

Cosmology

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دانشگاه تحصیلات تکمیلی علوم پایه زنجان

Big Bang Cosmology

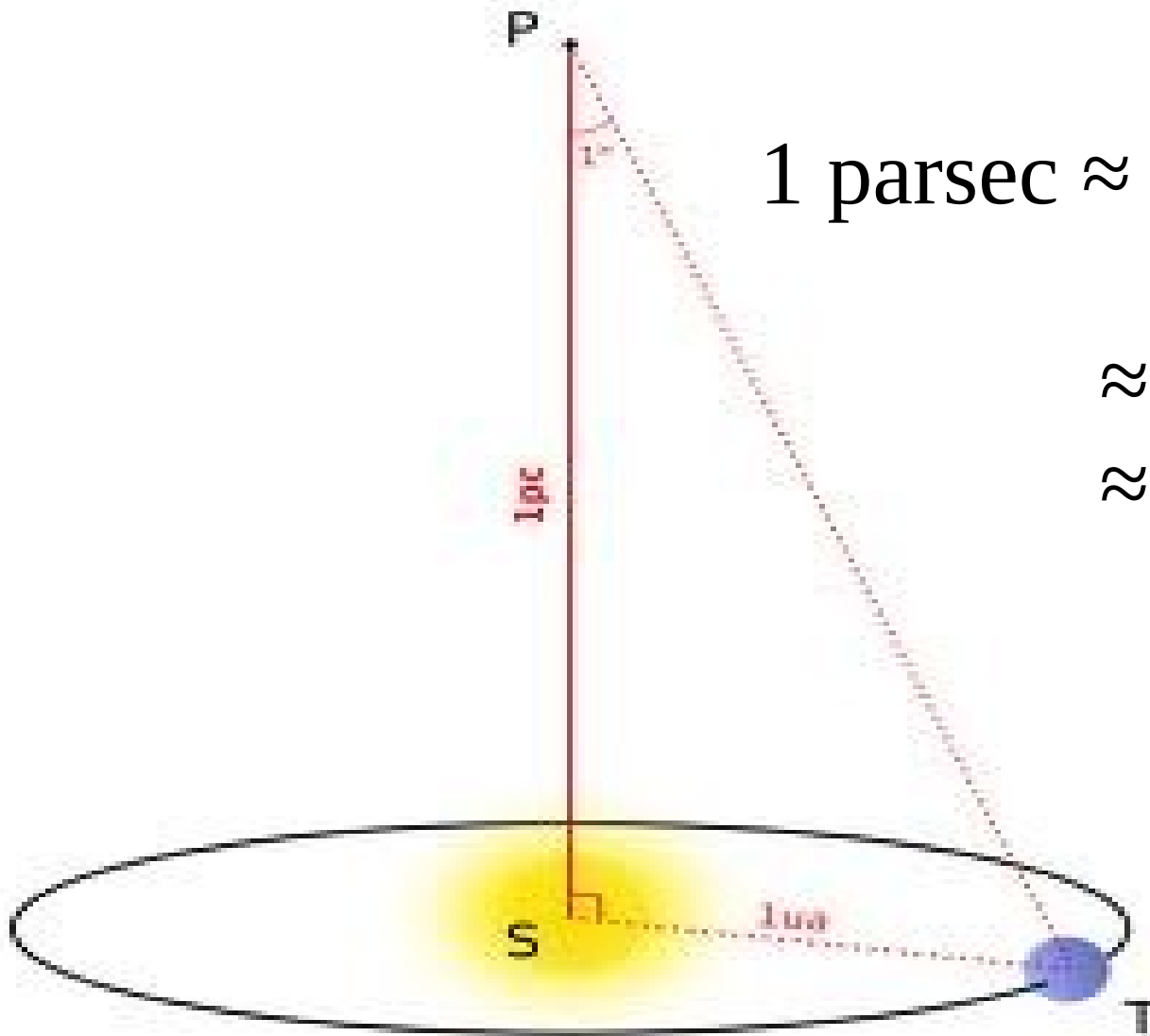
- **General Relativity**
 - ◆ Orbit of Mercury
 - ◆ Deflection of light by the Sun (1919)
- The matter in the Universe is **homogeneous** and **isotropic** when averaged over very large scales (300 Mpc and more).

Cosmological Principle

1 parsec $\approx 3 \times 10^{16}$ m

$\approx 206.26 \times 10^3$ AU

≈ 3.26 light years



Object	Distance
Alpha Centauri	1.3 pc
Crab nebula	2 kpc
Sun to the center of Galaxy	8 kpc
Andromeda (M31)	800 kpc
Virgo cluster	15 Mpc

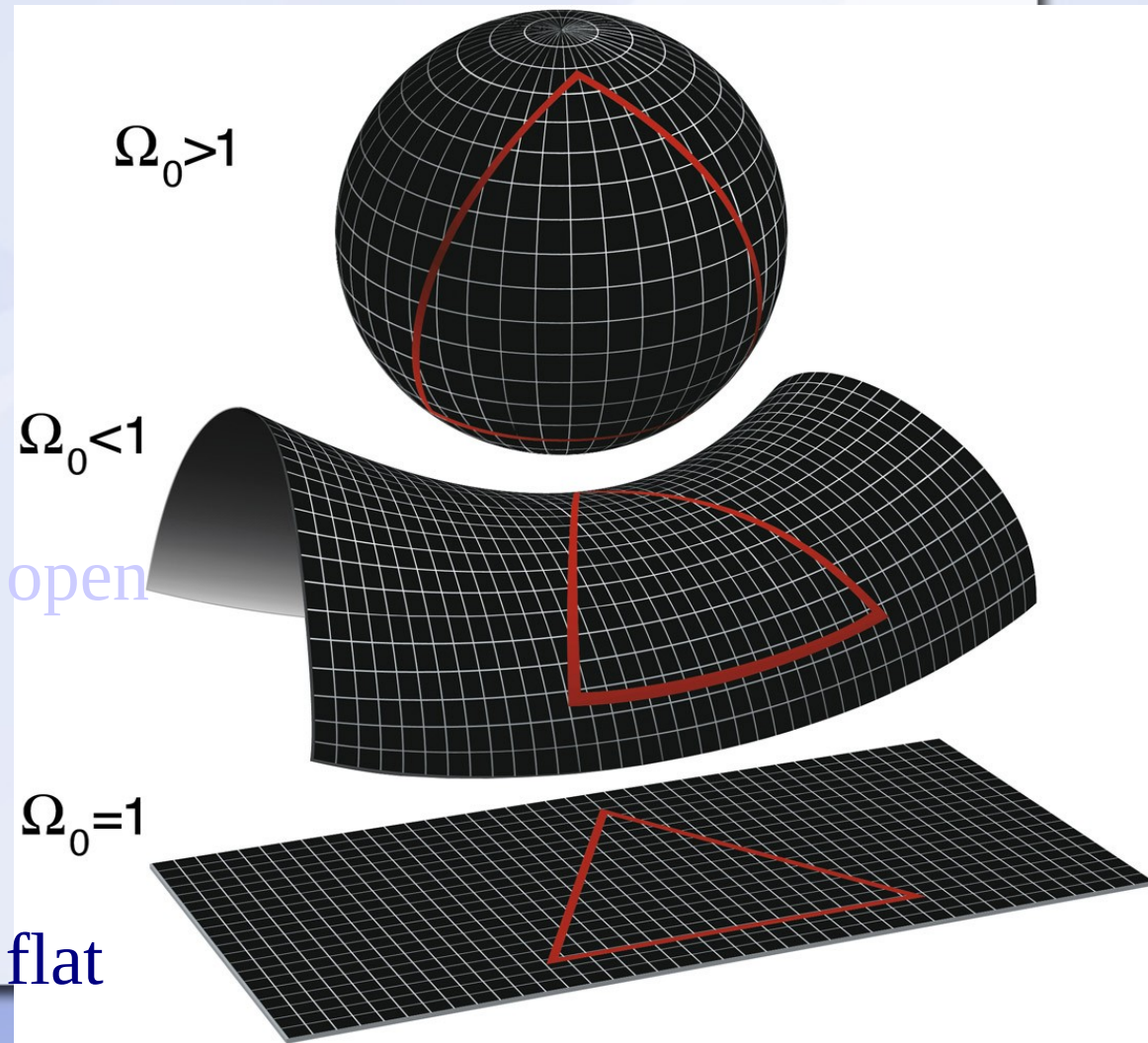
size of Milky Way ~ 30 kpc

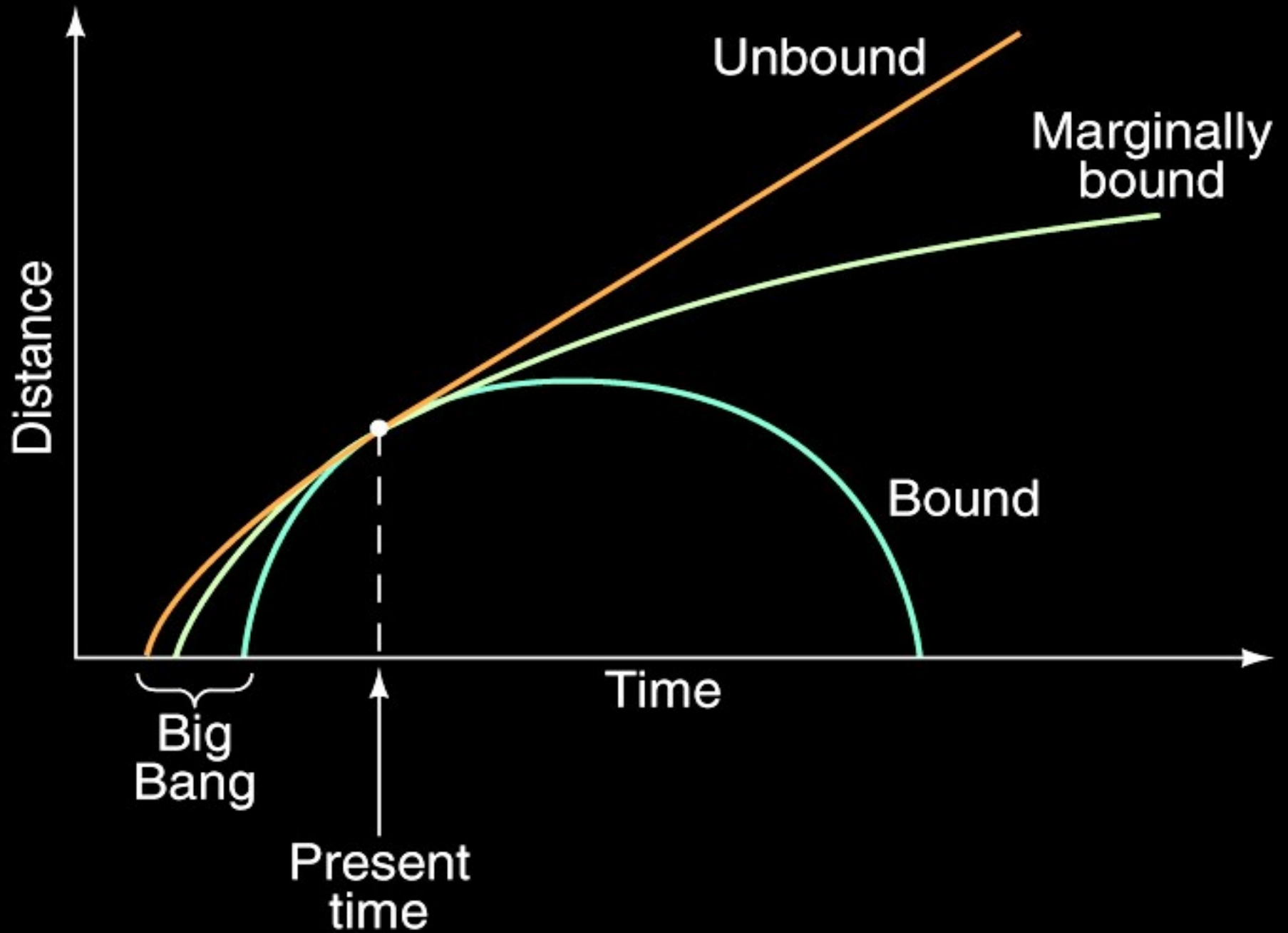
size of a cluster ~ 1-3 Mpc

Shape of the Universe

3 Possibilities in Einstein's General Relativity:

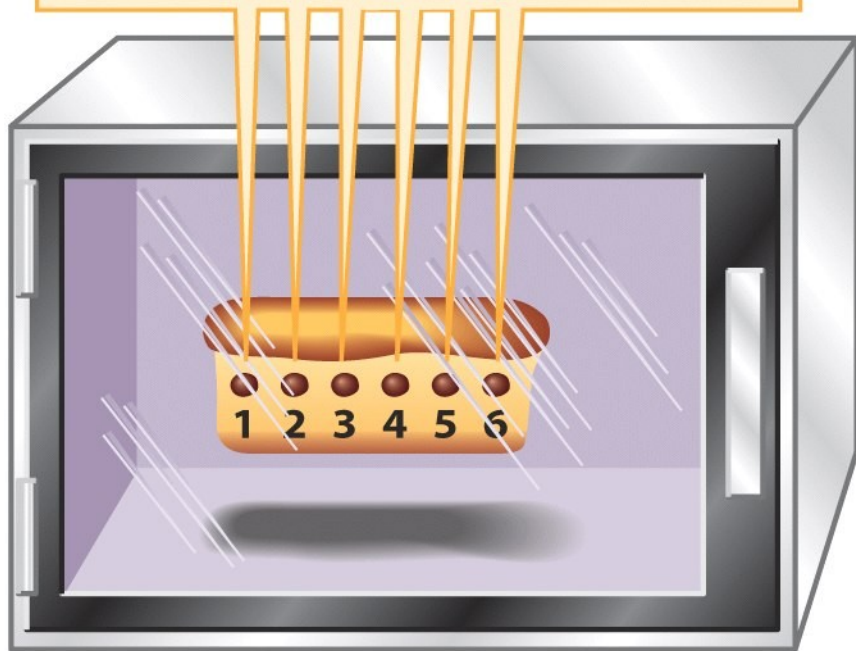
- finite – closed
- infinite and unbounded - open
- infinite and unbounded - flat



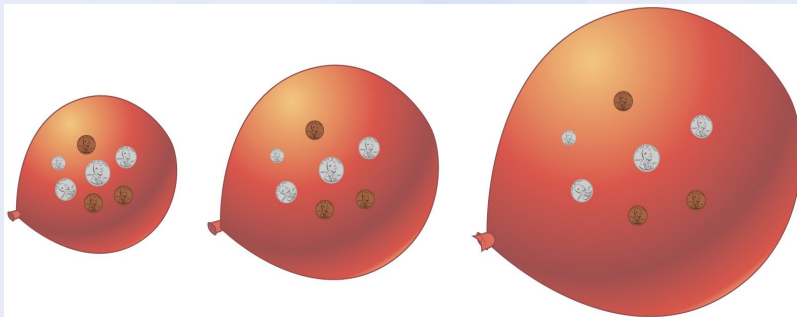
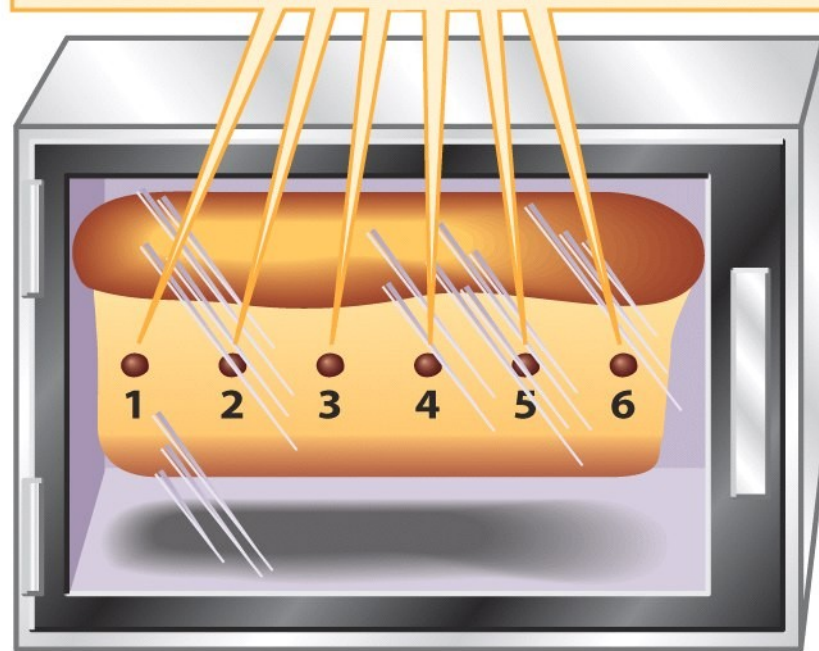


Hubble law

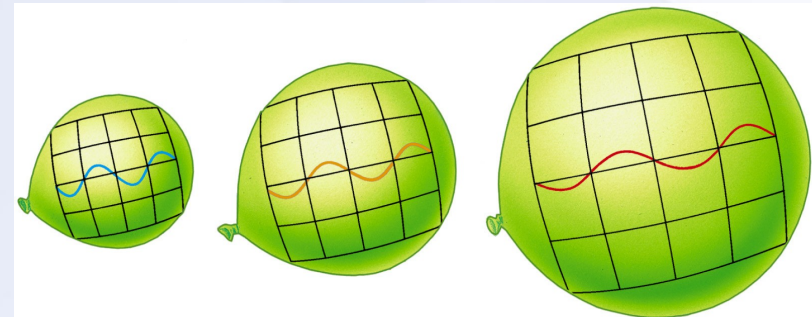
Six chocolate chips are evenly spaced within an unbaked cake.



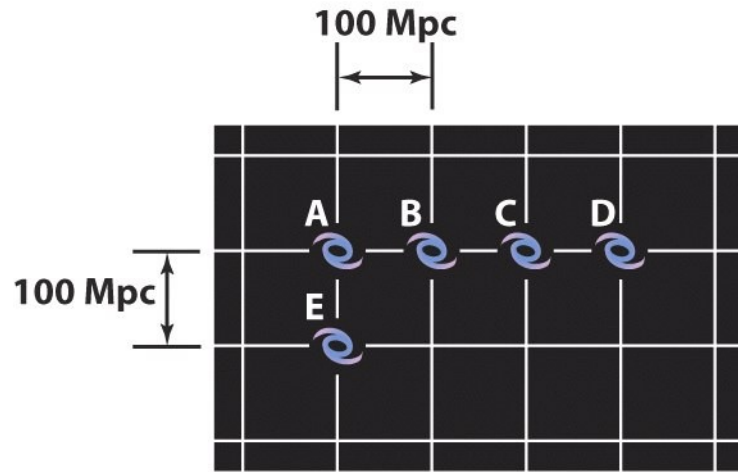
Each chocolate chip has moved farther away from all the other chips.



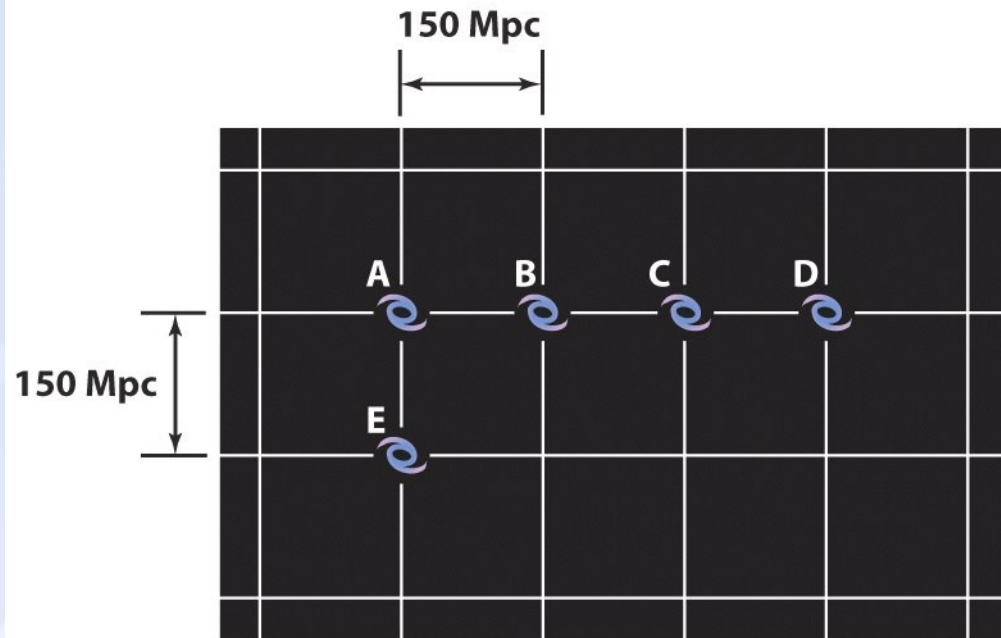
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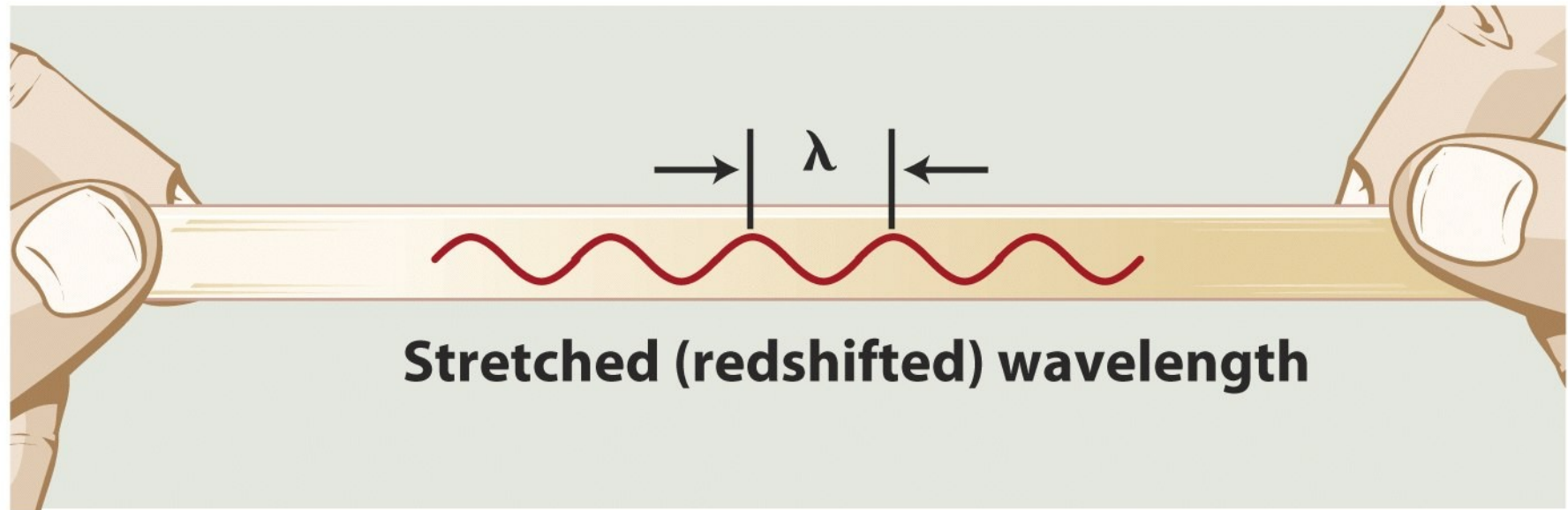
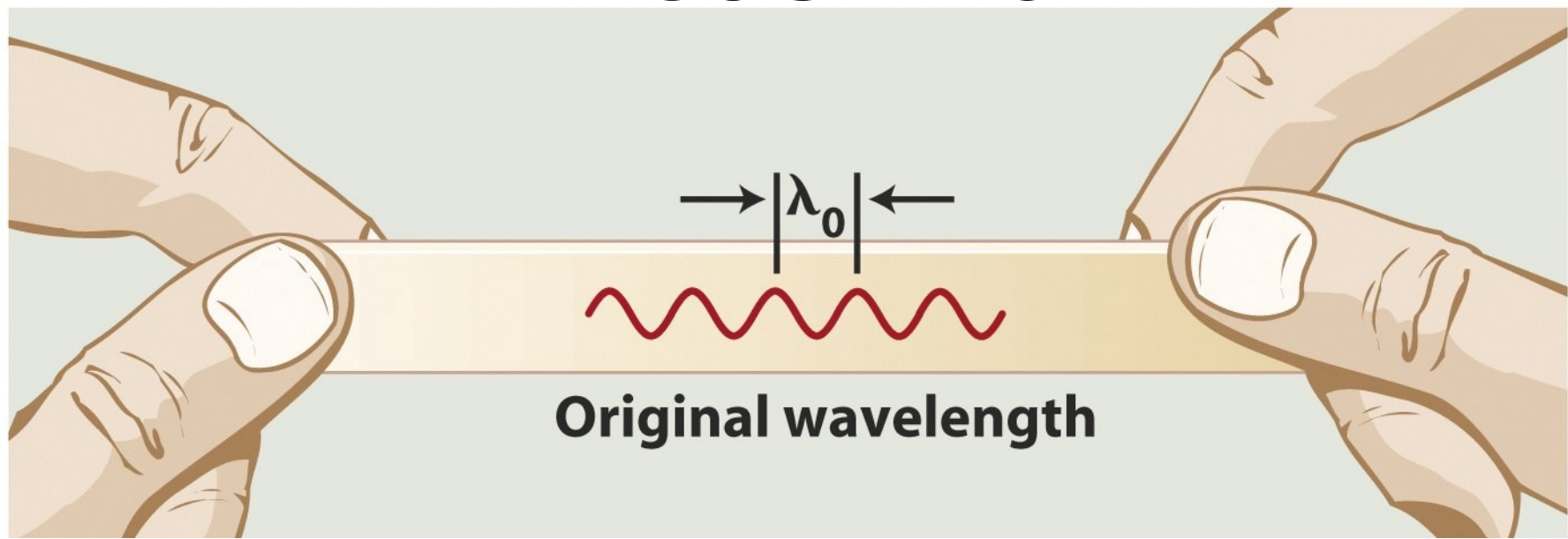


(a) Five galaxies spaced 100 Mpc apart



(b) The expansion of the universe spreads the galaxies apart

Redshift

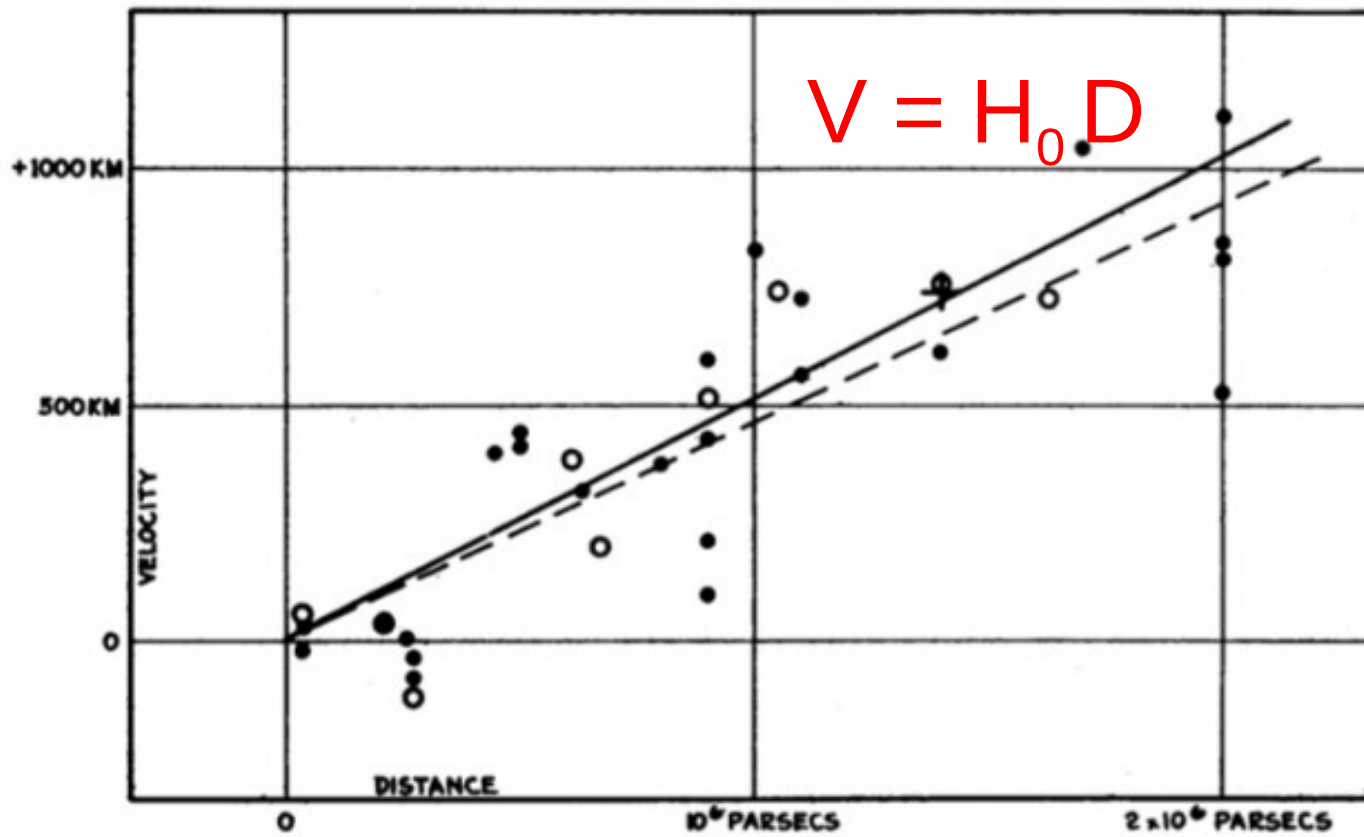


Formalism

Standard Candles

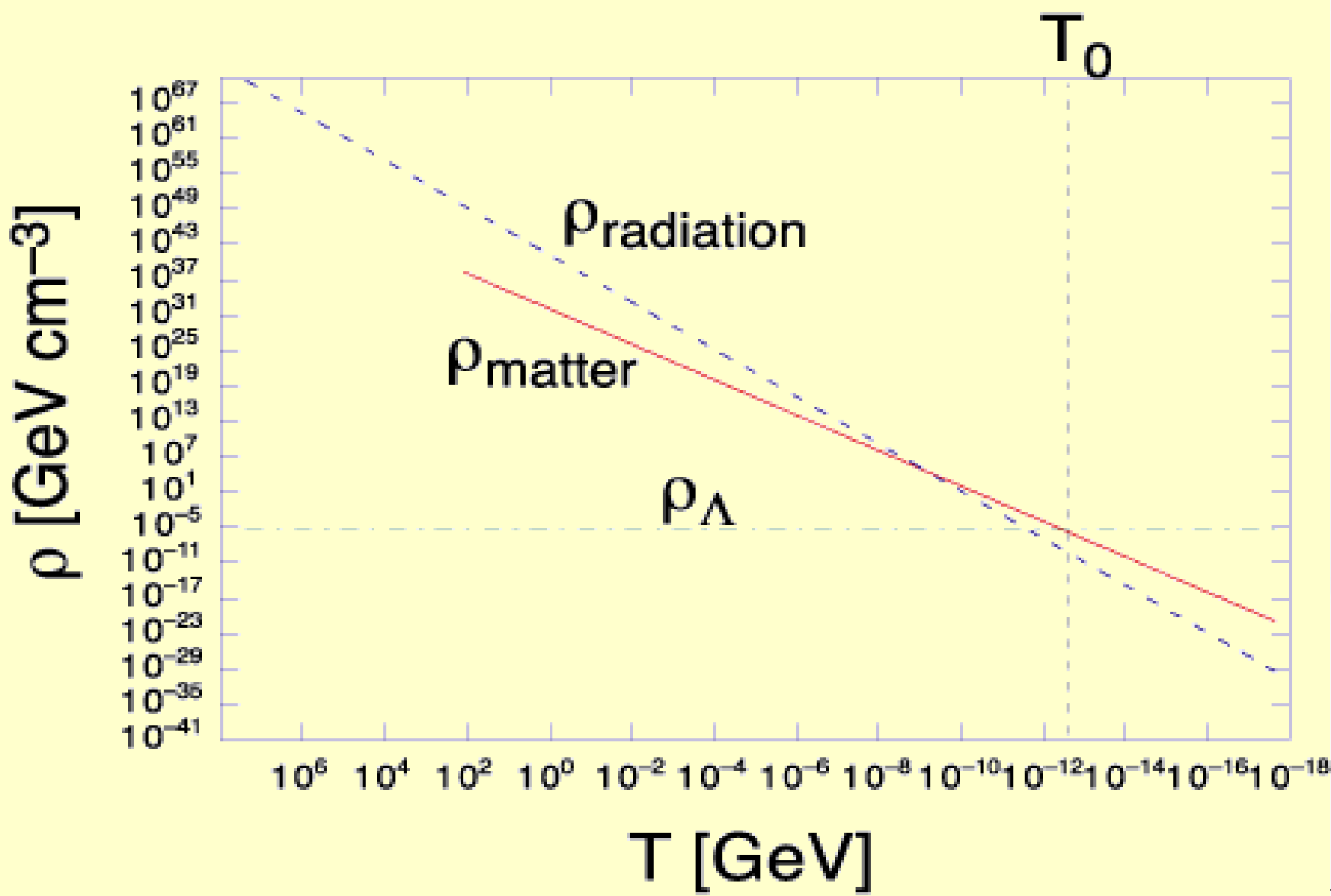


Velocity [km/s]

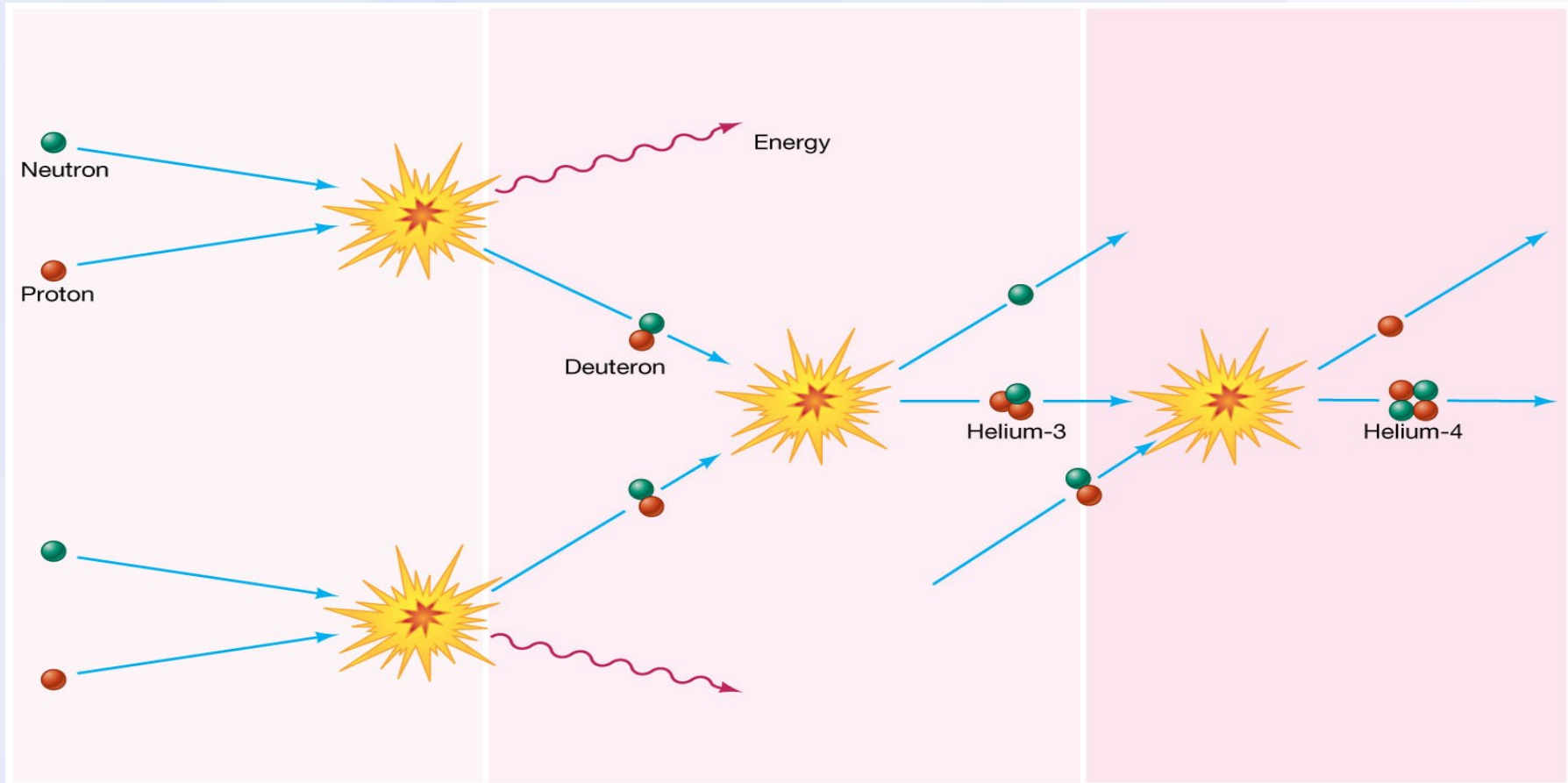


Distance [pc]

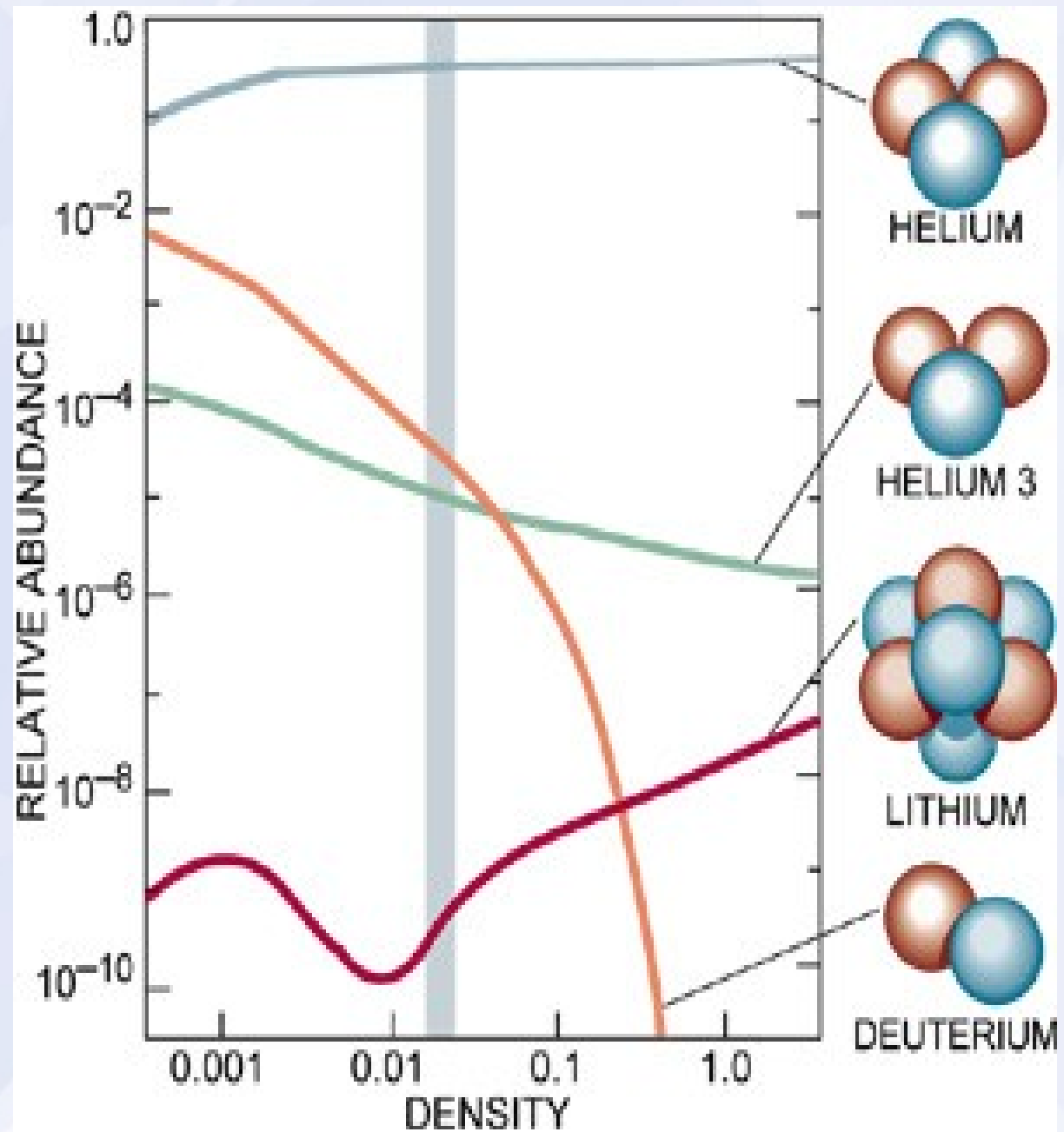
$$H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$$



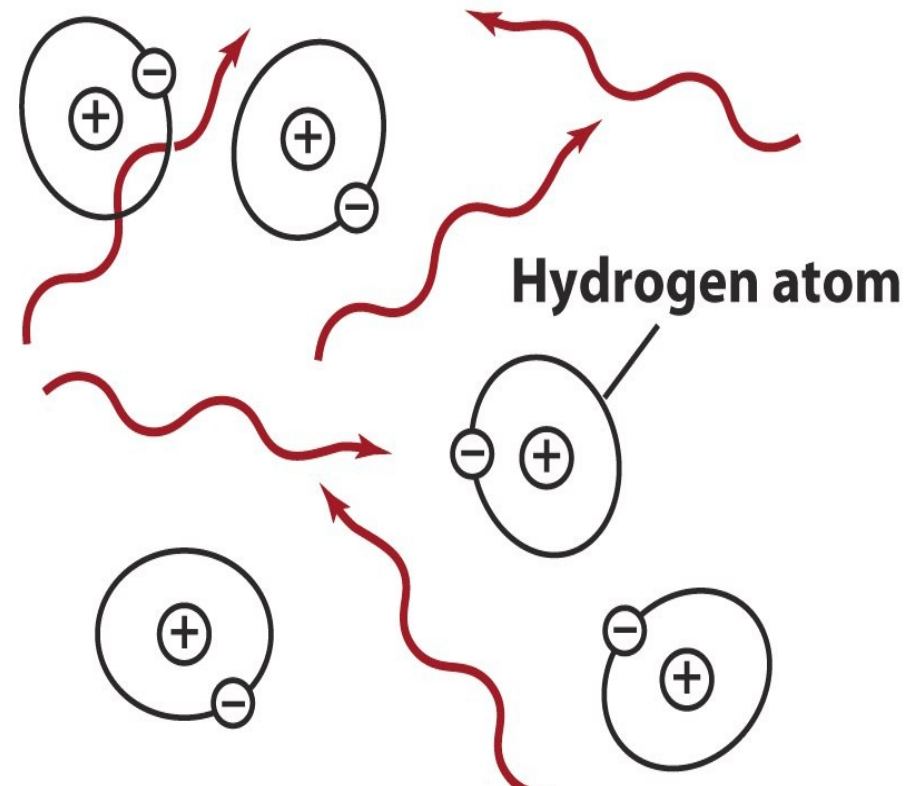
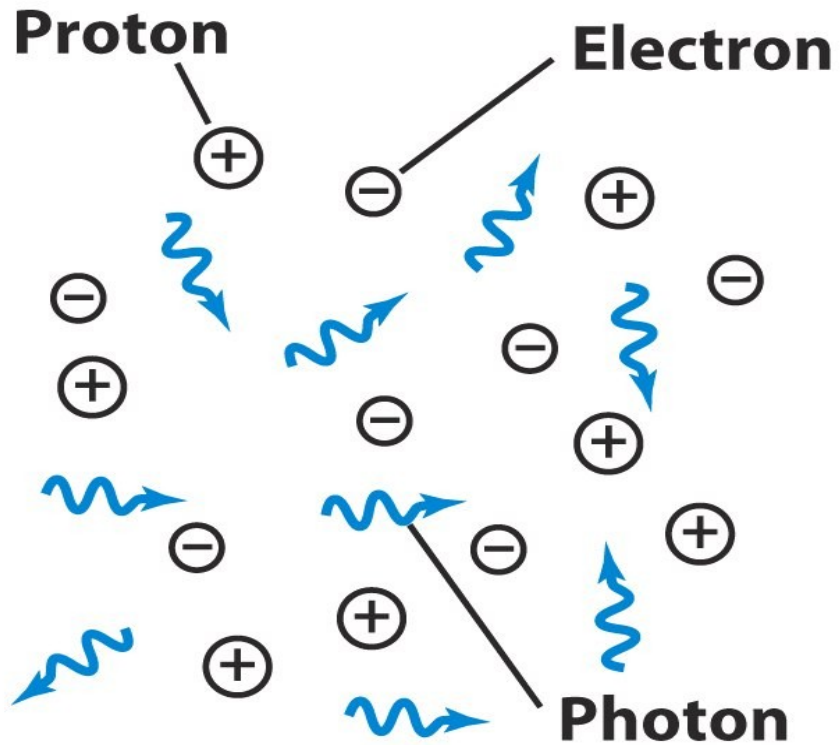
Big Bang Nucleosynthesis (BBN)



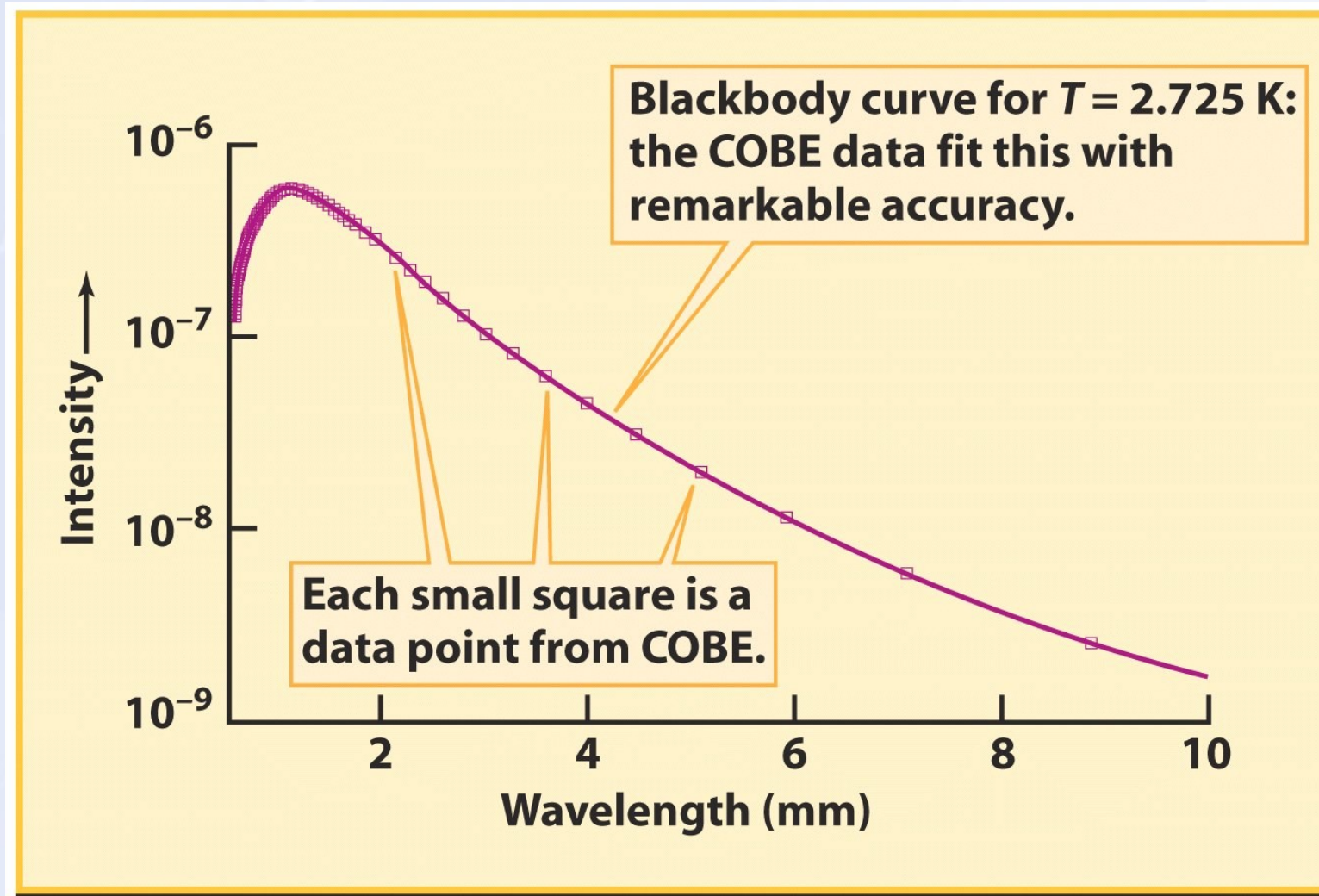
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Recombination



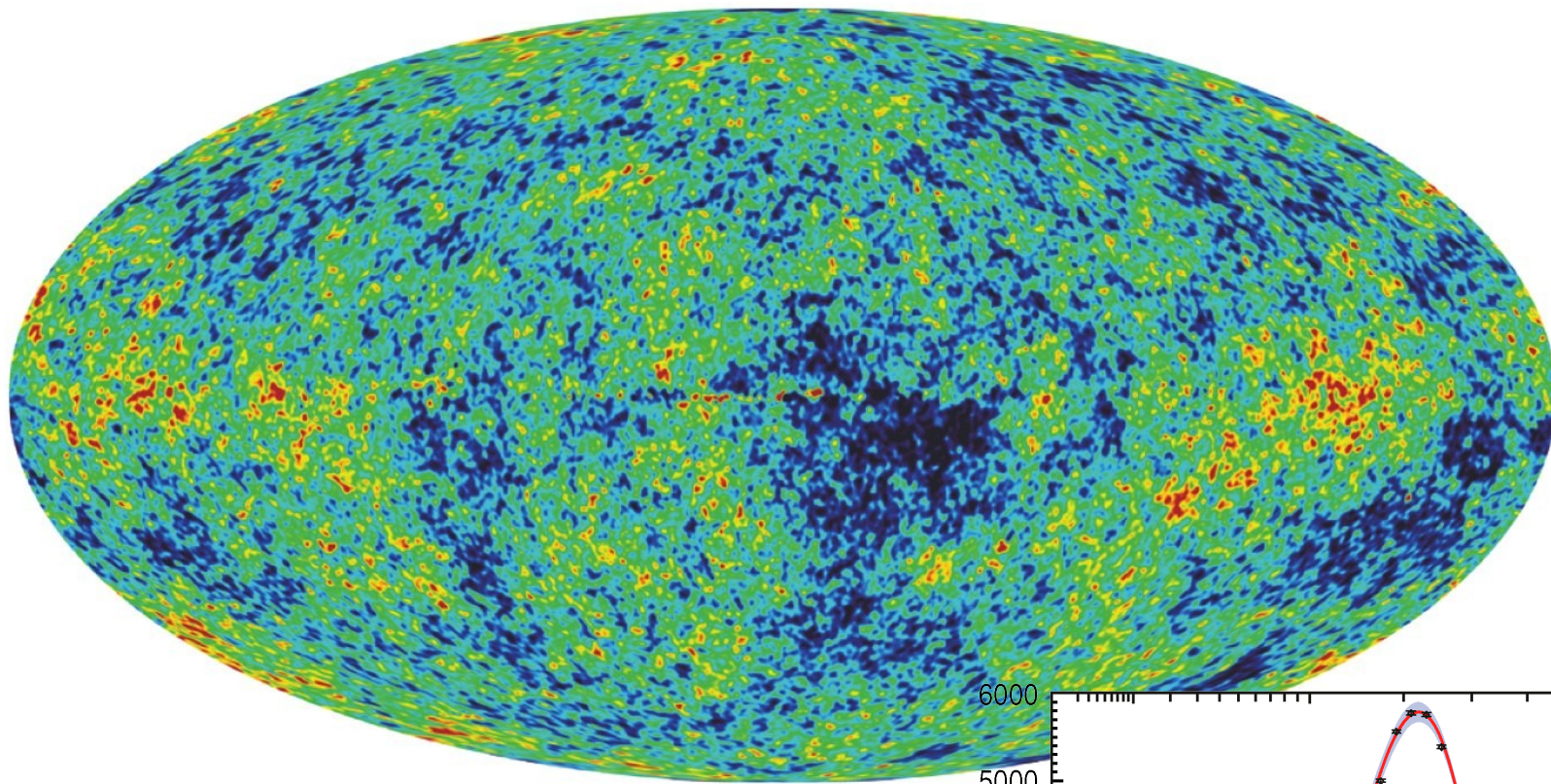
Cosmic Microwave Background (CMB)



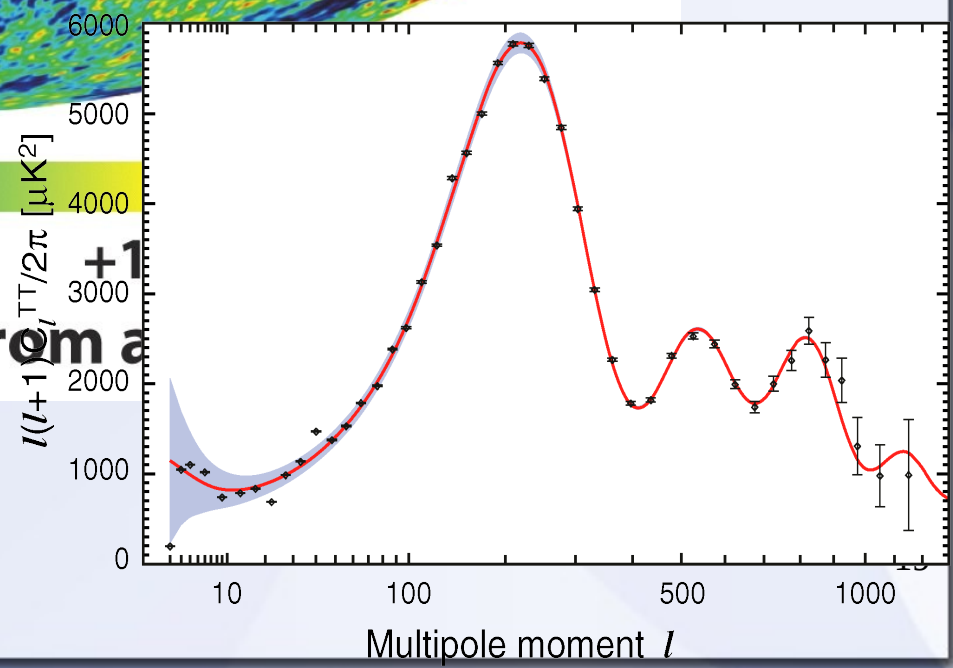
The spectrum of the cosmic microwave background

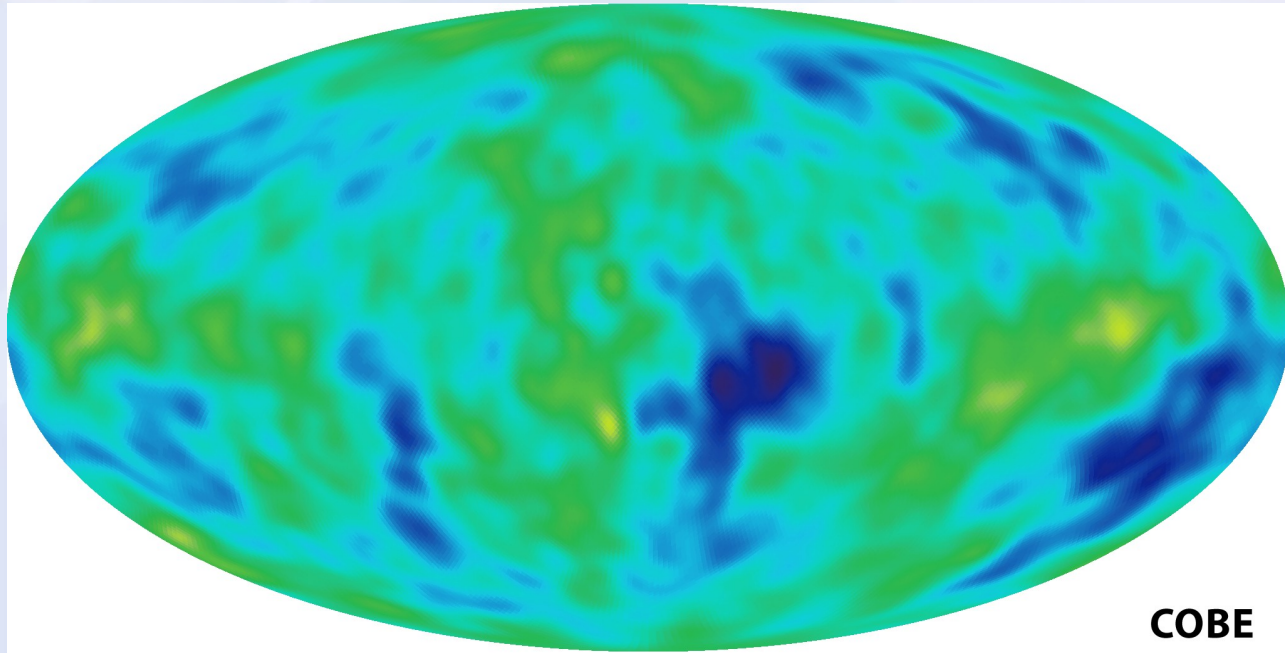
Temperature vs Wavelength

Temperature	Peak Wavelength
3K	About 1 mm (radio waves)
300K room temp	About 10 microns (infrared)
6000K surface of Sun	About 0.5 micron (visible light)
3,000,000 K	About 1 nanometer (x-rays, gamma-rays)

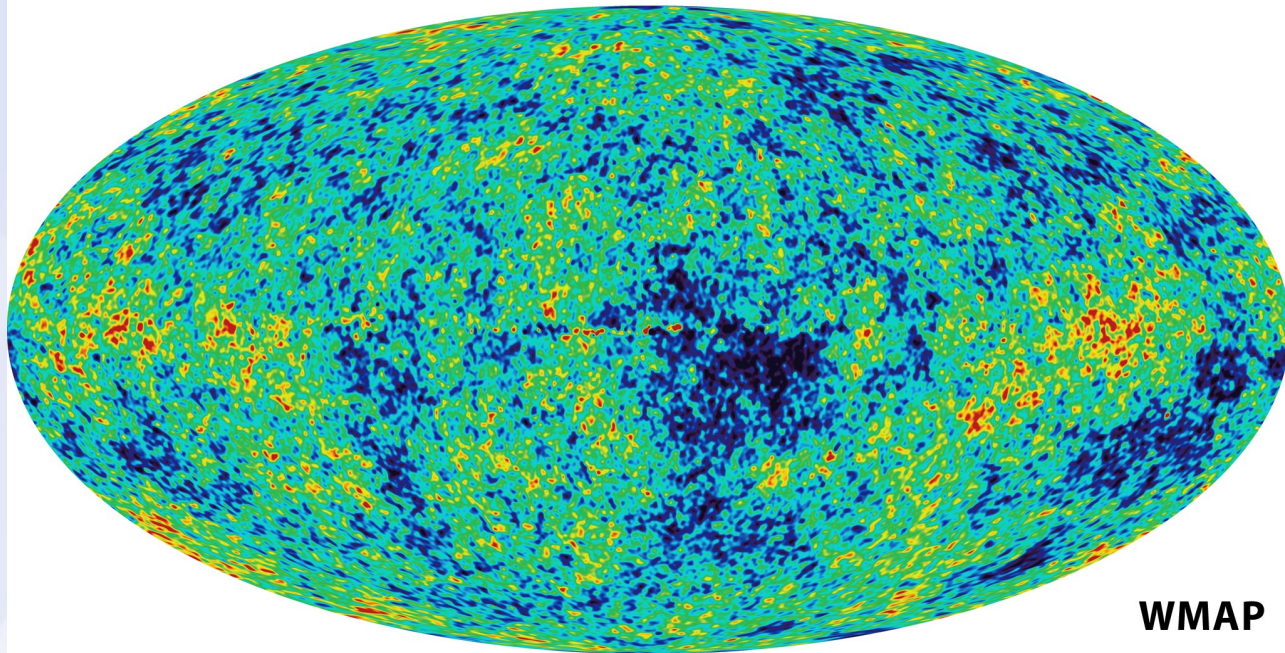


Temperature difference from a

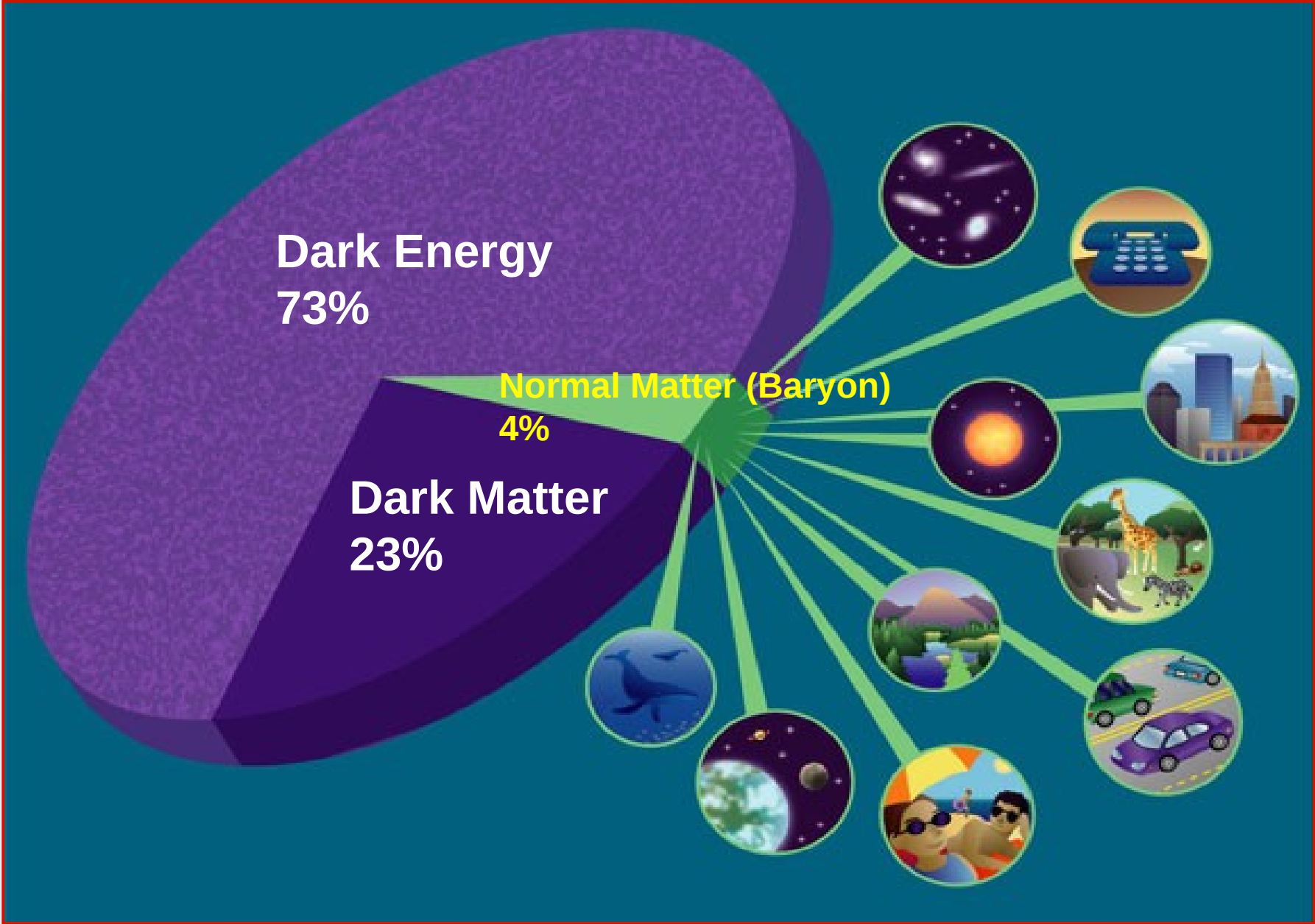




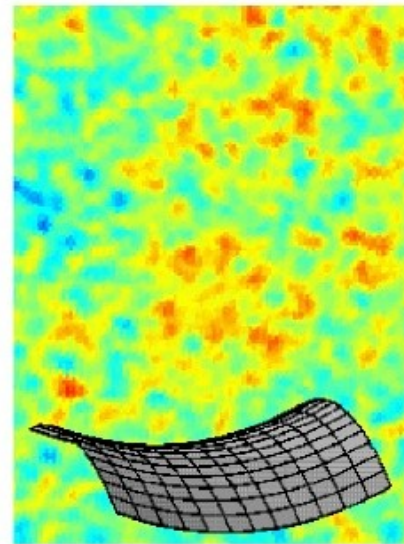
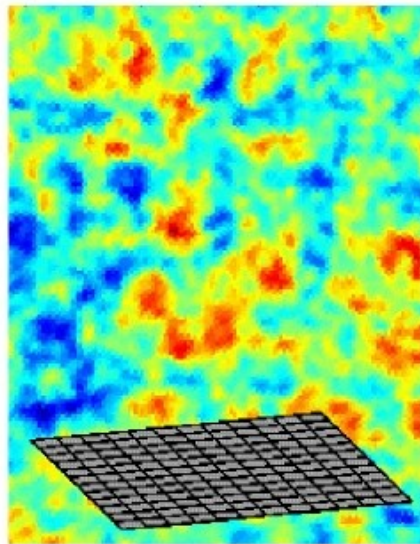
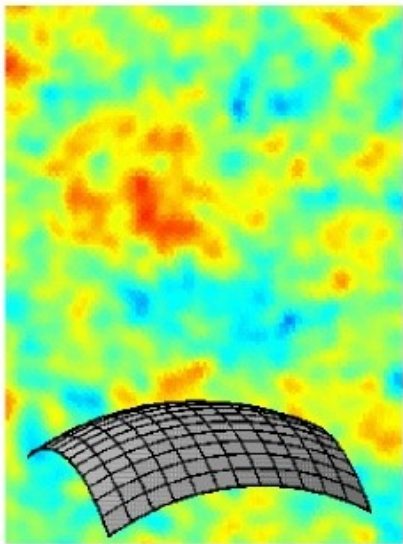
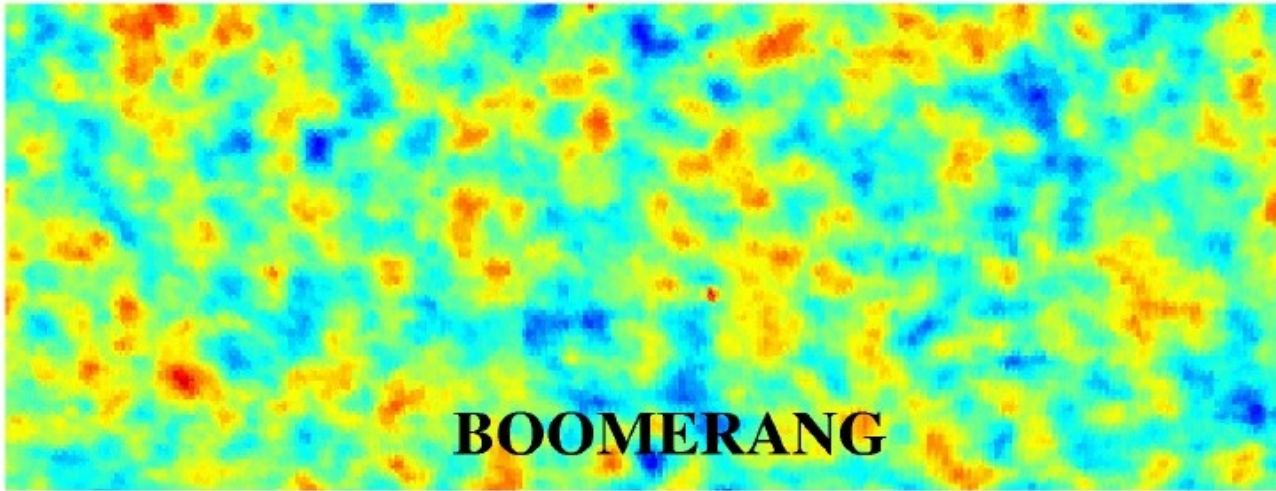
COBE



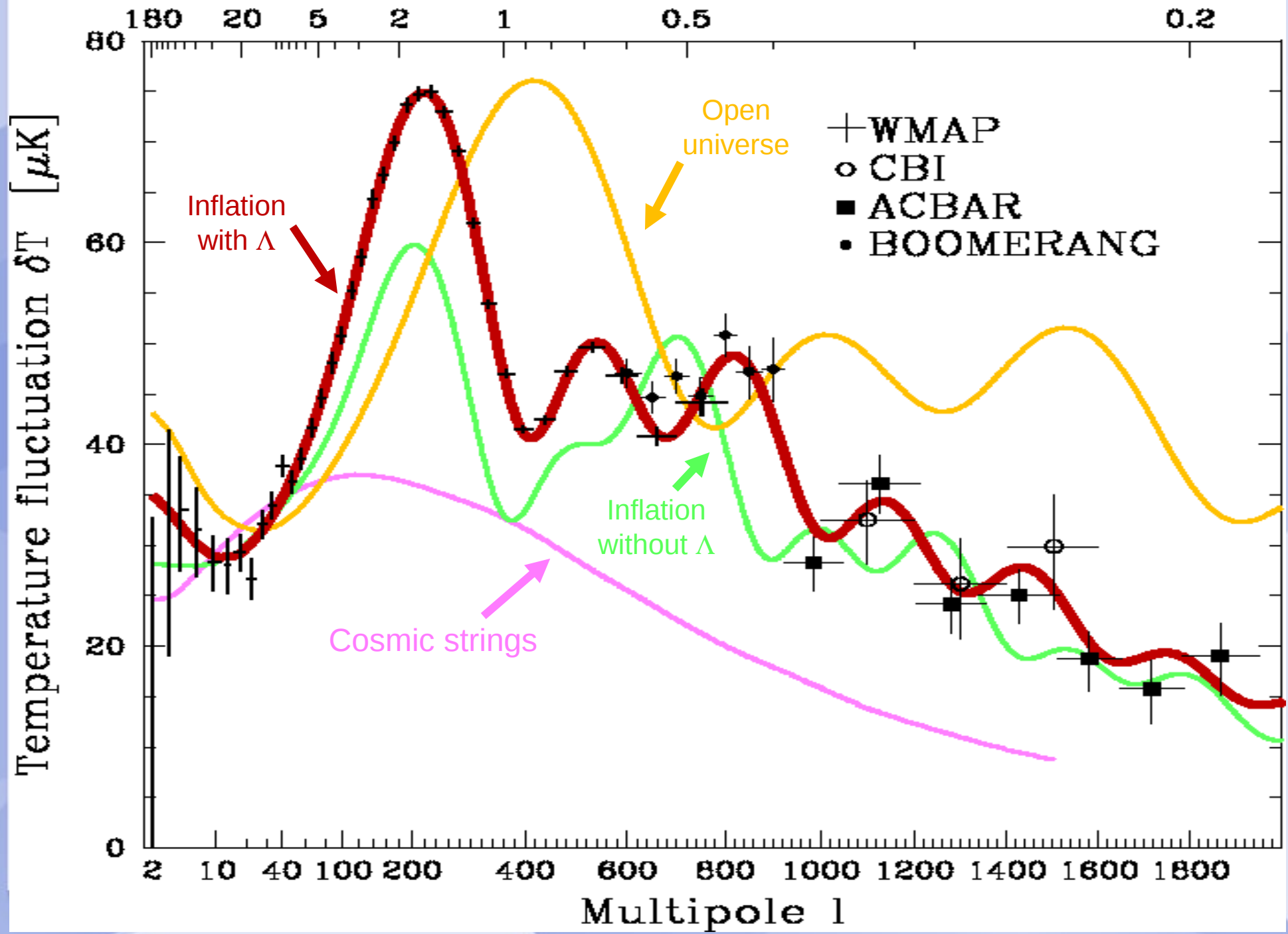
WMAP



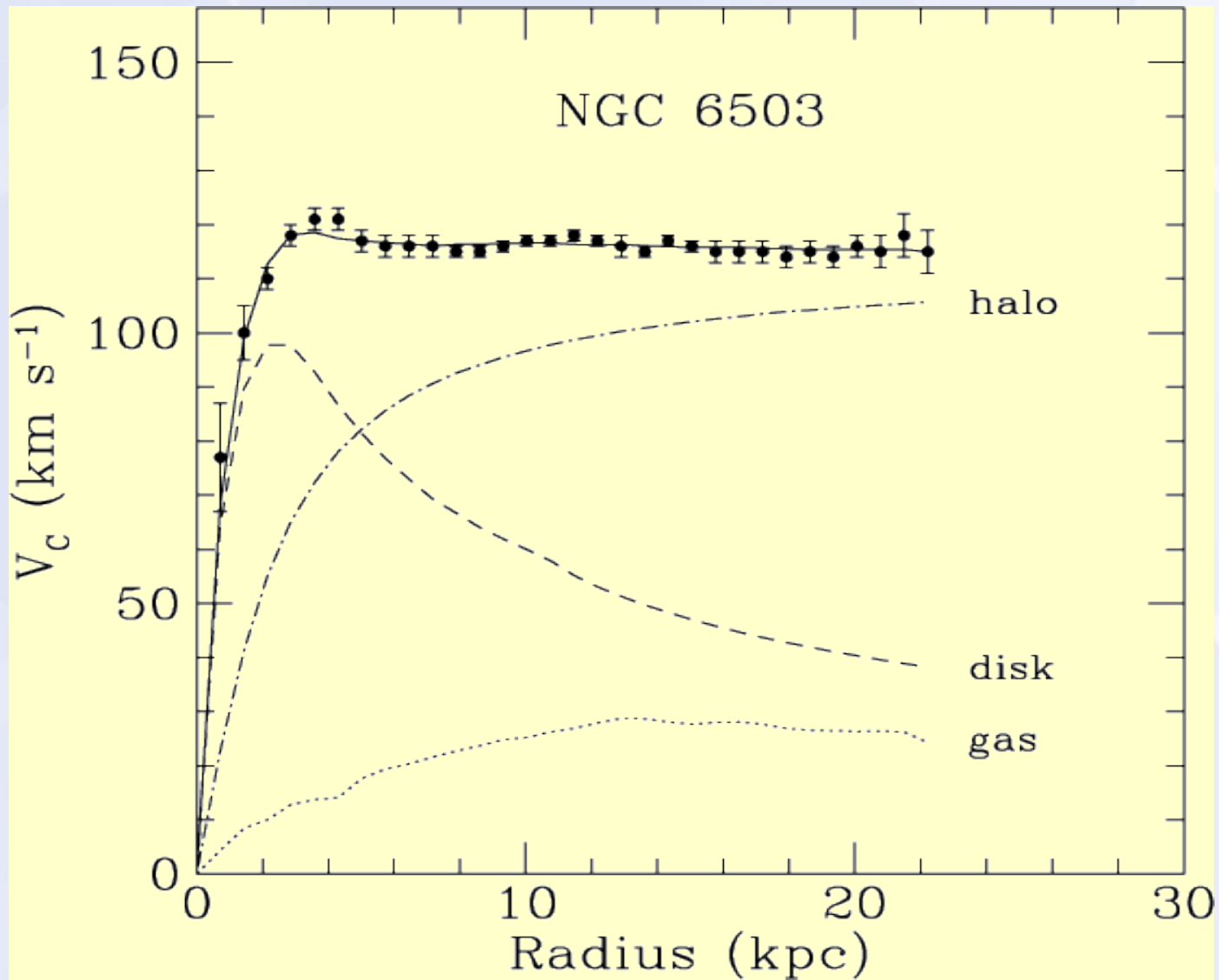
25°



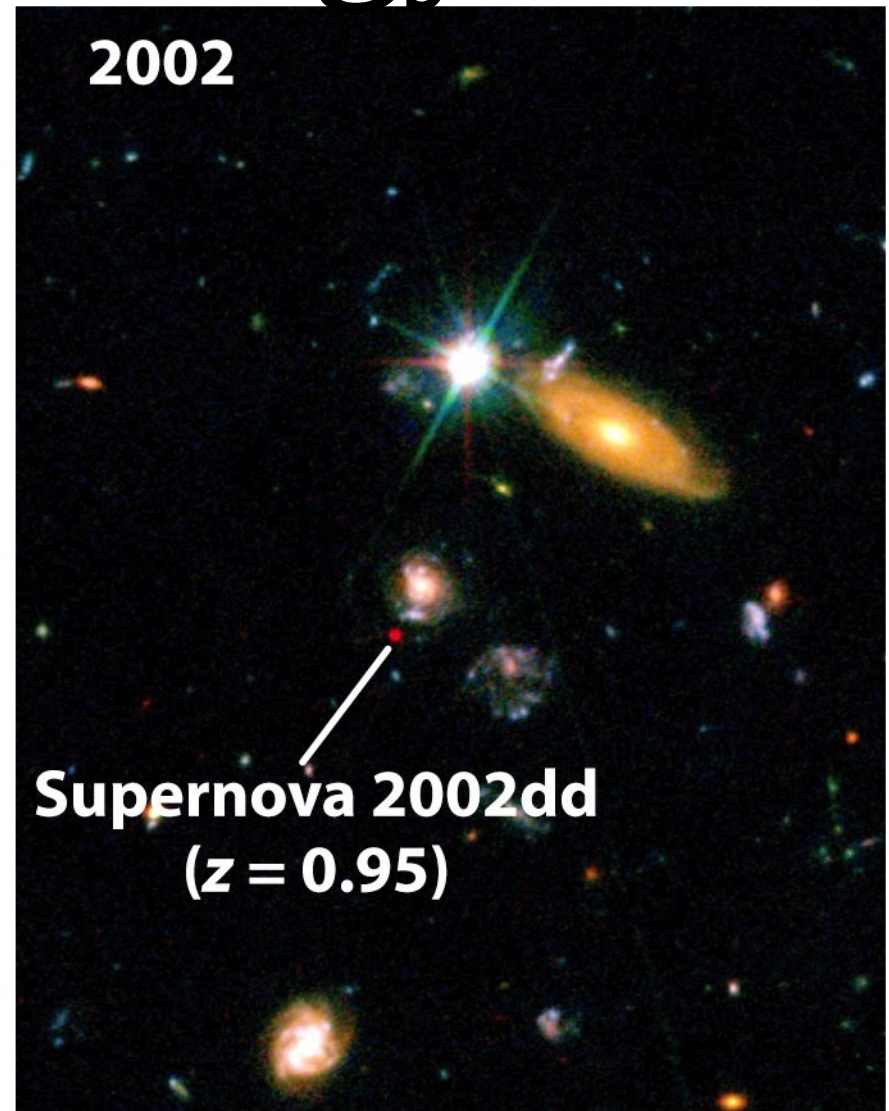
Angular wavelength in degrees



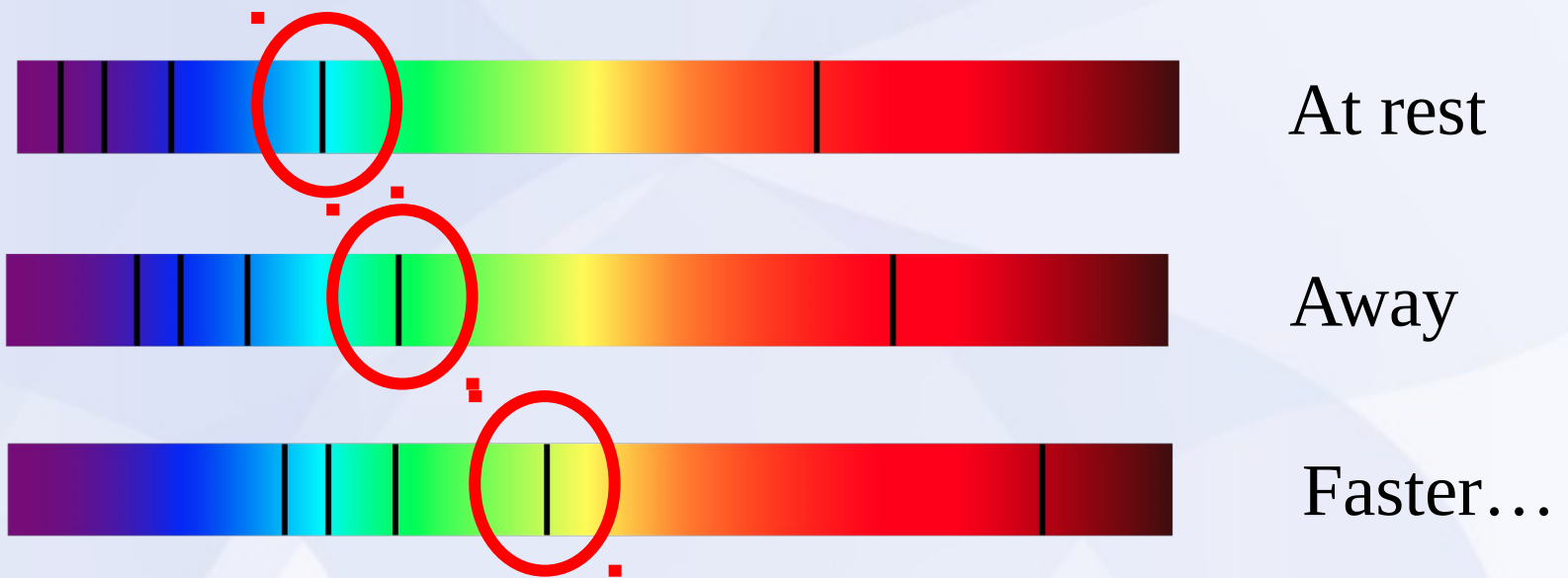
Dark Matter



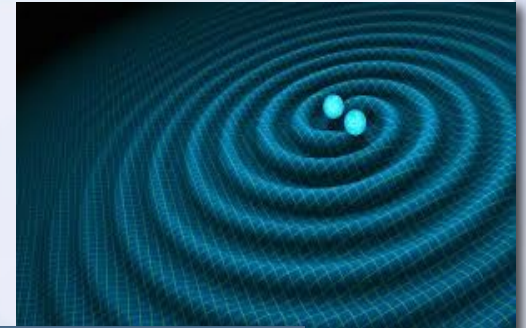
Dark Energy



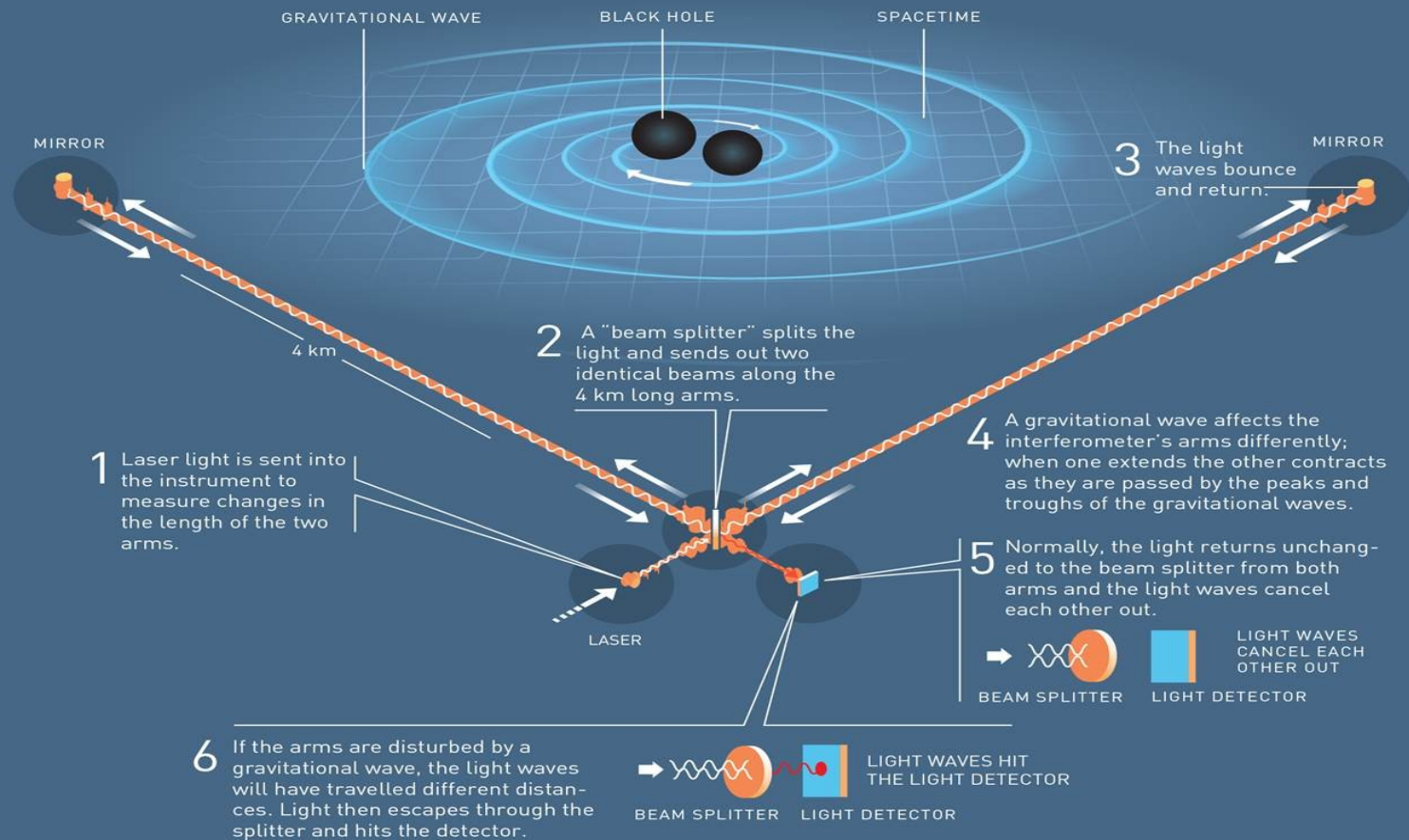
The expanding Universe...



Gravitational Waves

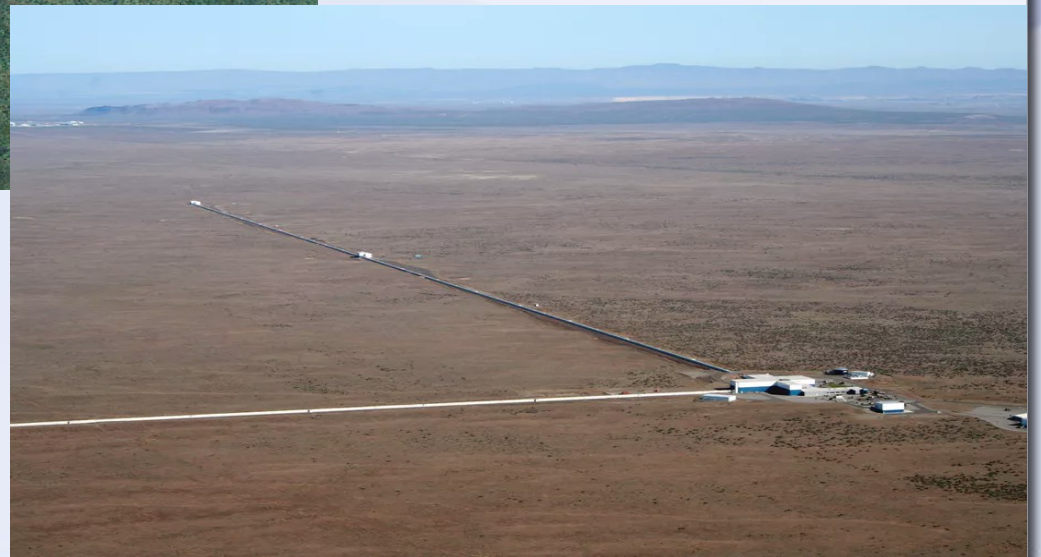
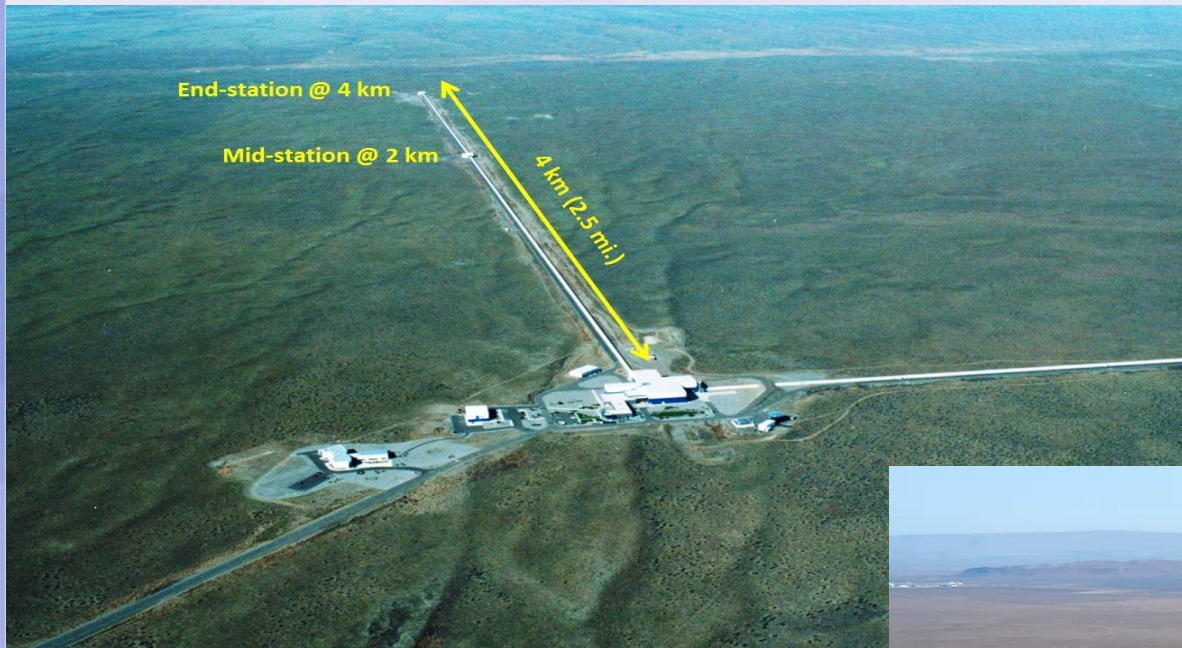


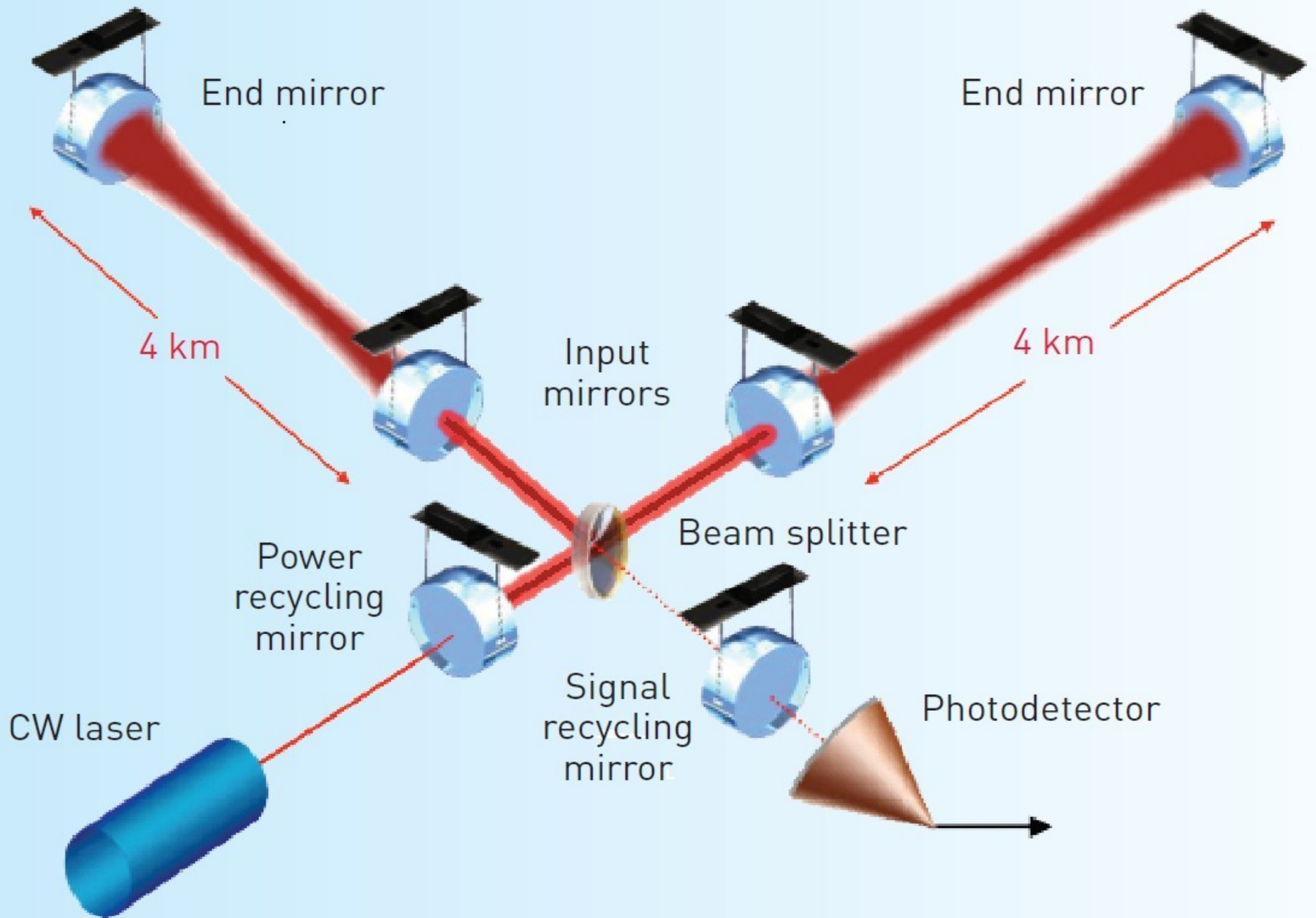
LIGO – A GIGANTIC INTERFEROMETER



LIGO

Laser Interferometer Gravitational
Wave Observatory



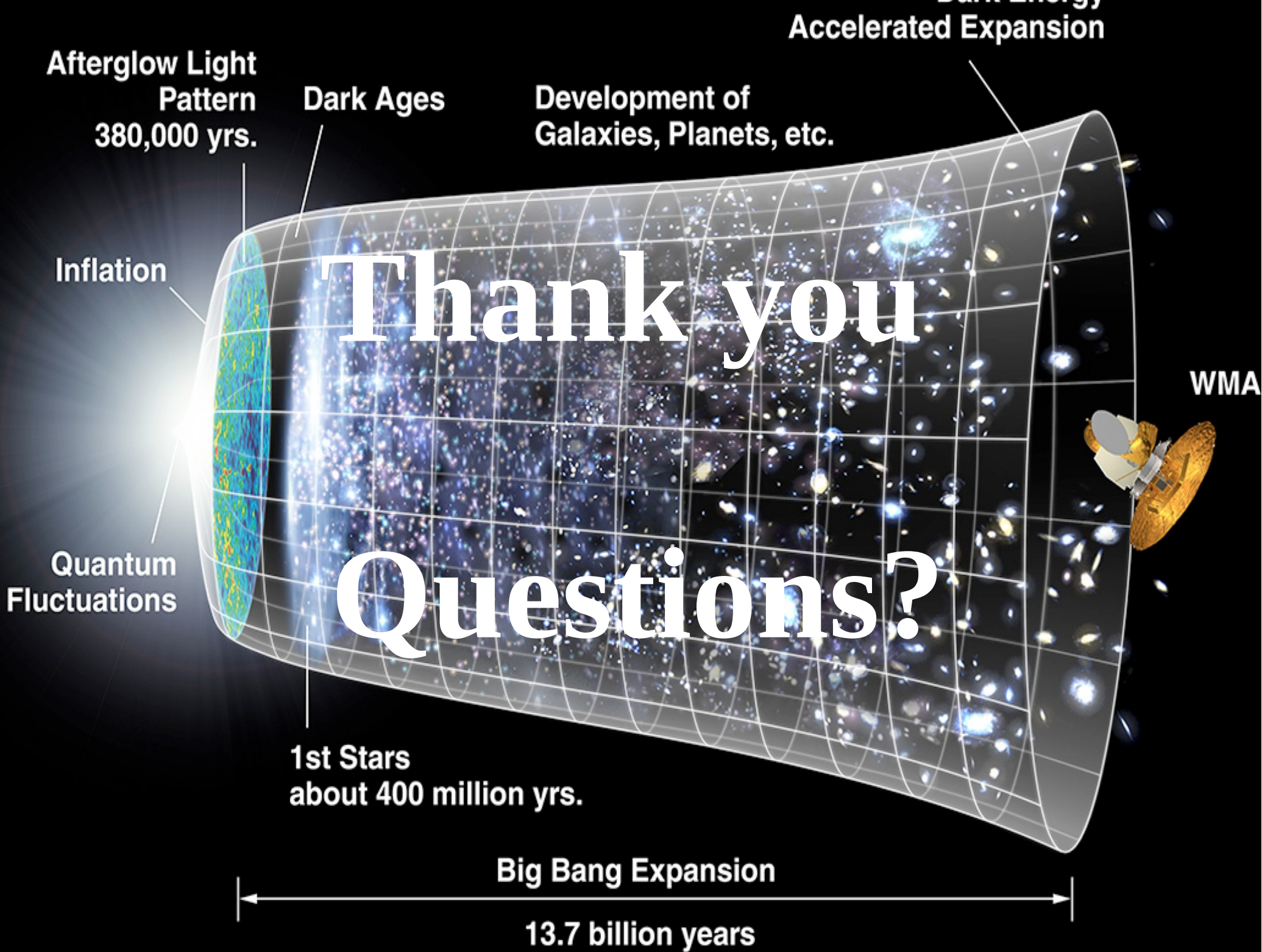


What do we know ?

- The Universe is made of baryons, Dark Matter and Dark Energy.
- The Universe is expanding.
- The Universe is flat.

Open Questions

- Dark Matter ?
- Dark Energy ?
- Future of the Universe ?



Thank you

Questions?