Estimation of the distance to the pulsar by measuring the dispersion delay of the pulse

1 Introduction

The electrons in the interstellar medium disperse the pulsed signal received by a radio telescope such as Ooty Radio Telescope (ORT) from a radio pulsar. This manifests itself as a broadening of an otherwise sharp pulse when a pulsar is observed over a finite band width. The amount of dispersion is proportional to the integrated column density of free electrons between an observer and the pulsar. A measure of this integrated column density of free electrons is Dispersion Measure (DM). Assuming the density of electrons in the inter-stellar medium (ISM) to be uniform, this quantity depends on the distance of the pulsar. Thus, if the DM can be measured, so can be the distance to the pulsar.

The pulse broadening mentioned above is also proportional to the band of frequencies over which it is measured and is smaller for smaller bandwidth. Thus, the broadening can be understood as a large number of pulse trains over several channels of small bandwidth, where the pulse at a channel with higher frequency arrives before that of the lower frequency, thus leading to a pulse smear. The pulse over one channel (with reasonably small bandwidth) can be assumed to be similar in shape to the pulse emitted by the pulsar and the time delay of this pulse between the highest and the lowest frequency channel can be used to estimate the dispersion delay (DM or distance). The details of physics related to ISM and the relationship between the dispersion delay and DM are discussed in (Lorimer and Kramer 2003).

2 Aim of the experiment

The aim of this experiment is to (a) estimate the dispersion delay for the pulsar being observed, (b) use this to estimate the DM of the pulsar, and (c) derive an estimate for the distance of the pulsar from its DM. ORT will be used to carry out observations of a select list of pulsars (given in Section ??). 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 Observation	Name of Recorded Data File for source
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Estimation of the distance to the pulsar by measuring the dispersion delay of the pulse

4 Analysis Procedure

The data recorded from the ORT is in plain binary. To make it useful for the analysis purpose, we have to convert it into a standard format through the pulsar pipeline, which is available at ORT.

To estimate DM, one has to split the data into different frequency channels. We are splitting the 16 MHz bandwidth into 8 sub bands each of which is 2 MHz wide, keeping 326.5 MHz as the central frequency. We will now fold each sub band to get 8 different profiles. One can use GNUPLOT to see the pulse. If one use the multi plot facility in GNUPLOT, we can clearly see that the pulses are not coming at the same point. This delay in arrival time can be measured precisely by the following method.

Plot each bands separately and do an appropriate fit to find the center of the pulse. This may give you the pulse width also. Armed with the position and error of the pulse in each sub band, you can obtain average time delay between two frequencies by employing a linear fit. DM and distance can be obtained from this delay

$$DM = kS * \frac{f1^2 * f2^2}{f1 + f2} \tag{1}$$

where $k = 2.4103 \times (10-4)$ MHz-2 cm-3 s-1 pc, $f1$ and $f2$ are the first and last frequencies of the band respectively and S is the slope of the curve. Find out the average electron density of the ISM (ne) and calculate the distance, l to the pulsar by using the formula,

$$l = \frac{DM}{ne} \tag{2}$$

The answer should contain the calculated error in the value also.
The step by step procedure of the analysis is given below.

1. Open a terminal and go to the folder where your data is saved. For example
   cd /scratch1/pos13 BNo./
2. To analyse the data, change the source to 'tcsh' by giving the following commands.
   $ tcsh
   $ source /scratch/soft/bin/path

3. Get the time stamp in MJD. The timestamp file is recorded with the data and gives time in IST. Ignore the seconds and add 1 to the minutes. This is the start time of acquisition. Convert this to UTC and then MJD.
4. Convert the data to filterbank format

    acqch1fft input file.bin -o output file.fil -nacc <> -mjd <>

    The value of -nacc will determine the sampling time of the data. A value of 16 will sample the data at 1 ms and value 1 will sample at 64 μs. -mjd is the Modified Julian Date (MJD) of the beginning of the observation. Find out the MJD of your observation, before analyzing the data, upto 12 decimal places.
5. Use the command 'dedisperse' to dedisperse the data as given below.

    dedisperse input file.fil -d 0.0 -b <No. of bands> > output file.sub.tim

    The value of '-b' you gave will split the 16 MHz band (318.5 to 334.5MHz) into respective number of sub bands.
6. To see the full band data, use '-b 1' in the dedisperse above argument.
7. Use the command 'reader' to get an ascii time series

    reader output file.tim > outputfile.asc

8. Use gnuplot to plot the time series. If the single pulses are visible, estimate the period from the time series.
9. Now, we are ready to fold the data. Fold data with the period (in milliseconds) which you found out in the previous step or previous experiment

    fold input file.tim −p <period> −n <bin number> −nobaseline > output file.sub.prof

    Give the period of the data after -p. Give the number of data points (bins) to you wish to fold the data after -n (usually give in multiples of 2).
10. Repeat the above procedure for all the files of the pulsars you observe.
11. After folding the data, fit it with a Gaussian function using GNUPLOT by defining
    the Gaussian function as follows

    $f(x)=a*exp(- ((x-b)**2/(2*c**2)))$

    Give the average values of a,b,c to fit it to the pulse profile.

    fit f(x) 'output file.sub.prof' via a,b,c

    This will fit the pulse with the Gaussian function. Note down the value of b with it's error. Also check the value of chi square, which will be given as WSSR in GNUPLOT after fitting. If you wish to see the fit, plot it using the following command

    plot 'output file.sub.prof' w l , f(x)

12. Repeat the same for all the profiles and create a text file with the center of the fitted profile (pulse arrival time) as the first column, the channel frequency as second column and the error in the fitting as the third column.

13. Plot the data file you have now created using the following code

    plot 'file name.txt' w yerrorbars

14. Fit your data with a line by defining the equation of line.

    f(x)=m*x+b

    Fit the data using the fit command.

    fit f(x) 'file name.txt' us 1:2 via m,b

    Find out the value of m i.e., slope and plot the fitted data as given below.

    plot 'file name.txt' w yerrorbars, f(x) w l This will be in units of ms MHz^{-1}. Note down the error and the chi square value.

15. Calculate the DM of the pulsar with your observations, using (1) and also the error.

16. Using the DM, you obtained with the above analysis, find out the distance to the pulsar using (2) with calculated error in the distance estimate.

17. Repeat the same analysis for all the pulsar you observed.

5 Analysis Log and plots

Slope of the Fitted line =   ms MHz^{-1}

DM of the pulsar =   pc cm^{-3}

Distance to the Pulsar PSR =   Kpc

6 Results

Dispersion Measure of the Pulsar PSR B =   pc cm^{-3}

Distance to the Pulsar PSR B =   Kpc

Estimation of the distance to the pulsar by measuring the dispersion delay of the pulse

7 Sources of Error in the experiment

Estimation of the distance to the pulsar by measuring the dispersion delay of the pulse

8 Discussions and Conclusions