

Observations of Radio Giant Pulses with GAVRT

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Abstract. Radio giant pulses provide a unique opportunity to study the pulsar radio emission mechanism in exquisite detail. Previous studies have revealed a wide range of properties and phenomena, including extraordinarily high brightness temperatures, sub-nanosecond emission features, and banded dynamic spectra. New measurements of giant pulse characteristics can help guide and test theoretical emission models. To this end, an extensive observation campaign has begun which will provide more than 500 hours on the Crab with a 34-meter antenna located in California, USA. The observations are being done as part of an educational outreach program called the Goldstone-Apple Valley Radio Telescope (GAVRT). This antenna has a novel wide bandwidth receiver which provides up to 8 GHz of instantaneous bandwidth in the range of 2.5 to 14 GHz. These observations will provide detailed information about the variability, amplitude distribution, and detailed frequency structure of radio giant pulses. In addition, a database of pulses from these observations and others of the Crab pulsar is being created which will simplify multiwavelength correlation analysis.

Keywords: Crab pulsar, Giant pulses, Radio astronomy instrumentation

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INTRODUCTION

Giant radio pulses from the Crab pulsar have been extensively studied over the years. Recent studies have largely fallen into two categories. The first are statistical studies of a large number of pulses, in which continuous time series from the telescope are recorded to disk and analyzed offline to extract the giant pulses [e.g. 1, 2, 3]. The time resolution for these studies has typically been longer than 1 microsecond and bandwidths are typically 100–200 MHz. Most of the available data has been taken around 1400 MHz. Cordes et al. [4] analyzed giant pulse statistics at several frequencies between 430 to 8000 MHz, but each frequency was observed separately. A few studies have used coordinated observations with multiple telescopes to study giant pulses at widely separated frequencies simultaneously [5, 6].

The second type of observations have probed the structure of individual pulses themselves, by recording the widest bandwidths technically feasible [7, 8, 9]. Continuously recording such large bandwidths is impractical, so the recording system must be triggered by a pulse detected in real time. The effective duty cycle and limited telescope time of these experiments has limited the sample sizes to of the order 100 pulses. These studies have uncovered a wealth of structure which has inspired and challenged many theoretical emission models [8].

These two categories of observations have raised many questions about the nature of the giant pulse emission mechanism and the effects of the interstellar medium on the radiation. A long term study of giant pulses from the Crab pulsar with higher time resolution and wide instantaneous frequency coverage has been undertaken with the

DSS-28 telescope, which will provide new information to help resolve these questions.

THE DSS-28 SYSTEM

The 34-meter DSS-28 radio telescope is operated by the Jet Propulsion Laboratory and the Lewis Center for Educational Research as part of the GAVRT educational outreach program which aims to enrich K-12 curricula by teaching students about radio astronomy. The students take data with the telescope to help scientists involved in the program. The antenna is equipped with a novel wide bandwidth feed which covers 2.5–14 GHz simultaneously [10, 11]. A set of four independently tunable dual polarization 2 GHz bandwidth receivers provide access to up to 8 GHz of instantaneous bandwidth. A flexible digital signal processing system made up of FPGA boards from the CASPER¹ group and high performance graphics processing unit (GPU) computer nodes enables a wide variety of pulsar observation modes. The two modes most commonly used for giant pulse observations are described below.

Wide bandwidth observations

In wide bandwidth mode, each 1 GHz subband is digitized and streams into a circular buffer. A trigger signal is formed by incoherently dedispersing the band in real time using the known dispersion measure of the pulsar. Depending on the expected length of the dispersed signal, the available memory can be broken up into many circular buffers. This allows bursts of pulses to be captured which are then transferred to disk for offline processing. Currently, a total of 8 GHz is brought from the receiver system at the vertex of the antenna to the signal processor in the pedestal. Thus, wide bandwidth observations are limited to 8 GHz with a single polarization or 4 GHz with both polarizations. Initial observations have been made with 8 GHz from a single polarization.

Continuously recorded observations

To record every giant pulse from the pulsar, it is possible to send raw voltage data from the digital system to a computer with a high performance GPU for real time coherent dedispersion. The implementation used at DSS-28 is based on the NRAO GUPPI machine [12]. Each GPU node is capable of processing a dual polarization 128 MHz subband. Currently we have two such nodes, so two arbitrarily tuned subbands can be processed simultaneously. The GUPPI code has been modified to search the coherently dedispersed time series on the GPU in real time for giant pulses. When a giant pulse is detected this way, the current block of dedispersed data can be written to disk at full time resolution. The highest detection rate for the coherently dedispersed 128

¹ <http://casper.berkeley.edu>

MHz subband has been found to be at the low end of the frequency range, around 2.6 GHz.

INITIAL RESULTS AND CONCLUSIONS

The wide bandwidth observations provide the most complete picture of giant pulse emission from 2.5 to 10.5 GHz. An example pulse is shown in figure 1. The emission clearly spans the entire frequency range. Note that since only one linear polarization is recorded, changes in polarization angle versus frequency could manifest as changes in intensity versus frequency. Faraday rotation in the interstellar medium will cause a change in polarization angle versus frequency, but using a rotation measure for the Crab pulsar of -42.3 rad m^{-2} [13], we expect intensity variations of less than 30% across the 2.5 to 10.5 GHz band. Since the rotation angle scales as λ^2 , the effect will be concentrated at the low end of the band. The initial sample of giant pulses shows a wide range of morphological features. As statistical information is accumulated, these features may shed new information on the emission mechanism. The statistics of the spectral characteristics of the pulses should help disentangle propagation effects from the intrinsic properties of the emission.

One aspect of the GAVRT giant pulse observation campaign is looking for correlation between radio giant pulses and gamma-ray photons detected by the Fermi telescope. For this project, over 100 hours of observations have been made in the continuous recording mode at 2.6 GHz in order to obtain the largest number of pulses possible. The number of giant pulses detected varies dramatically day to day. On some days, a giant pulse is detected every few seconds, while on other days the rate drops below one per every hundred seconds.

The extremely wide bandwidth receiver and signal processor installed on the DSS-28 antenna are well suited for studying giant radio pulses from the Crab pulsar. The ongoing observation campaign provides much greater simultaneous frequency coverage and observing time than previous studies. The data from this campaign is being stored in a database which will soon be openly accessible to other researchers and will also include data from other telescopes and wavelengths. The data set will allow statistical studies of pulse characteristics, both intrinsic and due to the interstellar medium.

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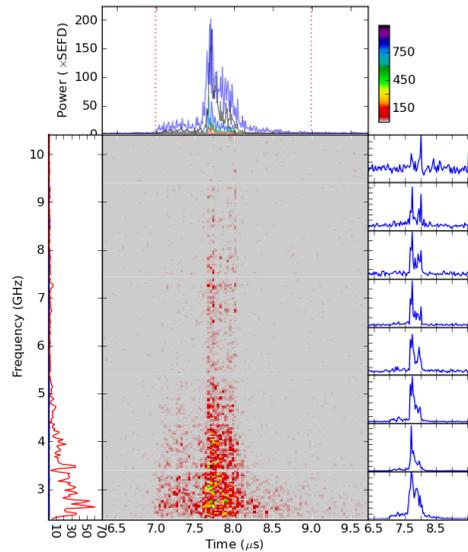


FIGURE 1. Example of a giant pulse captured at DSS-28. Note the 8 GHz instantaneous bandwidth. The panel to the left of the dynamic spectrum shows the average spectrum of the on-pulse region relative to the off-pulse region. The top and right panels show the intensity time series for each of the 8 subbands. In the top panel, each subband is plotted in a different color. The vertical dotted lines show the on-pulse region. The vertical scale of each of the right panels has been automatically set for each subband. This pulse occurred at the rotational phase of the main pulse.

REFERENCES

1. M. V. Popov, and B. Stappers, *A&A* **470**, 1003–1007 (2007), 0704.1197.
2. N. D. R. Bhat, S. J. Tingay, and H. S. Knight, *ApJ* **676**, 1200–1209 (2008), 0801.0334.
3. R. Karuppusamy, B. W. Stappers, and W. van Straten, *ArXiv e-prints* (2010), 1004.2803.
4. J. M. Cordes, N. D. R. Bhat, T. H. Hankins, M. A. McLaughlin, and J. Kern, *ApJ* **612**, 375–388 (2004), arXiv:astro-ph/0304495.
5. S. Sallmen, D. C. Backer, T. H. Hankins, D. Moffett, and S. Lundgren, *ApJ* **517**, 460–471 (1999), arXiv:astro-ph/9902386.
6. M. V. Popov, A. D. Kuz'min, O. M. Ul'yanov, A. A. Deshpande, A. A. Ershov, V. V. Zakharenko, V. I. Kondrat'ev, S. V. Kostyuk, B. Y. Losovskii, and V. A. Soglasnov, *Astronomy Reports* **50**, 562–568 (2006), arXiv:astro-ph/0606025.
7. T. H. Hankins, J. S. Kern, J. C. Weatherall, and J. A. Eilek, *Nature* **422**, 141–143 (2003).
8. T. H. Hankins, and J. A. Eilek, *ApJ* **670**, 693–701 (2007), 0708.2505.
9. A. Jessner, M. V. Popov, V. I. Kondratiev, Y. Y. Kovalev, D. Graham, A. Zensus, V. A. Soglasnov, A. V. Bilous, and O. A. Moshkina, *A&A* **524**, A60+ (2010), 1008.3992.
10. W. A. Imbriale, “Design of a Wideband Radio Telescope,” in *Proc. IEEE Aerospace Conference*, 2007, pp. 1–12.
11. G. Jones, *Instrumentation for wide bandwidth radio astronomy*, Ph.D. thesis, California Institute of Technology (2010), URL <http://resolver.caltech.edu/CaltechTHESIS:10122009-094525715>.
12. R. DuPlain, S. Ransom, P. Demorest, P. Brandt, J. Ford, and A. L. Shelton, “Launching GUPPI: the Green Bank Ultimate Pulsar Processing Instrument,” in *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, 2008, vol. 7019.
13. R. N. Manchester, G. B. Hobbs, A. Teoh, and M. Hobbs, *AJ* **129**, 1993–2006 (2005), arXiv:astro-ph/0412641.