OVRO RESULTS ON THE SUNYAEV-ZEL'DOVICH EFFECT, 1983-5

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ABSTRACT. Recent data taken with the 40-m telescope of the Owens Valley Radio Observatory at 20 GHz have confirmed the detections of the Sunyaev-Zel'dovich effect towards three clusters of galaxies, 0016+16, Abell 665 and Abell 2218. Rough measurements of the angular scale of the effect have also been made, and a comparison of these with the X-ray observations supports an isothermal model for the cluster gas.

1. OBSERVATIONS

In 1982 the 40-m telescope of the Owens Valley Radio Observatory was equipped with a sensitive receiver for the 1.25 - 1.65 cm band. This receiver uses a coupled-cavity maser amplifier (Moore & Clauss 1979) with a bandwidth of 400 MHz and a system noise temperature of 45 K. During the winter months, there are periods when the atmosphere above the Owens Valley is very dry, and at these times observations may be extended to many tens of hours and achieve noise levels close to those expected theoretically from the system characteristics (sensitivities better than 0.1 mK). Most of the winter observing time since 1983 has been devoted to two programmes that use this system to study the microwave background radiation. These are measurements of limits to the amplitude of primordial brightness fluctuations on angular scales 1.5 to 30 arcmin (Readhead, Moffet & Sargent 1986), and measurements of the Sunyaev-Zel'dovich effect, the predicted change in brightness of the microwave background radiation towards the hot gas atmospheres in X-ray clusters of galaxies caused by the scattering of photons of the background by hot electrons in the gas. Here we summarize the results of recent work at OVRO on the latter effect.

The 1.5 cm receiver on the 40-m telescope uses a cooled circulator to switch between two identical prime-focus feeds which are arranged symmetrically about the axis of the paraboloid. The beams are nearly circular, with half-power diameter 1.8 arcmin and separation 7.15 arcmin in azimuth. The observing procedure (Birkinshaw & Gull 1984) measures the difference in brightness between the target position and the average of two reference patches 7.15 arcmin to either side of it. Rotation in parallactic angle causes these reference patches to sweep out arcs on the sky about the target position, thus the data can be analyzed to locate confusing sources in these reference arcs as well as measure the brightness at the target position.

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Observations have been made of three rich clusters of galaxies (0016+16, Abell 665 and Abell 2218) for which significant Sunyaev-Zel'dovich decrements have been reported (Birkinshaw, Gull & Hardebeck 1984). In the 1983-4 and 1984-5 seasons, the main goal has been to measure the angular extent of the effect in declination. Blank-sky regions have also been observed to provide controls on the experiment.

2. RESULTS

2.1 Cluster data

The three clusters were observed at their centres and at points 2 and 7 arcmin north and south of the centres. The results of many observations over 1983-5 are shown in Table 1. A significant brightness decrement is seen in each cluster, whether measured from the zero level, or relative to the $\pm$ 7 arcmin positions: these brightness differences are -630 ± 85, -214 ± 49 and -345 ± 48 μK for 0016+16, Abell 665 and Abell 2218 respectively. Examination of the crude declination scans represented in Table 1 shows a smooth approach to a significant negative peak near the centre of each, with the exception of the point 2 arcmin north of the centre of Abell 2218, where interferometric data at lower frequencies (Birkinshaw 1986; Birkinshaw, Gull & Padman 1986) find a source (5C 20.92/94) which should produce a signal $\approx$ 400 μK. The data presented in Table 1 constitute convincing evidence for the Sunyaev-Zel'dovich effect in these three clusters.

Table 1. Cluster data

	$\Delta T/\mu K$		
	0016+16	Abell 665	Abell 2218
7' N	$+88 \pm 79$	-78 ± 55	-10 ± 51
2' N	-209 ± 65	-336 ± 44	$+309 \pm 40$
centre	-570 ± 54	-329 ± 33	-385 ± 29
2' S	-160 ± 72	-409 ± 49	-96 ± 34
7' S	-1 ± 118	-144 ± 48	-77 ± 56

The angular structure of the Sunyaev-Zel'dovich decrement can be shown to be of the form $(1 + \theta^2/\theta_{cx}^2)^{-1/4}$ if the cluster gas is isothermal, and if the X-ray angular structure of the cluster can be modelled accurately by a law of the form $(1 + \theta^2/\theta_{cx}^2)^{-1}$, where θ_{cx} is the X-ray core radius (Birkinshaw & Gull 1984). Values of θ_{cx} consistent with the X-ray results are found if this model is fitted to the data of Table 1, and the fitted central decrements of the clusters (deconvolved by the 40-m telescope beam) are about -1.6, -0.8 and -0.8 mK for 0016+16, Abell 665 and Abell 2218, respectively. The temperatures of the X-ray emitting gas in the clusters can be deduced from these results to be 14, 15 and 12 keV. These temperatures are consistent with the available X-ray data, and suggest that the strength of the Sunyaev-Zel'dovich effect in these clusters is due to their high gas temperatures. The consistency of the angular sizes and temperatures deduced with those inferred from X-ray images and spectra lends support to the isothermal model for the cluster atmospheres.

2.2 Blank sky data

Insufficient time was spent on the three reference regions selected for control observations for any useful limits to the primordial microwave background anisotropies on arcmin scales to be deduced (for such data see Readhead *et al.* 1986). Our data (Table 2) are intended to provide controls on systematic errors in the Sunyaev-Zel'dovich observations and to provide a rough estimate of the level of radio source confusion. The data of Table 2 show a scatter about zero of 161 μK, whilst the mean error in the measurements is only 62 μK. This can be interpreted as evidence for an intrinsic (confusion) scatter of about 130 μK, but there is no evidence for any systematic error exceeding about 150 μK. Since REF1 lies at a similar declination to 0016+16, and REF5 lies at a similar declination to Abell 665 and Abell 2218, and the reference regions are observed in similar conditions and at similar hour angles to the clusters, these data provide good limits to the systematic errors at the clusters.

Table 2. Blank sky data

	$\Delta T/\mu K$
REF1	$+34 \pm 56$
REF3	$+189 \pm 86$
REF5	-126 ± 43

3. FURTHER WORK

Although these data consitute strong evidence for the reality of the Sunyaev-Zel'dovich effect in these three clusters, there remains much work to establish an accurate angular structure for the effect (and hence to test whether the cluster gas is approximately isothermal). Further work must also be done on checking the fields of the clusters and the reference arcs for the presence of possible confusing flat-spectrum radio sources which may be distorting the results. For example, an analysis of the reference arc data for Abell 665 suggested contamination by a source near 08^h27^m, $66°05'$ which has subsequently been detected in VLA observations: however, since the source only appears over a limited range of parallactic angles, its effect on the Abell 665 scan data of Table 1 is not sufficient to mimic the observed decrement. Source survey work around the clusters is important so that the data of Table 1 can be used fully, without reservations about the source environment. Improved microwave background data, further X-ray data, and good velocity dispersion data for the clusters would allow an improved assessment of the gas environments in these very hot clusters to be made, and might enable useful limits to the value of the Hubble constant to be calculated.

4. REFERENCES

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