

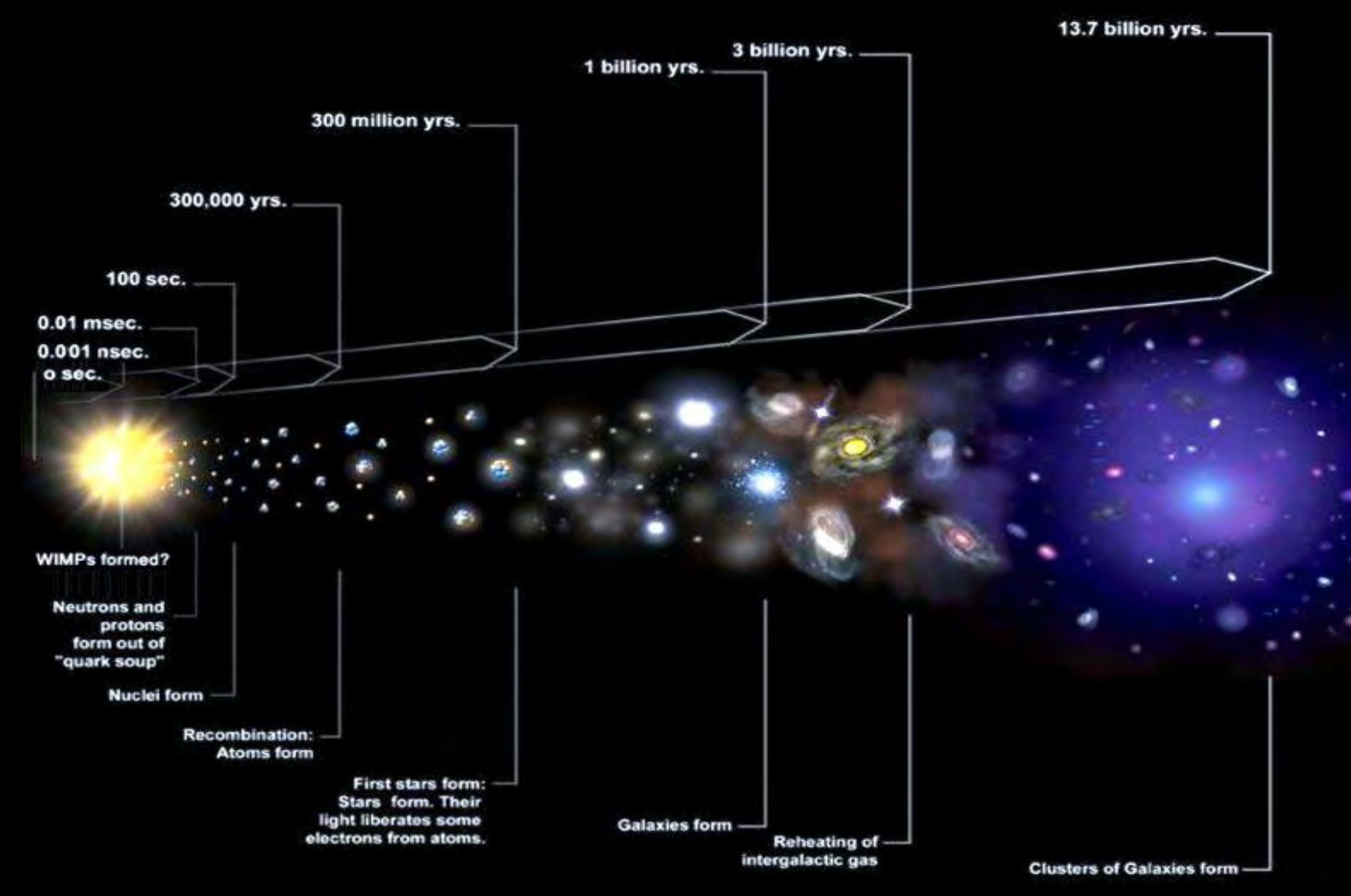
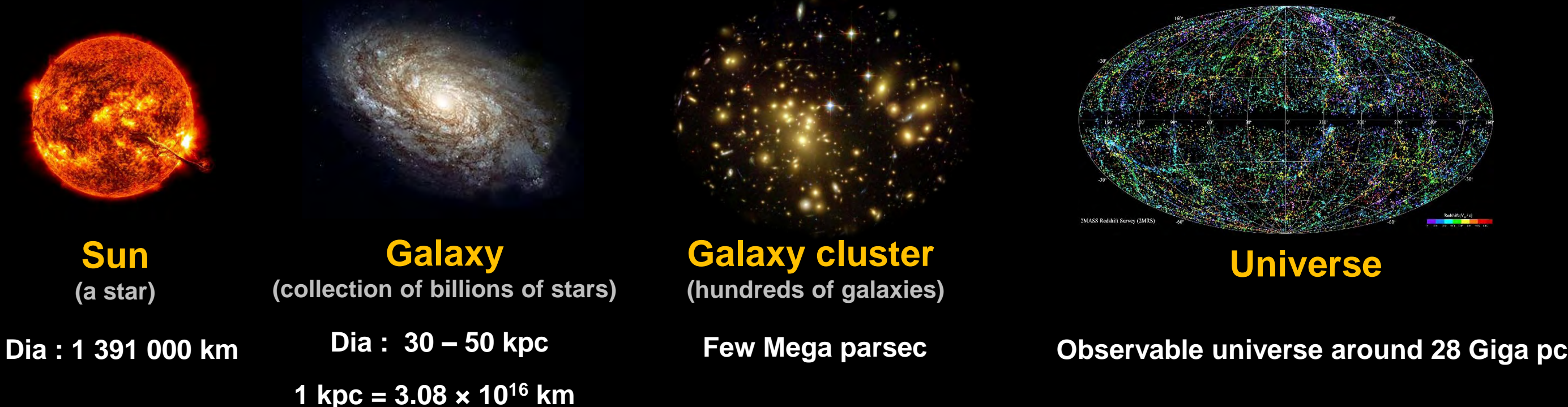
Cosmology

Studying the origin, evolution, and ultimate fate of the universe



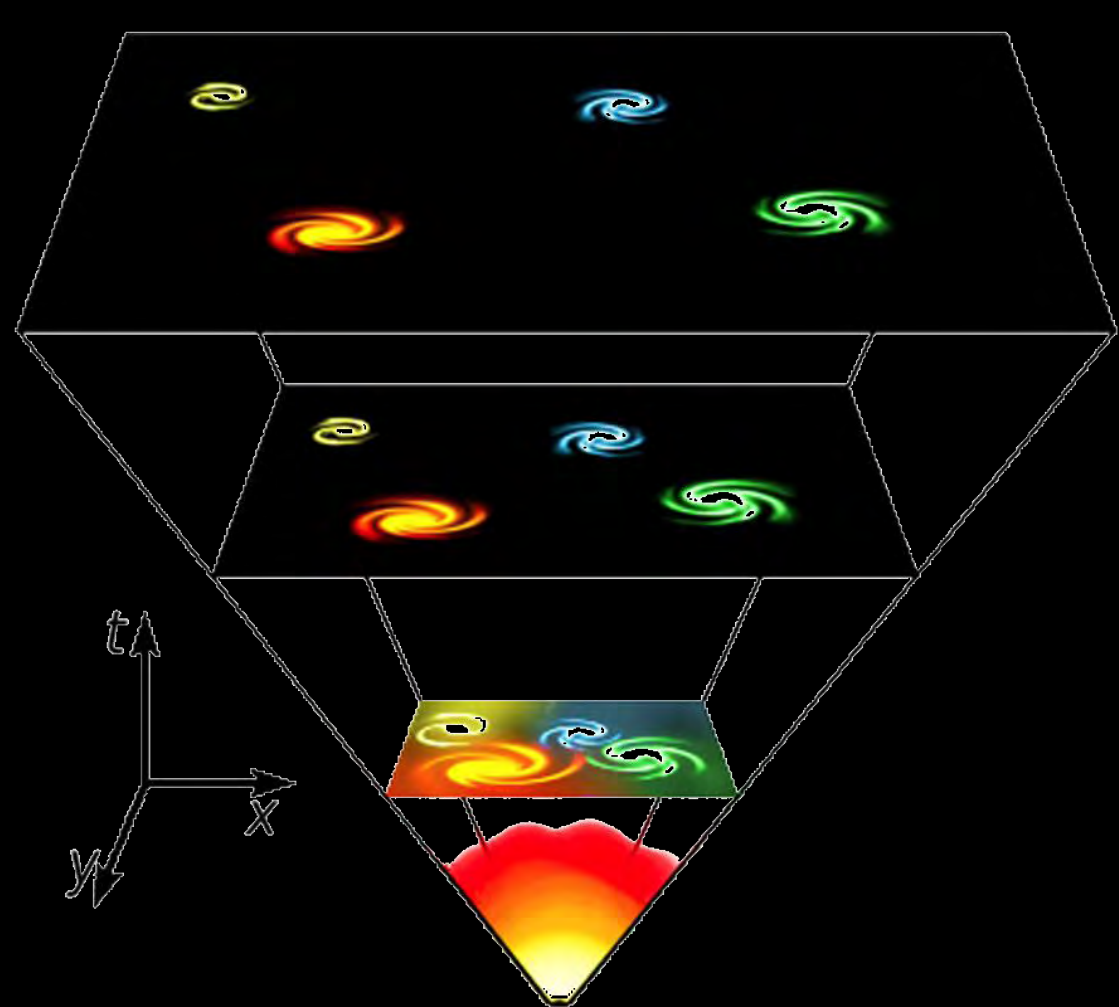
We Ask :

- What powered the Big Bang?
- What is the shape of the Universe? What is it composed of?
- When and how did the first stars and galaxies form?



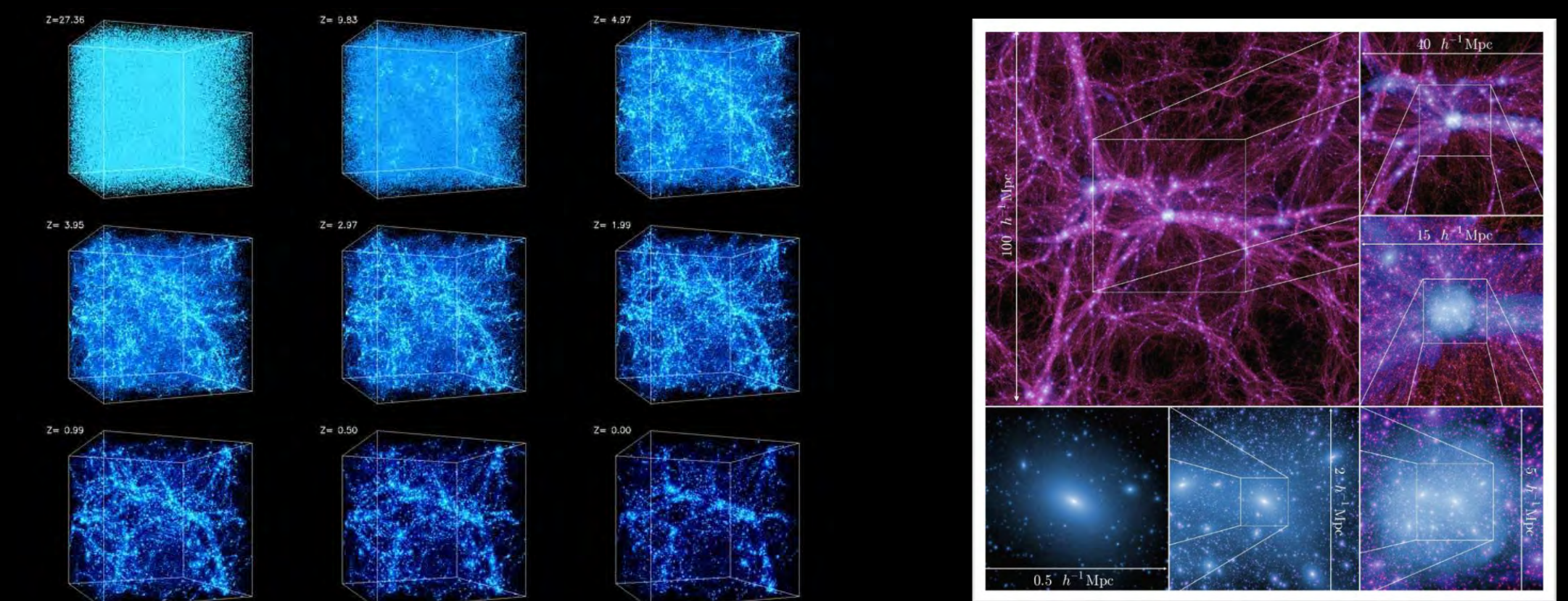
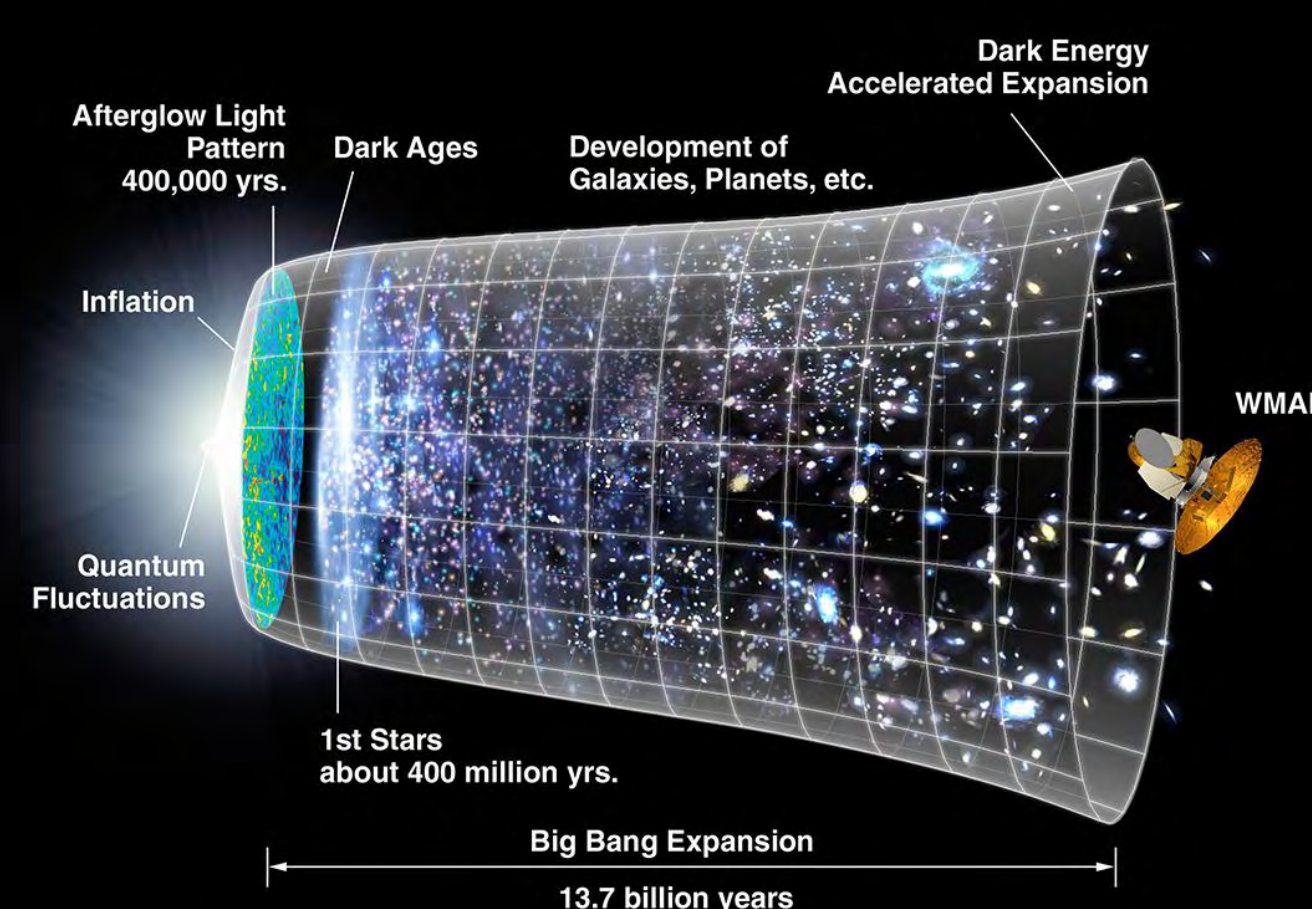
Scientists Reply :

Hubble's Law



In 1929, Edwin Hubble discovered that the galaxies were moving away from us. He determined the nature of the galaxies receding and gave us the Hubble's law : $v = H \cdot d$

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

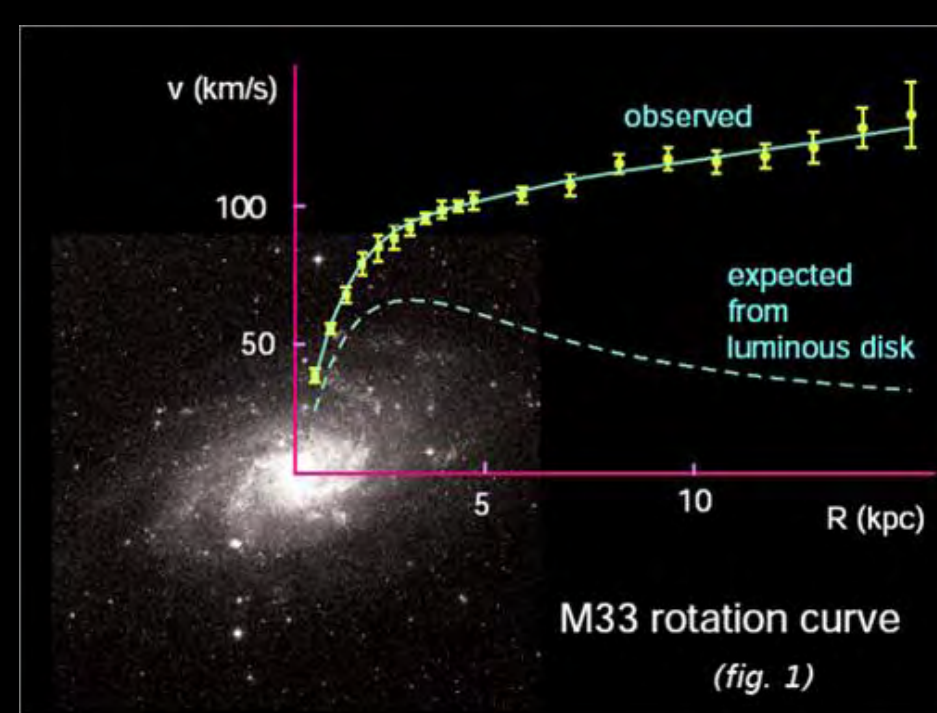


Gravity causes structures to form in the universe

Hubble's Law suggest that sometime in past all the galaxies were at a point, where density and temperature was infinite. 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, neutrons combined with protons to form the Universe's deuterium and helium nuclei in a process called Big Bang nucleosynthesis. Then, over a long period of time, gas clouds, stars, galaxies, and the other astronomical structures observable today.

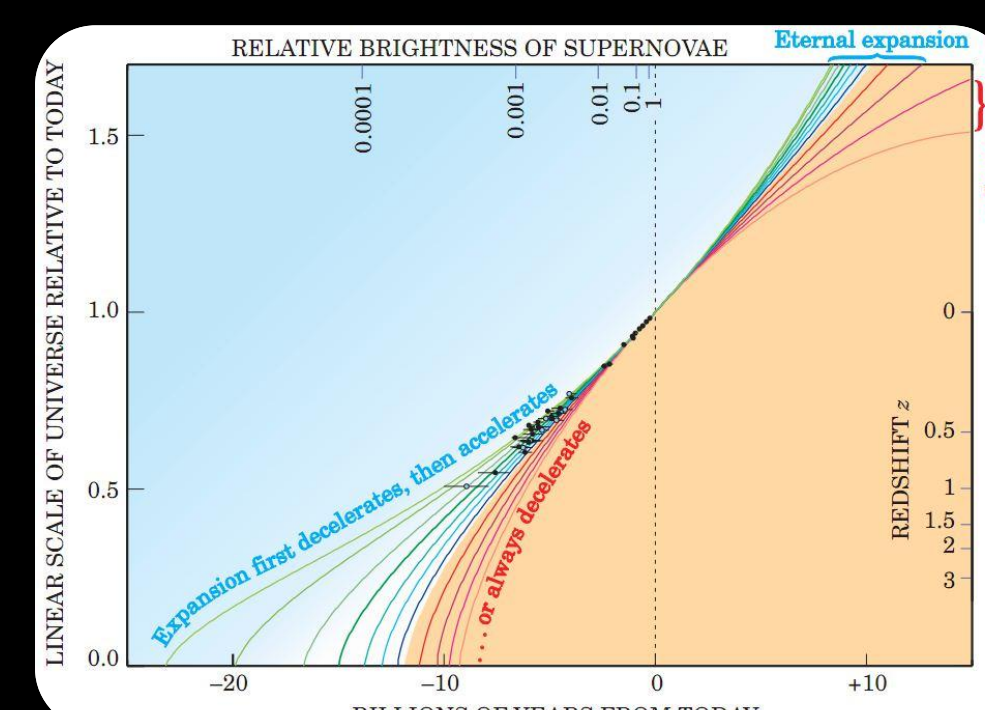
The universe is not totally smooth. In 1990 the COBE satellite detected ripples in the cosmic microwave background, the signature of primordial density fluctuations. These slight ripples in the early universe may have been generated by random quantum fluctuations in the energy field that drove inflation. These density fluctuations form the seeds of galaxies and galaxy clusters, which are scattered throughout the universe with a foamy large-scale structure on scales of up to about a billion light years. All these structures form because gravity amplifies the original fluctuations, pulling denser patches of matter together.

Dark Matter



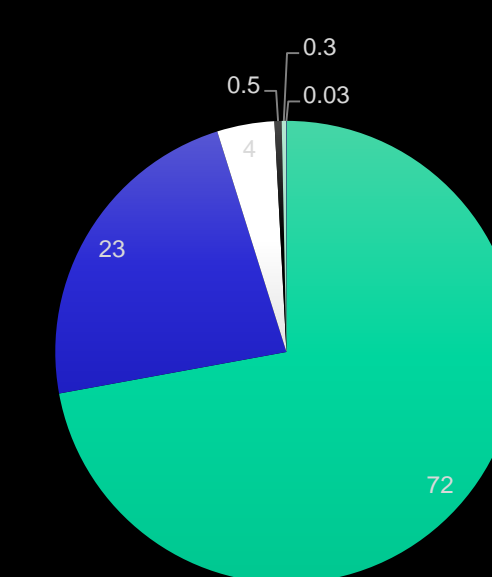
From the Newton's law one would expect the velocity with which a star revolve around a given galaxy beyond its centre bulge to fall as $R^{-1/2}$. However, observations unveiled that it is actually constant. This discrepancy in the galaxy rotation curve indicate the presence of a substantial amount of matter far from the center of the galaxy that is not emitting light known as Dark Matter.

Dark Energy



The presence of Dark Energy was revealed through a 10-year study of the spectacular astronomical events known as supernovae (extremely bright exploding stars). Light coming from far beyond Earth must cross expanding space. This shifts the colour of light waves towards the red end of the spectrum. If the expansion of the Universe were now slowing under the influence of gravity, supernovae in distant galaxies would appear brighter. Instead, the most distant supernovae seem to be dimmer. This means that the expansion rate of the Universe is accelerating due to some invisible, unidentified energy with negative pressure offsetting gravity.

Composition of the Universe



- Dark Energy (72%)
- Dark Matter (23%)
- Free Hydrogen & Helium (4%)
- Stars (0.5%)
- Neutrinos (0.3%)
- Heavy Elements (0.03%)

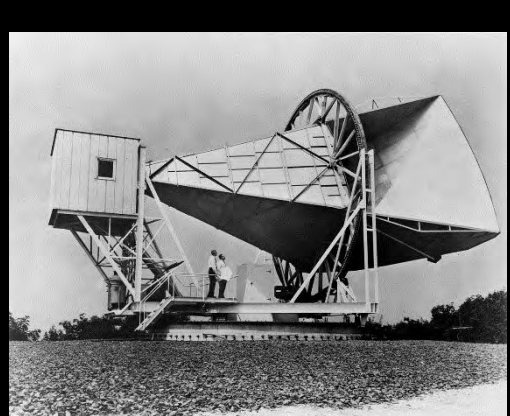
$$H = 70.5 \text{ km/s / Mpc}$$

$$\Omega_s = 0.97$$

We call this the Lambda CDM model of the Universe

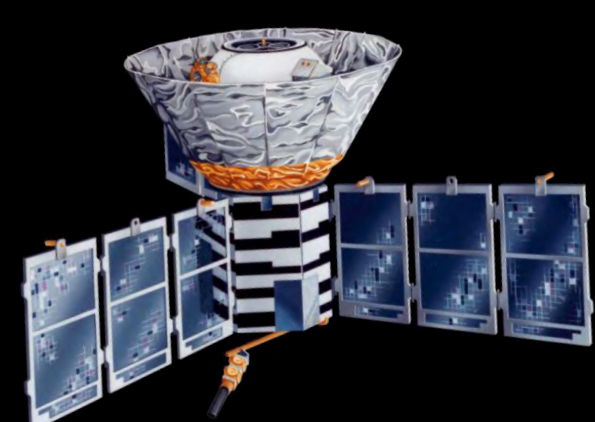
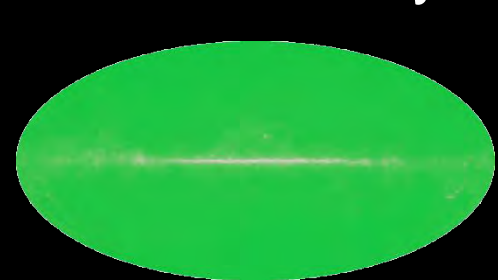
They Use :

The Missions



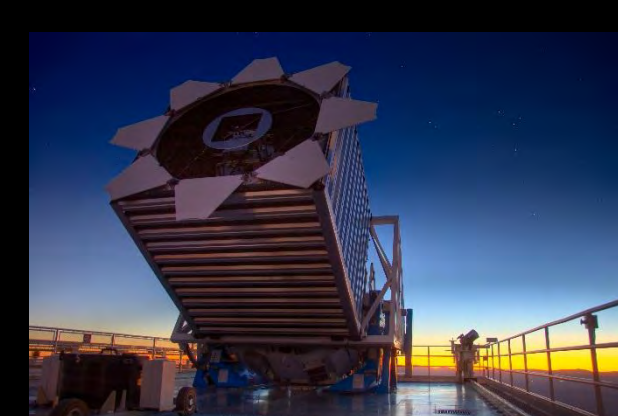
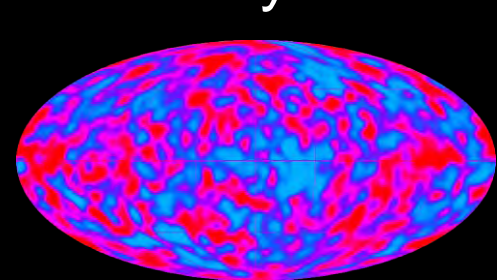
Penzias and Wilson (1965)

detected a 3.5 K temperature uniform all over the sky.



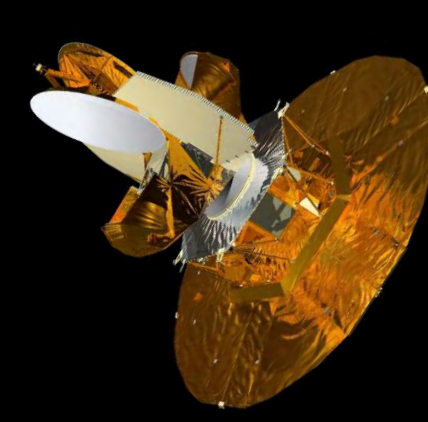
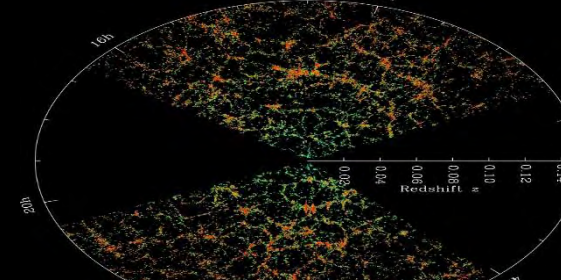
COBE (1989)

detected micro kelvin level fluctuations in CMB sky.



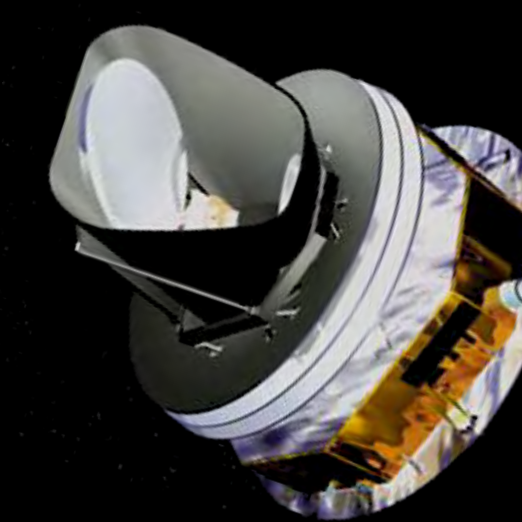
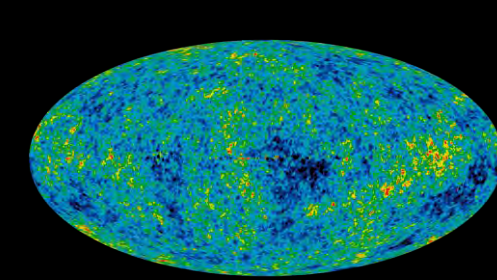
SDSS (2000 - present)

Collected data from huge number of galaxies.



WMAP (2001 - present)

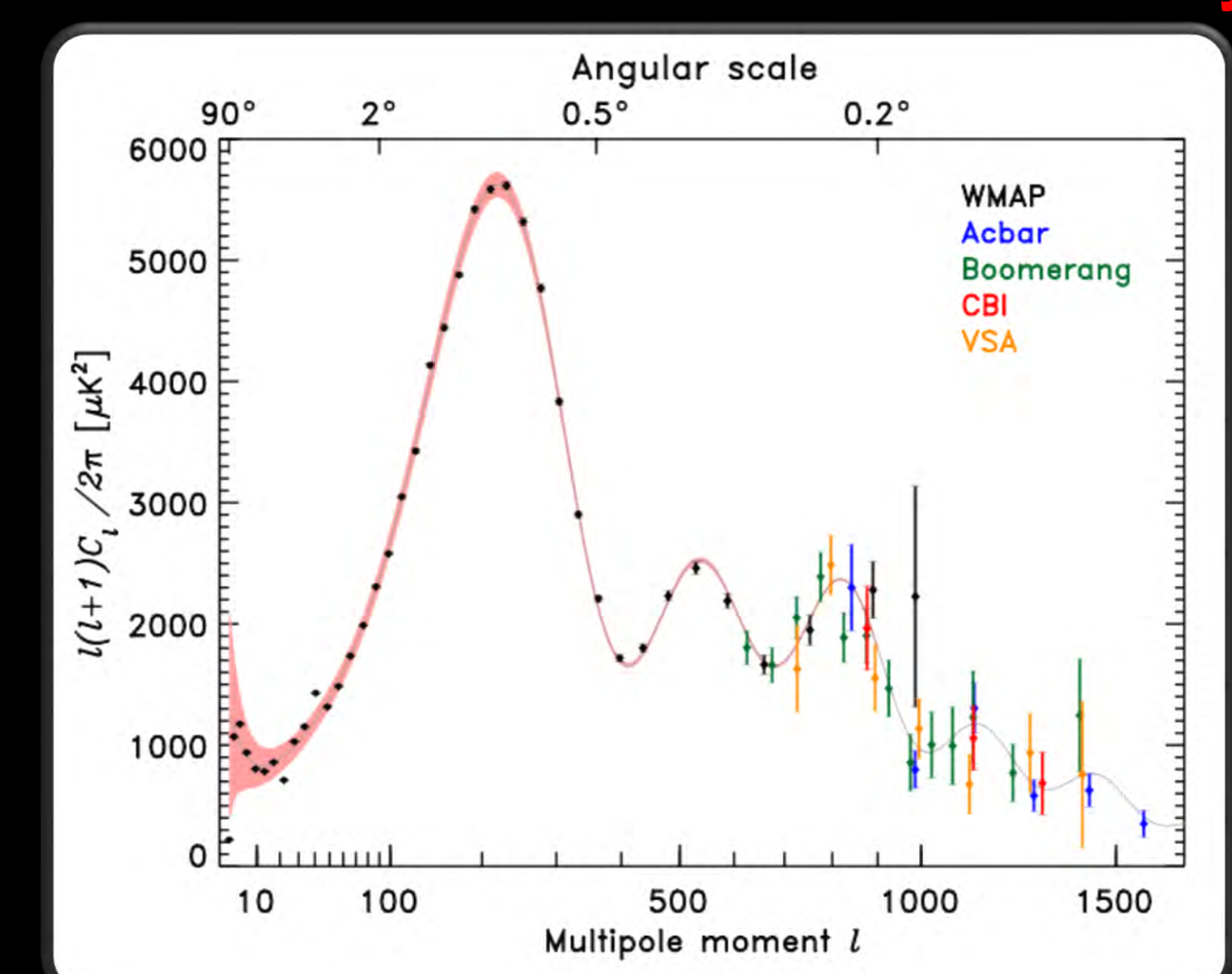
Observed CMB sky at an arc minute level of resolution



PLANCK (2009 - present)

Expecting to see high resolution CMB temperature and polarization map

Observation matches the theory



Observational dataset matches with the theoretical predications very accurately proving theory to be correct