

South Pole anisotropy measurements of the cosmic microwave background radiation at 1 degree using a 25-35 gigahertz (GHz) HEMT receiver

JOSHUA GUNDERSEN, JEFFREY SCHUSTER, AND TODD GAIER

Department of Physics
University of California
Santa Barbara, California 93106

Anisotropy measurements of the cosmic microwave background radiation (CMBR) provide a critical test for cosmological theories and have been placing ever greater constraints on theories of large-scale structure formation in the universe. Recently, significant levels of anisotropy have been found in the large angular scale measurements from the Cosmic Background Explorer (COBE) satellite's differential microwave radiometer (DMR) experiment (Smoot et al. 1992). Measurements at smaller angular scales are of special interest since they provide a probe of large-scale structures that could have formed inside the horizon size of the universe at the time of decoupling, roughly a few hundred thousand years after the Big Bang. Figure 1 shows the recent upper limits on CMBR anisotropies, including our 1988-1989 and 1990-1991 South Pole results, and the COBE DMR detection.

During the austral summer of 1990-1991 we took three instruments to the South Pole Station to study anisotropy in the CMBR. These three instruments were designed to measure anisotropies in the CMBR at seven different frequencies, ranging from 15 gigahertz (GHz) to 90 GHz, and at 3 different angular scales ranging from 30 minutes to 10 degrees. The most sensitive data has come from the four channel homodyne receiver, shown in figure 2, which incorporates an ultralow noise High Electron Mobility Transistor (HEMT) for direct amplification of the CMBR between 25 and 35 GHz (8-12 millimeters). The HEMT amplifier is cooled to 6 K in a ⁴He cryostat and operates with a receiver noise temperature of 30 K. The signal is detected full band and is also

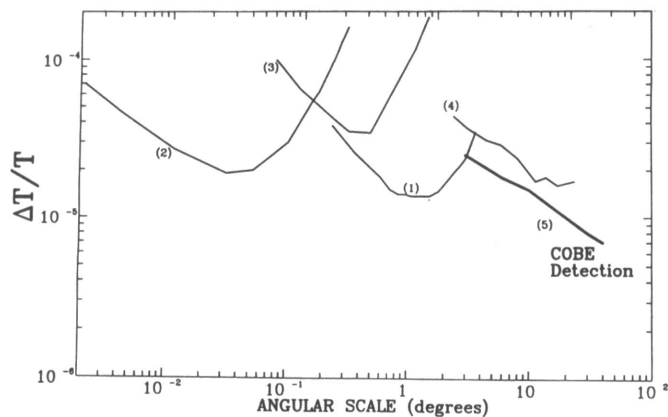


Figure 1. Gaussian autocorrelation limits on anisotropy in the Cosmic Microwave Background Radiation and the COBE detection. (1) Gaier et al. South Pole 1990-1991 (2) Readhead et al. 1989 (3) Meinhold and Lubin, South Pole 1988-1989 (4) Meyer, Cheng, and Page 1991 (5) Smoot et al. 1992.

split into four 2.5 GHz bands using an array of circulators and bandpass filters. This type of multifrequency measurement is necessary in order to discriminate between intrinsic CMBR fluctuations and confusing foreground sources.

This receiver was coupled to the Advanced Cosmic Microwave Explorer (ACME) platform, which is a 1-meter, off-axis Gregorian telescope with a nutating elliptical secondary capable of arc minute stabilization (Meinhold et al. 1991). The nutating secondary moves the microwave beam back and forth on the primary creating a sinusoidally chopped beam response on the sky. The total power measured in one beam position is then subtracted from the measured power in the other beam position and the difference is then integrated over a complete nutation cycle. When the 25-35 GHz system is in place on ACME, the beam width ranges between 1.3 degrees and 1.8 degrees at full width at half maximum (FWHM). The beam throw of the nutating elliptical secondary was 2.1 degrees on the sky. We observed for 500 hours between 16 December 1990 and 12 January 1991. From this 500 hours of data, 250 hours were considered usable. Much of the unusable data was removed due to weather/atmosphere or other systematic cuts that we implemented. During the 250 hours we performed sun scans, to check our beam, moon scans to check the calibration, galaxy scans to characterize galactic emission, zenith scans to characterize the atmosphere, and a variety of overlapping, deep CMBR scans to measure anisotropies.

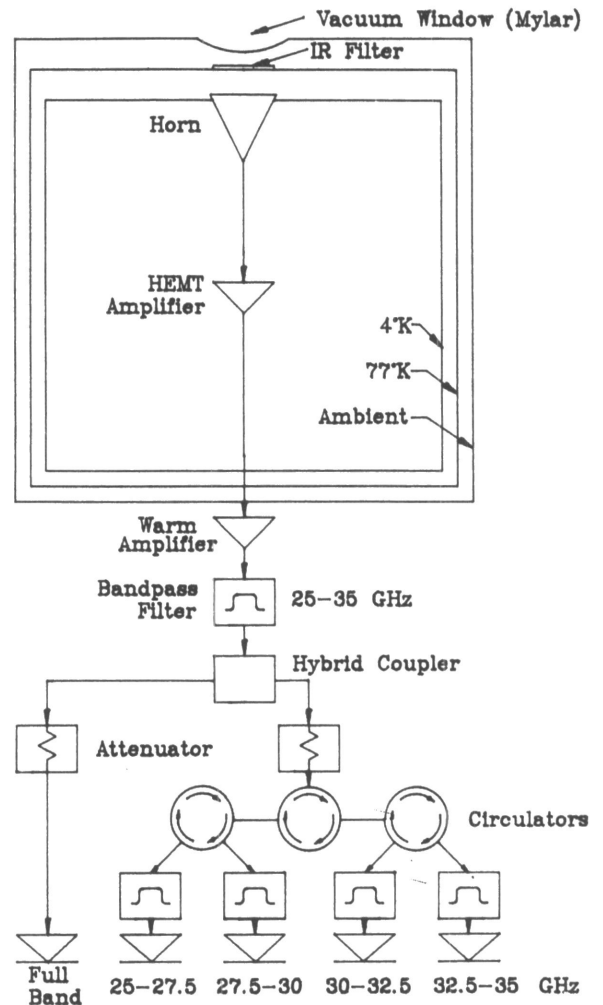


Figure 2. Schematic of the 25-35 gigahertz HEMT receiver.

The network of deep CMBR scans consisted of a raster scan of 9 positions in azimuth, each position separated by 2.1 degrees on the sky, repeated at six elevations, each separated by 45 minutes in declination. In addition, we performed an overlapping 13-point scan in azimuth at the lowest declination and an overlapping 15-point scan in azimuth at the second to highest declination. Each of these eight scans in azimuth obtained data with error bars less than 50 microkelvin (μK) per channel and two of the scans have error bars between 20 and 30 μK per channel. This compares to our 1988-1989 South Pole data, which had a single channel and a single scan with 50 μK error bars and compares to COBE's DMR which has obtained 50 μK error bars in its most sensitive pixels for its 53 GHz channel. The 1990-1991 measurements represent the most sensitive measurements of CMBR anisotropy to date.

The data from one of the elevations in the nine point raster scan has been analyzed in detail, as shown in figure 3. The lower frequencies have strong detections present, while the higher frequencies do not. This type of spectrum is not indicative of CMBR fluctuations. The 32.5-35 GHz channel imply a 95 percent confidence upper limit of $\Delta T/T \leq 1.4 \times 10^{-5}$ for gaussian fluctuations in the CMBR, shown in figure 1. This represents a factor of 7 improvement over previous limits at the angular scale $\theta_c = 1.2^\circ$ (Timbie and Wilkinson 1990). The details of the analysis are presented in Gaier et al. 1992. Work is proceeding on the analysis of the rest of the raster scan region and the adjoining larger 13 and 15 point scans.

This project would have not been possible without the Center for Particle Astrophysics and the support and encouragement of Bernard Sadoulet. The remarkable cryogenic HEMT amplifier was supplied by Mike Balister and Marian Pospiezalski at NRAO. This work was supported by National Science Foundation grant DPP 89-20578, the National Aeronautics and Space Administration under grant NAGW-1062, and the National Science Foundation's Center for Particle Astrophysics under grant NSF UCB AST88-0916. Much of the hands-on support came from other members of our lab group including Dr. Peter Meinhold, Tim Koch, Mike Seiffert, Mark Lim, Alex Wuensche, and Dr. Philip Lubin. Finally we would like to thank Bill Coughran and the entire Antarctic Support Associates staff for their work at the South Pole during the 1990-1991 austral summer.

References

- Gaier, T., J. Schuster, J. Gundersen, T. Koch, P. Meinhold, M. Seiffert, and P. Lubin. A degree scale measurement of anisotropy of the cosmic background radiation. *Astrophysical Journal Letters*, submitted.
- Meinhold, P. and P. Lubin. 1991. A medium scale measurement of the cosmic microwave background at 3.3 millimeters. *Astrophysical Journal Letters*, 370:L11.
- Meinhold, P., A. Chingcuanco, J. Gundersen, J. Schuster, P. Lubin, D. Morris, and T. Villela. 1991. A balloon borne millimeter-wave telescope and stabilized platform for measurements of anisotropy in the cosmic background radiation. *Astrophysical Journal*, submitted.

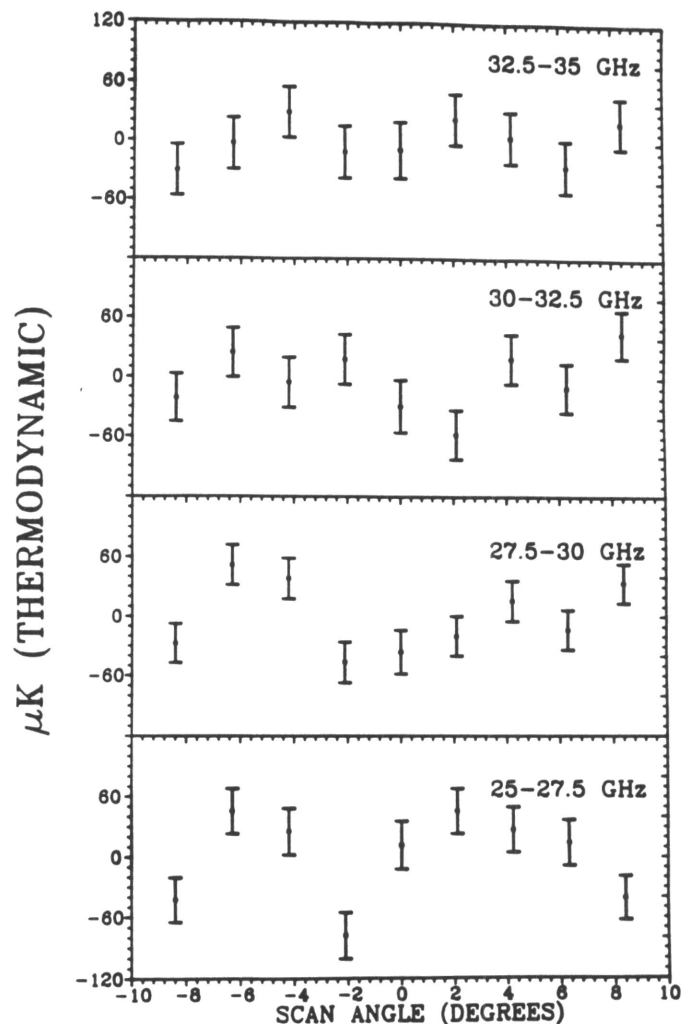


Figure 3. Binned data for the 25-35 gigahertz HEMT receiver from the nine-position scan centered at $a = 0.5^\circ$, $d = -62.25^\circ$. A linear component has been removed as a function of scan position. The error bars displayed are $\pm 1 \sigma$.

- Meyer, S., E. Cheng, and L. Page. 1991. A measurement of the large scale cosmic microwave background anisotropy at 1.8 millimeter wavelength. *Astrophysical Journal Letters*, 371:17.
- Readhead, A., C. Lawrence, S. Myers, W. Sargent, H. Hardebeck, and A. Moffett. 1989. A limit on the anisotropy of the microwave background radiation on arc minute scales. *Astrophysical Journal*, 346:566.
- Smoot, G., C. Bennett, A. Kogut, E. Wright, J. Aymon, N. Boggess, E. Cheng, G. DeAmici, S. Gulikis, M. Hauser, G. Hinshaw, C. Lineweaver, K. Loewenstein, P. Jackson, M. Janssen, E. Kaita, T. Kelsall, P. Keegstra, P. Lubin, J. Mather, S. Meyer, S. Moseley, T. Murdock, L. Rokke, R. Silverberg, L. Tenorio, R. Weiss, and D. Wilkinson. 1992. Structure in the COBE DMR First Year Maps. *Astrophysical Journal Letters*, submitted.
- Timbie, P. and D. Wilkinson. 1990. A search for anisotropy in the cosmic microwave radiation at medium angular scales. *Astrophysical Journal*, 353:140.