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GMRT MAPPING STRATEGIES

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ABSTRACT The Giant Metrewave Radio Telescope (GMRT) that is being built to operate at metre wavelengths, will encounter a number of problems that are specific to synthesis imaging at low frequencies. Some of these problems are highlighted and possible solutions that are being considered, are discussed.

INTRODUCTION

The Giant Metre Radio Telescope (GMRT) is a low frequency synthesis array that is being built near Pune (latitude 19°06′, longitude 74°03′E)by the Tata Institute of Fundamental Research, India (Swarup 1990). The array consists of 30 parabolic antennas each of 45m diameter that are distributed over a region of radius 14km. The currently planned operating frequencies of the array are 38, 153, 233, 327, 610 and 1420 MHz, the observing frequency being computer selectable. Because of its low latitude, the GMRT will be able to observe all sources in the declination range -60° to 90°. The first antenna is expected by beginning of 1991 while the entire array is projected to be completed by 1993.

GMRT ARRAY CONFIGURATION

The configuration of the thirty antennas was driven by the conflicting requirements of high angular resolution and high sensitivity to diffuse extended emission. While mapping with high angular resolution requires the u-v coverage to be as uniform as possible, high sensitivity to extended emission requires the density of measurements in the u-v plane to be peaked near the origin. Since, unlike the VLA, the 45m antennas are not moveable, these conflicting requirements have to reconciled in the configuration of the antennas. The final configuration of the GMRT (Fig. 1) consists of a central condensed array containing 12 antennas distributed over an area of diameter approximately 1km, and 3 arms in the rough shape of a Y. There are 6 antennas in each arm, which is roughly 14km in length. While the required position of the antennas along the arm was computed to optimise the u-v coverage, the actual position of the antennas was determined by logistical considerations like flatness of the site, access from existing roads, etc.

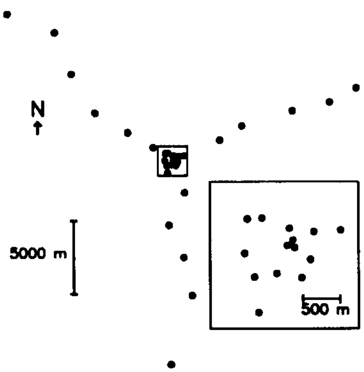

Fig. 1. The GMRT array configuration

Since the antennas in the central array are close to each other, they can be used as a phased array for certain kinds of observations. Initially, to maximize the sky coverage of the phased array for pulsar searches, it was proposed to have a periodic distribution of antennas in the central region which had a grating response. However, this idea has been dropped and the periodic pattern has been randomised. To measure the visibilities at the very short spacings, 3 antennas have have been located close to each other as an equilateral triangle of side 105m.

This composite array configuration gives satisfactory u-v coverage both at long and short spacings. In Fig 2 and 3, we show the full synthesis u-v coverages of the array at both long and short spacings.

PROBLEMS IN MAPPING WITH THE GMRT

The problems of synthesis mapping at metre wavelengths are considerably different from those at centimetre wavelengths. While the problems of interference and calibration are similar at both high and low frequencies, those of wide field mapping like the effect of the w term and nonisoplanaticity are essentially low frequency problems. For overcoming these problems, one needs considerable computing power which is now becoming available.

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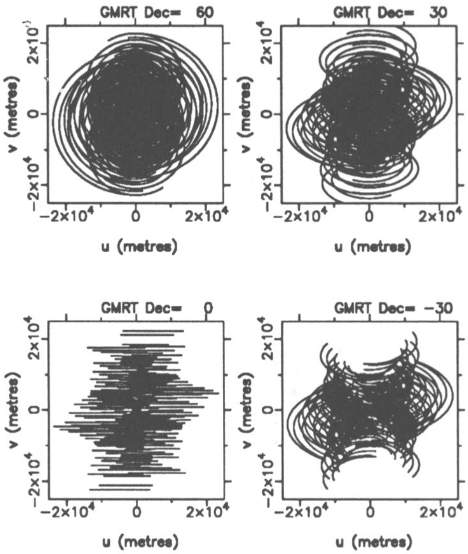

Fig. 2. The full u-v coverage of the GMRT for declinations −30°, 0°, +30° and +60°. Distances are given in metres.

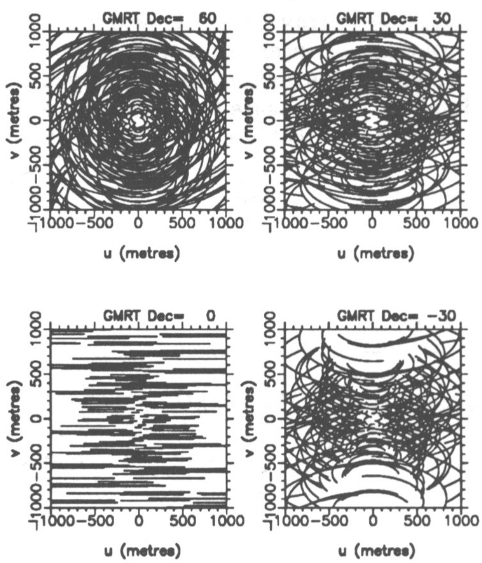

Fig. 3. u-v coverage of the GMRT at short spacings (upto 1 km)

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Interference

At low frequencies the radio frequency interference environment is quite bad. Observing with very narrow bandwidths helps in rejecting CW interference, but this also reduces the sensitivity of the system. The GMRT is being built with a 256 channel FX correlator and all observations will be made in a spectral line mode. Off line analysis will delete spectral channels affected by interference and process the remaining channels. The input of the FX correlator will have 4 bit sampling which will give a spectral dynamic range of about 45 db .

Calibration

At low frequencies, both amplitude and phase calibration will pose problems. Because of the large field of view, snapshot observations of secondary calibrator sources which are relatively weak , are likely to be affected by confusion, leading to noisy solutions for the antenna gains. This error can be reduced by measuring the fluxes and positions of stronger sources in the field of view of the calibrator and determining the antennas gains using the expected visibility of the calibration "fields".

Phase calibration at low frequencies is difficult because of propagation effects in the ionosphere. Refraction by the smooth curved ionosphere leads to errors in the apparent position of sources that can vary with both direction and time. This introduces phase errors when using the a phase calibrator that could be many degrees away from the field of interest. The situation is much worse when the ionosphere is disturbed. However the use of "self-calibration" can overcome this problem. Since the field of view is large at low frequencies, in any field there will be a number of strong compact sources that can be used for self-calibration and for establishing the absolute position of the map.

W-term

The map plane is a two dimensional Fourier transform of the observed visibilities only when all the visibilities have been measured in a plane or when the field of view is so small that the phase errors due the w-term can be neglected. Neither of these conditions will be valid for the GMRT which is a two dimensional array and which has a large field of view at low frequencies. To make high dynamic range maps one has to map the full field and this requires the use of 3-dimensional Fourier transforms which is computationally expensive (Perley 1988). The computational load can be drastically reduced by reducing the field of view by using individual elements of large diameters. The 45m diameter antennas of the GMRT were the largest that could be built within the existing budget. With these antennas, the problem of wide field mapping at 150 MHz should be comparable to that of the VLA in the B configuration observing at 327 MHz, which at present is tractable, but still computationally expensive. At lower frequencies the computational load will be severe and to handle it a 256 node parallel processor is being designed for the GMRT (Kulkarni and Subrahmanya, *this Conference*).

Non-Isoplanaticity of the Ionosphere

The central assumption in self-calibration is that there is just one gain error associated with each antenna. At low frequencies the field of view is so large that the separation of the lines of sight to the different sources at the height of the ionosphere can be larger than the scale size of phase fluctuation in the ionosphere. When this happens, on longer baselines, the ionospheric phase error can be different for different sources in the field, leading to direction dependent phase errors. While this problem is expected to be important at low frequencies, there is very little information regarding how severe this effect will be for the GMRT at the lowest frequencies. The magnitude of this error will depend on the scale size of the ionospheric phase fluctuations which can vary with time. While schemes for high dynamic range mapping under non isoplanatic conditions have been proposed (Schwab 1985, Subrahmanya 1989) there has been no implementation of any of these schemes and their viability has yet to be demonstrated.

Since the magnitude of this error is expected to change with time, a possible solution is to recognise and flag stretches of data where the ionosphere is disturbed. The problems with this approach are that there is no simple procedure for recognising bad ionospheric conditions and that if the ionosphere is stable only for a small fraction of the observing time, no useful maps can be made. When the ionosphere is very unstable, amplitude scintillations occur that can be easily recognised by single dish measurements. But even less extreme conditions that produce phase scintillation can be quite damaging to synthesis maps though they are harder to recognise since the phase of an interferometer can vary with time because of the distribution and structure of the sources in the field of view.

The GMRT with its special array configuration offers a possible way of recognising poor ionospheric conditions. During the off line analysis of the interferometric data, the antennas in the central array can be phased to behave as a single dish having a field of view much smaller than that of the individual antennas. An interferometer consisting of this phased array and a single antenna on the arms of the Y can be made to look at the different sources in the field individually by changing the phasing of the phased array. By studying variation of the interferometer phase with position in the field, one can get some idea of the fluctuation of the ionospheric phase over the field of view, and decide whether to accept or reject the data. At low frequencies, the field of view is so large that there will always be background sources which can be used for looking at the phase. But the number of sources that can actually be used depends on the beam shape and sidelobes of the central phased array. If the number of antennas in the central array is large, so that the sidelobe levels are small, the confusion limit of the phased central array will be small and it can isolate even the fainter source in the field. With the actual configuration of GMRT, one expects to find at least 2 background sources at 150MHz which are strong enough for studying non isoplanaticity. By examining the phases of these sources on all the interferometers possible with the central array, we can get an idea of the stability of the ionospheric phase over the array.

CONCLUSIONS

The GMRT is expected to be a powerful instrument at metre and decametre wavelengths. However, to reach its potential sensitivity limits, a number of problems like radio frequency interference, phase errors due to non coplanar baselines and variations of ionospheric phase fluctuations over the field of view, have to be overcome. Some of the problems can be overcome by selectively flagging the data, while others can be solved by improved analysis techniques. Both these approaches require considerable computing power. But with the decreased cost of computing and the development of a special purpose parallel processing computer for the GMRT, the required computing power may be available by the time the GMRT is completed.

REFERENCES

Perley, R. A. 1989, in *Synthesis Imaging in Radio Astronomy*, ed. R. A. Perley, F. R. Schwab and A. H. Bridle, Astron. Soc. of the Pacific Conference Series Volume 6, p. 259.

Schwab, F. R. 1984, *Astron. J* **89**, 1076.

Subrahmanya, C. R. 1990, in *URSI/IAU Symp. on Radio Astronomical Seeing*, ed. Wang Shoguan and Yang Yi-Pei, Chinese Acad. Sci., Beijing.

Swarup, G. 1990, *Indian J. of Radio and Space Physics* **19** 492.

Ron Ekers: Can you use your central compact array as a phased array and correlate it against the outer antennas? This approximation will not decrease S/N much and would dramatically reduce the computing load by reducing the field of view.

A. P. Rao: (No written response has been provided)

John Baldwin: If the ionosphere at Pune is similar as that at mid-latitudes then the phase irregularities are dominated by almost sinusoidal wavelike structures. Our experience is that the isoplanatic area will be bigger than the GMRT field at 153 MHz and simple correction techniques will work. The large day-to night variations mean that it is particularly important to make some measurements as soon as possible.