# IUCAA NCRA

# RADIO ASTRONOMY WINTER SCHOOL 2020

# VELA PULSAR
# OOTY RADIO TELESCOPE
# DATA ANALYSIS

NCRA • TIFR

*Submitted by*


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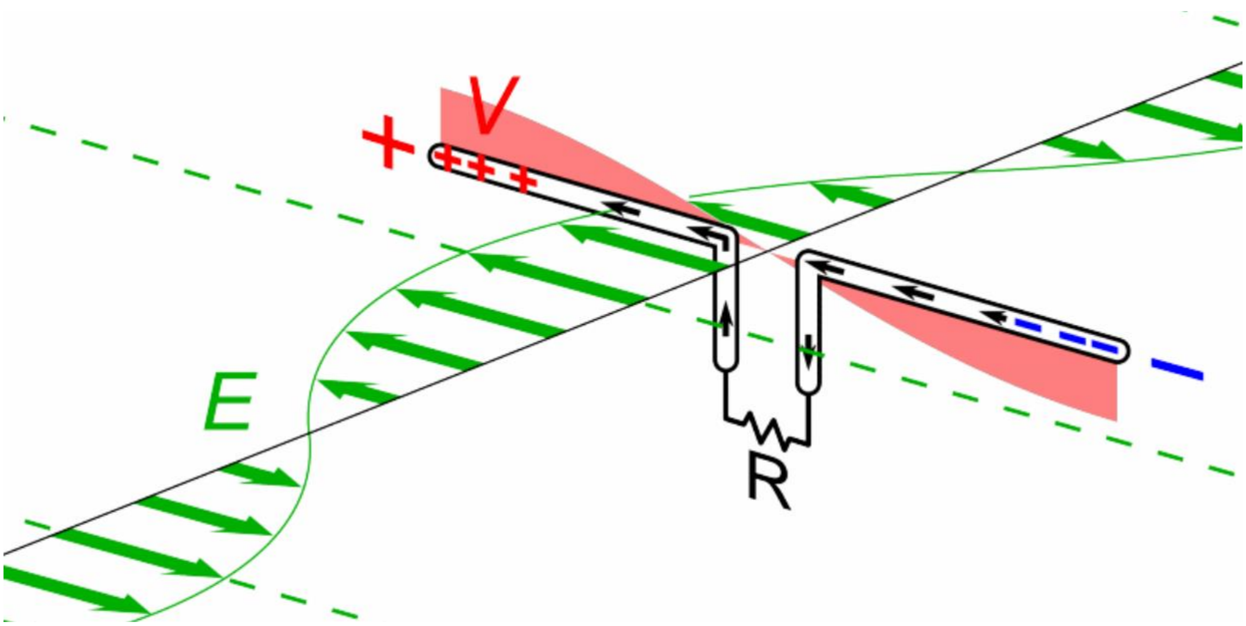
# ABSTRACT

This experiment was conducted as a part of Radio Astronomy Winter School (RAWS) 2020. We used the data corresponding to Vela Pulsar from the observations from Ooty Radio Telescope (ORT) to estimate the period of the pulsation. Using mathematical tools like Fourier transform we were able to identify the signal within the signal provided to us. With further data processing to counter the dispersion effect due interstellar medium (ISM), we were able to generate a time integrated pulse profile for the pulsar and estimate the period.

# PRINCIPLES INVOLVED

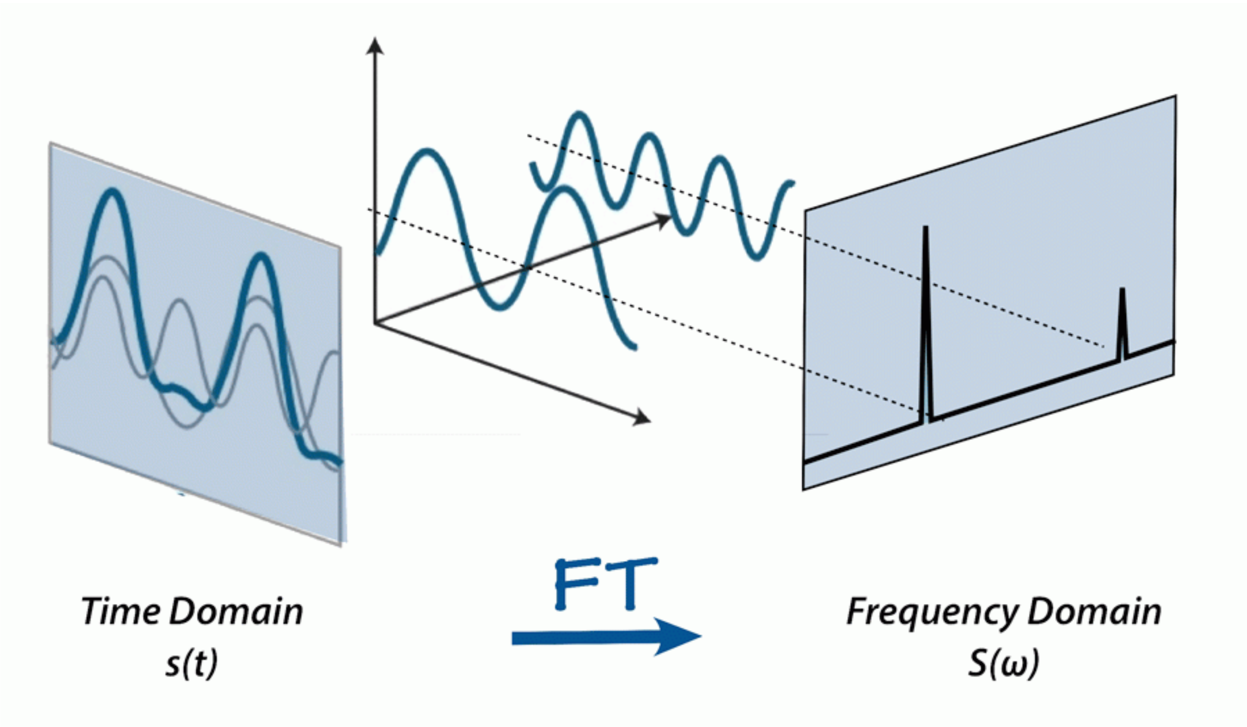
An antenna or aerial is the interface between radio waves propagating through space and electric currents passing through metal conductors, used for a transmitter or receiver. In reception, a wireless transmitter supplies an electric current to the antenna's terminals, and the antenna radiates the radiation from the current as electromagnetic waves (radio waves) (radio waves). An antenna intercepts some of the power of a radio wave at the receiving terminals for generation of an electric current applied to an amplified receiver.



As mentioned above when a time varying electromagnetic wave reaches the antenna, which gets converted to a time varying voltage output. This is further amplified and processed to get the final output. While processing the data, various mathematical tools were used to isolate the signal from the noise.

## Fourier Transform

From the concept of Fourier series, that any complex function can be represented with the help of different sinusoids. The Fourier transform is an extension of the Fourier series that results when the period of the represented function is lengthened and allowed to approach infinity.




Fourier Transform of x(t):

$$X(\omega) = \int_{-\infty}^{+\infty} x(t)e^{-i\omega t}\,dt$$

Inverse Fourier Transform of X(ω):

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} X(\omega)e^{i\omega t}\,d\omega$$

This provides a strong tool to convert between different domains making the collection and processing of data easy. Another important property that this tool provides is that, due to change in domain, we could easily separate and identify the inbuild signal that is present in the data. We will be using this property to extract the data from the Vela pulsar data that we collected.

Here we convert the time series data into the frequency domain. Fourier transform determines the amplitude and phase of the Sine waves which when combined reproduces the original time-varying non-periodic function. These are the few reasons why frequency domain is preferred-

- The electric field at the point of observation (by the telescope) varies in a particular way because of the superposition of waves of different frequencies, amplitudes, and phases.
- Which means, if we want to know how much contribution to the electric field comes from waves of each frequency (or in a frequency range), we have to take a Fourier transform of the electric field time series and obtain the amplitudes.
- And, since the power is proportional to the square of the electrical field, we can get the "Power spectral density" of the incident radiation

## Pulsars

Pulsars are highly magnetic neutron stars, that rotate at high velocities. These emit strong electromagnetic radiations out of the magnetic poles. If these are lined towards earth, we are able to see highly periodic signals coming from the star. As neutron stars are very dense and short, they produce very precise pulses ranging from milliseconds to seconds for an individual pulsar. The discovery of pulsars enables us to study about the never seen neutron stars.

## Dispersion of radio waves due to ISM

The path the light travels to reach us from the pulsar is filled with variety of particles and other substances that constitute the Interstellar Medium (ISM). The ISM disperses photons propagating through it as a function of photon frequency $\nu$ in a similar way to a prism. This leads to a frequency dependent delay thus making out signals distorted. The pulse with higher frequency will reach us first compared to the lower frequency, this is removed by calculating the dispersion measure and accordingly compensating for the time delay that occurred.

# PULSAR DATA

<u>Vela Pulsar</u>

The Vela Pulsar (PSR J0835-4510 or PSR B0833-45) is a radio, optical, X-ray- and gamma-emitting pulsar associated with the Vela Supernova Remnant in the constellation of Vela. Its parent Type II supernova exploded approximately 11,000–12,300 years ago (and was about 800 light-years away). Vela is one the brightest pulsars in radio frequencies, spinning with a period of 89.33milliseconds.

The data that we are using is a voltage time-series dataset collected simultaneously from the North and South Antennas of Ooty Radio Telescope. The data was processed using Python programming interface.

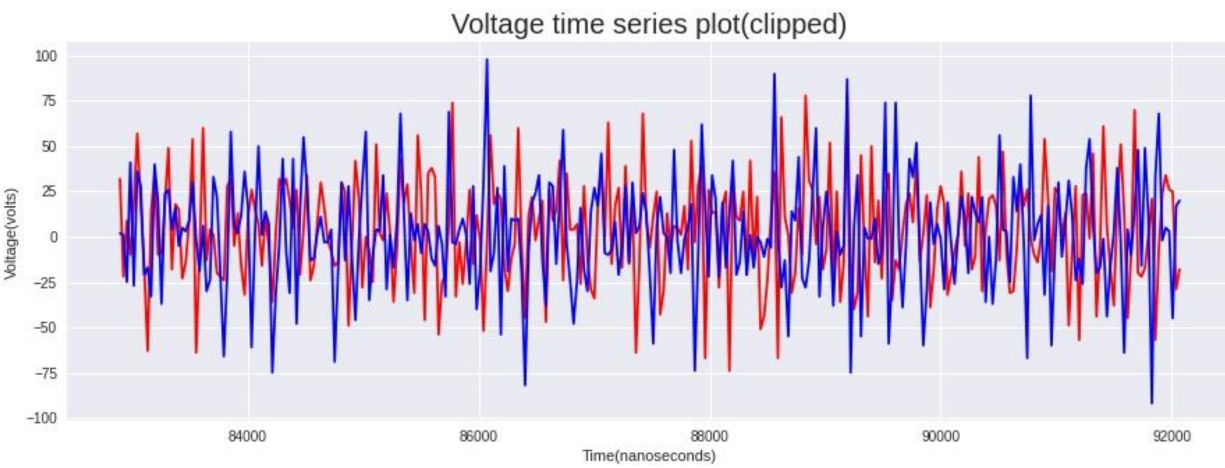



Fig1

The data was with a bandwidth of 326.5 ± 8.25 MHz. This was down converted to 0-16 MHz. The data is sampled at the Nyquist rate, i.e., two real valued voltage measurements in a period corresponding to the maximum variability timescale (maximum frequency). The time-resolution is,

$$dt = \frac{1}{2 * bandwidth}$$

$$= \frac{1}{2 * 16MHz}$$

$$= 30.3ns$$

Figure 1 shows a clipped part of the time series that was the input data for this analysis. Due to DC offset, the mean of the data was not zero. So we subtracted the offset to get the data for further processing. The next step we did was to compute the power by squaring the voltage. This will give us the Power Time series. We have also calculated and estimated a gaussian to both the histograms plots. We have shown all these plots below.

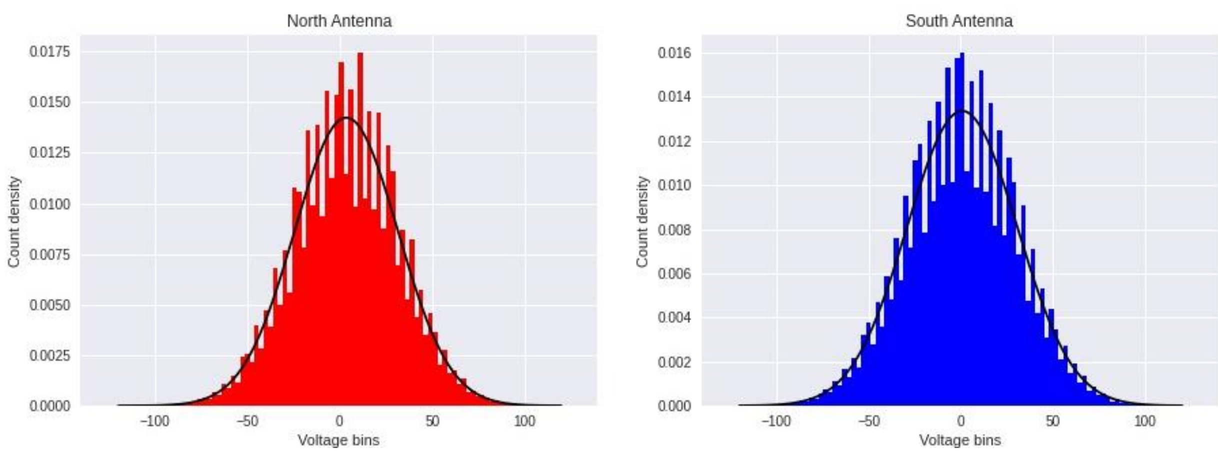



Fig2

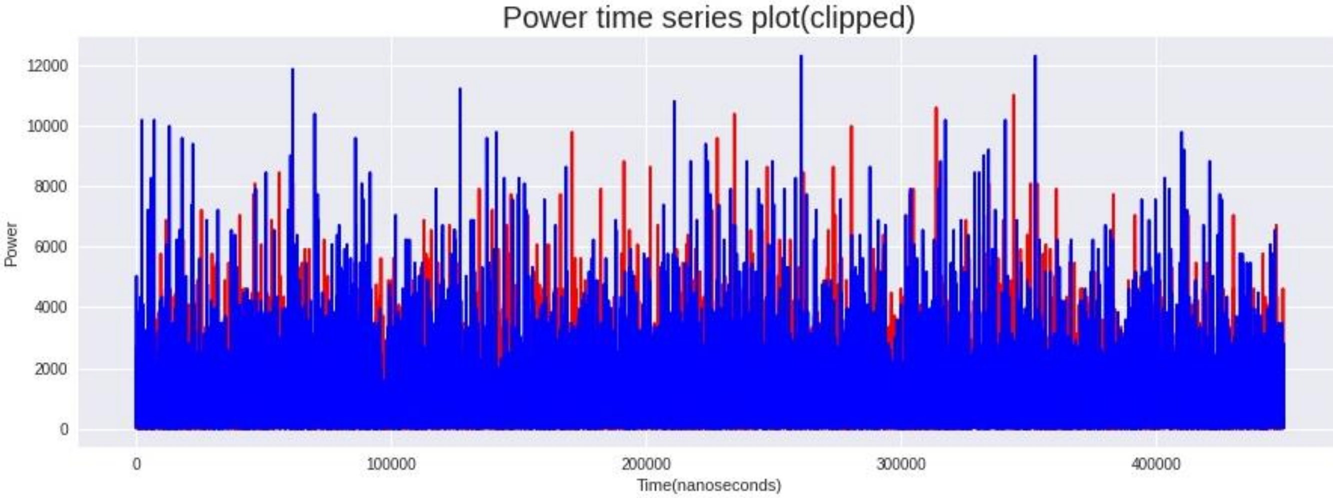



Fig3

# DATA PROCESSING AND ANALYSIS

After preparing the data, the next step was to produce the dynamic spectrum. We took the fast fourirer transform to obtain the contribution of various frequencies that produce the voltage time-series. To  maintain the time compenent after fourier tranform we divided the timeseries into time bins. This will help us in visuallzing the dymnamic spectrum. We performed a 256 point NFFT followed by coverting it to power by taking the absolute sqaure of the complex spectral amplitudes. We combined consecutive power amplitudes to get the final Power spectra. After calcuating the neccasities, we plotted the Dynamic Spectrum. After seeing the

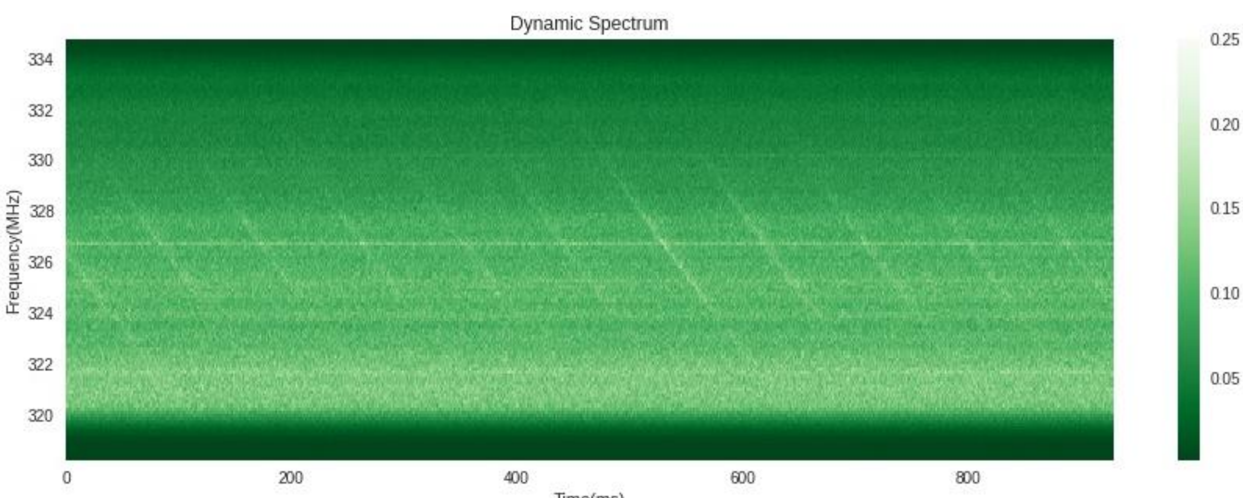



Fig4

Dynamic spectra, we can see that there is pulse that is hidden among all these noise. We have also plotted the Power Spectral Density, which was made averaging over the entire time series.

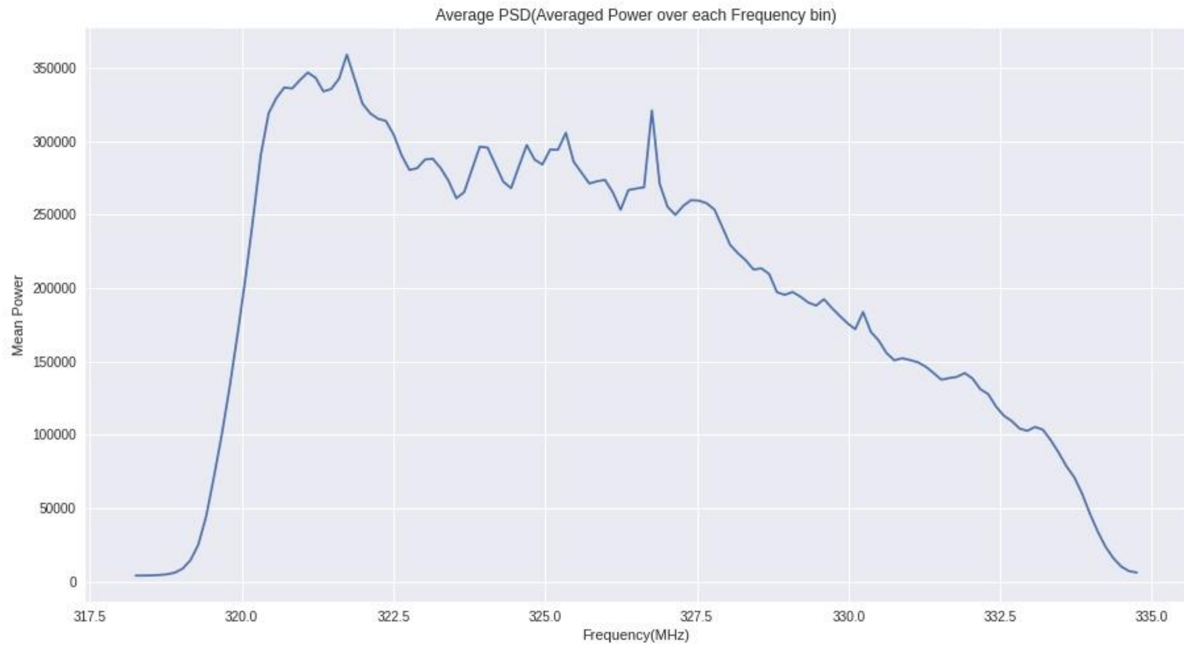
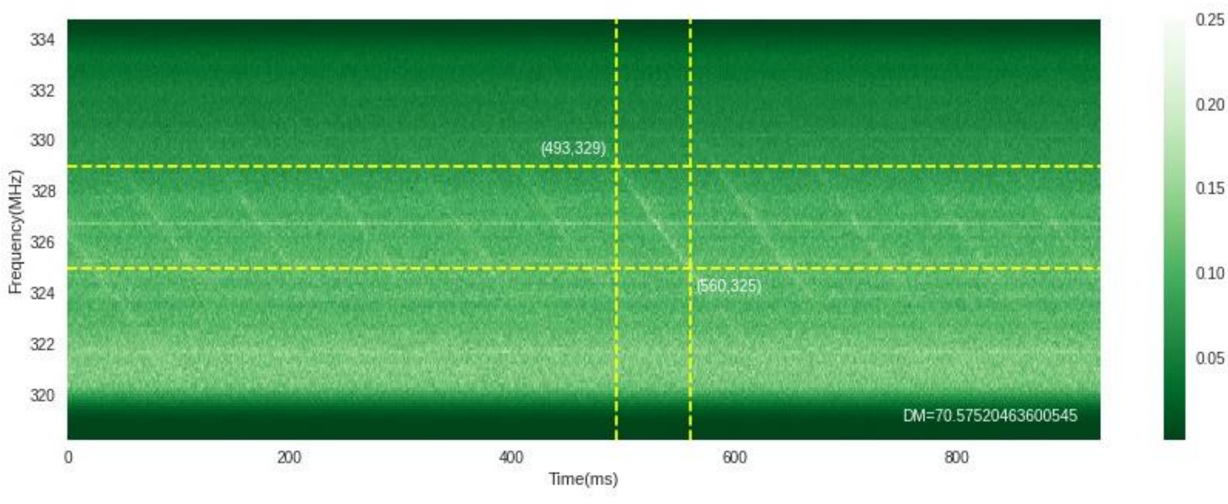


Fig5

The next step was to compensate for the dispesion effect scene in the spectra. Due to dispersion lower frequency is being delayed compared ti higher frerquecy. So the next step was to calcluate the Dispersion Measure.

$$DM \approx \frac{\Delta t}{4.144 * \ 10^3}\left(\frac{1}{v_2^2} - \frac{1}{v_1^2}\right)^{-1} \ pc \ cm^{-3}$$



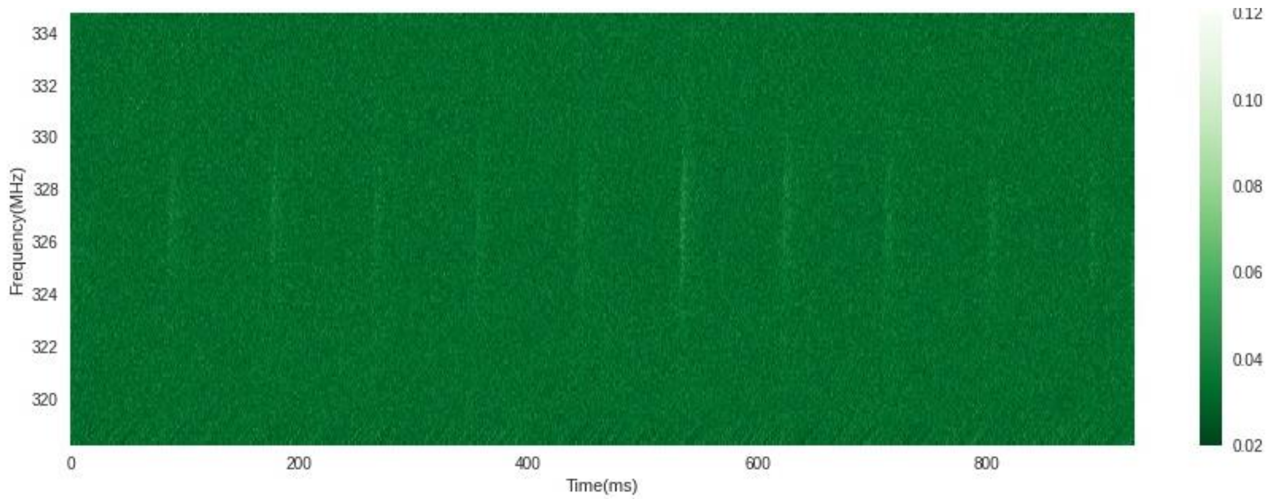

By choosing the appropriate frequency as per the spectrum , we found the DM to be

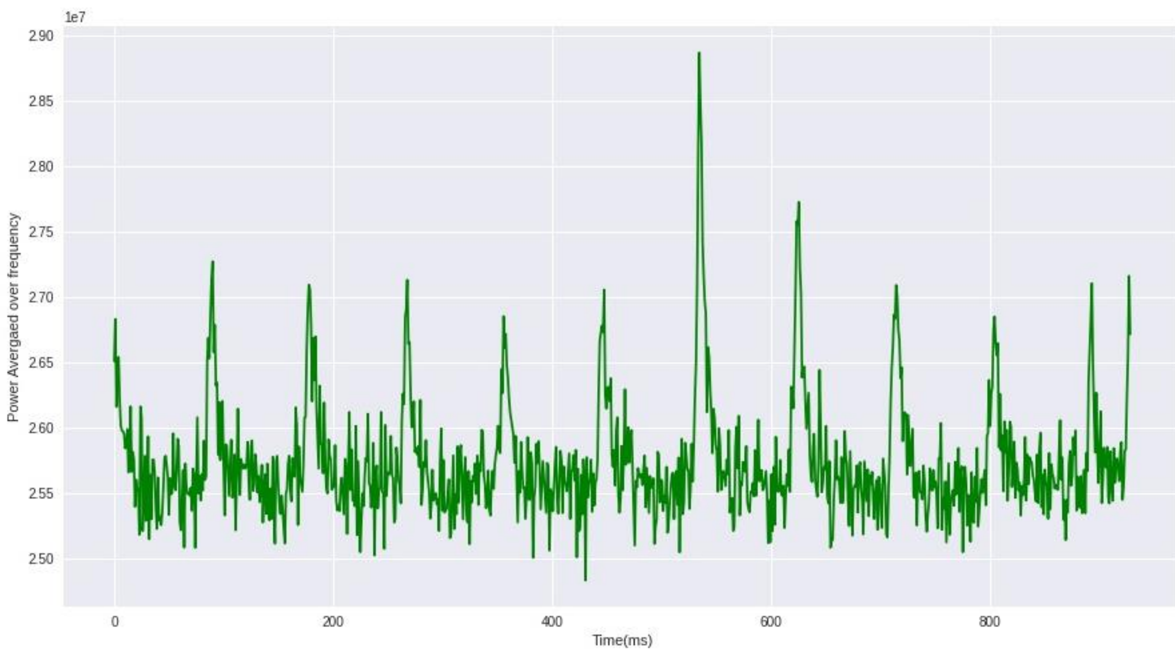
$$DM \approx 70.5752 \text{ pc cm}^{-3}$$

After finding the DM, we estimated the time delay of each frequency using the follwing formula,

$$t \approx 4.149 * 10^3 \left(\frac{DM}{pc\ cm^{-3}}\right)\left(\frac{\upsilon}{MHz}\right)^{-2}\ seconds$$

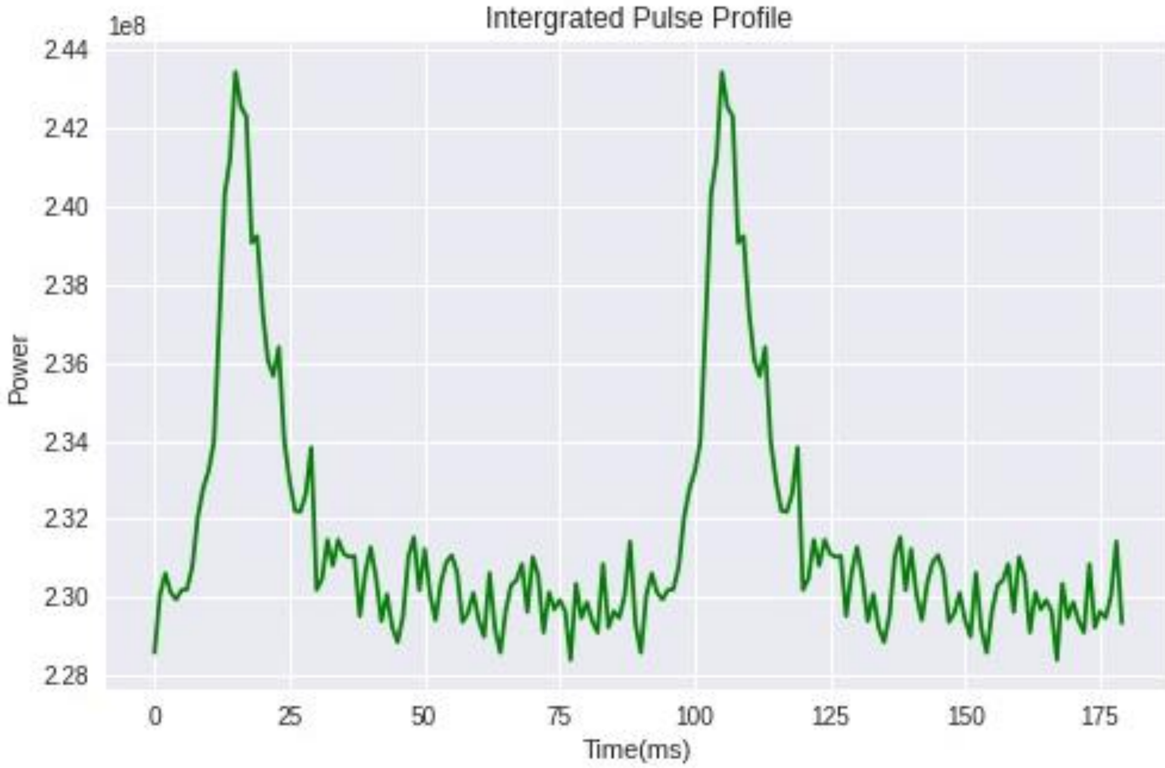
To find the relative delay between the signals, we choose the central frequency as referece and calculated the relative delay. Then after conversion of units from seconds to bins, we adjust the dispersion pattern to ge the final dedispersed spectra. We also plotted the Power (intgrated of frequency) vs Time.



With rough estiamtion by comaparing between peaks we found the time period to be near to 92 milliseconds. This is close to the actual value of 89.33milliseconds.

To get a better profile we folded the signal to over time to get a time integrated signal.



# INFERENCE AND CONCLUSION

With this problem we have studied and imployed different steps to extract the pulsar signal from the data collected by Ooty Radio Telescope. We explored how Fourier Transform can be imployed in selecting the different frequencies out of a signal. We also understood the effect of ISM in the form of dispersion effects in the signal. By estimating the Dispersion Measure, and estimating the time delay, we were able to eliminate the effect of dispersion. All of this helped us understand on how actual signal processing is conducted.

Further steps

We could try to imploy a machine learning alogorithm in calculating the period before folding of the signals. We have tried using Lombscargle method to predict the period but we wasn't able to complete it. After the workshop we will try our best to implement make this program to be efficient than it is now.