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Radio Sources in Galaxy Clusters at 15 GHz and Confusion in the Sunyaev-Zel'dovich Effect

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A major source of contamination in the forthcoming surveys of galaxy clusters by the Sunyaev-Zel'dovich effect will be radio sources. Preliminary results are presented from a study to understand their effects at 15 GHz. 68 X-ray luminosity-limited clusters over $z = 0.1$–0.3 were observed at 15.2 GHz. The excess over the background and foreground sources within the 0.25 Mpc core was 14 ± 4 times. The cluster radio luminosity function ($10^{22} \leq P_{15} \leq 10^{24}$) is reasonably consistent with extrapolation of previous estimates at 1.4 GHz. Using an analytic model, we estimate the level of confusion noise expected in an SZ experiment such as AMI. We find that confusion from cluster radio sources may be signficant up to $z \approx 0.5$. At higher redshifts, the upper limit on the confusion from cluster sources become comparable to background and foreground levels.

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1. Introduction

A number of experiments will shortly begin a survey of galaxy clusters using the Sunyaev-Zel'dovich (SZ) effect [1]. Some of the photons from the Cosmic Microwave Background (CMB) gain energy from the electrons in the hot cluster gas by inverse Compton scattering. In the Rayleigh-Jeans regime, the SZ effect will appear as a temperature decrement in the CMB. Prior to the all-sky survey to be conducted by Planck, the first wave of SZ survey experiments will be ground-based interferometers such as AMI [2, 3] and SZA [4], later followed by AMiBA [5]. These instruments will observe at 15, 30 and 90 GHz respectively. At these frequencies, radio sources are a major contaminant. To compound the problem, clusters frequently host radio sources. The correlation of radio sources with the SZ effect makes it imperative to understand their influence on a cluster survey. Despite their low observation frequencies, interferometers can exploit their large range of spatial frequencies to spatially filter out the compact sources from the extended SZ effect. This technique has been routinely applied in interferometric observations of the SZ effect. Sources above some flux density level $S_{\rm lim}$ will be detected and subtracted. However any residual sources $< \S_{\rm lim}$ will contaminate the detected SZ effect. The aim of this study is to understand the degree of source confusion in AMI. This paper presents some of the key results from the preliminary analysis of the data (also see [6]).

The target cluster were selected from the X-ray-selected ROSAT Brightest Cluster Sample (BCS; [7]). We selected clusters between the redshift range $0.1 \leq z \leq 0.3$. Those below the practical declination limit of the Ryle Telescope, $\delta \leq 15^\circ$ were rejected. We applied an X-ray luminosity threshold of $L_X \geq 10^{44}$ erg s^{-1} to reduce the selection effects arising from an X-ray flux-limited sample. Further work is needed to understand the selection effects in our sample. 68 clusters were observed with the Ryle Telescope at 15.2 GHz and sources were detected at 5σ-level. In its compact configuration, the synthesised beam is $\approx 25'' \times 25''$ cosec δ with a primary beam of $6'$ (FWHM). Each observation was at least 12 hours long and the typical map noise was 0.2 mJy. The BCS X-ray centroids were adopted in the analysis.

2. Source Count and Radio Luminosity Function

An excess of sources are expected in clusters over the counts from background and foreground sources (field sources). The sensitivity of the Ryle Telescope drops away from the pointing centre, so we selected sources detected within 0.25 Mpc of the cluster centres, where the sensitivity is best. This is believed to corresponds to the core-region of the clusters. These sources were binned by flux density, then normalised by the width of the bin and the area of the observation (the area with sufficient sensitivity to detect the faintest possible sources within the flux range of the bin). The error bars assume Poisson statistics. Figure 1 (left panel) shows the cluster source count compared to the field. The 9C source count [8, 9] at 15.2 GHz extends down to 1 mJy. A source count model [10] is also shown. There is an excess of 14 ± 4 (over the flux range $3 \geq S_{15} \geq 20$ mJy) in clusters over the field. Although the error bars are large, the slope of the source count in clusters is somewhat shallower. This phenomenon has also been observed with a higher significance at 1.4 GHz.

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We estimate the radio luminosity function (RLF) in the cluster following the method used by [11] and [12]. A nominal spectral index of $\alpha = 0.7$ (where $S \propto \nu^{-\alpha}$) was assumed for K-correction. Because the sensitivity of the observations are not uniform, the completeness of the RLF falls off for $P_{15} < 10^{22}$ W Hz^{-1} sr^{-1} and the two lowest luminosity data points in figure 1 (right panel) are anomalous. For comparison, the 1.4 GHz data from [12] have been extrapolated to 15 GHz. Our X-ray clusters are 63% richer than the Abell cluster sample in the 1.4 GHz study. To compensate for this, the 1.4 GHz RLF was scaled up. The RLFs are consistent within the error bars.

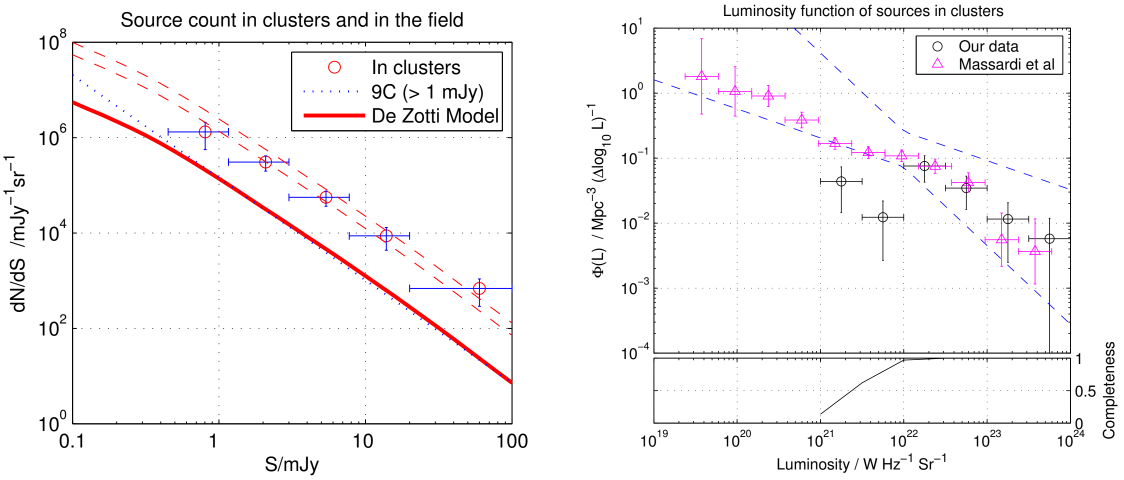

Figure 1: *Left:* The differential source count in clusters within 0.25 Mpc of the cluster centroid. The solid curve is the modelled field count [10] and the dotted line is the 9C source count (extrapolated for $S_{15} < 1$ mJy). The dashed lines indicate the excess over the model by a factor of 14 ± 4. *Right:* The RLF of 15 GHz radio sources in clusters (open circles). The lower plot is an indication of the completeness. The open triangles are the scaled 1.4 GHz RLF from [12], extrapolated to 15 GHz. The dashed curves indicate the range of the power-law fit normalised about $P_{15} = 10^{22}$ W Hz^{-1} sr^{-1}.

3. Confusion Noise

We modelled the RLF as a power law and derived an analytic expression to estimate the expected confusion noise in a representative cluster. In a 12-hour observation, AMI will be able to subtract sources with flux $S_{15} \geq 0.13$ mJy. Neglecting the evolution of the luminosity function will underpredict the level of source confusion at higher redshifts. For simplicity, pure luminosity evolution of the form $P(z) = P(0)\,(1+z)^{\psi}$ with $\psi = 3$ was assumed. The evolution of radio sources beyond $z \approx 2$ is not well understood and the results may not be representative of reality at higher redshifts. The shaded regions in the two panels of figure 2 is the expected mean confusion noise over the whole cluster due to cluster sources inside an AMI beam ($3\overset{\prime}{.}4$). The large uncertainty arises from uncertainties in modelling the RLF. The upper limit falls with redshift up to $z \approx 0.5$ and then flattens off at a level of approximately twice the confusion noise from field sources.

4. Conclusions

We observed 68 X-ray luminosity-selected clusters at 15.2 GHz. Within 0.25 Mpc of the cluster centres, an excess of 14 ± 4 times the level of field sources was found. The cluster RLF at

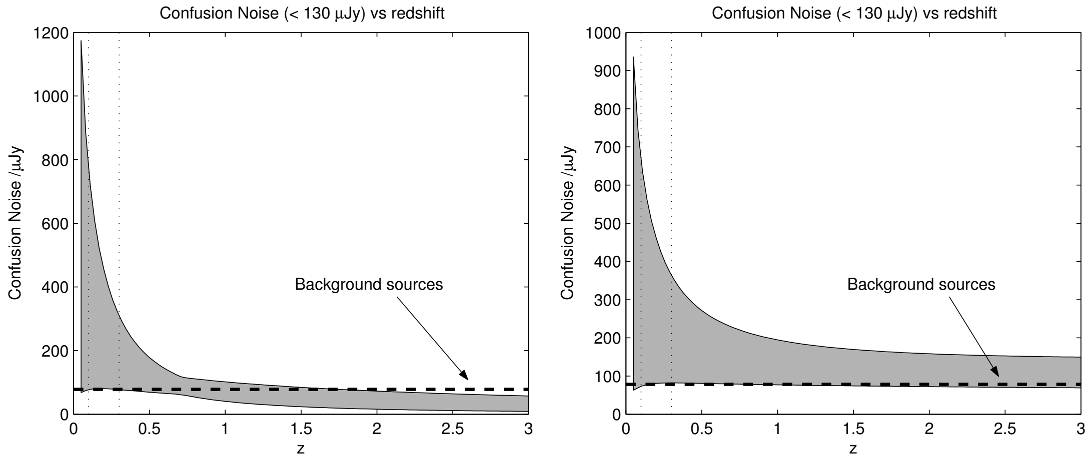

Figure 2: *Left:* The mean confusion noise in a representative cluster at 15 GHz if source subtraction is complete to 0.13 mJy. The shaded region is the range of expected confusion noise. The dashed line is the level of confusion noise expected in the field. *Right:* The confusion noise assuming pure luminosity evolution. The vertical dotted lines indicate the redshift range of our cluster sample.

15 GHz is broadly consistent with the extrapolated 1.4 GHz data. We analytically modelled the expected level of confusion in clusters in an AMI-beam. The uncertainty in the expected confusion noise is large but the upper limit falls with redshift up to $z \approx 0.5$. Thereafter, it is comparable to the level of confusion from field sources. A forthcoming paper will expand on the results presented here and carry out more realistic simulations of the expected confusion noise.

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