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The Effect on the AT of an Antenna at Perth

R.P.Norris
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Introduction

A group at the University of Western Australia is exploring the feasibility of moving an antenna from the Fleurs array to Perth Observatory. This note presents simulations to determine the value of such an antenna to the Long Baseline Array (LBA) of the Australia Telescope (AT) and to Australian VLBI. It should be noted that this document is an extension of earlier studies (AT/17.3.1/013 and AT/17.3.1/014), although, in order that this note be self-contained, it includes some introductory material (the sections on 'Background' and 'uv coverage') from that earlier study.

Background

The LBA at present consists of the tied array at Culgoora, the 22-m antenna at Siding Spring, and the 64-m antenna at Parkes. In addition, it is hoped to incorporate, on a collaborative basis, the antennas at Tidbinbilla (owned by NASA) and Hobart (owned by the University of Tasmania) in the array for perhaps one or two months each year. In addition, the Landsat antenna at Alice Springs has been, and hopefully will continue to be, used for a limited number of VLBI and LBA experiments. A VLBI antenna at Adelaide has also been proposed.

The three antennas at Culgoora, Siding Spring, and Parkes cannot , on their own, produce high quality synthesis images. Such images can, however, be produced by the addition of one or more antennas to the array. Because of the way the synthesis algorithms work, the effect of additional antennas is much greater than the simple increase in numbers. Thus adding a fourth antenna multiplies the amount of information by a factor of 2.0, whereas a fifth gives a further multiplication by a factor of 1.67, and so on. In qualitative terms, three antennas can produce a usable map only on the simplest structures, four antennas will generally produce a usable map , and five antennas can produce a high dynamic range map.

Thus, during the one or two months per year that the LBA collaborates with Tidbinbilla and Hobart to become a five-antenna array, the LBA is clearly capable of high quality synthesis imaging. However, this capability is limited by the geographical location of the antennas: they all lie approximately along a North-South line. The effect of this is that maps of sources at low absolute declinations will suffer from poor East-West resolution and imaging artefacts.

This defect can best be rectified by incorporating into the array an antenna which is East or West of the other antennas. Antennas situated at places such as Adelaide, Alice Springs, and Perth can therefore be expected to increase substantially the quality of the images from the LBA.

Whereas this is the principal benefit to be obtained from an antenna at Adelaide, the principal benefit obtained from an antenna at Perth is to treble the longest dimension of the array, resulting in a three-fold increase in resolution, so that the array including Perth could map objects a third of the size of those mappable with the five-station LBA.

U-V Coverage

The quality of a synthesis image depends not only on the number and separation of the antennas of an array, but also on their location. This is conveniently represented on a u-v diagram, which shows the apparent locations of the antennas as seen from the source. The Earths rotation causes these locations to appear as elliptical tracks in the u-v plane. The u-v plane is in the Fourier transform domain of the image, and so the tracks represent the sampled portions of the synthesised aperture. In general the best images are obtained from uniformly sampled u-v planes, and so a synthesis array should be designed to have as few major gaps in the u-v coverage as possible, since any gap will transform to a spatial frequency to which the array will be insensitive. The u-v coverage should also cover as large an area as possible, in order to achieve the highest resolution. Thus the goal of a designer of a VLBI array is to cover as much of the u-v plane as possible (for high resolution), whilst leaving as few gaps in that coverage as possible (for high image quality). The art of designing a good VLBI array is to balance these two factors.

The u-v diagrams to be shown here show a variety of gaps. The most pronounced is the East-West gap in the basic LBA for sources at near-equatorial declinations. Gaps such as this must be minimised in order to maximise the quality of the images.

Astrometry

As well as its function of mapping at high resolution, the LBA will also be used for astrometry. In particular, it is essential for instruments such as the Compact Array of the Australia Telescope that a framework of about 100 calibrator sources is available at declinations below -45° with positions measured to better than 0.1 arcsec. To obtain this accuracy using standard MkII VLBI techniques requires a baseline at least 3000 km long. At present, such a framework of calibrator sources is being built up using VLBI experiments between Tidbinbilla and South Africa, but the extreme length of this baseline (10000 km) means that many sources suitable for AT calibration are over-resolved, and so their positions cannot be measured. Thus we require a baseline about 3000 - 5000 km long. Such a baseline is obtainable in Australia only between Perth and the LBA. Thus the addition of Perth to the array would permit the construction of a calibrator frame without which the performance of the AT compact array will be seriously degraded in its first few years of operation.

The Effect of Perth

The Perth site was examined for its effect on the five-station LBA (Culgoora, Siding Spring, Parkes, Tidbinbilla, and Hobart) at four negative declinations (-80°, -60°, -30°, -10°). Positive declinations were not tested as the Northern sky is adequately observed by northern VLBI arrays.

Fig 1. shows the u-v coverage of the LBA. The first (left hand) column shows the u-v coverage of the five-station LBA (named LBA0), and the second column shows the effect of adding Perth. Each row shows the u-v coverage obtained for one particular declination. It is immediately apparent in the second column that (a) the Perth baselines complement the LBA baselines very effectively at northerly declinations, and (b) there is a large annular gap between the LBA0 coverage and the coverage from the Perth baselines at extreme southern declinations. The effect of this would be that northerly maps made with the Perth baselines would have high resolution with high image quality, but that southern maps would indeed have the high resolution promised by this large spacing, but that the image will contain defects caused by this gap - in particular it will omit structures of a certain range of sizes.

This shortcoming can be rectified by the addition of antennas at intermediate spacings. The remaining columns show the effect of including additional antennas at Adelaide or Alice Springs. Antennas at either of these sites help to fill in the annular gap, with Alice Springs being somewhat more effective than Adelaide. In both cases, the gap is filled particularly well at more northerly declinations. We may conclude from this than an array consisting of the five-station LBA, together with Perth and either Alice Springs or Adelaide, would be a powerful and effective high-resolution mapping instrument.

The effect of these u-v coverages are demonstrated in the CLEANed maps of a simulated source (at declination -60°) shown in Figure 2. The top map shows the original simulated source, and each of the other maps corresponds to one of the arrays in Fig. 1. The five-station LBA gives only a blurred image of the source, while the addition of Perth sharpens up the image but at the expense of degrading the image quality. The addition of either Alice Springs or Adelaide serves to give a high-resolution high-quality image. Naturally, the addition of both gives the best image of all.

Under each map is given the dynamic range of the map, which is a quantitative measure of the map quality. In line with the qualitative descriptions of the u-v coverage and map quality given above, the LBA on its own gives a high dynamic range but poor resolution, whereas the LBA+Perth gives a high resolution but a poorer (at declination -60°) dynamic range. Addition of either Adelaide or Alice Springs restores the dynamic range to nearly the original figure, and addition of both yields a dynamic range which is significantly greater than that of the LBA alone.

Conclusions

1) An antenna at Perth would be invaluable for astrometric VLBI experiments, and could remedy the current lack of an adequate framework of Southern calibrators for the AT Compact Array.

2) The addition of an antenna at Perth to the five-station LBA would result in an array which could produce high-quality high resolution maps at declinations just south of the celestial equator, where the LBA at present lacks the east-west baselines necessary to produce high quality images.

3) The addition of an antenna at Perth to the five station LBA together with an antenna at Adelaide or Alice Springs would result in an array which could map most of the Southern sky with high resolution and high image quality. Such an array would represent a major extension to the science available to the AT.

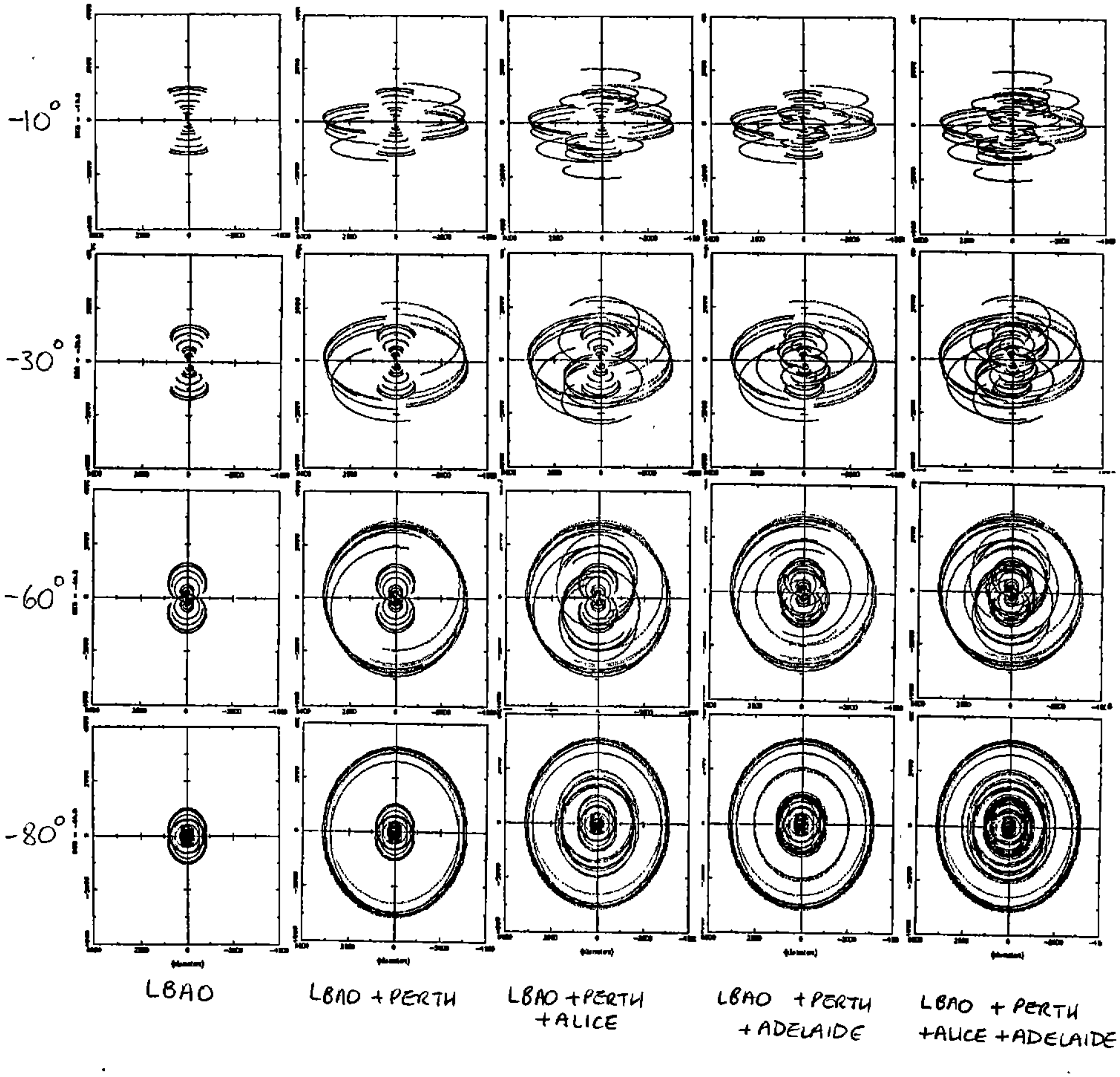
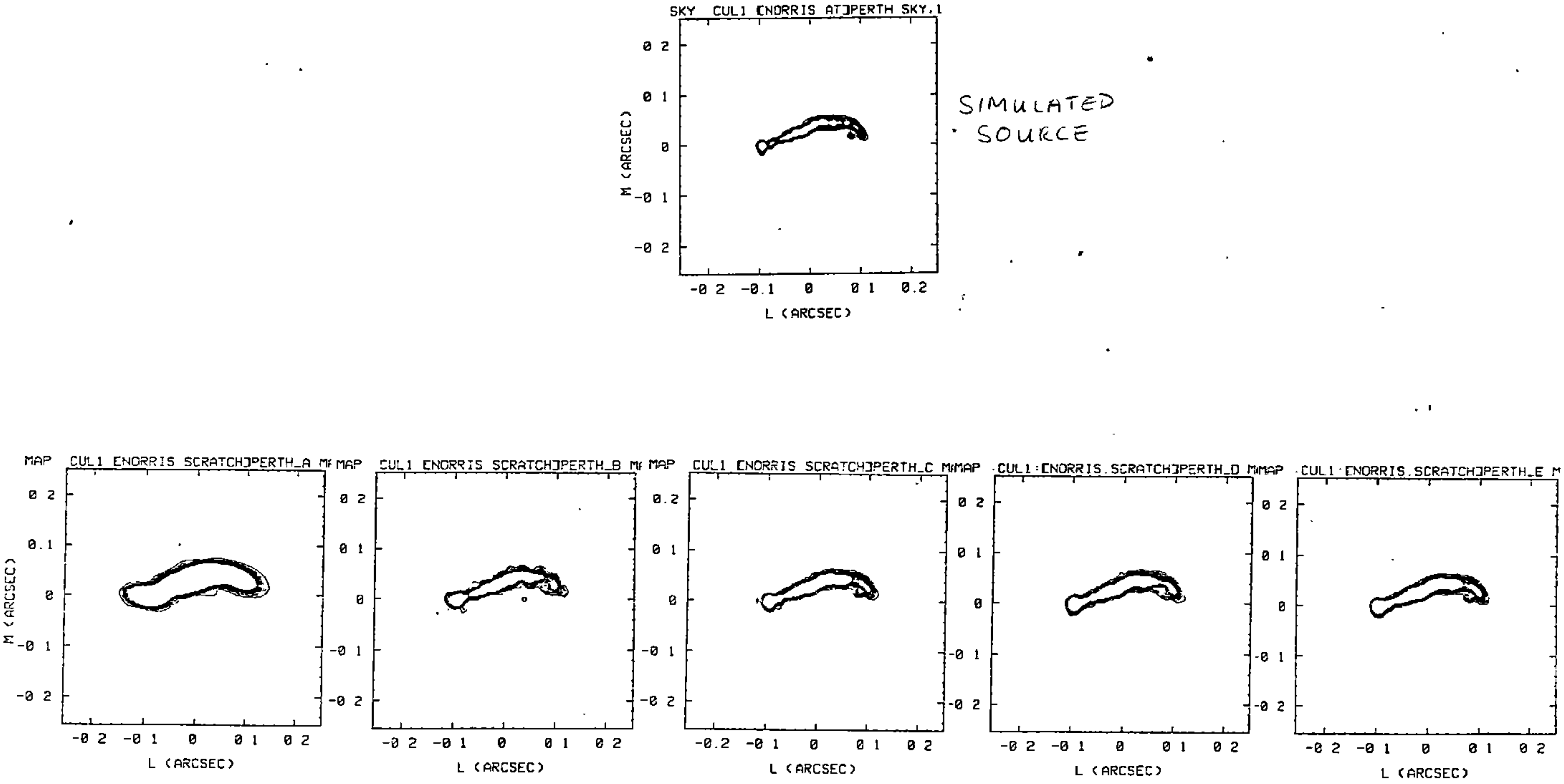

-10°
-30°
-60°
-80°
LBAO
LBAO + PERTH
LBAO + PERTH + ALICE
LBAO + PERTH + ADELAIDE
LBAO + PERTH + ALICE + ADELAIDE

FIGURE 1.



SIMULATED SOURCE

LBAO ONLY
DR = 32.0 dB

LBAO + PERTH
DR = 28.4 dB

LBAO + PERTH + ALICE
DR' = 31.6 dB

LBAO + PERTH + ADELAIDE
DR = 31.4 dB

LBAO + PERTH
+ALICE + ADELAIDE
DR = 33.1 dB

FIGURE 2.