The Expanded Giant Metrewave Radio Telescope

National Centre for Radio Astrophysics (NCRA)
Tata Institute of Fundamental Research (TIFR)
Priya Hande, Bela Dixit, Kaushal Buch, Narendra Nath Patra, AjithKumar B. S., Jayaram N. Chengalur, S. Sureshkumar, Vilas Bhalerao, Atul Ghalame, Yashwant Gupta, Swarna K. Ghosh, Nissim Kanekar

SUMMARY

The GMRT is presently the outstanding low-frequency interferometric array in the world, in sensitivity, frequency coverage and image fidelity. Over the next decade, a number of interferometric arrays, pathfinders to the Square Kilometer Array (SKA), will be coming online, making use of recent technology advances to obtain significantly improved imaging and spectroscopic capabilities at low frequencies. We are currently carrying out a detailed study of three possible expansions of the Giant Metrewave Radio Telescope (GMRT), each of which will allow the GMRT to retain its status as the most powerful low-frequency radio telescope in the world over the next decade. The three possible expansions are

- *1. Installing low-frequency focal plane arrays.*
- *2. A factor of 5 increase in the angular resolution, by installing new antennas on baselines extending to 100 km.*
- *3. An improved sensitivity to extended radio emission, by installing new antennas on very short baselines, at spacings much lower than 1 km.*

The project will yield a detailed analysis of the science outcomes enabled by each possible upgrade, as well as detailed feasibility studies, including prototyping a beam-former and a signal transport system for the focal plane array upgrade, a land survey to determine possible antenna sites for the putative long baselines, and simulations to determine the optimal antenna configuration and the number of new antennas that would be needed to achieve the science goals for both the long- and short-baseline options.

Expansion Directions

(A) Equipping the GMRT with low-frequency focal plane arrays (FPAs): This would result in a significant increase in the field of view of the GMRT, by a factor of ~ 25, along with an improvement in aperture efficiency.

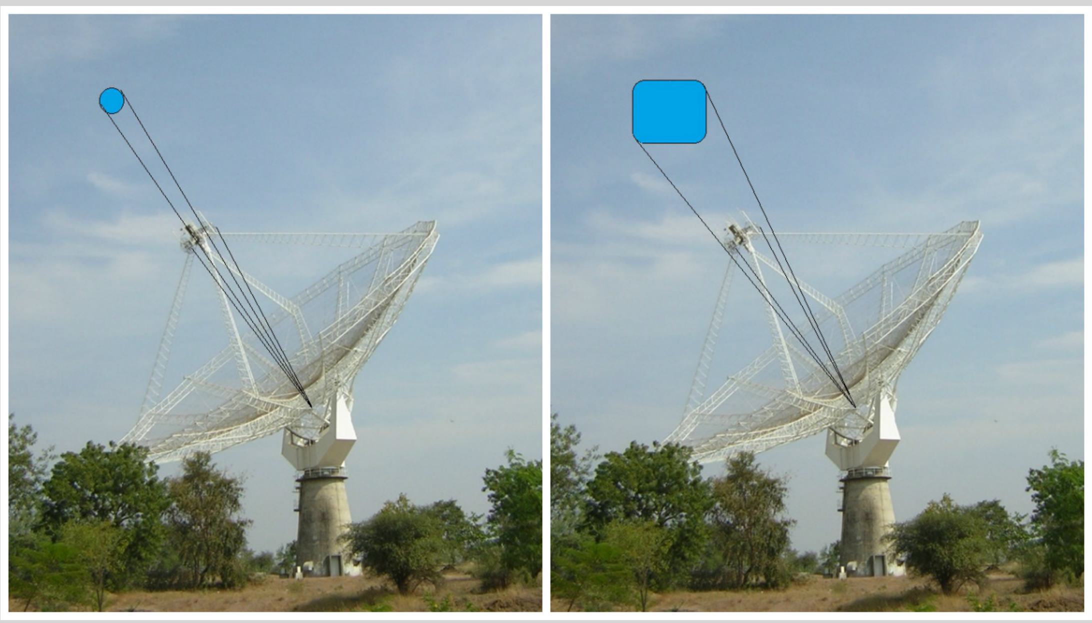


Figure 1: *A pictorial view of a GMRT antenna equipped with an FPA, thus yielding a significantly larger field of view.*

These will significantly improve the survey speed of the GMRT, allowing deep surveys for neutral hydrogen emission from galaxies at cosmological distances, as well as large-area surveys for pulsars and extragalactic radio sources. For example, equipping the GMRT with FPAs at frequencies 0.5 - 1 GHz would allow efficient neutral hydrogen surveys at high redshifts, z 1 - 1.5.

(B) Extending the GMRT to longer baselines, out to ~ 100 km: This would result in improving the angular resolution of the GMRT by a factor of 5. To be able to continue to detect "typical" extra-galactic sources in deep fields, it is necessary to improve GMRT's sensitivity at frequencies < 1 GHz by a factor of ~ 10 as well.

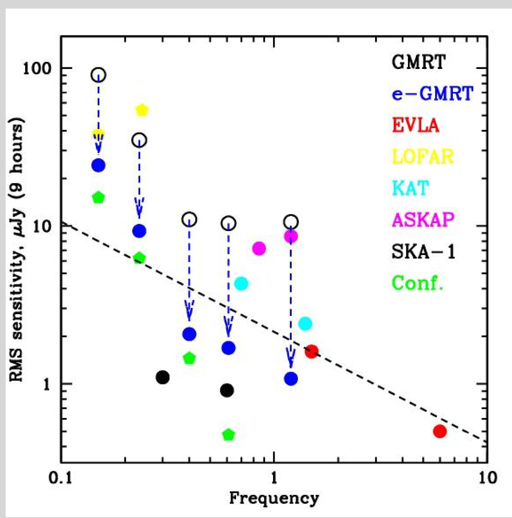


Figure 2: *The solid blue circles show the improvement in e-GMRT sensitivity on doubling the collecting area and extending to 50 km baselines. The circles in other colours show the sensitivity of the best present and proposed telescopes, while the dashed line shows the radio spectrum of a "typical" radio source.*

Due to the limit set by source confusion, this is only possible by increasing the baseline length, by a factor of ~ 5 (thus reducing the confusion limit by a factor of ~ 25, to ~ 0.8 microJy at 327 MHz and ~ 0.4 microJy at 610 MHz).

(C) Extending the GMRT to short baselines, at << 1 km: This would significantly improve the GMRT's sensitivity to extended radio emission, especially from complicated regions such as the centre of our galaxy. Low-frequency pulsar surveys and pulsar timing studies would also significantly benefit from an increase in the collecting area at short baselines.

Challenges

Focal Plane Array: Signal transport, especially from the antenna focus to the antenna base, digital signal processing at high data rates, radio frequency interference, and supporting a large focal plane array at the GMRT prime focus.

Longer Baselines: Data transport from distant antennas to the GMRT correlator, an entirely new correlator, and finding locations with good road and fibre connectivity where antennas can be placed, so as to yield good coverage of the visibility plane, so that the limiting sensitivity can be achieved.

Shorter Baselines: Decision on whether to use dishes of the same size as the present array (45-m) or build an array of smaller antennas (about 15-m diameter) in the GMRT central square and techniques to handle the effects of terrestrial interference.

A GMRT Focal Plane Array

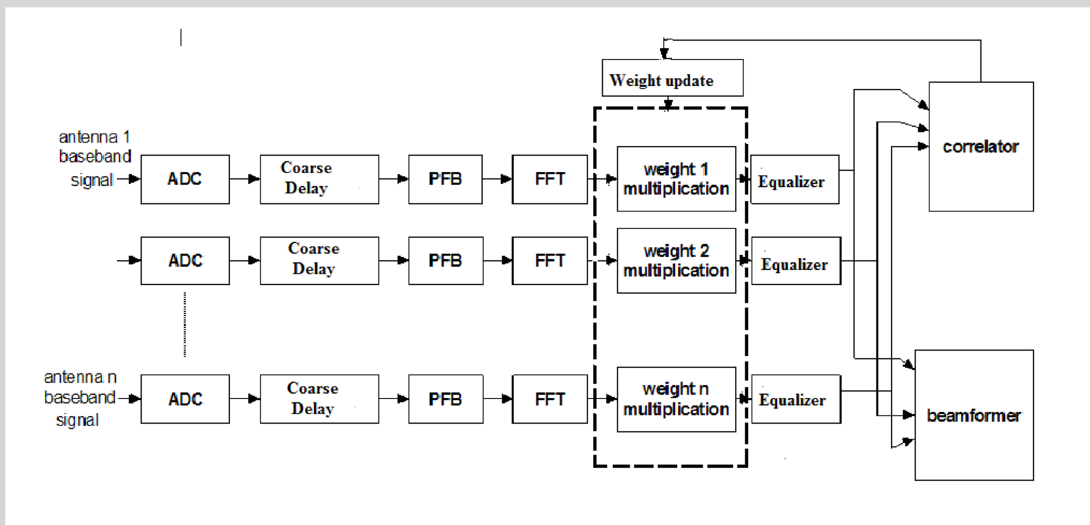
A remarkable way of gaining a larger field of view is to replace the single receiver element at the focus of each GMRT parabolic dish with an array of receiver elements at the focal plane of each dish, i.e. a "focal plane array" (FPA). Such an FPA is designed so that each of its elements receives signals from a different direction, and thus sees a different part of the sky. The field of view of each element would be the same as the present GMRT field of view, with a single receiever element. The total field of fiew of such an FPA would be the sum of the fields of view of the individual elements: with 25 elements, the field of view would be 25 times bigger than that of the present GMRT! Indeed, with such an FPA covering 0.5 - 1 GHz, the GMRT's net field of view would be around 50 times the size of the full moon!

Image Courtesy: ASTRON

The FPA system obtained from ASTRON (Netherlands), which is being used to prototype the GMRT FPA; the 72-element Array Feed is shown in the right panel, and the FPA computing racks in the left panel.

FPGA Based Beamfomer

We are currently designing an FPGA-based beamformer for the proposed Focal Plane Array. This is aimed at providing multiple beams in the field of view by building a backend using the FPGA-based ROACH (Reconfigurable Open Architecture Computing Hardware) board. The digitized time-domain baseband signals from different antenna elements are first transformed to the frequency domain, where they are multiplied by complex weights and added coherently to form multiple beams in the desired directions. A correlator operating in parallel provides the input for the computation of the beamformer weights.



Block diagram of FPGA based FPA Beamformer

Simulations of New Antenna Locations

Two of the proposed expansions involve increasing the number of antennas, placing the new antennas at large distances (out to 100 km) or increasing the density of antennas at short baselines.

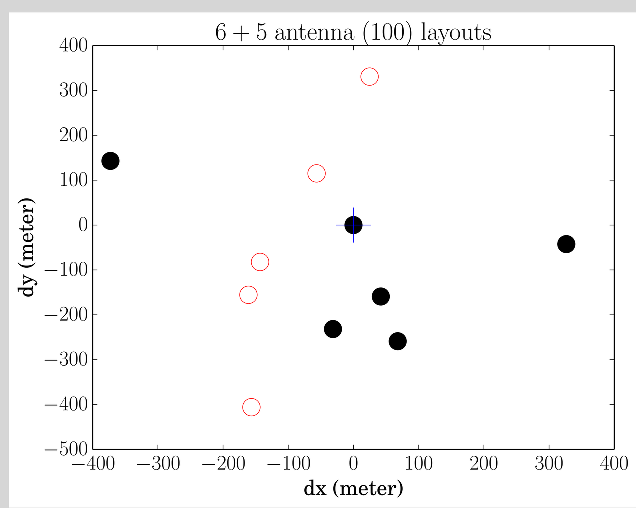


Figure 3: *Simulation results for short baselines: 6 additional antennas would be needed to optimize the GMRT performance on baselines out to 0.5 km*

We are presently carrying out simulations to identify both the optimal locations of the new antennas as well as the optimal number required to achieve the science goals, using a tomographic projection technique, pioneered by de Villiers (2007, AA, 469, 793). For example, Figure 3 shows an optimized layout for the GMRT central square at 1.2 GHz, with baseline lengths up to 500 metres. The filled circles represent the existing GMRT antennas while the empty circles show the location of the six new antennas that would be needed to achieve the required imaging quality.

Some results for uv-coverage has been obtained. The uv-coverage of existing short-spacing antennas (6 < 0.5km) and eGMRT short-spacing antennas (11 < 0.5km) for a typical full synthesis observation at declination -30 deg is shown in figure 4.

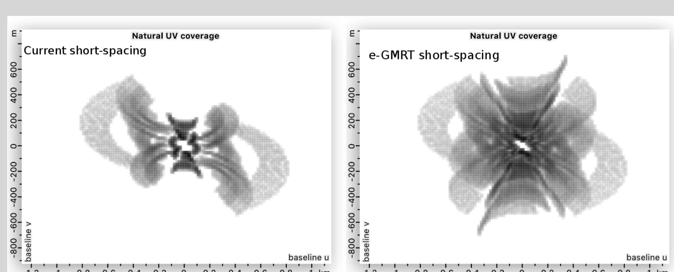


Figure 4: The panels show the interferometric response to extended sky emission for the short baselines of the current GMRT (left panel) and the e-GMRT (right panel). The additional 6 antennas dramatically improve the response of the e-GMRT!