

Week 4

April 21, 2018

Neutrinos in Cosmology: Little particles on the biggest scale



Cosmology is the study of the origin and behavior of our universe on its largest scales. Experimental efforts of increasing accuracy and theoretical advances have transformed Cosmology in a precise and quantitative branch of physics. This led to the development of a successful model for the evolution of the universe and its content. Neutrinos occupy a special place in this model as their phenomenology is different from that of other components and allows cosmological probes to be sensitive to sum of the three neutrino masses.

This week, we will discuss the role of neutrinos in the evolution of our Universe from the epoch where they were produced to their gravitational influence on the formation of cosmic structures.

I. Neutrinos in the primordial universe

Neutrinos are abundant in the primordial universe and make up to the 30% of its total content, when the universe is only minutes old. They are kept in thermal equilibrium by nuclear reactions involving neutrinos and other leptons. Once the rate of these nuclear processes becomes smaller than the rate at which the universe expands neutrino cannot interact with other particles and start free streaming throughout the universe without further interactions. This process is called decoupling and happens when the Universe is about one second old. The left over neutrinos constitute the relic neutrino background and experiments, like PTOLEMY, are being built in the hope of directly measuring it.

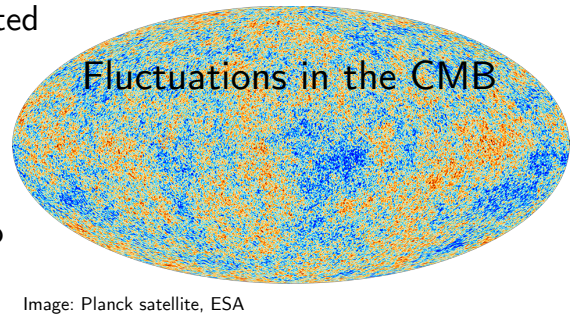
II. Neutrinos and Hydrogen recombination

Once neutrinos decouple their influence on the other components of the Universe comes through their gravitational interaction. In particular neutrinos make up about 11% of the content of the universe when Hydrogen atoms form (recombination). As the Universe cools down the capture of the electrons by protons becomes efficient and electrons cannot participate in Thompson scattering (the low energy limit of Compton scattering). This allows electromagnetic radiation to free stream to us mostly without interactions from about 378,000 years after the Big Bang. The relic electromagnetic background has been detected in 1964, by Penzias and Wilson, at microwave wavelengths and is called the Cosmic Microwave Background (CMB).

Small fluctuations are imprinted in the CMB due to the tight interactions between photons and ordinary matter (baryons) before recombination. These oscillations are the result of a balance between gravity compressing the photo-baryon fluid and its pressure reacting to this compression. Relic neutrinos contribute to the sharpening of these gravitational potential wells taking part in the driving of the oscillations.

Small fluctuations in the CMB were first detected by the CoBE satellite in 1989.

They were then measured to exquisite precision by the WMAP and Planck satellite and based on these data, it was possible to have indirect evidence for the existence of the relic neutrino background.



III. Neutrinos and the formation of cosmic structures

The free streaming of relic neutrinos plays a role in the formation of cosmic structures at later times. Since neutrinos have a small mass they are not diluted by cosmic expansion as fast as electromagnetic radiation and a small fraction (1%) is present when galaxies form.

Neutrinos have high thermal velocities and cannot be trapped in the gravitational potential wells where galaxies are forming. This leaves a distinct imprint on the clustering of galaxies that is suppressed on small scales.

Through this effect the next generation of cosmological experiments from satellite and the ground aims at measuring the sum of the three neutrino masses.