# Project 2: Radio Data Analysis

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**Office Hours:** Scheduled on Request with min 18 hrs notice

**Submission Format:** All code, and accompanying text submitted in .pdf, .py, .ipynb. All questions should be answered and code should be well commented along with a brief qualitative description of any outcome. Figures should have proper axis labels and all files should clearly indicate which problems they are associated with as a comment on the top of the file and in the file name.

**Code Software:** For this assignment you are expected to write the bulk of your code in python. This project has been designed with sigpyproc in mind, which can be installed as a python module.

**Goal:** The main goal of this project is to introduce you to how calibration is done, how to understand noise and noise statistics, and how to search for signals and to try and optimize them.

We will use data from CHIME, a radio telescope observing between 400-800 MHz located near Penticton, B.C.. The data provided is from the CHIME pulsar project.

# Part 1: Calibration

**Due Date: February 20th**

We have raw radio data that we want to calibrate to a known source. We have pointed our telescope towards this source and now need to calibrate our raw data, i.e. measured in ADC counts, to physical units, i.e. measured in Jy flux units.

1. Our calibrator source is 3C 129. It is a point source At 400 MHz the spectral flux is $S_{400} = 8.684$ Jy with a spectral index of $\alpha = -0.6$. Plot the spectrum of this source over the CHIME frequency band.

2. Load in the file *calibrator_source.fil*. Obtain the average spectrum of this calibrator source and plot it. Compare it to spectrum of the source, are there any odd features?

3. Create a transfer function, converting the ADC counts to Jy units. Apply it to the calibrator source data and create a waterfall plot. How does the data look, are there any odd features?

4. Load in the file *blank_sky.fil*. Apply the calibration transfer function to this dataset. Plot the average spectrum and create a waterfall plot. How does the data look, are there any odd features?

5. Calculate the mean and standard deviation per channel. Normalize each channel and create a waterfall plot of the dataset. What type of statistics describe the noise of this dataset?

# Part 2: Search For a Pulsar

**Due Date: February 27th**
With our telescope calibrated, we can now search for signals. We've been told there's a pulsar in our telescope's field of view and we want to see if we can detect it.

1. Somehow, we do not know the period of the pulsar but we do know the spectrum. It has a spectral density at 400 MHz of $S_{400} = 0.15$ Jy and a spectral index of $-1.5$. We have measured the noise of the blank sky. Assume it is the same in the direction of this pulsar. Note the signal-to-noise ratio (S/N) is proportional to the ratio of source flux density to the system equivalent flux density (which we obtained as the average spectrum of the blank sky data from the previous part) and the total number of samples being integrated,

$$S/N \propto \frac{S_\nu}{S_{sys}} \sqrt{N}.$$

   What is the expected S/N ratio of 1 single pulse at? How many times should we then need to fold or average over the pulsar period to observe the pulsar with $S/N \sim 2$?

2. Load in the file *pulsardata.fil*. You should find the S/N for 1 pulse to be quite small, therefore ensure RFI contaminated channels are flagged. Normalize the data per channel to standardize the statistics across all channels.

3. Radio waves propagating through the ISM are dispersed by the intervening plasma and have an arrival time delay depending on the observing frequency. The arrival time delay is given by,

$$\tau(f, DM) = k_{DM} DM \left( \frac{1}{f^2} - \frac{1}{f_{ref}^2} \right).$$

   Our two parameters to search over are the $DM$ and the period. If the channels are properly normalized then we can average across frequencies to further increase our S/N. Create a grid of dms to search over using the function *dmt_transform()* to obtain the S/N as a function of DM and time, $S/N(DM, t)$.

4. To search for the periodic signal, we will do it in frequency space. Take the Fourier transform of $S/N(DM, t)$ over time to obtain $S/N(DM, f)$. Plot a waterfall plot of this function. Obtain the S/N maximizing DM and period.

5. With the S/N maximizing parameters use the *fold()* function to fold the dataset into 1024 channels and 1 single pulse. Plot the waterfall for the folded pulse profile. Average over frequency to obtain the frequency averaged pulse profile and plot it.