Pulsar Observation at 175MHz using Gauribidanur Radio Telescope

Mahek Patel

BSc Astronomy and Astrophysics, Florida Institute of Technology, RASS Raman Research Institute

Supervisors: Prabu T, Sahana, Arul (Raman Research Institute)

INTRODUCTION

Pulsars are rapidly **spinning neutron stars**, the ultra-dense remnants of a massive stars explosion. These pulsars are around **10-15 km wide** but heavier than our Sun, they emit beams of radio waves as they spin, these beams sweep across space like lighthouse beams, and if Earth lies in their path we can detect them as precise, regular pulses. In this project, three pulsars were observed using the **Gauribidanur Diamond Array Telescope (GBD)**. Observation times were planned using tools like ***KStars***, which helped visualize sky maps and track pulsar positions to ensure accurate pointing during their transit. After data collection, the focus was on processing the signal by identifying pulse bins, subtracting background noise, smoothing the data to enhance signal-to-noise ratio, and generating clear average pulse profiles.

Parameter	J1921+2153	J0953+0755	J0534+2200
Period(s)	1.337302160*	0.253089348	0.033842426
Period Derivative (s/s)	1.3 x 10^{-15} *	2.3 x 10^{-16}*	4.2 x 10^{-13}*
DM (pc/cm^{-3})	12.4	2.94	56.77
Proper motion in Declination	22 (-34.4 km/s)	29.46 (-36.5 km/s)	2.65 (-25.1 km/s)
Distance from earth (kpc)	0.33	0.261	2

Table 1: Parameters of the observed pulsars (ATNF catalog)

WORKING OF TELESCOPE/PIPELINE

The Gauribidanur Diamond Array uses **64 Log-Periodic Dipole Antennas (LPDAs)**. In this project **32 LPDA** were used, each sensitive to a single polarization and operating in the **130–350 MHz broadband frequency range**. The array arranged into 4 subgroups with 16 antennas each. Sky signals are first amplified by **LNAs**, combined in-phase within and across **subgroups (4:1),** then further amplified. The RF signal is converted to optical using an **RFOF TX**, sent over a **300 m cable** and converted back to electrical at the lab with **RFOF RX.**

The signal splits: one path goes to the **Oscilloscope** for real-time monitoring, and the other to the **PDR**. From there, data flows through **ADC1 and ADC2**, where ADC2 output goes to **PC1**, and data gets temporarily stored in **RAM** and then saved in **hard disk**. This data is then used for **Pulsar Data Reduction** or stored in **Hierarchical Data Format (HDF5)** for further analysis.

After the **trigger** is sent, data collection begins. Once **one hour of data** is recorded, files are checked for packet loss. The **.pcap files are converted to .dada** format for compatibility with processing tools like **DSPSR**. Strong RFI is removed and affected channels are masked. Using **DIGIFIL**, the time-series is converted into a **de-dispersed filterbank**. These filterbank files are processed using **PRESTO search mode** and DSPSR then performs coherent dedispersion using the dispersion measure (DM) from the **.par file** and produces folded profiles in .ar format. Predict aligns pulse phases by calculating arrival times. Final outputs like **.ar and .fits files** can be viewed and analyzed with **PSRCHIVE tools**.

Figure 1: Gauribidanur Diamond Array Telescope

RESULTS OF PSR J1921+2153

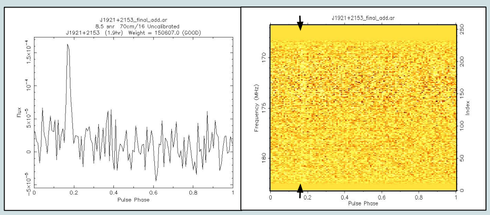

Figure 2: Pulse Phase vs Flux and Pulse Phase vs Frequency plot for dispersed data

The **left panel** shows the pulse profile of PSR J1921+2153. A sharp peak is seen near phase 0.2, indicating the presence of main pulse. **The right panel** displays a Frequency vs Phase. The bright vertical band indicates that pulse signal arrived simultaneously across all frequencies confirming the pulse was not smeared by dispersion.

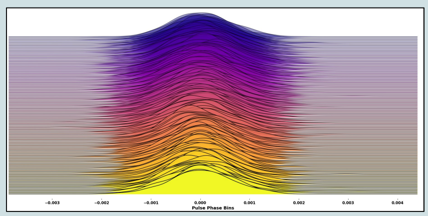

Figure 3: Joy Division Plot

In this plot above of the first discovered pulsar by Jocelyn Bell, individual sub-integration are stacked vertically by pulse phase. This plot visually emphasizes the structure of the pulse shape across the band. If the shape varies, it could be due to noise, interference, or changes intrinsic to the pulsar signal itself.

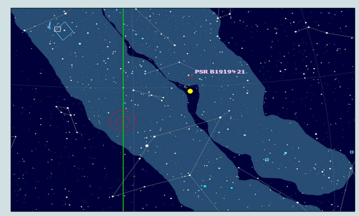

Figure 4: KStars map showing the position of pulsar in the galactic plane

This map marks the location of PSR J1921+2153 in the **Galactic Plane**, close to the constellation Vulpecula. Being situated in the dense region of the Galactic Plane, the pulsar's signal is heavily affected by **interstellar scattering** and **dispersion**, making it more difficult to detect and analyze accurately.

RESULTS OF PSR J0953+0755

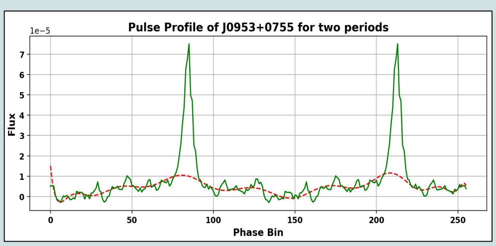

Figure 5: Flux (arbitrary units) vs Phase bin plot for two periods of added pulsar profiles

This plot shows the **smoothed**, **baseline-removed pulse profile** of PSR J0953+0755 over two full rotation periods (256 phase bins). The **green curve** displays the pulsar's signal, showing two distinct pulses per cycle. The **red dashed line** is a fitted curve to the off-pulse region, used to model and subtract the baseline. This enhances the pulse shape and improves **signal-to-noise ratio** (SNR).

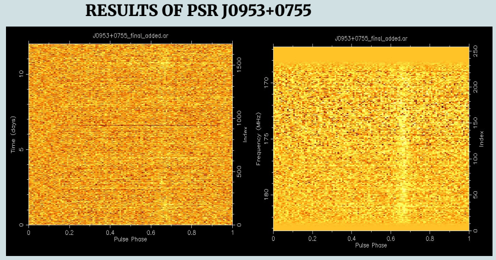

Figure 6: Time vs Pulse Phase and Frequency vs Pulse Phase

The left panel shows a **time vs phase plot**, where the x-axis represents pulse phase and the y-axis shows observation time over 6 days (6 hours). Each horizontal row is a **sub-integration** that is a folded segment of data. The recurring bright bands indicate consistent pulse detections. The right panel displays **frequency vs pulse phase**, where the pulse signal appears consistently aligned across all frequency channels. This confirms the pulse's presence across the full observing bandwidth.

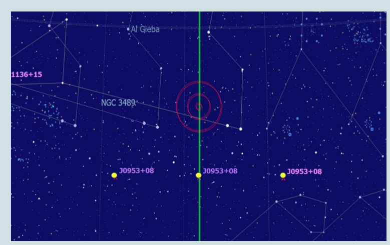

Figure 7: KStars map of Pulsar for 1 hour observation

This map illustrates the position of pulsar at the start till the end of the 1 hour observation. The pulsar is located in the constellation Leo.
Among the three pulsars observed during the project, J1919+2153 shows the most significant highest **proper motion**.

RESULTS OF PSR J0534+2200

The left-hand side image shows the **PRESTO prepfold** plot confirming the detection of the Crab Pulsar. In this, folding is done to **align and stack repeating pulses** in the radio data to make the pulsar signal clearer. The distinct pulse profile and strong result in the period search show that the signal is consistent. With a measured **period of 33.84 milliseconds** the plot gives clear evidence of a successful pulsar detection.

Sometimes, the CRAB pulsar may not be detected in the folded profile, especially if the signal is weak or affected by interference. In such cases, **PRESTO's single pulse search** becomes useful. It looks for individual bright pulses in the raw data rather than a repeating signal and DMs. If strong pulses appear at the expected dispersion measure (DM), it can confirm the pulsar's presence even when folding fails. This method is especially helpful for detecting pulsars affected by the **solar activity or** even by the intrinsic **slowing down of the pulsar** like CRAB pulsar.

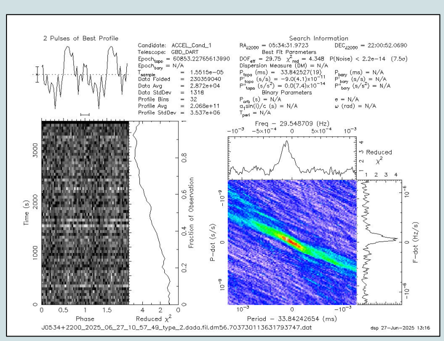

Figure 8: Prepfold search mode plot of CRAB Pulsar with detection

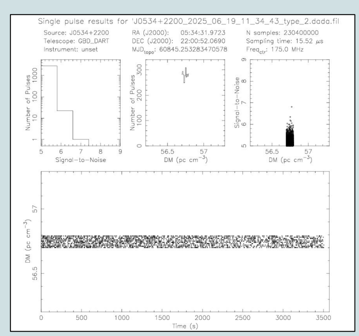

Figure 9: Single Pulse Profile of J0534+2200 for epoch corresponding to NO detection

CONCLUSION

During this project, successful detection of pulsars was achieved by doing observation from the Gauribidanur radio array. Some observations were initially affected by noise, which was later corrected through baseline removal and by combining profiles from consecutive days to improve signal quality. Variations seen in the pulse profiles across different days suggest possible effects from the interstellar medium and solar activity, showing how pulsar signals can be used to study both galactic and solar system environments. The Gauribidanur array has recently been upgraded to support dual polarization, which has already improved sensitivity, allowed better polarization studies, and enhanced overall data quality.

REFERENCES

[1]Bhattacharya, D. "Detection of Radio Emission from Pulsars: A Pulsar Observation Primer." *The Many Faces of Neutron Stars.*, vol. 515, ADS, 2025, p. 103, ui.adsabs.harvard.edu/abs/1998ASIC..515..103B.

[2]European Pulsar Network Database (EPN)." *Jodrell Bank Centre for Astrophysics*, University of Manchester, https://psrweb.jb.man.ac.uk/epndb/.

[3]*KStars: Desktop Planetarium*. Version 3.7.7.KDE Webmasters. https://kstars.kde.org/

[4] Manchester, R. N., Hobbs, G. B., Teoh, A. & Hobbs, M., Astron. J., 129, 1993-2006 (2005) (astro-ph/0412641). https://www.atnf.csiro.au/research/pulsar/psrcat

[5]Patel,M .GitHub. https://github.com/Mahek566/RASS_Project_code

[6]Ransom, S. M. New search techniques for binary pulsars. https://ui.adsabs.harvard.edu/abs/2001PhDT.......123R

[7]Smith, Francis Graham. *Pulsars*. 1977.

[8] W. van, Straten. PSRCHIVE Package. https://psrchive.sourceforge.net/manuals/

Email: patelmahekm1411@gmail.com, rass@rrimail.res.in