Effects of a variation of the fine structure constant on the CMB fluctuation spectrum

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We study the effects of a possible variation in the fine structure constant on the CMB temperature and polarization fluctuation spectrum. We discuss some properties that may distinguish this effect from changes in other cosmological parameters such as Ω_b, Ω_0 and H_0.

Unification schemes such as superstrings and Kaluza-Klein theories predict time variation of fundamental constants over cosmological timescales. Experimental bounds on the variation of fundamental constants are an important tool to check the validity of these theories. Bounds over different timescales have been placed from astronomical and geophysical methods. The best laboratory measurements give a limit of $\frac{\Delta\alpha}{\alpha} < 1.4 \times 10^{-14}$ during 140 days[1]. Astronomical methods are based mainly in the analysis of spectra from high-redshift quasar absorption systems, with a recent claim of $\frac{\Delta\alpha}{\alpha} = -1.5 + 0.3 \times 10^{-5}$ for a set of redshifts $0.5 < z < 1.6$

Time-dependence in α can also be constrained by the change it induces upon the pattern of cosmic microwave background (CMB) fluctuations[3,4]. The dominant effect is due to the change in the redshift at decoupling. While constraints from CMB data are much less stringent than those discussed above, they can test variations of α at much earlier times $(z \approx 1000)$. Here, we discuss whether CMB polarization measurements may help to distinguish the effect of varying the fine structure constant from similar effects due to variations of other cosmological parameters such as the density of baryonic matter and the total matter density of the universe.

The recombination and decoupling histories depend very subtly upon α through several physical quantities. We used the CMBFAST code[5] with appropriate modifications to determine the effects of a change in α. Figure 1 displays the change in the CMB temperature and polarization correlation function induced by a change in α at the time of decoupling of 3% compared to its present value, in a standard cold dark matter cosmological model (SCDM) with adiabatic scalar fluctuations.

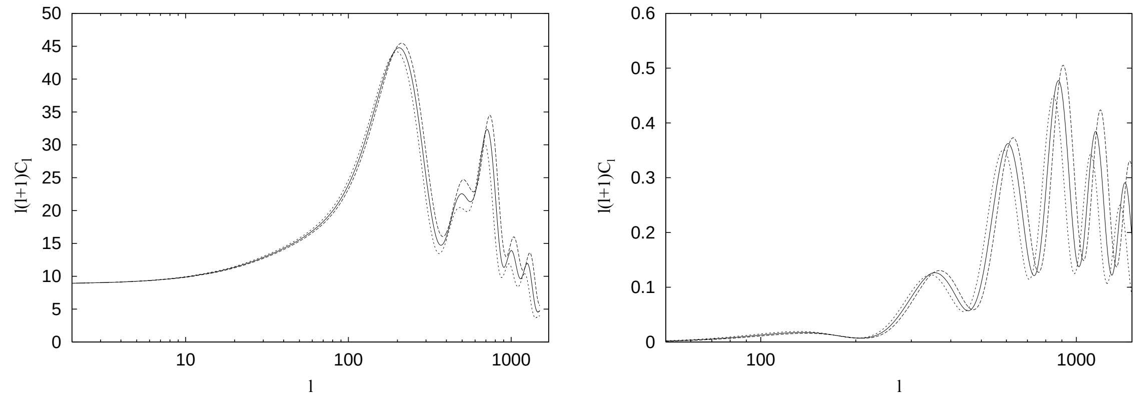

Figure 1: The spectrum of CMB temperature (left) and polarization (right) fluctuations in a SCDM scenario ($\Omega_b = 0.05, h = 0.65, \Omega_m = 0.95$) (solid curve), with an increase of α by 3% (dashed curve), and a decrease of α by 3% (dotted curve).

Qualitatively, the main effect of a variation in α is due to the change in the binding energy of hydrogen. The consequence is that decoupling occurs at a different temperature, higher if α increases. An increase in α also increases the Thomson scattering rate, which reduces the width of the visibility function and makes diffusion damping more effective. The effect displayed in Fig. 1 is reasonably well fitted as a shift of the spectrum along with a change in normalization and in the exponential damping at small angular scales described by $C_l^T \approx C_{l_0}^T(1+2\frac{\delta\alpha}{\alpha})e^{2\frac{\delta\alpha}{\alpha}(l/l_D)^2}$ and $C_l^P \approx C_{l_0}^P e^{2\frac{\delta\alpha}{\alpha}(l/l_D)^2}$, with $l = l_0(1+\frac{3}{2}\frac{\delta\alpha}{\alpha})$. $l_D \approx 950$ sets the diffusion damping scale. The shift in the position of the Doppler peaks, which basically depends upon the size of the horizon at last scattering[6], is comparable to the shift that a change in $\Omega_0 h^2$ by around 10% would produce. The change in the relative heights of the peaks is of the order of that produced if $\Omega_b h^2$ changes by around 30%.

The CMB linear polarization is proportional to its quadrupole anisotropy around the time of decoupling and also to the width of the last scattering surface, which decreases if α increases. This is the reason why $C_l^P/C_l^T \approx (1-2\delta\alpha/\alpha)$. This additional dependence suggests that polarization data, if available, may help to improve bounds on the time variation of the fine structure constant.

Acknowledgments

We thank M. Zaldarriaga for help in the use of CMBFAST and for useful suggestions.

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