

# SEARCH FOR RADIO EMISSION FROM EXTRASOLAR PLANETS: PRELIMINARY ANALYSIS OF GMRT DATA

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## Abstract

In early 2005, we began an observation campaign at the Giant Meterwave Radio Telescope (GMRT) to search for radio emission from extrasolar planets. At the operating RF of 150 MHz, we have determined that the GMRT has a sensitivity of 2 mJy over a bandwidth of 5 MHz and integration time of one hour. In this paper, we briefly discuss our target list, observational strategies, and our data analysis techniques. We also present some very preliminary results obtained from both our calibration runs of 2004 and the newly obtained data sets in 2005.

## 1 Introduction

Searches for radio emission from extrasolar planets have previously been carried out, most recently at the VLA [Bastian, et al. 2000]. The expected signal is thought to be very weak, and based on observations of the radio planets in the Solar System, the signal is expected to have structure at various time and frequency scales [Lecacheux, et al., 1998]. The GMRT [Swarup, et al. 1997], located about 80 km north of Pune, India, consists of 30 antennas, each with a diameter of 45 m. The antennas are spread over an area about 10 km across, making this array very well suited to carry out sensitive searches for radio emissions from extrasolar planets, with sub-arcminute position resolution.

We conducted a series of observations at the GMRT in 2005 [Winterhalter, et al. 2005]. These observations were carried out over three days in March 2005 with a center radio frequency near 150 MHz. During the first two days (Mar 7 and 8) we collected both interferometric as well as pulsar mode (phased array mode) data on a number of sources simultaneously. In interferometric mode, we used 22 of the 30 antennas, excluding one

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or two extreme antennas in each arm due to phase stability problems. On March 16, we recorded exclusively in pulsar mode. In this mode, we only used the central square array (CSQ), consisting of 11 antennas. The cluster of antennas in close proximity provides for a more phase stable system, which is more crucial in this mode of array operation since post-correlation phase corrections are not performed.

Our focus to date has been in characterizing the large scale structure of the dynamic spectra, identifying RFI and developing filters to remove them. In this paper, we will present our results from both the short calibration run of 2004 as well as our very preliminary look at the 2005 data set.

## 2 Target List

We selected six extra-solar primary targets based on our selection criteria as described by Winterhalter, et al. [2005]. Flux calibration and monitoring was carried out by observing strong, well understood sources in an OFF-ON-OFF mode, with a cycle time of five minutes, both at the start and the end of each observing session.

In addition to flux calibration we performed regular phase calibrations of the array by selecting strong nearby phase calibrators based primarily on our previous experience at the GMRT and the VLA. Phase calibrations were carried for five minutes before and after observing each target source.

In pulsar mode we also observed a number of bright pulsars in order to better understand the caveats of the instrument as well as our analysis techniques. Table 1 shows a listing of the observed pulsars and their characteristics.

Table 1: Listing of observed pulsars

Name	RA (J2000) (h:m:s)	Dec (J2000) (d:m:s)	Period (s)	DM ( $cm^{-3}pc$ )	Distance (kpc)	Flux at 400 MHz (mJy)
<i>B0950 + 08</i>	09 : 53 : 09.3	+07 : 55 : 35.7	0.253065	2.96	0.16	400
<i>B0329 + 54</i>	03 : 32 : 59.3	+54 : 34 : 43.5	0.714520	26.83	1.44	1500
<i>B1642 - 03</i>	16 : 45 : 02.0	-03 : 17 : 58.3	0.387690	35.73	2.91	393
<i>B1133 + 16</i>	11 : 36 : 03.2	+15 : 51 : 04.4	1.187913	4.86	0.27	257

## 3 Observing Strategies

Our strategy for detecting radio emissions from extra-solar planets is to look for both large scale (in time and radio frequency), as well as short, burst-like emission as observed in the case of Saturnian and Jovian emission. Our test calibrations have shown, however, that at both scales, there are significant contributions from other background sources, including Radio Frequency Interference (RFI), which may, in effect hide the desired signal. For this

reason, we have taken care to devote about 25% of our observing time on calibration runs in various modes to better understand the GMRT instrument and our data.

In the phased array mode of operation, at the expense of some loss in overall sensitivity, we divided the CSQ array into two subarrays. One subarray was then pointed to the desired source (extra-solar planet or pulsar), while simultaneously the second subarray was pointed about five degree away from the source in a cold piece of the sky as determined from archival maps at nearby frequencies.

The time resolution in pulsar mode was chosen to be 512 micro-seconds, while in interferometric mode the time resolution was set to 512 msec. To avoid RFI, we chose a bandwidth of 8 MHz, with a usable bandwidth of roughly 5.5 MHz for both subarrays. The frequency spectrum is divided into 256 channels in both observing modes. Over the three day observing period we collected about 70 GB of data in pulsar mode and about 40 GB in interferometric mode.

## 4 Data Analysis Techniques

### 4.1 Dynamic Spectra

To search for radio emissions, we estimate emission intensity as a function of both radio frequency and time at various frequency and time resolutions. These dynamic spectra (see Figure 1) are then corrected for both bandpass shape as well as gain variations, per our calibration data. We next apply an RFI removal algorithm to mask out pixels that are determined to be caused by RFI. The cleaned spectra are then dedispersed with a number of trial dispersion measures and integrated along the frequency axis. We then carry out a power search algorithm for events above a certain threshold.

This analysis is repeated for data obtained with the off-source subarray. The results are then compared to veto signals that are common in both data sets. This technique provides a powerful measure of vetoing “signals” that are seen in both dynamic spectra. We are currently fine tuning our analysis algorithms with pulsar data.

We also plan to understand certain “regular” features that we have observed in dynamic spectra obtained during our test calibration run in 2004. The observed features may be due to interstellar scintillation, as previously detected for some pulsars. Our fantastic time and frequency resolution should allow us to quantify these features with an autocorrelation analysis of the dynamic spectra.

We plan to develop more sophisticated time–frequency detection algorithms, such as match filter techniques, and chirp transforms to detect fine structured emissions as observed in the case of Jupiter.

### 4.2 Radio Maps

In interferometric mode, we have measured the visibility function along each baselines, which moves along tracks in the u-v plane as the Earth rotates (u-v plane is defined to

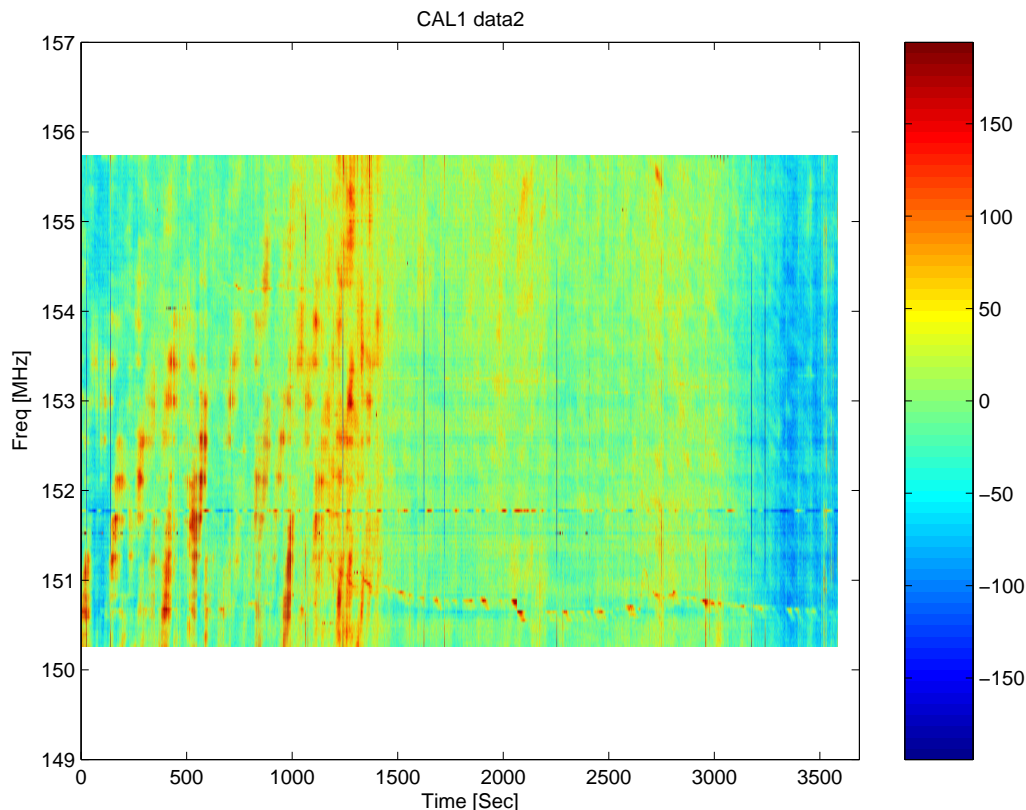


Figure 1: Dynamic spectra of *Upsilon And.* obtained during one of our calibration runs. The intensity scale is in arbitrary units.

be perpendicular to the source direction).

The sky brightness or map is obtained by the process of deconvolution, using the visibility function. This process involves using the CLEAN algorithm. The CLEAN algorithm refers to an iterative algorithm that essentially deconvolves the array's beam (dirty beam) from an observed brightness (dirty map) distribution of a source. We have used the AIPS (Astronomical Image Processing Software) package to reduce our data and obtain preliminary maps of our target's field of view. Our current maps have a sensitivity at the level of 7–10 mJy. With removal of RFI and further cleaning of the data, we expect our sensitivity to be improved by at least a factor of 5–10.

## 5 First Look at the Data

We have determined our sensitivity using deflection scales, by pointing off a strong source, followed by pointing at a known source, and then back to an off source position. Figure 2 shows one such deflection scan, where the “on” source is 3C48. With the CSQ antennas split into two subarrays, we have determined our sensitivity to be 8–10 mJy. During the calibration scans of 2004, we were able to achieve a sensitivity of 2 mJy with the full CSQ

array. We have confirmed these values by observing different radio sources, including known pulsars.

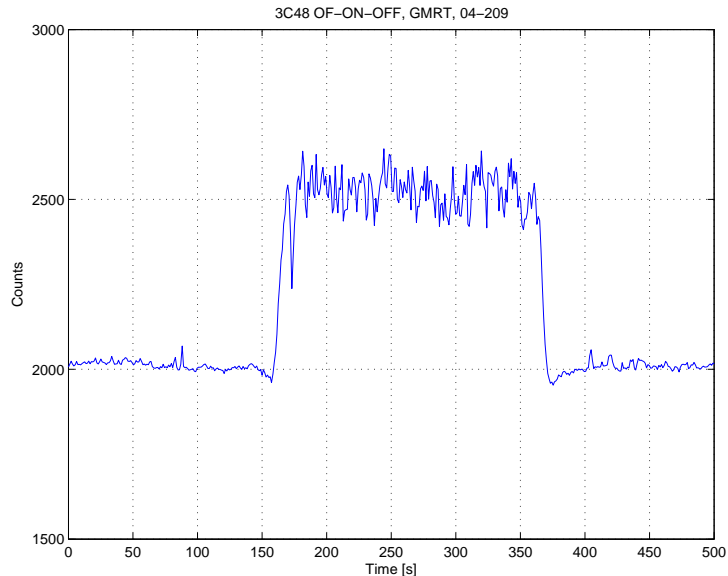


Figure 2: Deflection scale using 3C48 to determine array sensitivity.

As pointed earlier, we were able to record some pulsar data during the 2005 runs. We have used this data set to calibrate the subarrays, and determine gain differences between the two arrays. Figure 3 shows a folded pulsar profile, at the nominal pulsar period for PSR B1642-03. By varying the configurations and recording short scans, we were able to determine and monitor the sensitivity of each subarray and gain offset between them.

## 6 Conclusion

We have carried out our first campaign to search for radio emission from extrasolar planets using the GMRT array in India. We were able to operate the GMRT in both interferometric and phased array modes simultaneously. We adopted an observing strategy that allows us to discriminate RFI signals from the expected planetary emission. Our initial look at the data suggests that we have achieved a sensitivity at the level of a few mJy. In the coming weeks and months, we plan to carry out a robust search for both large scale and short scale emissions from our target list using a variety of time-frequency techniques.

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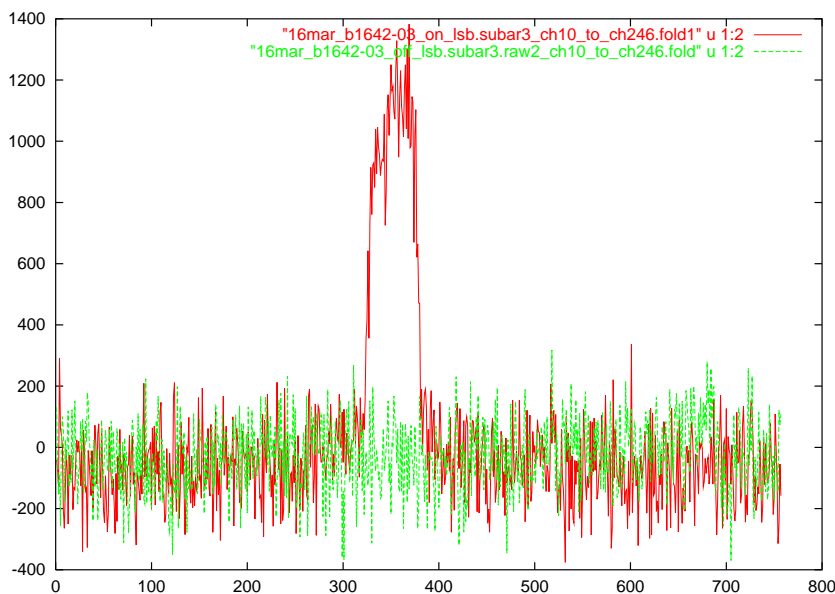


Figure 3: Folded profile with the nominal period of PSR B1642-03. The red curve shows the profile using the subarray that points to the pulsar, while the green curve shows a similar plot using the off source subarray.

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## References

- Bastian, T. S., G. A. Dulk, and Y. Leblanc, A search for radio emission from extrasolar planets, *Astrophysical Journal*, **545**, 1058–1063, 2000.
- Lecacheux, A., M. Boudjada, H. O. Rucker, J. Bougeret, R. Manning, and M. L. Kaiser, Jovian decameter emissions observed by the Wind/WAVES radioastronomy experiment, *Astronomy and Astrophysics*, **329**, 776–784, 1998.
- Swarup, G., S. Ananthakrishnan, C. Subrahmanya, A. Rao, V. Kulkarni, and V. Kapahi, The Giant Meterwave Radio Telescope, *High Sensitivity Radio Astronomy*, ed. N. Jackson and R. Davis, Cambridge University Press, Cambridge, 1997.
- Winterhalter, D., G. Bryden, I. Chandra, W. Gonzalez, T. Kuiper, J. Lazio, W. Majid, R. Treumann, and P. Zarka, Search for radio emission from extrasolar planets: the observation campaign, in *Planetary Radio Emissions VI*, H. O. Rucker, W. S. Kurth, and G. Mann (eds.), Austrian Academy of Sciences Press, Vienna, 2006, *this issue*.