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CMB Anisotropy Measurements During the Fourth Flight of MAX

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ABSTRACT

CMB anistropy data from the fourth flight of the Microwave Anisotropy Experiment (MAX) are reported. Three data sets were taken in low dust regions near the stars Gamma Ursa Minor (GUM), Iota Draconis (ID) and Sigma Herculis (SH) on June 15, 1993. For a Gaussian Autocorrelation Function (GACF) with coherence angle of 25' these yielded $\Delta T/T_{cmb}$ of $3.7^{+1.9}_{-1.1} \times 10^{-5}$, $3.3^{+1.0}_{-1.1} \times 10^{-5}$, and $3.1^{+1.7}_{-1.3} \times 10^{-5}$ respectively, for the most probable values and 95% confidence upper and lower limits. The spectrum of the signal is consistent with CMB.

1. Experiment

The experiment consists of bolometric detectors with four passbands for spectral resolution mounted on a balloon-borne one meter off-axis Gregorian telescope with a pointing accuracy of order 1 arcminute rms. The channels were centered at 3.5 cm^{-1}, 6 cm^{-1}, 9 cm^{-1} and 14 cm^{-1}. The detectors were cooled to 85 mK with an adiabatic demagnetization refrigerator. In previous flights, the beam was well described by a Gaussian function with FWHM of 30 arcminutes. However, for this flight, the beam FWHM was 33 arcmins for the 3.5 cm^{-1} channel and 45 arcminutes in the others. Differencing was done by sinusoidally chopping the beam on the sky via the secondary mirror at 5.4 Hz with an amplitude of 1.4°. Lockin detection was done both onboard and on the telemetered data stream. Observations consisted of 6 degree peak-to-peak smooth scans, taking 108 seconds to cross from one peak to the next and back again. Due to gyroscope drift, the scans were stopped periodically to update the pointing on a target star. Thus, the starfield provided the absolute pointing. Sensitivity was maximized by concentrating integration time on a limited region of the sky. The beam size, chop and scan strategy create a window function optimized to test Cold Dark Matter (CDM) theories of structure formation, with maximum sensitivity at about 15-60 arcminutes, corresponding to Legendre polynomials with l around 200.

The experiment was launched at approximately 1.00, June 16, 1994 UT from the National Scientific Balloon Facility in Palestine, Texas. After determining beam shape and location on Jupiter, we observed regions near the stars Gamma Ursa Minor (15h20m 71°50') at 5.97 UT for 0.88 hours, Iota Draconis (15h25m 59°36') at 7.15 UT for 0.45 hours, and Sigma Herculis (16h30m 42°46') at 8.73 UT for 0.71 hours. Calibrations were done before and after each scan and confirmed with the observation of Jupiter. From this we estimate a 10% error in the absolute calibration. Details of the procedure are available in Fischer et al. (1992).

2. Analysis

Due to a bad JFET, approximately 30-40% of the data was unuseable in the ID and SH scans. About 6% of the GUM scan was lost due to pointing error. The raw data has cosmic ray hits removed using the method from Alsop et al. (1992). This eliminates 15-20% of the remaining data. Offsets and gradients are removed on each half scan (a single pass from one peak to the next) and data taken near the scan turn around points are rejected. Data are binned into 21 bins with widths of 0.17° The performance of the detector per channel for each scan is summarized in Table 1.

Table1. Sensitivities achieved in flight in $\mu K\sqrt{sec}$, CMB units

Scan	3.5 cm^{-1}	6 cm^{-1}	9 cm^{-1}	14 cm^{-1}
Iota Draconis	578	540	751	2624
GUM	631	512	792	2954
Sigma Hercules	578	549	775	2683

As a comparison, COBE has a sensitivity of about $15mK\sqrt{sec}$. The data are plotted in Tantenna vs. scan angle in figures 1, 2, and 3 for GUM,ID and SH respectively.

Each scan shows statistically significant structure in each channel, except for the 14 cm^{-1} channel in ID and SH. As shown in table 2, it seems unlikely the signal is a product of chance.

Table2. Probabilities for consistency with gaussian random noise. neg = negligible probability

Band	GUM	Sigma Herc	Iota Drac
3 cm^{-1}	neg	neg	neg
6 cm^{-1}	neg	0.3	0.2
9 cm^{-1}	0.03	0.05	0.06
14 cm^{-1}	6×10^{-4}	0.83	0.24

The unchopped beam response is known to be $\leq$ 65dB from 13° - 35° off axis. We have achieved similar results from three different flights from the GUM region. Between each flight, the baffles were remade, and between MAX3 and MAX4, redesigned. Furthermore, GUM was observed at different elevation for each flight. Because sidelobe rejection is good and that varying configurations produce the same answer, we believe we can discount sidelobe contamination. As for foreground contamination, it is apparent from the data that the spectrum is not consistent with

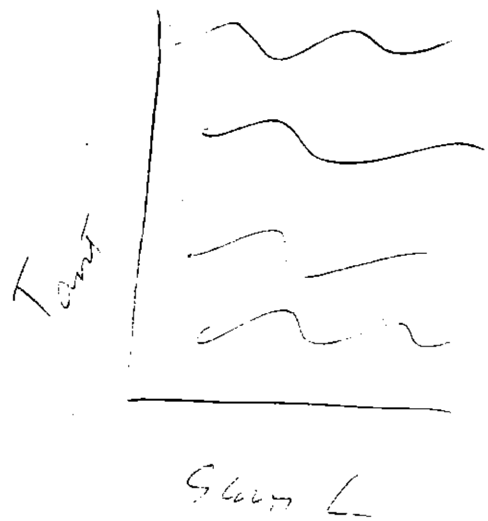

Fig. 1. GUM scan data plotted in μK Rayleigh Jeans vs. scan angle. The error bars are 1 σ error bars.

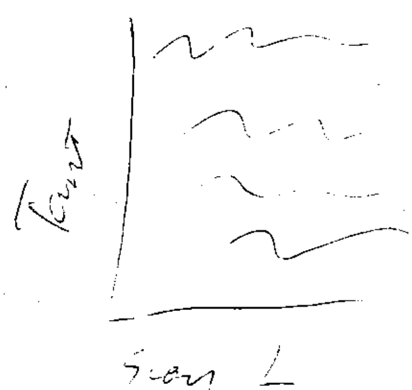

Fig. 2. ID scan data plotted in μK Rayleigh Jeans vs. scan angle. The error bars are 1 σ error bars.

interstellar dust in any scan or with direct earthshine. They are, however, consistent with CBR and synchrotron and free-free radiation. To attempt to distinguish between the three, we model the latter two as power law spectra, ΔTantenna $\propto \nu^{\beta}$, where β = -2.7 in the case of synchrotron radiation and β = -2.1 in case of free-free. The amplitude is estimated by extrapolating from the Haslam 408 MHz maps of our observed regions. Spectral analysis is complicated by the variation of the beam size with frequency. The morphology of the target must be considered, as unresolved sources will be diluted more at higher frequencies. Figure 4 is a color-color diagram showing the ratios of the signal bearing channels for different radiation and morphological models along with the observed ratios.

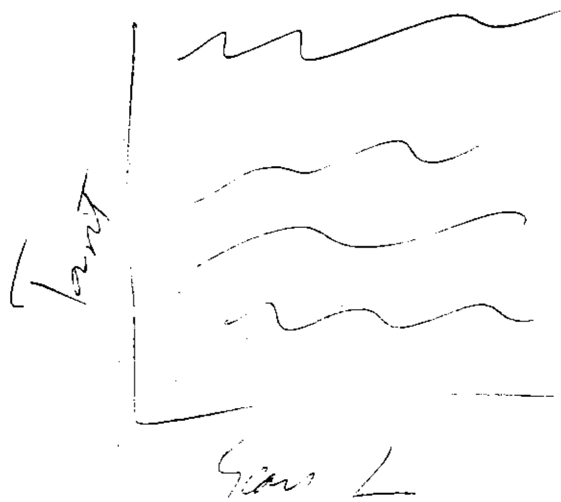

Fig. 3. SH scan data plotted in μK Rayleigh Jeans vs. scan angle. The error bars are 1 σ error bars.

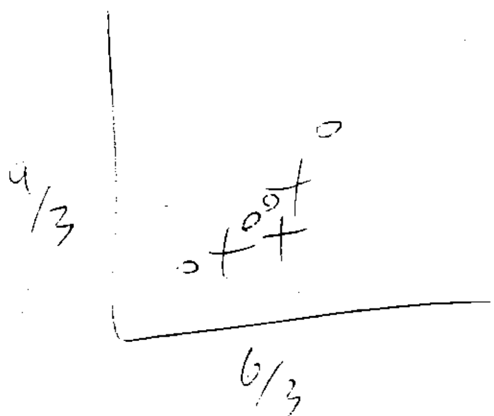

Fig. 4. Ratios of the signals in three of the channels. The best fit values for the scans with their 1 σ error bars as well as various models of emission and morphology are shown.

Despite the spectral confusion however, signals ¡ 1% of the amplitude observed can be attributed to synchrotron and at best $\sim$ 10% in the case of free-free emission. (Clapp et al. (1994), Devlin et al. (1994)) Under the assumption that all of the signal is due to CMB anisotropy we fit the data to a GACF with a coherence angle of 25 arcminutes, as described in Cheng, E.S. et al. (1994) We get for GUM, $3.7^{+1.9}_{-1.1} \times 10^{-5}$,for ID,$3.3^{+1.0}_{-1.1} \times 10^{-5}$, and for SH $3.1^{+1.7}_{-1.3} \times 10^{-5}$, as the most probable values for $\Delta T/T_{cmb}$ with 95% confidence upper and lower limits.

3. Discussion

MAX4 brings to six the number of successful scans by the experiment. Our findings are summarized in table 3. The notable outlier is the Mu Pegasus scan. This scan was different from the others in that there was significant interstellar dust contamination which had to be subtracted from the data. With this in mind, a simple statistical combination of all six scans yield a mean $\Delta T/T_{cmb}$ of $2.9 \pm 0.5 \times 10^{-5}$. The χ^2 is 16.9 with the probability of exceeding this χ^2 of 0.5%. Excluding the Mu Pegasus scan the mean is $3.6 \pm 0.2 \times 10^{-5}$, the χ^2 is 2.5 with probability of exceeding this χ^2 of 63%.

Table 3. MAX Results to Date. Most probable values for a GACF with coherence angle 25' obtained per scan and flight with 95% confidence upper lower limits.

Scan	$\Delta T/T_{cmb}$
MAX2 GUM	$4.5^{+5.7}_{-2.6} \times 10^{-5}$
MAX3 Mu Peg	$1.4^{+1.1}_{-0.7} \times 10^{-5}$
MAX3 GUM	$4.2^{+1.7}_{-1.1} \times 10^{-5}$
MAX4 GUM	$3.7^{+1.9}_{-1.1} \times 10^{-5}$
MAX4 Sigma Herc	$3.3^{+1.0}_{-1.1} \times 10^{-5}$
MAX4 Iota Drac	$3.1^{+1.7}_{-1.3} \times 10^{-5}$

4. Conclusions

The MAX4 flight has seen statistically significant structure in three regions of the sky, one of which has been observed twice before. Results are consistent with each other, giving a $\Delta T/T_{cmb}$ of approximately $3 - 4 \times 10^{-5}$, neglecting the Mu Pegasus results. In June 1994, MAX flew for the fifth time, observing two new low dust regions and also hitting Mu Pegasus at or close to the MAX3 orientation. With the 3.5 cm^{-1} channel, that flight should shed light on Mu Pegasus and add to our statistics of low dust regions.

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