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# THE USE OF BEAM-SETS IN THE ANALYSIS OF WIDE-FIELD MAPS FROM THE CLFST

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ABSTRACT The Cambridge Low Frequency Synthesis Telescope (CLFST) has baselines which are offset from the E-W direction by about 3°. The wide-field mapping problem has been overcome by the use of beam-sets, or artificial maps consisting of grids of synthesized beams, which incorporate the effects of both the geometric and chromatic aberration. By appropriate interpolation we can find a good approximation to the beam-shape at any point on a map.

## INTRODUCTION

The beam-set method is essentially a technique for survey work: for analysing wide-field maps rapidly and accurately to produce catalogues of positions and flux densities of large numbers of sources. It was developed for the analysis of the first part of the 7C survey at 151 MHz (McGilchrist et al. 1990) and was also used in constructing the 38 MHz survey (Rees 1990). Here it will be described in terms of the 151 MHz application; for more details see Waldram and McGilchrist (1990).

## MAPPING WITH THE CLFST

The CLFST is an earth-rotation synthesis instrument with a resolution at 151 MHz of $70''$x $70''$cosec$\delta$. It has a very well filled aperture and a wide field of view (9°x 9°), but the baselines are only approximately E-W, the mean offset being equivalent to about 2° from the equatorial plane; so the effective aperture generated in a 12-hr run is approximately the surface of a split cone of half-angle 88°. Since the aperture is not coplanar, there is not an exact 2D Fourier Transform (FT) relation between sky brightness distribution and observed visibilities. A map generated by a 2D FT shows a synthesized beam which varies over the field of view and becomes increasingly distorted with increasing distance from the phase centre. The chromatic aberration due to the finite bandwidth also produces significant beam-smearing in the wide field.

Various mapping strategies were considered. A method involving 3D FT followed by 3D CLEAN (Clark 1982, Perley 1989) was ruled out through lack of computing power. 'Mosaicing' — i.e. making a number of very small maps at a series of different phase centres (Clark 1982) — was a possibility, but, for our 7C fields, about 100 component maps would be required for each observation centre to achieve a sufficiently uniform beam over the whole field of view. It was decided to 'mosaic' to the extent of making maps at four different phase centres for each observation centre, to convert the 3D visibilities to 2D values in the equatorial plane, using a simple phase correction that is exact only at the phase centre, invert with a 2D FT and deal with the beam distortion at the source analysis stage.

### The problem of analysing the maps

At the map centre there are negligible phase errors and the synthesized beam is effectively undistorted. Away from the phase centre, however, the beam becomes smeared into a C shape; the peak is depressed in height and shifted in RA. For a given phase centre $\alpha_0, \delta_0$, and for small angles $\Delta\alpha, \Delta\delta$ from the map centre, the position shift in RA is approximately proportional to $\mathrm{cosec}\delta_0 \left[(\Delta\alpha)^2 + (\Delta\delta)^2\right]$. For maps at different phase centres, the distortion is independent of $\alpha_0$, but it is dependent on $\mathrm{cosec}\delta_0$, and so increases rapidly at low declinations. At the edge of our 7C maps, the RA shift may reach 1 arcmin and the depression in the peak of the beam, due to both geometric and chromatic aberration, may be as much as 50%. In order to find accurate source parameters, we need to know the correct beam-shape at each source position on the map.

## THE BEAM-SET AND ITS USE IN SOURCE FINDING

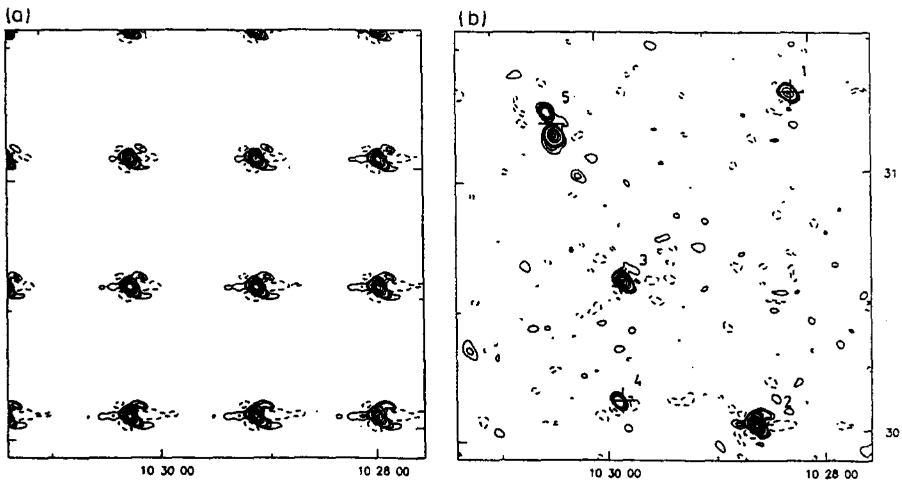
The beam-set is an artificial map, having effectively the same observation centre, phase centre, size and sampling as the actual map, but consisting simply of a grid of unit point sources or beams. The beam-shape at any position on the actual map can be calculated from a simple interpolation of the four nearest beams on the beam-set. The set incorporates the same geometric and chromatic aberration as the actual map. The beams are calculated from the model visibilities by a single 2D FT on one map and are placed far enough apart for the response from each to have fallen to essentially zero at the position of its neighbours. For the 7C maps, the spacing is 30′x 30′cosec$\delta$ (9x9 beams on each map) or, for declinations below 40°, 15′x 15′cosec$\delta$ (17x17 beams). In practice, since the beam distortion is independent of $\alpha_0$ , the same beam-set can be used for all maps with the same $\delta_0$, provided $\delta_0$ bears the same relation to the observation centre.

### Source finding

Having first scanned the map for local maximum pixels down to a chosen cut-off level we then, at each local maximum, find the appropriate beam by interpolation of the beam-set. We attempt to fit each source response with the correct beam-shape by minimising: $\sum_i (C_i - O_i)^2$ where $C_i = hB_i(x,y) + z$, over about 75 grid points around the source. $O_i$ is the observed map value and $C_i$ the calculated map value at the $i$th map grid point; $B_i(x,y)$ is the beam value at the $i$th point, corresponding to the beam centre at $(x,y)$, $h$ is the 'height' of the source and $z$ the local zero level. We use an iterative method, taking starting values and minimising with respect to small first order changes: $\delta x$, $\delta y$,

$\delta h$, $\delta z$. This converges well in two or three iterations for a point or nearly point source and returns a residual to indicate the goodness of fit, e.g. how much the source is extended. The method automatically takes care of the position shift and peak depression.

For an extended source, the position can be estimated by a number of different methods, such as interpolating on the map to find the peak position, or finding the centroid of flux. Any position measurement is then corrected by the appropriate shift in the peak of the beam, as calculated from the beam-set. The flux density can be found by CLEANing, using the beam-set to find the 'dirty' beam at that position on the map. Another method is 'integration', i.e. summing the map pixels down to a chosen contour level , and using the beam-set to find the appropriate normalization factor for conversion to flux density.




(a) Portion of a beam-set (b) Corresponding section of a 7C map

## ACCURACY AND COMPUTING TIME

There are two main sources of error in the beam-set method: first, the beam-shape may be changing too rapidly over the map for good interpolation to be possible, and secondly, the flux smearing may produce too low a signal-to-noise ratio on individual map pixels. These effects were investigated by making artificial maps of point sources — both without noise and with typical map noise — and fitting them with the beam-set. For our 7C fields at declinations above 30°, the errors were negligible compared with other errors in the survey; below 30°, we have successfully improved the interpolation procedure.

We can compare the computing time for the beam-set method with that for full 'mosaicing'. If the time to make one map is 1 unit, a beam-set takes 10 units (9x9 beams) or 40 units (17x17 beams). The source fitting time is negligible, being about 0.02 units per 100 sources for both methods. So, for

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n similar phase centres, the times are (10+n) units above Dec.40°, or (40+n) units below Dec.40°, for the beam-set method, compared with 25n units for 'mosaicing' (i.e. for 4x25 mosaic maps per observation centre). As the survey is extended the advantage in using beamsets will become considerable.

## CONCLUSIONS

The beam-set method has a number of advantages: it is accurate and very economical of computing time and power, and makes possible the rapid reduction of large amounts of data into source catalogues. It can deal with both the geometric and the chromatic aberration and, in fact, any aberration that can be modelled; the beam-set can incorporate the effects of missing spacings or samples, change of sampling interval or shadowing of aerials. The method does not depend on an analytic description of either the aperture or the beam, and is not limited to point or nearly point sources; it can be used in conjunction with CLEAN to analyse extended structure.

The technique works well for the CLFST because we have a well filled aperture and the geometry is such that the beam varies sufficiently slowly over the field of view. Does it have any application to other telescopes?

## ACKNOWLEDGMENTS

Part of this work was carried out in collaboration with Mark McGilchrist. It was first published in *M.N.R.A.S.* (Waldram and McGilchrist 1990) and permission has been given to reproduce here material from that paper.

We thank John Baldwin, Peter Warner, Sidney Kenderdine and Nick Rees for useful discussions and David Titterington for advice on computing.

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**David Murphy**: Can beam sets be used for HST image deconvolution?

**E. M. Waldram**: This had occurred to me but I don't know the answer. I will discuss it with Anthony Lasenby (MRAO) who is involved in working on the problem.