

Estimation of the Pulse broadening of pulsars due to interstellar scattering

1 Introduction

The free electrons in the interstellar medium (ISM) affects the pulsar signal in two different ways: cold plasma dispersion and scattering. The dispersion of the signals will result in delay in arrival times of pulses as a function of observing frequency and is measured as dispersion measure as explained in the experiment "Estimation of DM". Pulsar signals are also affected by fluctuations in the electron density in the ISM. This will give rise to random fluctuations in the refractive index of the medium. The pulsar signals traverse through these irregularities and will get scattered. This phenomenon is known as interstellar scattering of the pulsars.

Our Galaxy is populated with millions of pulsars, of which 2300+ have been discovered till now. Since the pulsars are located at different distances at different arms of the galaxy, the effect of the interstellar plasma can be clearly seen in the form of dispersion smearing and pulse broadening as a function of the observing frequency. As the DM of the pulsar increases, the scattering time scale increases as the relation $\tau_{sc} \propto \lambda^4 DM^2$, where λ is the observing wavelength. As a result, observations of high DM pulsars at longer λ is very difficult, since the pulsar signal will be highly scattered and the signal to noise ratio will be low. But a measurement of such a timescale will give a direct measurement of the electron density fluctuations in the line of sight. There are many HII regions (places of star formation in the galaxy) in the galaxy which are places of dense plasma. This will act as a scattering screen for the pulsars whose lines of sight are through them and the signal will get scattered, resulting in a pulse profile with an exponentially decreasing trailing edge component. This happens since the signal suffer multipath propagation and the pulses arrive at different times in the pulse phase. As a result, the scattering observed at low radio frequencies will be very high, especially for high DM pulsars. In many of the high DM pulsars, one may not be able to observe the pulse profile at low frequencies since the scattering timescale becomes larger than the period of the pulsar. Such measurements of τ_{sc} at multiple frequencies for all the pulsars will provide a better understanding of the interstellar medium in great detail.

2 Aim of the experiment

The aim of this experiment is to (a) estimate the pulse broadening observed due to scattering, (b) use this to estimate the scattering measure in the line of sight of the pulsar and (c) to find the reasons for the observed scattering. ORT will be used to carry out observations of a select list of pulsars (given in the attached sheet). The data are analysed with a pulsar pipeline using the procedure given in Section 4. The experiment also involves an interpretation of the results obtained, which the experimenter has to explain in the sheets provided at the end of this procedure.

3 Observations Log

Serial No.	Pulsar Name	HA	Time of Obs	Name of Recorded Data File for source
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

4 Analysis Procedure

One should obtain a good, dedispersed averaged pulse profile folded at the topocentric pulse period to perform this analysis. So the experimenter have to make sure that the DM and the period are correct.

Due to the scattering the pulsar signal suffered in the interstellar medium and the dispersion smear across the observed spectral channels, the pulse width will be broadened as an exponentially decaying trailing edge. This scattered pulse profile $P(t)$ can be expressed as a convolution of intrinsic pulse shape $P_i(t)$ with (1) the impulse response characterizing the scatter broadening in the ISM $S(t)$, (2) the dispersion smear across the narrow spectral channel $D(t)$ and (3) the instrumental impulse response, $I(t)$ defined as

$$P(t) = P_i(t) * S(t) * D(t) * I(t) \quad (1)$$

where $*$ denotes convolution. The scattering material is assumed to be concentrated in the line of sight of the pulsar, with a very small thickness (thin screen model) as compared with the distance of the pulsar from the observer. Thus, the impulse response function characterizing the scatter broadening can be written as

$$s(t) = \exp(-t/\tau_{sc}) \quad (2)$$

To get an estimate of the τ_{sc} , one has to fit the Eq. 2 with the trailing edge of the observed profile. This is a direct measurement of the amount of electron density turbulence in the line of sight of the pulsar. To get an estimate of the scattering strength, C_{ne}^2 in the line of sight of the pulsar, one could follow Eq. 3 assuming the Interstellar medium as a homogeneous medium with a Kolmogorov spectrum as

$$C_{ne}^2 = 0.002 \nu^{11/3} D^{-11/6} \Delta \nu_d^{-5/6} \quad (3)$$

where ν is the observing frequency in GHz, D is the distance to the pulsar in kpc and $\Delta \nu_d$ is the scintillation bandwidth in MHz. Where $\Delta \nu_d = 1.16 \times (2\pi\tau_{sc})^{-1}$. With the value of C_{ne}^2 , one can get an idea about the electron density fluctuations in the interstellar medium.

The step by step analysis using GNUPLOT is given below. This is given as an example to show the procedure, but one can use any software tool they are familiar with to do the analysis.

1. Follow the procedures for "Estimate the DM" and "Estimate the period" to get a dedispersed averaged profile of the pulsar. Use this profile to perform further analysis as given below.
2. Fit the trailing edge of the pulse profile with an exponential function as given below.

$$f(t) = a \times \exp(-t/\tau) + b \quad (4)$$

where you have to fit for τ_{sc} to get an estimate for the scattering timescale.

3. For fitting, use the "-sk" (in ms) option in the fold command to bring the peak of the profile at the first bin.
4. Open GNUPLOT in terminal and type in the equation as given below

$$f(t) = a * \exp(-t/tau) + b \quad (5)$$

5. Plot the profile for fitting the above function. Bring the peak of the profile to zero by following the below command

plot "test.prof" using (\$1-1):\$2 w l

6. fit the trailing edge of the profile by following the below command line argument

fit f(x) "test.prof" using (\$1-1):\$2 via a,b,tau

This will fit the observed profile and print out the values of a,b and tau. Note the reduced χ^2 values and also the fitting errors.

7. plot the profile along with the fit as follows

plot f(x),"test.prof" using (\$1-1):\$2 w l

And keep a plot of the profiles and fit along with fit values.

8. Now use the distance to the pulsar which you have calculated using the experiment "Estimate DM" to find the scattering strength, $\log_{10} C_{ne}^2$ in the line of sight of the pulsar using Eq. 3. Compare the value you obtained with earlier measurements to check the validity of your estimate.
9. Repeat the same analysis for all the pulsar you observed.

5 Analysis Log and plots

DM of the pulsar	=	pc cm ⁻³
Distance to the Pulsar PSR	=	kpc
Measured τ_{sc}	=	ms
Calculated log C_{ne}^2	=	m ^{-20/3}

6 Results

Dispersion Measure of the Pulsar PSR	=	pc cm ⁻³
Measured τ_{sc}	=	ms
Calculated log C_{ne}^2	=	m ^{-20/3}

7 Sources of Error in the experiment

8 Discussions and Conclusions