SOUTH POLE STUDIES OF THE ANISOTROPY OF THE COSMIC BACKGROUND RADIATION AT ONE DEGREE

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ABSTRACT

We have developed a system for making measurements of spatial fluctuations in the Cosmic Microwave Background Radiation at 3 mm wavelength, on an angular scale of .5 to 5 degrees. The system includes a telescope with a Gaussian beam with a full width at half max (FWHM) of 20 to 50 arc-minutes, an SIS (Superconductor-Insulator-Superconductor) coherent receiver operating around 90 GHz, and for balloon flights, a pointing system capable of 1 arc-minute RMS stabilization. We report on results from ground based measurements made from the South Pole station during December, 1988.

INTRODUCTION

Searches for structure in the spatial distribution of the Cosmic Background Radiation (CBR) are one of the few experimental tests of cosmological models. Currently no definitive detections of anisotropy have been made except for the dipole term, and limits of 20 to 200 parts per million have been established from 10 arc seconds to 90 degrees angular scale (see Figure 1). In the region from 1 to 10 degrees few experiments have been done with sufficient sensitivity to seriously constrain cosmological models, galaxy formation scenarios in particular. Recent reports of detection in this region are suggestive but may suffer from systematic problems.

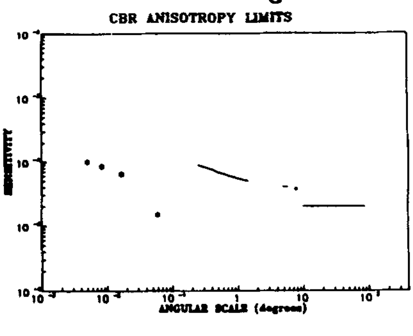

Figure 1

For theoretical and experimental reasons, interest in experiments in the .5 to 10 degree range has risen in the past few years. The two primary systematic difficulties with doing sensitive experiments in this angular range are the atmosphere, which has time varying structure, and galactic dust contamination, which must be modelled and possibly subtracted.

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OUR EXPERIMENT

We have chosen to work at 3 mm, where emission from the galaxy is low. While this choice of frequency reduces the problem of galactic contamination, problems with atmospheric emission are increased. Figure 2 shows the antenna temperature due to the atmosphere as a function of frequency at sea level, South Pole, and balloon altitudes. The plot is based on an atmospheric model with a standard temperature and pressure versus altitude profile, using water, oxygen and ozone absorption lines. It is evident that in order to work at 90 GHz, one requires either a very stable atmosphere or a high enough altitude that the emission lines are not saturated and the measurement can be done between molecular transitions. For example, at sea level, the atmospheric emission is more than 6 orders of magnitude higher than a desired sensitivity of $\frac{\Delta T}{T} = 10^{-5}$. We have built a system to make measurements on .5 to 5 degree scales, and have carried out experiments at balloon altitude and at the South Pole Station. We chose the South Pole as a ground observation site because of the low water content and previously reported high stability of the atmosphere there. For example, Figure 3 shows precipitable water for the time we were observing. Following is a brief description of the experiment and some of the results from the South Pole expedition.

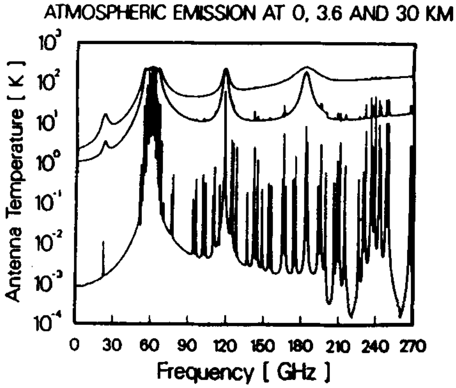

Figure 2

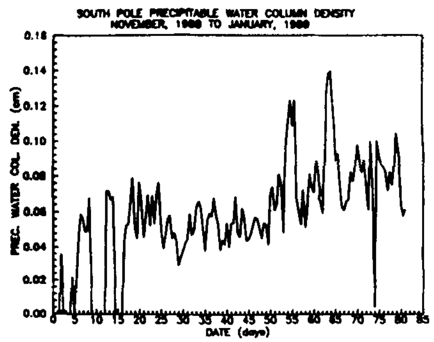

Figure 3

OPTICAL SYSTEM

Our optical system is an off axis Gregorian telescope, consisting of a 6.5 degree (FWHM) corrugated scalar feed, a 1 meter diameter, 1 meter focal length primary, with a confocal elliptical secondary mirror. The resulting beam can have a FWHM of 20 to 50 arc-minutes, depending on the secondary mirror used (our results are for a FWHM of 36 arc-minutes). Rotation of the secondary about the axis of the feed horn throws the beam horizontally on the sky. We chop the beam by a physical angle of 1 degree on the sky at 10 Hz to make a first difference measurement of temperature fluctuations. Our primary reason for using this configuration is the very low sidelobe response of such an antenna. For the central lobe, the beam is well approximated by a Gaussian of $\sigma = 15$ arc-minutes. $P(\Omega) = e^{-\theta^2/2\sigma^2}$ With a FWHM of 36 arc-minutes, the ratio of solid angle available for contamination to that in the beam puts stringent limits on the allowable sidelobe response. We measured our sidelobes down to -85 dB, without ground shields. In addition a ground shield was attached during data taking both during the balloon flight and at the South Pole.

SIS RECEIVER

A schematic of our detection system is shown in Figure 4. We use a Niobium SIS (Superconductor-Insulator-Superconductor) based coherent radiometer, operating at 90 GHz. Our mixer, HEMT IF amplifier (spot noise about 1 K), and cooled RF section enable us to achieve a system spot noise of about 33 Kelvin at a mixer physical temperature of 3.5 Kelvin. During data taking at the South Pole, our full band (0.6 GHz) noise was approximately 40 K, providing a theoretical system sensitivity (before chopping) of $\Delta T = 1.6 \frac{mK}{\sqrt{Hz}}$.

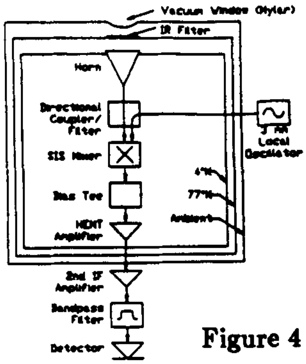

Figure 4

SOUTH POLE RESULTS

From late November, 1988 to early January, 1989, we made measurements from the South Pole station of CBR fluctuations and galactic emission.

Since galactic dust emission is a probable cause of error, we tried to get as much information for scaling known data to our frequency as possible. By comparing data from two of our balloon experiments at 90 GHz to the IRAS data at 100 microns, we obtain a cross calibration of approximately 10 $\frac{\mu K}{MJy/Sr}$ for the ratio of 3 mm emission to IRAS 100 micron emission. Using this number, along with a galaxy scan taken at the South Pole, we can estimate the contribution of dust emission to our data. We chose to measure in a region around RA=21.5, DEC=-73, where the IRAS 100 micron map shows a total intensity minimum of about 4-10 MJy/Sr, and first differences only of order 1-2 MJy/Sr. Using the galaxy data described above, this would be about 10-20 microKelvins in our data, which is small though not completely negligible compared to our errors (about 40 to 60 microKelvin per data point). We are currently at the point in sensitivity where even in the best parts of the sky, dust emission at 3 mm wavelength is near our detection limit. To do an order of magnitude more sensitive measurement will almost certainly require galactic subtraction preferably by multiple wavelength measurements.

CBR DATA

We observed 9 points with 1 degree physical chop angle on the sky, in a strip, spaced so that one beam from each point coincided with one beam from the next point. Several strips were measured to different sensitivities. This gives us a powerful test for systematic errors, as well as providing information on a variety of angular scales, from the beam sigma of 15 arc-minutes up to approximately 5 degrees. After time lost due to setting up, equipment problems and bad weather, we obtained about 80 hours of data, which reduced to about 70 hours after editing out radio interference and bad sky data. Our scan system gave us an efficiency (time spent on the measurement points) of only 60 percent, reducing the real data further to about 43 hours.

With a calculated statistical system sensitivity (on the sky) of 3 $\frac{mK}{\sqrt{Hz}}$, or 4

$\frac{mK}{\sqrt{Hz}}$ with sky shot noise included, we measured approximately 6 $\frac{mK}{\sqrt{Hz}}$ (RMS) on the sky for short time scales. Several runs were made of just atmospheric noise and are being investigated to help understand the nature of the sky noise.

RAW DATA FITTING

In order to work with the data, we have found it necessary to remove slow drifts in offset, which can be attributed to long term sky variations, changing electrical offsets, and temperature gradients on the primary. Our observing technique allows a natural way to remove such non- intrinsic shifts. Since we scan from one side of the strip to the other and then back in a period of about 30 minutes, linear variations on time scales long compared to 30 minutes can be removed without removing CBR structure. The results plotted in Figure 5 are the summed data for each point, with statistical error bars, where the raw data have been edited and piecewise linear fit in time, over times of approximately 3 hours. The results for a truncated Fourier fit subtraction, constructed to fit only structure longer than 3 scans, as well as a Legendre polynomial fit, are consistent with the linear fit presented. The error bars on this data set are consistent with the short term RMS fluctuations.

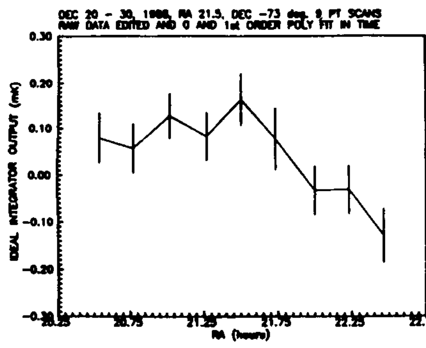

Figure 5

DATA ANALYSIS AND RESULTS

Looking at the data set in figure 5, a linear trend is evident across the points. Although this could be taken as an indication of intrinsic structure in the background radiation, we are unwilling to rule out some systematic effect to produce this. As an example, the sun was at RA of about 18 hours during our data taking, and contributions from this on the 100 μK level are not out of the question. We choose to remove the linear component from the data and consider the result to be our final set, which is shown in Figure 6. This set with error bars shown has a reduced chisquare of 1.53, corresponding to approximately 20 percent probability of being consistent with the null hypothesis. We are currently analyzing the data to test for various cosmological models, such as the cold dark matter galaxy formation model, scale invariant Gaussian fluctuations, etc.. These calculations will be presented in a forthcoming paper.

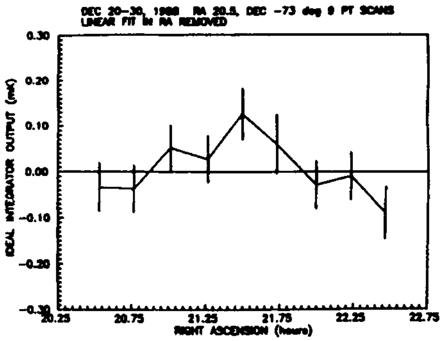

Figure 6

ACKNOWLEDGEMENTS

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