

Transient processing in SFXC

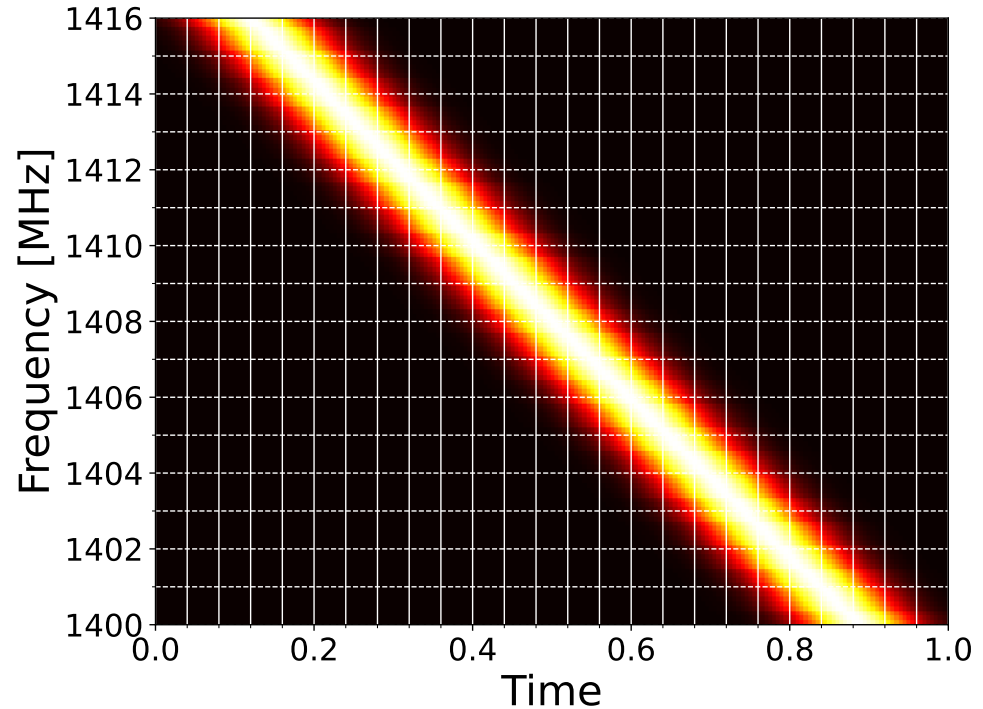
Aard Keimpema (keimpema@jive.eu)

Pulsars

- Pulsars are rotating neutron stars
- Light house effect: when beam moves over the earth we see a short pulse of radio emission
- Arrival times of pulsars can be predicted to very accuracy
- Pulsar timing software: tempo(2)
- Signal from pulsars are dispersed:

$$\Delta t = 4.15 \cdot 10^6 \cdot DM \cdot (1/v_0^2 - 1/v_1^2) [ms]$$

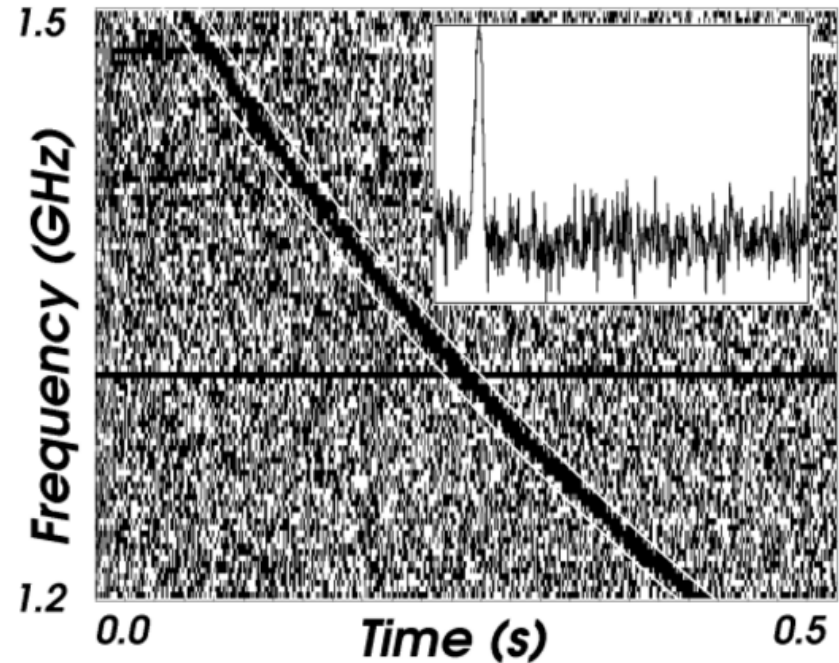
- DM = Dispersion measure
- v_0 , and v_1 frequencies [MHz]



Simulated dispersed pulse

FRBs

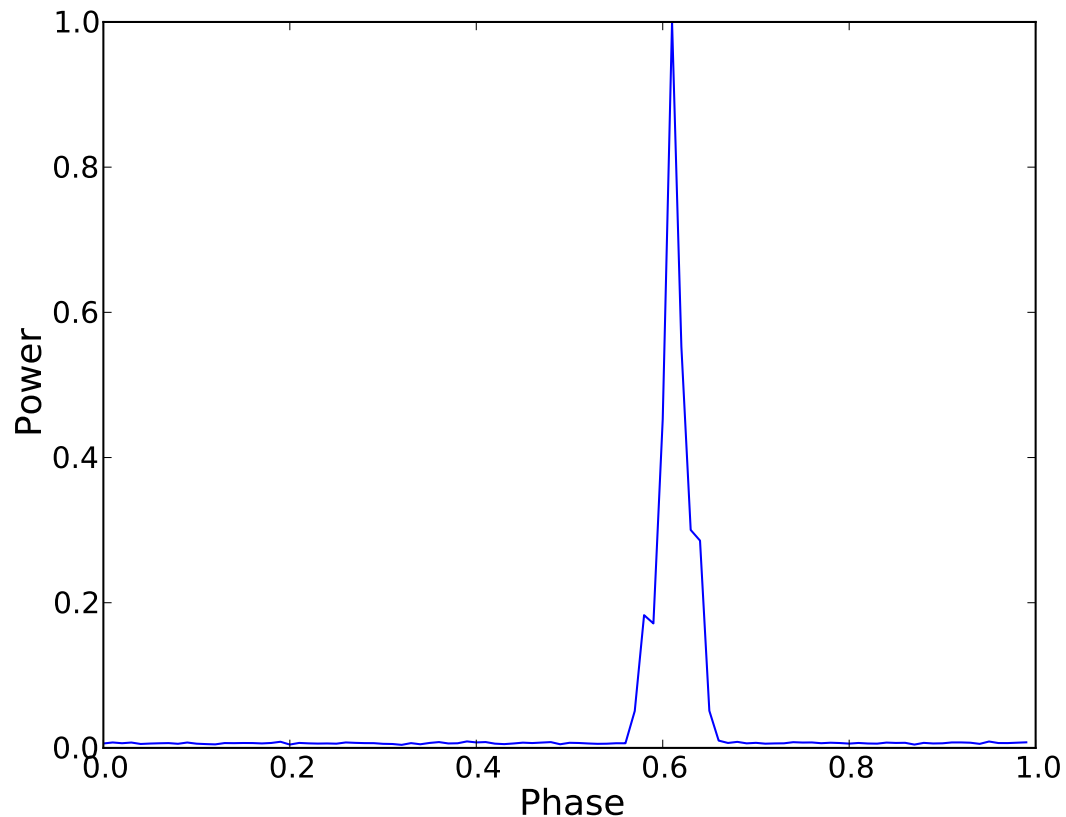
- Fast radio burst, are short burst of radio emission of extra-galactic origin
- Origin of FRBs is unknown, neutron stars are the prime suspect
- Some FRBs (56 out of 750) are repeaters, these are the prime targets for VLBI
- Arrival times of repeating burst can't be predicted a priori (though some sources have periodic active phases)
- Because FRBs are extragalactic they can have very high DMs ($>2000 \text{ pc cm}^{-3}$)



The first detected FRB, the Lorimer Burst

Pulsar binning

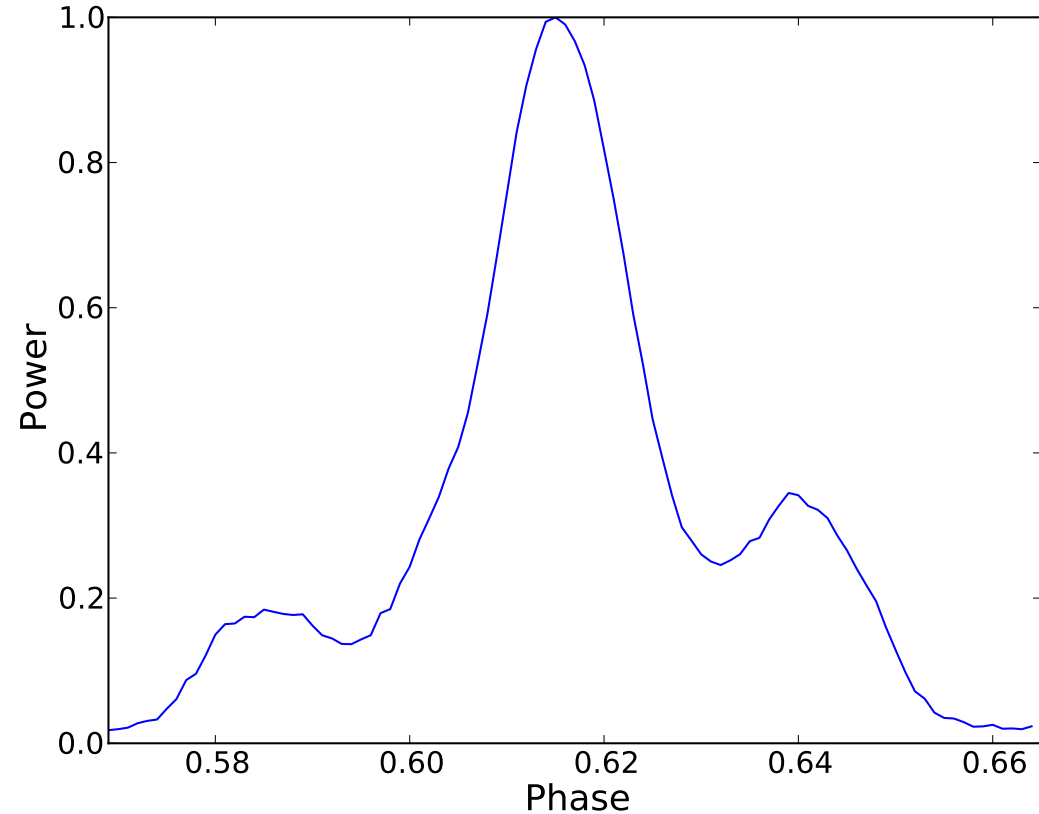
- Pulsar gating
 - Only accumulate correlation when pulsar signal is received
 - Increases signal to noise ratio
- Pulsar binning
 - Divide period in a number of time bins that are accumulated independently
- Pulse phase predicted using tempo polyco file (tutorial)



Pulse profile of PSR B0329+54

Pulsar binning

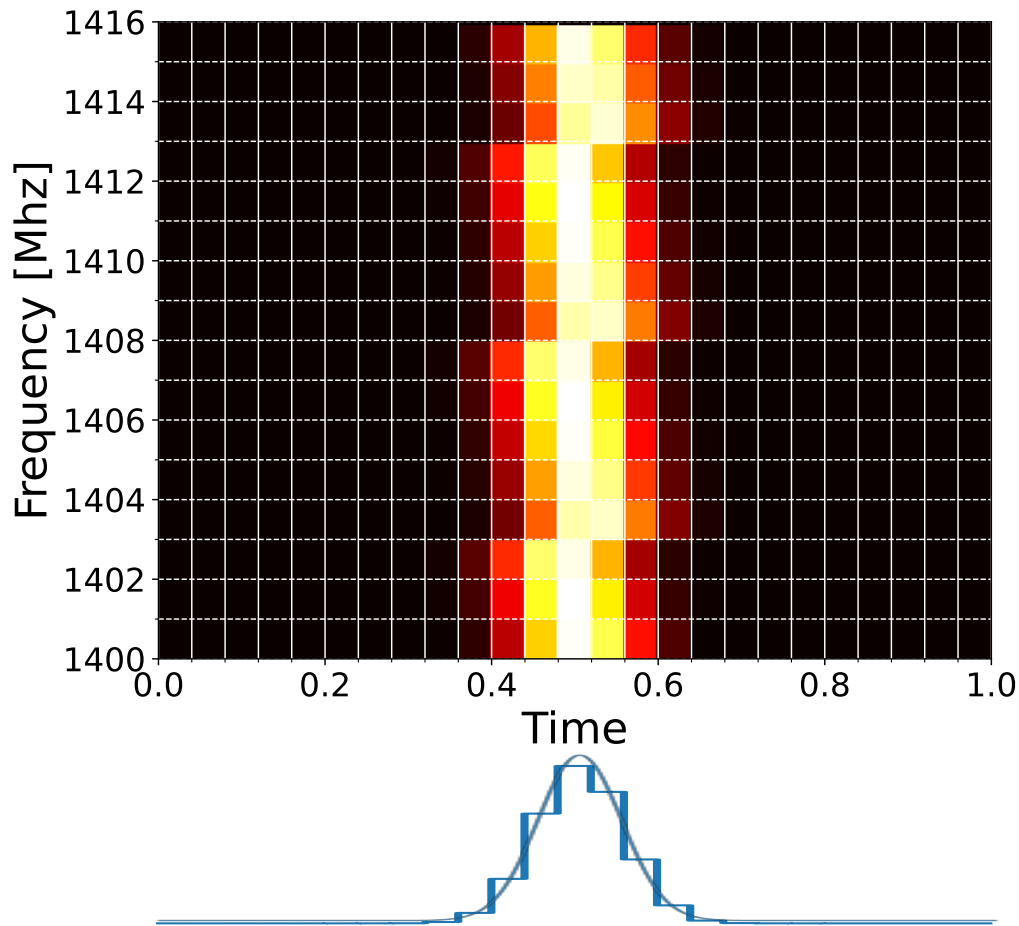
- Pulsar gating
 - Only accumulate correlation when pulsar signal is received
 - Increases signal to noise ratio
- Pulsar binning
 - Divide period in a number of time bins that are accumulated independently
- Pulse phase predicted using tempo polyco file (tutorial)



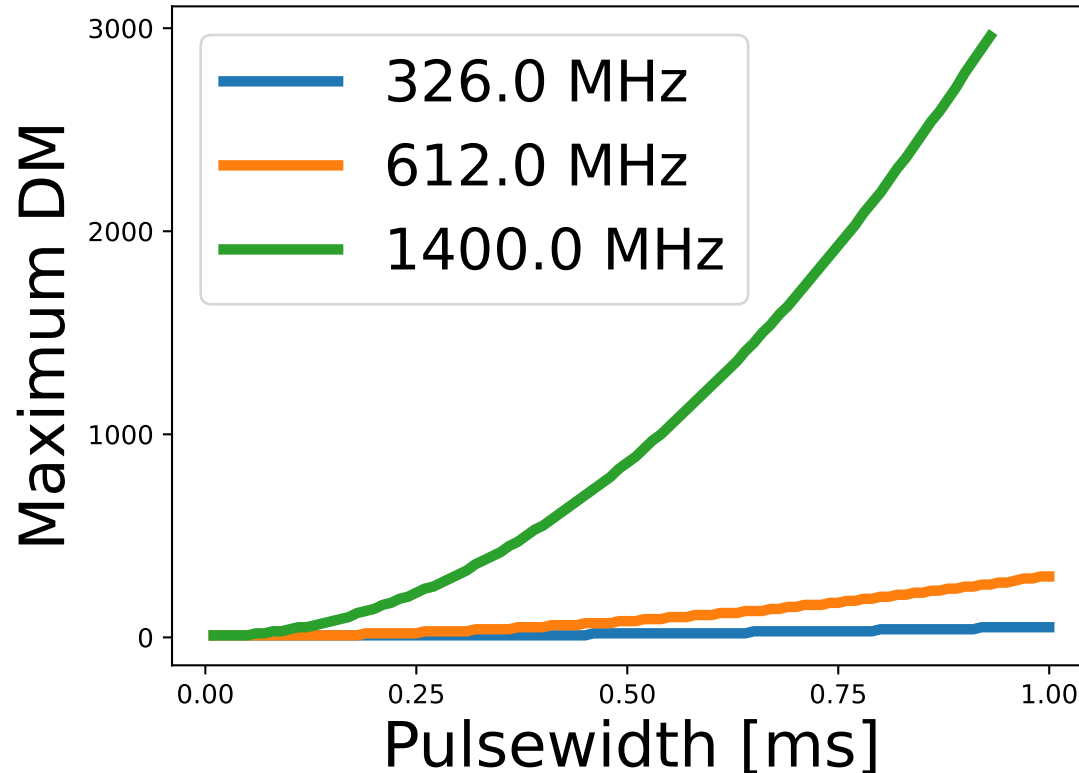
PSR B0329+54: 50 bins over pulse

Incoherent de-dispersion

- Algorithm
 - Correlate with a large number of spectral channels so that the dispersive effect in a single channel is small
 - After correlation shift each channel in time to compensate for dispersion
- Breaks down when required FFT size approached the pulse length
- But incoherent de-dispersion is significantly faster than coherent de-dispersion



Limits to incoherent dedispersion



- Maximum DM for which dispersive delay and FFT length are within 10% a pulse width.

Coherent de-dispersion

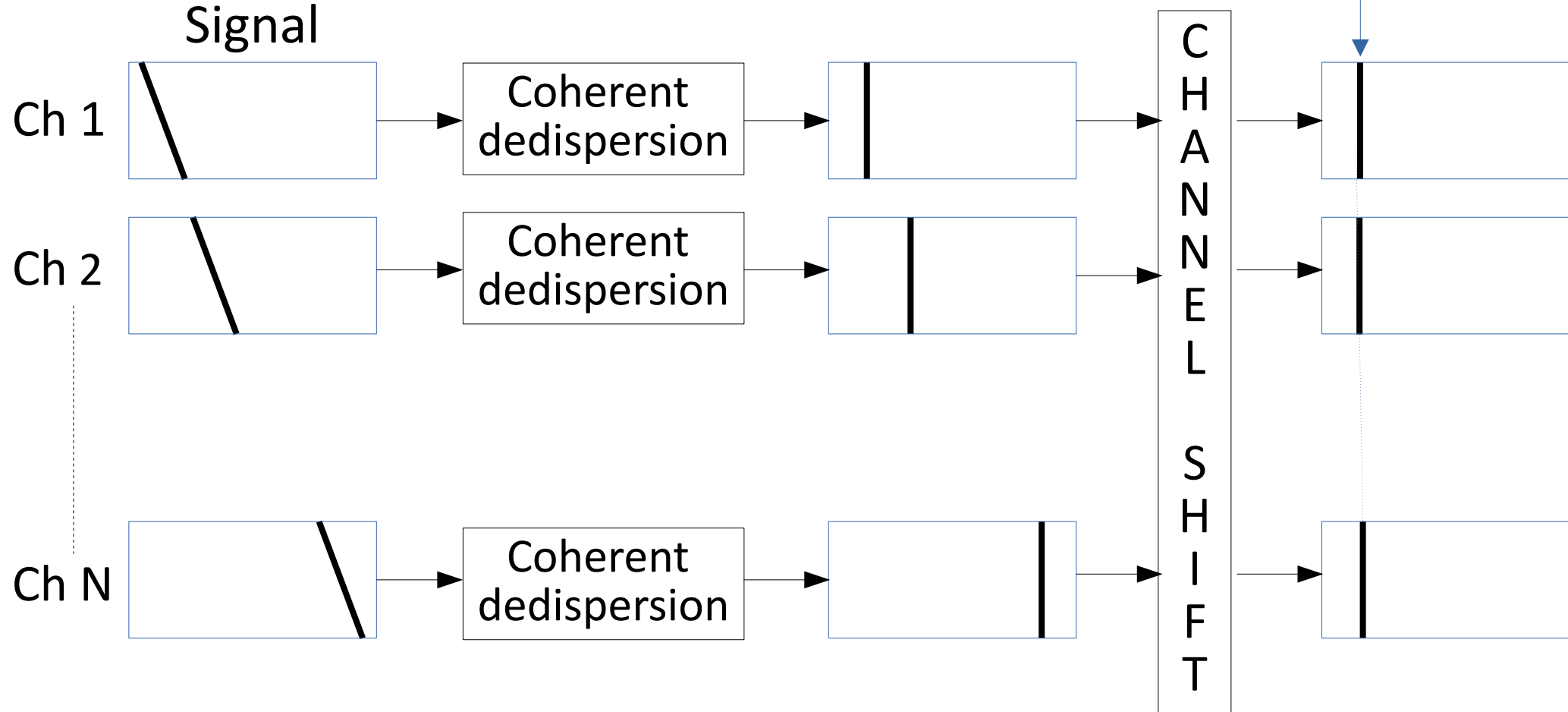
- Dispersive delay can be completely removed by applying a filter $H(u)$ with transfer function

$$H(v_0 + v) = \exp\left(\frac{-i 2 \pi D M v^2}{2.41 \times 10^{-10} v_0^2 (v_0 + v)}\right)$$

- Filter involves multiple very long FFTs (often 1M+ points)
- Very slow, but most accurate
- Filter removes dispersive delay within a sub-band, but not between sub-bands

Coherent filterbank

Aligned to centre
of top band



Example control file

```
pulsars: {  
  "PSR0329": {  
    nbins: 50,  
    polyco_file: file://polyco_PSR0329.dat,  
    interval: [0.57, 0.67],  
    coherent_dedispersion: false  
  }  
},  
fft_size_correlation: 2048,
```

- Define 50 bins between pulse phase 0.57 – 0.67
- Each bin is written to a separate output file

Example control file

```
pulsars: {  
    "PSR0329": {  
        nbins: 50,  
        polyco_file: file://polyco_PSR0329.dat,  
        interval: [0.57, 0.67 ],  
        coherent_dedispersion: false}  
    },  
    fft_size_correlation: 2048,
```

- Pulsar model in tempo polyco file
- *NB: polyco file must use geocentre as observatory*

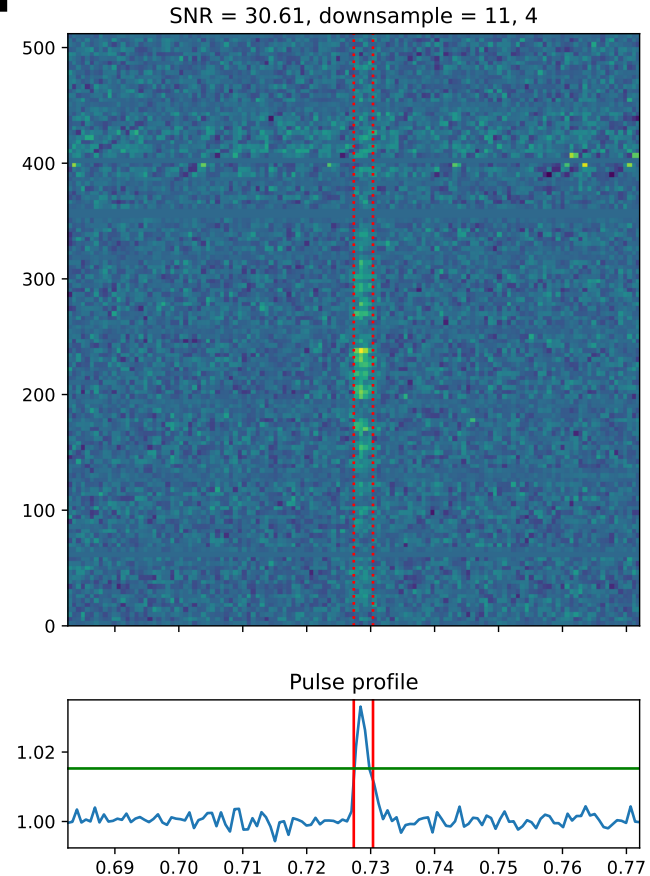
Example control file

```
pulsars: {  
    "PSR0329": {  
        nbins: 50,  
        polyco_file: file://polyco_PSR0329.dat,  
        interval: [0.57, 0.67],  
        coherent_dedispersion: false  
    }  
},  
fft_size_correlation: 2048
```

- Select de-dispersion method to use, default is incoherent de-dispersion
- `fft_size_correlation` controls the spectral resolution with which incoherent de-dispersion is performed

Filterbank output

- VLBI data can also be used for time-domain science
- SFXC can output dynamic power spectra in SIGPROC Filterbank, or PSRFITS format supported by most pulsar toolkits
- Filterbank files are created using the `cor2filterbank.py` script
- Also useful to find exact time ranges of bursts
- Limited dynamic range due to 2-bit quantisation
- Modern back-ends (like DBBC3) support up to 8 bit quantisation, supported by SFXC



De-dispersed filterbank output and pulse profile using Effelsberg

Creating filterbank output

```
filterbank: true,  
sub_integr_time : 128,  
pulsars: {  
    "PSR0329": {  
        nbins: 50,  
        polyco_file: file://polyco_PSR0329.dat,  
        interval: [0.57, 0.67],  
        coherent_dedispersion: true  
    }  
},
```

- Data is optionally coherently de-dispersed if
 - Current source is in the list of pulsars
 - `coherent_dedispersion` is true

Creating filterbank output

```
filterbank: true,  
sub_integr_time : 128,  
pulsars: {  
    "PSR0329": {  
        nbins: 50,  
        polyco_file: file://polyco_PSR0329.dat,  
        interval: [0.57, 0.67],  
        coherent_dedispersion: true  
    }  
},
```

- Sets the time resolution of the filterbank output
 - There must be an integral number of sub_integr_time per integration
 - There must be an integral number of fft_size_correlation per sub_integr_time

Creating filterbank output

```
filterbank: true,  
sub_integr_time : 128,  
pulsars: {  
    "PSR0329": {  
        nbins: 50,  
        polyco_file: file://polyco_PSR0329.dat,  
        interval: [0.57, 0.67],  
        coherent_dedispersion: true  
    }  
},
```

- Nbins, and interval are ignored
- No incoherent de-dispersion when coherent de-dispersion is disabled

Correlating FRBs

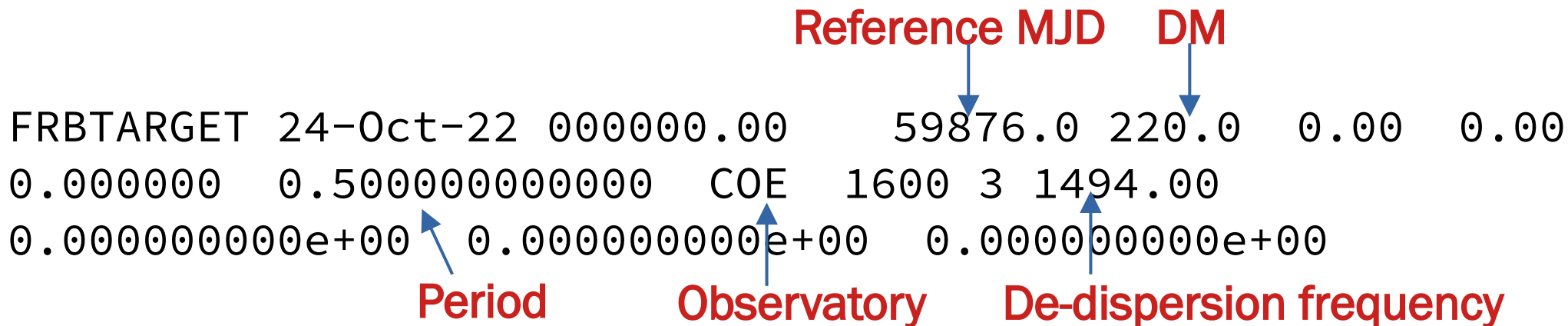
- To correlate an FRB we use the pulsar binning mode
- We create a dummy polyco file with a DM that matches the FRB, and has a pulsar period of two seconds
- We then set the interval time range in the pulsars block to match the FRB arrival time

Dummy polyco

FRBTARGET 24-Oct-22 000000.00 59876.0 220.0 0.00 0.00
0.000000 0.500000000000000 COE 1600 3 1494.00
0.000000000000e+00 0.000000000000e+00 0.000000000000e+00

Reference MJD **DM**

Period **Observatory** **De-dispersion frequency**

The diagram shows a text-based file format for a dummy polyco. It consists of three lines of text. The first line contains 'FRBTARGET', a date '24-Oct-22', a time '000000.00', a reference MJD '59876.0', a DM value '220.0', and two zeros '0.00'. The second line contains several zeros, a period '0.5', more zeros, the text 'COE', and three more values '1600', '3', and '1494.00'. The third line contains three scientific notation values '0.000000000000e+00'. Red text labels with arrows point to specific fields: 'Reference MJD' points to '59876.0', 'DM' points to '220.0', 'Period' points to '0.5', 'Observatory' points to 'COE', and 'De-dispersion frequency' points to '1494.00'.

- Period should be 0.5 (=2 seconds)
- Choose de-dispersion reference frequency to be the middle of the sub-band with the highest frequency
- Set reference phase and all components of the pulsar phase polynomial to zero

https://tempo.sourceforge.net/ref_man_sections/tz-polyco.txt

FRB correlation control

```
pulsar_binning: true,  
pulsars: {  
  "FRBTARGET": {  
    nbins: 1,  
    polyco_file: file://polyco_dummy.dat,  
    interval: [0.4995, 0.5005],  
    coherent_dedispersion: true  
  }  
},
```

- Suppose pulse was from 12h30m10.999s – 12h30m11.001s
- Because virtual pulsar had two second period, this translates to the above interval

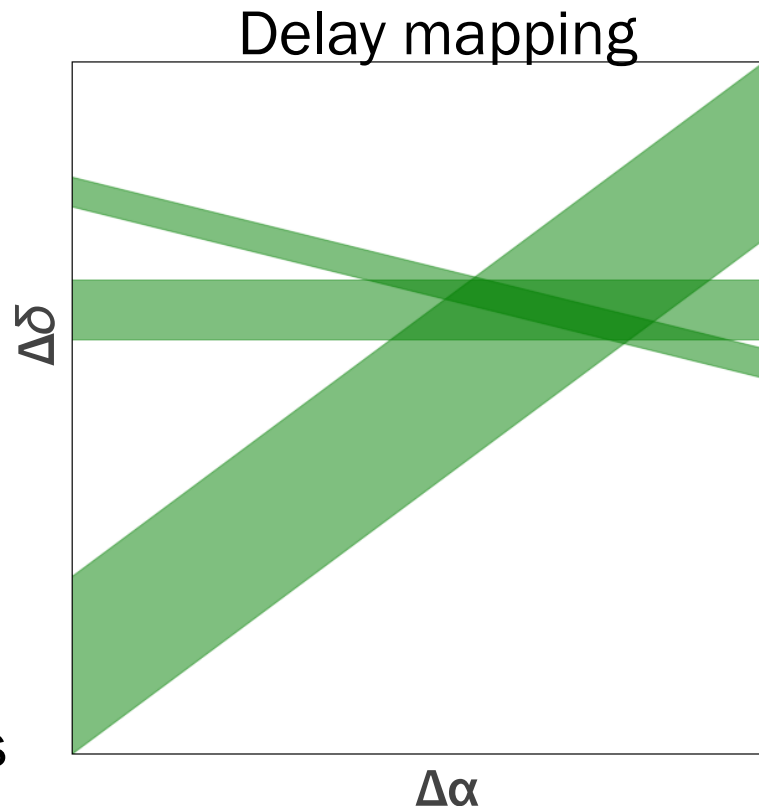
FRB correlation control

```
pulsar_binning: true,  
pulsars: {  
    "FRBTARGET": {  
        nbins: 1,  
        polyco_file: file://polyco_dummy.dat,  
        interval: [0.9995, 1.0005],  
        coherent_dedispersion: true  
    }  
},
```

- Suppose pulse was from 12h30m09.999s – 12h30m10.001s
- In this case pulse a two second interval boundary, we use a pulse phase > 1 to indicate this

Delay mapping

- When FRBs are discovered they often have poor initial localization
- Need to refine initial localisation before imaging
- Delay mapping: fit source position from baseline delays
$$\tau = \frac{1}{c}(u\Delta\alpha + v\Delta\delta)$$
- $\Delta\alpha$, $\Delta\delta$: right ascension, declination offsets



Each baseline delay defines a line,
source is in the overlapping region