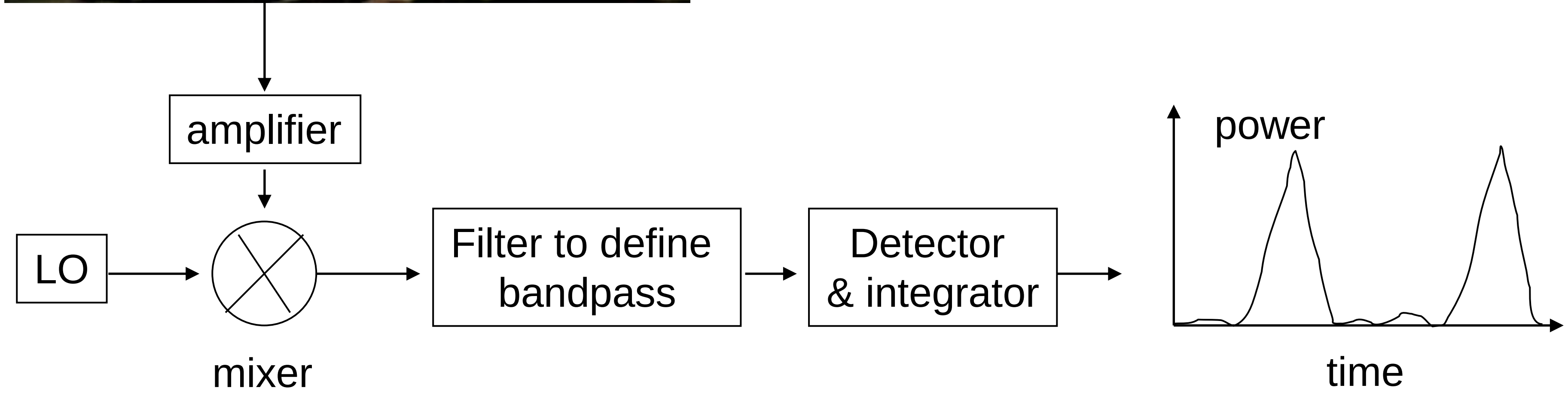
Pulsars and Supernovae II

4. DETECTION AND TIMING

single dish surveys
incoherent de-dispersion
search strategies
timing of known pulsars
the ATNF catalogue

Pulsar surveys

- The simplest form of radio pulsar survey searches the sky systematically for sources with rapid periodic variations in radio brightness



Pulsar surveys

- Pulsar surveys require high sensitivity on short timescales, and are mostly performed using the big radio photon buckets:

FAST
Guizhou, China

Lovell Telescope,
Jodrell Bank, UK

Parkes Telescope,
Parkes, Australia

Greenbank
Telescope
WV, US

Arecibo Telescope,
Puerto Rico ☹

- They are also computationally demanding, and most surveys are limited by available data processing speed.

Pulsar dispersion (last lecture!)

- This is usually written

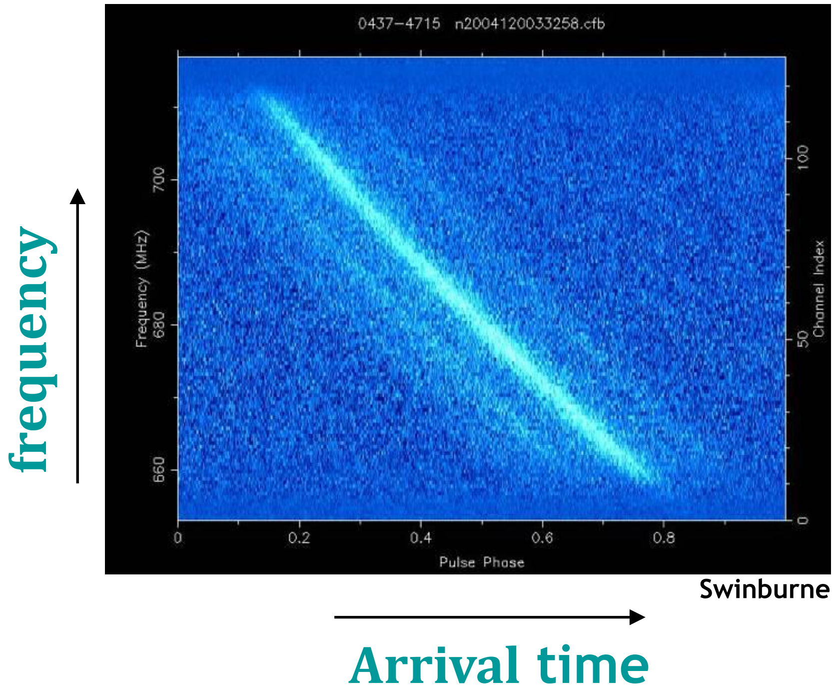
$$\tau_D = 4.15 \times 10^3 \frac{1}{f_{\mathrm{MHz}}^2} \, DM \ \text{ seconds}$$

where

$DM = \int_0^D n_{\mathrm{e,cm^{-3}}}(z) \ \mathrm{d}z_{\mathrm{pc}}$ is the dispersion measure.

- Radio dispersion transforms the pulses from pulsars into chirps:

  The highest frequencies arrive first.



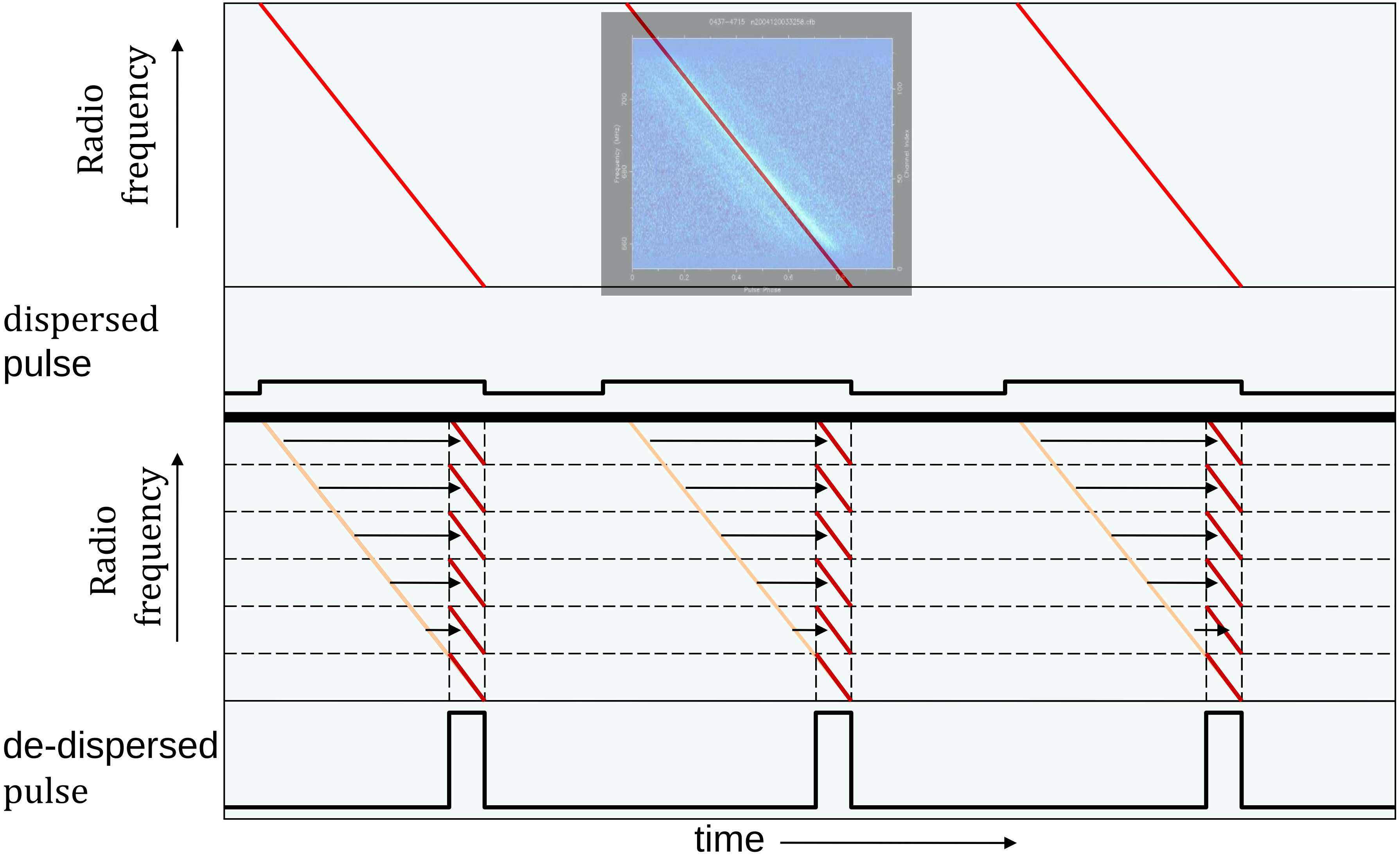
De-dispersion

- Pulses are always dispersed by the interstellar medium. The signal must be de-dispersed by breaking the passband down into many narrow frequency channels and applying a small time delay to each. The power from each passband can then be added to give a pulse with a much higher signal-to-noise ratio.

- This can be done with electronic filter banks or (more usually now) in software, after digitising the entire passband.

- If the passband is digitised one may also perform coherent de-dispersion in software that takes account of the phase relationship between the pulsar signal in each sub-band. This gives an even higher snr.

Filter-bank de-dispersion



Search strategies

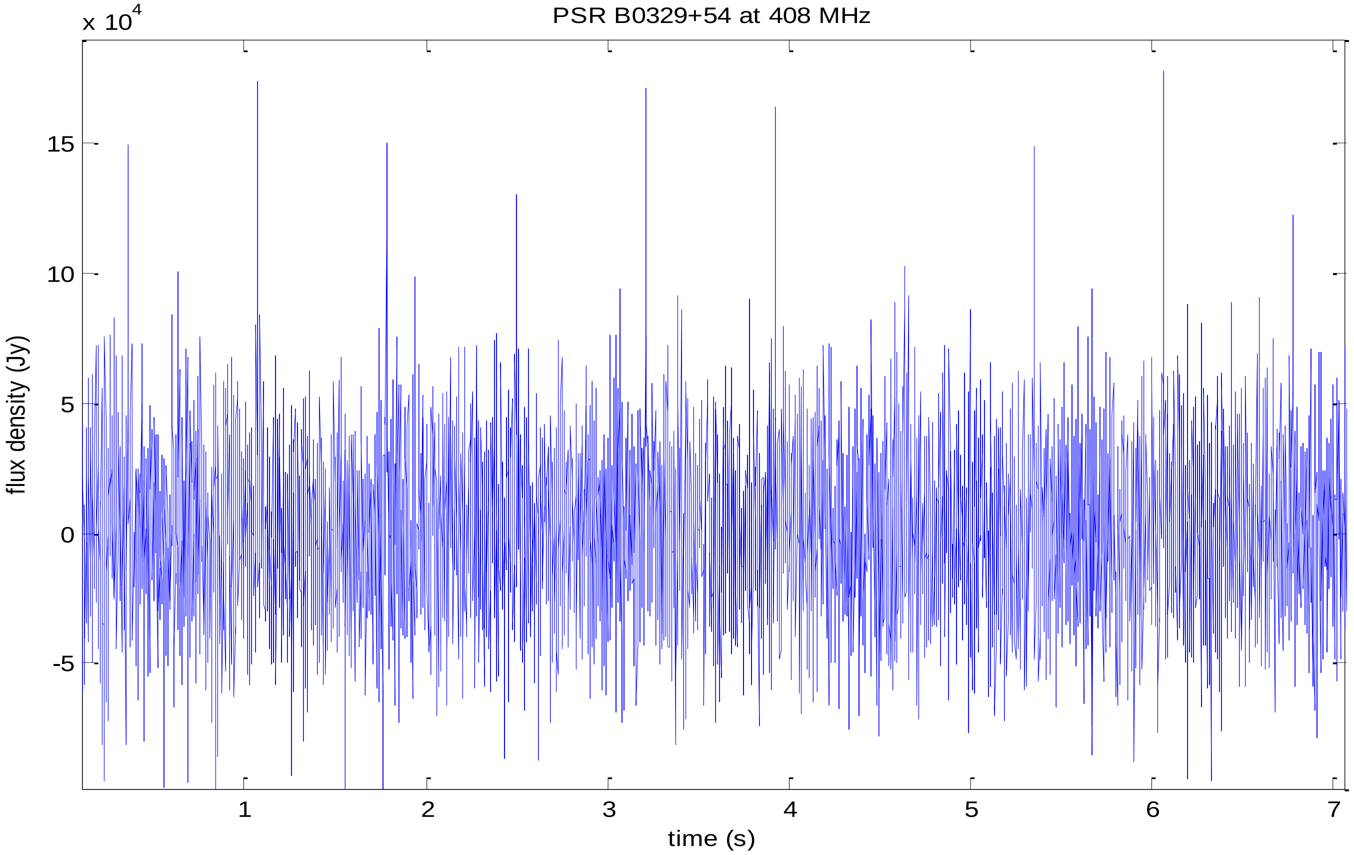
- To find new pulsars you must search the data for pulsar-like signals. In general, the pulsar will have unknown:
  - dispersion (smearing the pulse)
  - sky location (giving a Doppler shift that changes over time and depends on the sky location)
  - period
  - pulse shape

- In addition, the pulsar may be in a binary system, introducing another periodic Doppler shift, and may be accelerating, giving a large period derivative.

- If each patch of sky is search for only a short time (<30 min), only dispersion, period and pulse shape significantly affect the probability of detection (the others just move the *apparent* period away from the *true* period).

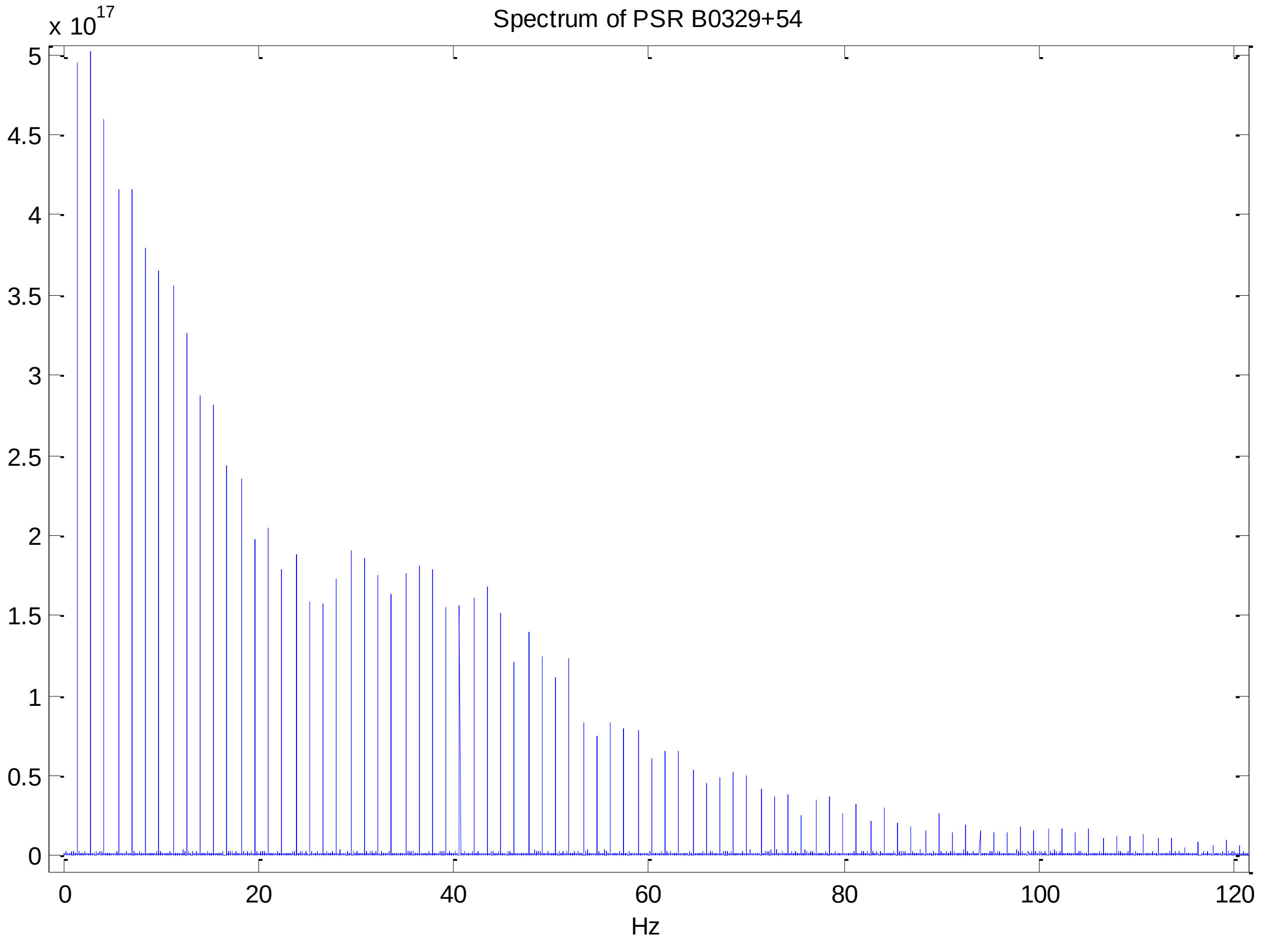
Period search

- The simplest way to look for a periodic signal is to perform a fast Fourier transform (FT) on the data. This 'concentrates' the power of many pulses into a small number of spectral frequency bins:



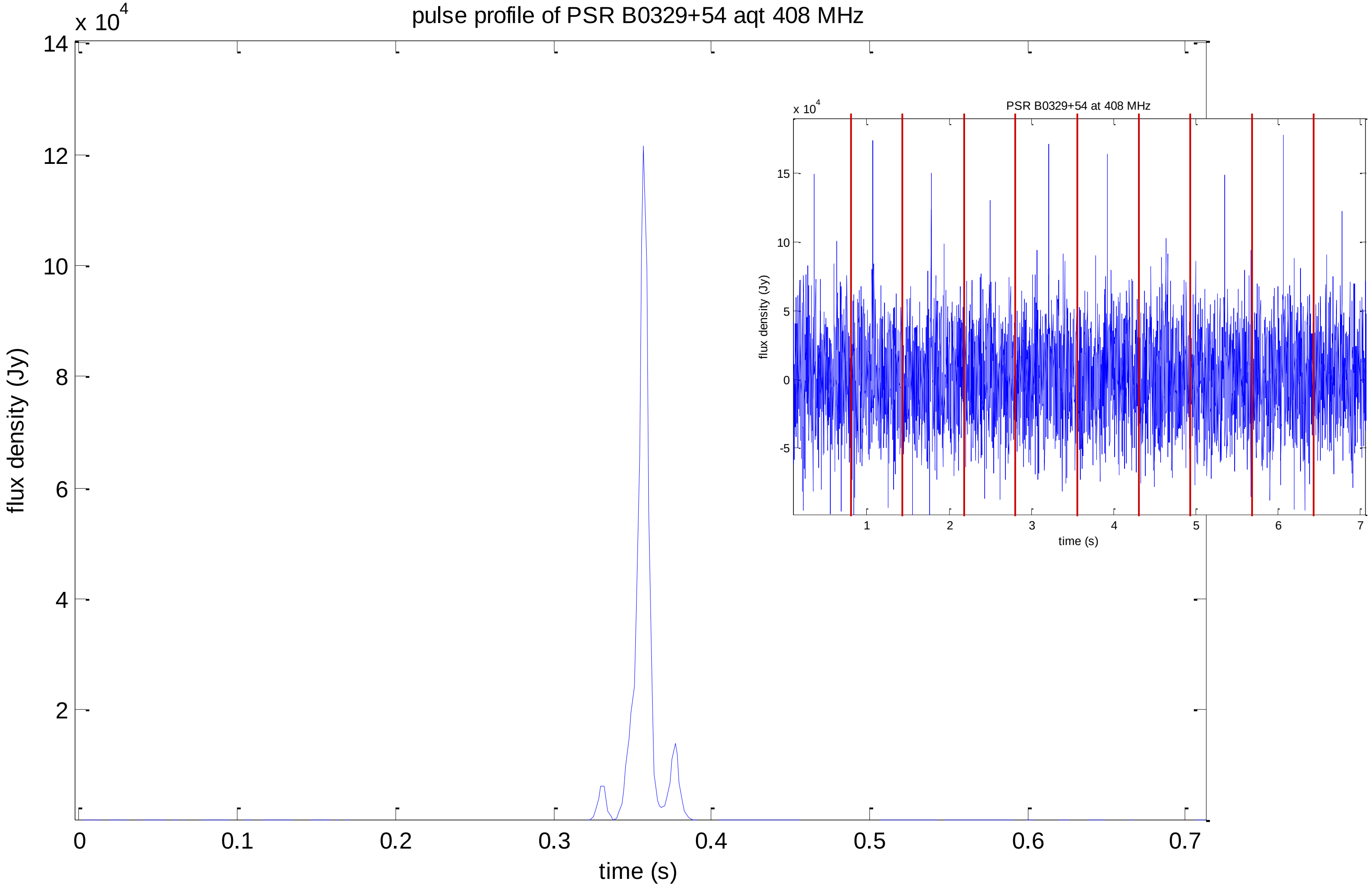
Period search – power spectrum

- A spectrum will generally show harmonics, and the profile of the harmonics reflects the Fourier transform of the pulse profile (think about the convolution theorem):

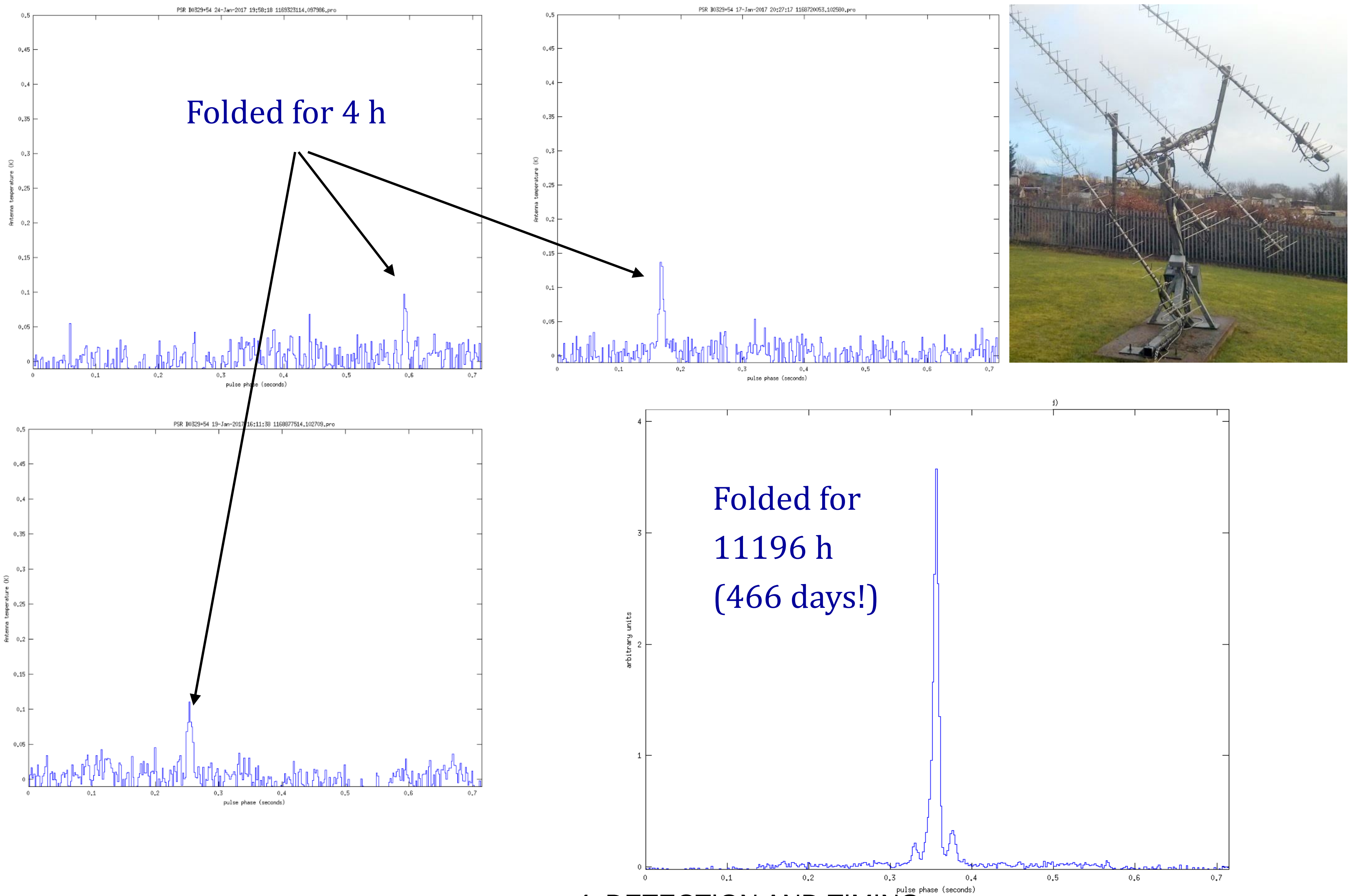


Period search – data folding

- Once the period is identified, the time series can also be folded to reveal the mean pulse profile:

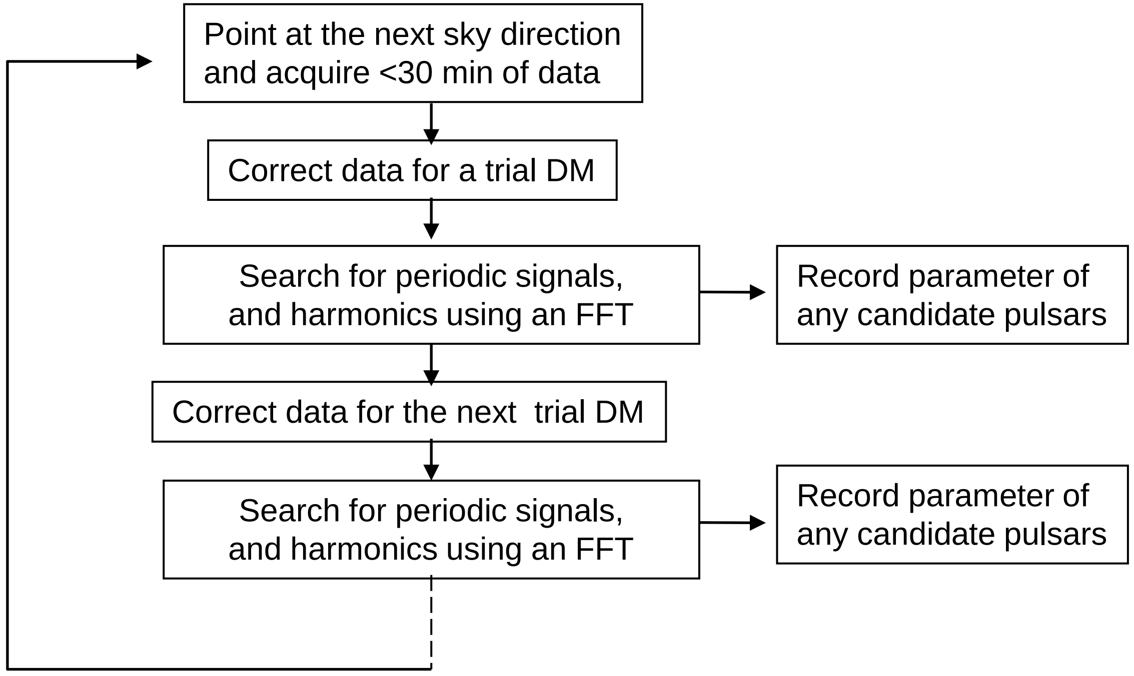


Acre road examples – PSR B0329+54



Search strategies

- So a good search strategy is:



- The candidate pulsars can then be followed up with intermittent observations over longer timescales to pin down sky position, true period and period derivative, etc…

Pulsar timing

- Once a pulsar has been identified it can be 'timed' – measure the time of arrival (TOA) of pulses with respect to atomic clocks. Use the measured pulse profile as a moving template.

- The raw TOAs are topocentric (measured locally). We need to convert them to TOAs in a reference inertial frame – the solar system barycentre (centre of mass) is the best we have.

- Time needs to be defined carefully. GR effects on clocks are important as are Shapiro delays due to the Sun and planets and the irregular rotation of the Earth. The best measurements of TOAs are only available retrospectively, once drift trends in the world's atomic clocks have been determined. The best pulsar timing accuracies right now are ~100 ns.

The ATNF catalogue

- For nearly all your pulsar data needs, see

  http://www.atnf.csiro.au/research/pulsar/psrcat/

  tabular and graphical data on nearly all radio pulsars.

Plotting: Matt Pitkin's psrqpy package.

- Docs at https://media.readthedocs.org/pdf/psrqpy/latest/psrqpy.pdf
- Example at https://jupyter.physics.gla.ac.uk/hub/user-redirect/lab/tree/examples/a345/PSN2/full_ppdot.ipynb