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## 2. Searching for a millisecond pulsar

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### Aims and objectives

- Learn the basic steps that are required to search for a pulsar
- Use the “presto” software package
- De-dispersing data sets
- Inspecting power-spectra of the data
- Study single pulses from PSR J0437–4715

### Background reading

- Tutorial on pulsar searching (M. J. Keith 2012, arXiv:1206.0588).
- The PRESTO home page: <http://www.cv.nrao.edu/~sransom/presto/>
- Manchester et al. (2001; MNRAS): The Parkes multi-beam pulsar survey - I. Observing and data analysis systems, discovery and timing of 100 pulsars
- Keith et al. (2010; MNRAS) The High Time Resolution Universe Pulsar Survey - I. System configuration and initial discoveries
- Cordes et al. (2006; ApJ) Arecibo Pulsar Survey Using ALFA. I. Survey Strategy and First Discoveries.

### Who to find if you get stuck during the student week

David Champion, George Hobbs, Mike Keith, Duncan Lorimer, Dick Manchester, Maura McLaughlin, Ryan Shannon, Ingrid Stairs

### Experts to discuss these topics with during the science week

The presto software package was mainly developed by Scott Ransom.

There will be numerous experts on pulsar searching at the science meeting. Such people include Dick Manchester, Mike Keith, David Champion, Duncan Lorimer, Scott Ransom, Simon Johnston, Ryan Lynch and Ingrid Stairs. The science meeting also will include talks on current and future pulsar surveys.

# 1 Getting some data

What is the value of finding more pulsars for PTA science?

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In this project you will attempt to “discover” the millisecond pulsar: PSR J1857+0943.

In which survey was this pulsar first detected?

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We will make use of observations from the Parkes pulsar 20 cm multibeam survey.

What was the observation time for each pointing in the Parkes multibeam survey?

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The raw data from the telescope has already been converted into the PSRFITS format and is available from /data/module2/1857.sf. Note that the Parkes Multibeam Pulsar Survey is not yet part of the Parkes Pulsar Data Archive, but the data will be included within a few months.

# 2 Running presto

We will make use of the presto search software. The first stage is to produce a time series that has been de-dispersed. As we’re assuming this is a standard pulsar search we do not know the dispersion measure and so let’s just start with  $DM = 0$ .

```
$ prepdata -psrfits -o 1857_dm0 -dm 0 -nobary 1857.sf
```

This should produce two files:

```
1857_dm0.inf  
1857_dm0.dat
```

You can view the .inf file to check that the information is correct about the observation.

What is the sampling time for this observation?

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What is the observing frequency and bandwidth?

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We can look at the data set using `exploredat`:

```
$ exploredat 1857_dm0.dat
```

Learn how to use the mouse and the key-strokes to inspect the data set.

Can you see any bursts of interference in this data set?

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Do you expect to see single pulses from the pulsar in this data set? If no, why not?

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The standard way to search for pulsars is to Fourier transform the time series and then search for significant periodicities. We can obtain a power spectrum of our data set using:

```
$ realfft 1857_dm0.dat
```

This produces a new file: 1857\_dm0.fft.

You can view this power spectrum using

```
$ explorefft 1857_dm0.fft
```

By eye, can you identify any periodicities in the data? What are their frequencies and corresponding periods?

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Use the ATNF pulsar catalogue to determine the known period, frequency and dispersion measure for PSR J1857+0943.

What is the power at the known frequency for PSR J1857+0943 in the power spectrum?

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### 3 Using the correct dispersion measure

As this is a known pulsar we can now de-disperse the original data using the known dispersion measure for the pulsar. Repeat the steps above `prepdata`, `realfft` and `explorefft` using the correct dispersion measure (make sure that you choose a sensible name for the output files).

Do you expect to see single pulses from the pulsar in the de-dispersed data set? Please justify mathematically.

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What is the power at the known frequency for PSR J1857+0943 in the power spectrum after de-dispersing the data?

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By eye you probably can see a significant periodicity with the correct frequency in the power spectrum. However, presto provides a tool to search the data set for pulsar candidates:

```
$ accelsearch -zmax 1 1857_dm13.dat
```

(note: check the name of the file that you created for the de-dispersed data set)

This software will produce two files. You can view 1857\_dm13\_ACCEL\_1. This lists each pulsar candidate.

Can you find PSR J1857+0943 in the candidate list?

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You can view the candidates using:

```
prepfold -accelcand 1 -accelfile 1857_dm13_ACCEL_1.cand 1857_dm13.dat
```

Can you see the pulse profile for J1857+0943?

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What do all the panels on the output plot mean?

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If this was a new discovery, what would you now do to confirm that it is a pulsar?

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Use prepfold to look at other pulsar candidates (e.g., use -accelcand 2). Where do these candidates come from? Are they real pulsars?

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What is the period of the pulsar according to presto? What is the period according to the ATNF pulsar catalogue? Why are they different?

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## 4 Signal-to-noise versus dispersion measure

In the example above we decided to de-disperse using  $DM=0$  and using  $DM=13.29 \text{ cm}^{-3}\text{pc}$ . Of course, in a pulsar survey we do not know what we're going to find and so do not know the correct DM that we should be using. Repeat the project above, but try different dispersion measures (try from  $10.0$  to  $15.0 \text{ cm}^{-3}\text{pc}$  in steps of  $0.2 \text{ cm}^{-3}\text{pc}$ ). Record the signal-to-noise of the pulsar detection as a function of dispersion measure.

What dispersion measure gives you the highest signal-to-noise pulsar candidate?

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## 5 How long does it take?

Pulsar surveys can take up a huge amount of observing and processing time.

How long did it take you to process one dispersion measure trial for one observation?

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How many observations were there in the Parkes multibeam pulsar survey?

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How many dispersion measure trials were used in the Parkes multibeam pulsar survey processing?

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Using your answers above, how long would it take you to process the entire Parkes multibeam survey data?

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## 6 Looking at PSR J0437–4715

We have made available another search mode data set at `/data/module2/t120322_063248.sf`. This observation was of PSR J0437–4715 which is much brighter than PSR J1857+0943. Process the data as above and ensure that you can “discover” this pulsar. Note that you’ll have to check the dispersion measure for PSR J0437–4715.

Can you see single pulses from this pulsar in the de-dispersed data set?

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Is the intensity of the pulses constant? Can you estimate the modulation index for the pulses?

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Do you notice anything strange about this time series after around 10 seconds?

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## 7 To think about

- Will the standard Fourier-domain search work if the pulsar has a binary companion?
- Is this technique optimal for detecting pulsars useful for the IPTA?
- How can you increase the sensitivity of a survey to millisecond pulsars?

- Astronomers use a few different software packages to search for pulsars. Use the internet to identify other packages that can be used to search for pulsars.

## 8 Publication

Find a publication on ADS that is related to this worksheet and summarise the basic conclusions of that paper.

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## 9 Mistakes

How many mistakes did you find in this worksheet?

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