Abstract

The universe is filled with nearly isotropic cosmic microwave background (CMB) radiation, which has a blackbody spectrum of temperature $T \approx 2.73$ K. In addition, there are tiny direction dependent deviations $\delta T$ from the mean temperature, $\delta T / T \lesssim 10^{-4}$. These CMB anisotropies result from small primordial perturbations. The initial conditions, deep in the radiation-dominated universe, can be a mixture of two different modes: adiabatic and isocurvature perturbations. The former means a primordial perturbation in the spatial curvature of the universe, whereas the latter means a spatial perturbation in the relative number densities of different particle species. Adiabatic and isocurvature primordial perturbations lead to a distinct imprint on the observed angular power — the CMB temperature variance $\langle (\delta T)^2 \rangle$ as a function of angular scale in the sky. Often, in the literature, a pure adiabatic primordial perturbation mode has been assumed.

We review the linear cosmological perturbation theory in the Newtonian gauge, and show how the primordial perturbations evolve into the observed anisotropies. According to the recent precision CMB data, the primordial perturbations are predominantly adiabatic. We constrain the amplitude of a primordial cold dark matter (CDM) isocurvature perturbation in phenomenological models where the adiabatic and isocurvature perturbations can be correlated or uncorrelated, and have a power-law spectrum with an independent spectral index for each component. Perturbations of this type arise naturally in multifield inflationary models, in inflaton-curvaton models, and in the pre-Big Bang model with axion and dilaton. Cosmic strings, quintessence, or brane collision could also give rise to isocurvature perturbations.

We find at the 95% confidence level that at most only 18% of the total primordial perturbation power can be in the form of the CDM isocurvature perturbation. In the observed temperature variance, an upper limit to the non-adiabatic contribution is 7.5%.

The determination of the conventional cosmological parameters can be affected by the possible presence of an isocurvature mode. We scan the likelihood function in an 11-dimensional parameter space by a sophisticated Markov Chain Monte Carlo method, and conclude that, of the standard parameters, the determination of the physical CDM density $\omega_c$ and the sound horizon angle $\theta$ (or the expansion rate of the universe, the Hubble parameter $H_0$) are affected the most. The physical baryon density $\omega_b$ retains nearly the same value as in the standard adiabatic $\Lambda$CDM model. These results suggest that the CDM isocurvature can play an important role in inferring the dark matter and dark energy contents of the universe.