Results From MAT: Localizing a Peak in the CMB Angular Spectrum to $l \approx 200$

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We report results from the 1997 and 1998 observing seasons of the Mobile Anisotropy Telescope. We detect anisotropy in the cosmic microwave background on scales from $l \approx 50$ to $l \approx 400$ at 30, 40, and 144 GHz. We find clear evidence for a peak in the spectrum localized at $l \approx 200$ with an amplitude, $\delta T_l \approx 85 \mu$K. We find that the data have a spectral index consistent with that of the CMB.

1 The Telescope

The MAT/TOCO experiment (the Mobile Anisotropy Telescope on Cerro Toco), is a collaboration between Princeton University and the University of Pennsylvania. It is a ground-based instrument that measured the degree-scale anisotropy in the cosmic microwave background from Cerro Toco, at 17,000 ft (5200 m) in the Northern Chilean Andes.

The MAT instrument is based on the design of the Saskatoon experiment (Wollack *et al.* [13]) and is described in Devlin *et al.*[1] and Torbet *et al.*[10] There are eight radiometry channels, two HEMT (High Electron Mobility Transistor) amplifiers [8] at 30 GHz and four at 40 GHz, and two at SIS (Superconductor-Insulator-Superconductor) mixer detectors at 144 GHz[3] with approximate resolutions of $0.^{\circ}9$, $0.^{\circ}7$, and $0.^{\circ}2$ respectively. There are a total of five corrugated feeds in the receiver. The radiation collected by each of the 30 and 40 GHz feeds is separated by an orthomode transducer into the two orthogonal polarizations and fed into separate HEMT amplifiers (maintaining polarization information). The two D-band horns each lead to a single SIS mixer, with one channel in each polarization.

The telescope optics are similar to those used in the Saskatoon experiment. Corrugated feeds underilluminate a 0.85m primary mirror which in turn underilluminates a flat (1.8m$\times$1.2m) chopping mirror (chopper). The chopper is a resonant, computer controlled mirror, which oscillates at ≈ 4.6 Hz in 1997 and ≈ 3.7 Hz in 1998. The telescope sits inside an aluminum ground screen which is fixed with respect to the primary, the receiver, and the chopper mount. The telescope pointing is determined through observations of Jupiter which are made between once and twice a day. In addition, two redundant encoders exist on both the azimuth bearing and on the chopper to assess the pointing. We find the absolute errors in pointing to be $0.^{\circ}04$ and the relative errors to be $0.^{\circ}01$.

2 Observations and Calibration

Data were taken during observing seasons in the fall of 1997 between Oct. 20 and Dec. 15 and in the fall of 1998 between Aug. 26 and Dec. 7 from the Atacama desert. As one of the highest, driest deserts in the world, this is an excellent place for millimeter and centimeter wave observations. In addition, the town of San Pedro de Atacama is only one a hour drive from the site and provides lodging and support facilities for a ground station from which the telescope can be remotely operated.

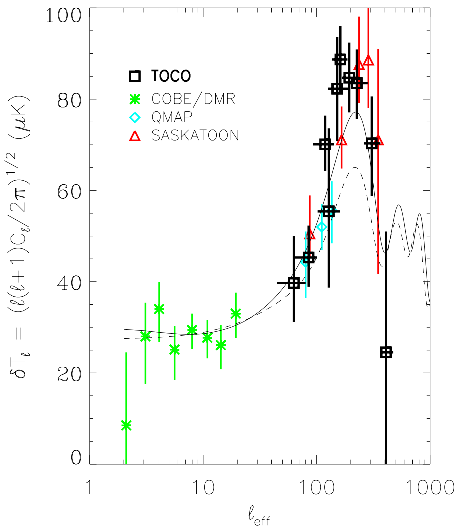
For observations of the anisotropy, we fix the telescope in azimuth and elevation with the primary optical axis at $az = 207.^{\circ}41, el = 40.^{\circ}76$ (1998). The sky rotates through the beam while the chopper scans in the azimuthal direction sweeping out an amplitude of $6.^{\circ}12$ on the sky (1998). We analyze CMB data from ≈ 600 square degrees in 1998 and ≈ 500 square degrees in 1997.

Observations of Jupiter, made every day, are used to calibrate the radiometer and to map the beams. In order to compensate for gain drifts on timescales shorter than 24 hours, we couple an internal calibration signal with an effective temperature of ≈ 1K to each of the detectors for 40 ms twice every 200 sec. We find that there is good long-term agreement between the Jupiter and internal calibrations. The intrinsic error in the calibration of the brightness temperature of Jupiter is 5%. The standard deviation in the measured solid angle of the beams is 5.5% in D1 and 4% in D2. The measurement uncertainty in the calibrations is 7%. The total 1σ calibration error (quadrature sum of above errors) is 10% for D1 and 9% for D2. When the two channels are combined in the final TOCO98 analysis, the error for the combination is 8%. The combined error in each of the HEMT channels in the final TOCO97 analysis is 10%.

3 The Data

The data reduction is discussed in Torbet *et al.* [10] and Miller *et al.* [5] and follows the Netterfield *et al.* [6] analysis of the Saskatoon data. Data taken during calibrations, observations of the galaxy and point sources, and bad weather are cut from the dataset used for analysis of CMB anisotropy. We then form synthesized beams which allow us to probe a range of angular scales and perform a likelihood analysis which produces the most likely value of δT in each range of l which are then plotted as shown in Figure 1.

We determine that the data has been properly selected when a set of consistency checks fail to show a signal. We look at the quadrature, the difference in signal between the first and second half of the chop; and the fast and slow dither, the difference of subsequent 0.5 second and 10 second averages respectively. We also examine the difference night to night and between the first and second half of the campaign. We examine these null tests for various cuts to the data until null test data are consistent with noise. We then consider the CMB signal produced by this set of cuts. This allows us to select the good data without biasing our results with expectations of what the signal should be. We also analyze the spectra of the observed fluctuations, comparing data taken at 30, 40, and 144 GHz and find that the spectral index of



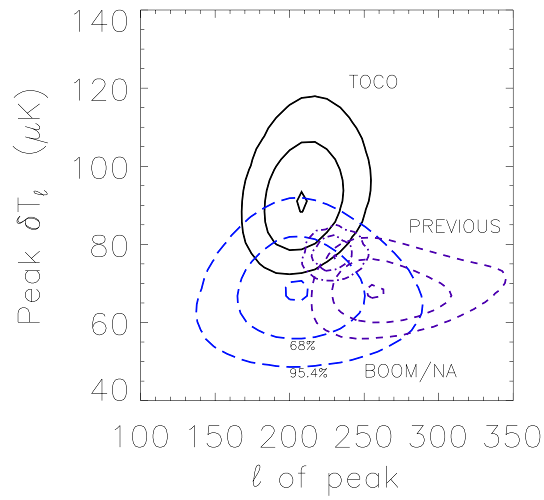


Figure 1: CMB Angular Spectrum as measured by TOCO97, TOCO98 D-band, QMAP, Saskatoon, and COBE/DMR. The TOCO98 point at $l = 409$ is as calculated by Dodelson and Knox[2] from likelihood contours presented in Miller *et al.* [5]. The Saskatoon calibration error is 11%, the QMAP data have an average calibration error of 12%, and the TOCO data have a calibration error of 10%. Both Saskatoon and QMAP are calibrated with respect to Cas A while the TOCO data are calibrated with respect to Jupiter. The models are computed with CMBFAST[9]. The solid line is a "concordance model" [12,11], $\Omega_\Lambda = 0.67$, $\Omega_m = 0.33$, $\Omega_b = 0.0041$, and $h = 0.65$. The dashed line is a "standard CDM model", $\Omega_m = 1$, $\Omega_b = 0.05$, and $h = 0.5$.

Figure 2: Likelihood contours for δT_l vs l for the position and height of the peak[4]. Calibration errors are included. The solid contours (black) are the constraints from the TOCO data alone. The large dashed lines (blue) show contours from BOOM/NA flight alone. The small dashed lines (purple) show data before TOCO and BOOM/NA (as defined in Knox and Page[4]), and the small dot-dashed (purple) contours show constraints when all the data are included.

the fluctuations is consistent with CMB. A more detailed analysis of foregrounds is currently being undertaken.

4 Results and Discussion

Figure 1 shows the angular spectrum of the CMB as measured by the MAT instrument along with points from COBE and measurements made by this group in preceding years. Evidence has existed for several years that there is a rise in the spectrum up to $l \approx 200$ and there have been indications that the amplitude of the spectrum is lower at higher l [7] but no single experiment had localized a peak. The combination of the TOCO97 HEMT data with the TOCO98 D-Band data provides a clear indication that the spectrum peaks at $l \approx 200$ with an amplitude of $\delta T_l \approx 85\mu$K [5], [10].

Results from the BOOMERanG North American Test flight have been recently announced and are presented elsewhere in these proceedings (Crill *et al.*). These data cover a very similar region of l-space to the TOCO data and their results agree with the TOCO results. Figure 2 shows contours in peak height and location computed for both the TOCO and BOOMERanG data sets [4]. It is exciting to note that the two data sets pick out the same best fit value of the location of the peak, $l \approx 210$[4]. Although the preferred value of the peak height differs between the two experiments, they agree within the 1σ error bars when the calibrations errors are included.

As discussed in Miller *et al.* and Knox and Page, the peak as seen by the TOCO data is consistent with adiabatic flat CDM models and inconsistent with open models, defect models, and simple isocurvature models, which all predict a peak which either has a different characteristic shape or is located at higher l.

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