Introduction to Pulsars Tutorial - DARA student workshop, 2021

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1 General Introduction

In this workshop, we will be working out a few things related to pulsar observations. In the first section, we will try to estimate the dispersion measure and related delays as a function of frequency etc. In the second section, we will see the effect of typical observing system parameters on the observed signal-to-noise ratio of the radio pulse.

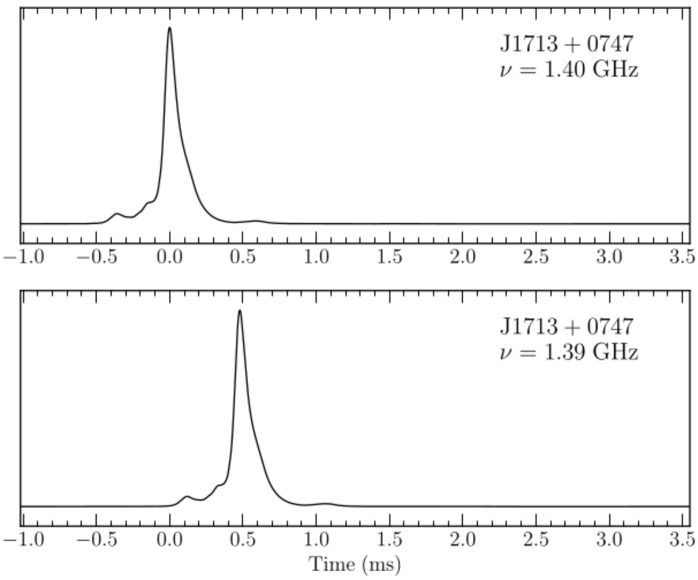
2 Determining the DM of the pulsar

In order to get a significant detection from the telescope data, the time-frequency array needs to be de-dispersed to the dispersion measure (DM) of the pulsar. Now, typically, if you are trying to search for a new pulsar, you may not have a very accurate DM value to begin with. That is usually the result of having a coarse trial DM grid for carrying-out the search. Let us see what how we can correct for the DM. Dispersion causes lower radio frequencies to travel slower (and hence delayed) with respect to the higher radio frequencies. The delay in ms is given by:

$$\triangle t \simeq 4.15 \times 10^6 \times (\nu_1^{-2} - \nu_2^{-2}) \times DM \quad (1)$$

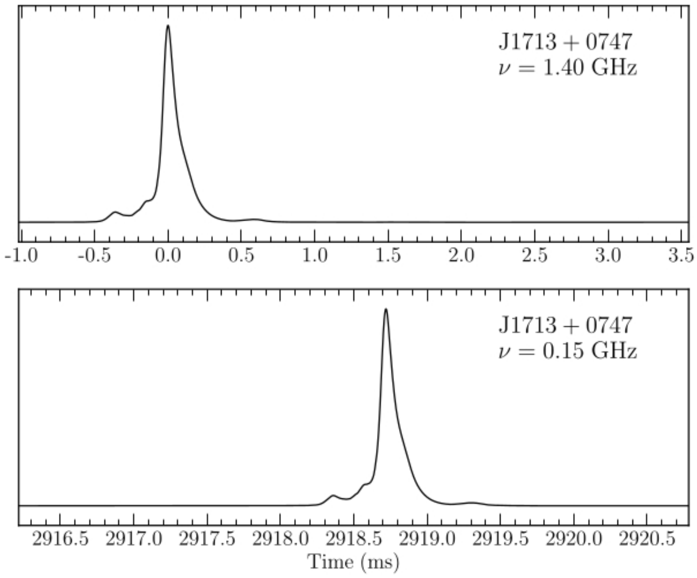
Where both frequencies are in MHz and the DM is in pc cm^{-3}.

During an observation, this is what you see:



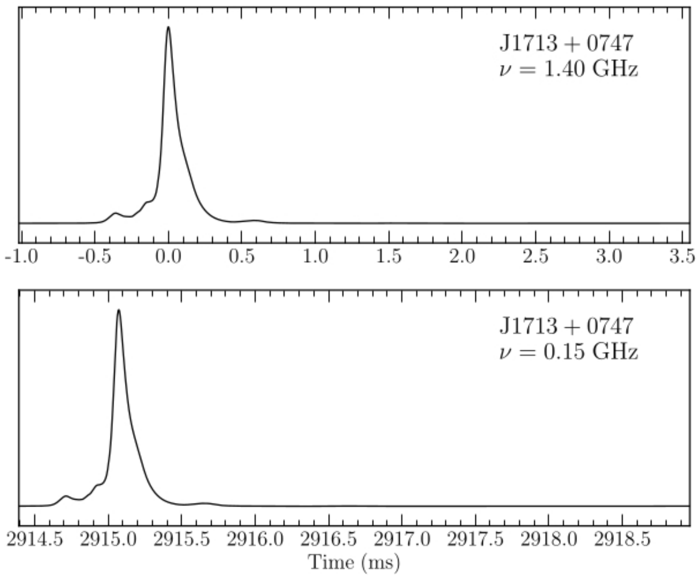
Using the information from the figure, can we estimate the DM? If yes, how much is it?

Let us expand the frequency range now. In one observation, this is what is observed:



Using the information from the figure, can we confirm the DM of the pulsar estimated in the previous step? If the DM is offset, by how much? If the period of the pulsar is 4.57 ms, how many periods elapsed before the pulse at 150 MHz was observed?

On another day, this is what is seen:



What is the DM for this observation?

3 The effect of system parameters on pulsar observations

Pulsars are typically weak radio emitting sources. The strength of the pulsar signal or the flux density is measured in Jansky (after Karl Guthe Jansky, who started the field of radio astrophysics). The unit is a very small unit of flux density because 1 Jy = 10^{-26} W m^{-2} Hz^{-1}. Typical pulsar flux densities are of the order milliJy, hence we need very large (hence sensitive) telescopes to observe pulsars. The signal-to-noise ratio (S/N) of the pulse profile is estimated using the radiometer equation. This equation is given by:

$$S/N = \frac{S_{mean} G \sqrt{n_p t_{int} \triangle f}}{T_{sys}} \sqrt{\frac{P - W}{W}} \tag{2}$$

where S_{mean} is the pulse averaged flux density of the pulsar in mJy, G is the gain of the system in K/Jy, n_{p} is the number polarizations summed, t_{int} is the integration time in s, $\triangle$f is the bandwidth in MHz, T_{sys} is the system temperature in K and P and W, both in s, are the period and pulse width at 10% of the peak. In the exercise, we will estimate the observing time for different pulsars and try to get a feeling for how different telescopes perform in terms of observing time for a given pulsar. In order to do this, we will use the python notebooks as a starting point. The notebook we will be using is named `DARA_PulsarObservationPlanning_2021_Student.ipynb`

Before we begin with the exercise, we need to convert the above equation in order to estimate the integration time for a given S/N. Do the conversion and confirm that the equation quoted in the python notebook is the same as what you get. The values for the system parameters given there are for the Kuntunse radio telescope. We will try out different values of pulsar parameters like period, pulse width, flux density. Next, we will try with different singe dish radio telescopes. In the last part, we will ask the questions: Do we need to modify the radiometer equation for interferometric arrays? If yes, how?

4 Optional task (time permitting)

There are two more python scripts provided, `generate_frb.py` and `Fold_utils.py`. These scripts provide a way to generate a single-pulse with given system and pulse parameters. There are also functions to carry-out de-dispersion and folding of the data as well. If time permits (and if there is interest), we will generate a single pulse and try some hands-on data analysis and plotting.