Volume 2 Article 8

May 2010

Giant Pulse Detection in the Andromeda Galaxy for Future Discovery of Extragalactic Pulsars

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GIANT PULSE DETECTION IN THE ANDROMEDA GALAXY FOR FUTURE DISCOVERY OF EXTRAGALACTIC PULSARS

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Abstract

With the Green Bank Telescope (GBT) in Green Bank, WV, radio data from the Andromeda Galaxy (M31) have been collected by the Naval Research Laboratory (NRL) and brought to West Virginia University (WVU) for processing. A search is being conducted for giant radio bursts from pulsars. Currently, the data are halfway through being analyzed. Several candidates have been sighted, and radio frequency interference is in the process of being continuously mitigated.

Introduction

Neutron stars are stars that contain roughly 1.3 - 2 solar masses, have a 10 - 20 km radius, and spin rapidly on their axis with a period which may range from 1.5 ms to 8.5s. Neutron stars are the results of the deaths of massive stars in supernova explosions. They are the dense cores of stars and the second densest objects in the Universe, next to black holes. In the formation of the neutron star, due to the conservation of angular momentum, the star spins faster as it collapses, while the magnetic field grows very large. We can detect the emission of a neutron star from radio waves and other electromagnetic radiation. This radiation is due to particles being accelerated along the magnetic field lines of the star. As the neutron star quickly spins, we can detect the pulses of radiation as if they were part of a lighthouse beam sweeping across our view.

Giant pulses are a phenomenon attributable to pulsars such as the Milky Way's Crab pulsar (PSR B0531+21). These giant pulsations are inferred to have an extremely high brightness temperatures – the brightness temperature is the equivalent temperature of a blackbody source required to produce the observed intensity - of 1035 K (Bhat et al. 2008). These high values imply that the emission mechanism is non-thermal in origin. These giant-pulses are the brightest ever detected in the universe (Cordes et al. 2004). It is predicted that the Andromeda Galaxy (M31) will have around 10 giant pulse emitting pulsars, assuming it as a spiral galaxy similar to ours, that the pulsars within have an age of 1000 years (similar to the Crab Pulsar), and that such pulsars are being born 1 in every 100 years (McLaughlin & Cordes 2003).

Currently, 1800 or so known pulsars are detected in the Milky Way Galaxy and the Magellanic Clouds. The discovery of extragalactic pulsars in M31 will contribute to future searches for neutron stars in other parts of space, helping to probe the extragalactic medium. Research is being done within West Virginia University's Physics department to search for and study pulsars. Given their extreme properties and peculiar features, pulsars have been able to give insight to, and help further the theories of general relativity and gravity (Taylor & Weisberg 1982; Lyne et al. 2004).

The following report will explain the methods of obtaining data from M31 using the Green Bank radio telescope, processing the data, the M31 results thus far, and ongoing and future plans to continue researching the M31 data.

Obtaining Data from M31

The observations of M31 took place with the Green Bank Telescope (GBT) by a team led by Dr. T. J. W. Lazio at the Naval Research Laboratory (NRL). There were seven 10-hour pointings at 330 MHz, as seen in Figure 1 (INSERT M31_giantpulse.ps):caption{The M31 galaxy with the seven respective pointings. The diameter at each circle is the GBT's primary beam at 330MHz with size of 35' (source of optical image?) and data for pulsar B1937+21, which emits giant pulses (Soglasnov et al. 2004) was also collected with the GBT for testing purposes.

The data were taken between August 17, 2004 and August 20, 2004 using the pulsar SPIGOT backend (Kaplan et al. 2005). The SPIGOT is an autocorrelation spectrometer which was used to synthesize a filterbank sampling a 50 MHz band split into 1024 contiguous frequency channels, sampled every 81.92μs per file.

In alliance with West Virginia University (WVU), the M31 data were transported from NRL, and

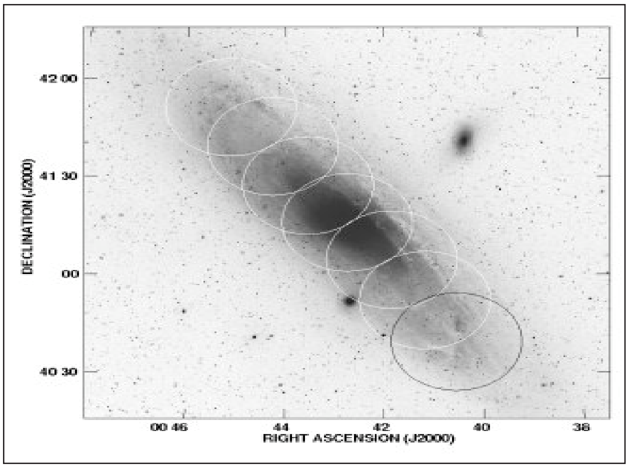

Figure 1 - The M31 galaxy with the 7 respective pointings. The diameter at each circle is the GBT's primary beam at 330MHz with size of 35'.

then copied from hard-drives onto the WVU servers for offline processing.

Processing the Data

This search for radio bursts within M31 began October 2008. The computer code implemented to process M31 data was first created and tested on test pulsar data, before serious trials were to commence.

A C-coded shell script program aptly named M31_search was created to turn the radio data into readable plots that could be interpreted. Within this program, the M31 data were processed using pulsar signal processing programs or sigproc-4.3.[1] Autocorrelation data from SPIGOT were first converted to the equivalent representation as a 1024 channel spectrometer (or "filterbank"). These filterbank data were then corrected for the effect of interstellar dispersion (see below) to produce a number of time series which were searched for individual pulses.

The dispersion measure (DM) is the integrated column density of electrons in space (INSERT, integral from '0 to l' n_e dl) that produces a medium with a frequency dependent refractive index though which the electromagnetic waves from the pulsar propagate. Electromagnetic waves with higher frequencies travel faster through this medium and arrive earlier than waves with lower frequencies resulting in a dispersion effect observed at the telescope. To correct for this effect, the data are dedispersed by delaying the high frequency channels in the filterbank files with respect to the lower frequency channels for many different trial values of DM.

Each pointing was dedispersed through a long list of approximately 9600 DM values that topped off at approximately 1000 pc cm-3. The list of DM values were generated by asserting that the distance over which to integrate was the distance to M31, being 2.53 +- 0.07Mly, while also taking into consideration the angle at which the M31 galaxy is tilted with respect to the view of the Earth, which is roughly 70o. By including the electrons which would contribute in the line of sight from the Milky Way, the with t being the thickness of M31, at 1.01kpc, the contributing DM from an emitting pulsar from M31 could then be estimated being:

DM = (integral from 0 to l) 2(n_e(t/cos(70))) dl.

The method of single-pulse searches was utilized, due to this method having more sensitivity than standard searches of periodicity, when looking for giant pulse pulsars (McLaughlin & Cordes 2003). The algorithm used averages each time series by adding together progressively greater numbers of adjacent time samples. At each averaging step, statistically significant signals are sought by computing the amplitude of each averaged sample to the local root-mean-square value. This quantity is known as the signal-to-noise ratio (S/N). The result of this so-called "matched filtering process" is to optimally search the data for pulses of a variety of widths. Specifically the signal-to-noise (McLaughlin & Cordes 2003) of a pulse from a single pulse search S/Nsp is (S/N)sp = η(N_pol *Δν * W)1/2 * S-1sys*Smax, where Ssys is the system noise, N_pol represent the number of polarization channels summed, η ~ 1 is the pulse shape dependent factor, Δν is the total bandwidth, and W is the pulse width.

The M31_search program generated single-pulse plots, and within each plot there contained three smaller plots; the first being the number of pulses versus S/N, the second being the number of pulses versus DM, the third S/N ratio versus DM, and a final plot to the bottom that shows pulses plotted versus DM and time.

Results

Each single-pulse plot generated has a time axis that ranges from 0 - 80 seconds, as the DM axis ranges from 0 - 1000 pc cm-3. Observations of the test pulsar B1937+21 were successful, in that discernible pulses are seen at the catalog DM of 71.04 pc cm-3, as seen in Figure 2.

As of now, there is no definite conclusion as to whether giant pulses have been found for M31. So far, probable candidates, such as the one seen in Figure 3, show a possible faint pulse. The S/N of this pulse is 7.1, the DM is calculated to be 55 pc cm-3, the width of the pulse was 31.92s, and the implied energy output was 8.45x104 Jy kpc2 .

In addition to candidates, there have been periodic, slanted pulses perhaps induced by narrow-band emission from an unknown source of radio frequency interference (RFI), as seen in Figure 4. RFI (most often originating from terrestrial electronics) interferes with radio astronomy and must first be recognized and excised. The S/N of this pulse was 17.6, the DM of the pulse was 188.8 pc cm-3, the width of the pulse was 0.50 s and the implied energy output at the distance of M31 is 1.676x106 Jy kpc2.

The implied energy outputs for the largest giant-pulses currently known from emitting pulsars, that have been run through a single pulse search (Johnston & Romani 2003), using 12 for the S/N -which is the average between the two M31 candidates- are as follows:

Crab Pulsar: 4.8x104 Jy kpc2
B0540-69: 2.01x106 Jy kpc2
B1937+21: 3.26x103 Jy kpc2
B1821-24: 8.7x103 Jy kpc2

Compared to what is known about pulsars in the Milky Way Galaxy, these implied energy outputs suggest that pulsars detected from M31 at these variables are much brighter and energetic than the usual. It would also imply that the second M31 candidate is simply RFI, since it has such a high flux that it could not be real.

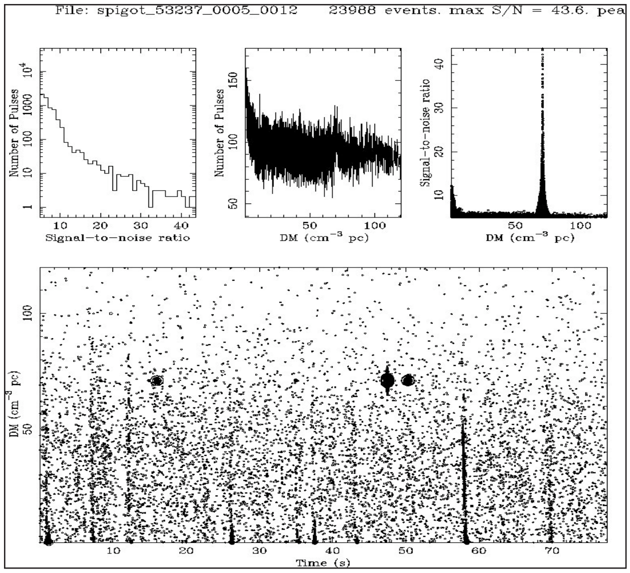

Figure 2 - The known giant-pulse pulsar, B1937+21, seen at a DM of 71.04 pc cm^{-3}. Though the pulsar has a period of 1.5 ms, what are seen here are instead giant pulses from the pulsar.

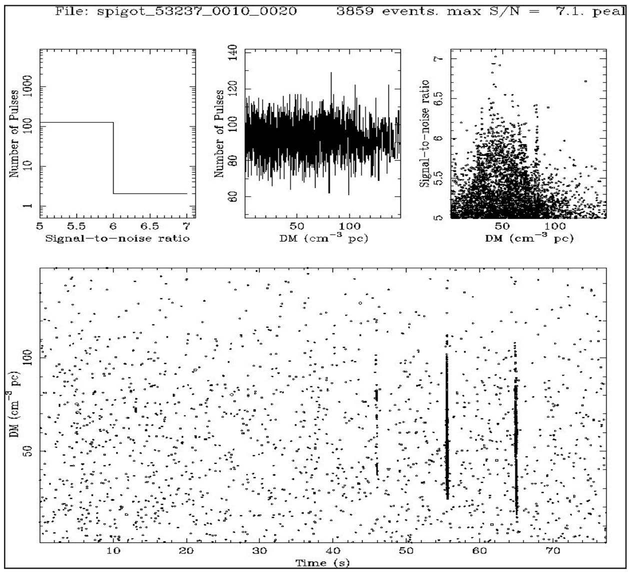

Figure 3 - Potential radio source at a DM of approximately 55 pc cm^{-3}.

Ongoing and Future Research

Initial processing of the test pulsar data has been completed and successful, and the research of actual M31 data is ongoing, with portions of the data yet to be analyzed. Further adjustments and calibrations must be made for certain files which had incorrectly applied initial calibration and were not working correctly with the sigproc-4.3 programs during processing.

Other searches of M31 and other galaxies are sure to follow by pulsar astronomers in the future and present, as technology and the software for observing extragalactic objects continues to improve.

Acknowledgements

Thanks to the NASA WV Space Grant Consortium, my research mentor Dr. Maura McLaughlin, and Dr. T. J. W. Lazio at the Naval Research Laboratory for making this research experience possible. I would also like to send acknowledgments to West Virginia University, for if it had not been for the existence of this school, then the WVU Physics department would not have been in existence, and therefore I would never have had the opportunity to study here and do pulsar research.

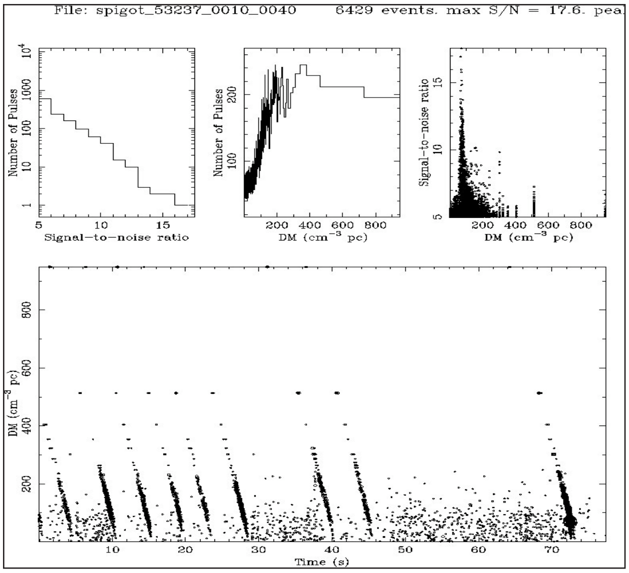

Figure 4 - Unknown source, potentially Radio Frequency Interference (RFI), causing slanted pulses, at a DM of approximately 188.8 pc cm^{-3}.

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NOTES

1. http://sigproc.sourceforge.net/