# Cyclic Spectroscopy on Arecibo Pulsar Data

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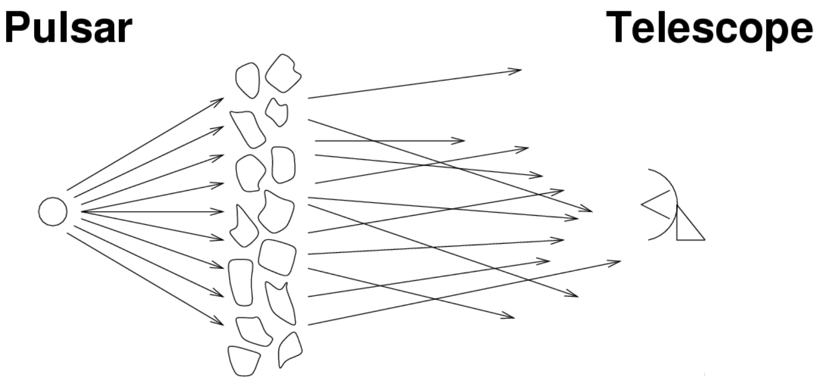
# Diffractive Scintillation

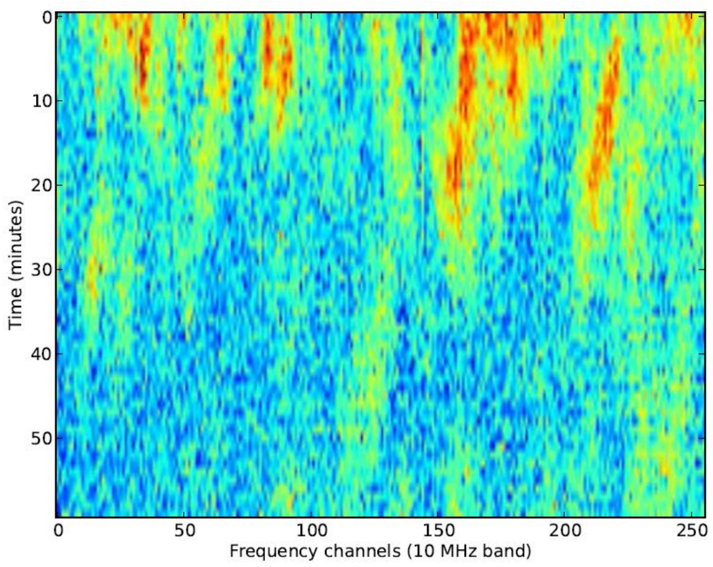



Diffraction from small scale irregularities

Short timescales ~minutes

Narrow bandwidths~1 MHz

J1713+0747 at 430 MHz




$$\Delta t_{DISS} \propto f^{1.2} d^{-0.6}$$

$$\Delta f_{DISS} \propto f^{4.4} d^{-2.2}$$

For a Kolmogorov medium

$$\tau_s = \frac{1.16}{2\pi \Delta f_{DISS}}$$

# Goals

- Improve timing by correcting for time variable scattering delay.
- Characterize the line of sight to understand the ISM.

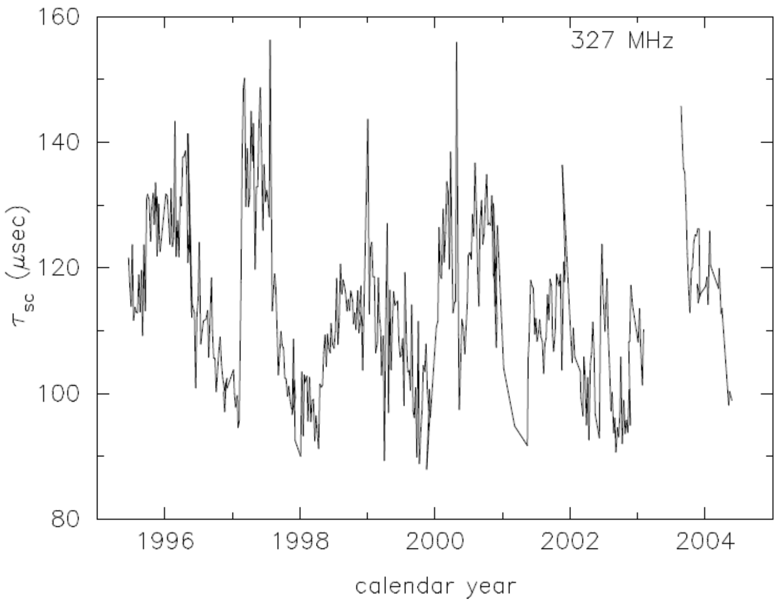



FIG. 2.— Measured temporal pulse broadening timescale ($\tau_{sc}$) as a function of time at 327 MHz.

Credit: Ramachandran et al. (2008)

# Theoretical background

Observed pulsar signal in the time domain

$$y(t) = h(t) * x(t)$$

In the frequency domain

$$Y(\nu) = H(\nu) X(\nu)$$

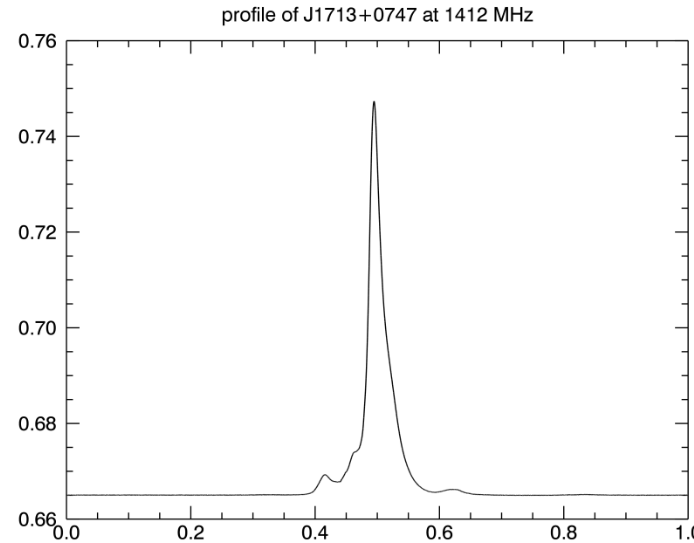
Cyclic spectrum

$$S_Y(\alpha,\nu) = H\left(\nu + \frac{\alpha}{2}\right) H^*\left(\nu - \frac{\alpha}{2}\right) S_X(\alpha,\nu)$$

# Arecibo Observations of J1713+0747

$p = 4.6\ \mathrm{ms}$

$P_b = 67.8\ \mathrm{days}$




Receivers :

327 MHz, 430 MHz, L - band

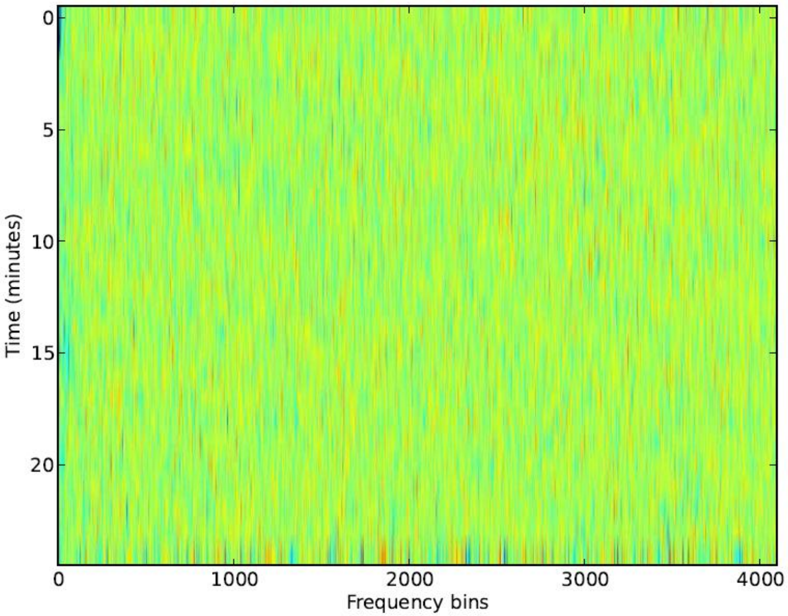
Backend : Mock spectrometers

Bandwidth : 10 MHz

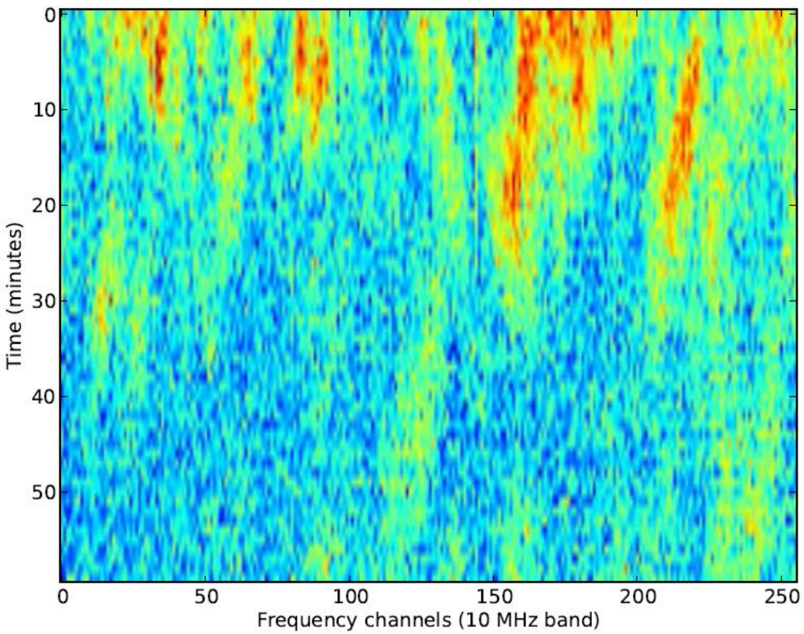
Integration time : 3600 s

Dual - frequency, on a total of 8 epochs.

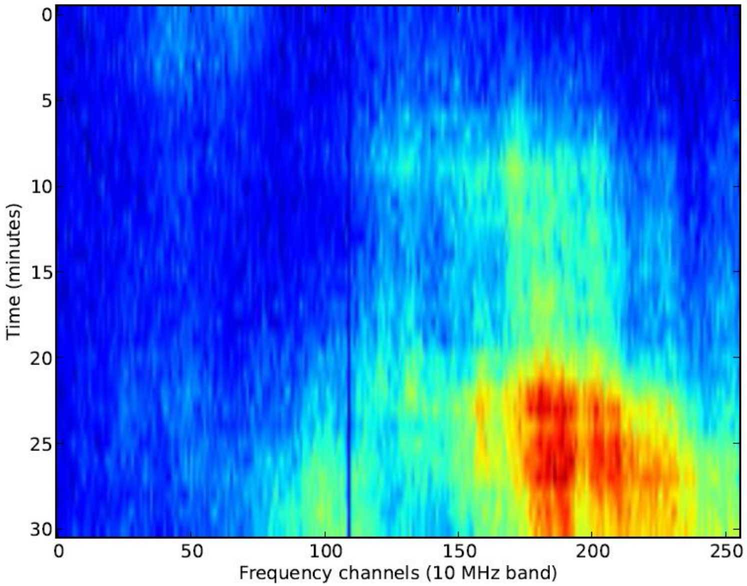
# Dynamic spectrum




B1937+21 at 430 MHz (data from Demorest 2011)




J1713+0747 at 430 MHz




B1534+12 at 430 MHz

# Estimated scattering times from dynamic spectrum

$$\tau_s = \frac{1.16}{2\pi\Delta f_{DISS}}$$

| PSR | $\Delta f_{DISS}$ (MHz) | $\Delta t_{DISS}$ (minutes) | Scattering time ($\mu s$) |
|---|---|---|---|
| J1713+0747 | 0.6 | 14 | 0.3 |
| B1534+12 | 1.1 | 11 | 0.1 |

# Periodic spectrum

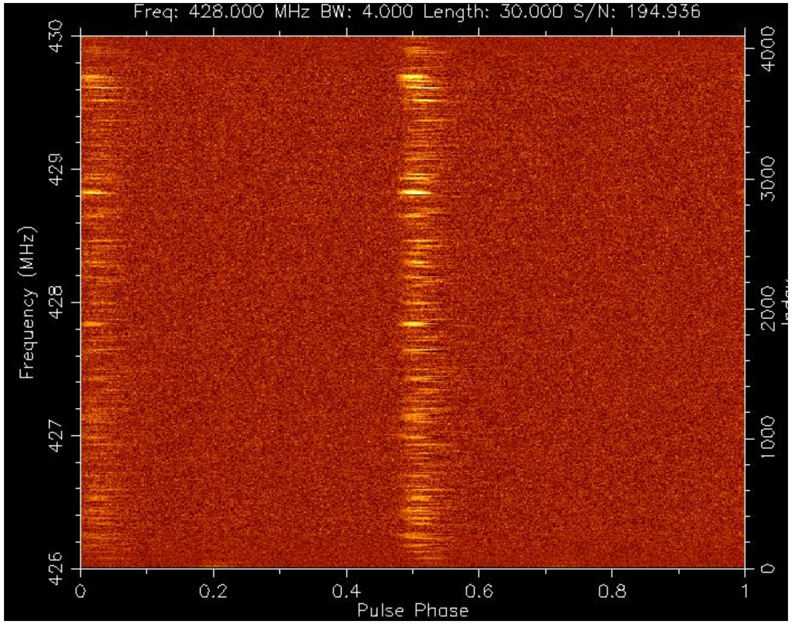
For the sampled voltage $x(t)$,

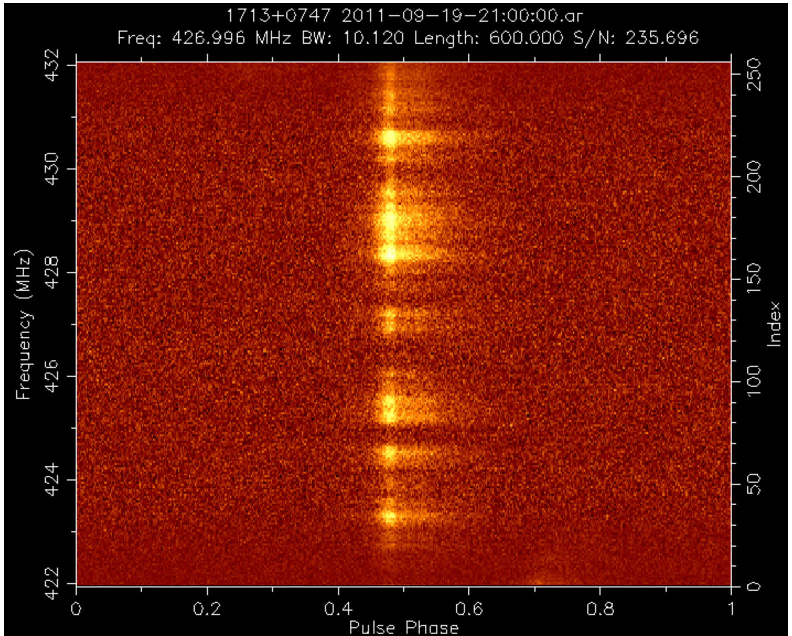
Periodic correlation:

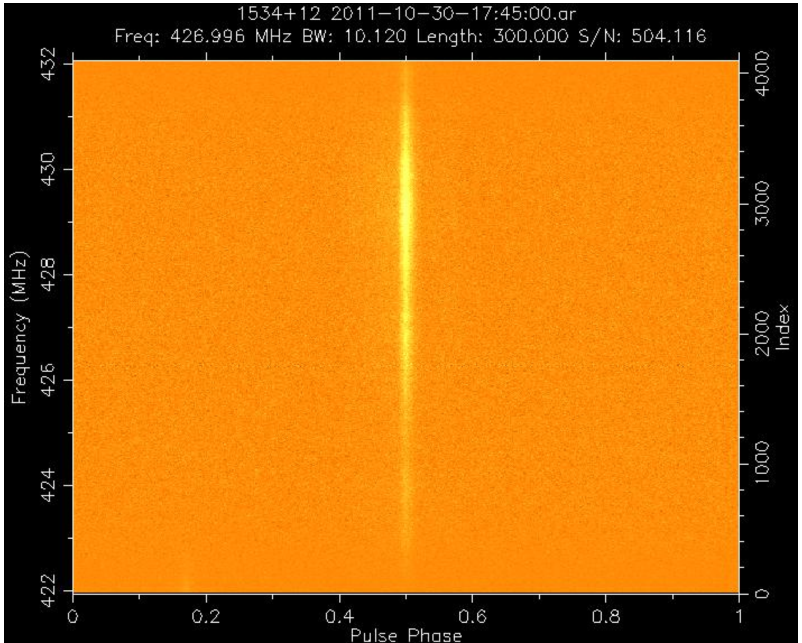
$$C_x\left(\phi(t),\tau\right) = E\left\{x(t+\tau/2)\,x^*(t-\tau/2)\right\}$$

Periodic spectrum:

$$S\left(\phi(t),\nu\right) = \sum C\left(\phi(t),\tau\right)e^{-2\pi i\tau\nu}$$



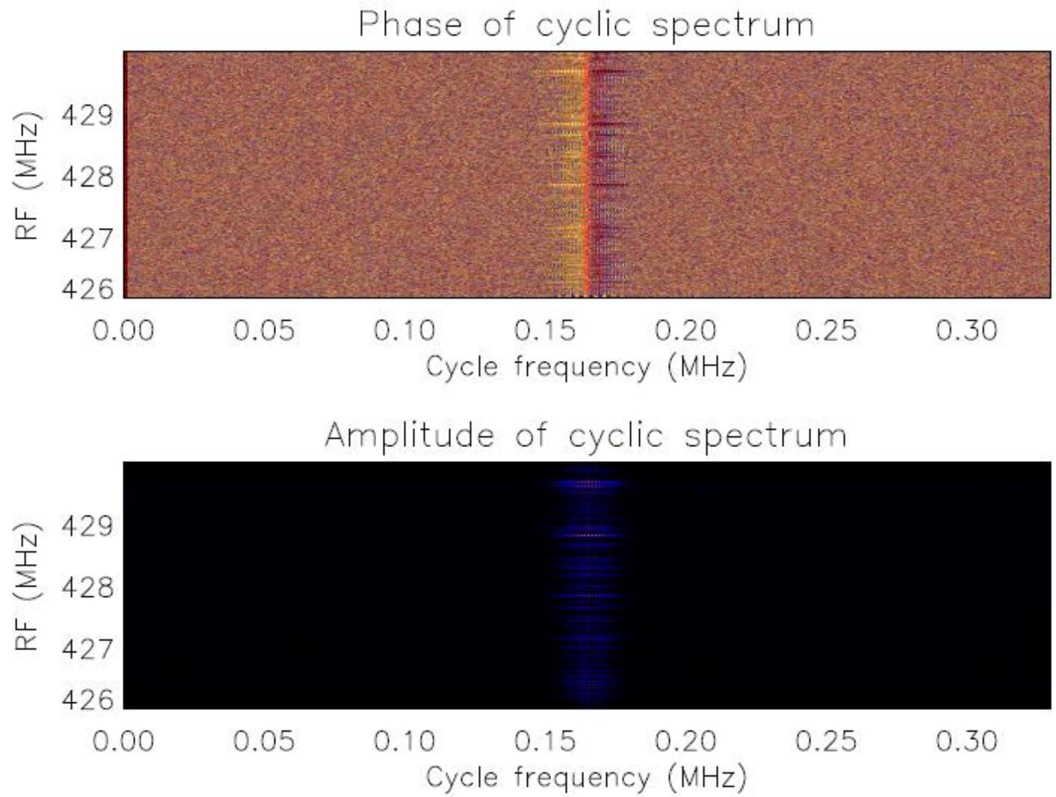



# Cyclic spectrum

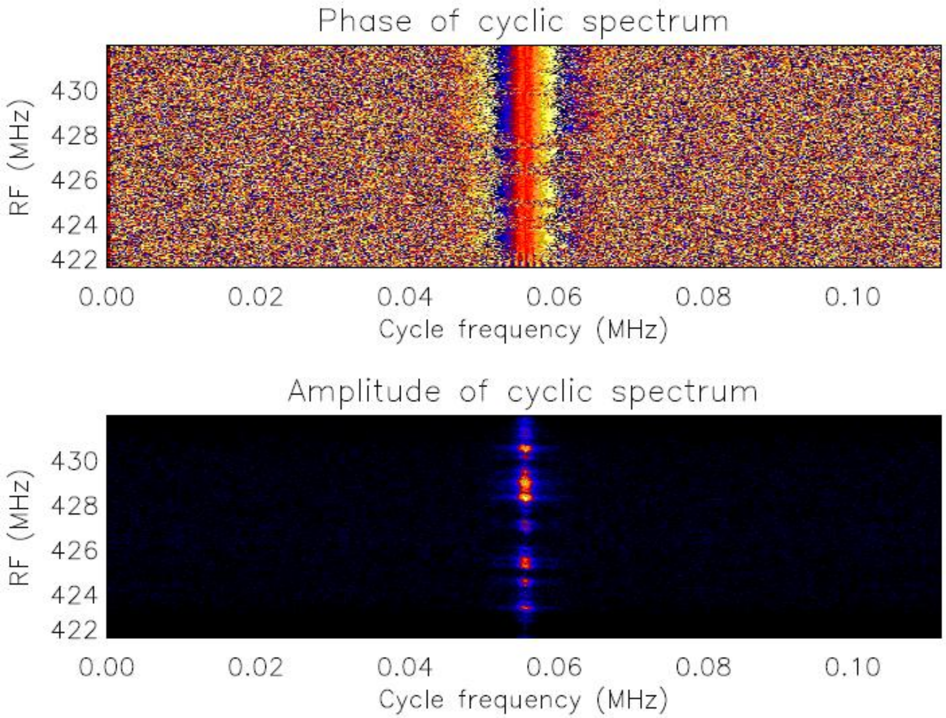
$$S(\alpha,\nu)=\sum S(\phi(t),\nu)e^{-2\pi i t\alpha}$$

B1937+21 at 430 MHz

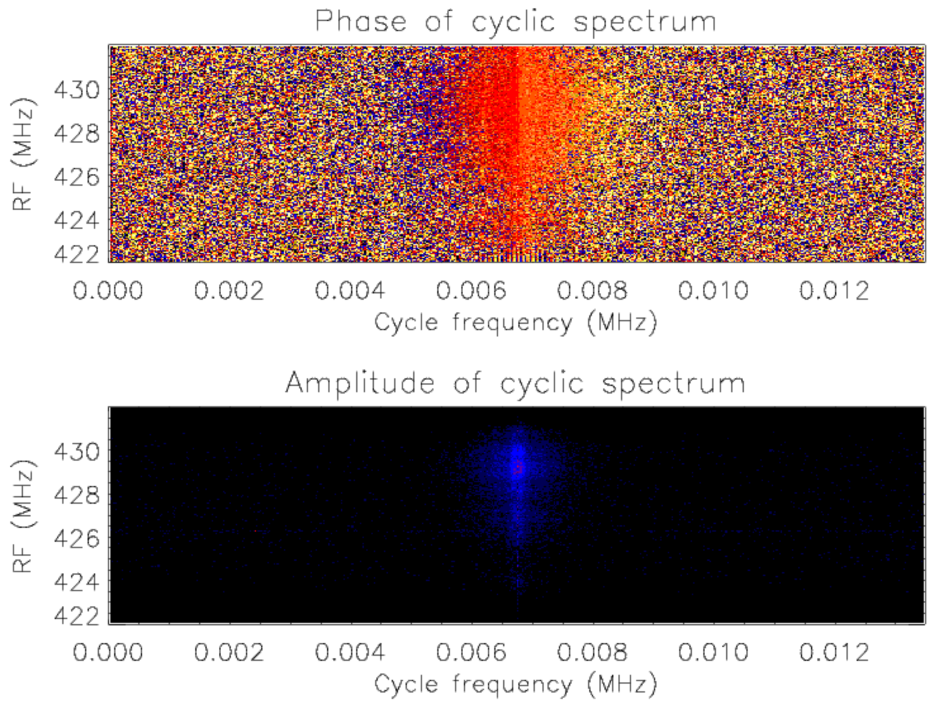


# Cyclic spectrum

J1713+0747 at 430 MHz

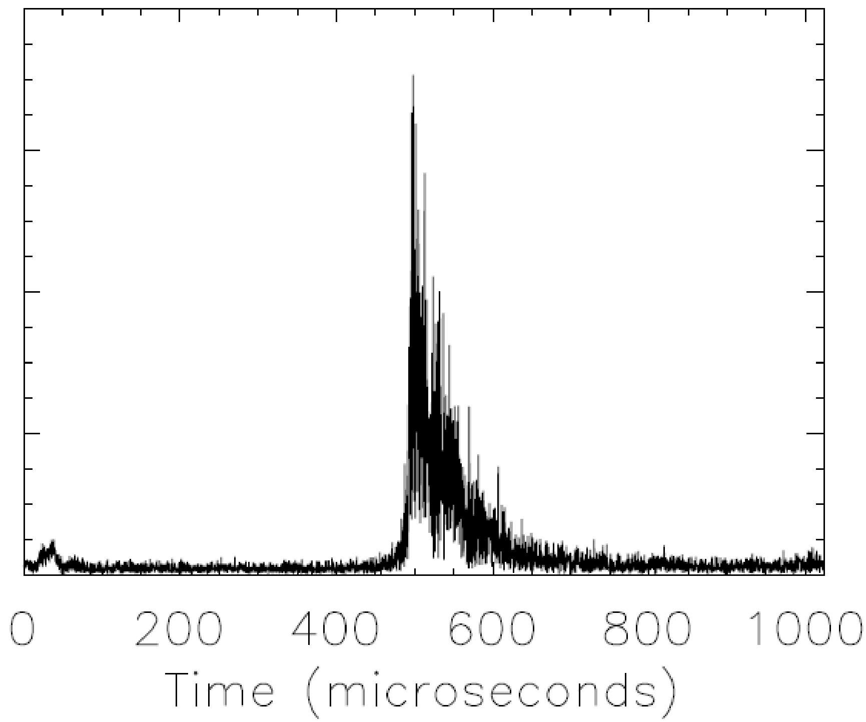



B1534+12 at 430 MHz



# Pulse broadening function

B1937+21 at 430 MHz



# Pulse broadening function

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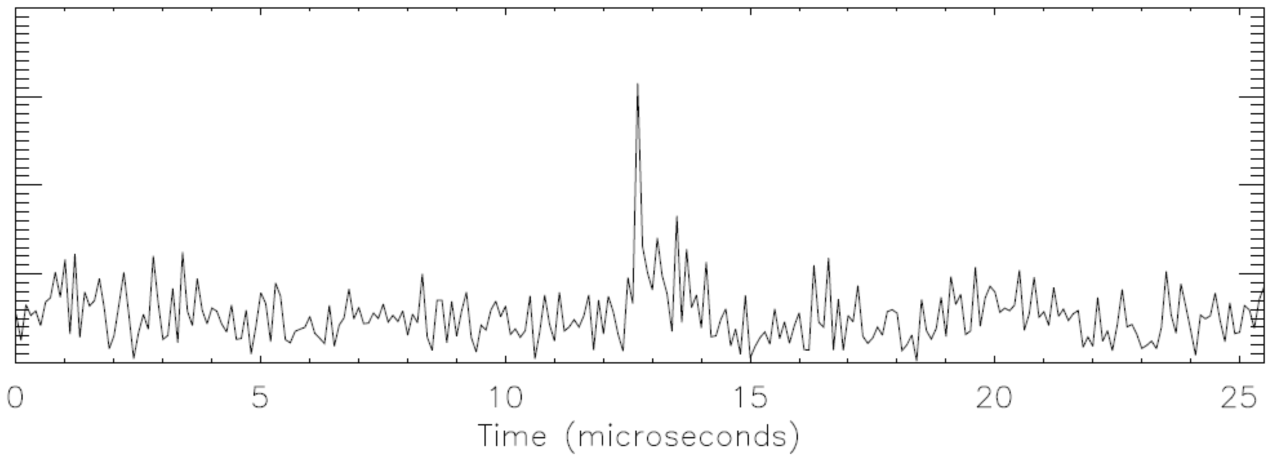
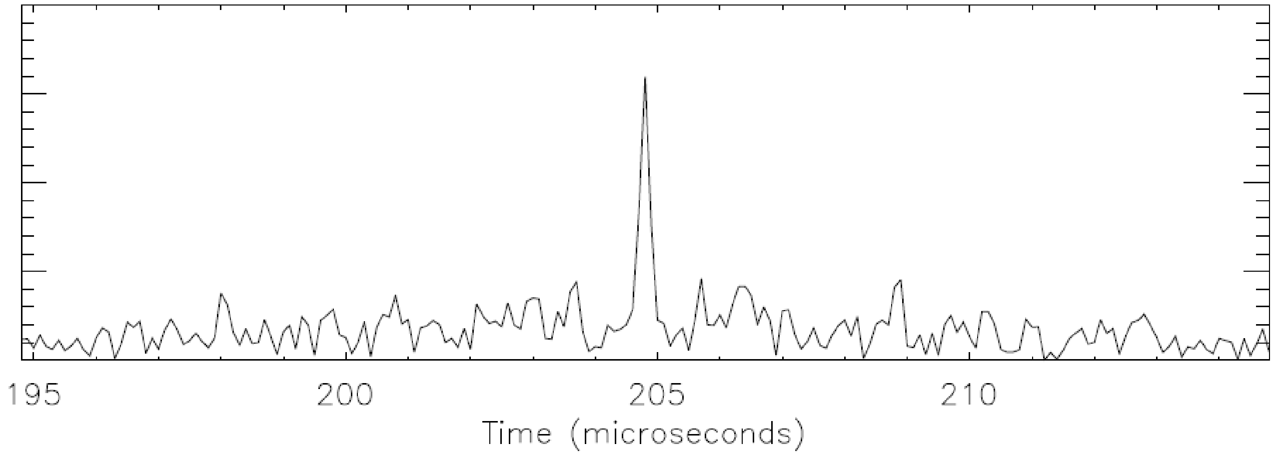



$\text{Predicted}: 0.3\,\mu s$

B1534+12 at 430 MHz




$\text{Predicted}: 0.1\,\mu s$

# Summary

- Cyclic spectroscopy can be used to recover PBFs.
- Allows to measure scattering delays.
- Next step is to correct TOAs.