# St. Stephen's College

**Department of Chemistry and Department of Physics**

(Under the Aegis of IQAC)

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# Collecting and Analysing Radio Data with an affordable Radio Telescope


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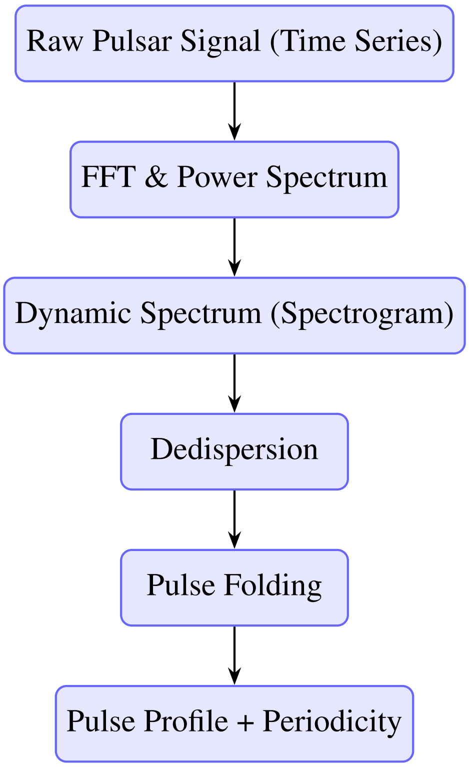
**Abstract**

This project explores the detection and analysis of the Vela Pulsar using dual-channel voltage time series data. The raw signals, captured via the Northern and Southern channels, were initially visualized and statistically characterized to evaluate noise behavior. Fourier Transform techniques were employed on segmented blocks to obtain the power spectrum, revealing periodic components associated with the pulsar's rotation. Dynamic spectra were constructed using short-time Fourier transforms, highlighting frequency-time evolution. A dispersion measure (DM) of 64.3 pc/cm$^3$ was applied to correct for interstellar medium effects, aligning dispersed signals through dedispersion. Post-dedispersion, the time series was folded over the known pulsar period ( 89 ms) to extract a clear pulse profile. Gaussian fitting was used to model the observed pulse. The results confirm successful detection and characterization of the pulsar signal, and demonstrate the effectiveness of spectral and time-domain analysis methods in radio pulsar studies.

**Keywords**

Vela Pulsar, Radio Astronomy, Fast Fourier Transfrom (FFT), Dynamic Spectra, Pulse Periodicity

### Graphical Abstract




### Introduction

This project focused on analysing radio telescope data from the **Vela Pulsar**, a well-known neutron star emitting periodic signals. The objective was to identify and study its pulse periodicity using time-series and frequency-domain techniques. Key methods included applying *Fast Fourier Transform (FFT)* to detect signal frequency, generating *power and dynamic spectra*, and implementing *dedispersion* to correct interstellar delays. The signal was then folded to extract timing and structural features.

### Methodology

The analysis was performed on voltage time series data obtained from the Northern and Southern radio telescope channels. The steps followed were:

1. **Data Preprocessing:** The raw voltage data were imported using `pandas` and visualized

to inspect signal quality. Statistical properties such as mean and standard deviation were computed, and histograms were plotted with overlaid Gaussian fits to assess noise behavior.

2. **Frequency Domain Analysis (FFT):** Fast Fourier Transform (FFT) was applied to the voltage data in 512-point chunks. Power spectra were calculated for each chunk and then averaged to enhance signal-to-noise ratio and detect dominant periodic frequencies.

3. **Dynamic Spectrum Generation:** Time-frequency representation was achieved using reshaped FFT blocks to generate dynamic spectra. These were plotted as 2D images with frequency vs time axes to visualize pulsar activity over time.

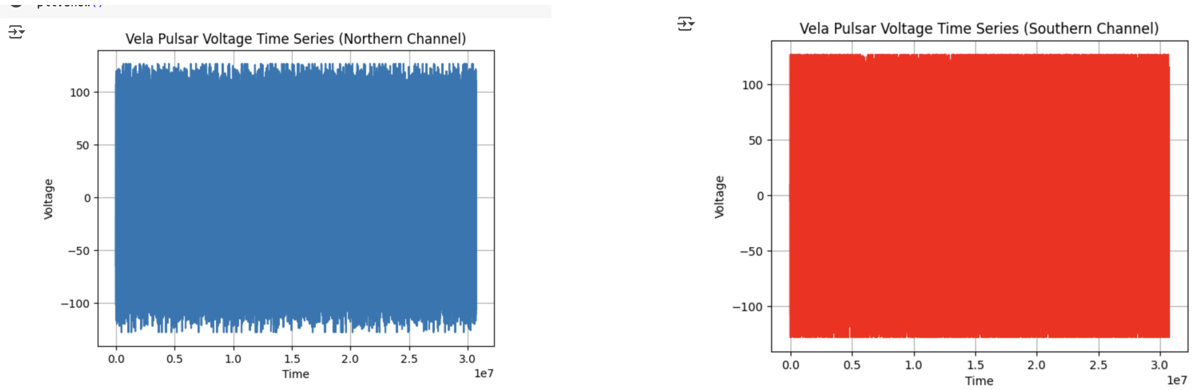
4. **Dedispersion:** Using a dispersion measure (DM) of 64.3 pc/cm³, frequency-dependent time delays caused by the interstellar medium were corrected. Each frequency bin was shifted appropriately to align the pulse signals.

5. **Pulse Profile Folding:** The dedispersed signal was folded over the known pulsar period ( 89 ms) to enhance periodic features. The resulting pulse profile was plotted and approximated using a Gaussian curve for analysis.

6. **Error and Signal Quality Analysis:** Root-mean-square (RMS) error was computed for the folded profile to assess the clarity and consistency of the pulse detection.

## Observations

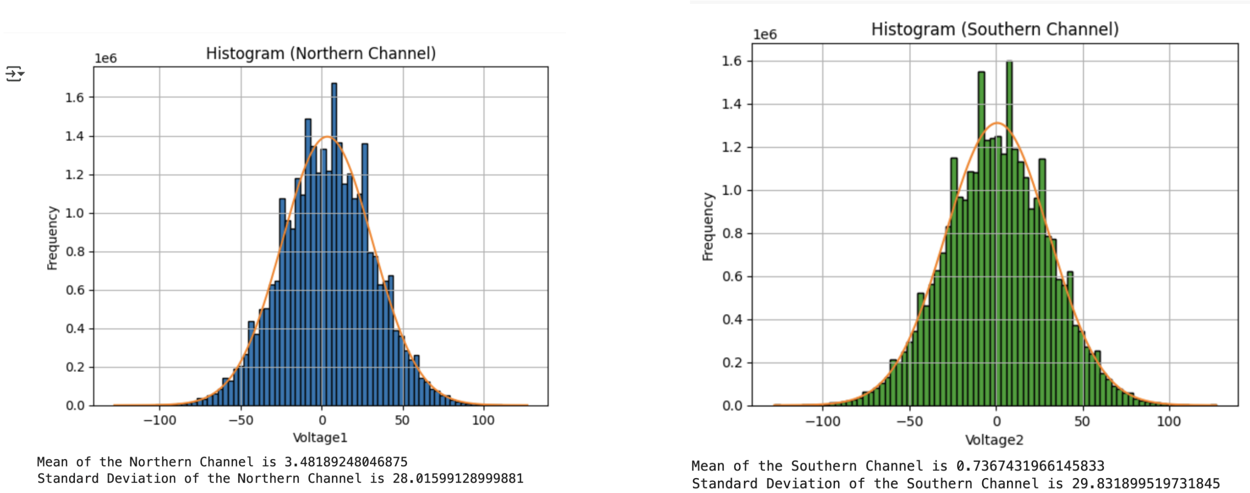
The observations have been conducted at a bandwidth of 16.5MHz and the data from two channels - Northern and Southern - is available to us.




(a) Voltage Time Series at the northern Channel

(b) Voltage Time Series at the southern Channel

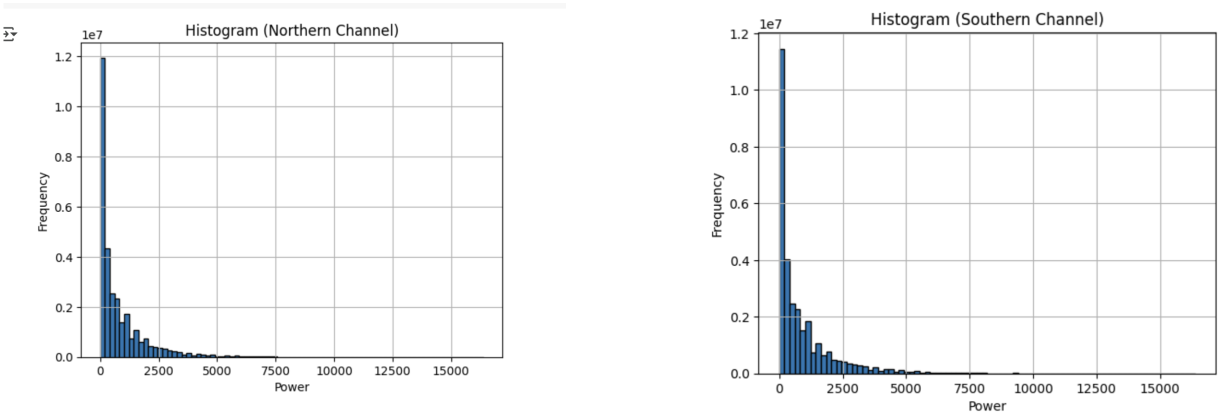
Figure 1: Voltage Time Series distribution for a total of approximately 10,000,00 randomly selected samples




(a) Histogram of the voltage at the northern Channel

(b) Histogram of the voltage at the southern Channel

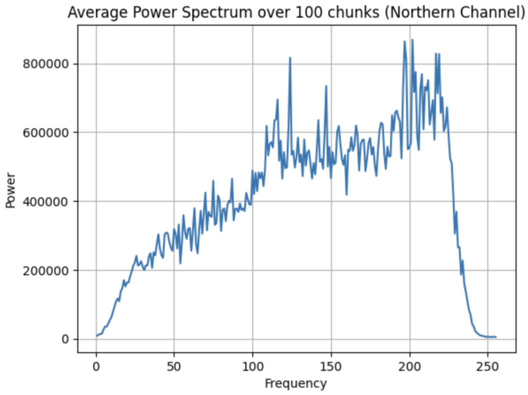
Figure 2: Histograms for the Voltage distributions



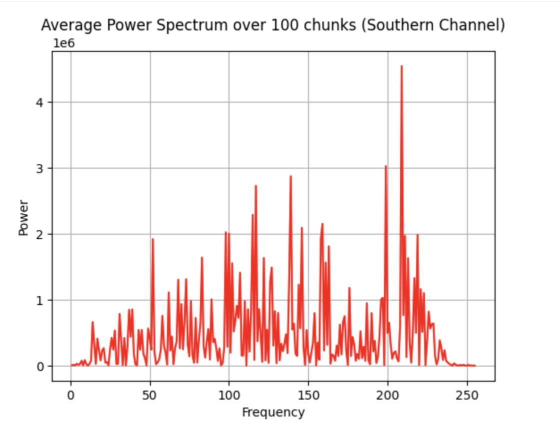

(a) Power Spectrum (Northern Channel)

(b) Power Spectrum (Southern Channel)

Figure 3: Power Spectrum

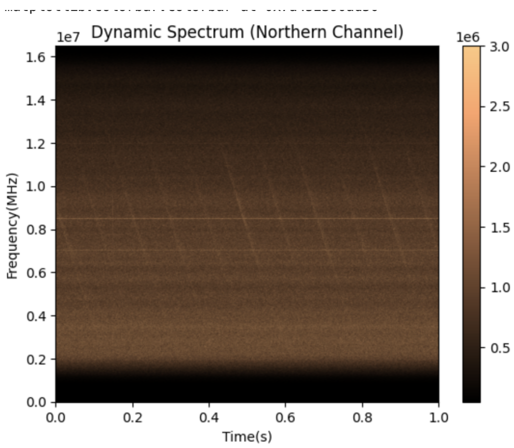



(a) Average Power Spectrum over 100 chunks after doing FFT (Northern Channel)

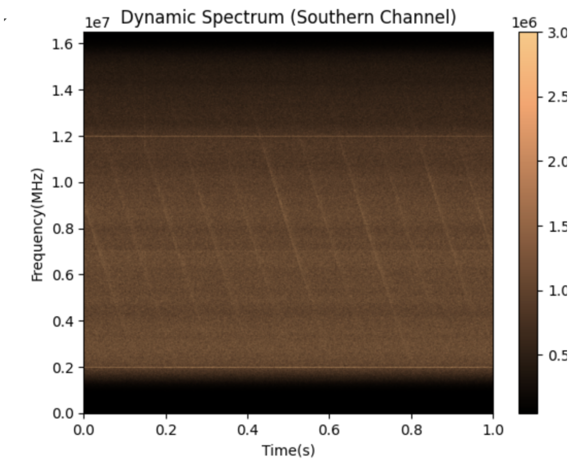



(b) Average Power Spectrum over 100 chunks after doing FFT (Southern Channel)

Figure 4: Average Power Spectrum after doing FFT

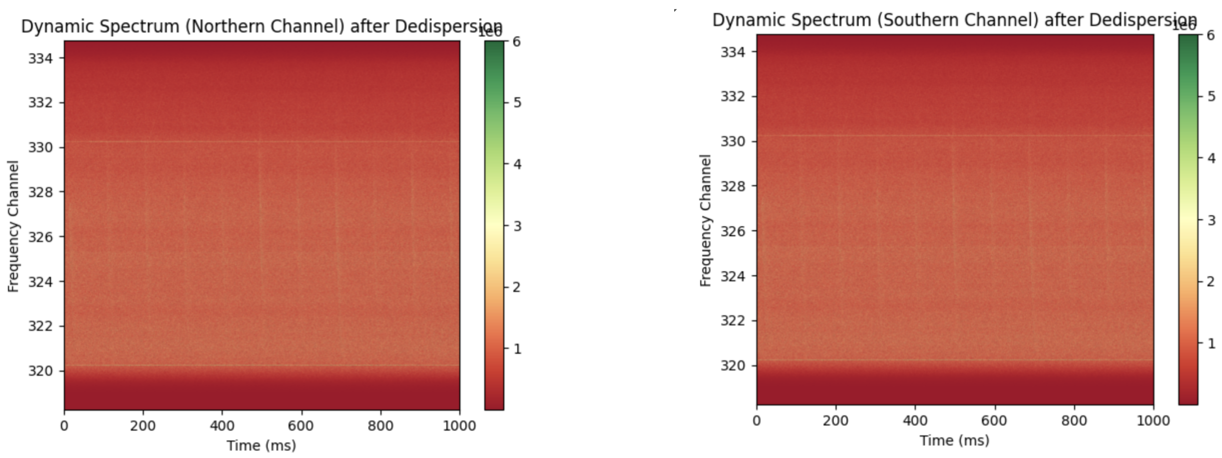



(a) Dynamic Spectrum (Northern Channel)




(b) Dynamic Spectrum (Southern Channel)

Figure 5: Dynamic Spectrum for both channels




(a) Dynamic Spectrum after Dedispersion (Northern Channel)

(b) Dynamic Spectrum after Dedispersion (Southern Channel)

Figure 6: Dynamic Spectrum for both channels after Dedispersion

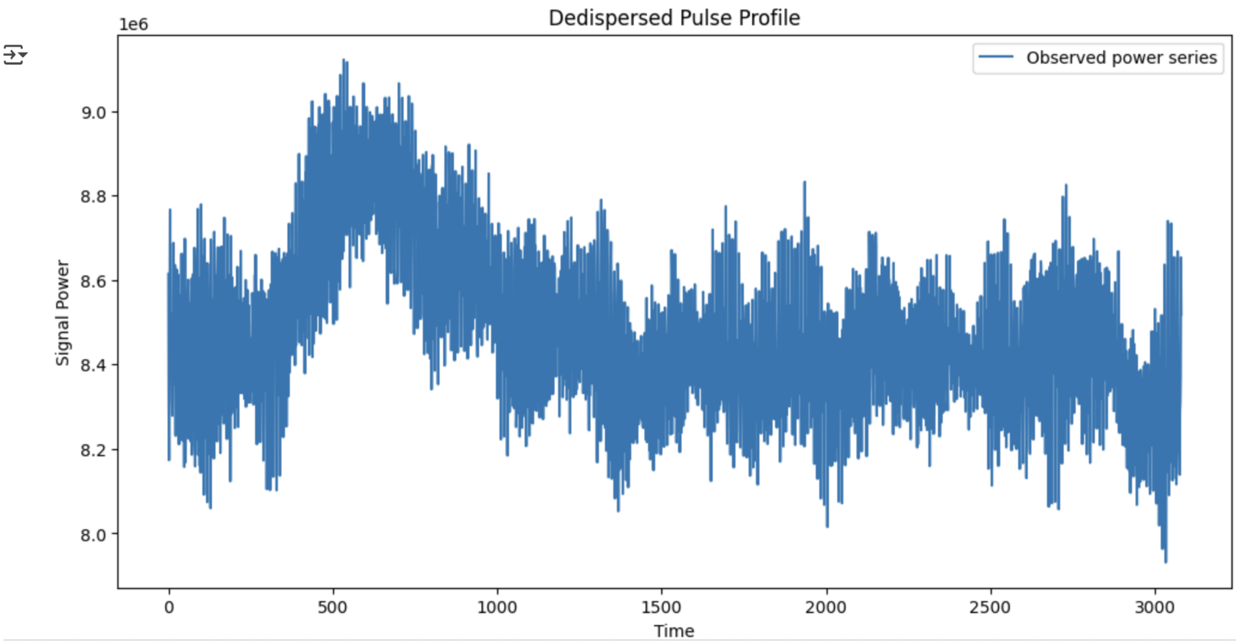



Figure 7: Dedispersed Pulse Profile

## Conclusion

The analysis of dual-channel voltage time series data from the Vela Pulsar successfully demonstrated the extraction of meaningful periodic signals embedded in noisy observations. The use of Fast Fourier Transform revealed dominant frequency components consistent with the known pulsar period, while the dynamic spectrum captured frequency-dependent signal evolution over time. Application of a dispersion measure (DM = 64.3 pc/cm$^3$) effectively realigned frequency bins through dedispersion, sharpening the pulsar signature across both channels. Pulse profile folding and Gaussian fitting further confirmed periodicity, with the resulting profiles displaying characteristic peaks at expected intervals. These results validate the effectiveness of spectral and time-domain techniques in detecting pulsar emissions and highlight the role of computational tools in modern radio astronomy.

## Acknowledgement

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## References

- James J. Condon and Scott M. Ransom (2016). *Essential Radio Astronomy*.
- Kishalay De. *Vela Pulsar Observations with the Ooty Radio Telescope.*.