

History and Fate of the Universe



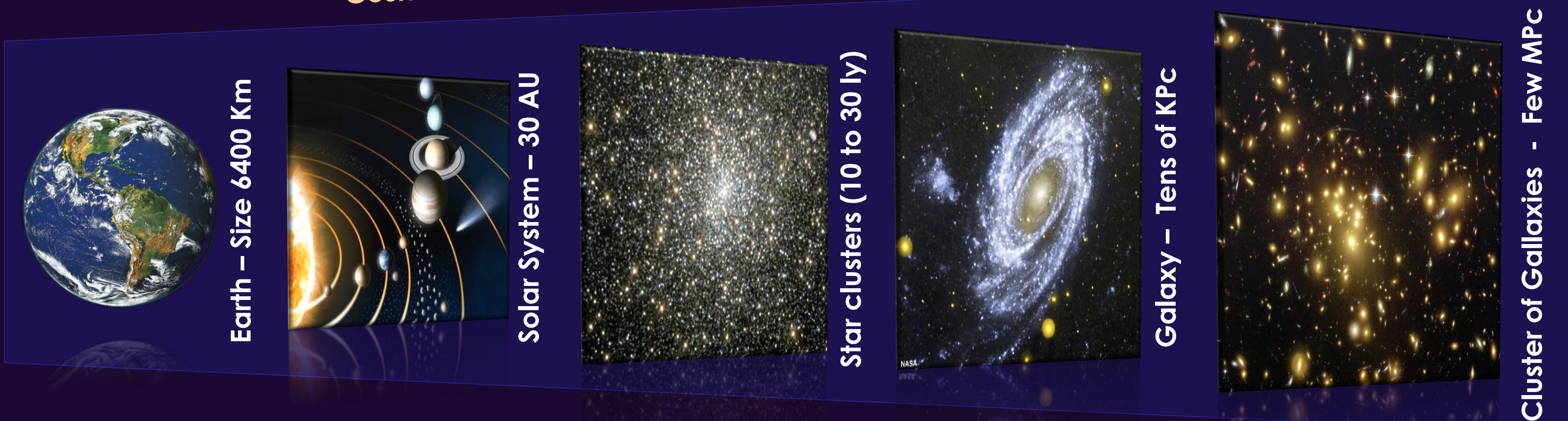
What is Cosmology?

Since the beginning of history, people have looked up into the sky and asked:

- Do stars change?
- How does the galaxies born?
- What do the stars tell us about the future?
- Where did the Universe come from?

Cosmology is the modern branch of physics that seeks to answer these kinds of questions. It is one of the most exciting disciplines of the physical science. It is concerned not so much with individual stars or galaxies in their own right, but rather with the properties of the Universe as a whole: its origin, evolution and eventual fate.

Cosmic Distance Ladder



A bit of History

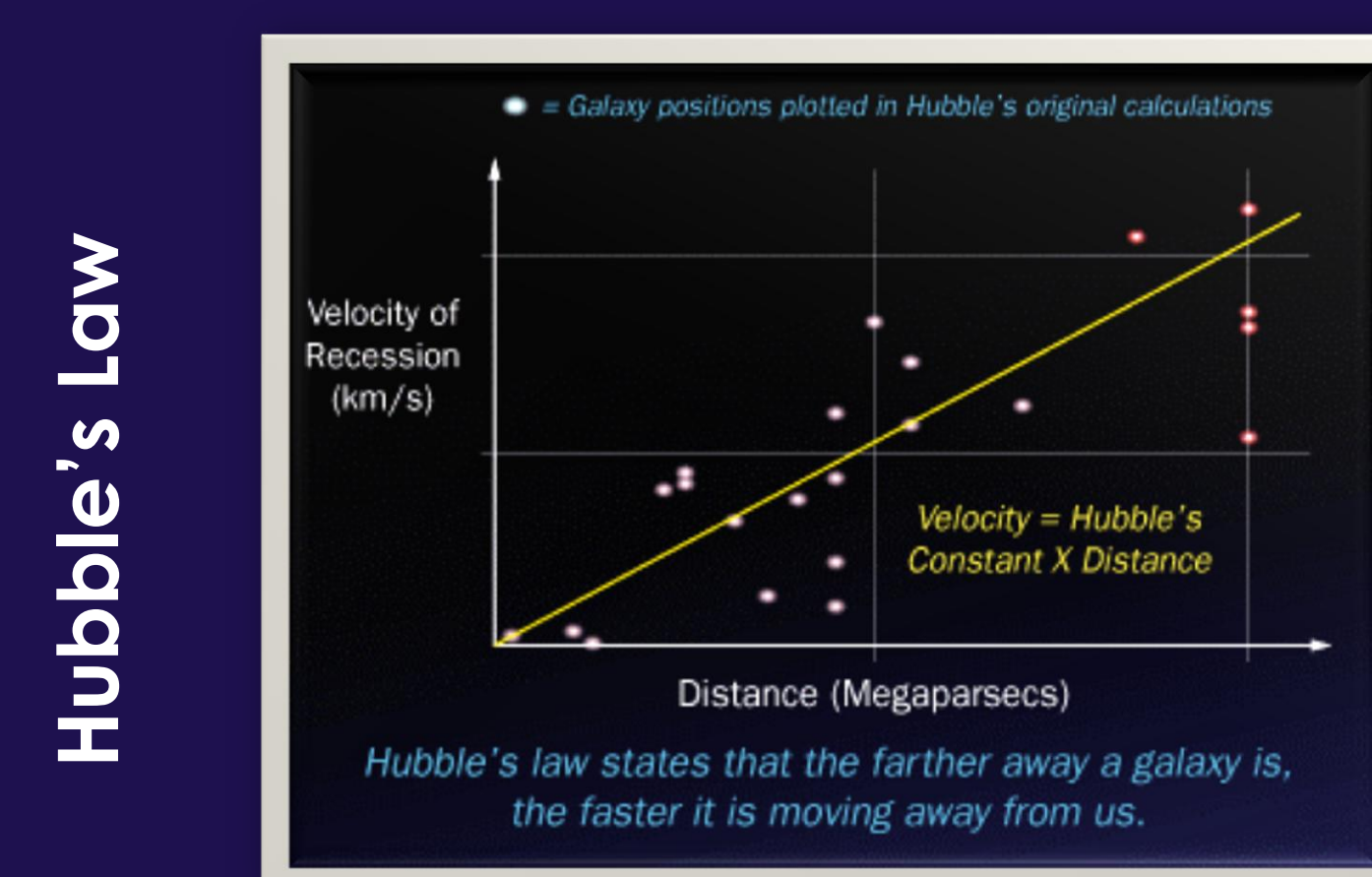
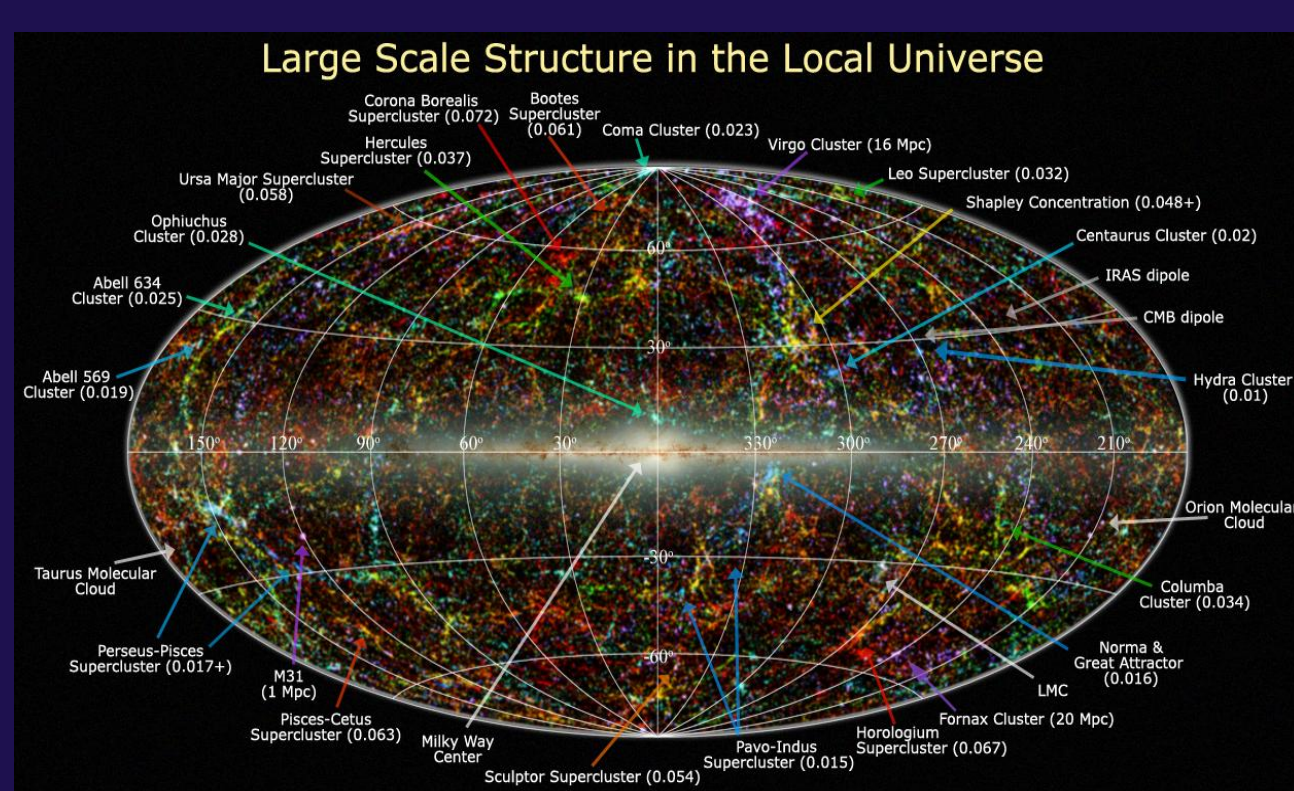
One of the first cosmological models was the **geocentric model** developed by the Greek astronomer Ptolemy. Ptolemy's model of the Universe placed the Earth at the center with the sun and planets located in concentric crystal spheres surrounding Earth. These spheres rotated, causing the sun and planets to appear to rise and set.

By the 1400s, scientists were beginning to question Ptolemy's model. Nicolaus Copernicus proposed a **heliocentric model** which placed the sun, instead of the earth, at the center of the solar system. Copernicus's model would later be championed by the famed scientist Galileo Galilei

Cosmological Principle

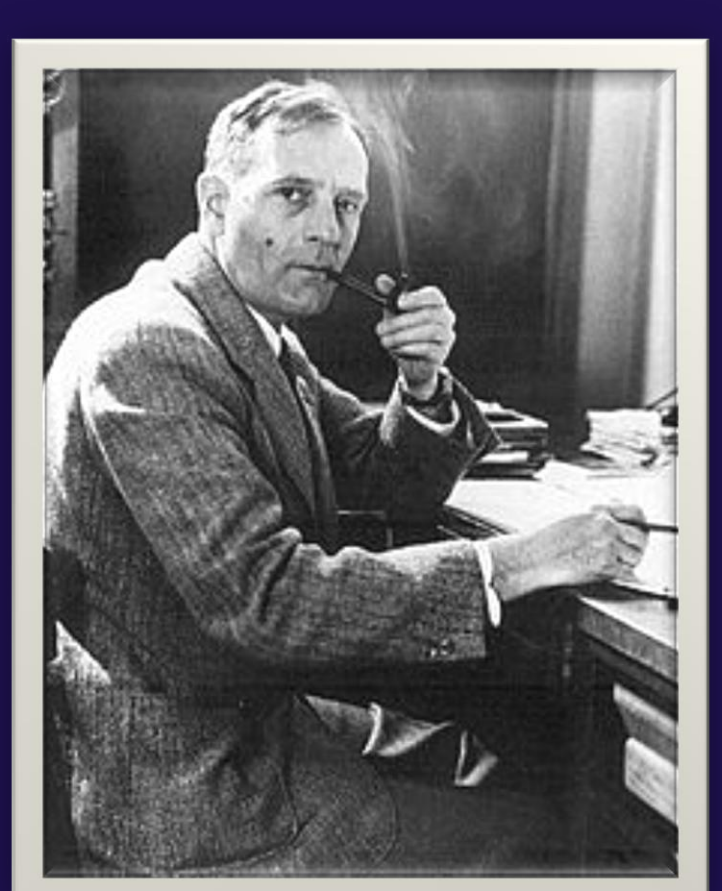
Today, cosmologists have a much grander view of the Universe, extending far beyond our solar system. Modern cosmologists think that the universe has no Center at all. Viewed on a sufficiently large scale, the universe looks much the same from all points (homogeneity) and in all the directions (isotropy).

The clusters themselves form superclusters which organize themselves into walls and filaments spanning a few hundred million lightyears. It is believed that at scales of around 100 Mpc, the lumpiness begins to homogenize and isotropize.



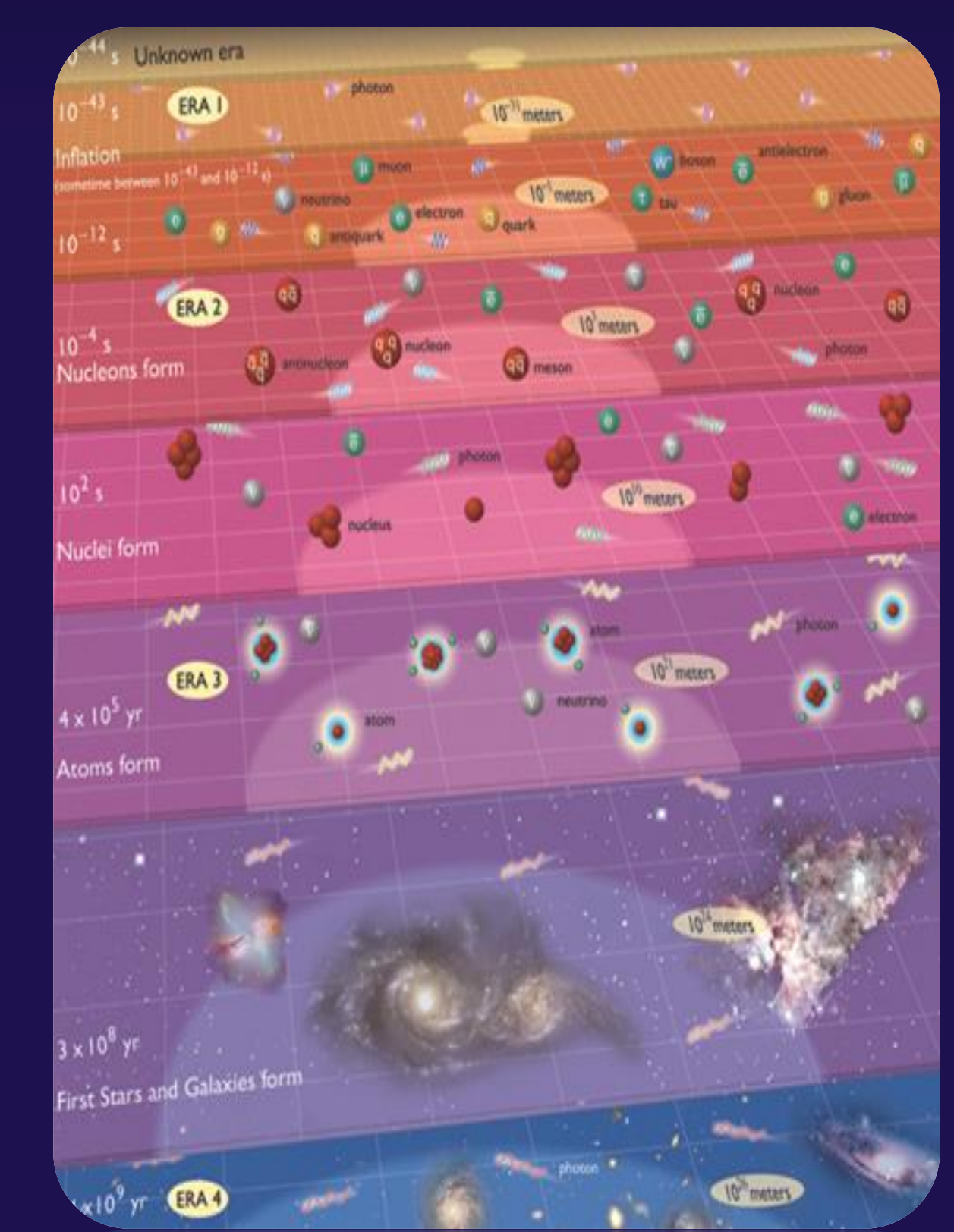
In 1929, after nearly a decade of observations from the telescope at Mt. Wilson, Edwin Hubble discovered that the galaxies were moving away from us. He determined the nature of the galaxies receding and gave us the Hubbles law : $v = H \cdot d$

v = velocity of the galaxy.
 H = Hubble's constant.
 d = distance to the galaxy.



Story of the expanding universe

Extrapolation of the expansion of the Universe backwards in time using general relativity yields an infinite density and temperature at a finite time in the past. Universe then very rapidly started expanding and cooling. Approximately 10^{-37} seconds into the expansion, a phase transition caused a cosmic inflation, during which the Universe grew exponentially. After inflation stopped, the Universe consisted of a quark-gluon plasma, as well as all other elementary particles. At about 10^{-6} seconds, quarks and gluons combined to form protons and neutrons. A few minutes into the expansion, when the temperature was about a billion kelvin and the density was about that of air, neutrons combined with protons to form the Universe's deuterium and helium nuclei in a process called Big Bang nucleosynthesis. Over a long period of time, the slightly denser regions of the nearly uniformly distributed matter gravitationally attracted nearby matter and thus grew even denser, forming gas clouds, stars, galaxies, and the other astronomical structures observable today.



How do we know if the story above is true ?

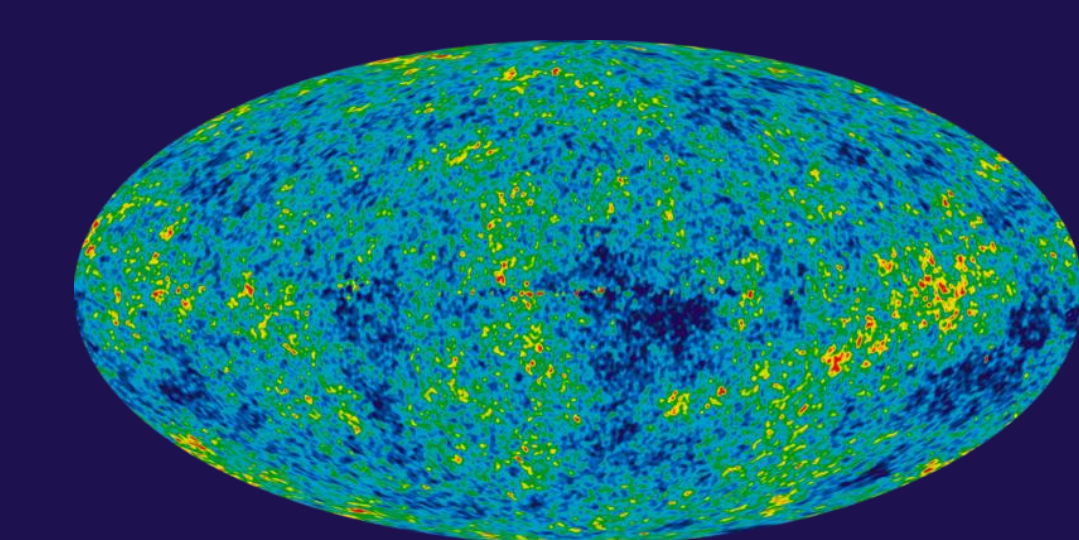
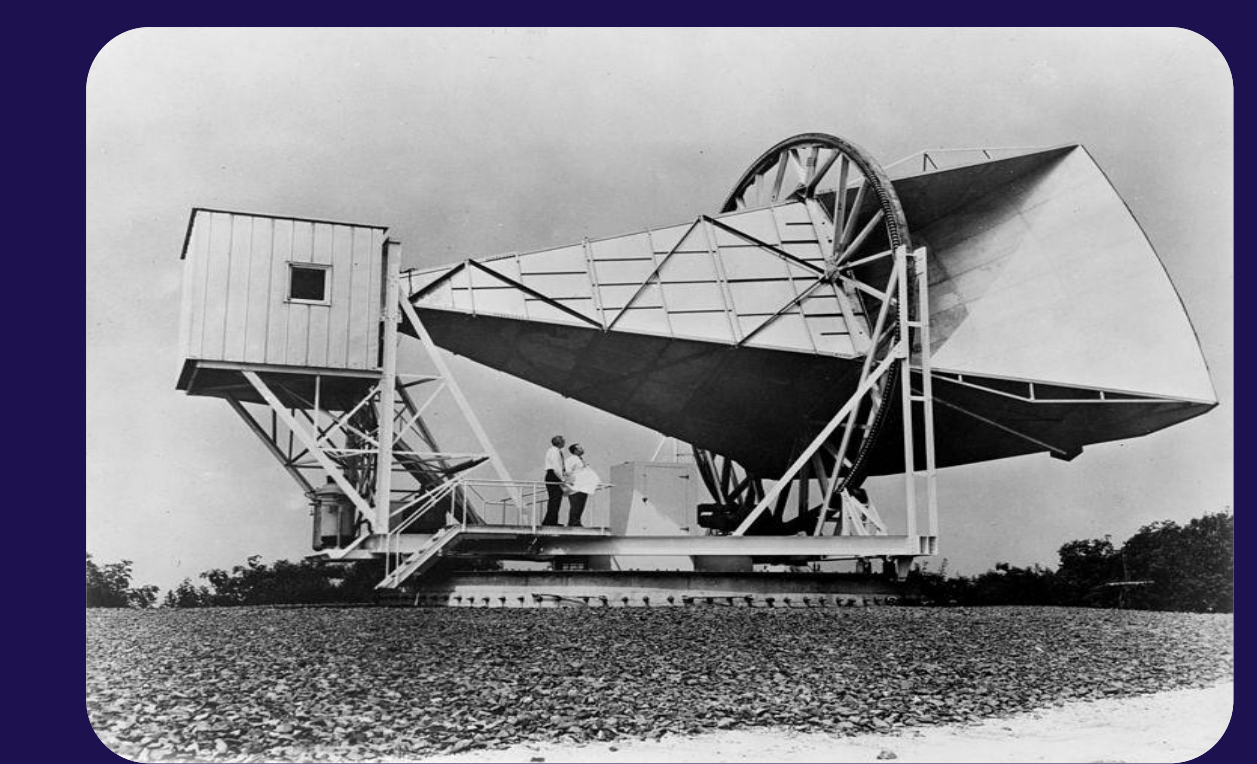
Like in archeology, cosmology finds clues to the past in relics. We can look back in time by looking out in space. Since light travels at the speed c , the time t we are looking back is $t=d/c$, where d is the measurable distance.

A relic from early universe is the "Cosmic Microwave Background" (CMBR). It is the radiation left over from an early stage in the development of the universe, and its discovery is considered a landmark test of the Big Bang model of the universe.

When the universe was young, before the formation of stars and planets, it was filled with plasma of matter and photons. As the universe expanded, the plasma filling it grew cooler. When the universe cooled enough, stable atoms could form. The photons then escaped from the plasma and have been propagating ever since, though growing fainter and less energetic, since exactly the same photons fill a larger and larger universe.

Gammow predicted the temperature of this radiation to be 5K. Precise measurements of CMBR shows that it has a thermal black body spectrum at a temperature of 2.725 K, which was very close to the original prediction. The spectrum peaks in the microwave range frequency of 160.2 GHz, corresponding to a 1.9 mm wavelength.

In 1965, Arno Penzias and Robert Woodrow Wilson at Bell Telephone Laboratories built a radiometer that they intended to use for radio astronomy and satellite communication experiments. Their instrument had an excess 3.5 K antenna temperature which they could not account for. Finally, they determined that the antenna temperature was indeed due to the microwave background. Penzias and Wilson received the 1978 Nobel Prize in Physics for their discovery.



To 1 part in 100,000 the CMBR is the same no matter in which direction one looks. The remaining tiny variations, are the seeds that later form galaxies and large cosmic structures. Thus, the CMB provides the earliest possible image of the Universe, and encoded within this image are signatures of the fundamental parameters of Cosmology.