A Search for CMB Decrements Towards Distant Cluster Candidates PC1643+4631 and VLA1312+4237 at 28.5 GHz

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ABSTRACT

Recently, Jones et al. (1997) used the Ryle telescope, operating at a frequency of 15 GHz, to detect a flux decrement in the direction of the quasar pair PC1643+461A,B. They interpreted this signal as the Sunyaev-Zel’dovich effect (SZE) produced by a distant cluster of galaxies. In the course of an effort to measure CMB anisotropies using the VLA at 8.4 GHz, Richards et al. (1997) detected a similar, but smaller, decrement which we refer to as VLA1312+4237. They also proposed that this signal might be explained as the SZE signal of a distant galaxy cluster. We report observations in the direction of these claimed sources with the Berkeley Illinois Maryland Association (BIMA) interferometer operating at 28.5 GHz. We find no evidence for SZE emission in the direction of either of the claimed sources. In the case of PC1643+4631, the BIMA data are inconsistent with the cluster emission model proposed by Jones et al. (1997) at greater than 99.99% confidence. Together with published x-ray and optical searches, these results make a compelling case against the existence of a massive cluster in the direction of PC1643+4631. Because of the different scales to which the VLA and BIMA instruments are sensitive, the BIMA observations are not as constraining for the VLA1312+4237 source. The BIMA data are inconsistent with the cluster model proposed by Richards et al. (1997) at ∼80% confidence.

Subject headings: cosmology: observation — cosmic microwave background — galaxies: clusters — techniques: interferometric
1. Introduction

The Sunyaev-Zel’dovich effect (SZE) is the scattering of Cosmic Microwave Background (CMB) photons by the hot plasma bound to massive clusters of galaxies. This scattering results in a spectral distortion of the CMB, observable at wavelengths from the radio to the sub-mm. At frequencies lower than ∼217 GHz, the SZE is observed as a decrement in the temperature of the CMB towards massive clusters of galaxies. Because the SZE surface brightness of distant clusters is independent of redshift, radio surveys have the potential to be a particularly powerful method of locating distant galaxy clusters. In low density universes, clusters are presently not evolving rapidly and should exist relatively unchanged to high redshift. The ability of cluster number counts, especially at high redshift, to distinguish between different cosmological models has been extensively discussed; for example see Barbosa et al. (1998).

 Significant detections of the SZE have been obtained for dozens of x-ray and optically selected clusters (see Birkinshaw 1998 for a review). Historically, the sensitivity and sky coverage of radio surveys have not been sufficient to allow the detection of unknown clusters through their SZ signal. However, recent advances in detector technology and observing strategy have placed the goal of using the SZE to search for distant unknown clusters within reach. Recently, two groups working with sensitive interferometers have claimed the detection of significant small angular scale decrements in the CMB which are not in the direction of known clusters of galaxies. These detections, if they were due to very distant clusters, would be of profound cosmological significance (Bartlett, Blanchard, & Barbosa 1998). The lack of supporting evidence for low redshift clusters in the direction of the claimed decrements, and the difficulty of reconciling very high redshift clusters with favored cosmological models, have prompted several authors to propose alternative explanations for the decrements (Natarajan & Sigurdson 1999, Dabrowski 1997).

We have observed fields containing each of the claimed decrements with the BIMA interferometer, configured with sensitive 28.5 GHz receivers, in an attempt to confirm the detections. In this work, we review the previous observations of these fields and explore the constraints that the BIMA results place on the explanation of the observed decrements being due to the SZE in distant clusters.

2. PC1643+4631 Observations

2.1. Ryle Telescope Observations

The Ryle telescope has been used by Jones et al. (1997) to image the surroundings of a number of radio quiet quasars at a frequency of 15 GHz. The deepest of these images was towards the z = 3.8 quasar pair PC 1643+4631A,B. The CLEANed map, containing baselines from 1.25–5.4 kλ, had a rms noise of 33 μJy in a 33″ × 42″ beam and was used to search for point sources. Three point sources with flux densities of 550 μJy, 200 μJy, and 150 μJy were detected and CLEANed from the visibility data. When only baselines shorter than 1.25 kλ were included, the east-west configuration of the Ryle telescope, produced a north-south elongated beam 110″ × 170″. They find an essentially unresolved decrement in the resulting map of −380 ± 64 μJy centered at α = 16h 43m 44.0s, δ = +46° 30′ 20″ (J2000). The authors interpret their signal as being due to the SZE in a massive cluster of galaxies. Modeling the emission by a spherical King model,

\[ \Delta T = \Delta T_0 \left(1 + \frac{\theta^2}{\theta_c^2}\right)^{-2} \delta + \frac{\theta^2}{\theta_c^2} \]  

with \( \beta = 2/3 \), they find a minimum value for the central temperature decrement of \( \Delta T_0 = -560 \mu K \), with a corresponding angular core radius of \( \theta_c = 60″ \).

2.2. X-ray

The ROSAT PSPC is sensitive to x-rays in the energy range 0.1 – 2.4 keV, and is therefore well suited to the study of high redshift clusters. One of the last observations of the ROSAT PSPC was used to search for the x-ray radiation that would be expected from a massive cluster capable of producing the PC1643+4631 CMB decrement (Kneissl, Sunyaev, & White 1997). The total time of exposure was ∼16 ks. Within a 1.5′ circular aperture around the reported position of the central decrement, there were only 13 counts compared to expected background of 15. This result was used to place a limit on the bolometric flux, \( f_x < 1.9 \times 10^{-14} \text{erg cm}^{-2} \text{s}^{-1} \) at 99.7% confidence. With these results, Kneissl, Sunyaev, & White (1997) established a conservative lower limit on the redshift of any isothermal object with temperature between 0.2 and 10 keV and capable of producing the observed SZE decrement, of \( z > 2.8 \). Open
models of the universe with $\Omega_m < 0.25$ predict only one cluster on the entire sky with redshift $3 < z < 4$ and mass $M > 2 \times 10^{15} M_\odot$.

2.3. Optical

The field for the radio observations was originally selected by Jones et al. (1997) due to the presence of two radio quiet quasars PC1643+4631A,B with redshifts $z = 3.79$ and $3.83$ separated by 198″. It was suggested by Saunders et al. (1997) that, despite the difference in redshift, the two quasars might be gravitationally lensed images of the same object. If correct, this system would be the largest separation lensed multiple image yet discovered. The x-ray results place any candidate for producing the SZE signal at too high a redshift to produce such lensing and another closer lensing mass of $\sim 10^{15} M_\odot$ would be necessary.

The field of PC1643+4631 has been extensively searched for an excess of faint galaxies which might be expected to be associated with a distant cluster. Using the lack of excess galaxies, Saunders et al. (1997) constrained the redshift of any cluster to be $z > 1$. This limit was revised downward somewhat by Cotter et al. (1998b), who used simulations to show that a cluster at redshift $z = 1$ would be difficult to locate in the PC1643+4631 field.

Deep UVR imaging is an efficient means to find $z = 3 − 4$ galaxies. Multicolor imaging has been used to place limits on the surface density number of Lyman-break galaxies at $z > 3$ in the direction of PC1643+4631 (Cotter & Haynes 1998; Haynes et al. 1998). These papers claim a $\sigma$ excess of galaxies over the number expected from the work of Steidel et al. (1998), although, as they point out, the number of objects leading to this result is small. Ferreras et al. (1998) have imaged the region surrounding PC1643+4631A in the UVR bands. The corner of their 3.8' × 3.8' frame includes the position of the reported decrement. They find that the Lyman-break galaxies are homogeneously distributed across the frame, and do not clump near the reported position of the decrement. This result is reproduced by Haynes et al. (1998). In fact, they find an anticorrelation between the position of Lyman-break galaxies and the P1643+4631 decrement, although the small number of galaxies makes the significance questionable. Given the magnitude limits of the observations, the authors claim it would be unlikely that galaxies at redshift $z = 3.81$ could be detected. They go on to propose that the dearth of galaxies in the direction of the PC1643+4631 decrement is consistent with the lensing signature of a massive cluster at $z \sim 2$. However, the x-ray results place any cluster capable of producing the claimed decrement at a redshift of $z > 2.8$, at which point it would be incapable of producing the supposed lensing. Therefore, we conclude that there is no optical evidence for a massive galaxy cluster in the direction of PC1643+4631A,B.

2.4. BIMA and OVRO Observations

We observed PC1643+4631 with our cm-wave receivers mounted on 9 of the 6.1 m telescopes of the (Berkeley Illinois Maryland Association) BIMA array. This system has been used to obtain high signal to noise images of the SZE toward more than 15 clusters, and for more than 20 clusters if we include observations with the same receivers mounted on the OVRO millimeter-array (see Carlstrom et al. 1999).

The primary beam at our observing frequency of 28.5 GHz is 6.6' FWHM. To achieve high brightness sensitivity, seven telescopes were arranged in a compact non-redundant configuration contained within a triangular region roughly 18 m on a side. To improve discrimination against point sources, the remaining two telescopes were placed at stations 47 m East and 70 m North from the center of the compact array. The primary beam and the range of projected baselines (0.6 kA to 8.3 kA) are well matched to the 15 GHz Ryle telescope observations (Jones et al. 1997). The position of the reported decrement, which we used for our pointing and phase center, is listed in Table 1.

The system temperatures, scaled to above the atmosphere, ranged from 35 K to 55 K, depending on atmospheric water vapor content and elevation of the source. The signals were combined in the BIMA 2-bit digital correlator configured for 8 contiguous 100 MHz sections each with 32 complex channels. After bandpass corrections were made and end channels dropped, channels from each correlator section were averaged to produce eight 100 MHz channels, and one wide-band 800 MHz channel. The equivalent noise bandwidth of the wide-band channel after accounting for digitization losses and dropped end channels was 540 MHz. Total on-source integration time for this field was 43.1 hours spread over 7 days during the period June 15 to August 15, 1997 and on Sept. 3, 1998. Using all the data to produce a naturally weighted image resulted in a beam-size of 34″ × 26″ and a map $\sigma$ of 91 μJy beam$^{-1}$ which corresponds to a Rayleigh-Jeans (RJ) temperature map $\sigma$ of
Applying a Gaussian $u$-cutoff of 0. Image by applying a filter to the visibility (the positions of the northern and southern sub-peaks. The VLA feature is elongated in declination, we give Table 1: BIMA pointing centers and source positions. The lines reading ‘BIMA Pointing’ give the coordinates of \( \text{rms} \) and an image \( \text{rms} \) to a RJ temperature map.

| Object           | Position | $\alpha$ (J2000) | $\delta$ (J2000) |
|------------------|----------|------------------|------------------|
| PC1643+4631      | BIMA Pointing | $16^h 45^m 11.278^s$ | $+46^\circ 24' 55.8''$ |
| PC1643+4631      | Ryle Source | $16^h 45^m 11.278^s$ | $+46^\circ 24' 55.8''$ |
| VLA1312+4237     | BIMA Pointing | $13^h 12^m 17.397^s$ | $+42^\circ 38' 05.0''$ |
| VLA1312+4237     | VLA North peak | $13^h 12^m 17.157^s$ | $+42^\circ 37' 44.5''$ |
| VLA1312+4237     | VLA South peak | $13^h 12^m 17.122^s$ | $+42^\circ 37' 15.0''$ |

Table 1: BIMA pointing centers and source positions. The lines reading ‘BIMA Pointing’ give the coordinates of the pointing and phase center for the BIMA observations. The VLA feature is elongated in declination, we give the positions of the northern and southern sub-peaks.

160 $\mu$K. We increased the brightness sensitivity of the image by applying a filter to the visibility ($u$-$v$) data. Applying a Gaussian $u$-$v$ taper with a half-amplitude cutoff of 0.8 k\( \lambda \) resulted in a beam-size of 101″ × 97″ and an image \( \text{rms} \) 185 $\mu$Jy beam$^{-1}$ which corresponds to a RJ temperature map \( \text{rms} \) of 26 $\mu$K. There appear to be several weak point sources in the images, but nothing resembling a CMB decrement.

In the summer of 1998, we performed supplementary observations with the OVRO millimeter array outfitted with the same 28.5 GHz receivers used for the BIMA observations. The large collecting area of the six 10.4 m OVRO telescopes and 2 GHz analog correlator provide excellent point source sensitivity. For a description of the OVRO system with Ka band HEMT receivers see Carlstrom, Joy, & Grego (1996). In the week of June 15-22 1998, we performed three deep observations each centered on one of the three point sources reported in Jones et al. (1997). The coverage was not uniform, but for each of the three observations the array produced a naturally weighted beam $\sim 11'' \times 13''$ and a map \( \text{rms} \) of $\sim 100 - 150 \mu$Jy beam$^{-1}$. Simultaneously fitting to all the OVRO and BIMA $u$-$v$, we detect three significant point sources in the field. The fluxes of the sources are all $\sim 200 \mu$Jy and their positions agree well with those of the three sources found in the Ryle observations. In Holzapfel et al. (1999) we give a detailed description of the procedure for measuring the point sources and list the positions and fluxes of the three significant sources. The point source model is important for the anisotropy analysis presented in that work, but as we will show here, has little effect on the cluster emission constraints.

The combination of the OVRO and BIMA data do not reproduce the claimed decrement. To quantify this result, we fit the $u$-$v$ data to the cluster emission model proposed by Jones et al. (1997) to describe the Ryle data. Fixing the position and shape parameters ($\beta = 2/3, \theta_c = 60''$) of the spherical King model, we fit for the central decrement. After subtracting the three detected point sources, we find a best fit central decrement $\Delta T_0 = +49 \pm 85 \mu$K. This result is clearly inconsistent with the minimal model used to fit to the Ryle data of $\Delta T_0 = -560 \mu$K.

Because of the different spatial scales of the cluster and point sources, the combination of the OVRO and BIMA data are able to simultaneously determine the positions and fluxes of the point sources while constraining the cluster emission model. We have repeated the fit for the central decrement while allowing the positions and fluxes of the three sources to simultaneously vary. The point source fluxes and positions are virtually unchanged from the previously determined values and the central decrement is found to be $\Delta T_0 = +48 \pm 90 \mu$K. In fact, removing the known point sources has no significant effect on the results; repeating the model fit without subtracting any point sources, we find $\Delta T_0 = +73 \pm 87 \mu$K. Therefore, the results we present are essentially independent of the point source model that we use. Over the broad range of point source models we have considered, the BIMA and OVRO data are inconsistent with the cluster emission model of Jones et al. (1997) at greater than 6$\sigma$.

To investigate what range of models for cluster emission the BIMA data are consistent with, we have fit the $u$-$v$ data to a grid of spherical King models (eqn. 1). The values of $\beta$ and the angular core radius $\theta_c$ are largely degenerate, so we have fixed $\beta$ to a typical observed value of 2/3. Fitting the models to our data, we can generate confidence intervals in the
two free parameters, the central temperature decrement $\Delta T_0$ and the angular core radius $\theta_c$. In Figure 1, we show confidence intervals for a large range of model parameters. For $\theta_c \sim 60''$, only points near $\Delta T_0 = 0$ result in acceptable fits to the data. The point marked with ‘x’ corresponds to the minimum King model used by Jones et al. (1997) to describe the Ryle data: $\beta = 2/3$, $\theta_c = 60''$, and $\Delta T_0 = -560 \mu K$. This model is inconsistent with the BIMA data at grater than 99.99% confidence.

Due to the East-West configuration of the Ryle array, the synthesized beam is considerably elongated in declination. Is it possible that weak cluster emission well matched to the Ryle beam could escape detection with BIMA? To answer this question quantitatively, we have used the BIMA data to constrain highly elliptical cluster models which would be well matched to the Ryle beam. Fixing the axial ratio to 2.0 and the major axis core radius to $\theta_c = 90''$, we find $\Delta T_0 = +15 \pm 80 \mu K$. If we assume that $\Delta T_0 = -560 \mu K$, the BIMA data are inconsistent with this model for emission at greater than 7$\sigma$. We conclude that elongated emission can not account for the discrepancy between the Ryle and BIMA results.

2.5. Discussion of PC1643+4631

The x-ray results imply that any cluster capable of producing the observed SZE decrement would have to be at a redshift of $z > 2.8$. The optical observations are not as constraining, but show no evidence of a massive cluster. The BIMA data we present are inconsistent with the model for the SZE emission proposed by Jones et al. (1997) at $> 99.99%$ confidence. This result is insensitive to the details of the point source and cluster emission models. Given the combination of the unlikely redshift range to which the x-ray constraints would push the cluster, and the significance of the BIMA non-detection, we find the evidence against a massive cluster in the direction of PC1643+4631A,B very convincing.

3. VLA1312+4237

3.1. VLA Observations

The Very Large Array (VLA) has been used to perform a sensitive search for CMB anisotropies on angular scales of 6'' to 80'' (Partridge et al. 1997). These observations consist of several hundred hours of observations at 8.44 GHz. The observed field, as defined by the primary beam half power points, was 5.2' wide centered on the coordinates $\alpha = 13^{h} 12^{m} 17.4^{s}$, $\delta = +42^\circ 38' 15''$ (J2000). This field was chosen to be free of point sources with flux density $S_{8.4 \text{GHz}} \geq 0.5$ mJy. All positive features brighter than 7 $\mu Jy$ (4.7$\sigma$) were located in the full resolution map and subtracted from the $u$-v data. The CLEANed 6'' resolution map had a rms noise of 1.5 $\mu Jy$, making it the most sensitive radio map at any frequency or resolution. An isolated, negative flux feature approximately 30'' $\times$ 65'' in size with a peak amplitude of $-250 \mu K$ was found in the residual map. After point source subtraction, the significance of the feature was 5.5 $\sigma$ with approximately 680 independent beams in the Field of View. In Richards et al. (1997), this feature is interpreted as the SZE signal of a distant cluster. The image is extended in declination with considerable substructure. It has a northern decrement of $-13.9 \pm 3.3$ $\mu Jy$ ($-250 \pm 60 \mu K$) in the 30'' resolution VLA image, and a southern decrement which is of similar amplitude. The positions of these two features are given in Table 1. Richards et al. (1997) describe the observed signal with a spherical King model at the position of the Northern Peak with $\beta = 2/3$, $\theta_c = 15''$, and central decrement $\Delta T_0 = -250 \mu K$.
3.2. X-ray

As related in Richards et al. (1997), Hu & Cowie (1996) obtained a sensitive ROSAT HRI image of the region containing the source. These observations were used to constrain the flux in the HRI 0.1 – 2.4 keV band, $f_x < 2 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ at the 3σ level. Fixing $\beta = 2/3$, Partidge et al. (1997) used the observed CMB decrement to estimate possible cluster parameters, specifically the cluster x-ray luminosity $L_x \sim 2 \times 10^{44}$ erg s$^{-1}$ and gas mass $M_{\text{gas}} \sim 10^{13} M_\odot$. The lack of observed x-ray emission is used to argue that the cluster, if it exists, must be at redshift $z > 1.5$.

3.3. Optical

Optical images of the region containing the decrement had been produced as part of the HST Medium Deep Survey. Two quasars at the identical redshift of $z = 2.561$ separated by 100″ were discovered in the image. For the two quasars to be the lensed images of a single object, an intervening mass of $\sim 10^{15} M_\odot$ would be required. Also, the spectra of the two objects appear to be radically different. The presence of these two quasars in such close proximity led Richards et al. (1997) to propose that they might be members of a cluster at that redshift.

Campos et al. (1998) have searched the vicinity of the quasar pair for evidence of galaxy clustering. They find 56 Ly-α emitting candidates in a 8′ × 14′ field. Four of the five spectroscopically confirmed objects form a 3′ (≈ 3 Mpc) filament with velocity dispersion 1000 km s$^{-1}$. This is several times the velocity dispersion one would expect for an unbound system of scale ≈ 3 Mpc. However, the velocity dispersion of only 4 objects cannot be used to identify a virialized system and many more spectra will be needed before this claim can be taken seriously.

3.4. BIMA observations

We observed VLA1312+4237 with our cm-wave receivers mounted on 9 of the 6.1 m telescopes of the BIMA array. Total on-source integration time was 35.5 hours spread over 8 separate days during the period June 15 to August 15, 1997. The configuration of the array was identical to that used for the observations of PC1643+4631. Using all the data to produce a naturally weighted image resulted in a beam-size of 33″ × 25″ and an image $rms$ of 100 μJy beam$^{-1}$ which corresponds to a RJ temperature map $rms$ of 169 μK. Applying a Gaussian $u$-$v$ taper with a half-amplitude cutoff of 0.8 kλ resulted in a beam-size 98″ × 94″ and an image $rms$ 189 μJy beam$^{-1}$ which corresponds to a RJ temperature map $rms$ of 29 μK. We also created maps limited in $u$-$v$ range to search for point source emission. There is no evidence for the presence of point source emission or a CMB decrement in any of the images.

The $u$-$v$ coverage of the VLA and BIMA data sets is complementary with little overlap. The brightness sensitivity of the BIMA data is highest at angular scales of 50 – 120″ while the sensitivity of the VLA data is highest at scales of 6 – 30″. We have investigated if the spherical King model suggested by Richards et al. (1997) is consistent with the BIMA data. Assuming the cluster to be described by model parameters $\beta = 2/3$ and $\theta_c = 15″$, we find a best fit value for the central decrement of $\Delta T_o = +31 \pm 151 \mu$K. For larger core radii, the constraints are stronger. Fixing $\theta_c = 30″$, we find $\Delta T_o = +38 \pm 118 \mu$K.

In Figure 2, we show confidence intervals for fits to a range of spherical King (eqn. 1) models for the cluster emission. Again, we have fixed $\beta = 2/3$. The ‘×’ marks the parameters proposed by Richards et al. (1997), which are $\Delta T_o = -250 \mu$K, and $\theta_c = 15″$ with the model centered on the position of the “Northern Peak”. The proposed cluster emission model is inconsistent with the BIMA data, although with only $\sim 80\%$ confidence.

The feature observed with the VLA appears to be quite elongated in declination. We have repeated the fits for cluster emission models which are better matched to the morphology of the reported VLA feature. For these observations, we have fixed the source position midway between the northern and southern peaks of the VLA image. Assuming the cluster profile to be described by an elliptical King model with an axial ratio of two and a major axis described by a core radius of $\theta_c = 30″$ aligned in the North-South direction, we find $\Delta T_o = +146 \pm 125 \mu$K. Assuming the central decrement to be $\Delta T_o = -250 \mu$K, the BIMA data are inconsistent with this elliptical model for the cluster emission at greater than 3σ.

3.5. Discussion of VLA1312+4237

We find no evidence for a massive cluster in the VLA1312+4237 field, but cannot rule out its presence with high confidence. The x-ray and optical data do
Fig. 2.— Confidence intervals for fits of the data from BIMA observations of VLA1312+4237 to a spherical King model. The '×' marks the values of model parameters adopted in Richards et al. (1997) to describe their observed decrement. The BIMA data are inconsistent with this model at ∼ 80% confidence.

not constrain the presence of the cluster at z = 2.61 as proposed by Richards et al. (1997), and there may be some evidence of structure in the distribution of background galaxies in addition to the two quasars in the vicinity of the proposed decrement. The angular scales probed by the VLA and BIMA instruments overlap very little, and comparison of the two data sets must be done through a model for the cluster emission. The model proposed by Richards et al. (1997) for the cluster emission is inconsistent with the BIMA data at ∼ 80% confidence. Further observations with the OVRO array, or a more extended configuration of the BIMA array, would permit a more significant test of the existence of a SZE decrement.

4. Conclusions

We have observed two fields containing claimed decrements in the CMB. In both cases, we do not detect the reported decrements and have been able to, with varying confidence, rule out emission described by the cluster models proposed by the authors of the detection papers. The BIMA observations are inconsistent with the cluster model put forth by Richards et al. (1997) for the decrement in the direction of VLA1312+4237, but only at ∼ 80% confidence.

Due to the similarity of the angular scales to which the BIMA and Ryle telescopes are sensitive, the constraints are particularly strong in the case of PC1643+4631. The BIMA data are found to be inconsistent with the proposed emission model at greater than 99.99% confidence. The x-ray and optical observations provide no support for a massive cluster in the direction of PC1643+4631. In a companion paper, we use the observations of both of these and five additional fields to place limits on arcminute scale CMB anisotropies [Holzapfel et al. 1999].

We expect that the SZE will become a powerful tool for the discovery of distant clusters. The realization of this goal is likely to require not only an increase in sensitivity, but also a better understanding of the systematic errors associated with each experiment. Ultimately, multifrequency measurements with different instruments provide the strongest discrimination against foreground confusion and systematic errors.

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