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The Giant Metrewave Radio Telescope (GMRT): Salient Features and Recent Results

S. Ananthakrishnan
NCRA-TIFR, Pune-411 007, INDIA
Presenter:S. Ananthakrishnan (ananth@ncra.tifr.res.in)

In this talk, presented on behalf of the scientists and engineers who built and commissioned the Giant Metrewave Radio Telescope (GMRT), we have given a brief outline of the instrument and some of the recent scientific results obtained from it. Studies that are relevant from the point of view of Ultra High Energy Cosmic Rays (UHECR) have also been taken up in GMRT. We also present data on the usage of the telescope by the international community.

1. Introduction: Radio Emission and UHECR

Radio wave emission is not high energy radiation, but its source is often the same as what emits X-rays and Gamma-rays. Using radio wave signals radio astronomers have discovered Quasars, Blazars & AGN and more recently radio astronomy has been used for studying Gamma-Ray Bursters (GRBs).

It is worth noting that Askaryan (1962) showed that when UHE Cosmic Ray particles interact with the atmosphere and produce air showers, the proton-electron showers produce radio emission in the$<$ 100 MHz band. Very recently, Falcke et al.(2005) have detected radio flashes of 50 ns pulses well correlated with air showers. The pulses appear to arise due to the interaction of the showers with the geomagnetic field and produce geo-synchrotron emission. Using Dipole antennas (LOFAR Proto-types) in the 43-73 MHz band, radio interferometry was used to produce the radio image. Such observations clearly demonstrate the usefulness of radio astronomy for studying phenomena in high energy astrophysics. In this talk we present a new radio astronomy array that has been commissioned in India in 2001 for frontline investigation of a variety of astrophysical objects.

2. The GMRT

The Giant Metre-wave Radio Telescope (GMRT) is a recent world class instrument for studying astrophysical phenomena at low radio frequencies (40 to 1450 MHz). GMRT has been designed and built in India by NCRA-TIFR as a national project at a low cost of about 15 million US (1992) $. The array telescope consists of 30 antennas of 45 metres diameter, each, operating at metre wavelengths, being collectively, the largest in the world at these frequencies. These antennas are spread over 25 km in diameter, with about half the antennas randomly located in a central one square km. area and the remaining ones along the three 14 km arms of an approximate ‘Y’ configuration. The longest baseline is 26 km and the shortest about 100 m. GMRT is located (Fig. 1a), (Lat. =19.1^o, Long. =-74.05^o, Alt. =650 m) near Khodad Village, about 80 km north of Pune city and 100 kms. east of Mumbai (Bombay). The array schematic is shown in Figure 1b.

Each of the GMRT antenna is an alt-az mounted dish (Figure 2). The dish has 16 parabolic frames which give the basic shape. The reflecting surface consists of a “Stretched Mesh Attached to Rope Trusses” (SMART) (Figure 3). The wire mesh size is matched to the large wavelengths of operation and varies from 10mm $\times$ 10 mm inside to 20 mm $\times$ 20 mm in the outer one third of the dish surface. As a result the efficiency varies from 60% below 1 GHz to 40% at 1.4 GHz. The specifications of GMRT are given in Table 1. The dishes can give a

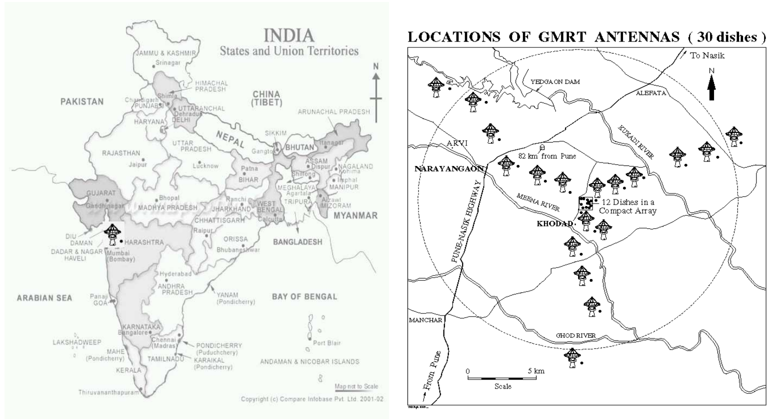

Figure 1. (a) Location and (b) Configuration of the GMRT

Figure 2. One of the 30 GMRT Antennas

declination coverage of -55^o to $+90^o$. The rotating turret at the prime focus enables one to rotate the different feeds for changing the frequency bands (Figure 4). The presently available feeds are in the 151, 325, 610/235 and the 1000-1430 MHz band. Some of the important sub-systems of the GMRT include Mechanical, Servo, Antenna feeds (including positioning & control), Analog Receiver chain, Optical fibre sub-system, digital Receiver chain, Telemetry sub-system, “On-line” Control and Monitor and Off-line data processing chain(s).

The digital back end is of particular importance, since the FX correlator, built by the GMRT scientists and engineers forms the ‘heart’ of the receiver system. It has the samplers, the delay system, the FFT pipe line and the multiplier and accumulator (MAC). The baseband signal is sampled (4 bits) and compensated for propagation delays. The data stream is fourier transformed and averaged to give 128 channels across the band. The channel width can range from 128 KHz to 0.5 KHz with the total bandwidth ranging from 16 MHz to

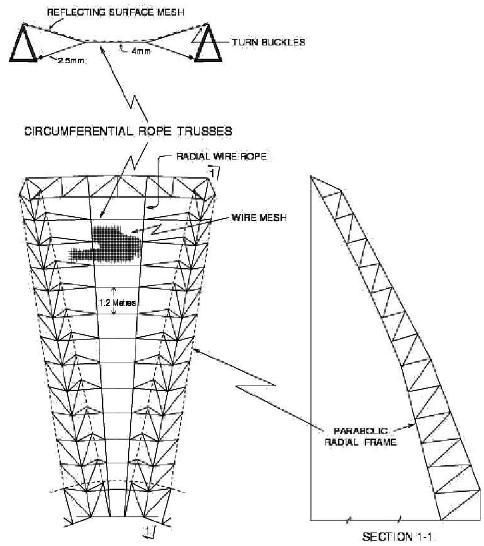

Figure 3. Explaining the SMART concept

300–360 MHz

580–650 MHz& 225–245 MHz

120–180 MHz

1000–1430 MHz Hz

Figure 4. Operating Frequencies of GMRT

64 KHz in each side band for each polarisation. The two side band correlator system gives 4 outputs, 2 RR and 2 LL, effectively doubling the band width of the system. However, it can also be programmed to give 4 stokes parameters for one of the two sideband systems. The integration times can be varied from 128 ms to 16 seconds based on the number of baselines and spectral channels. The data from the antennas can also be combined to give a single time series of spectra with a sampling interval of 16 ms. The data can be combined

Table 1. Some parameters of the 45-m GMRT Dish

Focal Length	18.54 m
Physical Aperture	1590 m^2
Mounting	Altitude – Azimuth
Elevation Limits	16° to 110°
Azimuth Range	±270°
Slew Rates	Alt – 20° / Min Az – 30° / Min
Weight of the moving structure	82 tons+Counter weight of 34 tons
Survival wind speed	133 km/hour
RMS Surface Error	< 10mm
Pointing Error	$\lesssim 1' arc' min$

Table 2. System parameters for the GMRT (in synthesis mode)

	Frequency(MHz)				
	150	235	327	610	1420
Primary Beam (deg)	3.2	2.0	1.4	0.8	0.4
Synthesized Beam (arcsec)	20	13	9	5	2
Effective Area (m^2)	30,000				18,000
System Temp ($\circ^K$)	450	180	110	100	70
RMS noise* in Image (achieved) (μ Jy=10-32W.$m^{-2}.Hz^{-1}$)	1mJy	200	100	60	30

either as voltages (coherent addition) or as powers (incoherent addition) depending on the user requirement. These have been especially important in the Pulsar programs.

The system parameters of the GMRT receiver are shown in Table 2. For more details on the receiver, control systems, etc, the reader is referred to Swarup et al. (1991) and Ananthakrishnan and Rao (2002) and/or to the web site: http://www.gmrt.ncra.tifr.res.in/gmrt_hpage/Users/doc/doc.html.

Table 3 gives a comparison between GMRT and other existing radio arrays.

Table 3. Some synthesis Radio Telescopes (cm & m waves)

Synthesis Radio Telescope	Location	No. of Antennas	Synthesis Aperture	Frequency Range
VLA	USA	27 × 25 m	33 km	1.4 GHz – 44 GH (74 MHz & 327 MHz)‡
WSRT	Netherlands	14 × 25 m	3 kAmi	327 MHz – 8000 MHz
AT	Australia	6 × 25 m	6 km	1.4 GHz – 44 GHz
GMRT	India	30 x 45 m	25 km	40 MHz – 1430 MHz (1700 MHz)‡
MERLIN	UK	6 x 25 m+1 x 76 m	400 km	408 MHz 5000 MHz
‡ Optional coverage				

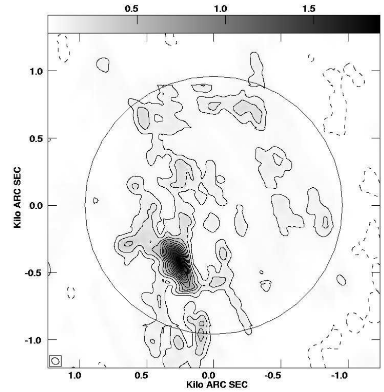

Figure 5. GMRT 150 MHz radio map of the Sun

3. Some Recent Scientific Results from GMRT:

- In this section we describe some of the scientific results from GMRT. GMRT has been used to observe a variety of astrophysical objects, such as the Sun, Planets, Young Stellar Objects, Pulsars, HII regions, galactic and extra galactic Supernova Remnants, Microquasars, Gamma-ray burst afterglows, Damped Lyman-alpha systems, HI absorption systems, Cosmic masers, Normal and Radio galaxies, Quasars and Multi-field systems. About 100 research papers have been published during the past 4 years of GMRT operation and a list can be found at www.ncra.tifr.res.in/ library.

  Here we give a brief random sample of the results obtained.

Solar observations using GMRT

Sun is being observed using the GMRT in all the bands. Figure 5 shows a very recent 150 MHz observation of the radio counterpart of a Coronal Hole. This is a high dynamic range (170:1) synthesis map and a comparison of it with EUV maps (Madsen, Ananthakrishnan, et al. 2005 -being submitted) shows that the Coronal Hole radio layer lies well below the X-ray and EUV layer and is useful for studying the structure of Coronal Holes.

Finding New Pulsars Using GMRT

A new pulsar (Figure 6) has been discovered in the Globular Cluster NGC 1851 (Freire, Gupta, et al., 2004). It is a millisecond Pulsar in a binary system with the highest known eccentricity of 0.88, which makes the apparent period of the pulsar change rapidly over the binary orbit. Four more Pulsars have been discovered, including some that are long period pulsars, using the coherent and incoherent mode of GMRT (Joshi, private communication, 2005). Search for pulsar counterparts of high energy sources also continues.

4. Galactic Centre region

Detection of Sgr A* (Black Hole candidate) in the Galactic Centre region using GMRT shows that it lies in front of the Sgr A West HII region. This is the first detection of the central compact source Sgr A* below 1 GHz, at 600 and 325 MHz. Detailed HI studies have been also done of several non-thermal filaments around this region (Roy & Rao, 2004) (Figure 7).

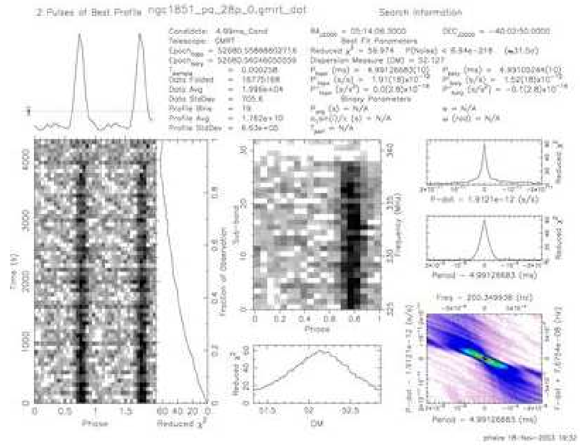

Figure 6. Millisecond Pulsar in globular cluster NGC 1851

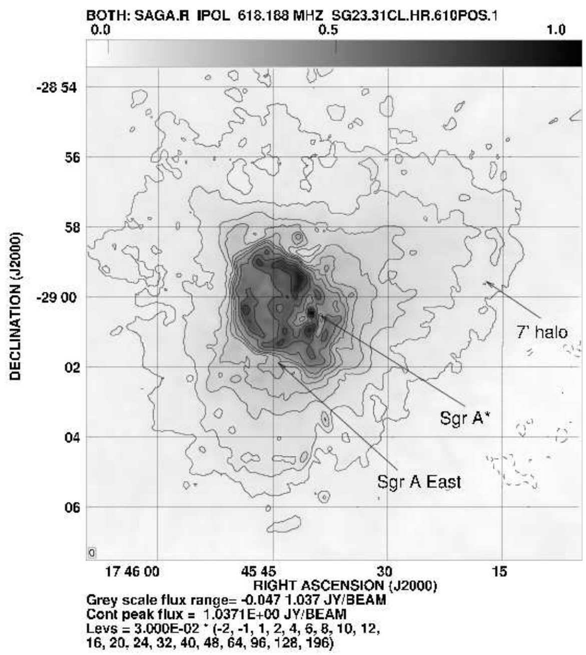

Figure 7. 49cm GMRT image of Sgr A

Finding of an organic molecule

Figure 8 shows the widespread 1065 MHz line emission from acetaldehyde (CH3CHO) molecular gas associated with the thermal continuum (grey scale) from the giant molecular cloud complex Sgr B2, near the centre of our Galaxy. The CH3CHO emission is coincident with HCHO absorption. The analysis indicates the presence of numerous shocks in the Sgr B2 complex (Chengalur and Kanekar, 2003a).

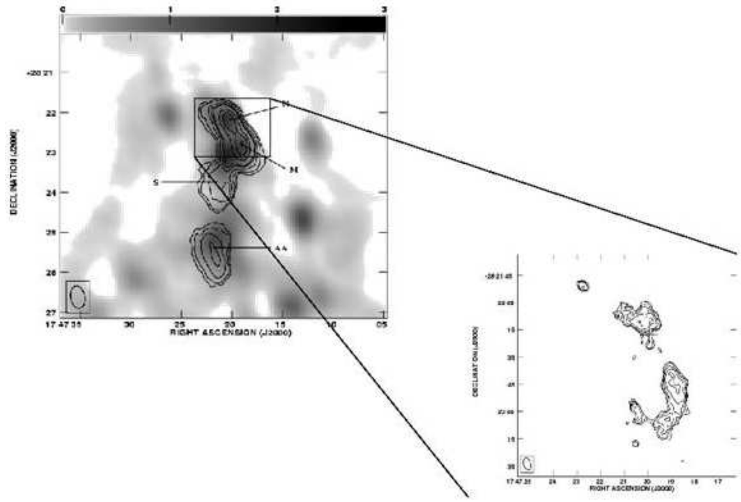

Figure 8. 1065 MHz line emission from Acctaldehyde

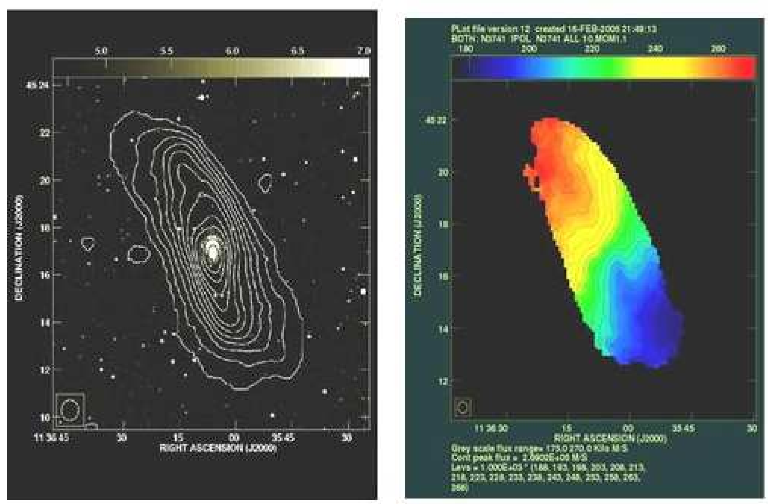

Figure 9. Dwarf Galaxy NCC 3741

Dwarf dark galaxy study

Study of dwarf irregular galaxy (Figure 9) NGC 3741 (M_B ∼-13.13) by making an integrated HI map shows that the HI gas disk is∼ 8.3 times Holmberg radius, making it the most extended HI disk known. The rotation curve has been measured out to 38 optical scale lengths. With a dynamical mass to light ratio of 107, this is one of the darkest irregulars. (Begum, Chengalur & Karachentsev 2005).

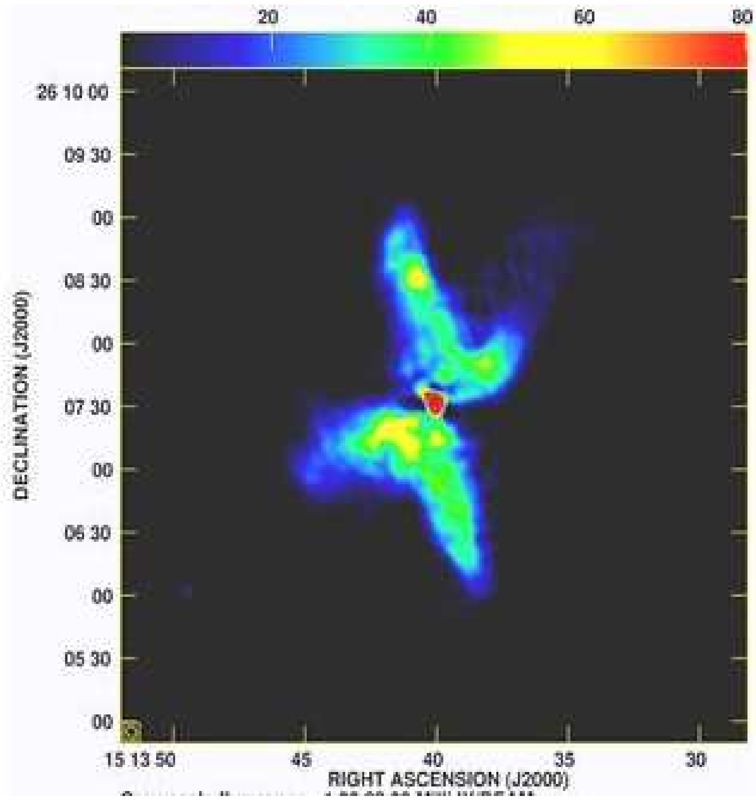

Figure 10. X-shaped peculiar radio galaxy 3C315.

Radio Galaxies and Quasars

GMRT images of Radio Galaxies with peculiar morphologies such as 3C315 (Figure 10), typically X-shaped, show that their evolution could be due to distinct epochs of activities with shifting of jet direction or due to mergers.(Lal and Rao, 2005). Deep GMRT 21 cm absorption spectra of 10 damped lyman-alpha systems, of which 8 are at redshifts of $z>1.3$ were obtained. These show that bright spiral galaxies have low spin temperature (Chengalur and Kanekar 2003b).

HI observations of superwind galaxy NGC 1482 with GMRT show two blobs of radio emission on the opposite edges of the galaxy . The GMRT contour map of 335 MHz emission superposed on a ‘CHANDRA’ image of X-ray emission indicates that there are no outflows of radio synchrotron plasma from the galaxy. (Hota and Saikia, 2005) (Figure 11).

Systematic hydrogen line studies have been made with the GMRT. High latitude HI absorption survey has been made leading to the detection of a population of ‘fast’ HI clouds (Mohan, Dwarakanath and Srinivasan, 2004). Associated HI 21 cm-line absorption has been detected in the red quasar 3C 190 at $z = 1.2$. A comparison with optical images shows linear filaments in optical, overlapping with the south-west radio jet (Ishwar Chandra and Dwarakanath 2003).

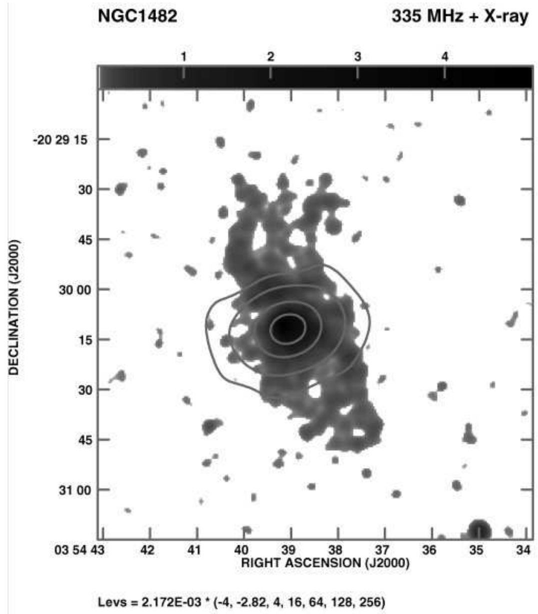

Figure 11. 335 MHz contour superposed on Chandra X-ray image of NGC1482.

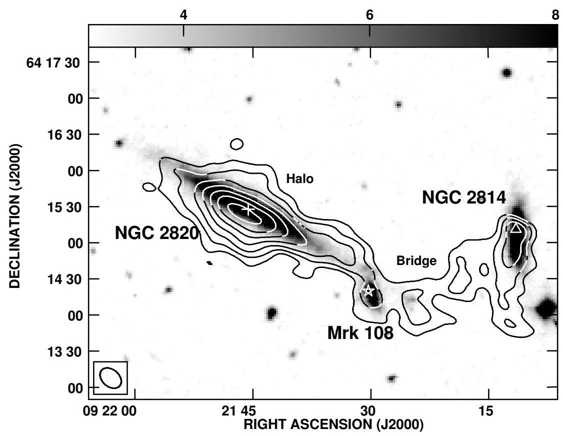

Figure 12. GMRT image of NGC2820 at 330 MHz

4.1 Nearby Galaxies

GMRT image of NGC 2820 and others in the Holmberg group of four galaxies reveal various tidal features (Figure 12), like a steep spectrum connecting bridge, a streamer and a tail. The group appears to have been subjected to both tidal and ram pressure due to the motion of the member galaxies in an intra-group medium (Ananthakrishnan, et al., 2003; Kantharia, et al., 2005).

COUNTRY	No. of proposals
Argentina	1
Australia	13
Canada	8
France	27
Germany	6
India	239
Italy	6
Japan	4
Korea	1
Mauritius	2
Netherlands	12
Poland	5
Russia	3
Spain	1
Taiwan	4
UK	32
USA	42
Total	**406**

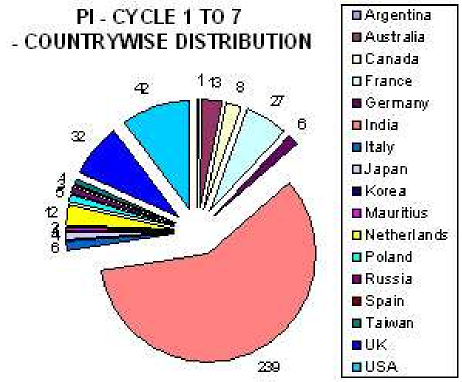

Figure 13. GTAC Chart

4.2 Gamma ray bursts

The Gamma Ray Burster GRB030329 was observed by GMRT two days after the burst, and then once a month for about a year. The flux density at 1280 MHz increased steadily over a few months and then decayed. The results have been used to constrain the double jet model proposed by Berger et al. (Resmi, et al. 2005).

4.3 Radio Synchrotron Emission as Tracer of High and UHECR Acceleration in Cosmic Sources

Gopal Krishna, Kulkarni and other co-workers have recently launched a GMRT survey at 325 MHz targeting nearby rich clusters showing elongated X-ray emission, in order to study particle acceleration at the shocks of the merging clusters of galaxies. In clusters such as Abell 3667 clumpy, extended soft X-ray emission profiles have been seen and Mpc-Scale, arc-shaped, diffuse radio synchrotron emission has been imaged on the opposite edges of the elongated ICM.

4.4 Co-ordinated Flux Monitoring of 5 Tev Blazars

Atleast 6 Blazars have been detected in the Tev region. The interesting question is whether the sources of Tev electrons are in Kpc scale jets. It is important to compare the Tev flux variability with variability in radio/optical synchrotron emission arising within the Blazar nucleus (Gopal-krishna, et al., private communication, 2005).

Many such programs are possible with the GMRT. Since GMRT is an international user facility, in the concluding section we would like to briefly outline the GMRT Time Allocation Procedure for all users. The GMRT Time Allocation Committee (GTAC) receives proposals twice a year, based on the AOs. Based on referee reports time is allotted by GTAC. Schedule is prepared locally at the GMRT Observatory based on local considerations, such as frequency required, maintenance periods, etc. GTAC Statistics are shown in the pie chart (Figure 13) and indicate the wide spread use of this new radio instrument.

5. Acknowledgements

I thank the National Organizing Committee of the 29th ICRC for inviting me to present the highlights of the design of the GMRT and some of the interesting results obtained from the recent observations with GMRT by my colleagues at NCRA and guest observers from around the world. I am thankful to my astronomer colleagues for making their results available to me for this presentation.

References

[1] Ananthakrishnan, S. and Rao, A.Pramesh, Proc. of TIFR Int'l Conf. Eds. R.K.Manchanda and B.Paul, 233, (2002)
[2] Ananthakrishnan, S., Kantharia, N.G. and Nityananda, R., BASI, 31, 421, (2003)
[3] Askar'yan, G.A., Soviet Physics, J.E.T.P., 14(2), 441, (1962)
[4] Begum, A., Chengalur, J.N. and Karachentsev, J.D., A&A, 433, 1L, (2005)
[5] Chengalur, J.N. and Kanekar, N., A&A, 403, 43, (2003a)
[6] Chengalur, J.N. and Kanekar, N., 25th meeting of the IAU, JD 15, 22nd July 2003, (2003b)
[7] Falcke, H., et al., Nature, May 19, 2005
[8] Freire, P.C.C., Gupta, Y., Ransom, S.M., Ishwara-Chandra, C.H. and Kaspi, V.M., ApJL, 606, 53, (2004)
[9] Hota, A. and Saikia, D.J., MNRAS, 356, 998, (2005)
[10] Ishwara-Chandra, C.H., Dwarakanath, K.S. and Anantharamiah, K.R., JAA, 24, 37, (2003)
[11] Kantharia, N.G., Ananthakrishnan, S., Nityananda, R. and Hota, A., A&A, 435, 483, (2005)
[12] Lal, D.V. and Rao, A.Pramesh, MNRAS, 356, 232, (2005)
[13] Mohan, R., Dwarakanath, K. and Srinivasan, G., JAA, 185, (2004)
[14] Roy & Rao, MNRAS, 349, L25, (2004)
[15] Resmi, L., et al., A&A, 440, 477-485 (2005)
[16] Swarup, G. et al., Current Science, 60(2), 95, (1991)