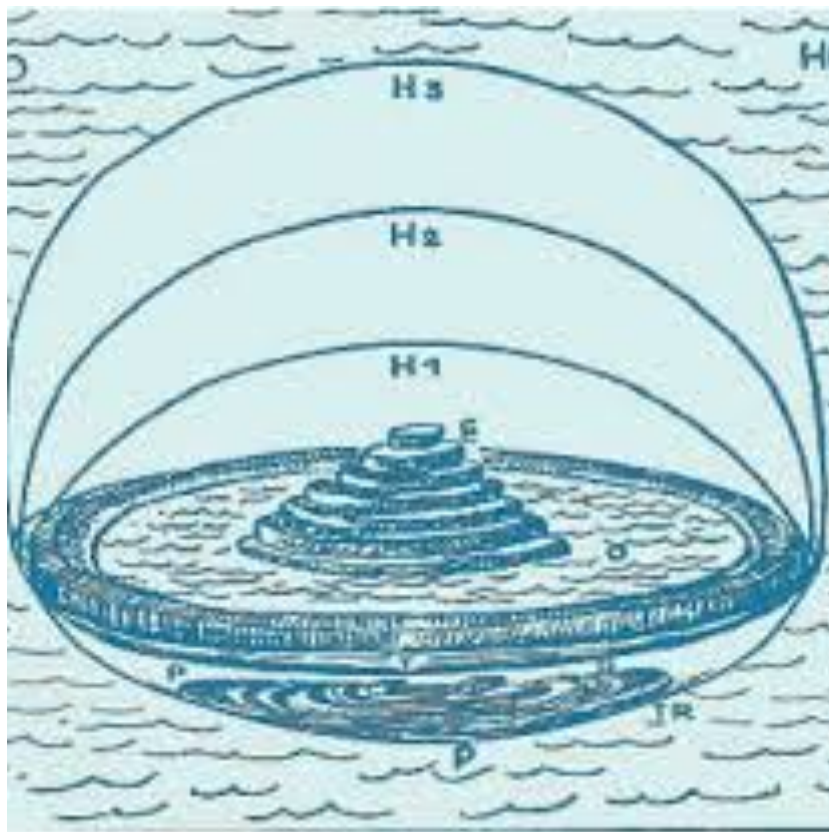


COSMOLOGY, DARK MATTER AND DARK ENERGY

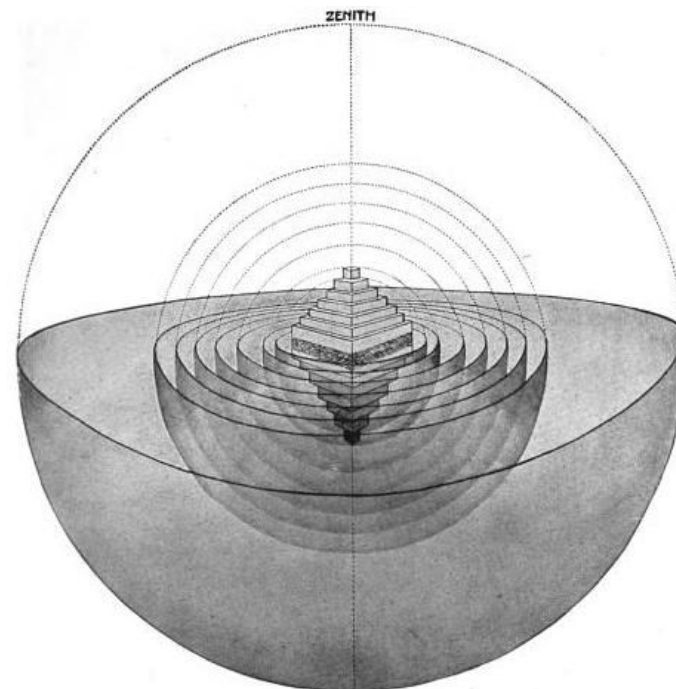
Wasutep Luangtip
Department of Physics,
Srinakharinwirot University

Early models of Universe

Sumerians (7000BC)



Babylonians (2000-500BC)



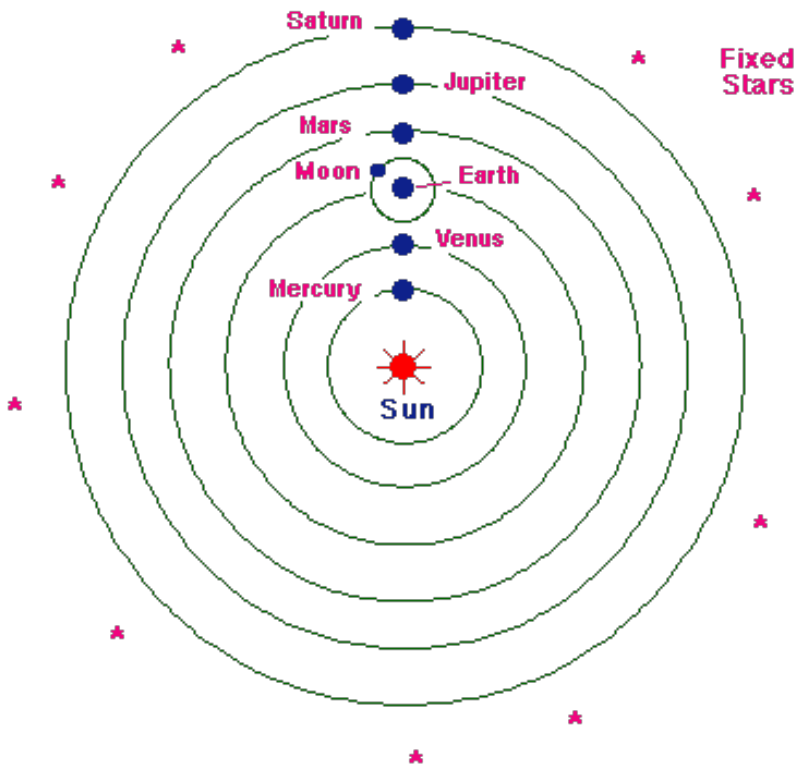
THE BABYLONIAN UNIVERSE

Illustrating pages 33-40

The upright central line is the polar axis of the heavens and earth. The two seven-staged pyramids represent the earth, the upper being the abode of living men, the under one the abode of the dead. The separating waters are the four seas. The seven inner homocentric globes are respectively the domains and special abodes of Sin, Shamash, Nabu, Ishtar, Nergal, Marduk, and Ninib, each being a "world-ruler" in his own planetary sphere. The outermost of the spheres, that of Anu and Ea, is the home of the God stars. The outermost sphere is the domain of the Moon, that of Anu, the outermost

Early models of Universe

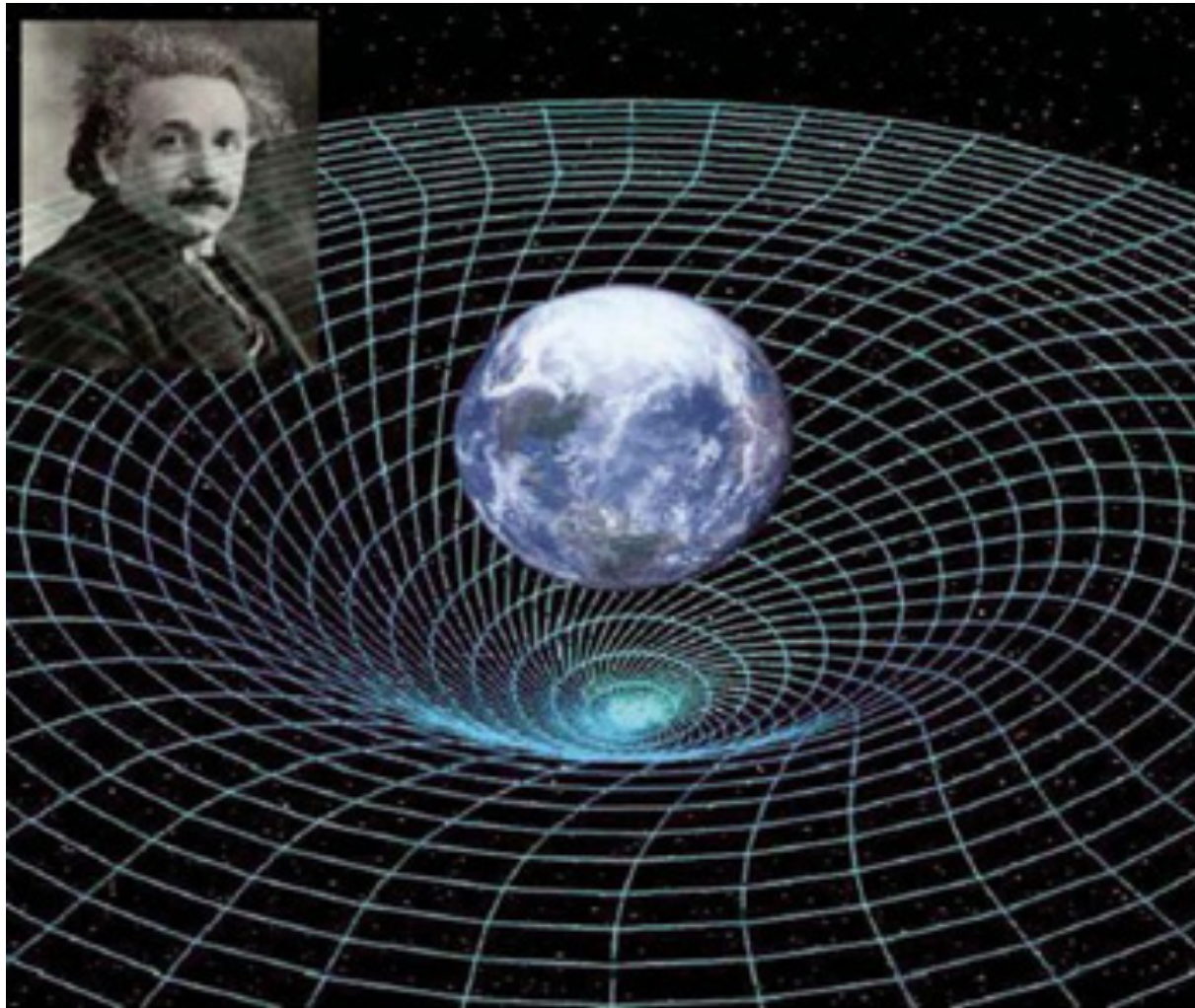
Copernicus (1473-1543)



Galileo (1564-1642)



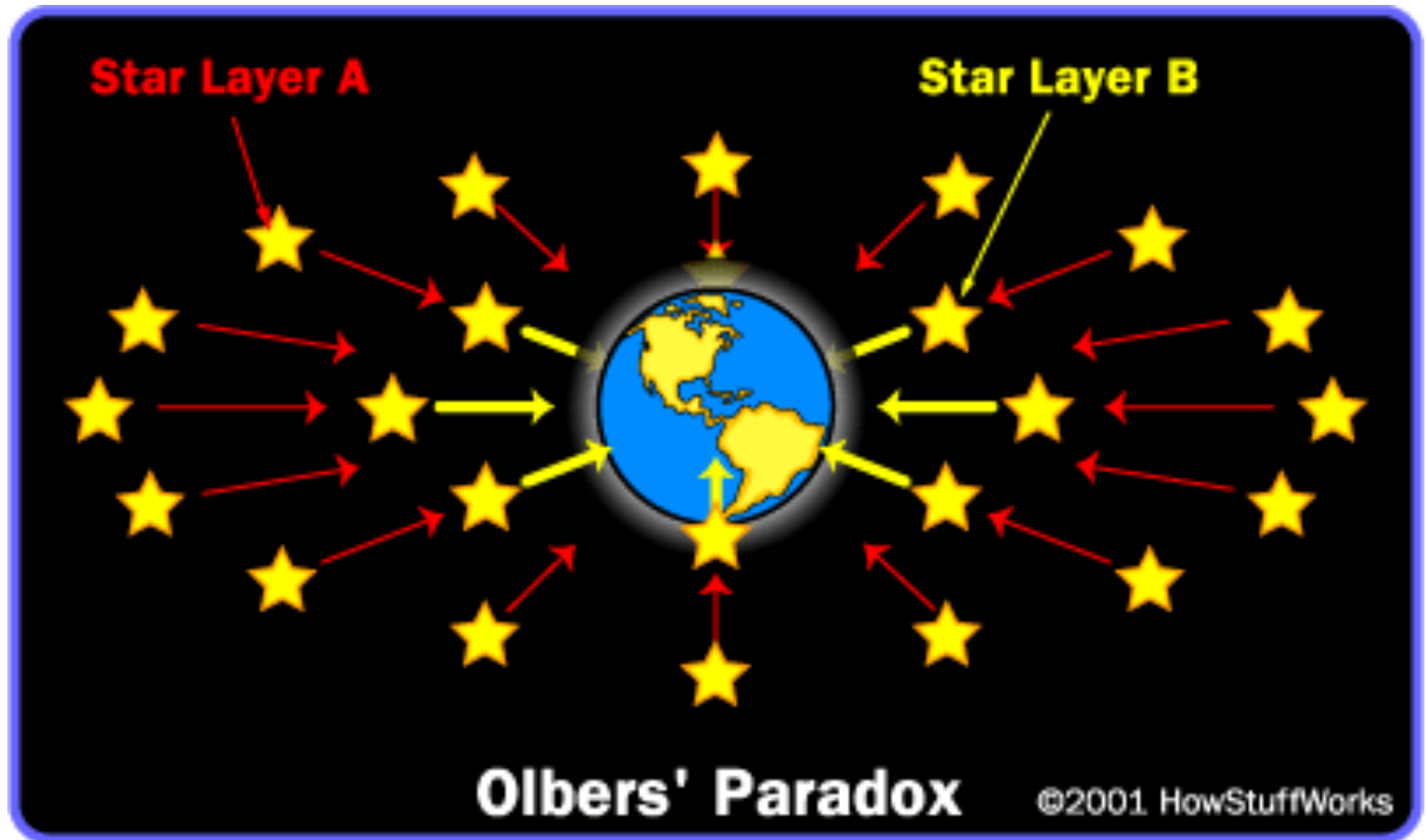
Modern Cosmology



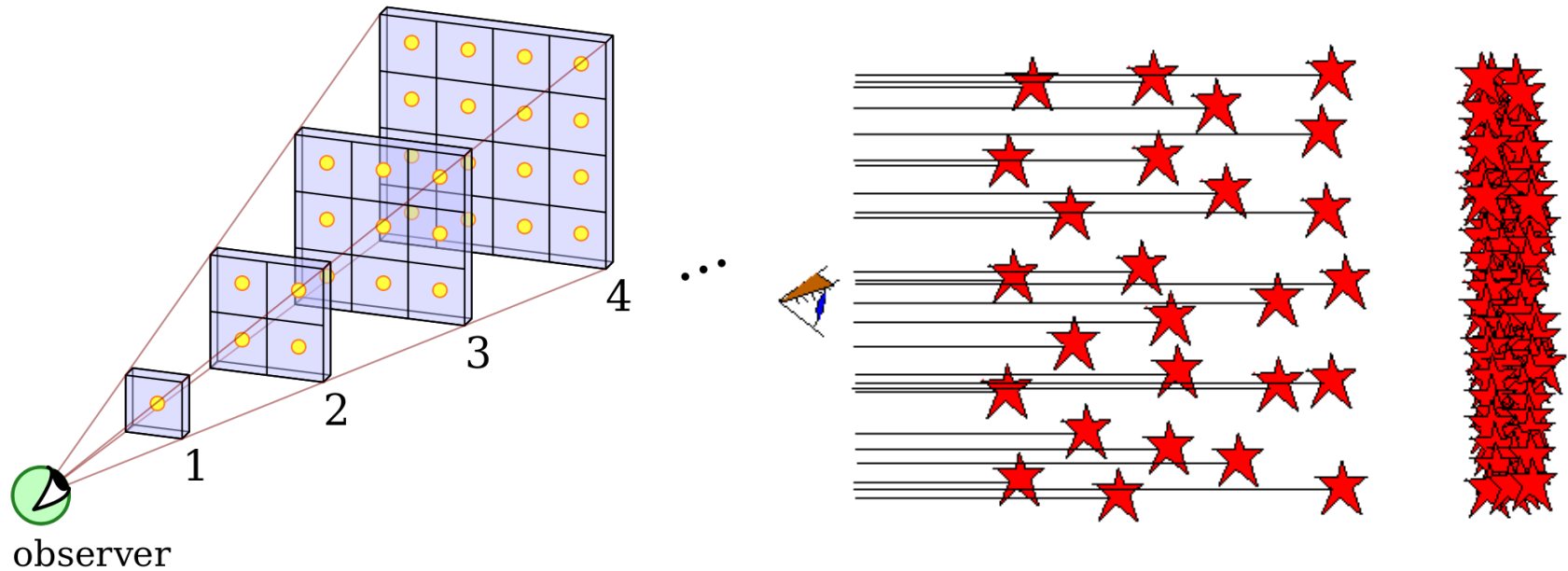
Origin of modern Cosmology: Olber's paradox



Olber's paradox



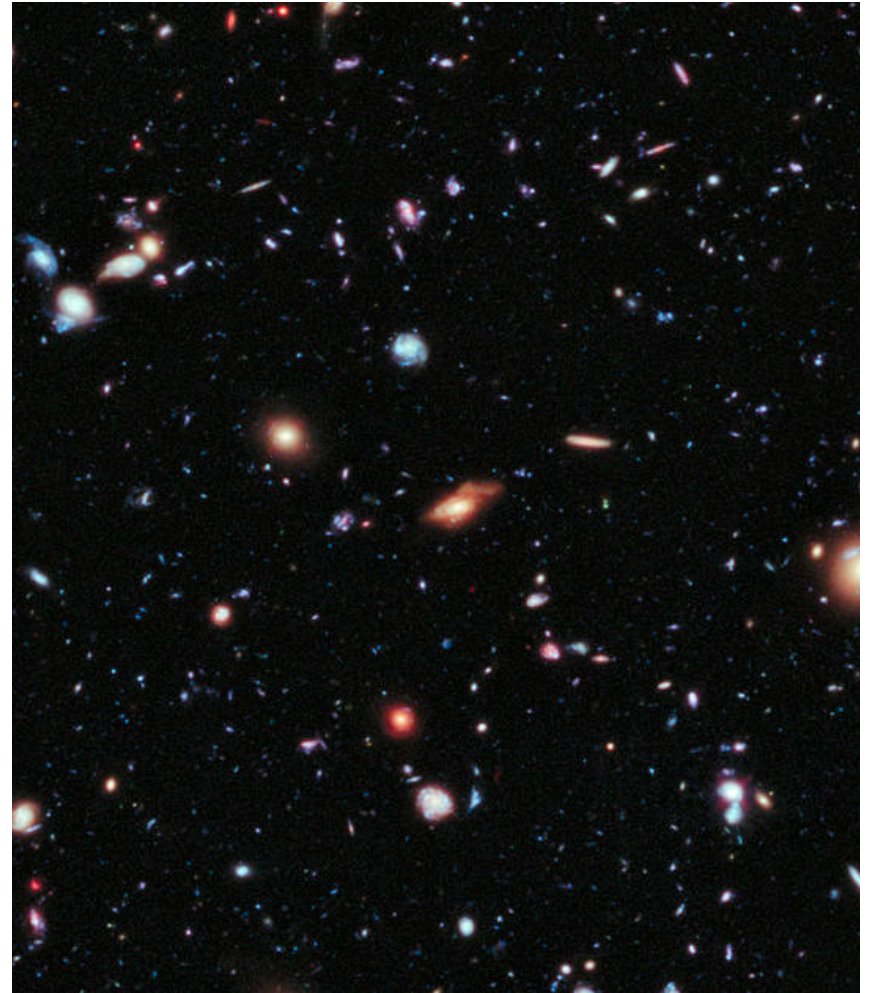
Olber's paradox



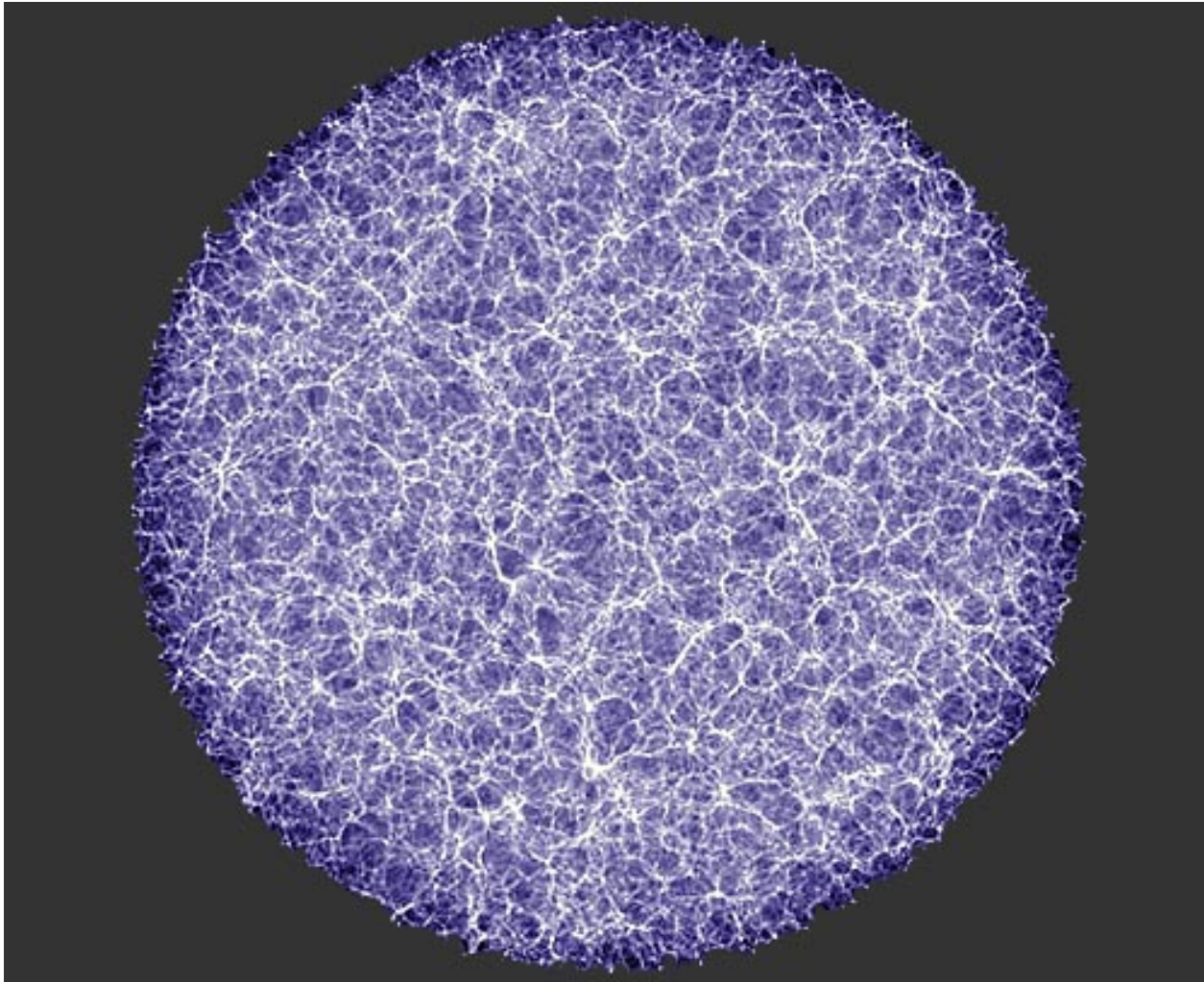
Olber's paradox

- Since the speed of light is finite.
- The universe is not static or
- The universe must have had a beginning!

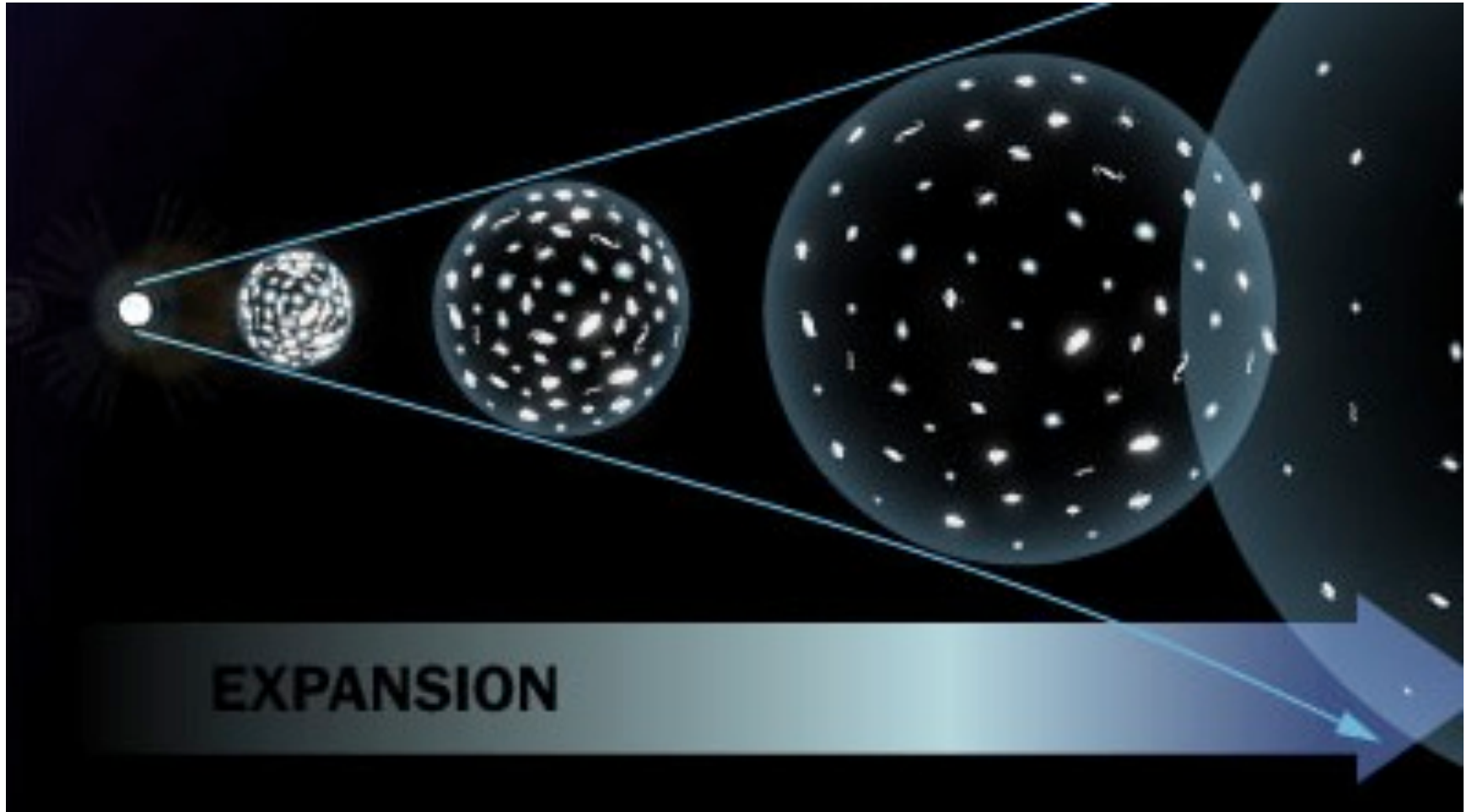
Cosmological principle



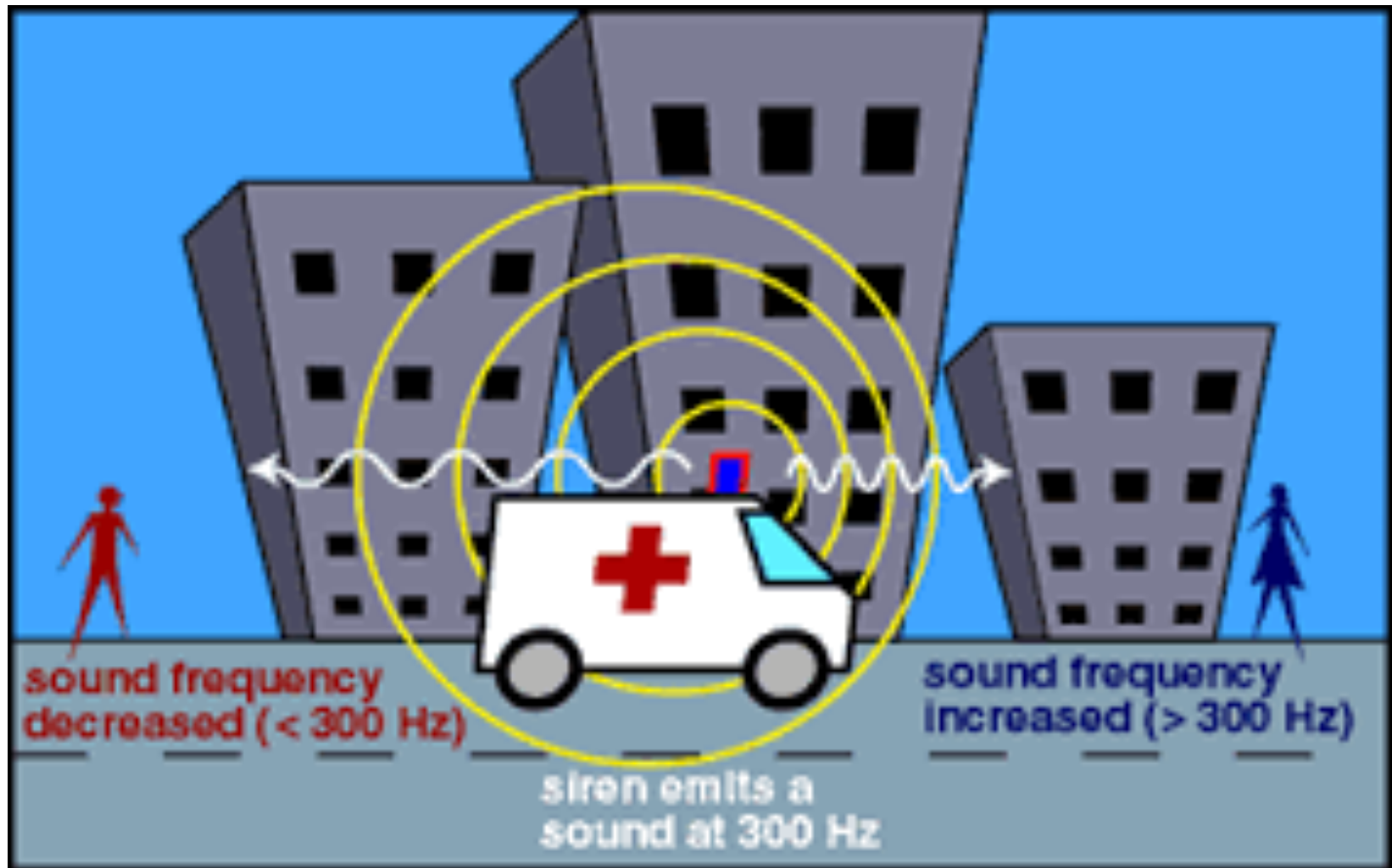
Cosmological principle



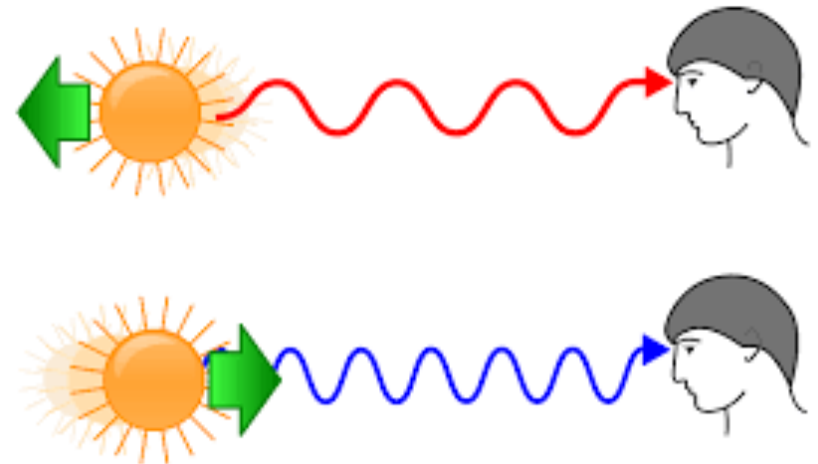
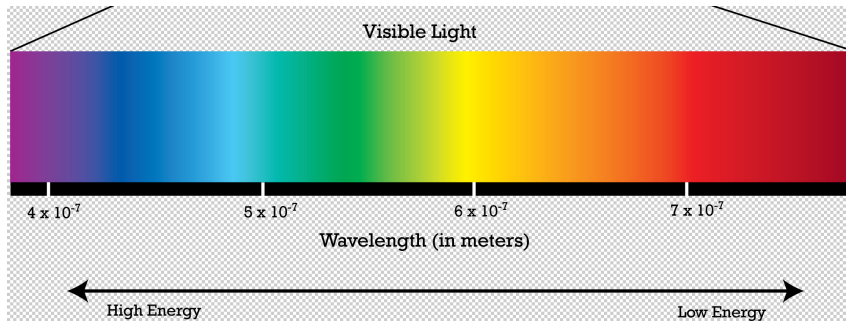
Expanding universe?



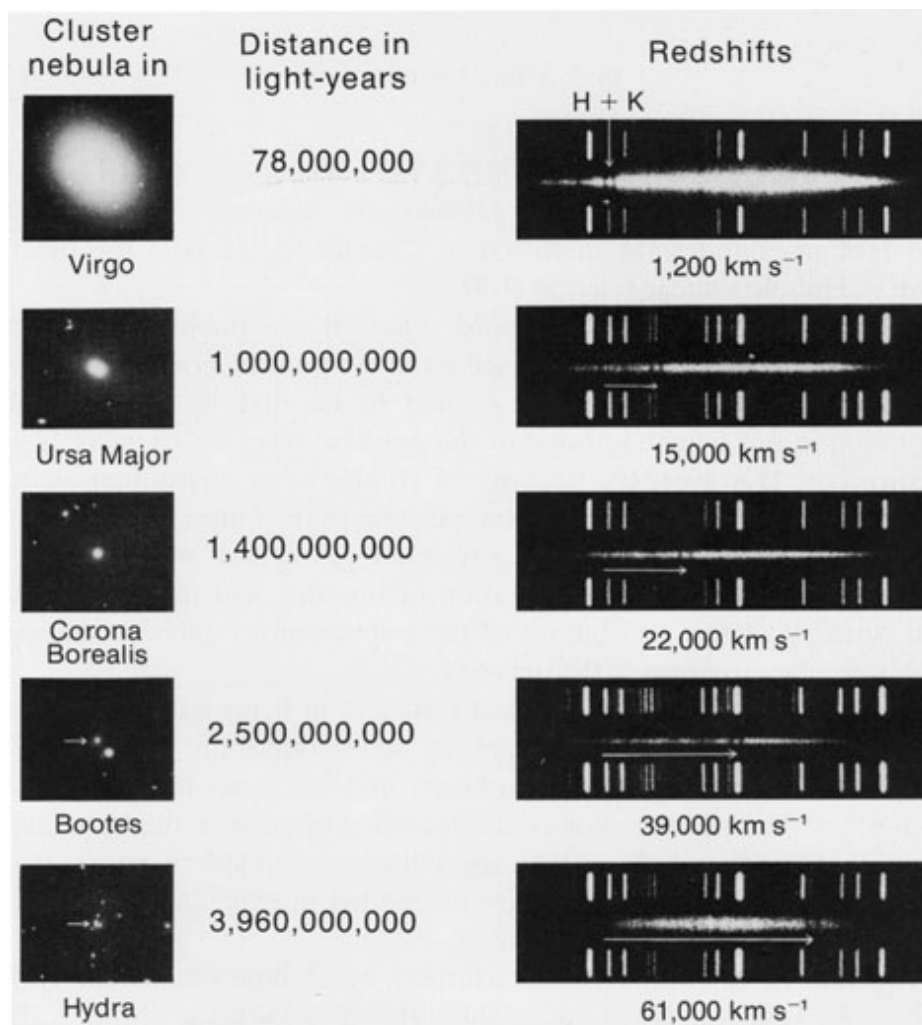
Doppler effect



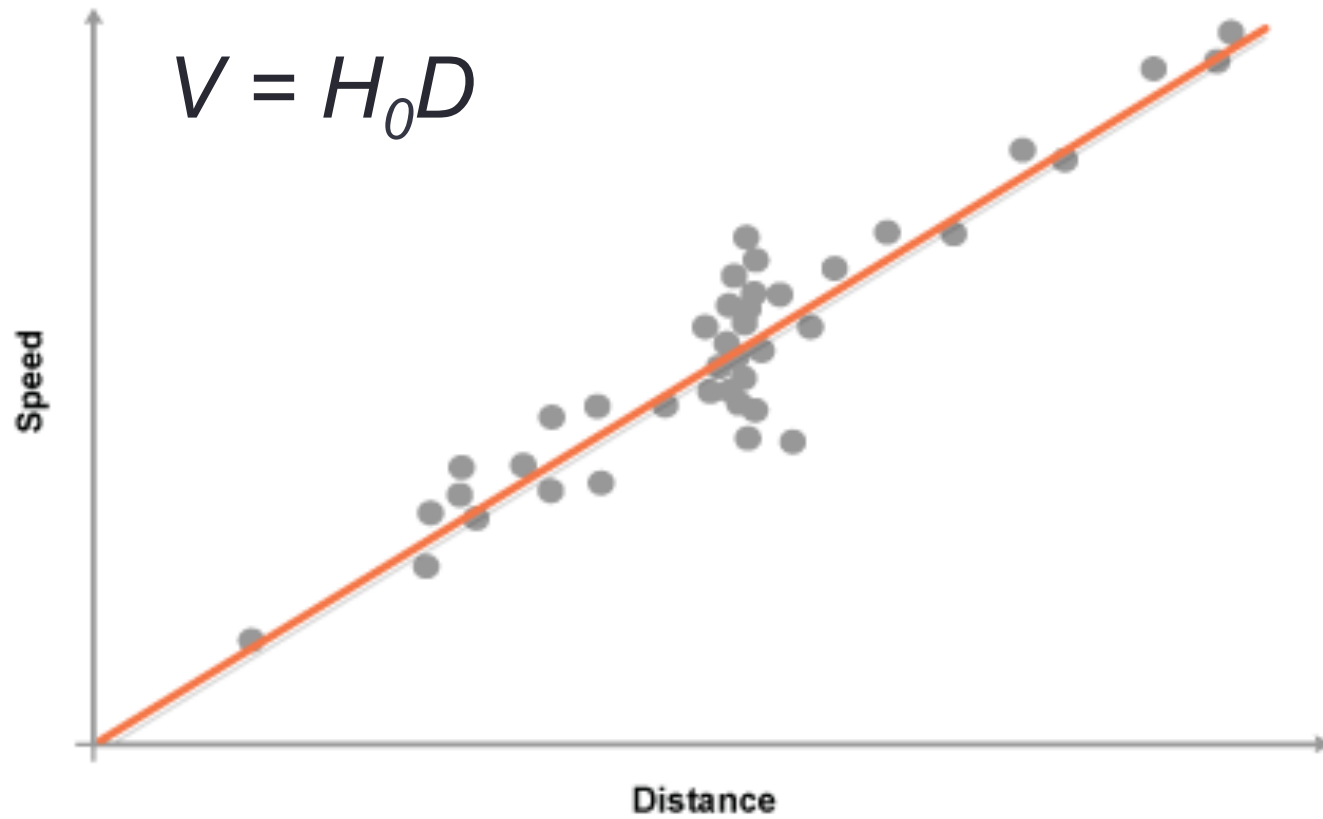
Doppler effect in light



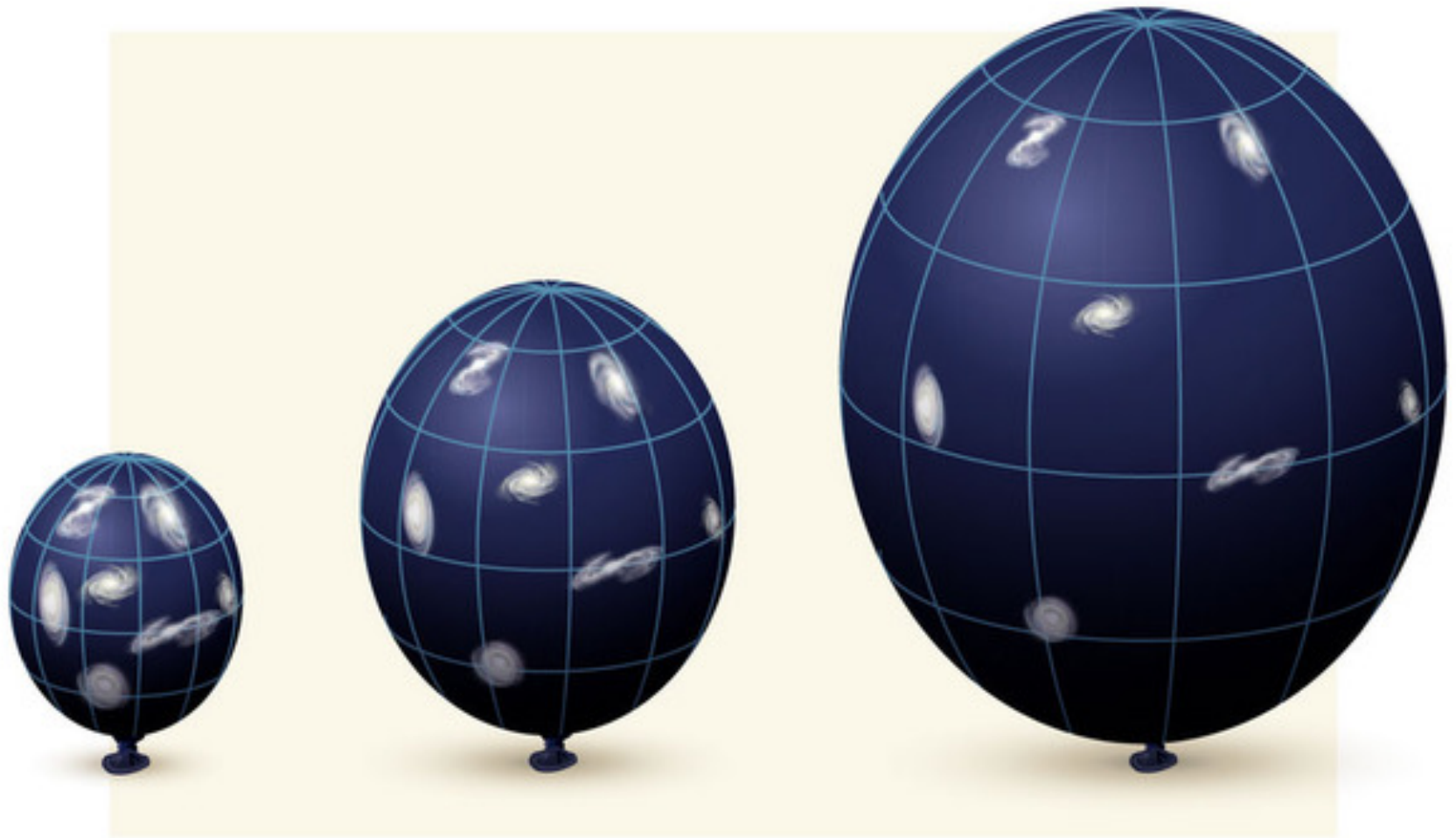
Hubble's discovery



Hubble Law



Expanding universe



Expanding universe

If the universe is expanding,
was there the beginning of universe?

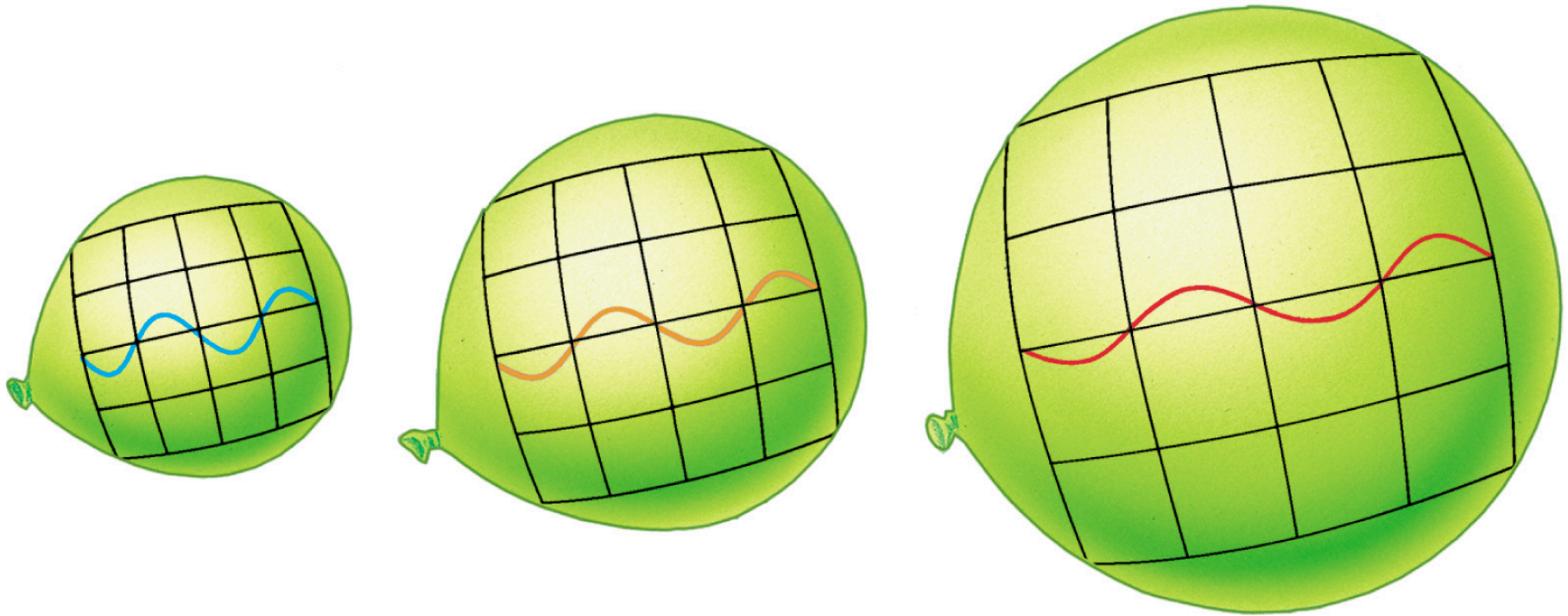
Evidence for a Big Bang



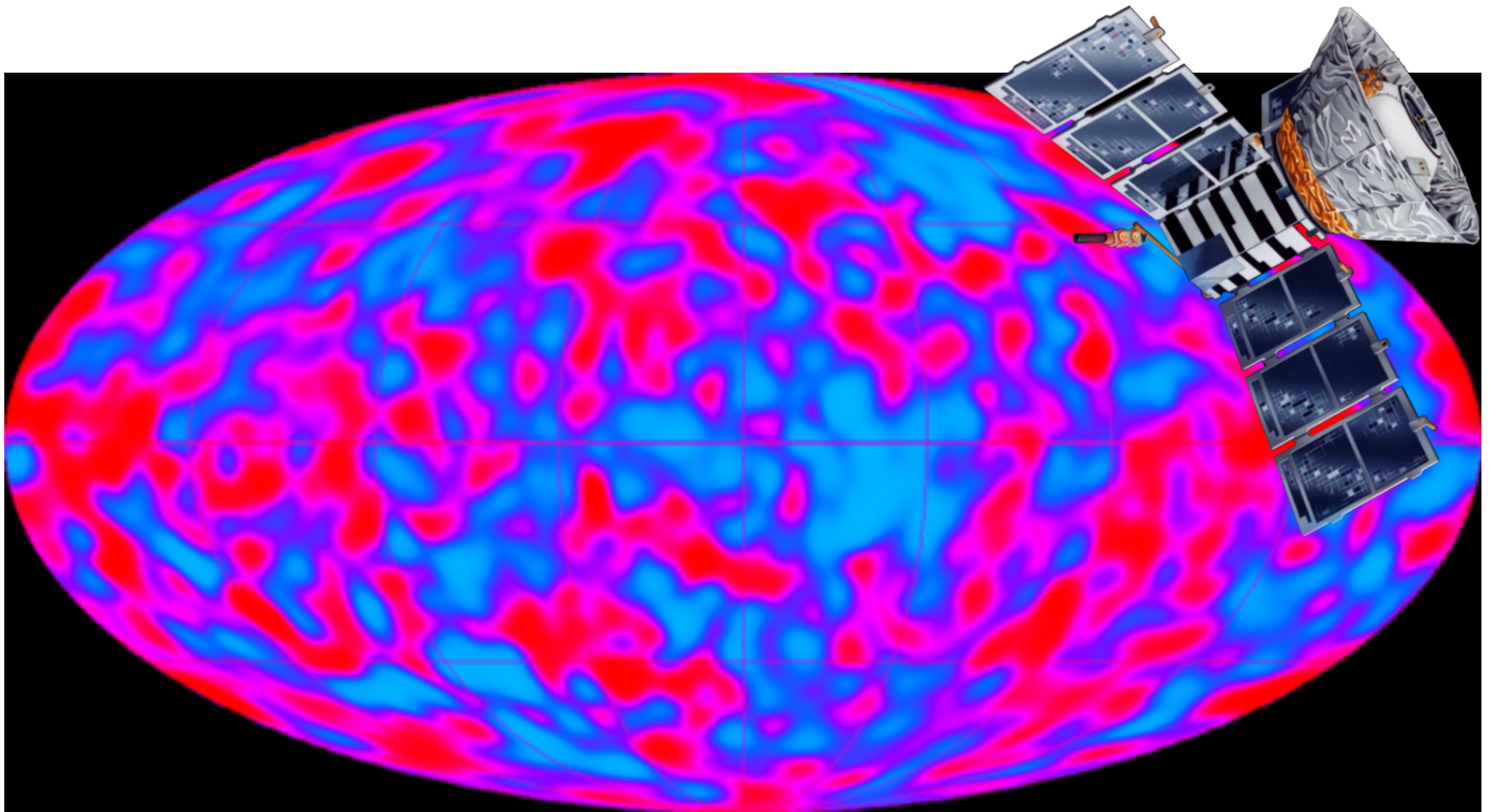
- In 1964, Arno Penzias and Robert Wilson carried out experiments using a microwave antenna for satellite communication.
- They discover a background microwave signal in all sky directions.
- In 1978, Penzias and Wilson were awarded the Nobel Prize for Physics for their joint discovery

Why cosmic microwave background?

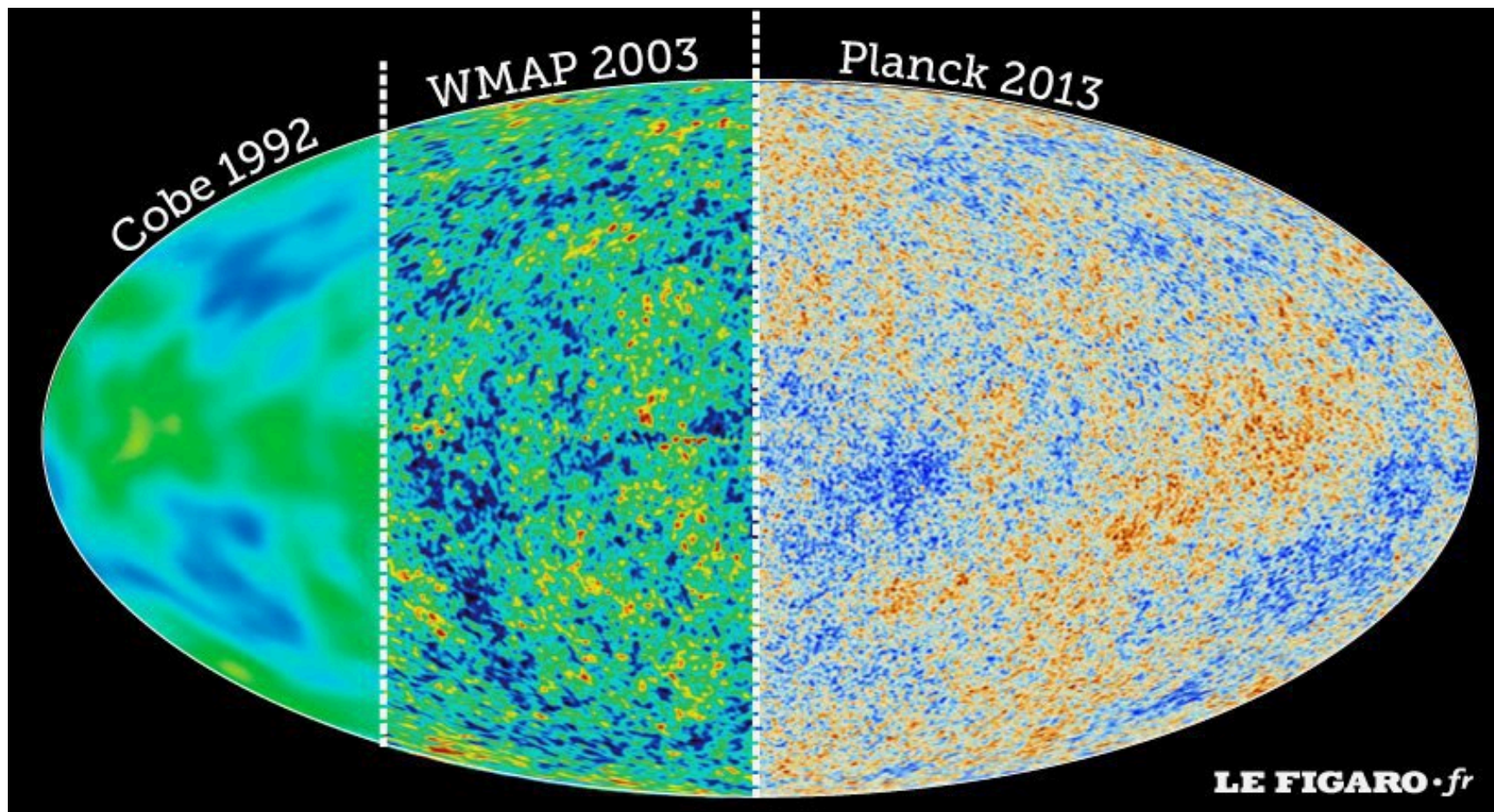
Cosmological Redshift



Cosmic Background Explorer (COBE)



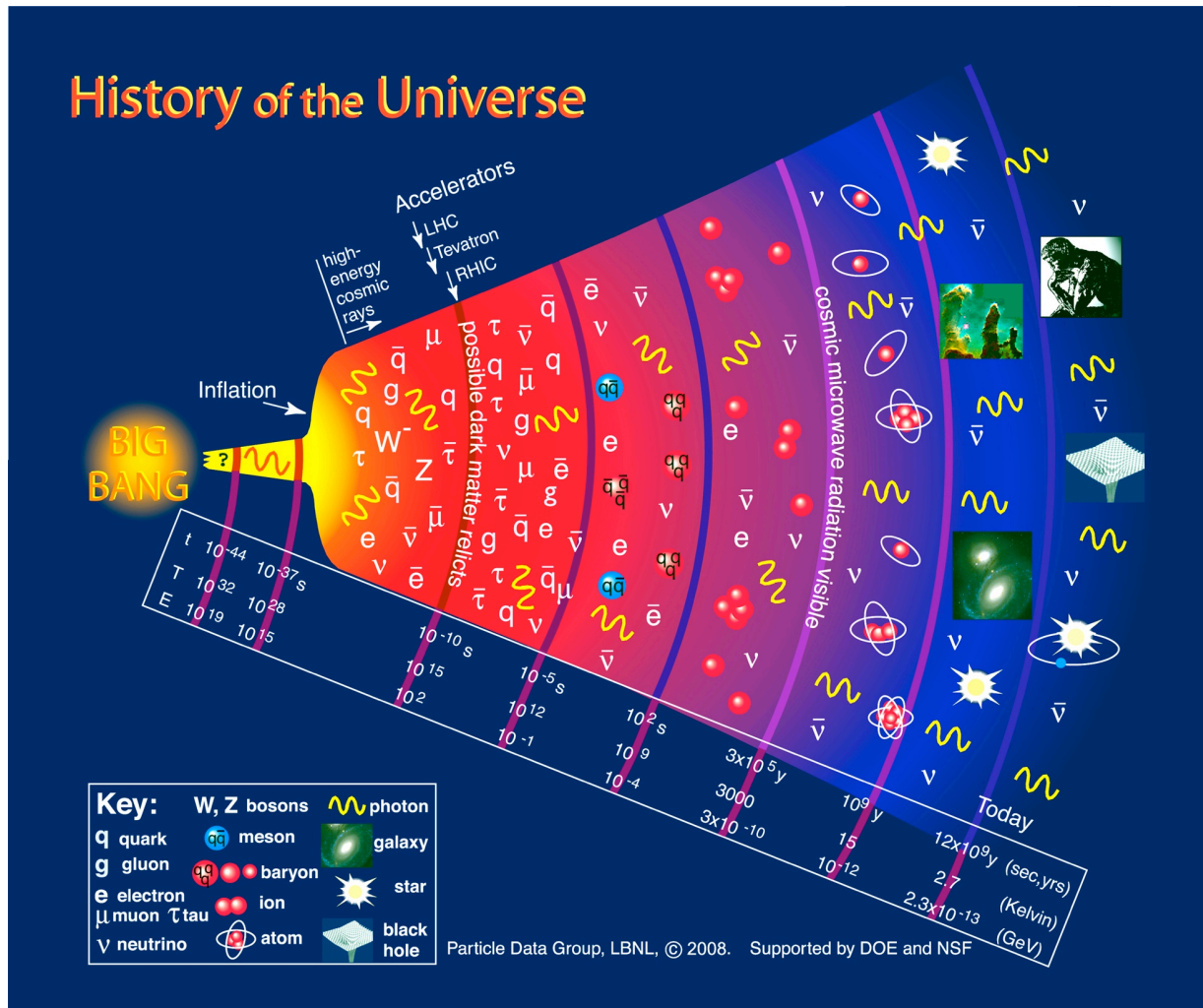
Cosmic microwave background



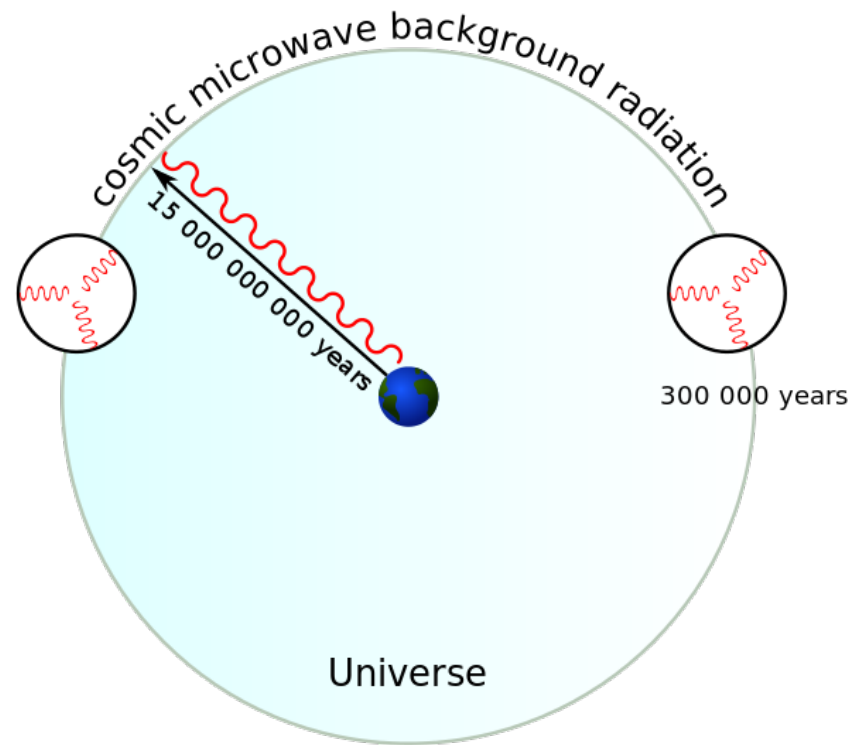
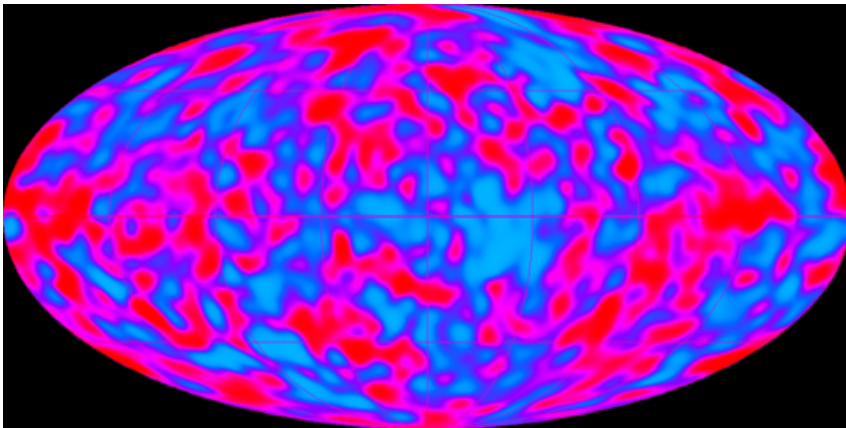
Four eras of universe

- Heavy particle era ($T < 10^{33}$ K, time $> 10^{-43}$ s)
- Light particle era ($T < 10^{12}$ K, time $> 10^{-4}$ s)
- Radiation era ($T < 10^{10}$ K, time > 10 s)
- Matter era ($T < 3000$ K, time $> 10^6$ years)

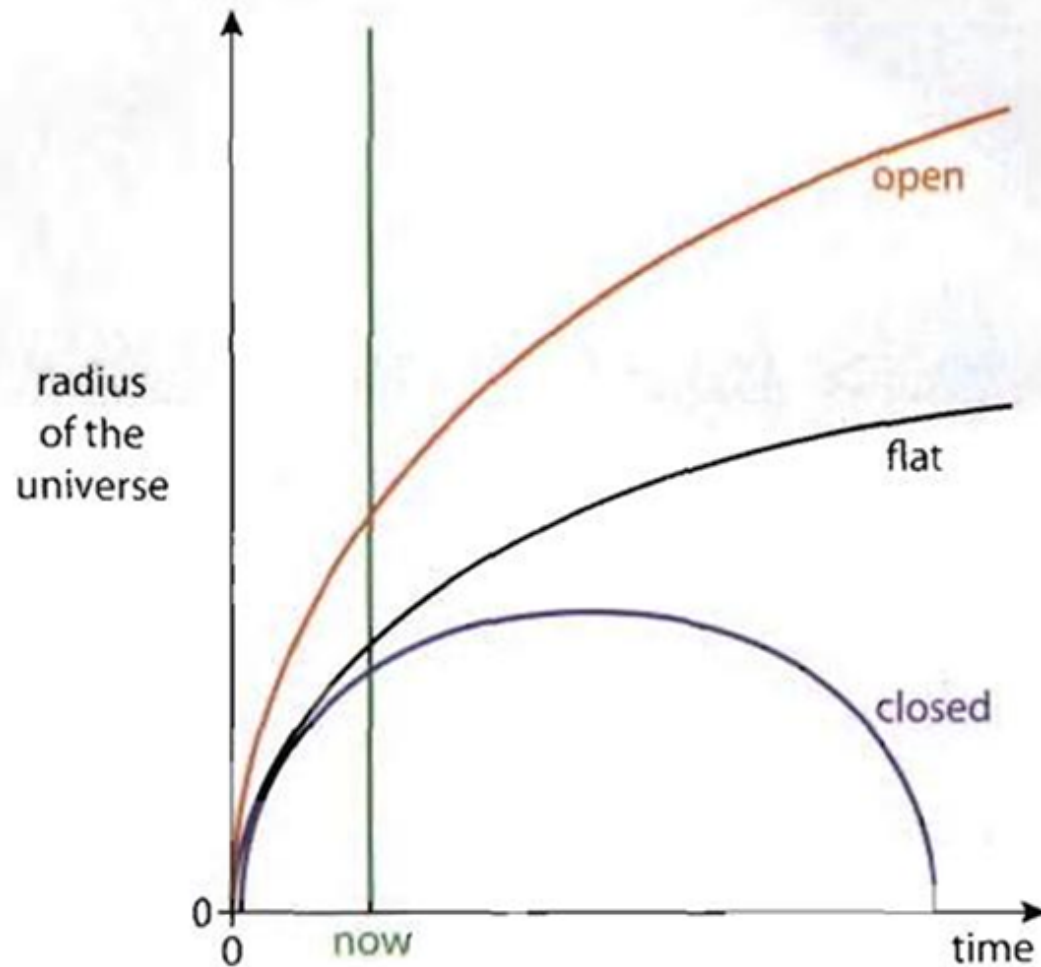
Evolution of Universe



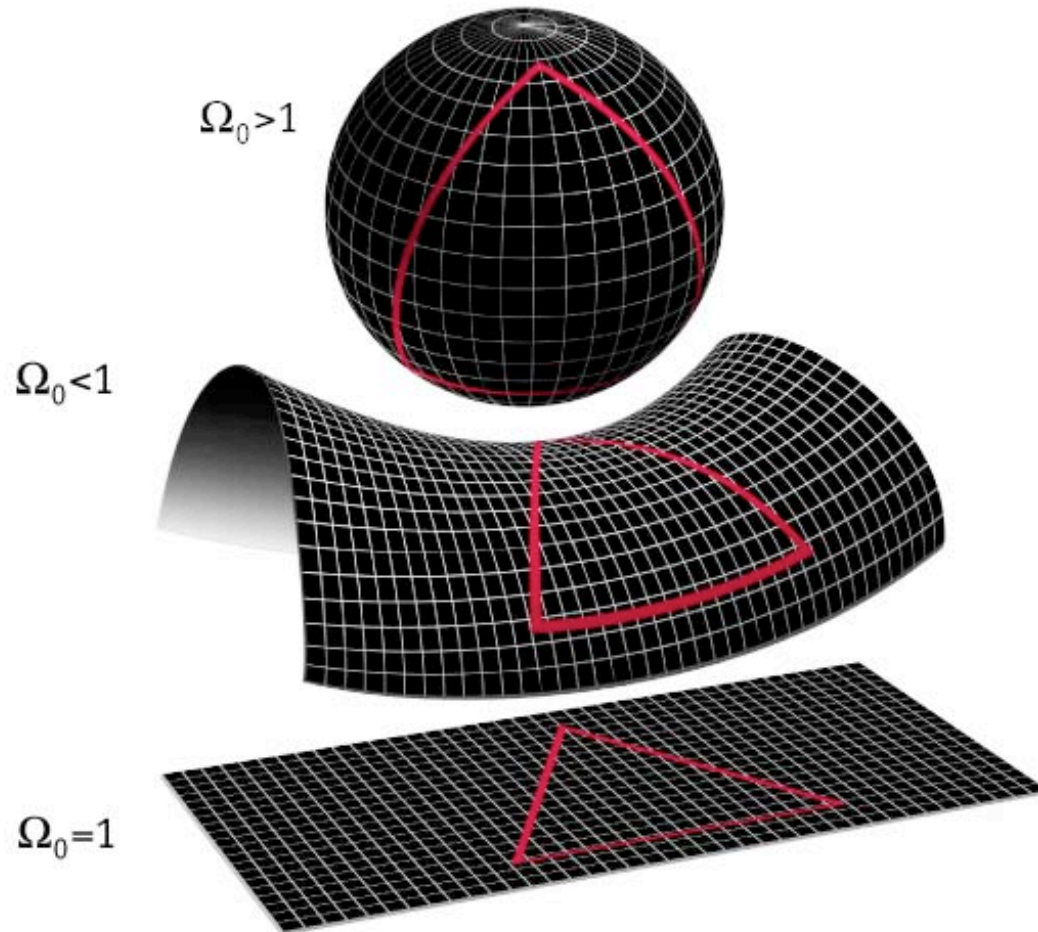
Horizon problem



Future of universe



Shape of the universe



DARK MATTER AND DARK ENERGY

Dark matter and Dark Energy

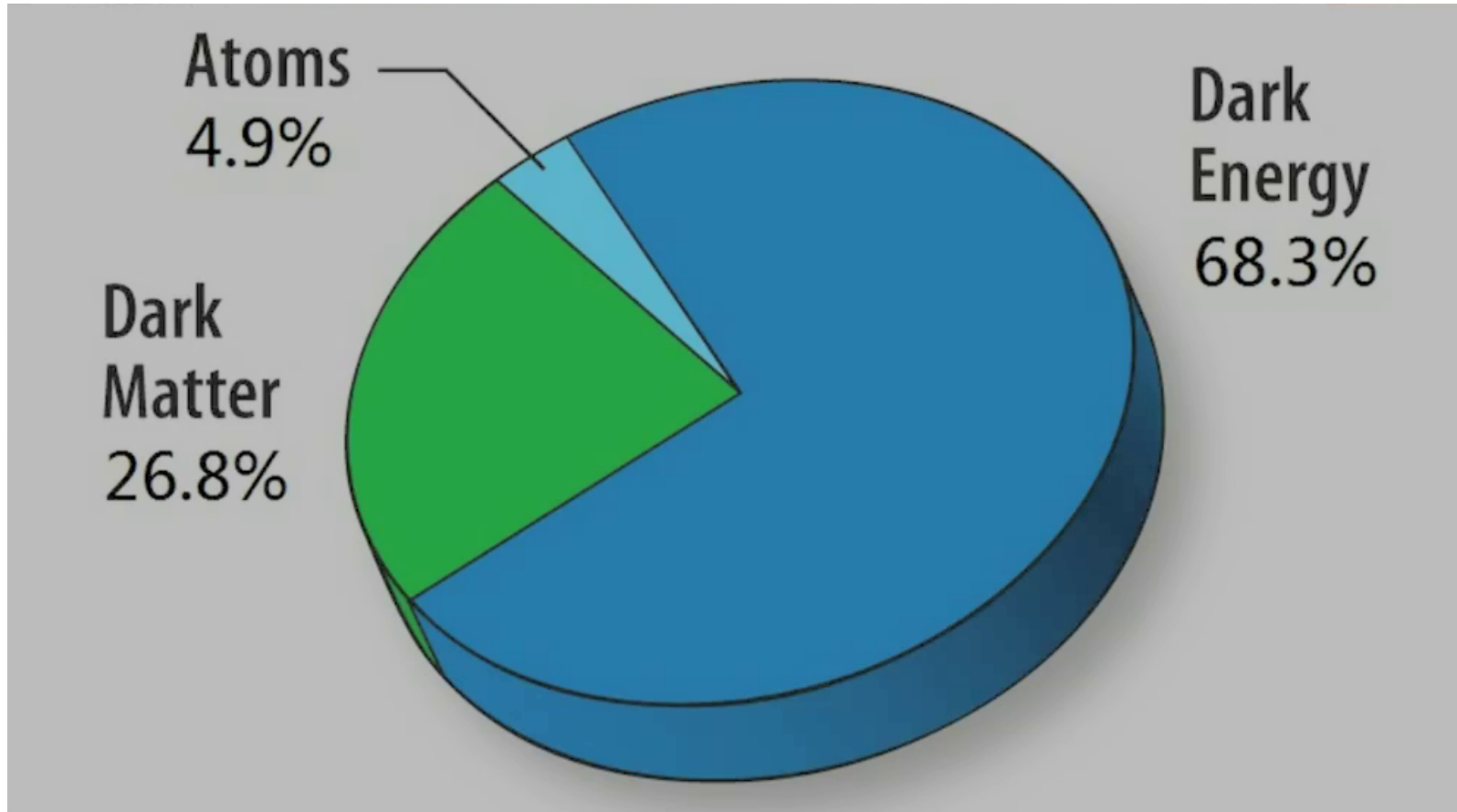
- Dark Matter

- An undetected form of mass that emits little or no light but whose existence we infer from its gravitational influence.

- Dark Energy

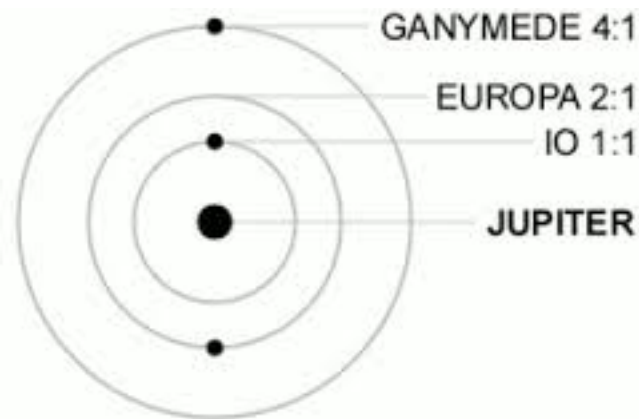
- An unknown form of energy that seems to be the source of a repulsive force causing the expansion of the universe to accelerate.
- It is much less well-understood.

Contents of Universe

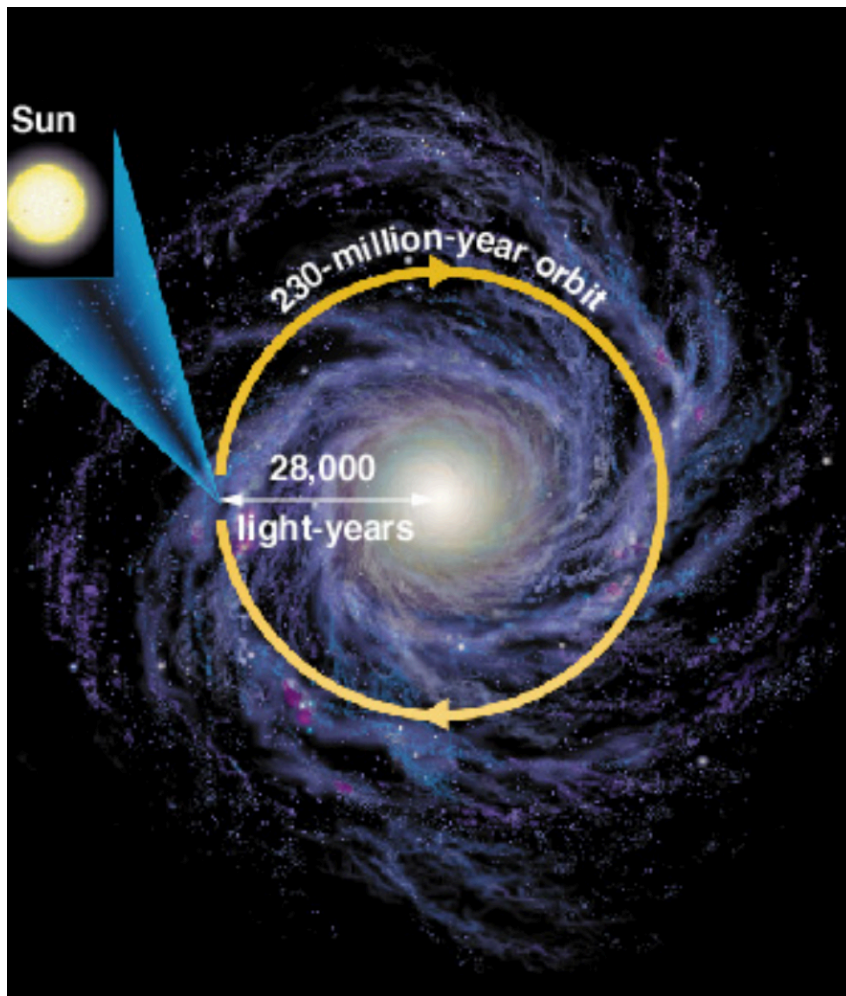


Measuring the (dark) matter mass

- Any non-luminous component of the Universe can only be detected indirectly, by its gravitational influence on the luminous (light-emitting) components.
- We can measure an object's mass from the orbital period & average distance of bodies in orbit around it.
 - Example: Find mass of Jupiter based on its moons' orbits.

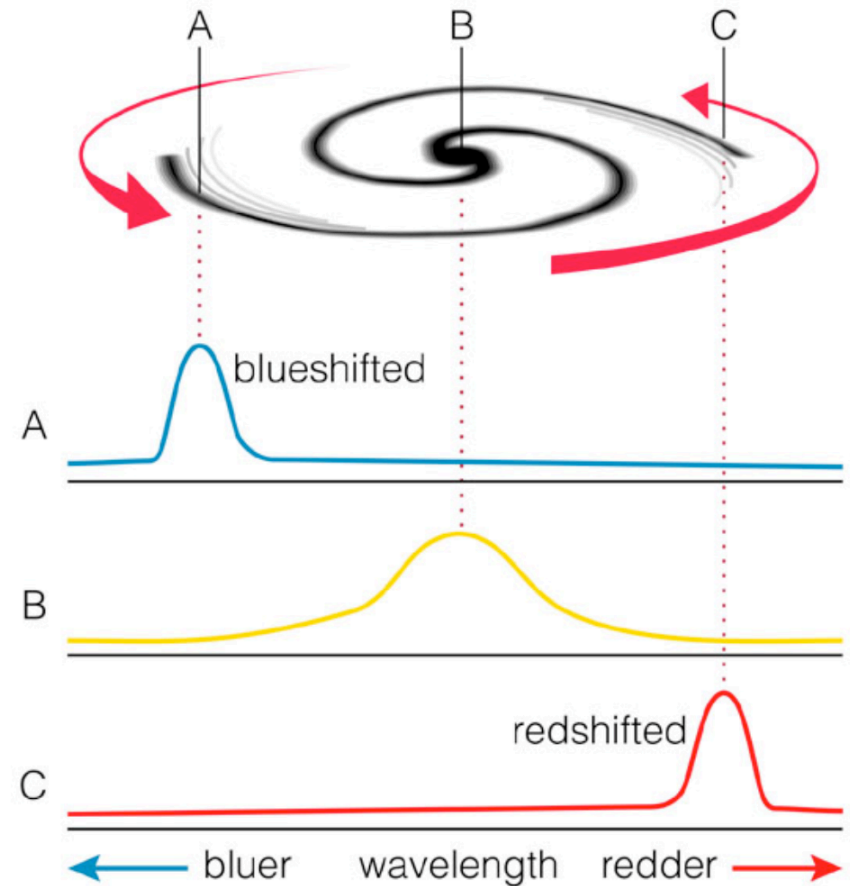


Measuring the (dark) matter mass

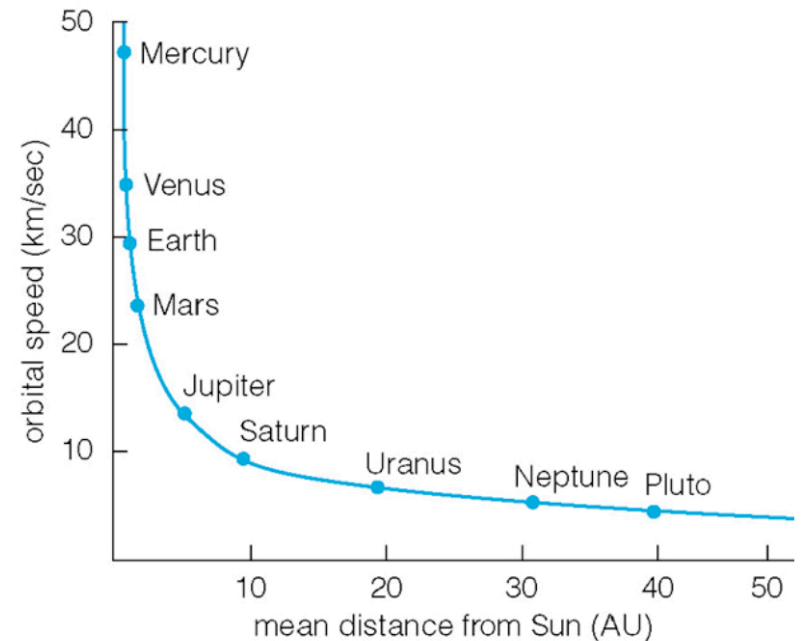
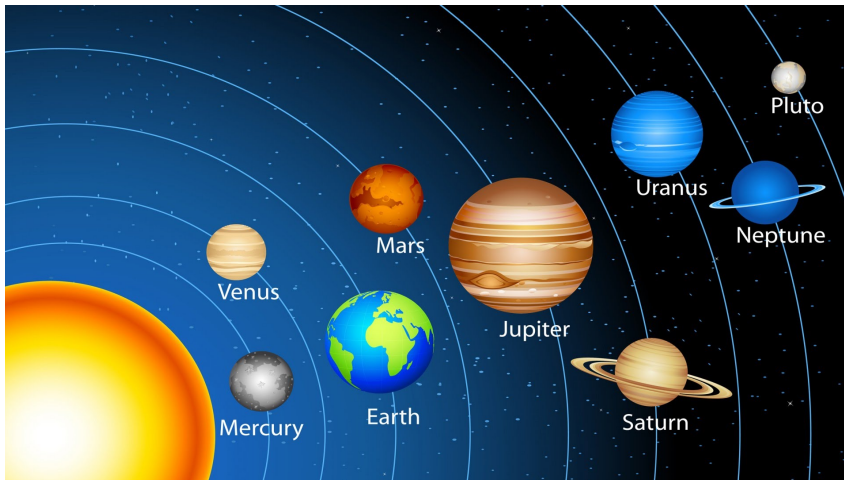


- Measuring the Sun's orbital motion (radius and velocity) gives us the mass inside Sun's orbit: $\sim 1.0 \times 10^{11} M_{\text{sun}}$.
- Note that we cannot measure the mass outside of the Sun's orbit in this fashion.

Measuring the (dark) matter mass

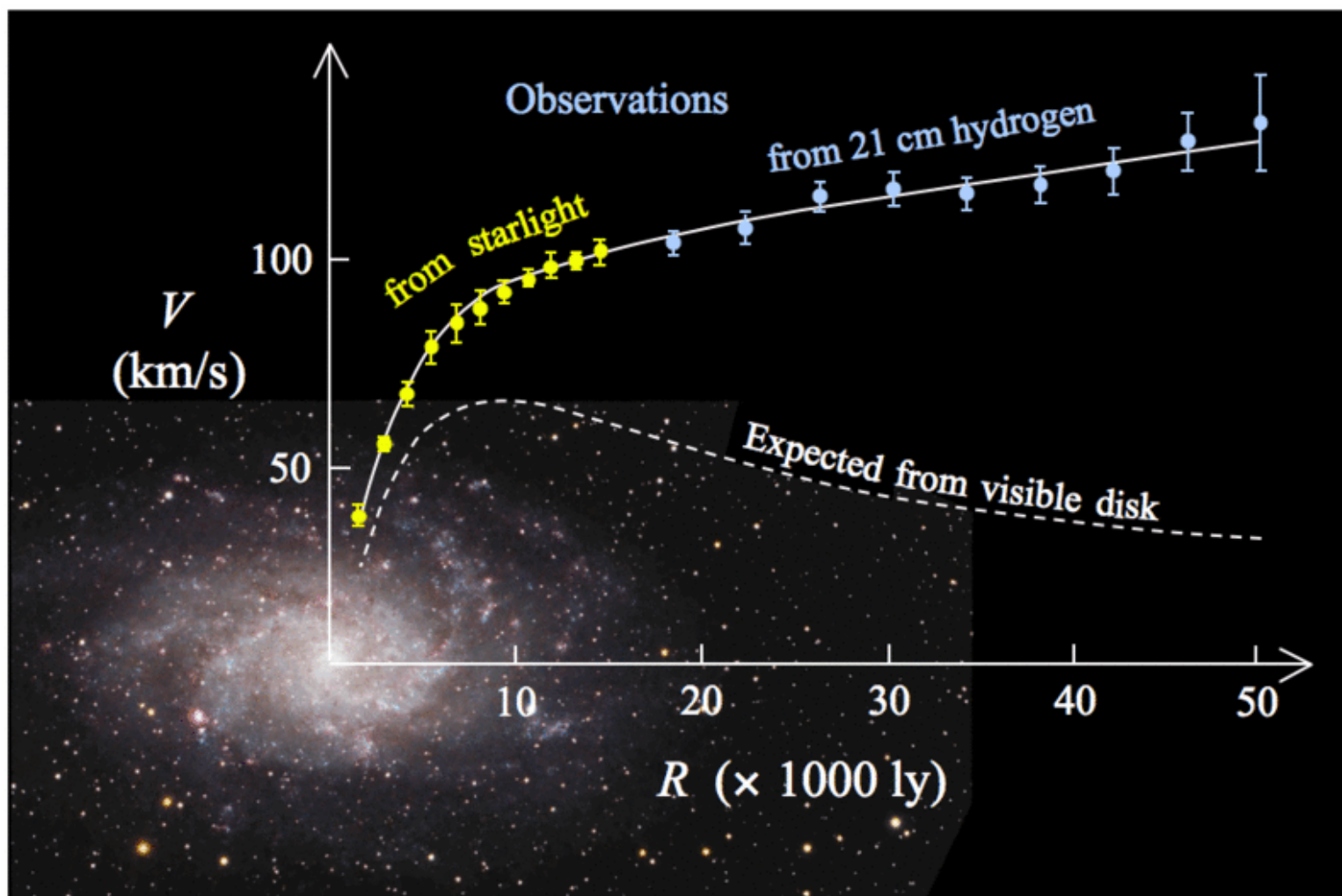


Rotation curve

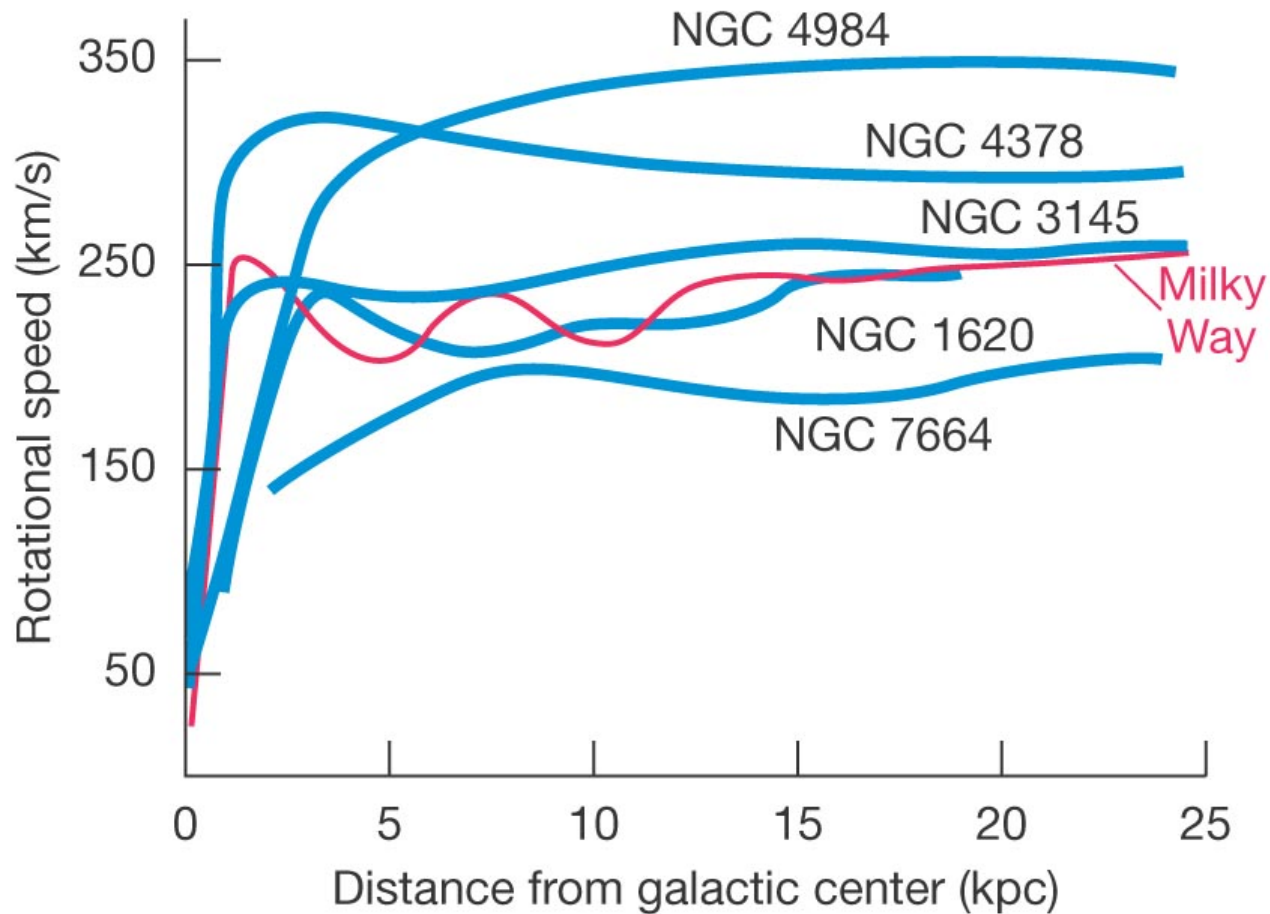


A plot of velocity versus orbital radius!

M33 rotation curve

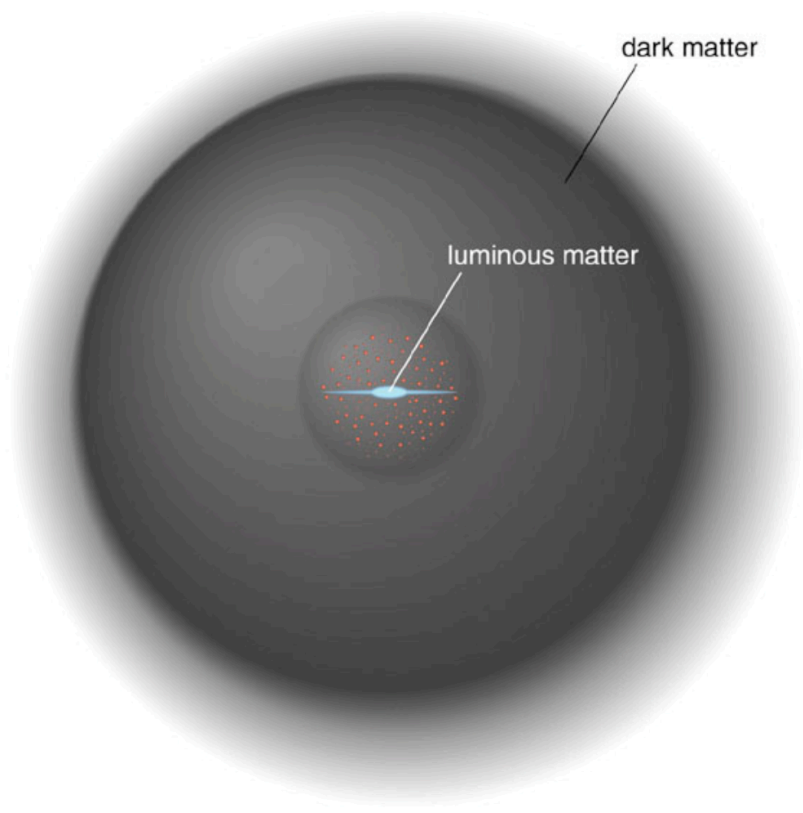


Rotational curve – more evidences



(b)

The true mass distribution of galaxies



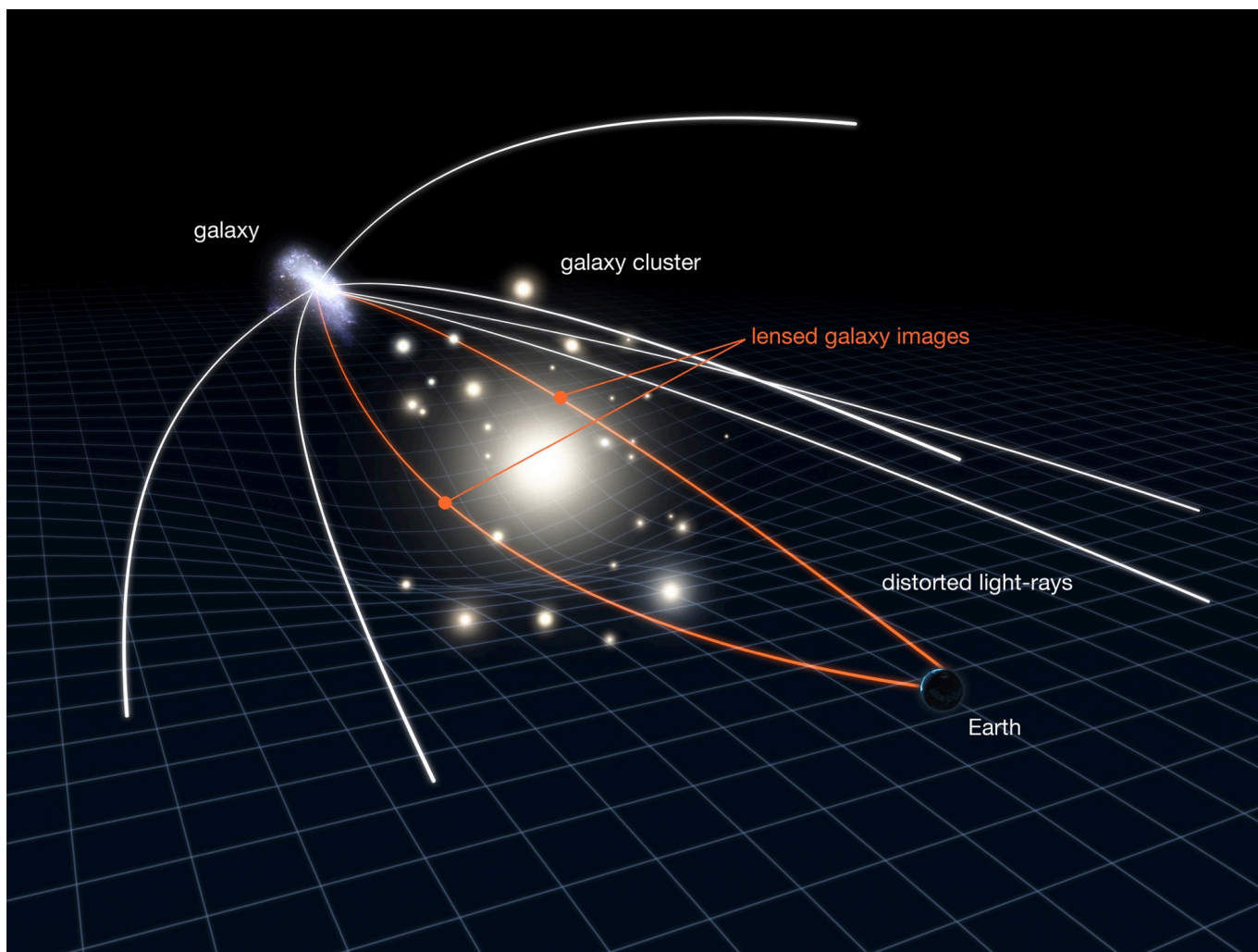
- The visible portion of a galaxy lies deep in the heart of a large **halo of dark matter**.
- The total mass in dark matter is about **10x more** than in stars!!

Other detection methods

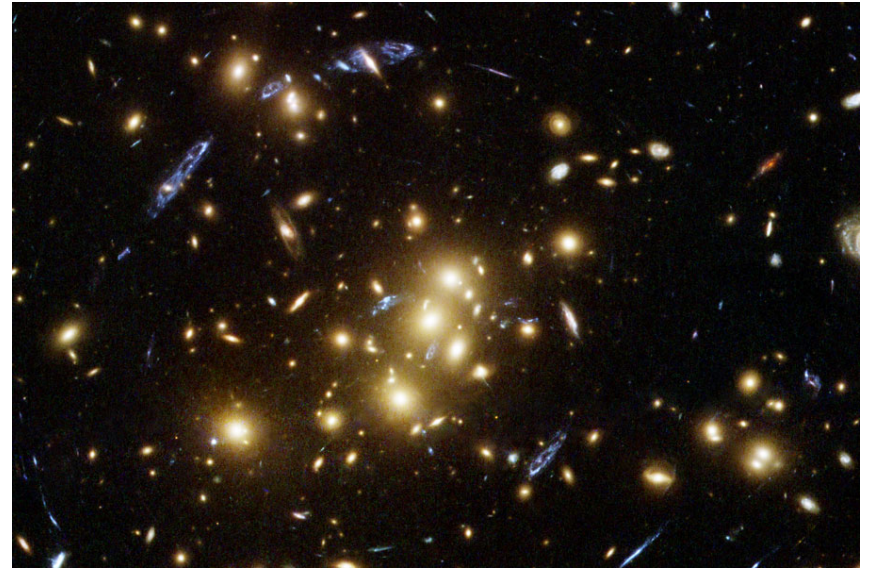
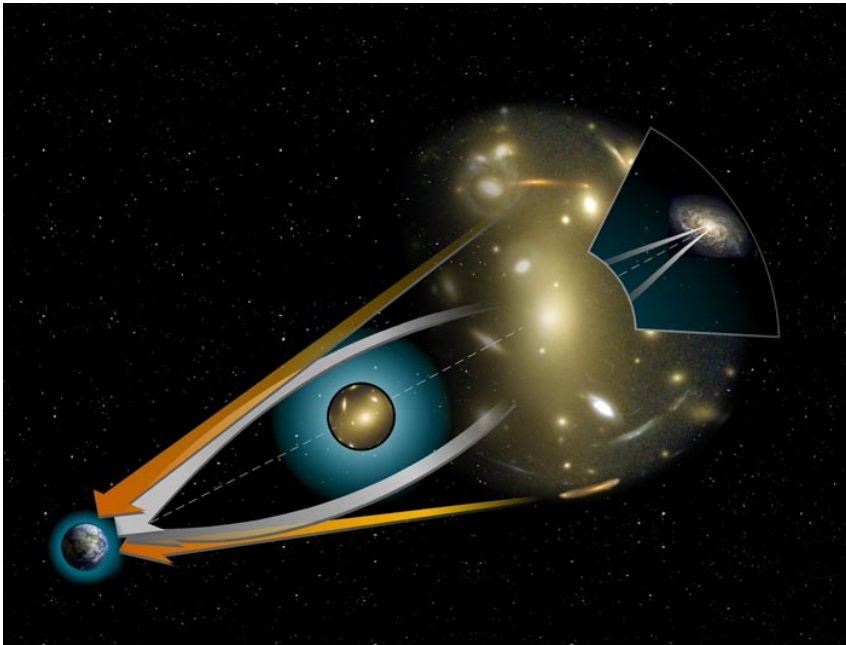


- Clusters contain large amounts of very hot X-ray emitting gas.
- **Temperature of this hot gas** measures the cluster's mass, the gas has to be held in the cluster by gravity.
 - 85% dark matter
 - 13% hot gas
 - 2% stars

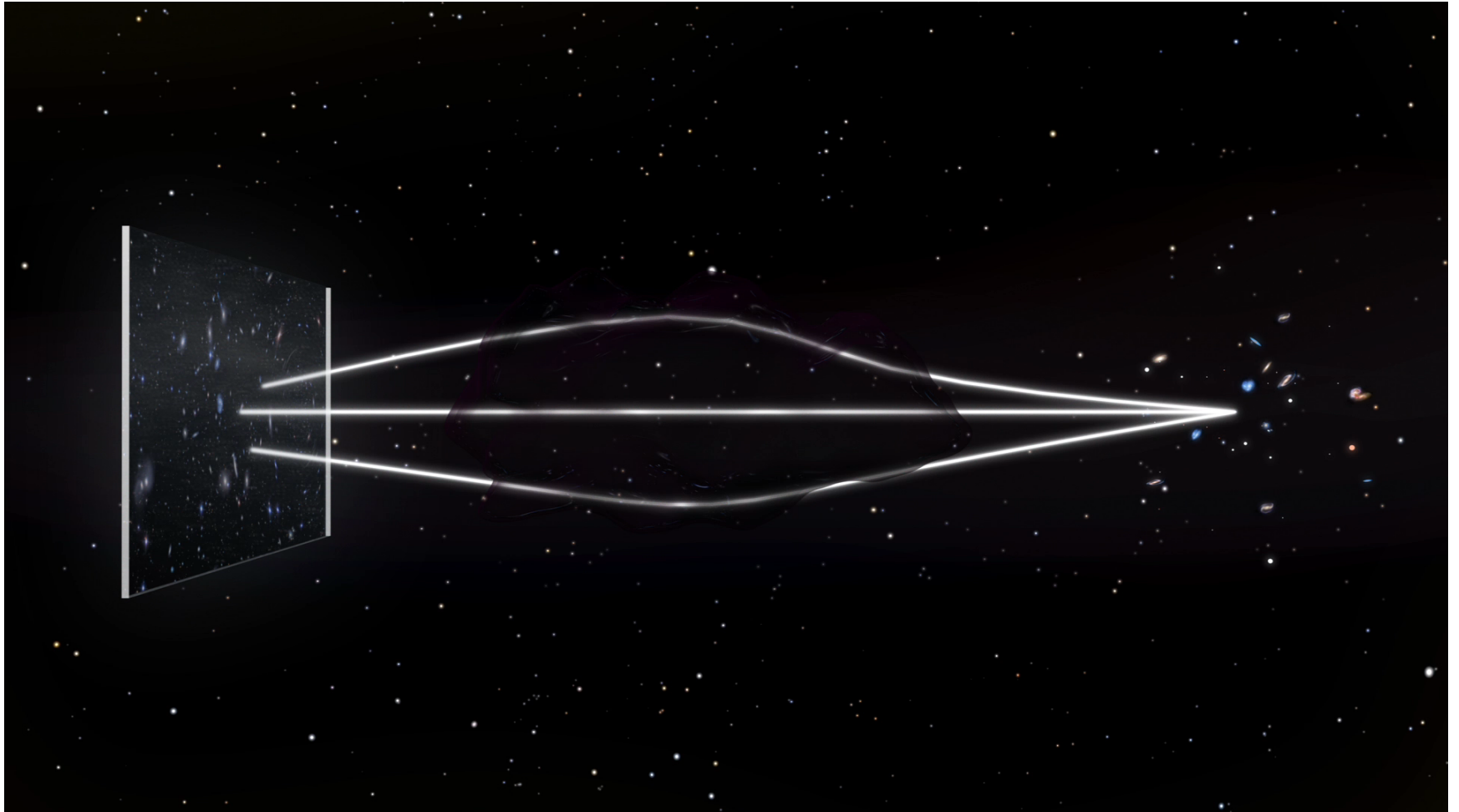
Other detection methods



Other detection methods



Other detection methods

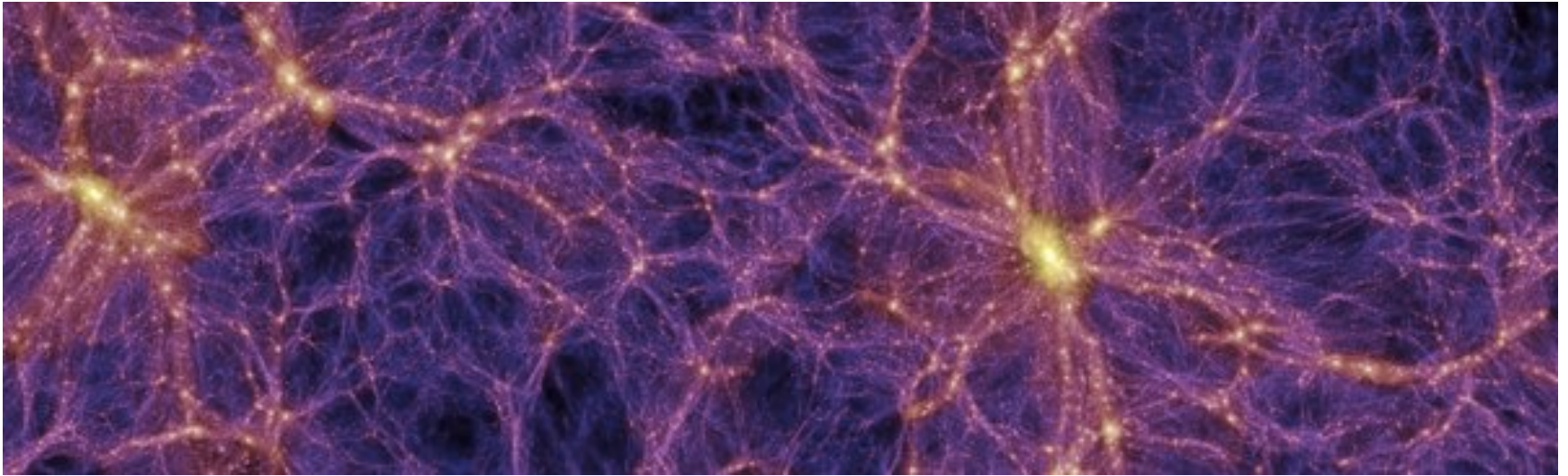


Does dark matter really exist?

Probability

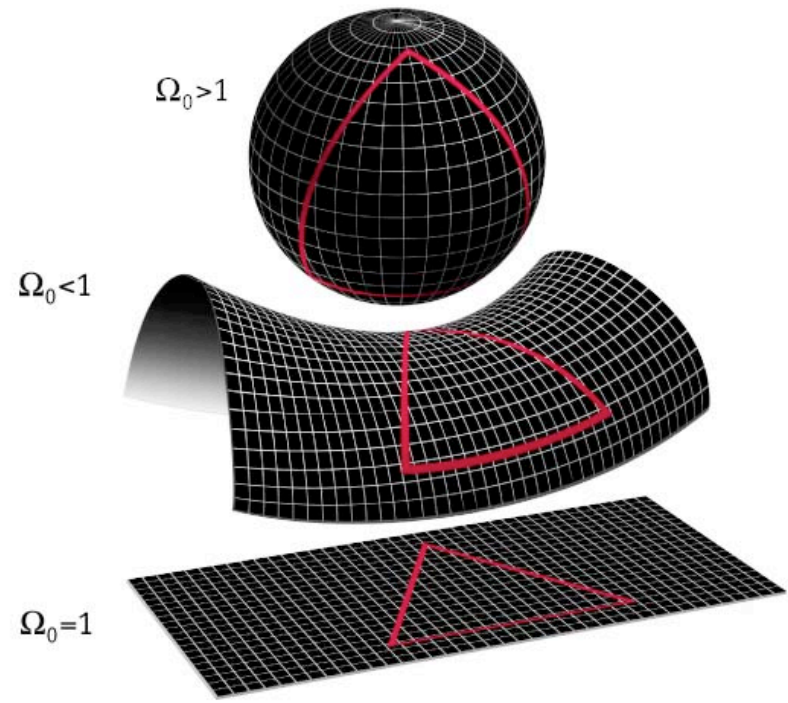
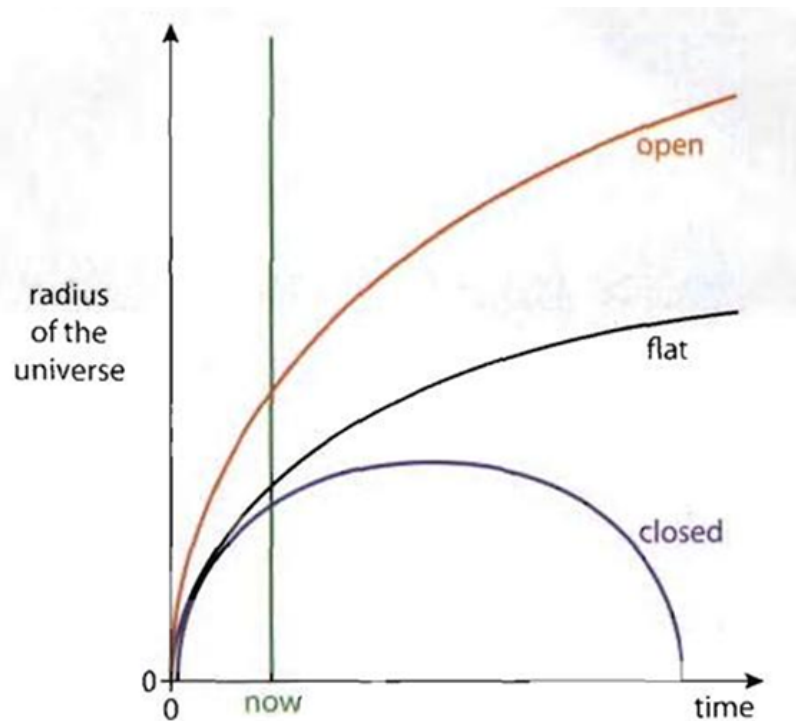
1. Dark matter really exists, and we are observing the effects of its gravitational attraction.
2. Something is wrong with our understanding of gravity, causing us to mistakenly infer the existence of dark matter.

Why do we worry about dark matter?



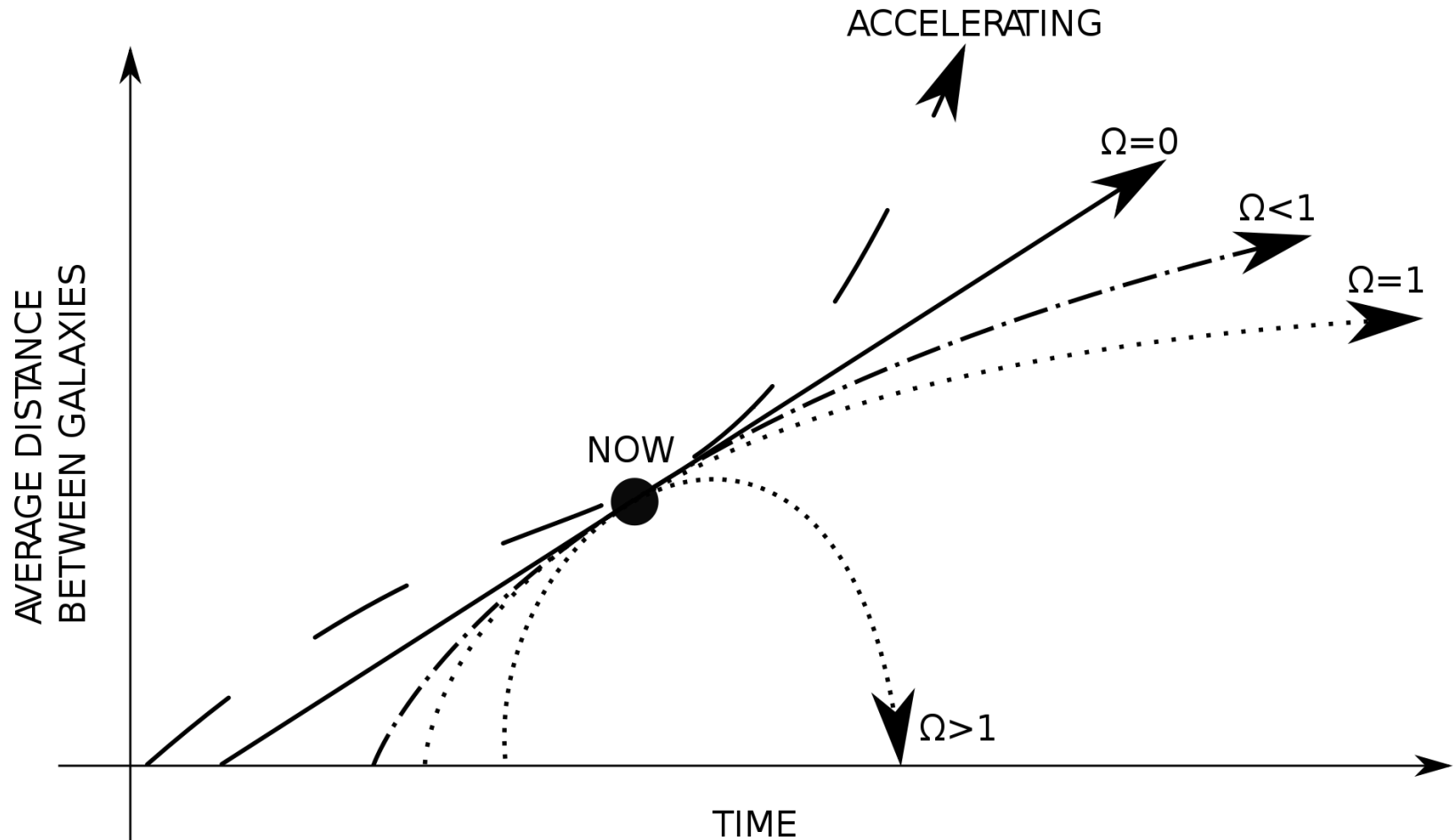
Structure formation!

Why do we worry about dark matter?



The future and shape of the universe depend on it!

Future of universe

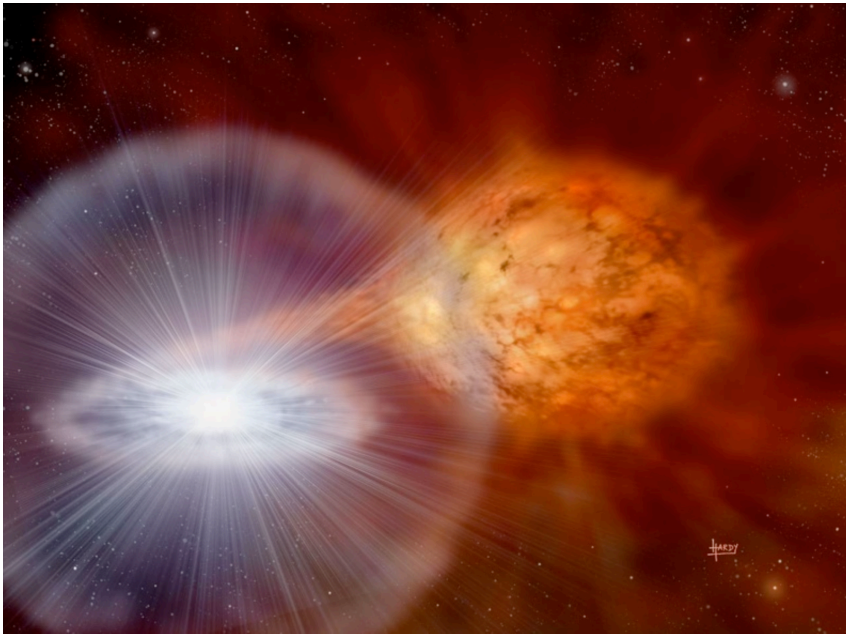


Need external energy to help in the expansion!

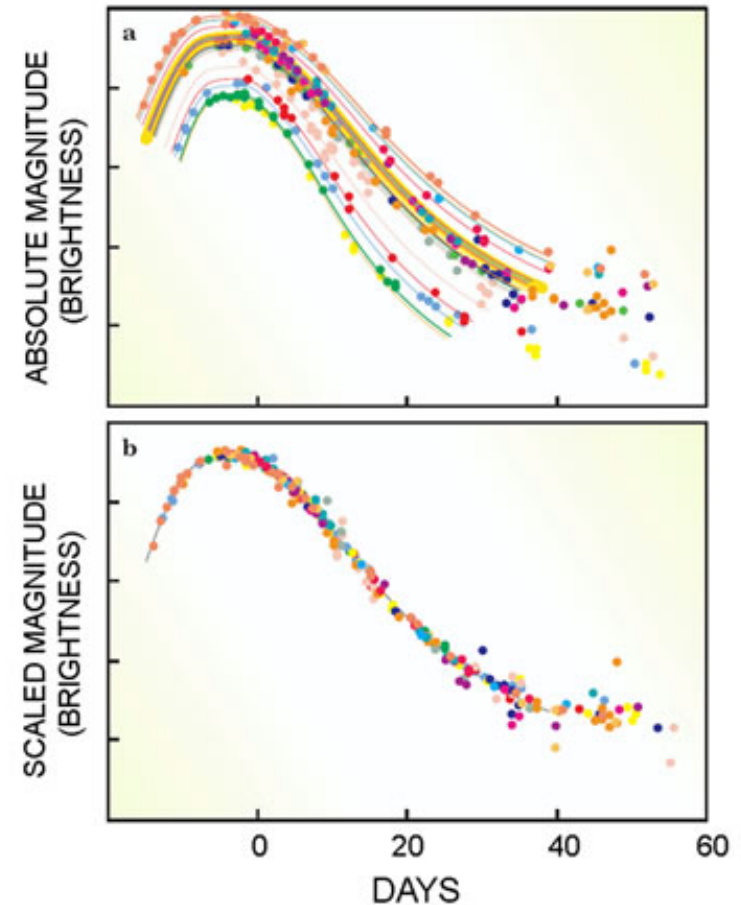
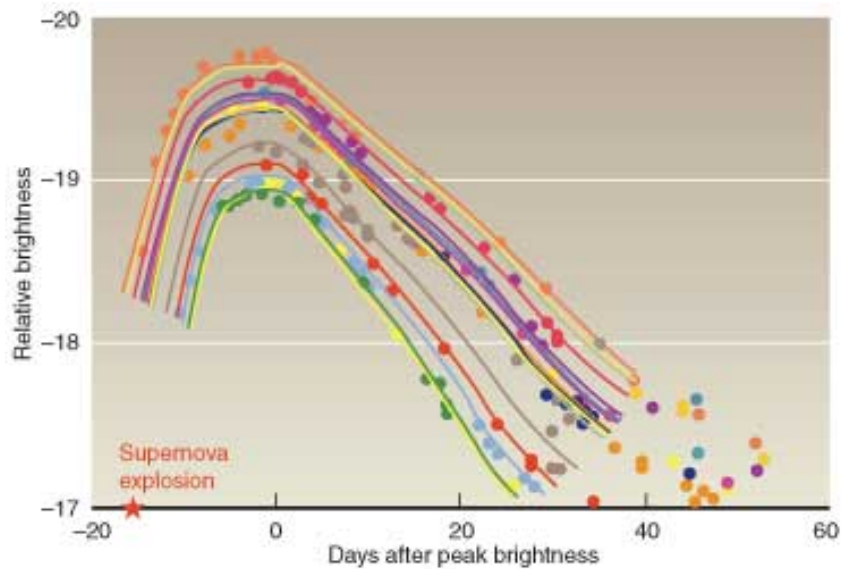
Measuring the expansion of the universe over its history



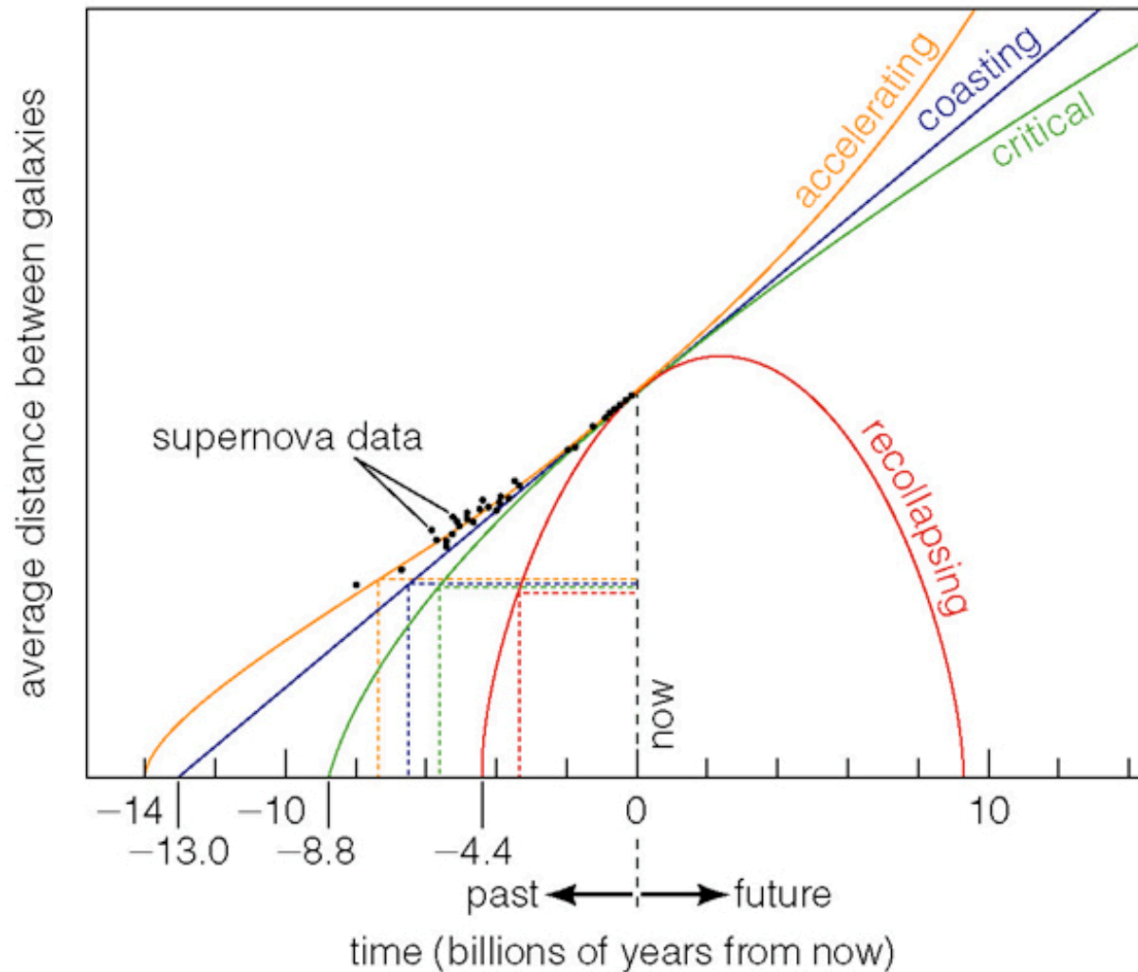
Standard Candles in the Universe: Type Ia Supernovae



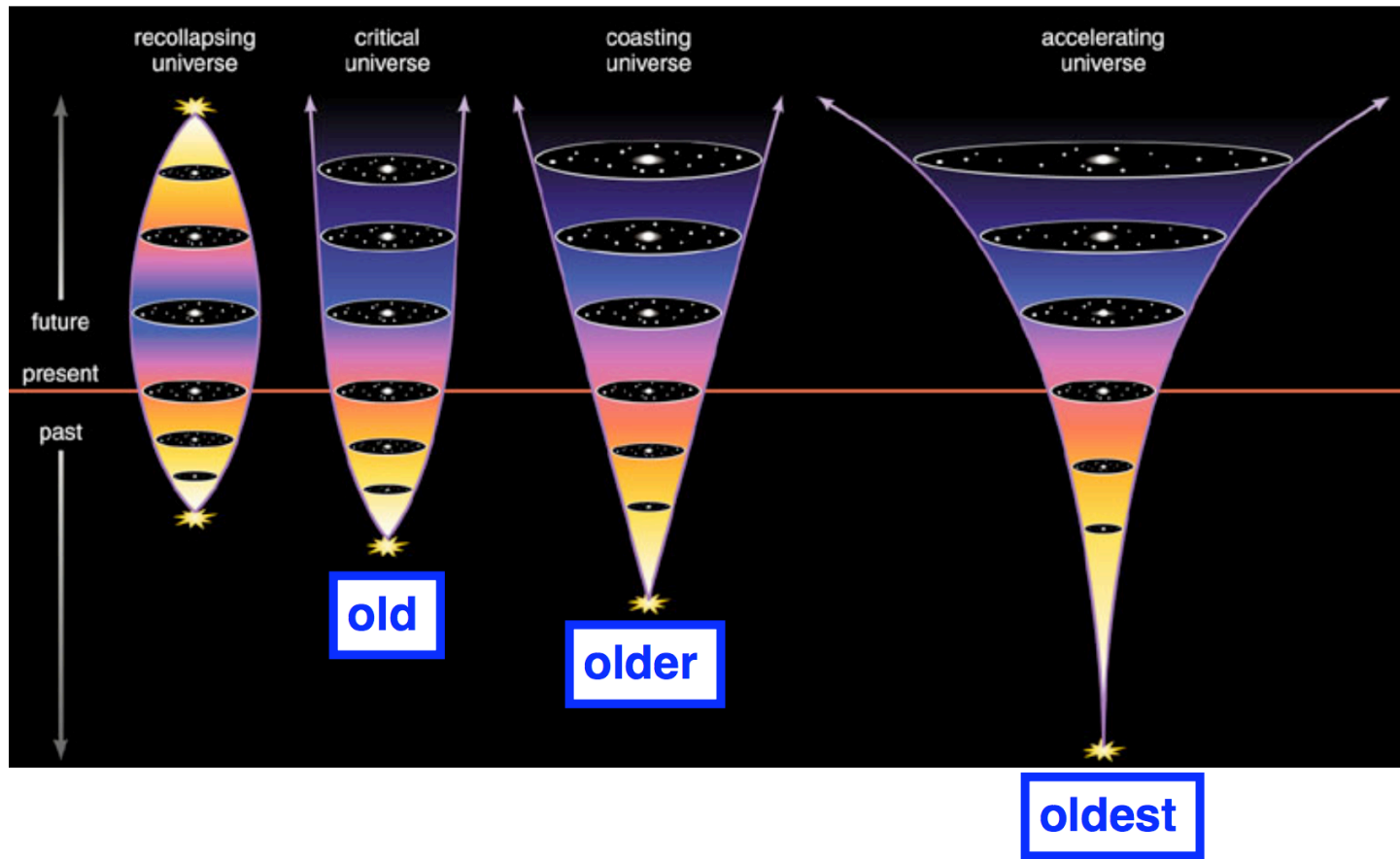
Standard Candles in the Universe: Type Ia Supernovae



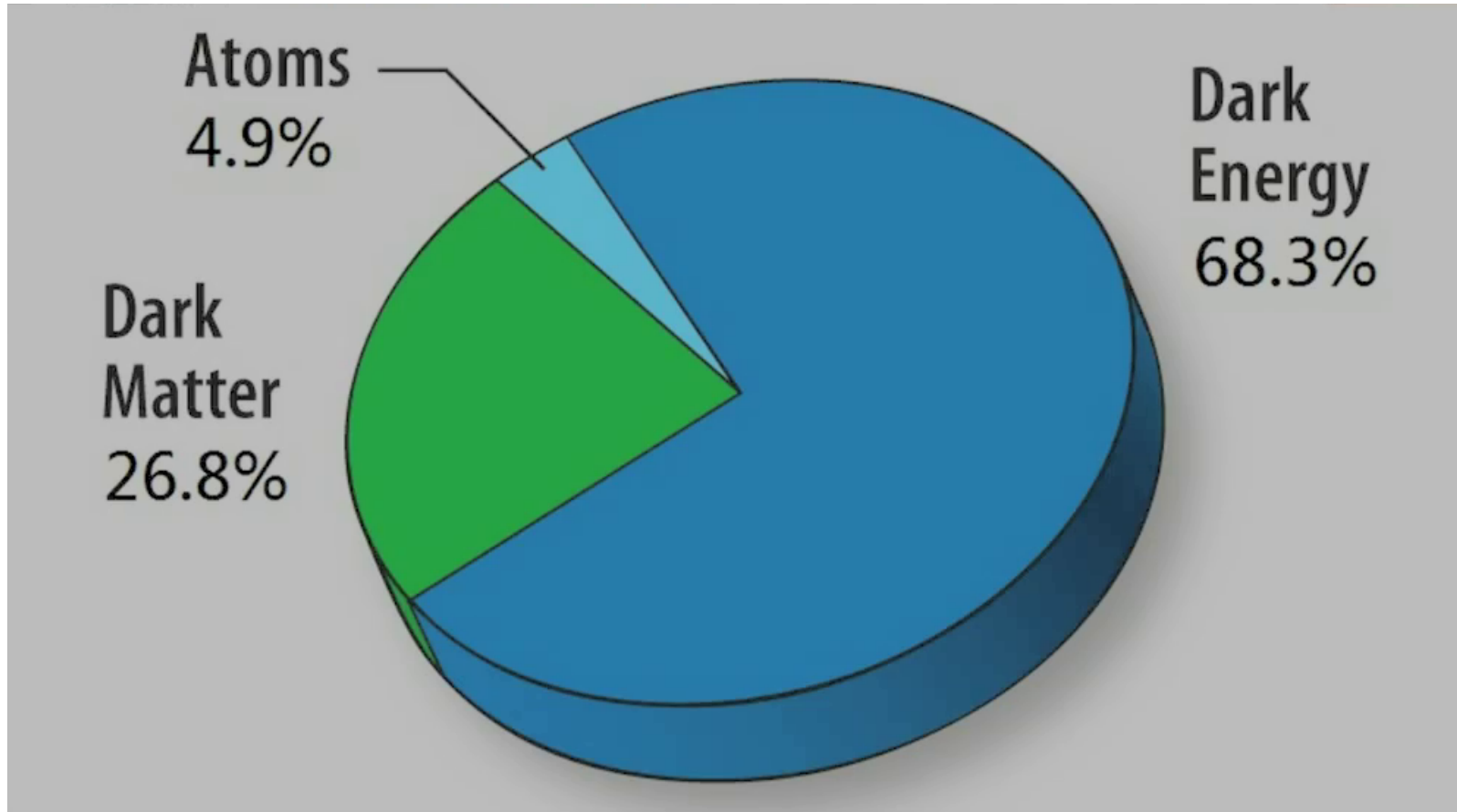
Accelerating universe fitted the best to the supernova data



The age of universe depending on the models



Contents of Universe



We know almost nothing about the universe