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LARGE SCALE STRUCTURE IN THE BACKGROUND RADIATION

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Introduction

One of the fundamental tests of the assumptions of isotropy and homogeneity is the measurement of the large angular scale structure of the cosmic background radiation. These measurements give us a snapshot of the universe at a time when the physical conditions were much different than now. In the twenty years since the discovery of the radiation, a substantial amount of attention has been given to developing this picture. We now have near full sky maps ($> 80\%$) from balloon measurements at 3 and 12 mm wavelength and from the Soviet Prognos 9 satellite at 8 mm.

Current Results

The dominant term visible in all of these maps is the dipole distribution with an amplitude of about 3 mK. Substantial galactic contamination is also evident in both the 8 mm and 12 mm data. Each experiment uses approximately gaussian beams and has a similar angular resolution with σ=2.5 ° (6 ° FWHM) for $P(\theta)=e^{-\theta^2/2\sigma^2}$. These experiments all use coherent detectors with about a 1 GHz bandwidth. The accuracy of the dipole amplitude is currently limited to about 5% primarily from calibration errors while the statistical error is 1 - 2%. The dipole directions of the 3mm and 12mm data have an error of about 1.5° primarily due to pointing reconstruction uncertainty (magnetometer errors) while the dipole directions of the 3mm and 12mm data are 1.6° apart. These data give a Solar velocity direction of $\alpha = 11.25 \pm 0.15$ hours, $\delta = -5.6 \pm 2.0\ ^\circ$ and an average dipole amplitude of 3.26 ± 0.23 mK where the increased errors include the slight differences between the dipoles. Using a Galactic Solar velocity of 230 km s^{-1} toward $l^{II} = 90^\circ$, $b^{II} = 0^\circ$, yields a Galactic velocity of 540 ± 50 km s^{-1} towards $\alpha = 10.6 \pm 0.3$ hours, $\delta = -23 \pm 5\ ^\circ$. Assuming that the velocity of the Sun relative to the Local Group is 295 km s^{-1} toward $l^{II} = 97.2^\circ$, $b^{II} = -5.6^\circ$ (Sandage, private communication 1986) gives an inferred Local Group velocity relative to the background radiation of 610 ± 50 km s^{-1} towards $\alpha = 10.8 \pm 0.3$ hours, $\delta = -25 \pm 5\ ^\circ$ or $l^{II} = 272 \pm 5\ ^\circ$, $b^{II} = 30 \pm 5\ ^\circ$. This gives an angle of 45° between the center of the Virgo cluster and the Local Group velocity. Figure 1. shows the map made by combining the 3mm and 12mm data and covers 90% of the sky with a limiting sensitivity of about 0.3 mK per 6° field of view. The map is given in celestial coordinates as a $\cos(\delta)$ projection. Figure 2. is the same map after removal of the dipole. In both maps the galactic emission was removed from the 12mm data. Figure 3. gives the autocorrelation of the residual map (Fig. 2.) as a function of angle. Monte Carlo simulation of the maps gives an error for the autocorrelation of 0.01 mK^2. No structure is apparent in the residual map, although as discussed below this is difficult to quantify precisely.

The Upper Limits Game

Looking for an uncertain signal, of unknown signature and of unknown magnitude is difficult at best. Subtle systematic errors, atmospheric statistics, long term detector stability, varying antenna sidelobe pickup and numerous other effects may cause an otherwise observable signal to disappear into the noise. The converse is also true. Witness the difficulty in confidently detecting the cluster (Zeldovich) cooling effect which for some clusters is apparently an order of magnitude above the current sensitivity level quoted for fluctuations in the background radiation. The proper statistical interpretation of data to produce null upper limits is argued to factors of 2-3, while cosmological models are being rejected at these same levels perhaps unnecessarily. These difficulties apply to a varying degree at all angular scales. One of the fundamental problems we face is not knowing what we are looking for. It is possible that even in the present maps a signal is present but we do not know its signature. Substantial effort is needed to more fully exploit the existing and future maps so that a real signal will not escape detection.

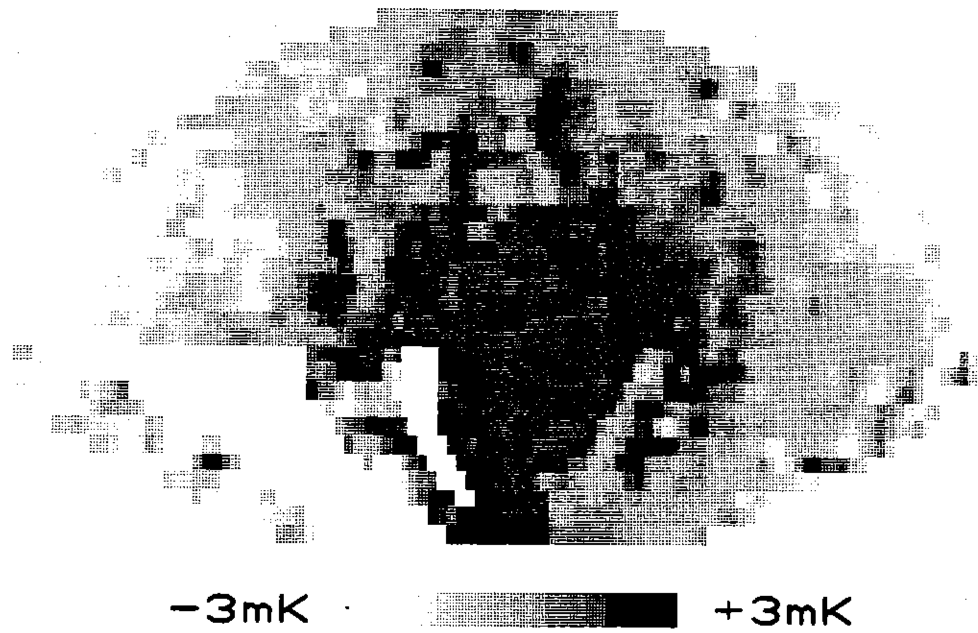

Figure 1 - Map of the sky in celestial coordinates at 3 and 12mm.

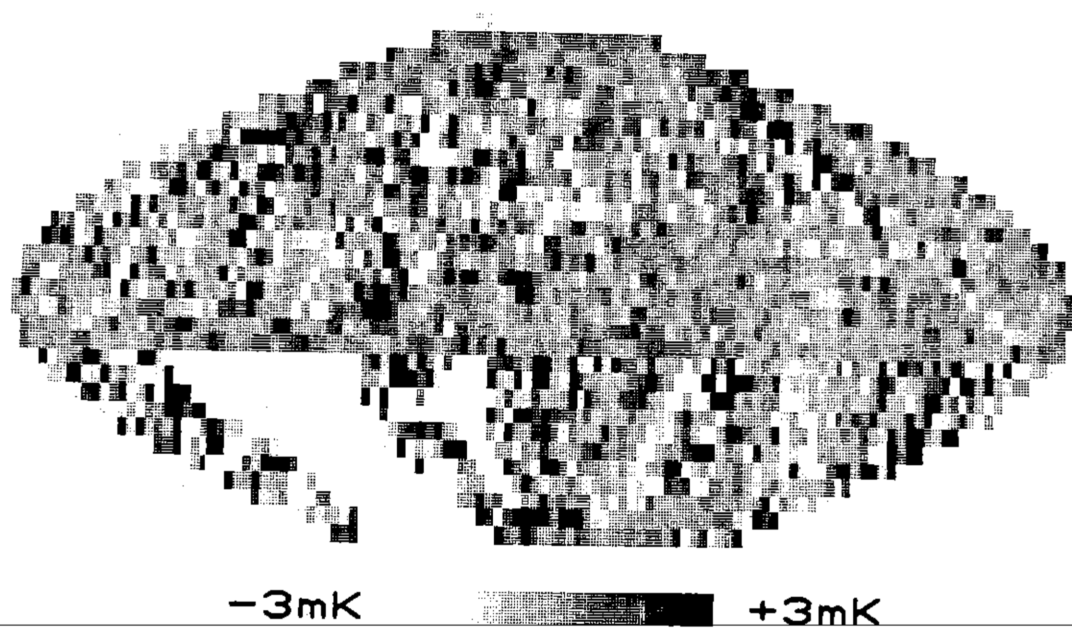

Figure 2 - Map of the sky after removal of the dipole.

Calibrators

Known calibrators or bench marks are useful as cross checks of the overall experiment performance. For large scale measurements there are several possibilities covering many order of magnitude. Known temperature targets are useful but do not test far field response. The moon is a good target for inflight calibration and tests both pointing and detector gain. The moon typically appears as about a 1 K signal in a 6° beam. This level insures high statistics in a short time while being small enough to avoid saturation effects. Unfortunately the moon is only good as a 3-5% absolute calibrator due to uncertainty in its radiometric emission. The dipole itself is a useful bench mark at the 10^{-3} level and observation of the earths orbital motion around the sun is another at the 10^{-4} level. At the 10^{-5} level planetary emission can be observed at a predictable level (factor of 2). Emission from our galaxy is another bench mark but our ability to a priori predict its magnitude is difficult particularly at millimeter wavelengths. For smaller angular scales down to tens of arc minutes, planetary emission is still a useful weak bench mark. At smaller scales, radio sources are available to some extent but cannot always be reliably predicted. Bench marks should be used whenever possible particularly if 1) they do not appreciably reduce the total observing time 2) they are predictable in value and 3) they produce a signal within an order of magnitude of the ultimate sensitivity. Such measurements would help the community judge the merit of each experiment.

Future Experiments

Currently upper limits on low order multipole moments (quadrupole, octupole) are $\sim 5 \; x \; 10^{-5}$. At this level galactic emission is already a serious consideration at 8 and 12 mm. By going to systematic multi-frequency measurements perhaps another order of magnitude in sensitivity can be gained. The COBE satellite to be launched by 1990 will make a one year measurement at 3,6 and 9 mm and should reach a sensitivity of 0.1 mK per 6° field of view and a few parts in 10^{-6} to low order multipole moments. COBE will also give us a much better understanding of the diffuse galactic emission which will then allow future ground based and airborne experiments to take advantage of this increased knowledge to make more sensitive measurements.

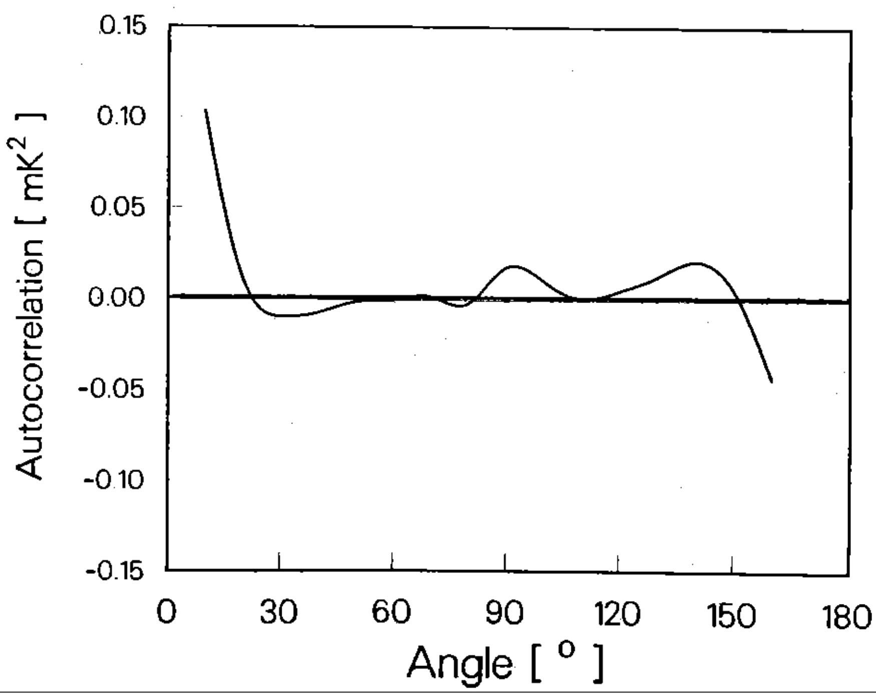

Figure 3 - Autocorrelation of residual map (Fig. 2).