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DUAL-FREQUENCY SYNTHESIS VLBI OBSERVATIONS OF 3C84 AT 18 CM WAVELENGTH

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ABSTRACT We present results of a multi-frequency synthesis VLBI experiment which employed observations at 1622 and 1707 MHz. Combining data from two frequencies gave a factor ~2 improvement in dynamic range over the single frequency images. We estimate map fidelity by comparing the images made separately from each frequency; while the dynamic range is ~1800, the fidelity index is only ~5.

INTRODUCTION

Multi-frequency synthesis (MFS) promises to be a very powerful technique for improving (u, v) coverage from a fixed antenna array (Wilkinson, Conway, Biretta 1988). It should be especially beneficial to VLBI, yet there have been almost no attempts to apply MFS to VLBI observations. We have performed a two-frequency VLBI synthesis observation in order to (1) investigate the improvement in image quality which might be attained with MFS, and (2) quantify the fidelity of VLBI images by comparing maps made largely independently at nearly the same epoch.

The radio galaxy 3C84 (z=0.018) was chosen for these tests, since it is a very strong compact radio source and should have a large ratio of peak intensity to thermal noise. It is a source with complex structure in the core region (*e.g.* Bartel, *et al.* 1988) and one of the few sources with detected sub-luminal motion (Marr, *et al.* 1989). We chose L band since a large fractional bandwidth can be obtained, and atmospheric effects and pointing errors are small. It should also allow one to follow the moving components which are now difficult to detect at higher frequencies.

OBSERVATIONS AND REDUCTIONS

Data at 1622 MHz were obtained on 3 Nov. 1989, and at 1707 MHz on the following day. The integration time was about 15 hours per antenna per frequency; the Mk II system was used. The number of antennas producing useful data was 13 and 11 at the respective frequencies.

The data were globally fringe-fitted, carefully edited, self-calibrated, mapped, and CLEANed in the standard way using AIPS and the Caltech package. Four unresolved sources provided amplitude calibration. The two data sets were mapped independently, except that a model derived from the 1622 MHz data was used in fringe-fitting both data sets. The separate maps are shown in Figs. 1a and 1b.

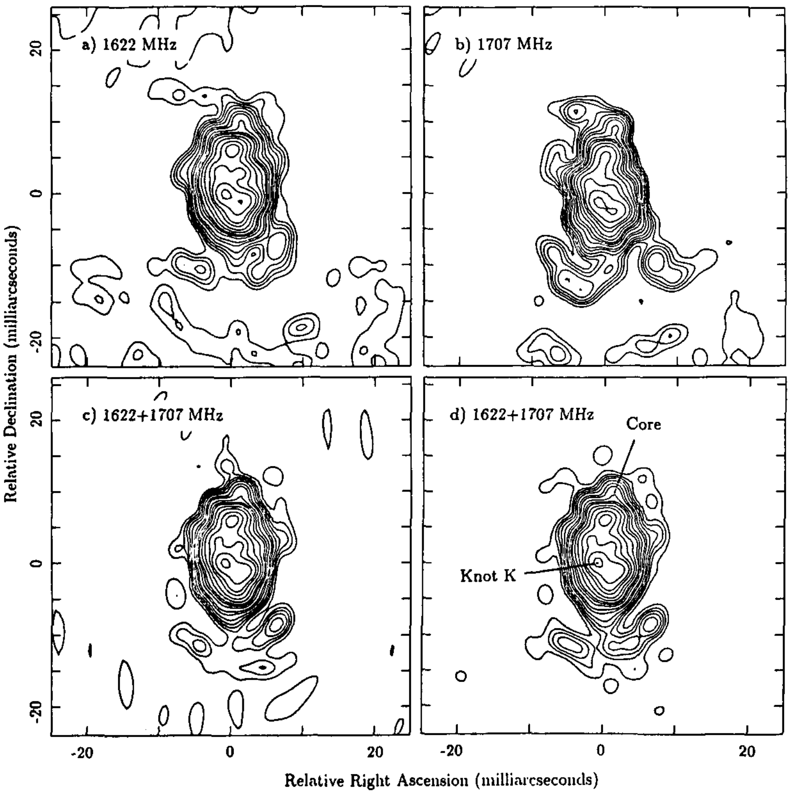

Fig. 1. Contours are at -0.4, 0.4, 0.7, 1, 1.4, 2, 3, 4, 6, 8, 10, 14, 20, 30, 40, 60, and 90% of the peak intensity. The FWHM of the circular beam is 3 mas. (a) 1622 MHz image; (b) 1707 MHz image; (c) image from combined 1622 and 1707 MHz (u, v) data; (d) same as (c) but with additional self-calibrations.

The (u, v) data were then combined and self-calibrated to make the map shown in Fig. 1c. More extensive self-calibration including correction of baseline dependent errors produced the "best" map shown in Fig. 1d. No special algorithms were used to treat spectral index variations.

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RESULTS

The maps reveal a complex and unusual structure. Comparison with higher frequency maps (Marr *et al.* 1989; Venturi, private comm.) suggests the northern-most bright feature is the core, and the brightest feature is the sub-luminal knot "K." While the total flux density in the VLBI map is 27 Jy, the peak brightness is only 4 Jy beam^{-1}. The complex structure and the lack of a dominant, unresolved component make it a severe test of VLBI imaging capabilities.

The dynamic range attained by the separate data sets is 1600:1 and 1900:1. The combined data give a dynamic range of 3300:1, roughly twice as large, indicating that dual-frequency synthesis can give a larger improvement than would be expected from merely doubling the integration time. The "best" map (Fig. 1d) has a dynamic range of 4900:1. The background r.m.s. is ~5 times the expected thermal noise, so there is still room for improvement.

The only important difficulty presented by the MSF technique was the presence of strong radio interference at the non-standard frequencies. Both data sets contained one or two antennas with highly erratic amplitudes caused by interference.

DYNAMIC RANGE VS. IMAGE FIDELITY

"Dynamic range," defined here as the ratio of peak intensity to r.m.s. background noise, is a very useful tool for evaluating map quality. However, it is possible that bright regions of the map have errors much larger than the background r.m.s. noise. Since we have two largely independent images, we can difference them and obtain a rough estimate of "fidelity" or accuracy in bright regions. Differences as large as ± 0.8 Jy beam^{-1} were found, even though the background r.m.s. is only $\sim$ 0.0025 mJy beam^{-1}. Hence, *the "dynamic range" can underestimate errors in bright regions by several orders of magnitude.*

One way of quantifying the fidelity is to compute for each pixel the magnitude of the fractional difference between the images. The median reciprocal of these values, or "Fidelity Index" (see Holdaway, this conference), is only ~5 for the present images. This value indicates average errors in the bright regions of around 20%.

FUTURE MULTI-FREQUENCY SYNTHESIS WITH THE VLBA

Since the VLBA comprises only ten antennas, it is desirable to augment the (u, v) coverage by some technique such as MFS. One of us (JB) is studying the multi-frequency imaging capabilities of the VLBA. Frequency response measurements have been made for a number of antennas. In general, the usable bandwidths are about twice those of the design specification. Measured $\Delta\nu/\nu$ are 49%, 18%, and 21% at L, C, and K bands respectively.

The baseband converters will be capable of simultaneously recording 8 separate 4 MHz bands spread over 500 MHz. The improvement in (u, v) coverage obtained by an 8 channel synthesis at L band is illustrated in Fig. 2.

It will be necessary to measure the radio interference spectrum at individual antennas to allow an optimum choice of frequencies.

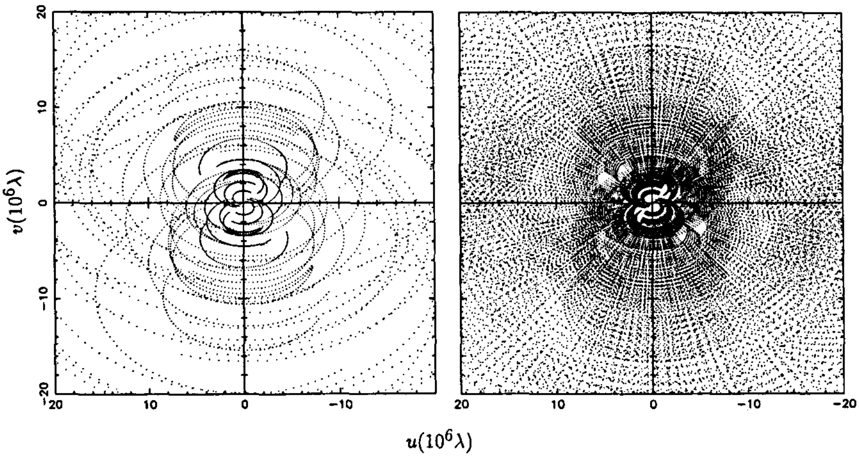

Fig. 2. Comparison of the (u, v) coverage from single frequency (left) and 8 frequency MFS observations (right) at L band with the VLBA.

CONCLUSIONS

1) Multi-frequency synthesis can give a large improvement in the dynamic range of VLBI images. For the present two-frequency synthesis, the improvement is about a factor of two.
2) The "dynamic range" can underestimate errors in bright regions by several orders of magnitude. For our two data sets the dynamic range is ~1800, but the fidelity index is only ~5.
3) Multi-frequency synthesis should be a very powerful technique for improving the (u, v) coverage of the VLBA.

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