HIGH SENSITIVITY OBSERVATIONS OF THE MICROWAVE BACKGROUND RADIATION

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INTRODUCTION

Angular fluctuations in the cosmic microwave background radiation are indicators of the seed structure at recombination ($z \simeq 1000$) which subsequently evolves into the present-day Universe ($z = 0$). Such measurements provide stringent tests of the cosmological theories of universal evolution and have implications for allowed values of the density and composition of matter in the Universe.

Observations on different angular scales give a direct indication of the amplitude of structure on different mass scales. The angular scale θ of adiabatic fluctuations of mass M is given by

$$\theta(\text{arcmin}) = 8.7\ \Omega^{2/3}\ h^{1/3}\ \left(M/10^{15}\ M_\odot\right)^{1/3}$$

where h is the ratio of the present value of Hubble's constant to an assumed value of 50 $\mathrm{kms^{-1}Mpc^{-1}}$ and Ω is the ratio of the present density of the Universe to that required for closure. Galaxies with masses of 10^{11} to 10^{12} $M_\odot$ will give rise to angular structure on scales of 10-20 arcsec while the largest scale structures known with dimensions of 100 Mpc and masses of 10^{18} $M_\odot$ will have dimensions on the scale of degrees. The adiabatic scenario requires that the temperature fluctuations at recombination are related to the matter density fluctuations by

$$\Delta T/T = \frac{1}{3}\ \Delta\rho/\rho \simeq 3\times10^{-4}\ \Omega^{-1}$$

This fluctuation amplitude applies to angular scales greater than a few tens of arcminutes; on progressively smaller scales the fluctuations are reduced by the "random walk" scattering in the finite depth of the recombination zone so that at 10 arcsec $\Delta T/T$ may be as low as 10^{-5}. We describe results for observations on the 10-20 arcsec scale and the 5°-15° scale.

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OBSERVATIONS ON A SCALE OF 10-20 ARCSEC

The broadband (400 MHz) interferometer operating between the MkIA (76-m) and MkII (35-m x 25-m) telescopes on a 430-m baseline (Padin & Davis 1986) was used to make a deep survey for fluctuations in the CMB at 5 GHz. The region chosen for study was adjacent to the cluster A576 which had been extensively studied at high sensitivity at Jodrell Bank (Lasenby & Davies 1983) and at the VLA. The field centre was RA=$07^h17^m55^s$; Dec=$55^\circ51'30''$; the only source expected in the field was detected at the correct level on the edge of the primary beam. At 5.0 GHz, the area synthesized is the MkIA beam 2.6 arcmin in diameter while the interferometer baseline provided a 20" resolution. There were accordingly some 50 independent resolution elements sampled in the survey region from which an estimate could be made of the fluctuation amplitude. This interferometer is a simple and clean system free from spurious responses and whose sensitivity is entirely limited by receiver noise. The amplitude of receiver noise was determined from the higher delay components of the interferometer which correspond to positions outside the main beam of the MkIA. Repeated 24-hr tracks were made on the field from which 7.7 x 10^5 secs of data were accumulated.

Any fluctuations in the sky (i.e. the CMB) observed with the interferometer will have an angular distribution attenuated by the primary beam. From a study of the radial autocovariance, the set noise and sky noise contributions can be separated. This leads to a limit on the power spectrum of background fluctuations of 3.74 x 10^{-8}K with 95% confidence at a wavenumber corresponding to an angular scale of 35". For fluctuations containing a realistic blend of wavenumbers our sensitivity maximizes for those with an equivalent Gaussian FWHM of 15". At 95% confidence level the upper limit to the amplitude of such fluctuations is 1.6 mK which corresponds to $\Delta T/_T < 5.8 \times 10^{-4}$.

We consider that this is a "clean" result from a system with a low level of spurious effects. Although this upper limit is still a factor 10 higher than may be expected from primordial fluctuations arising at recombination, it is of relevance to scenarios which envisage the re-ionization of low-redshift matter at z = 3-10.

OBSERVATIONS ON A SCALE OF 5° TO 15°

A high sensitivity experiment to measure CMB fluctuations at 10.4 GHz on a high site has been running over the last two years. The observing system consists of a dual channel receiver recording continuously the difference between a central 8° (FWHM) beam and two adjacent beam positions displaced by $\pm 8^\circ$. The cryogenic receivers have system noises between 80 and 100K and a bandwidth of 500 MHz. The observing site at Izana, Tenerife, lies at a height of 2300 metres and is above the inversion layer for most of the year. In one day the fixed beams sweep a 24-hr RA scan through the sky.

The programme has two aims, firstly to survey a large area of the sky, namely all Right Ascensions at Declinations between Dec= -15° and $+55^{\circ}$; this will allow a detection of any rare high amplitude components of the fluctuation spectrum. The second is a deep survey of limited areas at Declinations 0° and 40°. The observations are continuously calibrated from a switched noise source and have frequent primary calibrations via the Moon and the Sun.

We will discuss here the analysis of the deep survey made at Dec=40°. The equivalent of 10 days of observations were stacked and used to estimate the amplitude of the true sky auto-covariance function (ACF). The observing system has sensitivity to structure on angular scales between about 5° and 15°; it can be shown analytically that for our system the maximum sensitivity is on a scale of $10\overset{\circ}{.}6$ (FWHM). A maximum likelihood analysis was made of the data at Dec=40° between RA = 12^{h} and 17^{h}, a region clear of any obvious confusing effects from the galactic plane. The analysis showed that a non-zero variance is preferred over a zero one. The equivalent standard deviation on the $8\overset{\circ}{.}3$ scale of the observing beam is 0.10 mK corresponding to $\Delta T/_T = 3.7 \times 10^{-5}$. This is for a Gaussian-shaped true sky ACF with FWHM = $10\overset{\circ}{.}6$ corresponding to the scale of our maximum sensitivity and with height adjusted for what we would observe in our $8\overset{\circ}{.}3$ beam. The $\Delta T/_T$ of the unsmeared intrinsic ACF is 0.16 mK corresponding to $\Delta T/_T = 5.8 \times 10^{-5}$. The likelihood analysis showed that virtually all the probability is contained in the interval 0 to 0.20 mK in ΔT, leading to a firm upper limit on the sky fluctuations of $\Delta T/_T < 7.3 \times 10^{-5}$ as seen in the $8\overset{\circ}{.}3$ beam.

The fluctuations apparently detected in this experiment could be intrinsic to the CMB or due to emission from irregular emission patches at high galactic latitude or a combination of both. We are pursuing observations to separate these contributions to the observed fluctuations.

The results of this experiment on a scale of $\sim 8^{\circ}$ have direct consequences for theories of the evolution of the Universe for two reasons. Firstly, the intrinsic fluctuations on this scale cannot be smoothed out by subsequent reionization. Our result rules out most baryon-dominated models (with adiabatic fluctuations) in which $\Omega < 0.1$ and places strong constraints on pictures involving weakly interacting dark matter.

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DISCUSSION

SILK: When the galactic emission is modelled and subtracted out, as you presumably can do with an all sky map, what is the residual signal, if any, that you find for $\delta T/T$?

DAVIES: Our observations can be corrected for the (lumpy) emission from the Milky Way using published 408 and 1400 MHz surveys by adopting a value for the spectral index. However the spectral index of this emission around 10 GHz is not well-known (somewhere between 2.7 and 3.0) and the wavelength baseline is large, so there is a major uncertainty in making the correction. This is why we are making high sensitivity observations of the galactic emission at 5.0 GHz. If for example we assume a spectral index of 2.8 the galactic contribution to $\delta T/T$ for the $\delta = 40^{\circ}$ scan is 1.8×10^{-5}, and then the intrinsic CMB fluctuations would be $\delta T/T \simeq 2 \times 10^{-5}$.

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