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NEW LIMITS ON SMALL-SCALE ANGULAR FLUCTUATIONS IN THE COSMIC MICROWAVE BACKGROUND

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ABSTRACT

Using the 31 GHz dual-channel receiver at the 11 meter NRAO telescope at Kitt Peak, we have searched two regions at $\delta = 80°$ for fluctuations in the cosmic microwave background. No significant evidence for small-scale anisotropies was found. At the 95% confidence level, the upper limit on fluctuations $\Delta T/T$ was $\sim 2 \times 10^{-4}$ on angular scales comparable to the beam width (3$'$.6). On a larger angular scale of 7$'$, the upper limit was $\Delta T/T \lesssim 8 \times 10^{-5}$.

Subject headings: cosmic background radiation — radio sources: general

I. INTRODUCTION

How and when galaxies, clusters, and other gravitationally bound systems form are important unsolved problems in cosmology. It has long been realized that careful observations of the small-scale angular structure of the cosmic microwave background may provide important information about protogalactic and protocluster perturbations (Sunyaev and Zel'dovich 1970; see Boynton 1977 and Sunyaev 1977 for recent reviews). The relationship between the amplitude of density perturbations, $\Delta\rho/\rho$, and the amplitude of fluctuations in temperature of the cosmic microwave background depends on a number of factors, most of which operate to make $\Delta T/T$ lower than $\Delta\rho/\rho$. Among these are the effects discussed by Sunyaev and Zel'dovich (1970) and the possibility of Thomson scattering in a hot intergalactic medium (Gunn and Peterson 1965). While no certain predictions of $\Delta T/T$ can be made, it appears that fluctuations of order $\Delta T/T \approx 10^{-4}$ can reasonably be expected, especially on angular scales of a few arc minutes (Sunyaev 1977). The angular scale of temperature fluctuations depends on the mass of the density perturbations, and on the present values of Hubble's constant, the deceleration parameter q_0, and the mean mass density of the Universe, ρ_0. For large redshifts, the following approximation may be used (Weinberg 1972):

$$\theta \sim \frac{q_0 H_0}{c}\left(\frac{6M}{\pi\rho_0}\right)^{1/3} .$$

A number of individuals and groups have already reported upper limits on $\Delta T/T$ on angular scales of $\sim 1'$–$10°$ (see Boynton 1977 for a recent review). The measurements of Carpenter, Gulkis, and Sato (1973), Caderni *et al.* (1977), and Pariiskii, Petrov, and Cherkov (1977) are particularly relevant. However, some published measurements have not been described in detail, some are in fact erroneous, and some have not yet been fully corrected for instrumental effects (for a fuller discussion, see Partridge 1979). Hence it seemed worthwhile to try to improve published limits on fluctuations in the cosmic microwave background on a range of angular scales corresponding to the mass of galaxies, clusters, and even larger systems. Accordingly, I have undertaken a series of measurements on the cosmic microwave background on angular scales ranging from a few arc seconds to several degrees. Reported here are the first results, on an angular scale of 3$'$–7$'$, approximately the scale for which the maximum fluctuation amplitude is predicted by Sunyaev (1977). This particular angular scale is also of interest because it is approximately that expected for protocluster fluctuations, and for fluctuations in the microwave background which may be produced at much later epochs by Compton scattering by hot gas in clusters of galaxies (Fabian and Rees 1978, and references therein).

The observational technique is described in the following section. In § III, the raw data are presented. In § IV, a number of necessary corrections are described in some detail. The corrected data are then analyzed statistically in § V to see what conclusions these measurements allow us to draw about fluctuations in the cosmic microwave background. Finally, some additional relevant measurements are reported.

II. OBSERVATIONS

The measurements were carried out in 1978 April with the 31.4 GHz dual-channel receiver at the Cassegrain focus of the National Radio Astronomy Observatory 11 m telescope in Tucson. Two orthogonally polarized channels were available; since the signals we sought were expected to be unpolarized, the outputs were added together. Each channel had a double-sideband bandwidth of 1 GHz, and at the time we used them the receivers had system noise temperatures of $\sim$570 K. The full width of the main beam at half-power was θ_H = 3$'$.6, and assuming a Gaussian profile

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the main beam solid angle was 14.6 (arcmin)^2. Beam switching (at 2.5 Hz) in azimuth only was employed, so that the elevations of the two beams were always equal. The separation of the two beams was 9′. During a given scan, the telescope was held fixed so that drift scans were obtained.[2] This procedure reduced time-varying sidelobe pickup. Data were recorded every 20 s. The calculated system noise was thus $T_s(\Delta\nu t)^{-1/2} \approx$ 4 mK antenna temperature for each 20 s integration.

Two regions at $\delta = +80°$ were chosen for detailed study, one with right ascension between 3^h0^m and 3^h15^m, the other with α between 9^h0^m and 9^h07^m. Both regions were free of cataloged radio sources (Dixon 1978) to 0.2 Jy at 1400 MHz. In addition we have made a detailed interferometric survey of the region at $\delta = 80°$, $\alpha = 3^h$, at 3.7 cm and 11 cm (Martin, Partridge, and Rood 1979) and have found no sources which would contribute significantly to our measurements at $\lambda = 9$ mm, assuming a positive spectral index from 8 to 31 GHz.

High declination regions were chosen so that the drift time of a source through the main beam was relatively long—83 s per half-power beamwidth θ_H.

All scans were made while the regions under study were within 3 hours of transit; elevation angles never fell below 35°. The scans at $\alpha = 3^h$ lasted 14 minutes, so that we obtained 40 separate 20 s integrations in each scan. Because less time was available for the scans at $\alpha = 9^h$, we shortened the scans in order to keep the integration time per point approximately the same.

After a few scans (18 in all) were rejected because of instrumental malfunction, cloudy weather, or other problems, we were left with 78 scans of the region at 3^h and 101 of the region at 9^h. In addition, we had earlier made 40 scans of the same region at 3^h using a slightly different technique (see above).

III. RAW DATA

These 219 drift scans formed our raw data set. At this stage, the numbers were still in terms of antenna temperature, corrected *only* for atmospheric extinction (an automatic correction made at NRAO).

To remove very occasional bursts of radio frequency interference, and also instrumental drift, each scan individually was treated as follows:

1. A trial polynomial of the form $a_i + b_i t + c_i t^2$ was fitted to each scan i, and this fitted polynomial was then subtracted from the raw data of each scan i to remove instrumental drift and offset. The coefficients of the t^2 term were rarely significant, and no significant differences in the final results were found using a linear fit only.
2. The standard deviation of the resulting residuals was found.
3. Any individual point having a residual exceeding 3 times the standard deviation was then dropped (no more than 2 values needed to be rejected from any of the 219 scans).
4. A new polynomial fit was made to the remaining data in each scan. As before, these polynomials were subtracted from the data.
5. Finally, the standard deviation of the residuals from step (4) was found. Proper account was taken of the loss of degrees of freedom caused by the polynomial fit. We label the standard deviation of the nth scan S_n.

After this treatment, we had roughly 40 measurements in each scan (or roughly 20 in the case of the shorter scans at 9^h). We label the mth point in the nth scan X_{nm}. After the corrections discussed in next section were applied, these $N \times M$ arrays, one for each of the two regions studied, became the bases for the statistical analysis of the data.

IV. CORRECTIONS

We shall want eventually to compare our measured values X to the temperature of the cosmic microwave background to find a value for the fractional fluctuation, $\Delta T/T$. To do so, we must first make a number of corrections to the entries X_{nm}.

1. *Conversion to thermodynamic temperature.* At $\lambda = 9$ mm, we are no longer in the Rayleigh-Jeans region of the microwave background spectrum. Hence small differences in *antenna* temperature, which assumes the Rayleigh-Jeans law, are not equivalent to the same differences in *thermodynamic* temperature. In fact, $\Delta T \approx \Delta T_A[1 + (1/12)(h\nu/kT)^2]$ (see Boughn, Fram, and Partridge 1971). Adopting 2.8 K for the thermodynamic temperature T of the cosmic microwave background, we find $\Delta T = 1.025\Delta T_A$.[3]

2. *Telescope efficiency: conversion to sky or brightness temperature.* This correction has frequently been overlooked (by Pariiskii 1973 and Stankevich 1974, for example), leading to underestimates of the true fluctuation level $\Delta T/T$. To convert fluctuations observed in antenna temperature to fluctuations in sky or brightness temperature, one must take account of the aperture efficiency of the telescope employed. This was determined by the NRAO staff to be 0.40 ± 0.02 for the 11 m telescope at $\lambda = 9$ mm, at the time we used it.[4] For sources comparable in size to the main beam solid angle, the efficiency is somewhat higher. The NRAO staff in Tucson (M. Gordon and B. Ulich) have estimated 0.55 for the total efficiency for sources $\gtrsim \theta_H$ or 3′.6, and I have adopted this figure.

3. *Degradation of signal caused by drift, etc.* During a single 20 s integration, the sky drifted by only a fraction of the telescope beamwidth. Hence adjacent 20 s integrations in a given scan cannot be considered completely independent. To sidestep this problem, each data array was divided into four groups. Columns

[2] Some early measurements, made in 1977 April, also employed position switching (ON–OFF technique) in which the telescope was moved by 9′ every 10 s to place the region under study alternately in the two beams.

[3] This correction was *not* correctly made in an earlier paper (Boynton and Partridge 1973). With this point corrected, those measurements lead to an upper limit of fluctuations of $\Delta I/I = 1.8 \times 10^{-3}$, not 3.7×10^{-3} as reported.

[4] See also NRAO Technical Data Sheet Number 6, 1978 November.

1, 5, . . . , 37 formed the first group; columns 2, 6, . . . , 38 the second; and so on. Thus two consecutive measurements *within* any group were separated by 80 s. Each group can then be considered a set of almost independent measurements of the sky temperature. Even this procedure, however, did not completely eliminate *overlap* between the two consecutive measurements within a single group (between col. [1] and col. [5], for instance). Assuming a Gaussian beam pattern of full width at half-power $\theta_H = 3\rlap{.}'6$, one can show that the overlap for drift scans at $\delta = 80°$ degrades the measurements by a factor of ~ 0.93. At a later stage of the analysis (see § V) measurements are combined by fours; in this case the overlap correction factor is 0.88.

In addition, the drift of the sky during an individual 20 s integration will further reduce the signal from a *point* (or very small) source. At worst, this "smearing" degrades signals from point sources by ~ 0.92. No such correction is necessary for sources of angular scale $\gtrsim \theta_H$.

The error beam of the 11 m telescope at $\lambda = 9$ mm contains $\lesssim 5\%$ of the total power (B. Ulich, private communication). Since the error beam is large (FWHM $\sim 90'$) compared to any of the angular scales considered here, including the length of the drift scans, we can neglect contributions it might make to $\Delta T/T$.

Finally, we note that the reference beam rotated by $\sim 100°$ on the plane of the sky during a single day's observing period; hence any fluctuations in the reference beam were largely averaged out. For a few scans made near transit, however, the reference beam crossed and overlapped a portion of the drift scan. Hence there was some loss of independence in the data. Since these measurements were used to search for fluctuations on angular scales less than the beam throw of 9′, this loss of independence is ignored.

Compounding all of the corrections listed above, we find that the entries X_{nm} must be corrected as follows to convert them to measurements of ΔT directly comparable to the temperature of the microwave background:

a) For "point" sources, multiply X's by 3.00.

b) For sources $\gtrsim \theta_H$ in size, multiply X's by 2.12.

V. STATISTICAL ANALYSIS

We turn now to the task of extracting an estimate of the fluctuations in the microwave background from our *corrected* values of X_{nm} (see Boynton and Partridge 1973 for a similar analysis).

As a first step, we average the data in each column. First a straight, unweighted average was taken:

$$\langle X \rangle_m = \left(\sum_n X_{nm} \right) \Big/ N \, .$$

We also formed a *weighted* average, using as weights the variances of the individual scans, $1/S_n^2$:

$$\langle X_w \rangle_m = \sum_n (X_{nm}/S_n^2) \Big/ \sum_n (1/S_n^2) \, .$$

TABLE 1

FULLY CORRECTED TEMPERATURES (in mK) AS A FUNCTION OF POSITION IN THE SKY (or column number) FOR 101 SCANS OF A REGION NEAR $\alpha = 9^h$, $\delta = 80°$

Column No. m	Unweighted Avg. $\langle X \rangle_m$	Unweighted Std. Dev. of Mean	Weighted Avg. $\langle X_w \rangle_m$	Weighted Std. Dev. of Mean
1......	−0.94	0.73	−0.49	0.55
2......	−0.71	0.70	−0.34	0.56
3......	+0.69	0.80	+0.43	0.62
4......	+1.56	0.84	+1.04	0.70
5......	+1.50	0.83	+0.42	0.67
6......	+0.42	0.81	+0.31	0.62
7......	+0.44	0.85	+0.18	0.62
8......	−0.80	0.83	−0.04	0.65
9......	−1.86	0.82	−1.25	0.64
10......	0	0.86	−0.19	0.66
11......	−0.19	0.75	−0.24	0.59
12......	+0.64	0.75	+0.31	0.61
13......	−0.51	0.77	−0.24	0.59
14......	−0.21	0.87	+0.30	0.66
15......	−0.05	0.81	−0.07	0.62
16......	+0.26	0.79	+0.04	0.61
17......	−0.42	0.80	−0.25	0.66
18......	+0.19	0.82	−0.07	0.64
19......	−0.44	0.77	−0.20	0.59
20......	+0.87	0.76	+0.48	0.58

NOTE.—The results of both straight (unweighted) and weighted averaging are displayed. The weighted averages are also displayed in Figure 1.

The results for 101 scans of the region near 9^h (made in 1978) are displayed in Table 1. The weighted averages are also shown in Figures 1–3 for all scans. All the corrections listed in § IV above have been made.[5] The variances, and the standard deviations of

[5] Assuming, to be conservative, the low value of 0.4 for telescope efficiency.

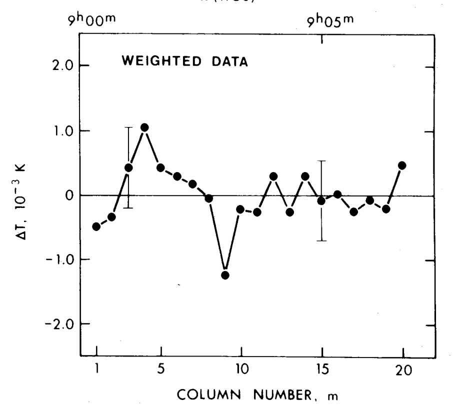

FIG. 1.—Fully corrected values of measured ΔT as a function of position (or column number m) for scans made near $\alpha = 9^h$. The data shown here are the weighted averages of 101 scans (see § IV). Two typical error bars are shown—these are $\pm \sigma_m$, the standard deviation of the mean of the measurements in column m. The data shown appear also in Table 1. An efficiency of 0.40 has been assumed.

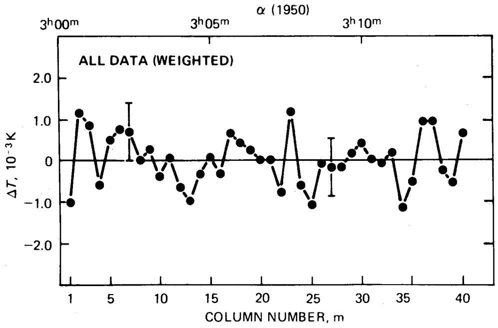

FIG. 2*a*

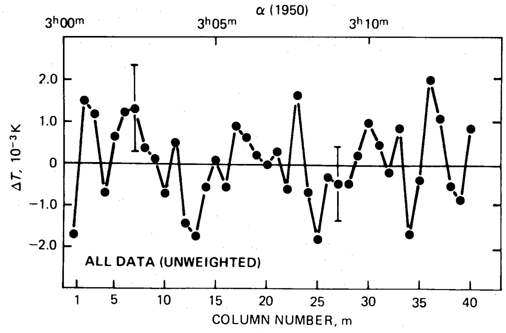

FIG. 2*b*

FIG. 2.—Fully corrected values of measured ΔT as a function of position for scans made near $\alpha = 3^h$. (*a*) Weighted average of 118 scans; (*b*) the same data combined in a straight, unweighted, average of the 118 scans. The data shown in (*a*) are the (properly weighted) combinations of 40 scans made in 1977, and 78 additional scans made in 1978. See Fig. 3.

the means of the $\langle X \rangle$'s, which we write as σ_m, were computed in the usual way from the n values in each column, corrected for loss of degrees of freedom (§ III). In this averaging process, the variances measure only system noise, including instrumental and atmospheric noise.

A similar averaging process applied to the individual *rows* of the $N \times M$ data arrays would provide information about the *combination* of system noise *and* fluctuations in the temperature of the microwave background (see Boynton and Partridge 1973). In fact these variances were quite close to the column variances. We may thus infer that the variance introduced by fluctuations in the microwave background was not large compared to the system noise of ~0.8 mK, found from the column variances.

However, as recognized first by Conklin and Bracewell (1967), there exist means of removing (some of) the system noise on a statistical basis to produce a more precise estimate of the sky fluctuations. We adopt a related method used earlier by Boynton and Partridge (1973) which permits us to estimate the confidence level of our results.

We wish to test, against the hypothesis that the mean squared sky fluctuation σ_s^2 is zero, the hypothesis that σ_s^2 is equal to some nonzero value, $\hat{\sigma}^2$. We begin by constructing the statistical quantity

$$\mathscr{S} = \sum_m \frac{\langle X \rangle_m^2}{\sigma_m^2(\sigma_m^2 + \hat{\sigma}^2)} \cdot \qquad (1)$$

As noted above, the quantities σ_m^2 are calculated from the variances found when summing down the columns. Also, the quantities $(\sigma_m^2 + \hat{\sigma}^2)$ would be similarly related to the variances found when summing along rows *if* $\hat{\sigma}$ were equal to the true value of the sky fluctuation, σ_s. Hence the terms

$$\frac{\langle X \rangle_m^2}{(\sigma_m^2 + \hat{\sigma}^2)}$$

in the sum (1) are independent unit-normal variables *if* $\hat{\sigma}^2 = \sigma_s^2$ so that $\mathscr{S}$ would be a χ^2 variable except for the additional factor of σ_m^2 in the denominator. This may be thought of as a weight.

Let us define

$$R \equiv \sum_m (\sigma_m^{-2}) \Big/ \sum_m (\sigma_m^{-2})^2 \, . \qquad (2)$$

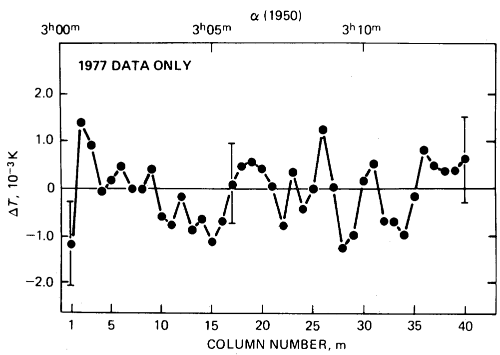

FIG. 3*a*

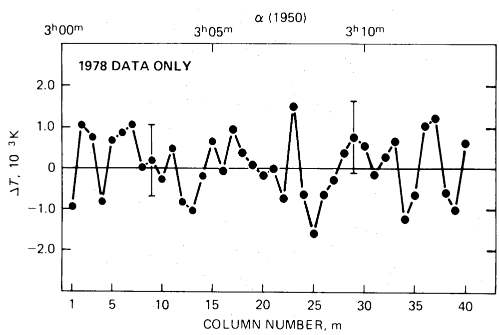

FIG. 3*b*

FIG. 3.—Two independent scans of the region at $\alpha = 3^h$, made a year apart. Weighted averages are shown in each case. If real fluctuations in the microwave background were present, these plots would show correlated structure.

Then the product $R\mathscr{S}$ is approximately distributed as χ^2 on ν degrees of freedom, where

$$\nu = R \sum_m (\sigma_m^{-2}) . \quad (3)$$

We have applied this method separately to each of the four groups of data in each $N \times M$ array, in order to avoid loss of independence caused by overlap (see § IV, ¶ 3). The results are summarized in Tables 2 and 3. The values of $R\mathscr{S}$ found with $\hat{\sigma} = 0$ appear in col. 2. Using χ^2 tables for ν degrees of freedom, we have calculated upper limits on $(\sigma_s^2)^{1/2}$ at the 95% confidence level; these appear in column (5) of the tables. There is less than a 5% chance that $(\sigma_s^2)^{1/2}$ could be larger than these limits, given the scatter in our data. In four cases, any value of $(\sigma_s^2)^{1/2} > 0$ is excluded at the 95% confidence level (formally $\hat{\sigma}^2 < 0$). Since $(\sigma_s^2)^{1/2}$ cannot be imaginary for physical reasons, zeros are written for the upper limits on the sky fluctuations in these cases. These values are the major results of this experiment. They are expressed in thermodynamic temperature corrected to the sky (true brightness temperature), so they can be compared directly to the 2.8 K temperature of the cosmic microwave background.

Note that the results from the *weighted* data provide the most accurate estimators of the true sky variance.

Finally, measurements on adjacent positions of the sky can be combined to provide an estimate of sky variance $(\sigma_s^2)^{1/2}$ on larger angular scales. For instance, if we combine by addition four adjacent measurements, we obtain an angular scale of $\sim 7'$. The effective beam pattern in this case can be approximated by a Gaussian of full width at half-amplitude of 3′.6 convolved with a square wave of width 3′.5. Since this angular scale is greater than the beamwidth θ_H, an efficiency of 0.55 is used in converting measurements of antenna temperature to brightness temperature. For the data grouped in this fashion, the results are shown in Table 4.

TABLE 2

ANALYSIS OF DATA OBTAINED AT $\alpha = 9^h$, $\delta = 80°$

Group (1)	$R\mathscr{S}$ if $\hat{\sigma} = 0$ (2)	ν (3)	Typical σ_m (mK) (4)	Upper Limit on $(\sigma_s^2)^{1/2}$ (mK) (5)
Weighted Data				
1.........	5.13	4.89	0.62	1.18
2.........	0.95	4.93	0.62	0
3.........	0.85	4.98	0.61	0
4.........	2.87	4.92	0.62	0.83
Unweighted Data				
1.........	10.27	4.95	0.79	2.29
2.........	1.67	4.87	0.81	0.53
3.........	1.39	4.96	0.79	0.38
4.........	6.12	4.96	0.80	1.71

NOTE.—See equations (1), (2) and (3) for definitions of terms. The value of $\mathscr{S}$ which enters in col. (2) is calculated with $\hat{\sigma} = 0$. We have also calculated an upper limit on $(\sigma_s^2)^{1/2}$ at the 95% confidence level using χ^2 tables for ν degrees of freedom. These results, in col. (5), are expressed in fully corrected brightness temperature, which may be directly compared with the 2.8 K temperature of the cosmic microwave background.

The data which enter into this analysis are laid out in Table 1 and Fig. 1.

TABLE 3

ANALYSIS OF DATA OBTAINED AT $\alpha = 3^h$, $\delta = 80°$

Group	$R\mathscr{S}$ if $\hat{\sigma} = 0$	ν	Typical σ_m (mK)	Upper Limit on $(\sigma_s^2)^{1/2}$ (mK)
1977 Data Only (Weighted)				
1.........	3.27	9.83	0.96	0
2.........	6.17	9.86	0.95	0.72
3.........	4.57	9.60	0.92	0.43
4.........	2.95	8.18	0.93	0.18
1978 Data Only (Weighted)				
1.........	9.76	9.93	0.78	1.12
2.........	6.05	9.93	0.77	0.68
3.........	6.03	9.86	0.77	0.69
4.........	3.40	9.94	0.76	0
All Data (Weighted)				
1.........	10.27	9.93	0.71	0.87
2.........	8.50	9.94	0.70	0.76
3.........	6.55	9.91	0.70	0.56
4.........	4.36	9.84	0.68	0.25
All Data (Unweighted)				
1.........	14.61	9.61	0.90	1.53
2.........	13.60	9.83	0.85	1.33
3.........	12.06	9.50	0.90	1.27
4.........	13.29	9.79	0.87	1.31

NOTE.—Both the 1977 and the 1978 scans were combined in the last 8 rows, taking proper account of the fact that the 1977 measurements consisted of on-off temperature differences, and hence that the estimated value of $\hat{\sigma}^2$ was $2\sigma_s^2$. (See Figs. 2 and 3 for the individual measurements, and Table 2 for a further description of entries.)

VI. CONCLUSIONS AND DISCUSSION

The major result of these observations is that there is no significant evidence for temperature fluctuations on an angular scale of several arc minutes. An examination of columns (2) and (3) of Tables 2 and 3 will show that the probability of a *significant* nonzero value of $(\sigma_s^2)^{1/2}$ is in no case greater than $\sim 70\%$, for the weighted data.

A further check is provided by the separate runs made on the region at $\sim 3^h$ in different years using different techniques. Real temperature fluctuations in the microwave background would have produced a similar pattern in Figures 3*a* and 3*b*. There is no apparent similarity. In addition, these two sets of measurements of the same region were cross-correlated; no significant correlation was found.

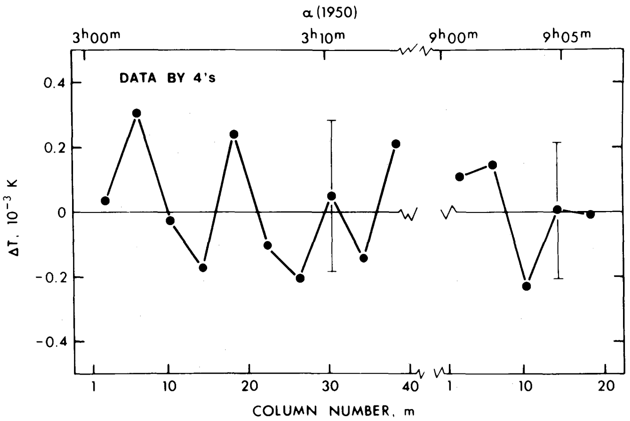

FIG. 4.—Here the individual measurements have been combined in sets of 4. Weighted data are shown, for both regions surveyed. An efficiency of 0.55 was used (see text).

Because of the polynomial fit discussed in § III, these results do not, of course, contain any information about possible inhomogeneities on the larger angular scales comparable in size to the regions surveyed.

Therefore, these results will be treated as upper limits on the fluctuation in the microwave background. Considering for the moment only the weighted data, we see from Tables 2 and 3 that $(\sigma_s{}^2)^{1/2}$ on angular scales $\sim\theta_H = 3'.6$ typically lies in the range 0.3–0.8 mK. Hence, at the 95% confidence level, $\Delta T/T \lesssim 2 \times 10^{-4}$. On a larger angular scale of $\sim 7'$, where several measurements can be combined to increase the integration time, we find $\Delta T/T \lesssim 8 \times 10^{-5}$ from Table 4, again at the 95% confidence level.

TABLE 4

WEIGHTED DATA COMBINED IN FOURS, CORRESPONDING TO AN ANGULAR SCALE OF $\sim 7'$

Region	$R\mathscr{S}$ $\hat{\sigma} = 0$	ν	Typical σ_m (mK)	Upper limit on $(\sigma_s{}^2)^{1/2}$ (mK)
3^h........	5.48	9.99	0.245	0.16
9^h........	3.11	4.99	0.22	0.29

NOTE.—The upper limits are at the 95% confidence level. Combining data from the two regions gives an even lower upper limit on $(\sigma_s{}^2)^{1/2}$. See Table 2 for further description of entries.

Only the results of Stankevich (1974), which are in error by at least a factor of 2, and of Pariiskii, Petrov, and Cherkov (1977), which may also be in error (see Partridge 1979), are of roughly comparable sensitivity in this range of angular scales.

The present upper limit on $\Delta T/T$ of $\lesssim 8 \times 10^{-5}$ on a scale of $\sim 7'$ is close to the predictions made (for a particular adiabatic model) by Sunyaev (1977). As he points out, the formation of bound systems at redshifts larger than 3 would require even larger density perturbations at $z \sim 1000$, and hence would generate values of $\Delta T/T$ exceeding the limits set here. Thus observations of fluctuations in the microwave background are beginning to constrain theories for the formation of bound systems in the universe.

These results also bear on the searches for perturbations in the microwave background intensity produced by passage of the radiation through gas in clusters of galaxies (Rudnick 1978; Birkinshaw, Gull, and Northover 1978; Lake and Partridge 1979). It appears that cosmic fluctuations will not contribute unwanted background noise of more than a few tenths of a millikelvin to such searches. On the other hand, as all three of these papers point out, negative searches for the "cooling" effect produced by clusters can also be used to set limits on cosmic fluctuations of the kind considered in this paper. Since the observations are directed at clusters of galaxies, of course, the regions surveyed are hardly randomly located. Nevertheless, the results of Lake and Partridge (1979) can be used to show that in the vicinity of 13 clusters, $\Delta T/T \lesssim 2 \times 10^{-4}$ on a scale $\sim 3'.6$. These results are mentioned here because they were obtained with the same instrument (and in some cases on the same dates) as the results reported in this paper.

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