Transient processing in SFXC

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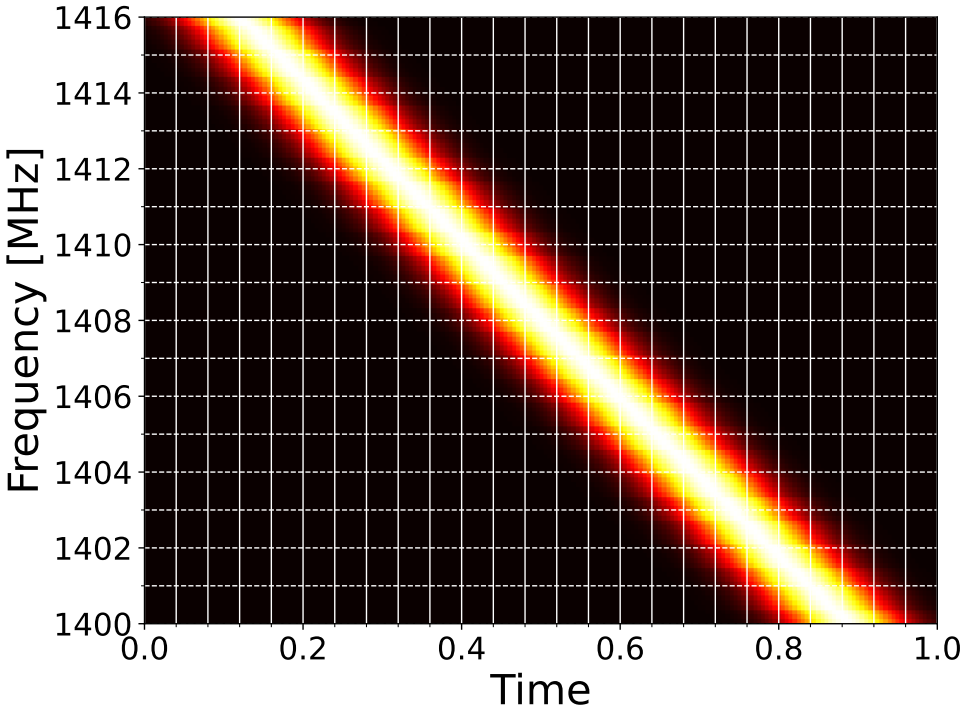
Pulsars

- 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:

$$\Delta t = 4.15 \cdot 10^6 \cdot DM \cdot \left(1/\nu_0^2 - 1/\nu_1^2\right)[ms]$$

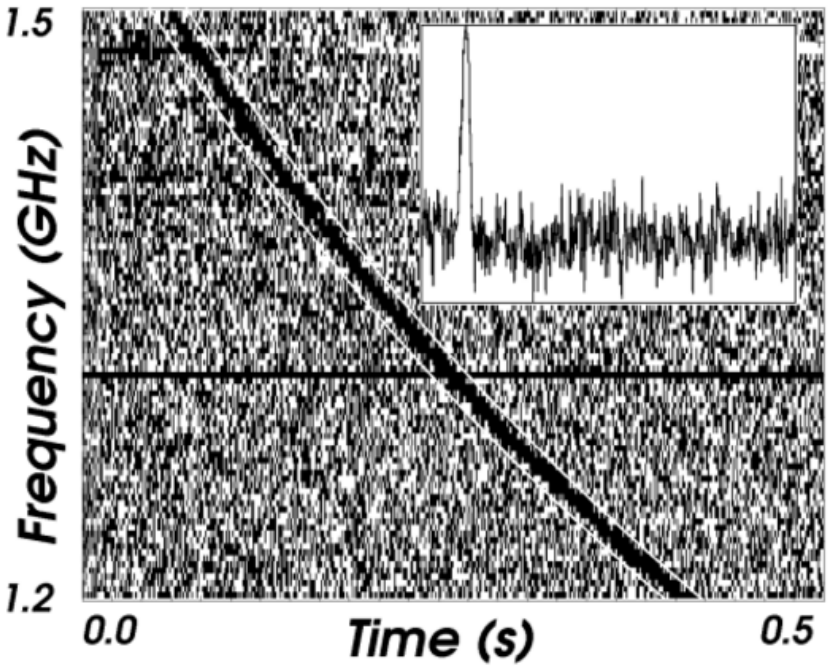
- DM = Dispersion measure
- ν_0, and ν_1 frequencies [MHz]



Simulated dispersed pulse

FRBs

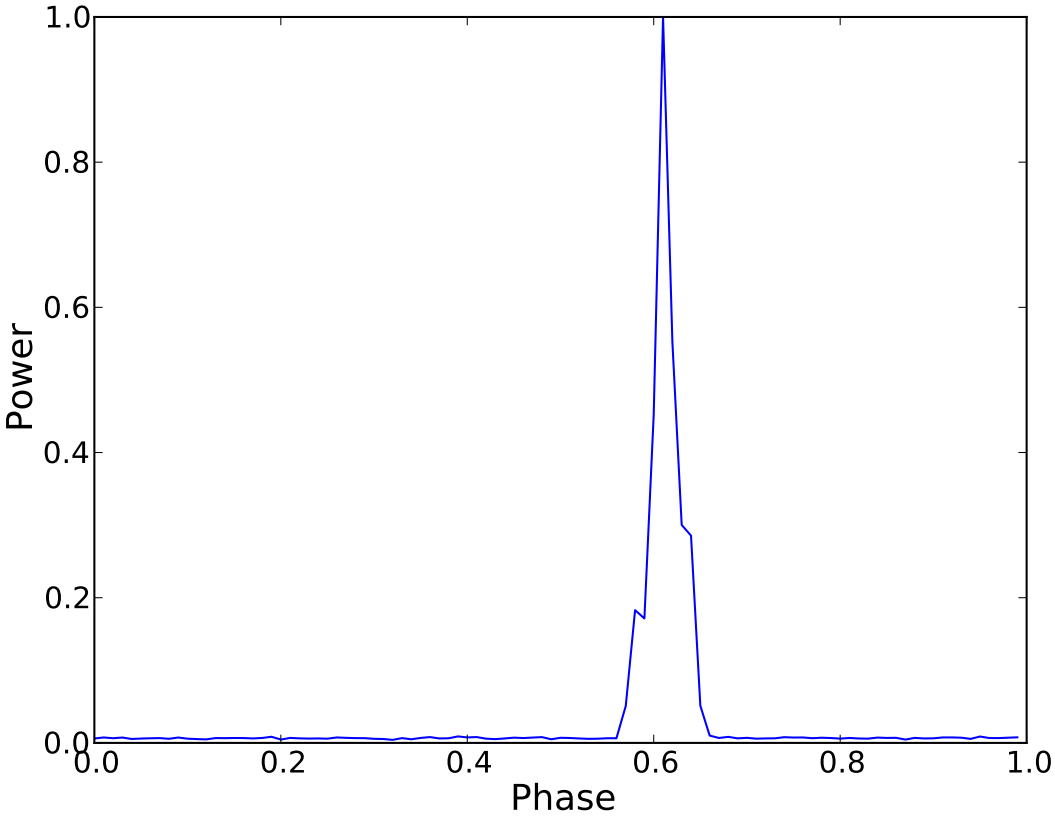
- Fast radio burst, are short burst of radio emission of extra-galactic origin
- Origin of FRBs is unknown, neutron stars are the prime suspect
- Some FRBs (56 out of 750) are repeaters, these are the prime targets for VLBI
- Arrival times of repeating burst can't be predicted a priori (though some sources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



The first detected FRB, the Lorimer Burst

Pulsar binning

- Pulsar gating
  - Only accumulate correlation when pulsar signal in 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

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  - Only accumulate correlation when pulsar signal in received
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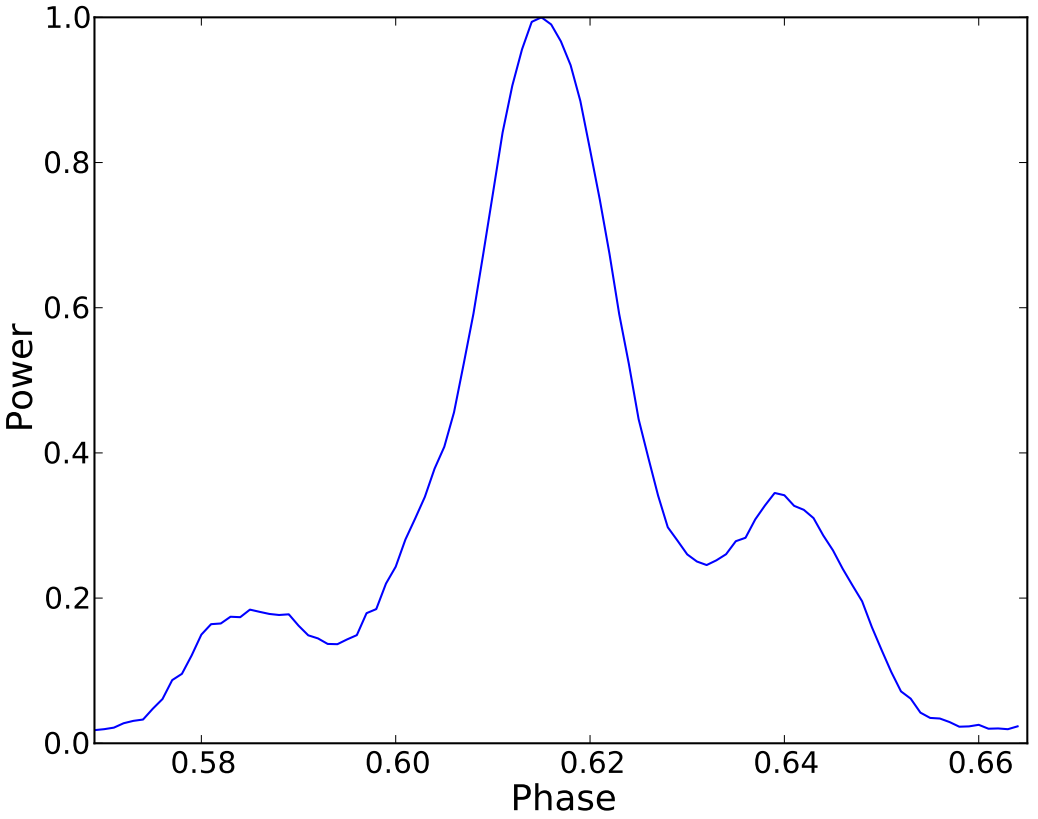
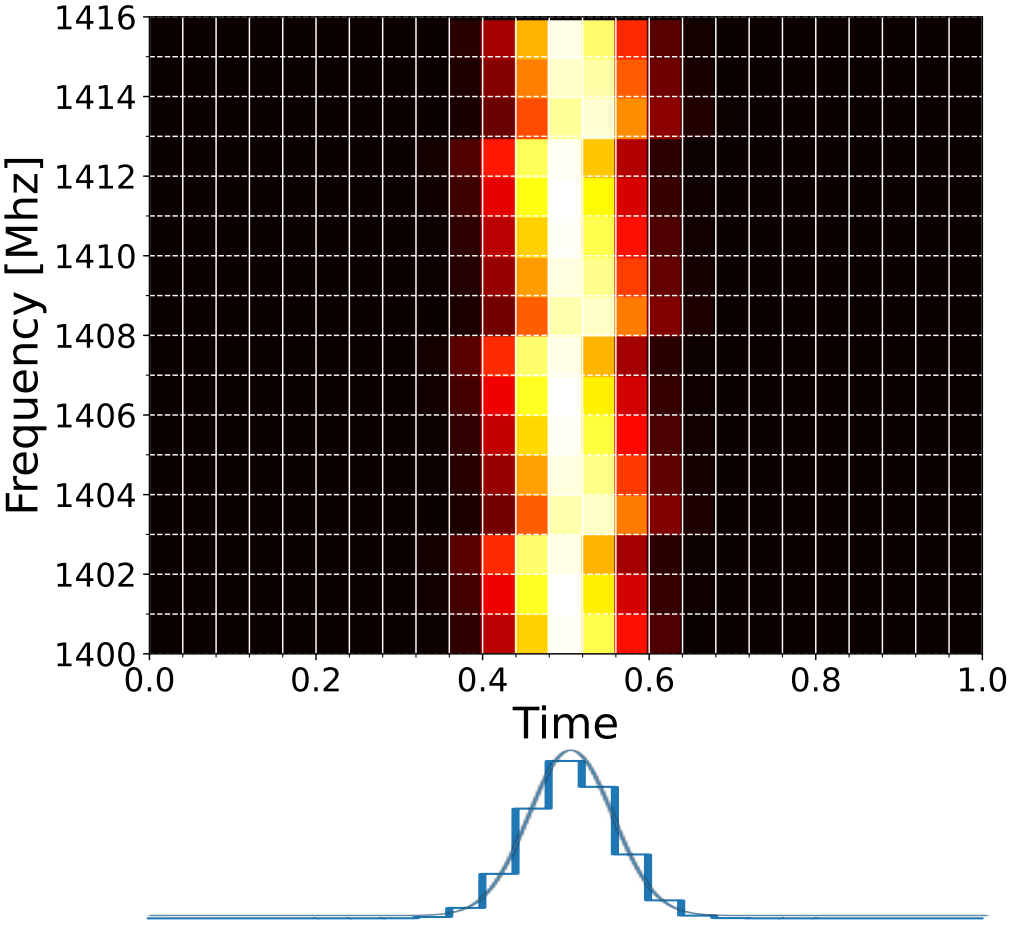


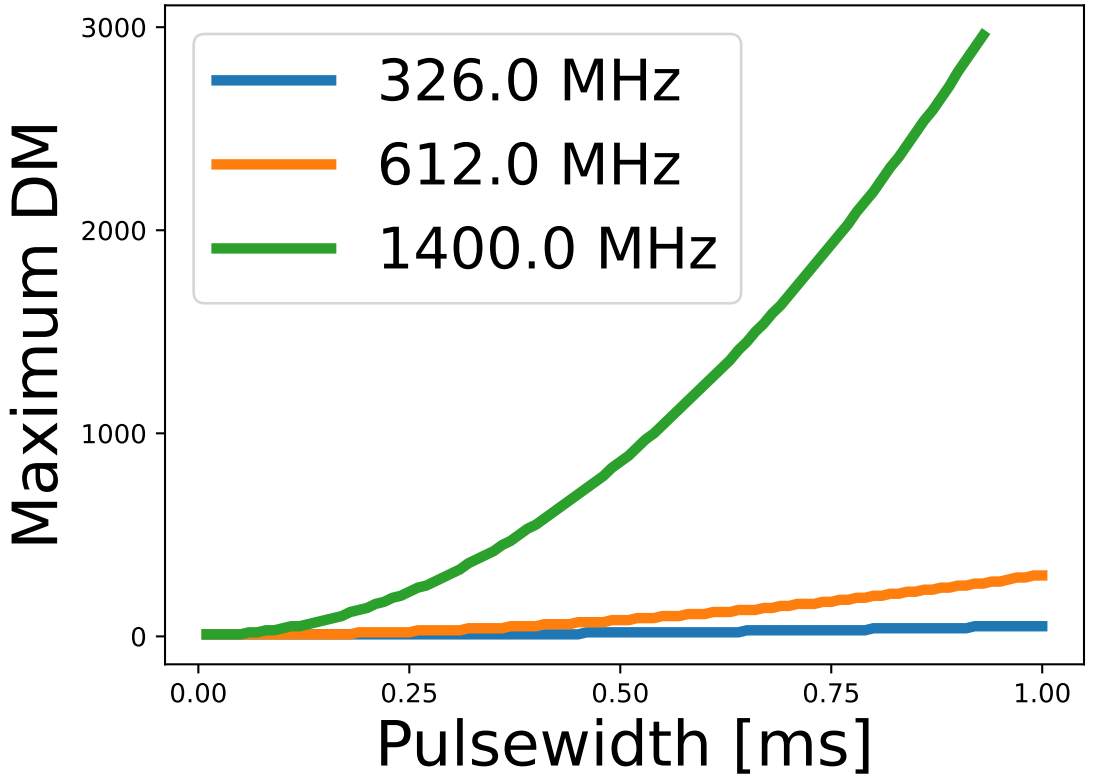
PSR B0329+54: 50 bins over pulse

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.

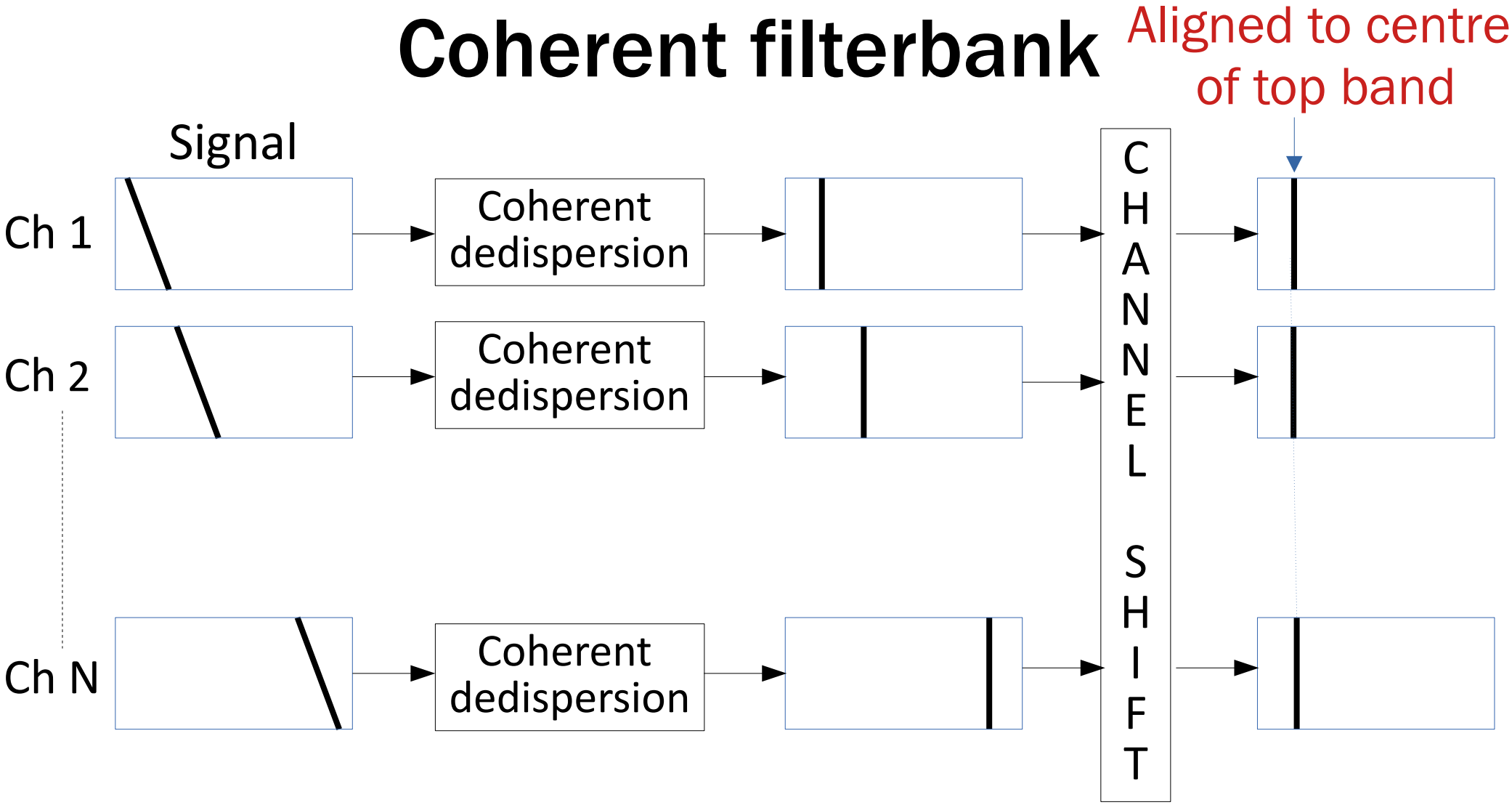
Coherent de-dispersion

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

$$H(\nu_0+\nu)=\exp\left(\frac{-i2\pi DM\nu^2}{2.41\times10^{-10}\nu_0^2(\nu_0+\nu)}\right)$$

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

Coherent filterbank



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*

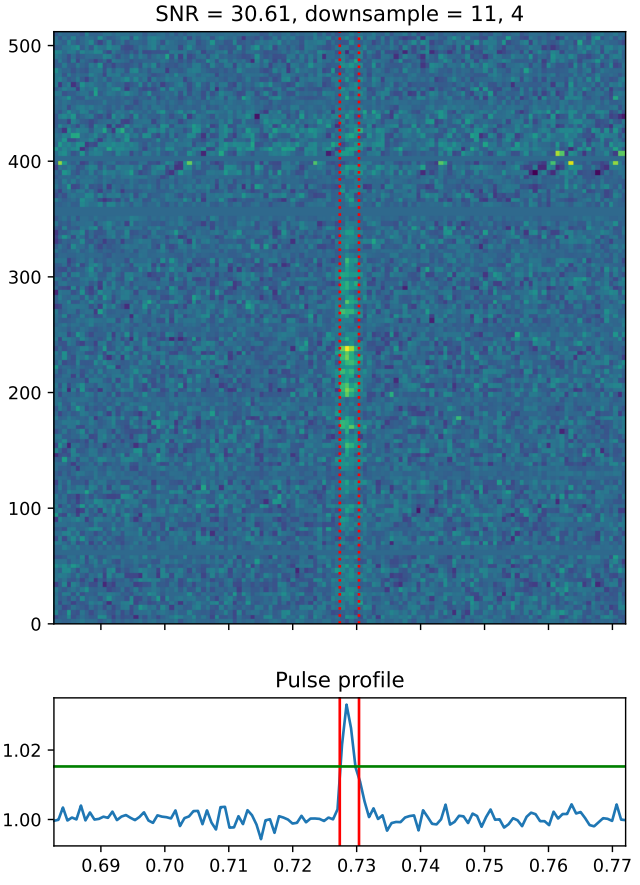
Example control file

```
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

Flilterbank 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

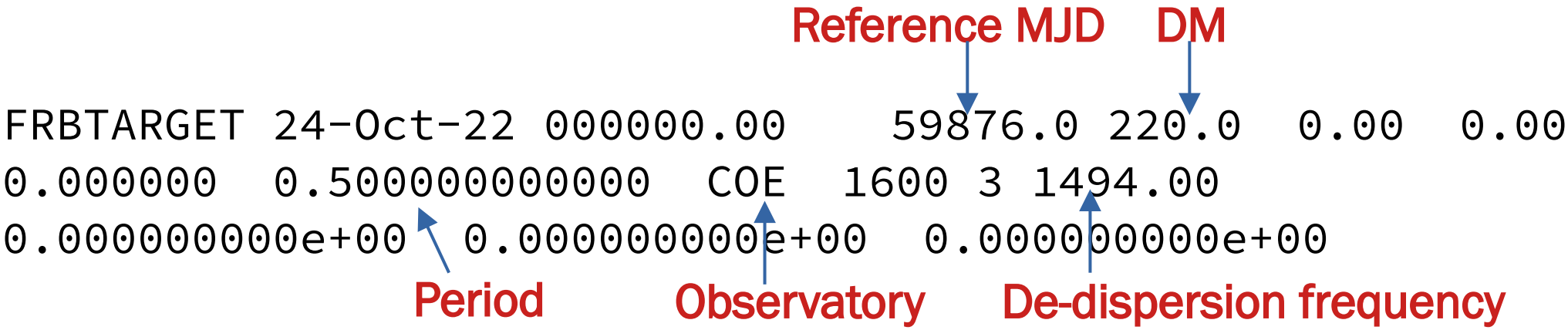
```
filterbank: true,
sub_integr_time : 128,
pulsars: {
   "PSR0329": {
      nbins: 50,
      polyco_file: file://polyco_PSR0329.dat,
      interval: [0.57, 0.67],
     coherent_dedispersion: true
   }
},
```

- 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



- 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
   }
},
```

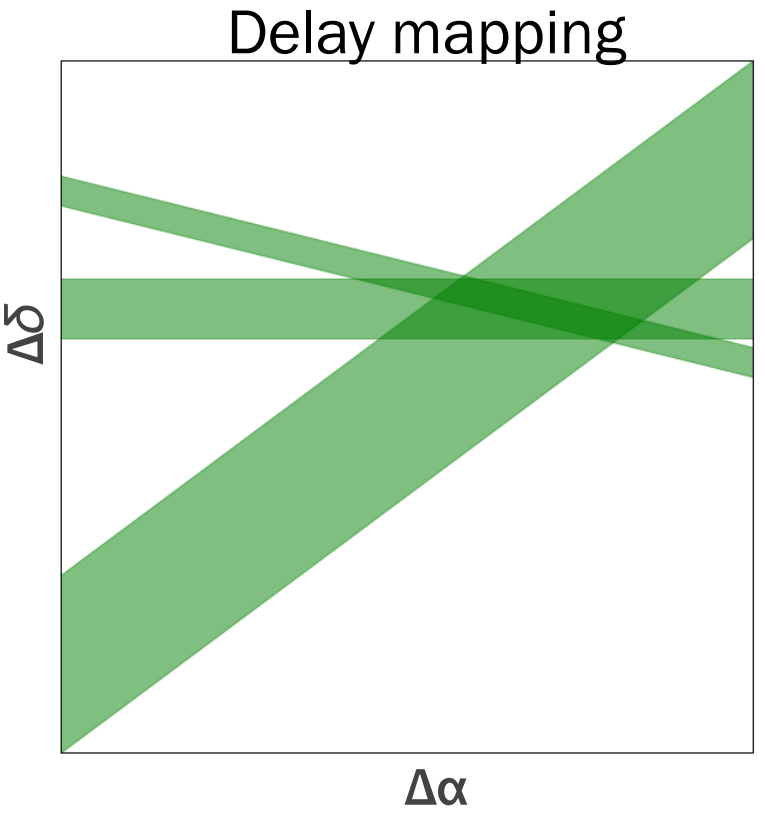
- Suppose pulse was from 12h30m09.999s – 12h30m10.001s
- In this case pulse a two second interval boundary, we use a pulse phase > 1 to indicate this

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

$$\tau = \frac{1}{c}(u\Delta\alpha + v\Delta\delta)$$

- Δα, Δδ: right ascension, declination offsets



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