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Radio Source Counts at 15 GHz: Implications for CMB Experiments

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Abstract. In preparation for Very Small Array (VSA) observations we have surveyed the first three VSA fields at 15 GHz using the Ryle Telescope in Cambridge, finding 217 sources with flux density greater than $\sim$ 20 mJy over 178 deg^2. This is the highest radio frequency at which a survey has been done that is relevant to the issue of radio source contamination in CMB experiments. Our results show that source fluxes, and indeed the existence of many sources, cannot be predicted at 15 GHz by extrapolation from lower frequency. The spectra and variability of the sources and their implications for CMB experiments at cm-wavelengths are discussed.

1. Introduction

The Cosmic Microwave Background (CMB) is viewed through a foreground of discrete radio sources. On the angular scales of interest to primordial CMB work such sources are generally unresolved and, given that they are Poisson distributed (i.e. multipole coefficient C_l is proportional to multipole number l), their power spectrum increases as l^2. It therefore becomes increasingly important to remove point sources correctly as we attempt to measure the CMB power spectrum at larger values of l. These sources also pose a particular problem for cm-wavelength experiments since, until the present results, there has been no suitable high frequency survey above 5 GHz. This paper describes the extent to which point sources will affect observations with the Very Small Array (VSA; see P. Scott, these proceedings) and the strategy we use to ensure that they are correctly removed. As part of this work we have surveyed 178 deg^2 of sky at 15 GHz (see Waldram & Pooley, these proceedings); the results and implications of this survey are discussed.

2. Source Confusion and the VSA

The VSA is a 14-element interferometer array observing in the range 26-36 GHz, and has a flux sensitivity of approximately 20 mJy in 28x7 hours. The level to which sources must be subtracted in a VSA field depends on both its flux sensitivity and on the confusion noise, σ_{conf}, remaining from unsubtracted sources. In order that our observations are not dominated by confusion noise we must therefore ensure that the rms noise on a VSA map from unsubtracted sources is

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less than the thermal flux sensitivity. Following Scheuer (1957), we have

$$\sigma_{conf} = \left[N \frac{(\beta - 1)}{(3 - \beta)} \right]^{1/2} S_{sub}$$

where S_{sub} is the flux density limit down to which sources are subtracted, N is the number of sources per VSA synthesised beam that are subtracted and β is the slope of the differential source counts, $dN/dS \propto S^{-\beta}$.

To calculate this confusion noise, we need to know both the normalisation and the slope of the differential source counts at our observing frequency. These are not well known, although our 15-GHz programme of Ryle Telescope observations for the Cosmic Anisotropy Telescope indicates that there are 3 sources per square degree brighter than 10 mJy and that β is around 1.8 (O'Sullivan 1995). Adopting this value we find that our subtraction scheme must reach S_{sub} = 80 mJy at 30 GHz if we are to ensure that the confusion noise is significantly lower than the flux sensitivity of the VSA ($\sim$ 20 mJy).

3. Source Subtraction Strategy for the VSA

Source subtraction for the VSA is a two-stage process. First we survey the selected VSA fields at 15 GHz using the Ryle Telescope. We aim to reach an rms noise level of σ = 4 mJy, in order to identify all sources above 20 mJy at 15 GHz. This survey is deep enough to ensure that we can find all sources above our desired goal of 80 mJy at 30 GHz, even allowing for sources with a spectral index as steep as -2 between 15 GHz and 30 GHz. We then monitor each source at 30 GHz using a separate single baseline interferometer working simultaneously with the VSA.

4. Observations at 15 GHz

We have currently surveyed 178 deg^2 of sky at 15 GHz and found 217 sources with flux densities greater than 20 mJy (σ = 4 mJy). These preliminary results show that the population of observed sources at 15 GHz cannot be extrapolated from lower frequency surveys such as the NVSS 1.4 GHz (Condon et al. 1998) and the Green Bank 4.8 GHz (Gregory & Condon 1991). On the basis of their spectra between 1.4 GHz and 4.8 GHz, extrapolation predicted 252 sources to be brighter than 20 mJy at 15 GHz. Only 154 of the predicted sources were seen, but a further 63 sources were found that were not predicted. Of the 63 unpredicted sources, 12 do not appear in the Green Bank catalogue at all. The spectral index distribution between 4.8 GHz and 15 GHz for all the sources observed with the Ryle Telescope is shown in Figure 1(a). The spectral indices span a wide range confirming that sources cannot simply be subtracted on the basis of their spectra. Furthermore, the dark bars in Figure 1(a) represent those sources that were found but were not predicted to be brighter then 20 mJy from the 1.4 GHz and 4.8 GHz data. A large fraction of these sources have flat or inverted spectra and will become increasingly important at higher frequency.

A specific example of a source spectrum is given in Figure 1(b). It is of a bright source that was not predicted to be greater than 20 mJy at 15 GHz.

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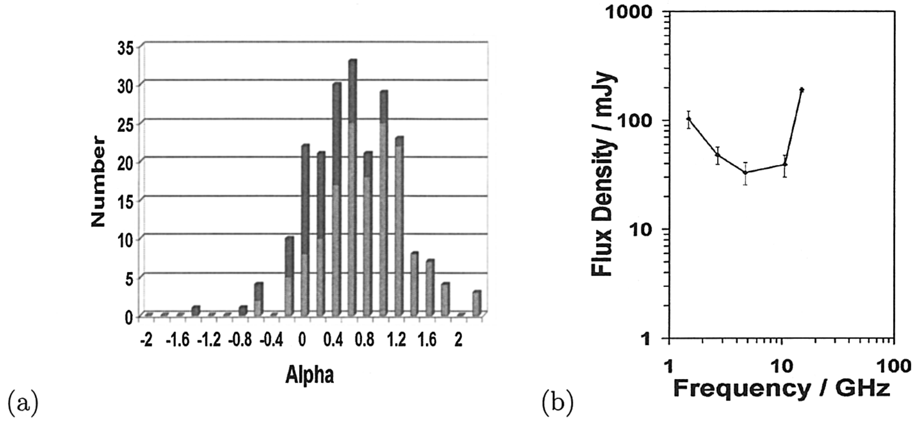

Figure 1. (a) Spectral index distribution, $\alpha_{4.8}^{15}$, of sources observed with the Ryle Telescope (flux density $\propto \nu^{-\alpha}$). (b) Spectrum of a source not predicted to be > 20 mJy at 15 GHz from 1.4 and 4.8 GHz data.

Measurements of its flux density at 1.4, 2.7, 4.8 and 10.5 GHz by Neumann et al. (1994) indicate a predicted flux density of around 10 mJy at 15 GHz. However, we found the flux density of the source to be 190 mJy at 15 GHz - well above the required subtraction level for the VSA of 20 mJy. Another feature of this source is that its apparent spectral index between 10 GHz and 15 GHz is -4, implying some combination of variability and intrinsically rising spectra, both of which are associated with the synchrotron-self-absorbed (SSA) spectra expected from compact sources. This is the behaviour expected in the population as we move to a frequency regime in which many sources will be SSA.

5. Implications for CMB experiments

The preliminary results from our 15 GHz survey allow us to quantify the effect of incorrect source subtraction on the recovery of the CMB power spectrum. Using our differential source count at 15 GHz we estimate the power spectrum due to point sources (Figure 2). The unfilled circles in Figure 2 show the power spectrum due to all point sources assuming no source subtraction. It is clear that for l greater than about 500, CMB power spectrum estimation from data at around 30 GHz without source subtraction will be heavily contaminated by sources. The filled circles in Figure 2 show the power spectrum due only to sources with flux densities less than 80 mJy i.e represents those sources remaining after the VSA source subtraction strategy has been implemented and under the pessimistic assumption that all sources have spectra rising between 15 and 30 GHz with an index of -2. Our subtraction strategy is evidently adequate to allow VSA measurement of the CMB power spectrum up to $l = 1000$. For work at higher l we will need to increase the depth of our initial 15 GHz survey.

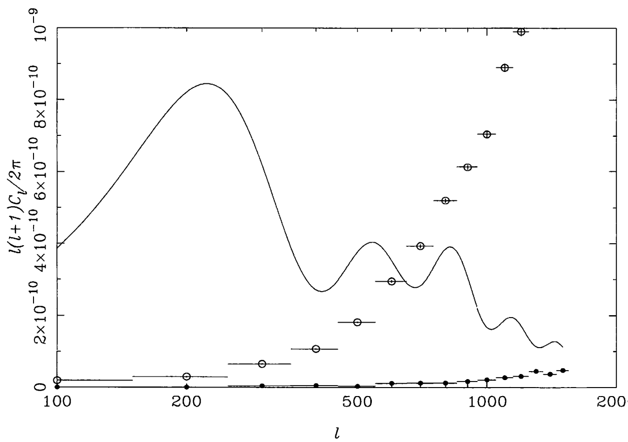

Figure 2. Power spectrum of sources in the absence of source subtraction (circles), pessimistic (see text) power spectrum of sources after VSA source subtraction (solid circles), and simulated CMB power spectrum (solid line).

6. Conclusions

Source subtraction is essential for the VSA to avoid our power spectrum being dominated by source confusion. The results of our Ryle Telescope survey at 15 GHz have shown that source fluxes and the existence of many sources cannot simply be predicted by extrapolation from low frequency surveys. Thirty percent of the sources found in our VSA fields were not predicted by extrapolation of their spectral index between 1.4 GHz and 4.8 GHz, and a large fraction of rising and flat-spectrum sources have been found. Many of the sources were also found to be variable. In order to perform effective source subtraction, one must simultaneously observe sources at the same frequency as the CMB observation, enabling the correct subtraction of both variable and rising spectrum sources.

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References

Condon, J. J., Cotton, W. D., Greisen, E. W., Yin, Q.F., Perley, R. A., Taylor, G. B., & Broderick, J.,J. 1998, AJ, 115, 1693

Gregory, P. C. & Condon, J. J. 1991, ApJS, 75, 1011

Neumann, M., Reich, W., Furst, E., Brinkmann, W., Reich, P., Siebert, J., Wielebinski, R. & Trumper, J. 1994 ApJS, 106, 303

O'Sullivan, C. M. M. 1995, PhD Thesis, University of Cambridge

Scheuer, P. A. G. 1957, Proc. Camb. Phil. Soc., 53, 764