Compactness of Weak Radio Sources at High Frequencies

W. A. Majid\textsuperscript{1}, E. B. Fomalont\textsuperscript{2}, D. S. Bagri\textsuperscript{1}

Abstract.
We have obtained 8.4 GHz VLBA observations of a 31-GHz complete sample of \( \sim 100 \) sources between 10 and 100 mJy. The main goals of these observations are: to determine the angular size, radio spectra and identification for a weak sample of high frequency sources; to find the fraction of sources which have sufficiently compact emission for use as calibrators for VLBI observations; and for design considerations of the proposed DSN Array. We find that a large fraction of observed sources have VLBI detections. A majority of these sources have most of their emission in a compact < 1 mas radio core, with remaining sources having steep radio spectra. The source list was provided from GBT observations to remove discrete sources in the CBI fields.

1. Nature of High Frequency Radio Sample
Carrying out a VLBI survey of a complete and unbiased sample of weak radio sources at high frequencies provide fundamental astronomical information on the statistical and morphological properties for this class of astrophysical objects. Previous surveys of the nature and structure of weak radio sources have been carried out at relatively lower frequencies, often at 1.4 GHz (e.g. Garrett et al. 2005). At the mJy level, the proportion of AGN’s are decreasing and the population begins to be dominated by galaxies that have significant star forming regions. These are typically less than 3', with about 30% showing milliarcsecond emission (Muxlow et al. 2005).

However, the angular characteristics of sources above 8 GHz are not well-known at the mJy level. We plan to determine the percentage of compact milliarcsecond emission, its orientation and accurate core position for better optical identification. We also plan to study spectral index correlation versus galaxy type and compare our results with similar studies carried out for brighter sources and similar surveys at lower frequencies.

2. VLBI Calibrators at the mJy Scale
Differential VLBI is routinely used to determine spacecraft positions with accuracies of \( \sim 1 \) mas using compact radio sources with flux > 300 mJy at 8.4 GHz within about 5-10 degrees of the spacecraft. Further improvement in accuracy

\textsuperscript{1}Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, U.S.A
\textsuperscript{2}National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, U.S.A
is possible by observing calibrators with smaller angular separation with spacecraft, reducing tropospheric and astrometric errors. Since sources with flux \( \sim 10 \) mJy can be detected with a pair of 70m antennas of the Deep Space Network (DSN), much fainter calibrators can be used. One of the goals of this survey will be to determine what fraction of faint sources are useful as VLBI calibrators.

Furthermore, NASA’s DSN is considering a new generation of large number of small \((\sim 12 - m)\) antennas. The increased sensitivity of the array along with relatively large primary beam may allow for in-beam phase referencing at 8 GHz if the percentage of mJy sources with milli-arcsec components is sufficiently high. We estimate that 30\% of such sources are compact, that is 1/5 of the sky will contain a sufficiently strong VLBI calibrator in the primary beam (Majid & Bagri 2007). At the proposed 32 GHz spacecraft telemetry, in-beam calibration will be very rare, but a calibrator within 2 deg will permit position determination at the 0.1 mas level.

3. Source Selection and Summary of Observations and Data Reduction

We compiled a list of \( \sim 100 \) sources complete to 10 mJy at 31 GHz from recent observations by the GBT (thanks to B.Mason, NRAO) in two right ascension fields near the equator at 02h and 20h. All sources from the 1.4 GHz NRAO VLA Sky Survey (NVSS) above 6 mJy were observed and detected by the GBT (Condon et al. 1998). We carried out 8 GHz VLBA observations of each source with a GBT flux density \( > 10 \) mJy in January 2007 during two 10-hour observing sessions. In a typical phase referencing nodding style, each source was observed alternately with a near-by phase calibrator (J2036-0629 and J0239-034). On-source integration time was 4 minutes, while calibrator observations were carried out with an integration time of 30-sec. Each target was observed 3 times during an observing session in order to improve \((u,v)\) coverage. In addition, we also included a few 30-min segments of observations of strong ICRF sources around the sky in order to improve the tropospheric delay model.

The NRAO Astronomical Image Processing Systems (AIPS) was used for the data calibration and subsequent imaging. Fringe fitting was carried out for each phase reference calibrator. The phase, delay and delay rate solutions obtained were interpolated and then applied to the program source visibility data. The typical imaging process involving several iterations of CLEANing and phase calibration resulted in images with an rms thermal noise error of \( \sim 1 \) mJy. Because the apriori position error of the sources were as large as 2” with the NVSS position, detection could only be made at the 5 – \( \sigma \) level over the large-field of view using the shorter VLBA baselines. With an rms noise level of 1 mJy, detections could be made at the 5 mJy level.

4. Preliminary Results

Of the 65 sources observed we detected 33 sources. The majority of detected sources are unresolved at the mas scale radio structure. Using the JMFIT program in AIPS, we fitted each image with a two-dimensional gaussian and determined the peak to total flux density distribution, which we refer to as the
compactness factor. For each source in the sample, we also obtained a spectral index using the NVSS and GBT flux density measurements at 1.4 and 31 GHz respectively.

Figure 1 shows the distribution of the spectral index for the detected and undetected sample. As expected, there is a clear trend towards flatter spectra in the detected sample, while the undetected sample tends to have steeper spectrum. We also see a clear correlation in compactness factor with the spectral index.

We attempted to identify optical counterparts for each source in the sample. We used the I-band digitized Palomar Schmidt archives to search for possible counterparts down to a magnitude of 20. Our preliminary analysis shows that a large fraction (2/3) of compact sources have positional association with an optical counterpart, while only \( \sim 15 \% \) of undetected sample indicate any association with an optical source.

Figure 1. Spectral index distribution for the undetected and detected samples. The undetected sample tend to show steeper spectra, while the distribution of the detected sample increases gradually as the spectra get flatter and reaches a peak at spectral index of \(-0.2\). Spectral index is obtained from measured flux density at 1.4 and 31 GHz.
5. Conclusions

We carried out a small 8 GHz VLBA survey of a complete sample of radio sources down to a flux density of 10 mJy. Sources were identified from a sample of NVSS sources with 31 GHz GBT detections. We detected $\sim 50\%$ of the observed sources with VLBI components. As expected sources with flatter spectra tend to exhibit mas emission. In addition, we note that the compactness factor increases for sources with flatter spectra. Our preliminary results also indicate a relationship between optical identification and source compactness.

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