Cosmic background anisotropy measurement at 10 degrees

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The cosmic background radiation is believed to be the remnant of the primeval fireball from which the present-day Universe evolved. When observed with a radiometer (radiotelescope), the cosmic background radiation has a temperature of about 2.75 kelvin. Measurements of the degree of uniformity (isotropy) of the cosmic background radiation serve to provide information about the early Universe.

Numerous measurements of the isotropy of the cosmic background radiation have shown it to be uniform to $\Delta T/T < 2 \times 10^{-5}$ (where T = 2.75 kelvin on arc-minute scales. Experiments at scales greater than 10 degrees have measured a dipole anisotropy, believed to be a result of the peculiar motion of our galaxy with respect to very distant objects.

The region of 1 to 10 degrees remains a relatively unexplored angular size. Two groups have recently reported anisotropy on this scale at a level approximately equal to 5×10^{-5} (Melchiorri et al. 1981; Davies et al. 1987). This is particularly significant because it occurs at a level predicted by many theories of galaxy formation. Unfortunately these results are also controversial because they were close to experimental sensitivity limits and may be marred by systematic errors in the experiment. To test these results we decided to make a measurement at the 10-degree scale at two microwave frequencies. The Amundsen-Scott South Pole Station was chosen as a site for this measurement because the cold high-altitude environment serves to reduce atmospheric interference with the measurement. Figure 1 shows the expected atmospheric emission at the South Pole.

We chose to make our measurement at 15 and 25 gigahertz where atmospheric emissions, as well as signals from our galaxy, are low. By using two frequencies, we can determine whether a signal is galactic in origin or truly reflects anisotrophy in the cosmic background radiation. Because we are trying to make very sensitive measurements, a low-noise receiver is desired. In both systems, we employ low-noise cryogenic high electron-mobility transitor amplifiers. In each system, two antennas with 7 degree beams pointed 10 degrees apart feed the signal into a cryogenic microwave switch operating at 100 hertz. Cryogenic requirements for the system are met using a closed cycle helium gas refrigerator needing only electricity to operate. The switched signal is fed into the high electron-mobility transistor amplifier where the signal power is multiplied by 1,000. The signal is further amplified by a low-noise warm amplifier and then converted to a direct-current signal. This direct-current signal is passed to a lock-in amplifier which electronically differences the signal from the two sky positions.

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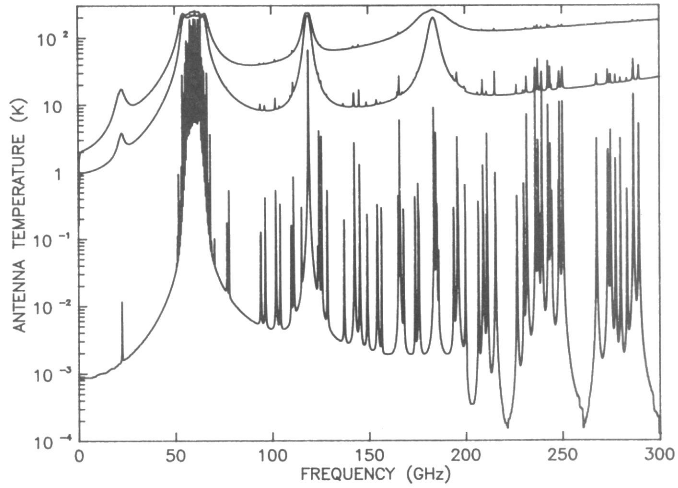

Figure 1. South Pole Atmospheric Emissions. This is the predicted atmospheric emission as a function of frequency. The calculation is based on theoretical water (H_2O), oxygen (O_2), and ozone (O_3) line shapes assuming 300 microns precipitable water based on South Pole balloon data included in this article. For comparison, the upper and lower plots are atmospheric emissions at sea level and balloon altitudes, respectively. (K denotes kelvin. KM denotes kilometers. GHz denotes gigahertz.)

The total noise of each system was about $4mK/\sqrt{Hz}$ including atmospheric noise.

Because these are highly sensitive measurements, excess noise due to systematic drifts and atmospheric disturbances must be minimized. A slow second chop on the sky serves this purpose. By moving the whole apparatus back and forth on the sky, "second" subtracting these signals results in measurements on smaller time scales making the system less susceptible to drifts and atmospheric noise. We then let the rotation of the Earth change our field of view.

The instrument operated as expected. Atmospheric radiometric temperatures of 2.7 kelvin at 15 gigahertz and 5.5 kelvin at 25 gigahertz were measured and are close to the theoretically predicted values for the South Pole. To ensure the system was operational, the galactic plane was allowed to drift into the beam. The data including the galactic crossing is in figure 2. The galaxy appears as a bump with amplitude 9 mK, roughly twice the value predicted by scaling galactic maps from low frequencies, but the theories are not well understood at these high frequencies (25 gigahertz).

By putting together scans, we can build up integration time, reducing noise signal and increasing our ultimate sensitivity. Figure 3 shows just such data. Data from different scans at close sky positions are binned and averaged together. A rough attempt was made at removing galaxy signal as well as the signal due to the dipole anisotropy. An additional residual linear trend remained; because we are not sensitive to such large angular scales, this trend was removed. This data is slightly oversampled with points displayed at 2.5 degrees apart on the sky or roughly one-third of a beamwidth. The reduced χ^2 of this set is 0.95 for 19 degrees of freedom and is consistent at the 50-percent level with random noise, i.e., no structure is immediately obvious. These results are preliminary and more analysis must be done.

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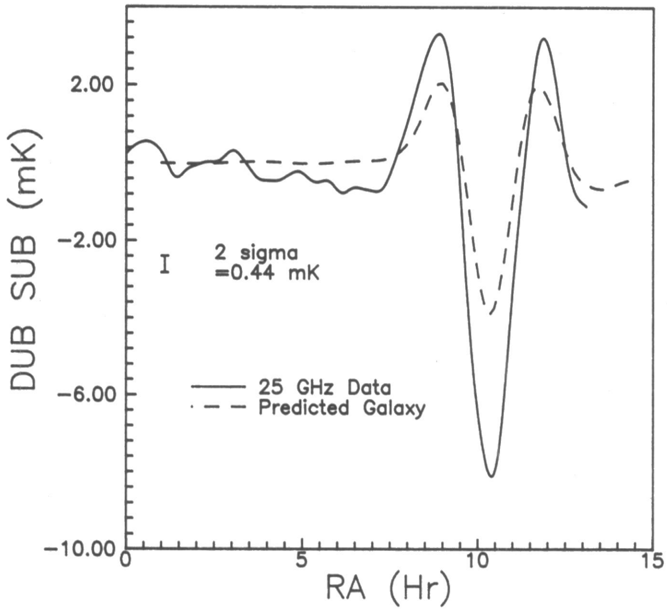

Figure 2. Twenty-five gigahertz (GHz) data including galaxy emission. The drift scan data are grouped into 30 second bins and double-subtracted. For display purposes the data are filtered and the average 2-sigma error bar is shown. The expected signal from the galaxy based on maps made at low frequencies is included.

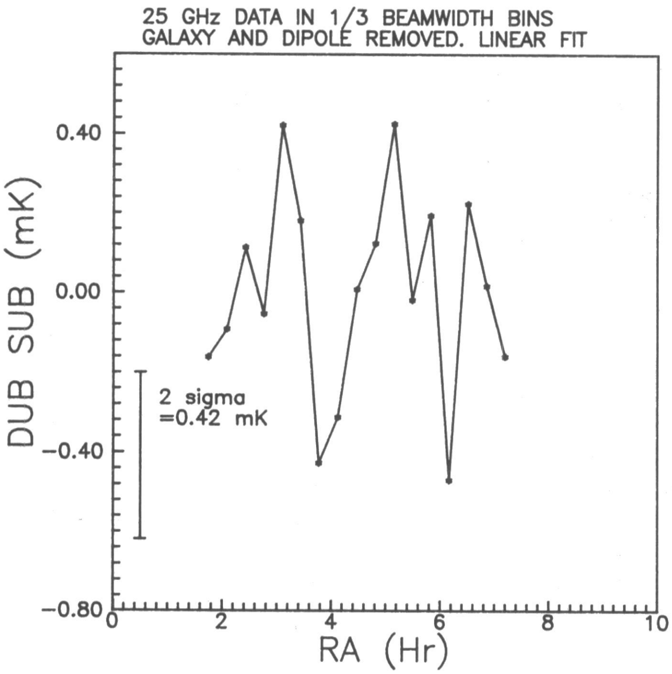

Figure 3. Twenty-five gigahertz (GHz) data. The data are binned into one-third beamwidth bins and are slightly oversampled. The galactic component as well as a dipole component have been removed. A slight linear trend remained in the data and was also removed. A 2-sigma error bar is included.

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