1980

Microwave Search for Ionized Gas in Clusters of Galaxies

George Lake

Bruce Partridge
Haverford College, bpartrid@haverford.edu

Repository Citation

(with G. Lake*) Search for Ionized Gas in Clusters of Galaxies, Astrophysical Journal, 237, 378, 1980.

1980

Microwave Search for Ionized Gas in Clusters of Galaxies

George Lake

R. Bruce Partridge
Haverford College

Repository Citation

(with G. Lake*) Search for Ionized Gas in Clusters of Galaxies, Astrophysical Journal, 237, 378, 1980.

THE ASTROPHYSICAL JOURNAL, **237**:378–389, 1980 April 15

MICROWAVE SEARCH FOR IONIZED GAS IN CLUSTERS OF GALAXIES[1]

GEORGE LAKE
Princeton University

AND

R. B. PARTRIDGE
Haverford College[2]; and Institute of Mathematical and Physical Sciences,
University of Tromsø, Tromsø, Norway

Received 1979 June 27; accepted 1979 October 19

ABSTRACT

Using the 11-meter NRAO[3] telescope at $\lambda = 9$ mm, we have examined 16 clusters of galaxies for evidence of a change in temperature of the cosmic microwave background radiation which might be produced by inverse Compton scattering by electrons in hot intergalactic gas. For 15 of the clusters, no significant evidence of the effect was found at a level of sensitivity comparable to other published studies. In particular we do not confirm the effect reported for Abell 2218. We do detect a significant temperature decrement in Abell 576.

Subject headings: galaxies: clusters of — galaxies: intergalactic medium — radio sources: galaxies

I. INTRODUCTION

Evidence from X-ray observations of clusters of galaxies suggests that they contain intergalactic plasma at a temperature of approximately 10^8 K which emits thermal bremsstrahlung (see Lea *et al.* 1973; Kellogg, Baldwin, and Koch 1975; Gursky and Schwartz 1977; Mitchell, Ives, and Culhane 1977; and references therein). Although numerous models for the origin and distribution of the plasma have been presented (Gunn and Gott 1972; Lea 1975; Gull and Northover 1975; Cavaliere and Fusco-Femiano 1976; Bahcall and Sarazin 1977; Sarazin and Bahcall 1977; Gould and Rephaeli 1978; see also Rephaeli 1977), the amount and distribution of the plasma is still not certain. Several years ago, Sunyaev and Zel'dovich (1972) pointed out another observable consequence of hot gas in clusters of galaxies: inverse Compton scattering by electrons in the plasma would increase the energy of photons of the microwave background as these photons pass through the cluster. The fractional change in intensity of the microwave background is:

$$\frac{\Delta I}{I} = f(x) \int_0^\tau \frac{kT_e}{m_e c^2}\, d\tau \,, \tag{1}$$

where τ is the optical depth for Thomson scattering through the cluster, T_e is the electron temperature of the plasma, and m_e is the electron mass. The function $f(x)$ is given by:

$$f(x) = \frac{xe^x}{e^x - 1}\left(\frac{x}{\tanh \frac{1}{2}x} - 4\right), \tag{2}$$

where $x = h\nu/kT_r$, and T_r is the temperature of the microwave background radiation, which we take to be 2.8 K. It is worth noting explicitly that this effect lowers the intensity (and therefore the antenna temperature) of the microwave background in the Rayleigh-Jeans region. This follows from the fact that the inverse Compton process conserves photon number while increasing the photon energy. Since estimates of the optical depth for Thomson scattering are uncertain, $\Delta I/I$ cannot be precisely predicted. Estimates varying from 10^{-5} to 3×10^{-4} have been published, based on different models for the distribution of the plasma (see Gull and Northover 1975; Sarazin and Bahcall 1977; Gould and Rephaeli 1978).

The detection of this effect in clusters of galaxies would offer several benefits:

1. It would confirm the existence of plasma in the clusters, thereby strengthening the hypothesis that it is thermal bremsstrahlung which produces the observed X-ray flux from clusters.
2. Since $\Delta I/I$ is proportional to the electron number density, n_e, whereas the X-ray flux is proportional to n_e^2, observations of both would permit n_e and the so-called "clumping factor," $\langle n_e^2 \rangle / \langle n_e \rangle^2$, to be found, and this in turn would help discriminate among the models for the distribution of the plasma.
3. Combined X-ray and microwave observations can provide an independent measure of H_0 and q_0

---

[1] Research supported in part through National Science Foundation grants to Princeton University and Haverford College.

[2] Permanent address.

[3] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

(Birkinshaw 1979; Boynton and Murray 1978; Cavaliere, Danese, and De Zotti 1978; Gunn 1978; Silk and White 1978).

4. Detection of the effect would confirm the cosmological origin of the microwave background.

II. OBSERVATIONAL CONSIDERATIONS

At least three other groups (Pariiskii 1973; Birkinshaw, Gull, and Northover 1978*a*; Rudnick 1978) have sought or are seeking to detect the inverse Compton cooling of the microwave background produced by cluster plasma. Pariiskii, working at a wavelength of 4 cm, reported a positive detection of approximately -10^{-3} K or -1 mK for the Coma cluster, a result in agreement with the early observations of Gull and Northover (1976) at a wavelength of 3 cm, but not with the subsequent analysis of Birkinshaw, Gull, and Northover (1978*a*). The latter also observed several other Abell clusters, most of them known X-ray sources, and claim to have detected the effect in two or possibly three of them. However, Rudnick, observing at 2 cm, reports no statistically significant evidence for cooling of the microwave background by the clusters he has observed (at roughly comparable sensitivity). The apparent disagreement reflects the difficulty of these observations (see Rudnick 1978). The expected signals are small. Most clusters contain radio sources which may produce spurious signals (these could be of either sign in an observation which employs beam switching). Finally, the plasma itself will emit bremsstrahlung radiation even at centimeter wavelengths, emission which may mask the signal sought.

In view of these problems, we decided to make our observations at a shorter wavelength than used by others; $\lambda = 9$ mm, using the 11 meter NRAO telescope in Tucson. The use of a short wavelength offered three advantages. First, most radio sources are less intense at short wavelengths, so that our observations were less troubled by radio emission from sources within or near the clusters. Second, confusion is less of a problem (see Rudnick 1978).[4] The final advantage of shorter wavelength measurements, as shown in § VI below, is that thermal bremsstrahlung can be neglected.

Observations at short wavelengths present two problems, however. For a 2.8 K blackbody spectrum, $\lambda = 9$ mm is not truly in the Rayleigh-Jeans region. The antenna temperature at 31.4 GHz is only 2.1 K, and it is only for antenna temperature that $\Delta T/T = \Delta I/I$. This loss in sensitivity, however, is partially compensated by the increase in magnitude of the function $f(x)$ in equation (1). A more fundamental difficulty is that receivers are noisier and the atmosphere is more emissive at 9 mm than at centimeter wavelengths. These are expected to be sources of statistical error, and we preferred to accept the possibility of larger statistical errors to avoid sources of possible systematic errors.

III. OBSERVATIONAL TECHNIQUE

All observations reported here were made with the 11 m NRAO telescope in 1977 April, 1977 December, and 1978 April, using the nutating subreflector and the dual-channel Cassegrain receiver at 31.4 GHz.[5] Two orthogonal polarizations were detected simultaneously, each by a receiver with a double-sideband bandwidth of 1.0 GHz. We added the two polarizations. The system noise temperatures for the two receivers during our runs were typically 570 K; hence the rms system noise expected for a single 30 s integration was ~8.2 mK expressed in brightness temperature (i.e., corrected for instrument efficiency).

Beam switching at 2.5 Hz, and the usual position switching or ON-OFF technique, were employed. For the latter, a cluster was placed alternately in the two beams defined by the two positions of the nutating subreflector. Each ON or OFF measurement was typically 30 s long; eight OFFS alternating with seven ONS made up a single run.

The measured half-power full width of the antenna pattern at 31 GHz was 3'.6, and it was well approximated by a Gaussian profile. The measured aperture efficiency of the antenna system to a point source on axis was 0.40 ± 0.02 (but see § VI below).

The separation of the two beams was 9', the largest beam throw that did not degrade the performance of the antenna. The beam switch was always purely in azimuth to ensure that the zenith angles of the two beams, and hence their paths through the Earth's atmosphere, were equal. Beam switching in azimuth only caused the reference beam to rotate in celestial coordinates as the hour angle of a source changed. The rotation can be specified by the parallactic angle β defined by

$$\beta \equiv \tan^{-1}\left[\frac{\sin H/\cos\delta}{\tan L - \tan\delta\cos H}\right],$$

where δ is the declination of a source, H is its hour angle at the time it is observed, and L is the latitude of the observatory, in this case 31°57'. The rotation of the reference beam is shown schematically in Figure 1 for a typical source. Note that this technique tends to diminish any possible contributions of weak point sources lying in the reference beam arcs.

Most observations were made with the main beam centered on the cluster centers, as given in Table 1, so that the reference beam arcs were 9' away. For observations of low-redshift clusters, which were expected to be larger in angular size, we offset the main beam very slightly from the cluster center in order to shift the reference beam arcs further from the center. The geometry of the beams for an offset scan is shown in Figure 2. The offsets used for the main beam were approximately one-half the angular size of the cluster

---

[4] Using the same instrument at 9 mm, Partridge (1980) established an upper limit of ~0.6 mK on confusion and/or sky fluctuations at the 95% confidence level.

[5] Two preliminary runs (Lake and Partridge 1976) were made earlier with the 31 GHz prime focus receiver. The noise figure was much higher than that of the Cassegrain receiver used later; hence the quality of the data was lower, and they are not included here.

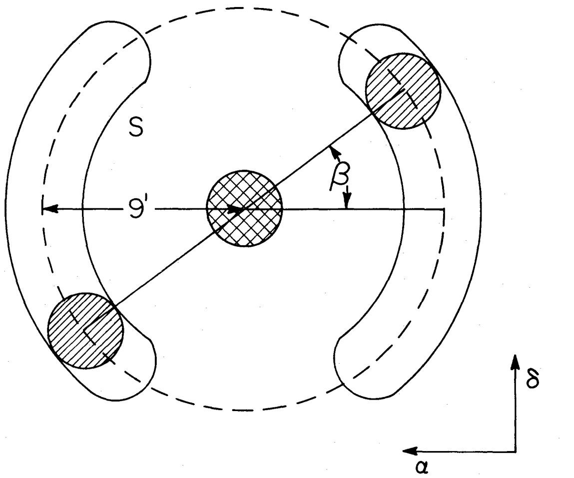

FIG. 1.—Beam pattern for the observations of clusters when no beam offsets were used. The main beam is shown crosshatched; the reference beam, dashed. Half-power contours are plotted. The angle β, which depends on the declination and hour angle of the source, is defined in the text. This arrangement was used for the observations of Abell A2125; in the figure, S marks the position of the source discussed in § VII.

core radii (Bahcall 1974), and, for convenience, were made entirely in azimuth. The offsets are given in column (4) of Table 1. For Coma (Abell 1656) only, we made an additional series of observations, labeled "Coma offset," at 12′ and 21′ from the cluster center. The positions of the antenna beams for our observariations of Coma are shown in Figure 3.

The data presented here were obtained during periods of clear weather (or light cirrus cloud) only. The instrument was calibrated every 1–2 hours, and measurements of atmospheric extinction (typically 2–4% at zenith) were made each time we moved to a new cluster. All data were automatically corrected for extinction.

Part way through our runs, we discovered two instrumental effects which produced spurious differences of a few millidegrees (mK) in antenna temperature. The first was a sudden jump in measured values of ΔT as the telescope crossed meridian *if* the transit occurred at high elevations. We have therefore excluded *all* data taken at elevations above 65°. The second effect was an elevation-dependent offset in the switched signal (ON minus OFF) which was present for sources in some, but not all, ranges of declination (see Figs. 4, 5, and 6). Since we were not able to determine

TABLE 1

CLUSTERS OBSERVED

Source	R.A. (1950)	Decl. (1950)	Offset if used
A376	$02^{\rm h}42^{\rm m}40^{\rm s}$	36°39′20″	
A426	03 15 50[a]	41 18 00[a]	
A545	05 30 00	−11 34 00	
A576	07 17 20	55 50 00	2′
A665	08 26 18	66 04 00	
A777	09 22 42	78 28 30	
A910	09 59 12	67 25 00	
Coma	12 57 24	28 15 00	3′
Coma offset[b]	...	...	12′[b]
5C 4.81	12 56 56	28 10 40	0′[b]
5C 4.85	12 57 11	28 13 40	0′[b]
A1689	13 08 58	−01 06 30	
A2079	15 26 02	29 02 55	1′.5
A2125	15 40 26	66 28 45	
A2142	15 56 12	27 22 00	
A2218	16 35 43	66 19 30	
A2319	19 19 36	43 52 00	1′.5
A2645	23 38 48	−09 19 00	
A2666	23 48 24	26 52 40	3′

[a] Offset ~3′ in R.A. from cluster center to avoid 3C 84.A.
[b] See Fig. 3.

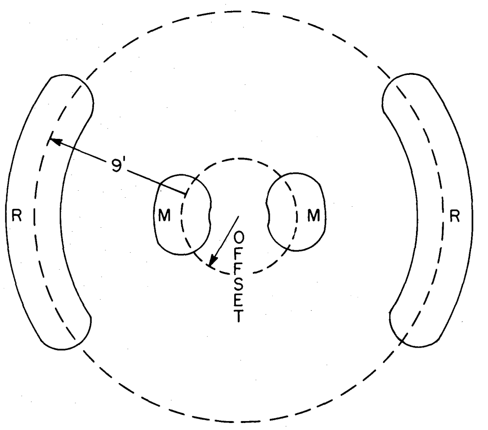

FIG. 2.—Typical beam pattern for observations of clusters when a beam offset was used (drawn here for an offset of 3′). M labels the two positions of the main beam; R labels the reference beam. The length of the main and reference beam arcs, of course, depends on β and the duration of the observations.

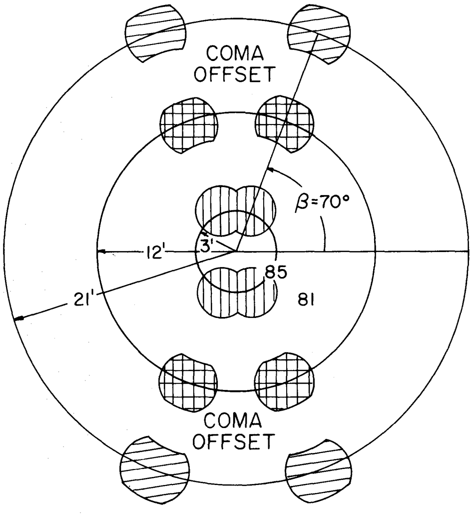

FIG. 3.—Beam pattern for the observations of the Coma cluster (*vertical hatching*) and "Coma offset" (*horizontal hatching*). The overlap region is crosshatched. The cluster was observed in a restricted range of hour angles only; hence β was always ±70° ± 2°. Positions of the two radio sources 5C 4.81 and 5C 4.85 are indicated (see § VIII).

1980ApJ...237..378L

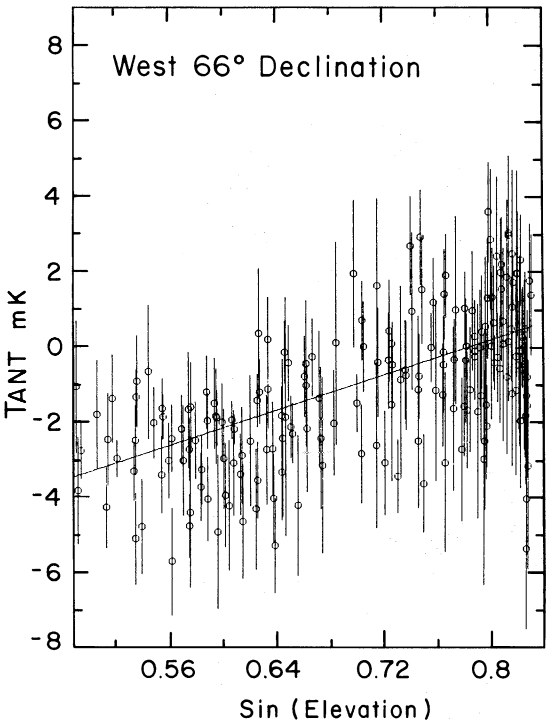

FIG. 4.—Plot of measured beam-switched temperature difference, in antenna temperature, for all sources and blank sky regions near +66° declination. Only data taken in the west, after transit, are shown. The error bars are ±1 σ. The straight line is the fitted function discussed in § V.

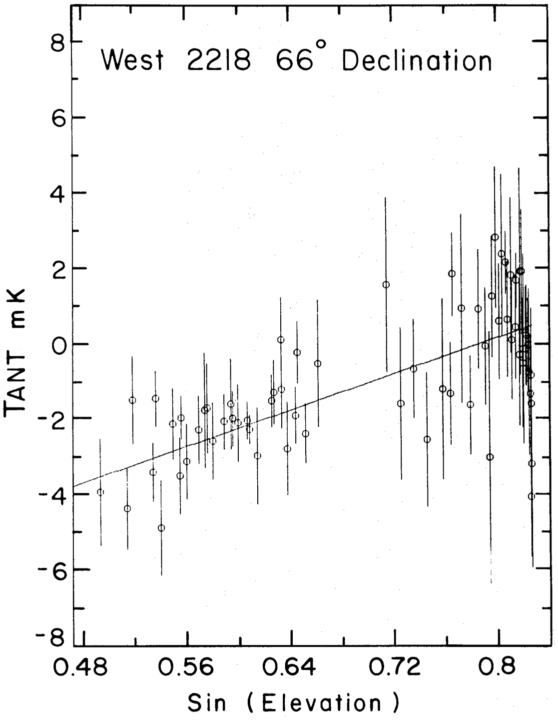

FIG. 5.—As for Fig. 4, except that only measurements of a single cluster, Abell 2218, are shown. The straight line is the fitted function from Fig. 4.

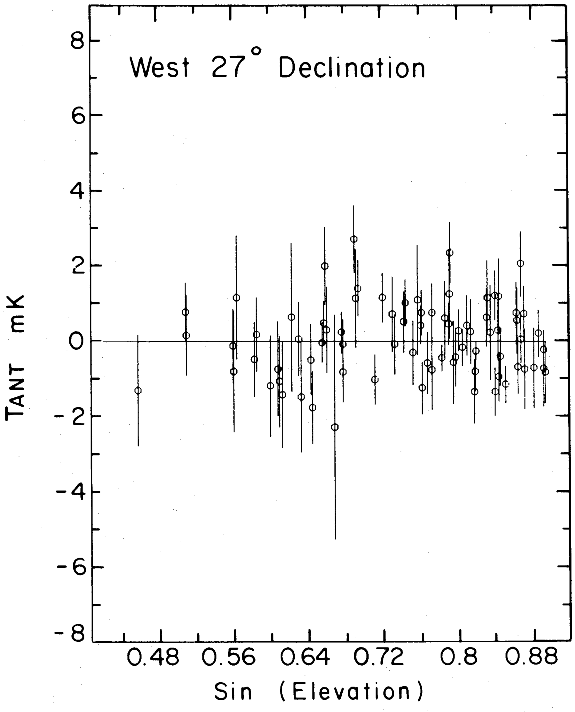

FIG. 6.—As for Fig. 4, for measurements of both sources and blank sky at +27° declination. Note the absence of an elevation-dependent offset at this declination. Data with sin (EL) > 0.9 were excluded from this analysis.

the origin of these offsets, we made extensive observations of nominally blank sky at the same declinations and over the same hour angles as our cluster observations. The technique used to subtract these offsets, when present, is described further in § V. Finally we note that the elevation-dependent effect was particularly strong at $\delta \approx 66°$ (see Fig. 4), and is responsible for the large, and probably erroneous, negative temperature offsets reported by Lake and Partridge (1977) for Abell clusters 2125 and 2218, both of which lie near $\delta = 66°$.

IV. SOURCES

We observed the 16 Abell clusters listed in Table 1. The clusters were selected either because they are known X-ray sources or because they are among the richest clusters in Abell's catalog (1958). Among the clusters which are X-ray sources, we selected those which had the highest ratio of X-ray luminosity to radio luminosity, since the former is nominally a measure of the quantity of intergalactic gas, and the latter is a source of unwanted background radiation. The radio frequency measurements or upper limits were taken from Fomalont and Rogstad (1966), Ryle and Windram (1968), Willson (1971), and Owen (1974, 1975). The coordinates of the cluster centers shown in Table 1 were taken from Bahcall (1974) where available, or directly from Abell (1958).

To ensure that our measurements on Coma were not affected by radiation from outlying regions of the radio sources 5C 4.81 and 5C 4.85, we observed these sources directly at 31 GHz. The positions were taken from Jaffe, Perola, and Valentijn (1976). See Figure 3.

Finally, we observed blank sky regions at $\delta = +80°$, $+66°$, $+27°$, $-01°$ and $-23°$ over the same range of hour angles as our cluster observations to enable us to eliminate the offsets described above.

V. ANALYSIS OF THE DATA

The first step in our procedure was to eliminate data taken during periods of excessive atmospheric noise. This was done by examining chart recordings of total power and switched power which were maintained throughout our runs. In all roughly 15% of the data was rejected in this manner.

Each run consisted of seven recordings with the source in one of the two beams (an ON), alternating with eight recordings with the source in the other beam (an OFF). For each run we computed seven values of the antenna temperature as

$$(\Delta T_A)_i = 0.5(T_{\rm on})_i - 0.25[(T_{\rm off})_{i-1} + (T_{\rm off})_{i+1}] .$$

This procedure eliminates linear drift in the system, and should subtract the contribution from the atmosphere. The seven values of $(\Delta T_A)_i$ in each run were then treated as follows:

1. For each run we computed a mean temperature and a standard deviation, σ_r.

2. Next, all runs on both sources and blank sky were grouped by declination, keeping the observations in the east and west separate. These groups were examined for a systematic error by fitting a function $\alpha + \beta[\sin(\mathrm{EL}) + \gamma]$, where EL is the elevation and γ is chosen such that the parameters α and β are uncorrelated. That is, γ is fixed such that the covariance matrix for α and β is diagonal. Any run greater than 3 standard deviations from the fit was rejected, and the fit was recomputed. In this process, typically 5% and never more than 15% of the runs were dropped.

3. If at this point we saw no evidence for any systematic elevation-dependent offset, i.e., if α and β were consistent with zero (i.e., a χ^2 test for α and β set to zero was consistent with this null hypothesis), we combined the runs for each cluster using the usual weight σ_r^{-2}. Any run more than $3\sigma_r$ from the newly computed mean was rejected ($\sim 5\%$ of the total, typically), and the values ΔT_A and σ were recomputed. These values of ΔT_A appear in Table 2, column (2).

a) Treatment of the Data Which Showed an Elevation-dependent Offset

If the parameters α and β *were* significant, i.e., if a systematic elevation-dependent offset was present, we proceeded as follows:

4. First, we subtracted the fitted function from the runs on a given cluster, then combined the residuals to find ΔT_F and σ_F for this cluster. As in (3), σ_r^{-2} was used as a weight.

5. Next, we once again grouped all the runs on

TABLE 2

RESULTS OF THIS WORK

ABELL CLUSTER (1)	$\Delta T_A \pm \sigma$ (mK) (2)	N (3)	χ^2 (4)	$\Delta T/T \pm \sigma \times 10^{-4}$ (5)	SOURCE CORRECTION (mK) (6)	CORRECTED VALUES $\Delta T/T \pm \sigma \times 10^{-4}$ (7)	$n_* r_{c*} T_*$	
							$b = 1$ (8)	$b = 1.5$ (9)
376	1.00 ± 0.42	8	19	6.7 ± 2.8	$\lesssim +0.03$	6.9 ± 2.8	...	...
426	1.97 ± 0.60	3	1	13.1 ± 4.0	?	?	...	...
545	0.90 ± 0.24	18	39	6.0 ± 1.6	...	...	...	...
576	−0.68 ± 0.15	42	49	−4.6 ± 1.0	...	...	19.4 ± 4.3	18.8 ± 4.1
665	−0.55 ± 0.37	25	38	−3.7 ± 2.5	...	...	32.4 ± 21.8	45.8 ± 30.8
777	−0.12 ± 0.24	17	16	−0.8 ± 1.6	...	...	8.0 ± 16.0	10.9 ± 21.8
910	0.12 ± 0.29	26	66	0.8 ± 2.0	...	...	−5.5 ± 13.0	−6.7 ± 16.1
Coma (1656)	0.10 ± 0.12	33	43	0.7 ± 0.8	$\gtrsim -0.20$	−0.7 ± 0.8	+3.1 ± 3.8	+2.4 ± 2.9
Coma offset	0.04 ± 0.23	10	8	0.3 ± 1.6	...	...	...	...
1689	−0.61 ± 0.47	21	39	−4.1 ± 3.1	...	...	35.9 ± 27.6	50.8 ± 39.2
2079	−0.02 ± 0.13	28	42	−0.2 ± 0.9	...	...	0.7 ± 4.3	0.7 ± 4.3
2125	0.39 ± 0.24	55	56	2.6 ± 1.6	+0.035	2.8 ± 1.6	...	...
2142	−0.25 ± 0.42	13	34	−1.7 ± 2.8	−0.03	−1.9 ± 2.8	...	...
2218	0.43 ± 0.21	70	56	2.9 ± 1.4	−0.035	2.6 ± 1.4	...	...
2319	−0.03 ± 0.11	32	70	−0.2 ± 0.7	−0.13(?)	−1.1 ± 0.7	...	...
2645	1.26 ± 0.38	11	13	8.4 ± 2.5	...	...	...	...
2666	0.33 ± 0.17	35	61	2.2 ± 1.1	...	...	...	...

NOTE.—In column (2) the measured antenna temperature difference, and its associated standard deviation of the mean, are given for each cluster. See § V, and eq. (3). Column (3) gives the number of degrees of freedom for each set of observations. The quality of the data can be judged by comparing N to the value of χ^2 for the data, given in the following column. In column (5), the corrections discussed in § VI have been applied to convert the measurements to radiation temperature, and thus to $\Delta T/T$. A telescope efficiency of 0.55 was assumed. Column (6) lists the corrections, expressed in antenna temperature, required for point sources in the fields of the clusters (§ VII), and these corrections are applied to give the final results in column (7). In the last two columns, results obtained by fitting our measurements to a model for the intergalactic gas are given (see § VI*d*, especially eq. [5]). Fits were not made for clusters which appear to be dominated by radio emission, such as A426.

clusters and blank sky by declination, this time with one-half the appropriate value of ΔT_F subtracted from the cluster measurements. After this operation, we repeated steps (2) to (4) above to obtain refined values of ΔT_F and σ_F. The factor of $\frac{1}{2}$ was employed to ensure stability of this iterative algorithm. We found that only one iteration was necessary. The final values of the fitted temperature decrement appear in Table 2, column (2).

b) *Assignment of Errors*

In the final assignment of errors, we included the error introduced by the fitting procedure in a manner we believe to be conservative. We assumed that the error in α is correlated to the error in ΔT whereas the error in β is orthogonal. Hence we assigned as final error

$$\sigma = \{(\sigma_F + \Delta\alpha)^2 + [\Delta\beta \Delta \sin(\mathrm{EL})]^2\}^{1/2}, \qquad (3)$$

where $\Delta\alpha$ and $\Delta\beta$ are the errors in α and β, and $\Delta \sin(\mathrm{EL})$ is the range in the sine of the elevation over which the data were taken.

c) *Results and Checks*

Systematic offsets were found in declination ranges of +66°, −01° and −23° only (see Fig. 4, as an example). No elevation-dependent offsets were found at other declinations, but we note that the range of elevation covered at $\delta \sim -10°$ was small. We had too little blank sky data at $\delta = -23°$ to determine the fit to better than a few mK, so that we have chosen not to include some observations of Abell clusters 140 and 1146.

Since we had a great deal of blank sky data at +66°, we repeated the fitting procedure using *only* the blank sky data to determine the parameters α and β. The results were consistent with the results of our regular procedure, given the resulting errors.

We made several additional checks of our methods. As noted above, data taken in the east and the west were analyzed separately. The separate results were checked for consistency, and in all cases passed the test; that is, the results agreed to within the resulting errors. We also looked at data taken on different nights or during different observing runs, and again found that the results were consistent to within the assigned errors. We also divided the data for one cluster (A2218) into two elevation bins. We found the data subsets taken above and below an elevation of 53° were both consistent with the final result at the 0.5 σ level. Finally, we analyzed all the blank sky data, and found that all blank sky runs were consistent with $\Delta T = 0$.

VI. CORRECTIONS TO RAW DATA

Thus far the results are in antenna temperature, corrected only for extinction. These are shown in column (2) of Table 2. A number of corrections are necessary before these results can be compared with theoretical predictions. In this section we will discuss all of the corrections except for the occasional correction required, for some clusters, for emission by point sources (§ VII).

a) *Telescope Efficiency*

To convert measured antenna temperatures to sky or brightness temperatures, it is necessary to take account of the aperture efficiency (including ohmic losses, blocking, etc.) of the telescope employed. The efficiency of the 11 m telescope at the times we used it was 0.40 ± 0.02 for point (or very small) sources on axis. For sources comparable in size to the main-beam solid angle, the efficiency was somewhat higher. The NRAO staff (B. L. Ulich, private communication) have estimated 0.55 for the efficiency when observing sources which fill the main beam, and we have adopted this figure.

b) *Conversion to $\Delta T/T$ or $\Delta I/I$*

At $\lambda = 9$ mm, we are not in the Rayleigh-Jeans region of the microwave background spectrum. Hence the fractional change in radiation temperature is not identical to the measured change in sky temperature divided by the temperature of the cosmic microwave background. The correction factor is small, however: $\Delta T/T = 1.025\Delta T_{\mathrm{sky}}/2.8$, where we assume 2.8 K for the temperature of the microwave background.

Values of $\Delta T/T$ and the associated 1 σ errors are given in column (5) of Table 2.

Conversion to $\Delta I/I$, for comparison to equation (1), can be effected by dividing our measured values of ΔT_A by 1.16.

c) *Thermal Bremsstrahlung*

As pointed out in § II, one reason we selected the relatively short wavelength of 9 mm for our observations was to minimize possible errors introduced by thermal bremsstrahlung emission from the hot gas in the clusters we observed. For those clusters with known X-ray properties, the bremsstrahlung emission at 9 mm can be estimated. The result is always less than a few per cent of the expected signal (i.e., 0.02 mK for Coma), and is ignored in the rest of our analysis. This calculation, of course, does not account for the possible contribution by cooler gas (see Tarter 1978).

d) *Beam Geometry*

The nearby clusters are large compared to the separation of our main and reference beams. Hence some microwave decrement due to the Sunyaev-Zel'dovich effect may be present in the reference beam as well as the main beam. In addition, the more distant clusters do not fill the main-beam solid angle, and thus the observed ΔT will be less than the true decrement (see Tarter 1978). To compute these effects, one must assume a model for the radial distribution of the intergalactic gas in clusters, and then convolve it with our beam pattern.

As an example, we have chosen the isothermal models described by Sarazin and Bahcall (1977). These models are characterized by the temperature and a parameter b describing the spatial extent of the gas:

$$n(r)/n_0 = [\rho(r)/\rho_0]^b$$

with

$$b = \frac{\mu v^2 m_p}{kT},$$

where $n(r)/n_0$ and $\rho(r)/\rho_0$ are the density distributions of the intergalactic gas and the galaxies, respectively; μ is the molecular weight of the gas; v is the line-of-sight velocity dispersion; and m_p is the proton mass. For these models, the change in the microwave background temperature is given by

$$\Delta T = 0.05 f(x)\left(\frac{n_0}{10^{-3}\ \mathrm{cm}^{-3}}\right)\left(\frac{T}{10^8\ \mathrm{K}}\right)\left(\frac{r_c}{0.25\ \mathrm{Mpc}}\right) \times \frac{\Gamma(3b/2-\frac{1}{2})}{\Gamma(3b/2)}\left(\frac{r^2}{r_c^2}+1\right)^{-3b/2+1/2} \mathrm{mK}\,, \quad (4)$$

where $f(x)$ is given by equation (2). In equation (4), n_0 is the number density of the gas at the cluster center, and r_c is the cluster core radius. Γ is the usual Γ-function.

For two different values of the parameter b, we have convolved our beam pattern with this model. The results appear in Table 2, where we give the values of

$$n_* r_{c*} T_* = (n_0/10^{-3}\ \mathrm{cm}^{-3})(T/10^8\ \mathrm{K})(r_c/0.25\ \mathrm{Mpc}) \quad (5)$$

derived from our measurements.

It is tempting to combine these values with measurements of the X-ray luminosities of clusters to place limits on Hubble's constant (Birkinshaw 1979; Boynton and Murray 1978; Cavaliere, Danese, and De Zotti 1978; Gunn 1978; Silk and White 1978). We have not done so since we believe it is important to determine the parameters of the models with more accuracy first.

VII. CORRECTIONS FOR POINT SOURCES IN THE CLUSTERS OBSERVED

As stated above, we believed our choice of $\lambda = 9$ mm for our observations would substantially reduce the contribution of radio sources in the clusters. It nevertheless seemed prudent to confirm directly that point sources would not contribute significantly to our observations, whether in the main or reference beams. Some data on radio sources in clusters were already available (for instance, the surveys of Owen 1974, 1975; Owen, Rudnick, and Peterson 1977; Birkinshaw 1978), but most published measurements are at such long wavelengths that extrapolation to $\lambda = 9$ mm is uncertain. Nevertheless, these surveys do permit us to make rough estimates of the possible contributions of point sources to our measured values of ΔT (expressed in antenna temperature in what follows) for some clusters.

a) Corrections Based on Published Surveys

Birkinshaw's (1978) catalog of sources in A376 contains five sources located within $\sim 12'$ of our cluster center. None of these sources is close enough to the cluster center to contribute significantly to the main beam. However, sources A376.5 and A376.6 lie near the arcs traversed by the reference beam during our observations. From Birkinshaw's results, we can estimate a spectral index of $\lesssim +1.4$ for A376.5 since only an upper limit is given at 408 MHz. If we extrapolate the flux density to 31 GHz using $\alpha = 0.7$, and consider the geometry of our beam, we find that this source will contribute negligibly to our measured values of ΔT_A. A376.6 has a spectral index of $\lesssim 0.85$. Making the same extrapolation to 31 GHz with $\alpha = 0.7$ gives $S \sim 8$ mJy, corresponding to ~ 0.1 mK *if* the source were centered in the reference beam of the 11 m telescope. In fact, it lies $\sim 1\overset{\prime}{.}7$ from the center of the reference beam, and in addition, since the reference beam moves through an arc in the plane of the sky, the contribution is diminished still further. When the beam geometry is considered, we find that A376.6 contributes less than -0.03 mK to our measured ΔT_A.

Searches for the Sunyaev-Zel'dovich (1972) effect in Coma (A1656) have been hampered by the presence of two radio sources, 5C 4.81 and 5C 4.85, in the cluster. Corrections for these sources, based on direct measurements of their 31 GHz flux, will be discussed in § VIII.

For Abell 2079, the surveys of Owen (1974, 1975) extrapolated to 31.4 GHz give $S = 21$ mJy for a source $\sim 5'$ from the cluster center. When the beam geometry is included, the source can be shown to contribute negligibly to our values of ΔT_A.

Our own observations of A2218 (discussed below) suggest that no *point* sources are present in the cluster strong enough to have any effect on our measurements. However, Schallwich and Wielebinski (1979) have recently reported the detection at 2.7 GHz of an *extended* source at the center of A2218, with a flux density at 2.7 GHz of ~ 14 mJy in our beam. No information on the spectral index is available; but if we assume $\alpha = 0.7$, we find $S \sim 2.5$ mJy, which could contribute up to $+0.035$ mK to ΔT at $\lambda = 9$ mm.

Abell 2319 is a more complex case (Haslam *et al.* 1977; Birkinshaw 1978). These results for the flux at 2695 MHz are discordant, unless some sources are resolved. Adopting the results of Birkinshaw for the source A2319.9 which lies near our cluster center, we estimate the spectral index in the frequency range 408–2695 MHz to be 0.8; and extrapolating, we find $S \sim 10$ mJy at 9 mm. Since A2319.9 lies between our main beam and one arc of the reference beam, it produces a negligibly small contribution to ΔT_A. Source A2319.8 lies near the main beam position we used. If we consider only Birkinshaw's (1978) results at 408 and 1407 MHz, we find $\alpha \lesssim 1.6$; unless $\alpha < 0.4$, the source makes a negligible contribution (< 0.05 mK). With their larger beam solid angle, Haslam *et al.* (1977) find $S = 75$ mJy at 2.7 GHz. If we *assume* $\alpha = 0.7$, as we did above for A2218, we find $S = 13.5$ mJy at 31.4 GHz, which gives a contribution of ~ 0.13 mK to ΔT_A when the beam geometry is considered. Although we regard this correction as quite uncertain, we have included it in Table 2.

None of the sources in Abell chapters 576 or 2666 cataloged by Birkinshaw (1978) appear to be strong enough or close enough to our cluster center to affect our measurements of ΔT.

b) *Further Interferometric Search for Point Sources*

The extrapolations discussed above are in many cases quite uncertain. In addition, several of the clusters of interest have not been included in the published surveys. We therefore decided to supplement the published surveys by observing a number of our clusters at $\lambda = 11$ and 3.7 cm using the NRAO three-element interferometer at Green Bank. The observations were made in 1977 October and 1978 April (as a small part of another project). Baselines of 100, 600, 1200, 1800, and 1900 meters were employed, though not all clusters were observed at all baselines. In addition, for most of the clusters, coverage in the *u-v* plane was spotty, so the data in Table 3 should be regarded with caution. Our aim was not to obtain definitive maps of the clusters, but to locate point sources which might contribute spurious signals to our 9 mm observations. Point sources were found in the $20' \times 20'$ fields of six and possibly seven of the clusters. The positions (and estimated errors in them, including lobe ambiguities in some cases) are given in columns (2)–(5) of Table 3. Fluxes were found using standard NRAO reduction procedures; the fluxes were corrected for delay loss and for the primary beam response. Except for the relatively strong source in Abell 2125, the tabulated fluxes may be uncertain by as much as 50%, and more when the source was resolved.

Our data on the few point sources identified at both 11 and 3.7 cm permit us to make a rough extrapolation to find the flux at 9 mm, assuming the spectral index does not change below 3.7 cm. The results of these calculations appear in column (8). Next we calculate the contribution such a source would make to the measured antenna temperature *if the source were centered* in the beam of the 11 m telescope. In fact, none of the sources fell near the cluster centers. When the beam geometry was taken into account, possible contributions to our observed values of ΔT_A were sharply reduced. Assuming a Gaussian profile with half-power beamwidth of $3'.6$, we find that no source would have contributed more than 0.01 mK antenna temperature, except the source in Abell 2125. This source lay $\sim 3'.25$, or 0.9 half-power beamwidths, from the center of one portion of one of the reference arcs near Abell 2125 (see Fig. 1). We estimate that roughly one-fifth of our data on A2125 were taken with the reference beam near the source. With this value, we find the source contributes -0.035 mK in antenna temperature to our results. We wish to note, however, that the extrapolation of the flux to 9 mm is probably an overestimate, since it assumes a sharply rising spectrum below 3.7 cm.

Abell 2142 also deserves mention. The source we detected lies 0.85 beamwidths from the center of our beam. It is presumably the same as source 10W 156 (Harris, Bahcall, and Strom 1977) and the source detected by Owen (1974) and Haslam *et al.* (1978), for which the published flux densities at 610, 1400, and 2700 MHz are respectively 390, 130, and 122 mJy. It is clear that our observations resolved the source and that our values for flux in Table 3 are therefore underestimated. If we adopt $S_{610} = 390$ mJy from Harris *et al.* and $S_{2700} = 122$ mJy from Haslam *et al.*, we find $\alpha = 0.78$, and a source contribution of $\sim +0.03$ mK. Using our results alone, or in combination with the 610 MHz flux, would, of course, produce a much lower contribution.

c) *Conclusions*

Clearly none of these corrections significantly changed our results. We wish to reemphasize, however, that the corrections were based on the assumption of an unchanging spectral index from the shortest measured wavelength to 9 mm. If the source spectra flattened, the contributions would of course be larger in magnitude. Even if $\alpha = 0$ below 3.7 cm, however, none of the sources listed in Table 3 would qualitatively alter our conclusion that ΔT is consistent with zero for most of the clusters we observed.

VIII. DISCUSSION OF INDIVIDUAL CLUSTERS

The major conclusion of this work is that we find no reliable and significant evidence for the Sunyaev-Zel'dovich cooling in any of the clusters we observed, except for Abell 576 (see Fig. 7).

a) For 10 of the clusters, numbers 376, 545, 576, 777, 1656, 2079, 2142, 2319, 2645, and 2666, there was no evidence that the elevation-dependent offset discussed in §§ III and V was present.

Only one of these shows evidence of a significant temperature decrement. This is Abell cluster 576, which is also reported by Birkinshaw, Gull, and Northover (1978*a*) to show a temperature decrement of ~ -1 mK. The absence of "cooling" in the other clusters is consistent with the results of Birkinshaw, Gull, and Northover (1978*a*) and Rudnick (1978) for clusters we observed in common.

On the other hand, three clusters, 376, 545, and 2645, show temperature *excesses* above the $2\,\sigma$ level. We are not confident of the reality of the positive ΔT's for 545 and 2645. As we pointed out in § V*c* above, while no elevation-dependent offset was detected at $\delta \sim -10°$ where these clusters lie, the range of elevation covered in our observations was small. Hence we could have missed a systematic offset, and we had too few blank-sky data to check this. Along this same line, it is suggestive that both clusters have $\Delta T \sim +1$ mK.

The negative results for Coma cluster deserve further discussion. Coma is a nearby, large cluster with a

TABLE 3

RESULTS OF INTERFEROMETRIC OBSERVATIONS OF SELECTED CLUSTERS

ABELL CLUSTER (1)	α_{1950} (2)	EST. ERROR (3)	δ_{1950} (4)	EST. ERROR (5)	FLUX (mJy)		CALCULATED SPECTRAL INDEX (8)	EXTRAPOLATED 9 mm FLUX (mJy) (9)	CONTRIBUTION TO ΔT_A, IF CENTERED (mK) (10)	COMMENTS (11)
					11 cm (6)	3.7 cm (7)				
576	$07^h17^m22^s$	$\pm 3^s$	$+55^\circ 47\overset{\prime}{.}4$	$\pm 1'$	10	<8	>0.20	<6	<0.08	A576.2 (Birkinshaw 1978), resolved
665	08 26 58	$\pm 10^s$	+66 02.7	$\pm 2'$	19	<9	>0.68	<4	<0.05	Possibly 665A (Owen 1974), $S = 120$ at 21 cm
777	09 21 20	$\pm 40^s$	+78 34.5	$\pm 1\overset{\prime}{.}5$	22	17	0.24	12	0.16	Resolved?
910	09 58 26	$\pm 15^s$	+67 31.5	$\pm 1'$	29	<12	>0.80	<4	<0.05	
1146	...	...	...	...	<16	<16	...	...	...	
1689	13 08 57	5^s	−01 01	$\pm 3'$	19	<10	>0.59	<5	<0.07	11 cm "source" may be spurious
2079	...	...	...	...	<23	<15	...	...	...	
2125	15 41 13	$\pm 2^s$	+66 32.1	$\pm 0\overset{\prime}{.}2$	42	67	−0.43	120	1.6	Possibly A2125.7 (Birkinshaw 1978)
2142	15 56 10	$\pm 3^s$	+27 25	$\pm 1'$	19	<9	>0.68	<3	<0.04	Possibly source found by Owen (1974), $S = 130$ at 21 cm; see also Haslam *et al.* (1978); resolved
2218	...	...	...	...	<10	<13	...	...	...	
2645	...	...	...	...	<12	<12	...	...	...	

NOTE.—In column (10), the contribution to our measured ΔT is given, assuming the source was centered in our beam. When beam geometry is taken into account, the real contribution is greatly reduced. See text.

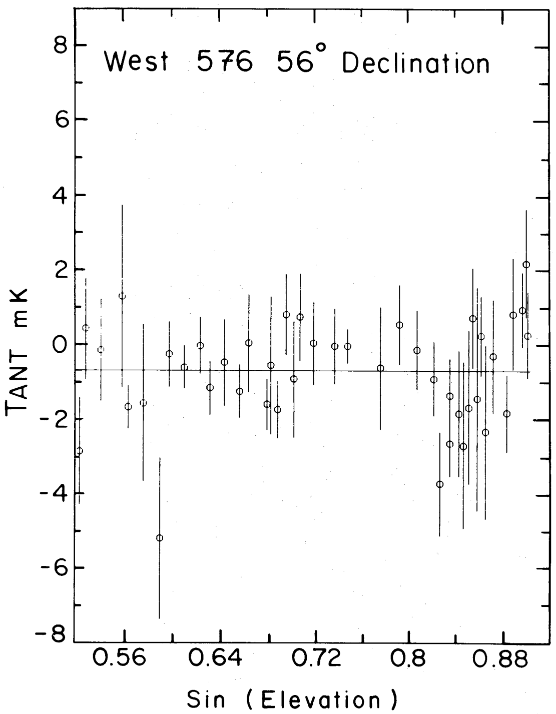

FIG. 7.—Observations of Abell 576. The straight line is the computed mean diminution, ΔT_A.

core radius nearly equal to the angle of our beam throw. Could our use of beam switching with a beam throw of only 9′ have canceled out the signal we sought? We checked this hypothesis in an approximate way by combining measurements made near the cluster center with the "Coma offset" measurements made further away (see Fig. 3). *Adding* these two measurements permits us to compare the antenna temperature observed 3′ from the cluster center with the antenna temperature observed 21′ from the center. The result is $+0.14 \pm 0.26$ mK, indicating that the reduction in the measured antenna temperature from Coma is less than 0.4 mK at the 2σ level. Next consider the possibility that microwave radiation from one or both of the two strong radio sources in Coma, 5C 4.81 and 5C 4.85, may have biased our results. First, an examination of Figure 3 shows that both sources lay out of our beams at the times we observed Coma. Second, we measured the antenna temperature of both sources directly at $\lambda = 9$ mm. The 2σ upper limits for 5C 4.81 and 5C 4.85 were 1.0 mK and 1.4 mK, respectively. Given both these direct measurements and the geometry of our beams, it can be shown that the contribution of these two sources is less than 0.2 mK (antenna temperature).

b) Next come a group of clusters where we suspect or know that systematic offsets may have been present, and have been corrected for; and which show no significant "cooling." This group includes three clusters at $\delta \approx 66°$, viz., A910, A2125, and A2218. Also in this category is A1689, for which the present result is consistent with the value we published earlier (Lake and Partridge 1977). These new results for A2125 and A2218 are clearly inconsistent with our earlier results, because of the systematic effect we discovered after the publication of that preliminary paper. Our failure to detect a temperature decrement or "cooling" in A2125 is in agreement with Birkinshaw, Gull, and Northover's (1978*a*) results on the same cluster.

Our results on A2218, on the other hand, are inconsistent with their reported $\Delta T = -1.1$ mK at roughly the 5σ level (see Birkinshaw, Gull, and Northover 1978*b*). We do not understand the origin of this discrepancy. The small difference in our choices of cluster centers is unlikely to have been responsible. Neither Birkinshaw *et al.*'s results nor ours required corrections for point sources. The extended source reported by Schallwich and Wielebinski (1978) is unlikely to be the cause of the discrepancy; a spectral index of $\alpha \lesssim -3$ between 10.6 and 31.4 GHz would be required to reconcile the results (assuming the source contributes 0.85 mK brightness temperature at 10.6 GHz as suggested by Schallwich and Wielebinski).

c) There is one additional cluster which shows a marginal Sunyaev-Zel'dovich cooling, Abell 665. In this case, our results are slightly discordant with those of Birkinshaw, Gull, and Northover (1978*a*).[6] Since, in observations of 16 clusters, we would expect 2–3 negative values of ΔT more than 1σ from zero, our result can certainly not be regarded as significant. Further observations will be required to determine whether or not the temperature decrement we observe is real. We note that it is the richest cluster in Abell's catalog (but see Dressler 1978). However, as Pravdo *et al.* (1979) point out, the optically richest clusters appear to be underluminous in the 0.2–60 keV X-ray band, which suggests a negative correlation between richness and gas content.

d) We made only a few observations of the Perseus cluster, Abell 426, discontinuing our work when we discovered clear evidence that radio sources in the cluster were swamping any possible Sunyaev-Zel'dovich signal even at our wavelength of 9 mm.

IX. GENERAL CONCLUSIONS

Only four of the 16 clusters we observed have measured values of ΔT which can be more negative than -1 mK (sky or brightness temperature) at the 2σ level. Since the clusters we surveyed have a wide range of X-ray luminosity, velocity dispersion, richness, and cluster core radius, our limits on the microwave decrement may be helpful in constraining models for the origin and distribution of intergalactic plasma in clusters. The constraints on some well observed clusters, such as A777, A1656, A2079, A2125, and A2319, are particularly tight.

---

[6] The agreement is better with more recent results (Birkinshaw, private communication).

In general, we will leave to others detailed comparisons of our results with the theoretical models. We would, however, like to make three general points concerning our results.

First, it is clear that the apparent correlation we noted in 1977 (Lake and Partridge) between cluster richness and the size of ΔT is not supported by these further studies. The apparent correlation we reported was based on observations of three richness class 4 clusters; we now know that the values for ΔT reported for two of them were erroneous, because of the systematic effect discussed in §§ III and V. Our present work shows no significant correlation between ΔT and richness. It appears, therefore, that the amount of gas in clusters does not correlate with richness. This is in accord with the work of Pravdo *et al.* (1979), who find no positive correlation between the richness of a cluster and its thermal bremsstrahlung X-ray emission.

Next, we note that of the roughly 20 clusters observed by us or by other groups, only two—numbers A576 and A2218—are reported to have a significant decrement. Why have we (and others) not detected the Sunyaev-Zel'dovich effect in other clusters? Our failure to detect a microwave decrement, especially in clusters known to be X-ray sources such as A2079 and A2319, may indicate that bremsstrahlung *emission* from cooler gas is masking the inverse Compton cooling (Tarter 1978). Such emission could help explain some of our positive values of ΔT. It may also be that the so-called clumping factor $\langle n_e^2 \rangle / \langle n_e \rangle^2$ is substantially greater than unity. If the latter is the case, our results favor models where the hot gas is physically clumped; or more probably models with a high central concentration (which raises $\langle n_e^2 \rangle / \langle n_e \rangle^2$ averaged over the cluster), rather than those with a more uniform distribution of gas. High resolution X-ray studies by *HEAO 2* may help resolve this issue.

On the other hand, why does A576, and possibly A2218 (Birkinshaw, Gull, and Northover 1978*b*), show a microwave decrement? Since many other comparable clusters do not appear to produce a significant cooling, it is reasonable to ask what is special about these two? Neither is an especially luminous X-ray source. Neither differs in richness or morphology from other clusters we have observed.

Finally, we note the presence of five positive values of ΔT at the 2 σ level (in addition to the measurement of Abell 426). While some may be spurious (see § VIII above), further measurements would be advisable.

The questions raised in the previous paragraphs bring us to our final point: caution should be used when these or other microwave measurements are used to constrain theoretical models.

These measurements could not have been made without the patient help and advice of the NRAO staff at Tucson. We wish to thank especially the operators, and Drs. Gordon, Hollis, Rhodes, and Ulich. We would also like to acknowledge the assistance of the NRAO staff at Green Bank and Charlottesville. We benefited from helpful conversations with Mark Birkinshaw, Paul Boynton, Rod Davies, Steve Gull, Anthony Lasenby, Jerry Ostriker, Bob Rood, Larry Rudnick, and David Wilkinson. Ed Cheng and Ed Groth of Princeton allowed us to use their nonlinear fitting program for the reductions discussed in § V.

This work was supported in part by the National Science Foundation grant to one of us (R. B. P.); the other was supported by an NSF Graduate Fellowship and by an NSF grant to Princeton University.

Finally, R. B. P. would like to acknowledge the hospitality of the Institute of Mathematical and Physical Sciences of the University of Tromsø, Norway, where this paper was written.

REFERENCES

Abell, G. O. 1958, *Ap. J. Suppl.*, **3**, 211.

Bahcall, J. N., and Sarazin, C. L. 1977, *Ap. J.* (*Letters*), **213**, L99.

Bahcall, N. A. 1974, *Ap. J.*, **193**, 529.

Birkinshaw, M. 1978, *M.N.R.A.S.*, **184**, 387.

———. 1979, *M.N.R.A.S.*, **184**, 387.

Birkinshaw, M., Gull, S. F., and Northover, K. J. E. 1978*a*, *M.N.R.A.S.*, **185**, 245.

———. 1978*b*, *Nature*, **275**, 40.

Boynton, P. E., and Murray, S. S. 1978, privately communicated *HEAO B* proposal.

Cavaliere, A., Danese, L., and De Zotti, G. 1978, preprint.

Cavaliere, A., and Fusco-Femiano, R. 1976, *Astr. Ap.*, **49**, 137.

Dressler, A. 1978, *Ap. J.*, **226**, 55.

Fomalont, E. B., and Rogstad, D. H. 1966, *Ap. J.*, **146**, 528.

Gould, R. J., and Rephaeli, Y. 1978, *Ap. J.*, **219**, 12.

Gull, S. F., and Northover, K. J. E. 1975, *M.N.R.A.S.*, **173**, 585.

———. 1976, *Nature*, **263**, 572.

Gunn, J. E. 1978, in *Observational Cosmology*, ed. L. Maeder and G. Tammann (Geneva Observatory).

Gunn, J. E., and Gott, J. R. 1972, *Ap. J.*, **176**, 1.

Gursky, H., and Schwartz, D. A. 1977, *Ann. Rev. Astr. Ap.*, **15**, 541.

Harris, D. E., Bahcall, N. A., and Strom, R. G. 1977, *Astr. Ap.*, **60**, 27.

Haslam, C. G. T., Kronberg, P. P., Waldthausen, H., Wielebinski, R., and Schallwich, D. 1978, *Astr. Ap. Suppl.*, **31**, 99.

Jaffe, W. J., Perola, G. C., and Valentijn, E. A. 1976, *Astr. Ap.*, **49**, 179.

Kellogg, E., Baldwin, J. R., and Koch, D. 1975, *Ap. J.*, **199**, 299.

Lake, G., and Partridge, R. B. 1976, *Bull. AAS*, **8**, 354.

———. 1977, *Nature*, **270**, 502.

Lea, S. M. 1975, *Ap. J.* (*Letters*), **16**, 141.

Lea, S., Silk, J., Kellogg, E., and Murray, S. 1973, *Ap. J.* (*Letters*), **184**, L105.

Mitchell, R. J., Ives, J. C., and Culhane, J. L. 1977, *M.N.R.A.S.*, **181**, 25P.

Owen, F. N. 1974, *A.J.*, **79**, 427.

———. 1975, *A.J.*, **80**, 263.

Owen, F. N., Rudnick, L., and Peterson, B. M. 1977, *A.J.*, **82**, 677.

Pariiskii, Yu. N. 1973, *Soviet Astr.—AJ*, **16**, 1048.

Partridge, R. B. 1980, *Ap. J.*, in press.

Pravdo, S. H., Boldt, E. A., Marshall, F. E., McKee, J., Mushotzky, R. F., Smith, B. W., and Reichert, C. 1979, *Ap. J.*, **234**, 1.

Rephaeli, Y. 1977, *Ap. J.*, **212**, 608.

Rudnick, L. 1978, *Ap. J.*, **223**, 37.

Ryle, M., and Windram, M. D. 1968, *M.N.R.A.S.*, **138**, 1.

Sarazin, C. L., and Bahcall, J. N. 1977, *Ap. J. Suppl.*, **34**, 451.

Schallwich, D., and Wielebinski, R. 1979, *Astr. Ap.*, **71**, L15.
Silk, J., and White, S. D. M. 1978, *Ap. J.* (*Letters*), **226**, L103.
Sunyaev, R. A., and Zel'dovich, Ya. B. 1972, *Comments Ap. Space Phys.*, **4**, 173.
Tarter, J. C. 1978, *Ap. J.*, **220**, 749.
Willson, M. A. G. 1971, *M.N.R.A.S.*, **151**, 1.
Zel'dovich, Ya. B., and Sunyaev, R. A. 1969, *Ap. Space Sci.*, **4**, 301.

Note added in proof.—Recent work by Perrenod and Lada (*Ap. J.* [*Letters*], **234**, L173 [1979]) at the 11 meter NRAO telescope confirms the presence of the systematic offsets discussed in this paper. However, their final results are consistent with ours only for A665, and not for the other two clusters we observed in common. For A2319, they find a significant positive ΔT; and for A2218, they find $\Delta T \sim -1$ mK at the position observed by Birkinshaw, Gull, and Northover (1978*b*). We plan further observations to resolve these differences.

GEORGE LAKE: Department of Astronomy, University of California at Berkeley, Berkeley, CA 94720
R. B. PARTRIDGE: Haverford College, Haverford, PA 19041