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Constraints on the Tensor Mode from Large Scale Structure Observations

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Abstract. Observational data on the large scale structure (LSS) of the Universe are used to establish an upper limit for the amplitude of the tensor mode marginalized over all other cosmological parameters within the class of adiabatic inflationary models. It is shown that the upper 1σ limit for the contribution of a tensor mode to the COBE DMR data is T/S< 1.

1. Introduction

The ratio of tensor to scalar fluctuations (T/S) is important for discriminating among large number of inflation models as well as for the determination of the cosmological parameters. The tensor mode contributes to the temperature fluctuations of cosmic microwave background (CMB) at the largest angular scales. Its amplitude can be determined by comparing the 4-year COBE data (Bennett et al. 1996) with the large scale structure observations to which only the scalar mode contributes. The main reason why present data does not lead to a stringent limit is that the inferred contribution of a tensor mode strongly depends on practically all other cosmological parameters. Most notable on the spectral index of primordial power spectrum of scalar perturbations, n_s, but also on the values of cosmological constant Ω_Λ, the dark matter content and its nature, spatial curvature Ω_k, the Hubble parameter h and the baryon content Ω_b. This means that T/S must be determined simultaneously with all these parameters from wide range scale of cosmological observations. Similar investigations show that mixed dark matter model with cosmological constant (ΛMDM) can explain virtually all cosmological measurements (Novosyadlyj et al. 2000). The goal of this paper is to determine the upper limit on the ratio T/S in the framework of ΛMDM models. We restrict ourselves the sub-class of models without early reionization.

We find the parameters of cosmological model which matches the observational data on the large scale structure of the Universe best and by marginalization over all other parameters determine the upper limit on T/S.

2. Experimental data set and method

Our approach is based on the comparison of observational data on the structure of the Universe over a wide range of scales with theoretical predictions from the linear power spectrum of density fluctuations. The form of the spectrum strongly depends on the cosmological parameters Ω_m, Ω_b, Ω_ν, N_ν, h and n_s. Minimization of the quadratic differences between the theoretical and observational values divided by the observational errors, χ^2, determines the best-fit values for the above mentioned cosmological parameters and the amplitude of the power spectrum of scalar mode. For this we use the following observational data set: the location and amplitude of the first acoustic peak in the angular power spectrum of the CMB temperature fluctuations deduced from the CMB map obtained in the Boomerang and MAXIMA-1 experiments; the power spectrum of density fluctuations of Abell-ACO clusters obtained from their space distribution; the constraint for the amplitude of the fluctuation power spectrum on $\approx 10h^{-1}$Mpc scale derived from a recent optical determination of the mass function of nearby galaxy clusters, from the evolution of the galaxy cluster X-ray temperature distribution function and from the existence of three very massive clusters of galaxies observed so far at $z > 0.5$; bulk flows of galaxies in sphere of radius $50h^{-1}$Mpc; the constraint for the amplitude of the fluctuation power spectrum on $0.1 - 1h^{-1}$Mpc scales and $z \approx 2-3$ derived from the Ly-α absorption lines seen in quasar spectra; the data on the direct measurements of the Hubble constant $\tilde{h} = 0.65 \pm 0.10$ which is a compromise between results obtained by different groups; the nucleosynthesis constraint on the baryon density derived from the abundance of inter galactic deuterium $\widetilde{\Omega_b h^2} = 0.019 \pm 0.0024$. (For references and more details of the observations used see Durrer & Novosyadlyj 2000).

One of the main ingredients for the solution for our search problem is a reasonably fast and accurate determination of the linear transfer function for dark matter clustering which depends on the cosmological parameters. We use accurate analytical approximations of the MDM transfer function $T(k;z)$ depending on the parameters Ω_m, Ω_b, Ω_ν, N_ν and h given by Eisenstein & Hu (1999). The linear power spectrum of matter density fluctuations $P(k;z) = A_s k^{n_s} T^2(k;z) D_1^2(z)/D_1^2(0)$, where $A_s = 2\pi^2\delta_h^2(3000\text{Mpc}/h)^{3+n_s}$ is the normalization constant for scalar perturbations, $D_1(z)$ is the linear growth factor and δ_h is the matter density fluctuation at horizon scale.

The Abell-ACO power spectrum is related to the matter power spectrum at $z = 0$, $P(k;0)$, by the cluster biasing parameter b_{cl}: $P_{A+ACO}(k) = b_{cl}^2 P(k;0)$. We assume scale-independent linear bias as free parameter of which the best-fit value is determined together with the other cosmological parameters.

The dependence of the position and amplitude of the first acoustic peak in the CMB power spectrum on cosmological parameters n_s, h, Ω_b, Ω_{cdm} and Ω_Λ is obtained with the analytical approximation given by Efstathiou & Bond (1999) which has been extended to models with non-zero curvature ($\Omega_k \equiv 1 - \Omega_m - \Omega_\Lambda \neq 0$) by Durrer & Novosyadlyj (2000). The accuracy of this approximation in the parameter ranges which we consider is better then 5%.

The theoretical values of the other experimental constraints are calculated as described in Durrer & Novosyadlyj (2000).

3. Results and Discussion

We consider the normalization of the scalar mode δ_h^{LSS} as free parameter which is determined together with the cosmological parameters Ω_m, Ω_Λ, Ω_ν, N_ν, Ω_b,

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h, n_s and b_{cl} by the Levenberg-Marquardt χ^2 minimization method. Hence, we have eight free parameters (the number species of massive neutrino is discrete and fixed). The formal number of observational points is 24 but, as it was shown in Novosyadlyj et al. (2000), the 13 points of the cluster power spectrum can be described by just 3 degrees of freedom, so that the maximal number of truly independent measurements is 14. Therefore, the number of degrees of freedom for our search procedure is $N_F = N_{\rm exp} - N_{\rm par} = 6$. The model with one sort of massive neutrinos provides the best fit to the data, $\chi^2_{min} = 5.8$. The best fit parameters are $\delta_h^{LSS} = (2.95 \pm 2.55) \cdot 10^{-5}$, $\Omega_m = 0.40 \pm 0.08$, $\Omega_\Lambda = 0.66 \pm 0.07$, $\Omega_\nu = 0.05 \pm 0.05$, $\Omega_b = 0.038 \pm 0.010$, $n_s = 1.14 \pm 0.31$, $h = 0.71 \pm 0.09$ and $b_{cl} = 2.4 \pm 0.3$ (standard errors). The best-fit value for density perturbation at horizon scale from the 4-year COBE data δ_h^{COBE} for the same model is larger then the best-fit value determined from LSS characteristics, $\delta_h^{COBE} = 4.0 \cdot 10^{-5} > \delta_h^{LSS}$. This implies that COBE $\Delta T/T$ data may contain a non-negligible tensor contribution. The ratio T/S is given by $T/S = (\delta_h^{COBE} - \delta_h^{LSS})/\delta_h^{LSS}$. The best fit value of this parameter implied by the best-fit values of δ_h^{COBE} and δ_h^{LSS} from the data used above is $T/S = 0.36$, if we use just the Boomerang data (de Bernardis et al., 2000) for the amplitude and position of the first acoustic peak, and $T/S = 0.18$ from the combined Boomerang + MAXIMA-1 (Hu et al., 2000) data. Since the standard error is rather large, $\approx 90\%$, we determine upper confidence limits for T/S by marginalizing δ_h^{LSS} over all the other parameters. This procedure yields $T/S < 1$ at 1σ C.L. and $T/S < 1.5$ at 2σ C.L. from the Boomerang data alone for the amplitude and position of the first acoustic peak. If we use the combined Boomerang + MAXIMA-1 data the limits are somewhat lower, 0.9 and 1.3 correspondingly, due to the higher amplitude of the first acoustic peak measured by MAXIMA-1. The 1σ upper constraint on the tensor mode obtained recently by Kinney et al. (2000) from the Boomerang and MAXIMA-1 data on the CMB power spectrum for the same class of models (T/S< 0.8 in our definition) is close to the value obtained here.

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