VLBA IMAGING OF SOURCES AT 24 AND 43 GHZ

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ABSTRACT. We have imaged the sub-milli-arcsecond structure of 274 extragalactic sources at 24 and 43 GHz in order to assess their astrometric suitability for use in a high-frequency celestial reference frame. Ten epochs of observations with the Very Long Baseline Array were conducted over the course of ∼5 years, resulting in a total of 1339 images produced for 274 sources at K-band and 132 sources at Q-band. A detailed analysis of the images allowed us to characterized the effects of intrinsic source structure on the astrometric observations. We find that the average flux densities for the sources imaged at these higher frequencies is ∼1 Jy, with epoch-to-epoch variations of less than 20%. We also find that the intrinsic structure of the sources is reduced at 24 and 43 GHz relative to typical X-band results. Finally, we find that variations of the flux density contained within the radio core relative to the total source flux density are less than 8% on average at 24 GHz. Our results indicate that there are numerous sources available at high frequencies, and these sources persist over relatively long periods of time. In addition, the sources are more compact at these higher frequencies and should provide high-quality astrometric reference points resulting in an improved celestial reference frame.

1. INTRODUCTION

As part of a collaborative effort to extend the International Celestial Reference Frame (ICRF) to higher radio frequencies, we have observed a number of extragalactic sources at Q band (43 GHz) and K band (24 GHz) using the 10 stations of the Very Long Baseline Array (VLBA) operated by the National Radio Astronomy Observatory (NRAO). The long term goals of this program are: 1) to develop a high-frequency celestial reference frame (CRF) with a variety of applications including improved deep space navigation, 2) to provide the astronomical community with an extended catalog of calibrator sources for VLBI observations at 24 and 43 GHz, and 3) to study source structure and source stability at these higher frequencies in order to improve the astrometric accuracy of future reference frames.

Over the course of 5 years from 2002–2007, 10 epochs of VLBA observations were recorded for the high-frequency reference frame program. All 10 of these epochs included observations at 24 GHz. Additionally, four of the 10 epochs included simultaneous observations at 43 GHz and two of the epochs included observations at X-band (8.4 GHz). Details concerning the observing strategy, data calibration, astrometric analysis, and construction of a high-frequency catalog will be presented in a forthcoming paper by Lanyi et al. (2009). In these proceedings, we concentrate on the imaging aspects of the program, specifically source flux density, intrinsic source structure, and the variations of each of these quantities. In §2 we briefly summarize the data calibration and imaging process, whereas §3 and §4 contain the results of the analysis of the resulting images. A more detailed discussion of the entire high-frequency imaging program will be presented in a forthcoming paper by Charlot et al. (2009).

2. DATA CALIBRATION AND IMAGING

Data from the 10 epochs of VLBA K- and Q-band observations were calibrated and corrected for residual delay and delay rate using the NRAO's Astronomical Image Processing System (AIPS). Initial amplitude calibration was accomplished using system temperature measurements taken during the observations combined with NRAO-supplied antenna gain curves. Fringe-fitting was performed using solution intervals equal to the scan durations and a point source model in all cases. After correction for residual delay and delay rate, the data were written to FITS disk files, and subsequent image processing was carried out using the Caltech DIFMAP software package.

The visibility data for each frequency band were edited, self-calibrated, Fourier inverted, and CLEANed. Self-calibration and imaging was performed using an automatic script in an iterative procedure that corrected the data for residual amplitude and phase errors. A point source model was used at the beginning and convergence was achieved when the peak in the residual image became less than a specified factor times the root-mean-square (rms) noise of the residual image from the previous iteration. The 1–2% of sources with emission structure too complex or too extended for the automatic imaging script to handle were imaged by hand, i.e. in an interactive mode, following the same prescription as that for the automatic mode. Subsequent image analysis was performed outside of DIFMAP using the CLEAN components models resulting from the imaging of each source.

3. SOURCE FLUX DENSITY

For sources to be effective astrometric references (e.g. for spacecraft navigation and astronomical phase referencing) they should have relatively high flux densities and little variation in the flux density over time. From the CLEAN components models derived from the imaging, the total source flux densities ($S_{\rm total}$) were determined for all of the sources in all sessions in both frequency bands. From $S_{\rm total}$ we computed the mean flux density ($\bar{S}$) per source averaged over all sessions in which the source was observed. Plotted in Figure 1 are the distributions of $\bar{S}$ for all of the sources imaged in the program including 138 sources at X band, 274 sources at K band, and 132 sources at Q band. The mean (median) values of the distributions are approximately 1.5 (0.8) Jy at X band, 1.1 (0.7) Jy at K band, and 1.4 (0.9) Jy at Q band. Similar results were found for the 97 sources that were common to all three observing bands, where the mean (median) values were found to be 1.7 (0.9), 1.5 (0.9) and 1.5 (1.0) Jy at X, K and Q bands, respectively. It should be noted that the higher average Q-band flux densities (than K-band) are likely due to a selection effect, since these sources were drawn from a pool of strong sources with an X-band flux of >300 mJy. The K-band flux density results, however, contain sources for which this minimum X-band cut-off criteria was relaxed to ~200 mJy.

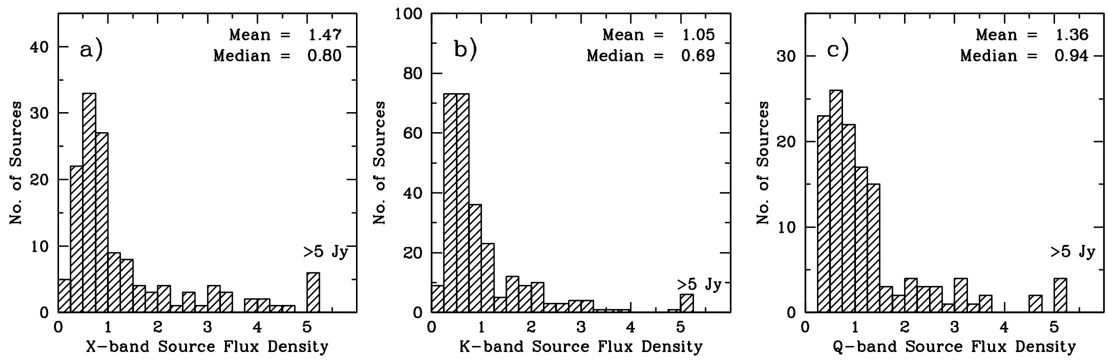

Figure 1: Distributions of the mean (averaged over all epochs) source flux density ($\bar{S}$) at a) X band, b) K band, and b) Q band. There were a total of 138, 274, and 132 sources, respectively, for which the flux density was measured at each of the three bands in our VLBA data set.

We characterized the extent to which the total flux density varied over time by computing the flux density variability index ($\sigma_S/\bar{S}$), which is the standard deviation of the measured flux densities per source divided by the mean. A minimum value, $\sigma_S/\bar{S} = 0.0$, indicates no variation in the flux density with time.

We determined $\sigma_S/\bar{S}$ for 235 sources at K band and 132 sources at Q band that were observed in two or more VLBA epochs. We computed mean (median) values of the flux density variability of 0.18 (0.16) for the K-band sources and 0.19 (0.15) for the Q-band sources. Thus we find that the average epoch-to-epoch flux density variations are less than ~20% at both K and Q band. These results are limited to the ~5 yr period over which our data were recorded and by the ~10% variations in the absolute flux density scale of the data.

4. SOURCE STRUCTURE

The structure of the sources was characterized using the structure index (SI), first described in Fey & Charlot (1997). The structure index for each source at each epoch was determined using source CLEAN components models derived from the images. Structure indices were determined in a manner similar to that presented in Fey & Charlot (1997, 2000). Figure 2 compares the distributions of the source structure indices derived from our VLBA observations at the three bands, X, K, and Q. The figure plots histograms of the maximum SI drawn from all available sessions in which the structure index for a particular source was determined. There were a total of 138 sources at X band, 274 sources at K band and 132 sources at Q band for which the SI was measured. The figure shows a greater number of $SI = 1, 2$ (the most compact) sources at progressively higher frequencies. The percentage of $SI = 1, 2$ sources is 71, 85, and 92% for X-, K-, and Q-band, respectively. Similar results were found for the 97 sources common to all three frequencies, where the percentage of sources having $SI = 1, 2$ is 71% at X, 87% at K, and 93% at Q band. These results suggest that the impact of source structure should be reduced at higher frequencies.

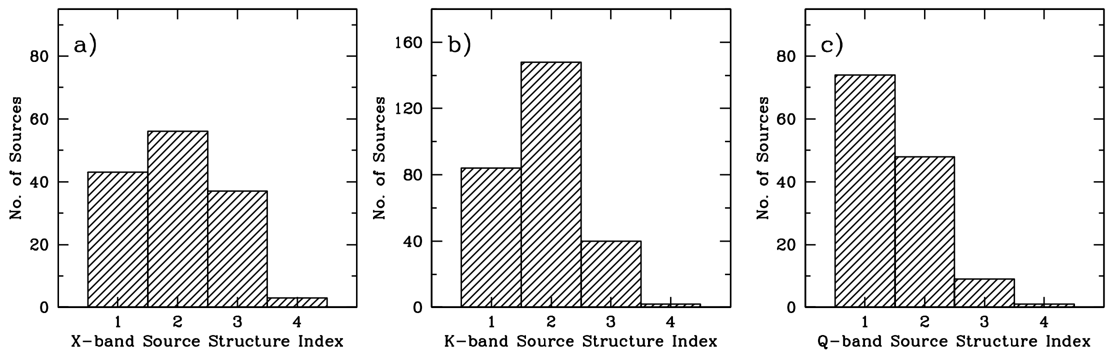

Figure 2: Distributions of values for the maximum source structure index (SI) at a) X band, b) K band and c) Q band. There were a total of 138, 274, and 132 sources, respectively, for which the maximum SI was measured at each of the three bands in our VLBA data set.

To characterize the changes in source structure over time we introduce the source compactness, C, and the compactness variability index ($\sigma_C/\bar{C}$). Both are computed on a continuous scale between 0.0 and 1.0 and are more sensitive to small changes in the structure over time. The compactness, C, is the ratio of the flux contained within the synthesized beam to the total image flux ($S_{\rm beam}/S_{\rm total}$). A value of $C = 1.0$ represents a point-like source with no extended emission. The source compactness variability index is defined as the standard deviation of the compactness divided its the mean ($\sigma_C/\bar{C}$), similar to the flux density variability index. A value, $\sigma_C/\bar{C} = 0.0$, corresponds to no variation in the compactness over time. Shown in Figure 3 are the distributions of source compactness variability index for sources imaged in more than one session at K and Q band, respectively. The mean (median) compactness variability for the 235 sources at K band is 0.08 (0.06). For the 82 sources at Q band mean (median) values of $\sigma_C/\bar{C}$ are slightly smaller 0.07 (0.05). These results indicate that, on average, the high-frequency radio emission from the core of these sources relative to the total flux density varies by no more than about 8% at either frequency. As in the case of the flux density variability, the compactness variability results are limited to the ~5 yr period over which our VLBA data were recorded.

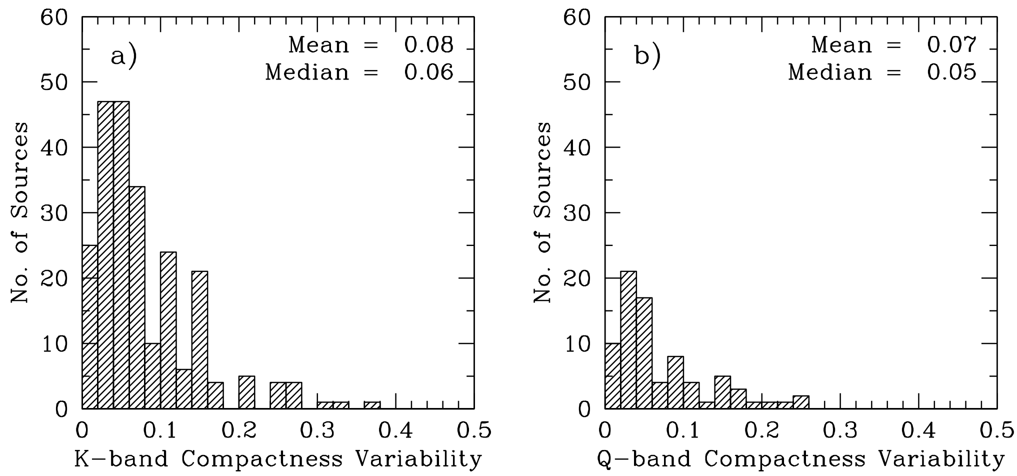

Figure 3: Distributions of the source compactness variability index ($\sigma_C/\bar{C}$) for sources at a) K band and b) Q band. There are a total of 235 sources observed in more than one epoch at K band, and a total of 82 sources observed in more than epoch at Q band. A minimum variability, $\sigma_C/\bar{C} = 0.0$, indicates no variation in the compactness over time.

5. CONCLUSIONS

We have produced a combined total of 1339 K- and Q-band images of 274 extragalactic sources from ten epochs of VLBA data observed as part of a program to select high-frequency sources for use in spacecraft navigation and future celestial reference frames. A detailed analysis of the images allowed us to characterized the strength of the sources, the intrinsic structure of the sources, and the variability of each of these quantities. We find that the distributions of source flux density at K and Q band show mean values greater than 1 Jy for each of the two high-frequency bands. Epoch-to-epoch variations are less than 20% over the ∼5 yr observing period. We also find a clear dependence of source structure index, SI, on observational frequency. The percentage of sources with $SI = 1, 2$ (the most compact) increases from ∼70% at X band, to ∼85% at K band, to ∼92% at Q band. This result suggests decreased effects due to source structure at higher frequencies. Finally, we find that variations in source structure, as measured by the source compactness variability, are less that 8% on average. Our results indicate that there are numerous sources available at high frequencies, and these sources persist over relatively long (5 years) periods of time. In addition, the sources are more compact at these higher frequencies and should provide high-quality astrometric reference points.

6. REFERENCES

Charlot et al., 2009, "The Celestial Reference Frame at Higher Radio Frequencies. II. VLBA Imaging at 24 and 43 GHz", AJ, submitted.

Fey, A. L., & Charlot, P., 2000, "VLBA Observations of Radio Reference Frame Sources. III. Astrometric Suitability of an Additional 225 Sources", ApJS, 128, 17.

Fey, A. L., & Charlot, P., 1997, "VLBA Observations of Radio Reference Frame Sources. II. Astrometric Suitability Based on Observed Structure", ApJS, 111, 95.

Lanyi, G. et al., 2009, "The Celestial Reference Frame at Higher Radio Frequencies. I. VLBA Astrometric Observations at 23 and 43 GHz", AJ, submitted.