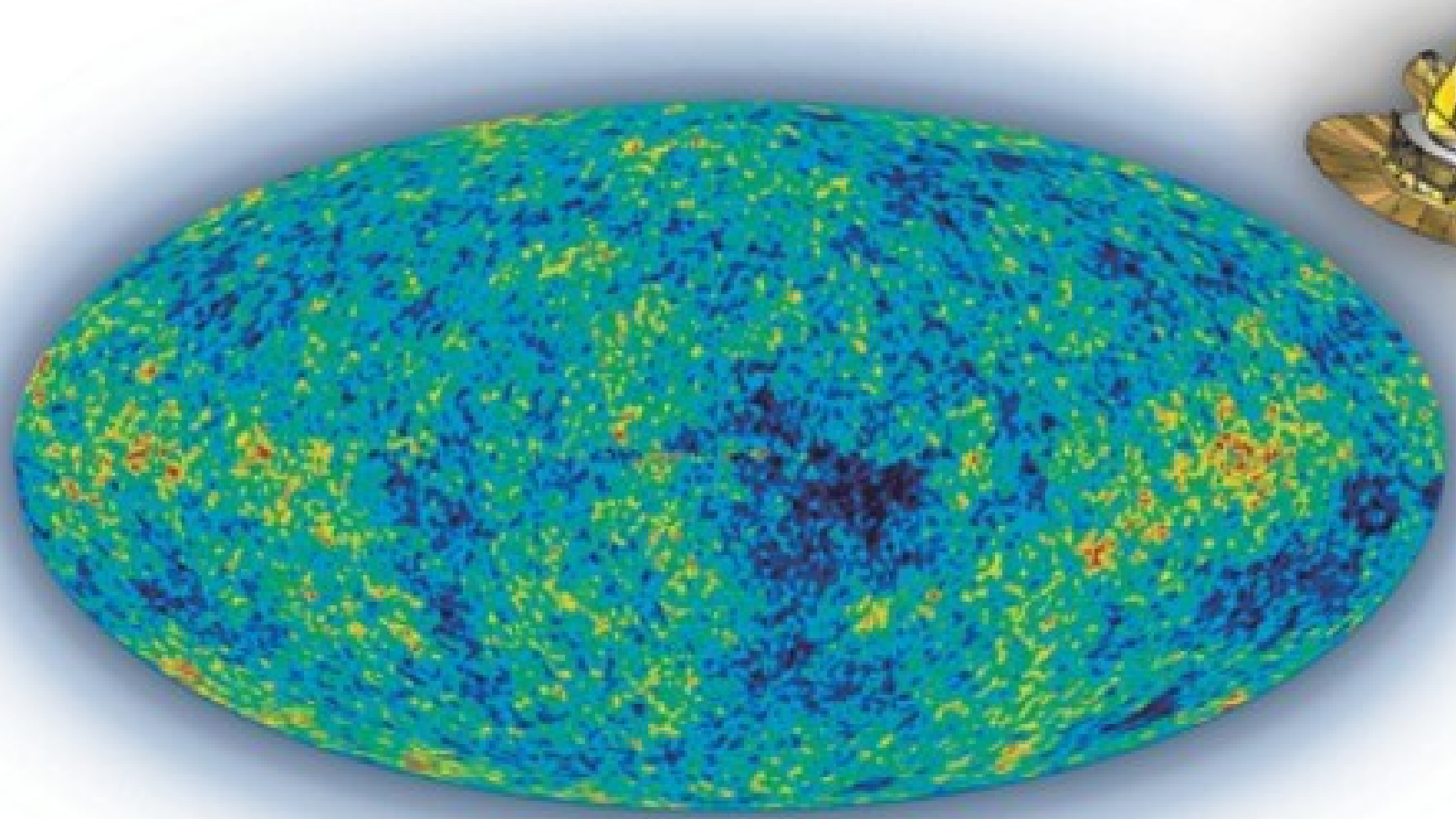


A Before recombination: The universe was opaque

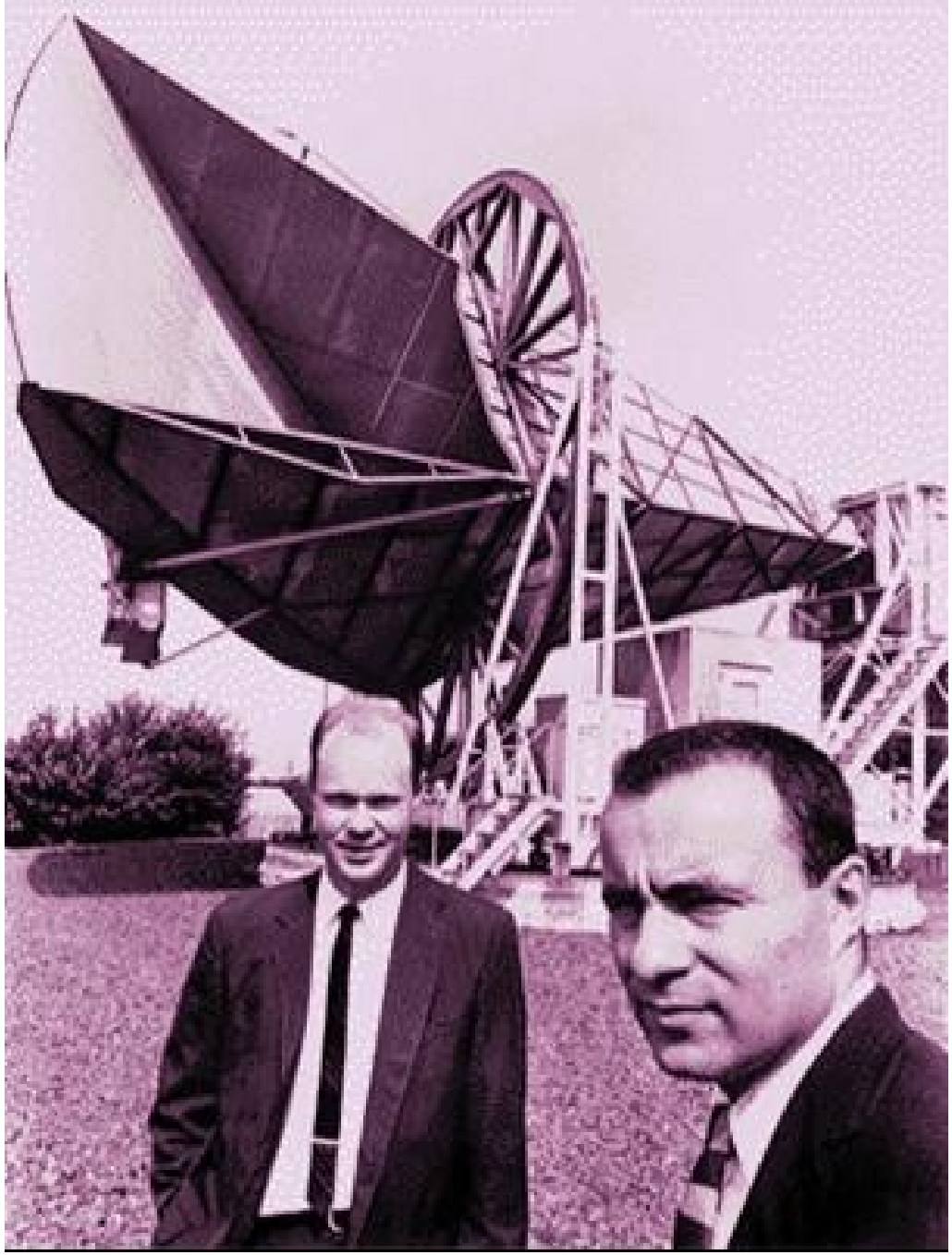


B After recombination: The universe was transparent

Cosmic Microwave Background

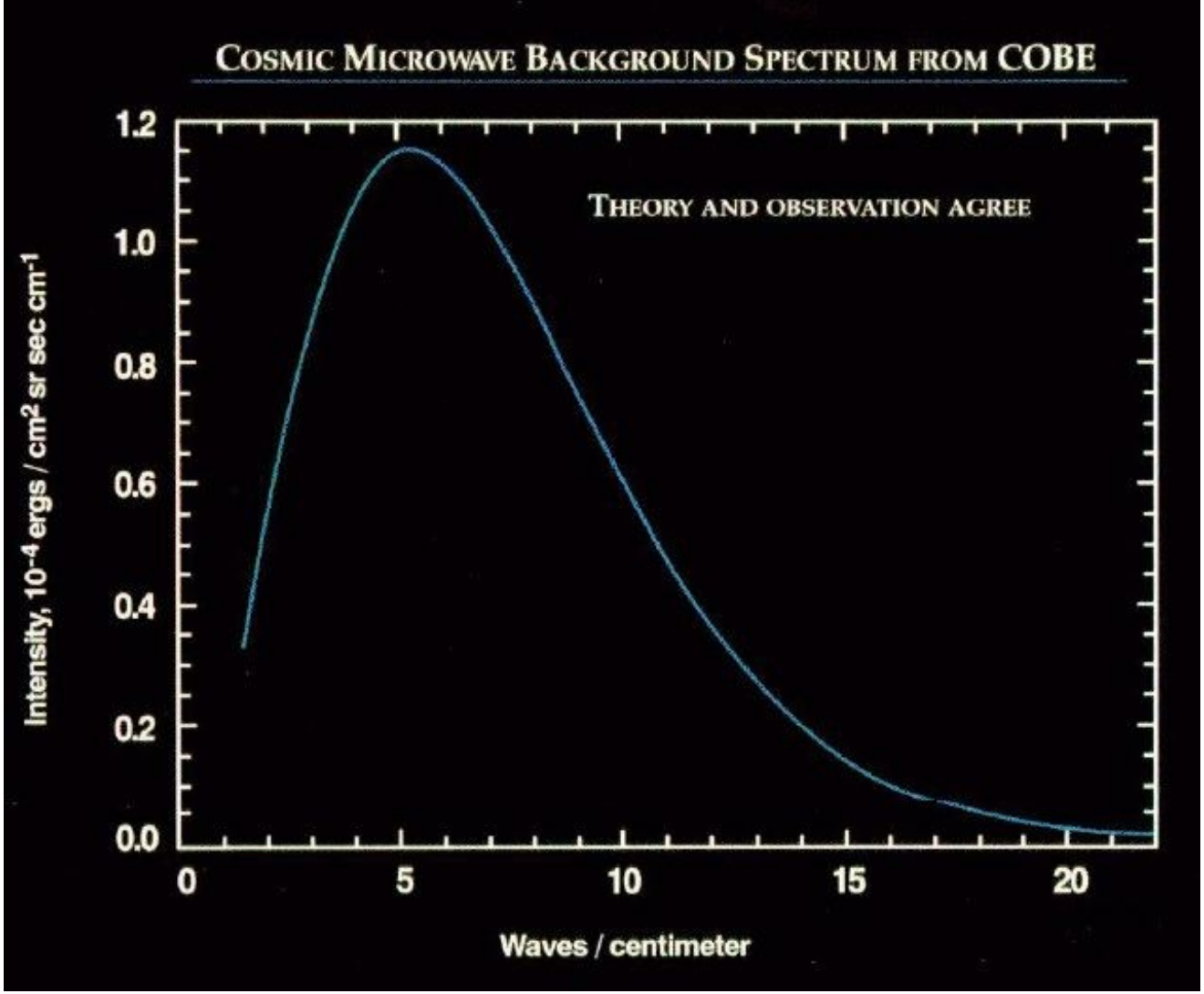


The Universe glows at 2.7 K in every direction.



Discovered by Arno Penzias and Robert Wilson in 1960-65 while employed by AT&T's Bell Labs and attempting to find the source of noise in an antenna used to bounce telephone signals bounced off metallic balloons high in the atmosphere.

They won the Nobel prize in 1978.



Radiation is a blackbody spectrum originally emitted at 3000 K but red shifted by a factor of 1000.

Three pieces of evidence for the Big Bang model

- Hubble expansion: galaxies are moving away from us with speed proportional to distance.
- The ratio of Helium to Hydrogen in gas clouds unaffected by stars matches with that predicted.
- The cosmic microwave background: a 2.7 K glow seen in all directions.