LOW FREQUENCY RADIO SURVEYS: SEARCHING FOR CLUSTER HALOS AND RELICS

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Abstract

Recent advances in low frequency radio ($\nu < 0.5$ GHz) instruments and techniques have made possible deep, high resolution surveys. Such surveys are ideal for finding the diffuse, steep-spectrum radio emission coming from halos and relics known to exist preferentially in clusters of galaxies which are undergoing major mergers. Here we describe two major surveys currently underway, which have the potential for discovering many such halo/relic systems. The first is the *XMM-Newton* Large Scale Structure project (XMM-LSS) in which a $8 times 8$ square degree region will be mapped by *XMM-Newton*. The XMM-LSS project includes a low-frequency radio survey at both 325 and 74 MHz in order to compare the location of radio sources and the large scale structure. The second survey we describe is the VLA Low-frequency Sky Survey (VLSS) which is a NRAO-NRL collaboration to map the entire northern sky at 74 MHz. We describe both surveys, their current progress and identification of halo/relic candidates from the data acquired so far.

1 Radio counterpart to the *XMM-Newton* Large Scale Structure Survey

1.1 Introduction

The *XMM-Newton* Large Scale Structure Survey (XMM-LSS) is a deep X-ray survey designed to map the distribution of groups and clusters of galaxies out to a redshift of $z = 1$ (Pierre et al., 2001). The planned X-ray identification of cluster candidates combined with spectroscopic follow-up will provide an unprecedented view of the large scale structure of the universe. With the prospect of these data, we conducted a low-frequency VLA survey of the XMM-LSS region in order to investigate the relationship between the population of cosmological radio sources and large scale structure.

Table 1: A-configuration observation results

Frequency MHz	Resolution $''$	RMS Noise mJy bm^{-1}	Survey Area deg^2	Source Detect.
325	6.3	0.8	5.6	256
74	30	55	110	211

1.2 Preliminary A-configuration observations

Preliminary A-configuration observations have been taken. The observation parameters for both 74 and 325 MHz are summarized in Table 1. While most sources were unresolved, or only slightly resolved, there were several extended sources imaged in each frequency. Samples of some of the largest sources are shown in Fig. 1 and 2. For a comprehensive description of these observations, see Cohen et al. (2003). The main sci-

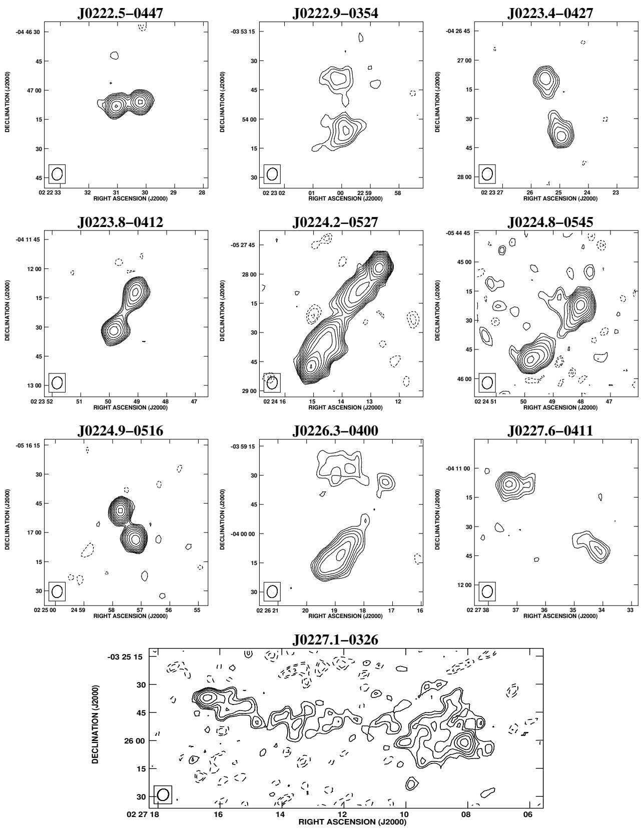

Figure 1: A sample of some of the larger resolved sources from the XMM-LSS radio counterpart observations at 325 MHz. The angular scale is the same in each image. Contour levels are at 2.5 mJy beam^{-1} $\times$ (-2, -1.4, -1, 1, 1.4, 2, 2.8, 4, 5.8, 8, ...) for each image.

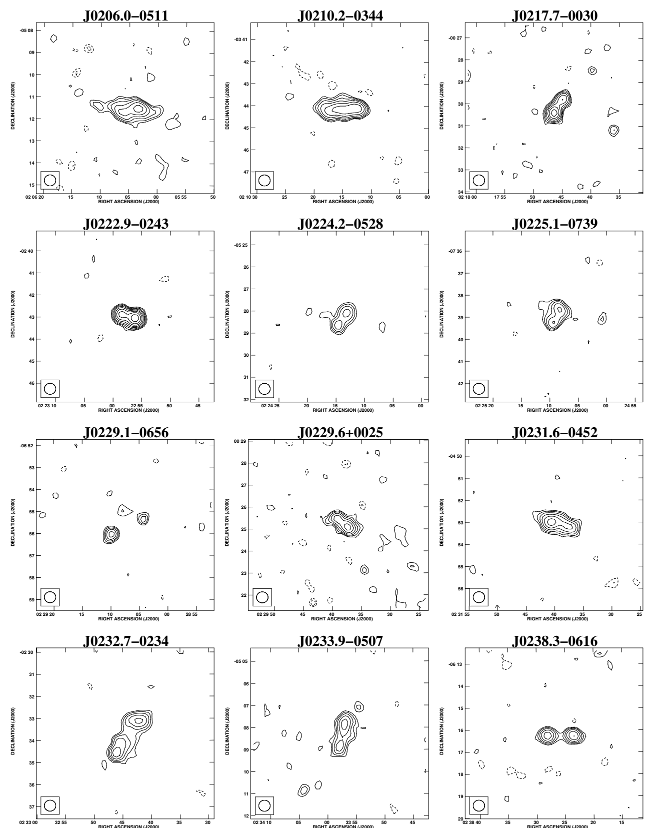

Figure 2: A sample of some of the resolved sources from the XMM-LSS radio counterpart observations at 74 MHz. The angular scale is the same in each image. Contour levels are at 150 mJy beam^{-1} $\times$ (-2, -1.4, -1, 1, 1.4, 2, 2.8, 4, 5.8, 8, ...).

entific results from these low frequency surveys will come from comparison to the X-ray and optical data in this field. The *XMM-Newton* observations have begun, and several candidate clusters have been identified. Preliminary comparisons should come soon.

2 VLSS: The VLA Low-frequency Sky Survey

2.1 Introduction

The new 74 MHz system on the Very Large Array, fully implemented in 1998 (Kassim, Perley, Erickson & Dwarakanath, 1993), has opened up a new window into the previously unexplored regime of very low frequency radio observations at high sensitivity and subarcminute resolution. Already, this system has been used to explore a variety of subjects including the ISM, supernova remnants, the galactic center environment, cool gas in normal galaxies, galaxy clusters, large scale structure and high redshift radio galaxies. In order to further explore the scientific potential of this new frequency-resolution regime, a VLA Low-frequency Sky Survey (VLSS) is in progress. The goal of this survey is to map the entire sky north of $\delta \geq -30°$, to a resolution of $80''$ with a 5σ source detection limit of 0.5 Jy beam^{-1}.

2.2 Preliminary data

The VLSS observations are taken with the B-configuration VLA with 1.5 MHz bandwidth centered on 73.8 MHz, with 2 polarizations and 6.67s integrations. We designed a roughly hexagonal grid of pointing centers, with a separation of $\Delta \approx 0.72\times\theta_p \approx 8.6°$, where $\theta_p \approx 11.9°$ is the FWHM primary beamwidth.

Figure 3 shows the pointing grid as well as maps of the regions of sky covered so far. Our grid contains a total of 523 pointings, and so far we have observed 260 of these. Once the data is reduced and verified, it is made publicly available on the VLSS web site

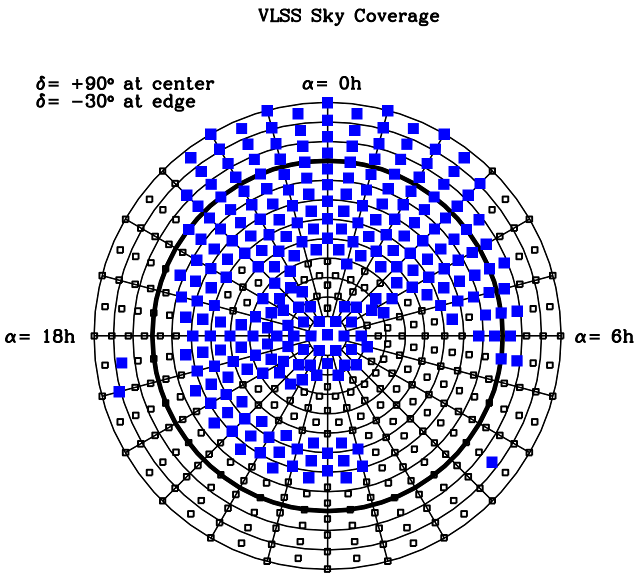

Figure 3: Current status of VLSS observations. This shows the grid of planned pointings with the large filled squares representing pointing for which maps have been produced. This mapped region will be available on-line by June, 2004.

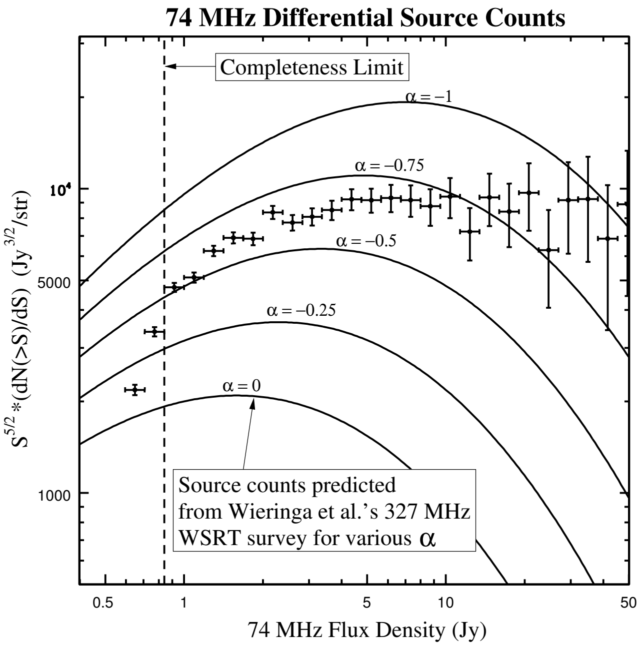

Figure 4: Euclidean normalized differential source count for the current VLSS data. The solid lines represent the source counts from a deep WSRT 327 MHz survey (Wieringa, 1991) projected to 74 MHz according to various assumed spectral indices.

(http://lwa.nrl.navy.mil/VLSS) in the form of a catalog browser and postage stamp image server. At the time of this write-up, we have reduced, verified and cataloged the data from 54 of these fields, and so only these data currently appear on our web site. However, we plan to have all the data currently observed available at our web site by June, 2004.

Even those 54 fields finished so far cover a sky area of 0.9 steradians which represents nearly 10% of the full survey. In this region, we have detected 6,406 sources at the 5σ level.

2.3 Preliminary analysis

2.3.1 Source counts

With this many sources, it is possible to determine meaningful statistics on the properties of sources at 74 MHz. Figure 4 shows the differential source counts. It is clear from comparison to a deep WSRT survey (Wieringa, 1991) that the difference between 74 MHz and 327 MHz source counts is more complicated than a simple spectral index adjustment.

2.3.2 Spectral measurements

We measure the spectral index of each VLSS source by comparing to the flux density in the 1.4 GHz NVSS catalog (Condon et al., 1998). Nearly every VLSS source had a NVSS counterpart within $45''$, and the median spectral index was $\alpha = -0.8$.

For those sources with counterparts in both the NVSS and the 325 MHz WENSS catalog (Rengelink et al., 1997), we plot a radio color-color diagram of α_{325}^{1400} versus α_{74}^{325} (Fig. 5). First we note a clear positive correlation between the spectral indices in these two frequency intervals. We also find that most sources have $\alpha_{325}^{1400} < \alpha_{74}^{325}$, with a median difference of 0.16. To raise α_{74}^{325} by 0.16, requires a lowering of $S_{74\mathrm{MHz}}$ by 27%, which is much higher than the flux density error for the average source, and also much higher than the 74 MHz flux scale error estimate of 5% (Kassim et al., 2004). We therefore detect a significant flattening in the average spectrum of these sources.

2.3.3 Searching for halos and relics

One major scientific goal of this survey is to explore ultra-steep spectrum (USS) objects ($\alpha < -1.2$; $S \propto \nu^{-\alpha}$). USS objects are most often high redshift radio galaxies, pulsars or cluster halos. Cluster halos can be identified by their location relative to known clusters as well as by their diffuse morphology and lack of relation to radio galaxies within their clusters as identified in

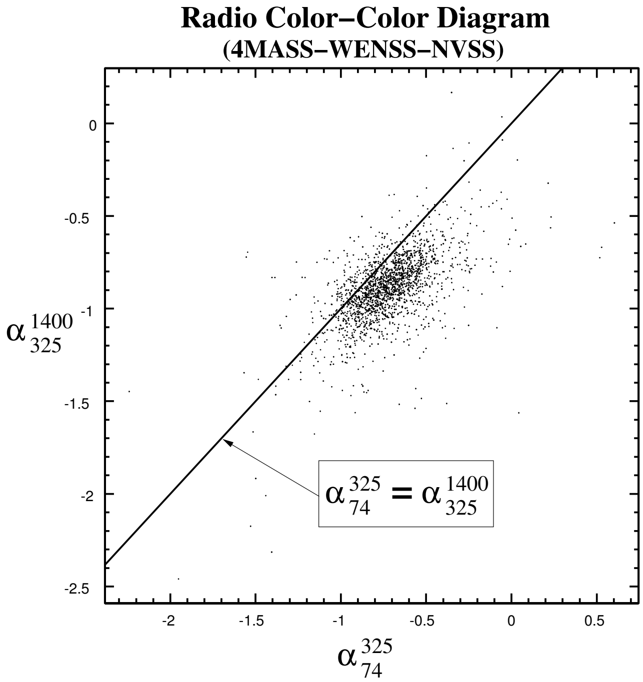

Figure 5: Radio color-color diagram for the VLSS region overlapping the WENSS survey. Flux measurements at 74, 325 and 1400 MHz were taken from the VLSS, WENSS and NVSS catalogs respectively. Note that most sources have a spectrum that flattens in the lower frequency interval. The median spectral index change for these sources is: $Med(\alpha_{74}^{325} - \alpha_{325}^{1400}) = 0.16$.

higher frequency surveys such as NVSS.

2.4 Future plans for VLSS

The VLSS observations are now about halfway complete. During the next VLA BnA and B-configurations, (December, 2004 to April, 2005) we have been awarded time to observe most of the rest of the sky and we estimate that we will have then observed about 90% of our planned survey area. We anticipate having this data reduced, verified and cataloged so that we can make it publicly available by late 2005. After this point we will only require smaller amounts of time to complete the survey and conduct re-observations of high noise or failed observations.

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