Wideband Technique

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InPTA STUDENT WEEK - 2022

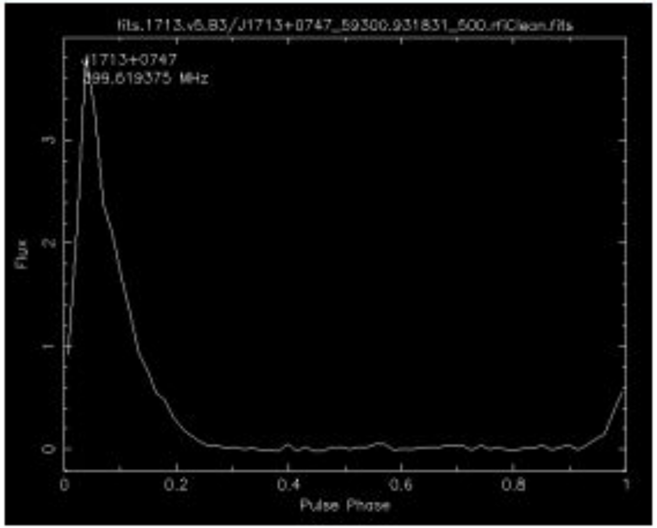
Narrowband v/s Wideband Technique

- In the recent years, the radio telescopes are upgraded with **Wideband receivers** and associated backends to obtain precise ToAs

- Profile evolution and ISM effects (Dispersion Measure and Scattering) makes it difficult to attain better precision with traditional narrowband method

- Pennucci et al. 2018, first provided an algorithm for the simultaneous measurement of DMs and ToAs from wideband pulsar data, called the ”wideband timing technique”.

Introduction - Narrowband



High S/N profiles are added and then are scrunched in frequency and time.

We fit gaussians to it and create an analytical template (paas).

This analytical template is used to generate ToAs by cross correlating the template with the folded profile of each epoch (pat).

Dispersion measure (DM) is obtained using frequency resolved ToAs over several epochs and then fitting for DM.

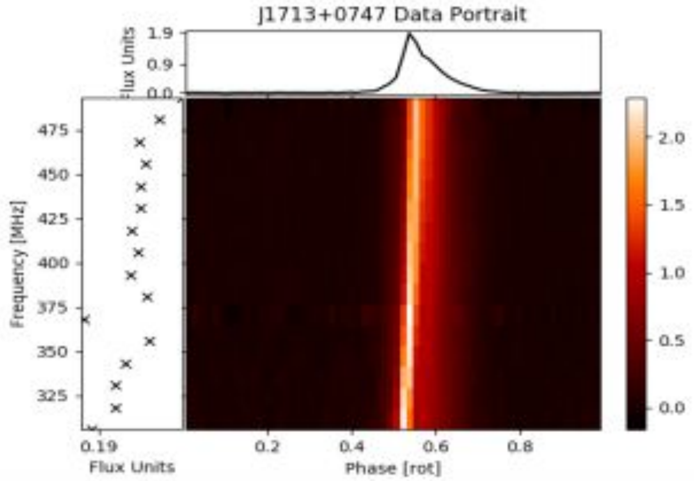
$$\chi^2(\phi, a) = \sum_k \frac{|d_k - a\, t_k e^{-2\pi k \phi}|^2}{\sigma_k^2}$$

Introduction - Wideband

Averaging of the data for each pulsar is performed, while maintaining frequency resolution to arrive at a high S/N mean "portrait" (a collection of aligned mean pulse profiles across a contiguous frequency band). (ppalign)[1] [2]

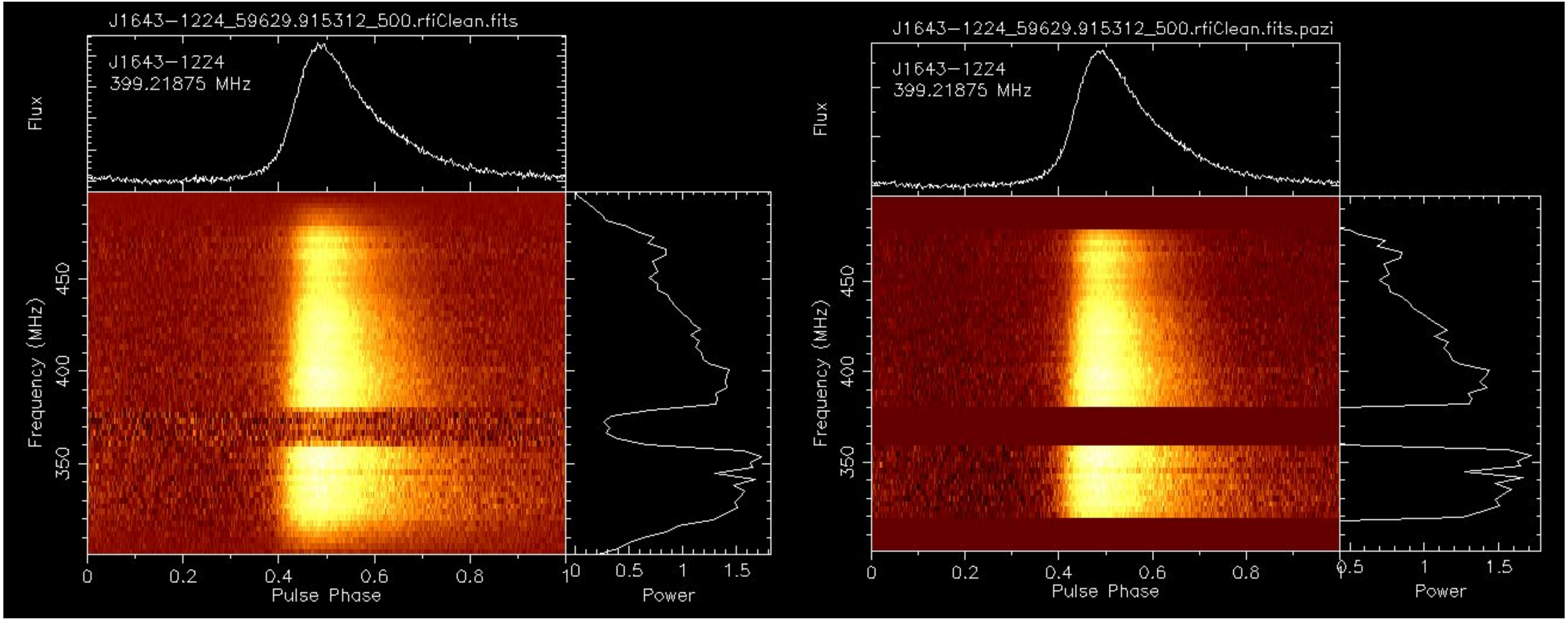
A principal component analysis is performed on the average portrait.

The most significant eigenvectors and the mean profile are smoothed to become noise-free basis functions ("eigenprofiles"). (ppspline)



$$\chi^2 = \sum_{n,k} \frac{|d_{nk} - a_n t_{nk} e^{-2\pi i k \phi_n}|^2}{\sigma_n^2}.$$

Removing RFI channels



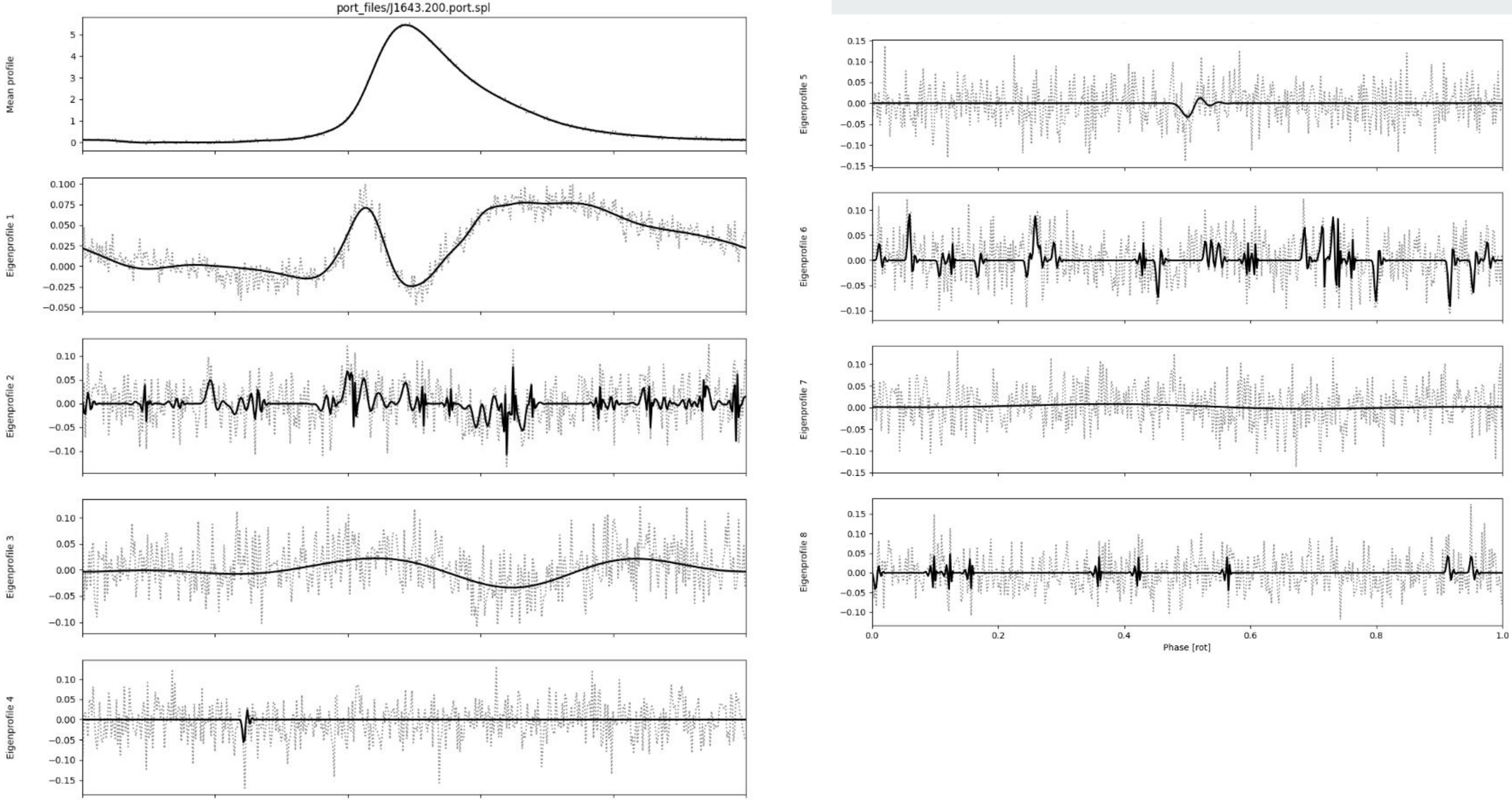
ppallign

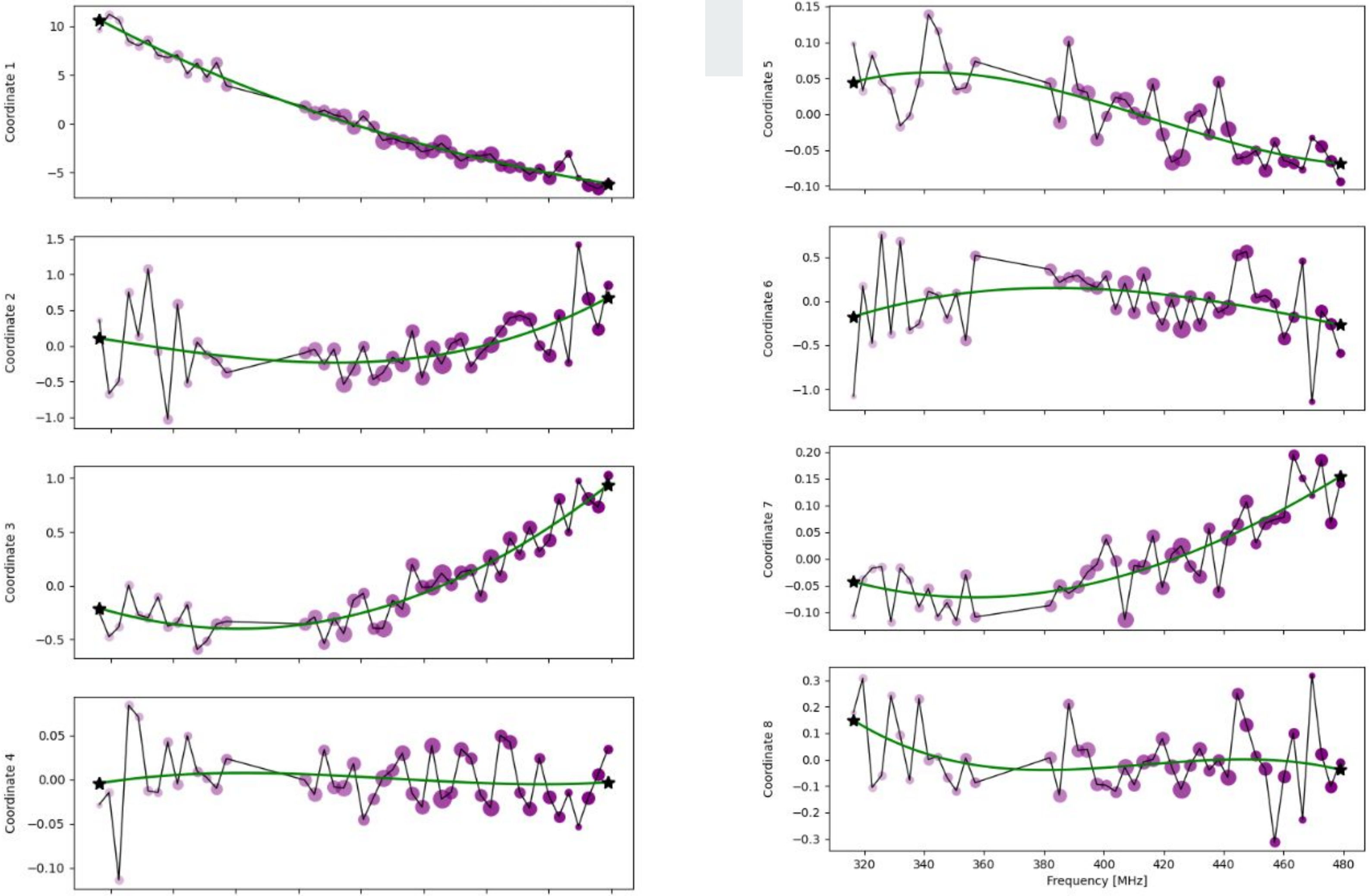
- Aligns multiple data files and add them to create a “portrait”
- In InPTA with uGMRT we are only using single data file to create portrait
- It is stored as port file (.port)

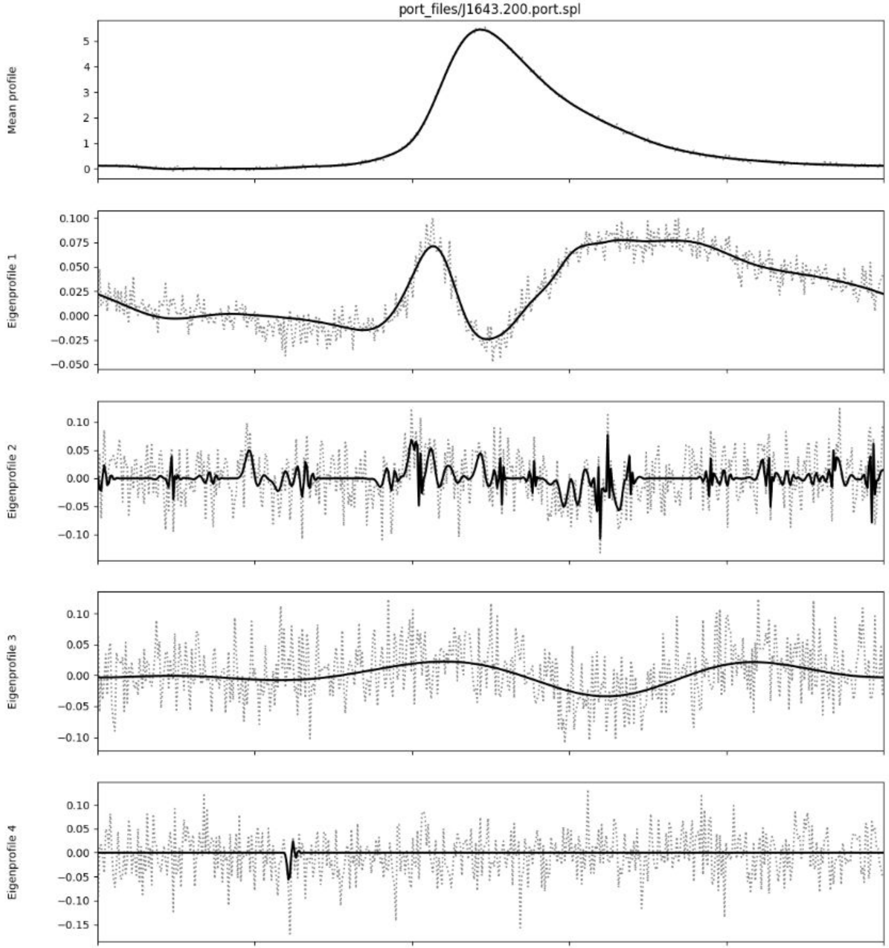
ppspline

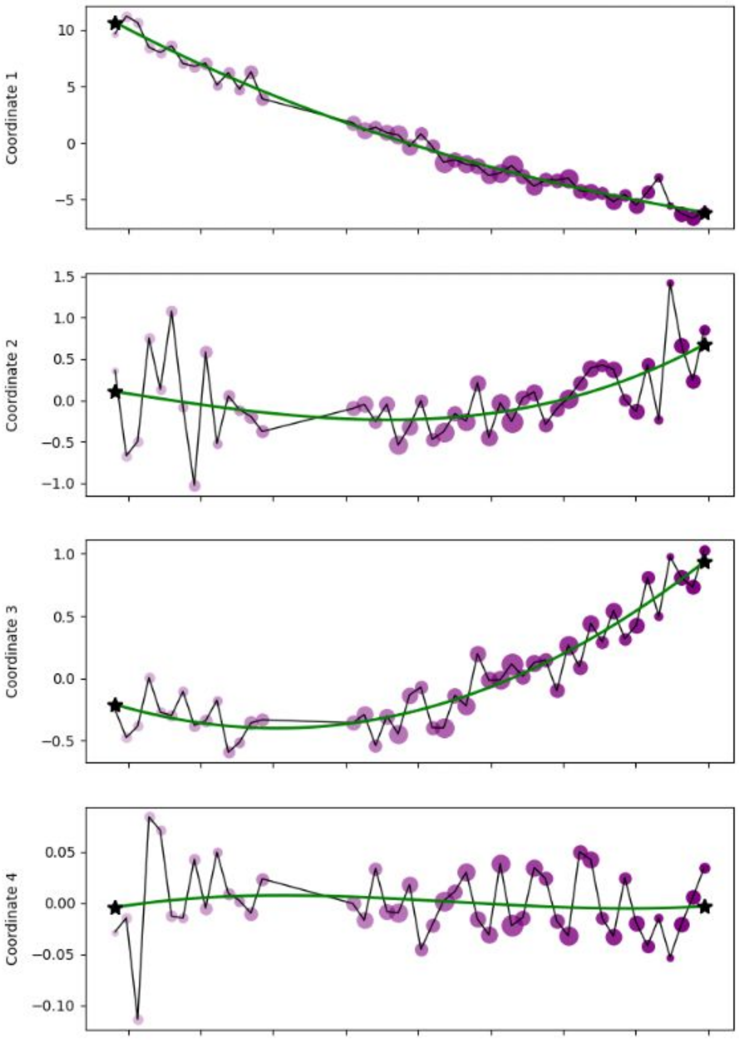
- ppspline performs PCA on our portrait
- It decomposes our data into eigenvectors or eigen profiles
- It produces and analytical template

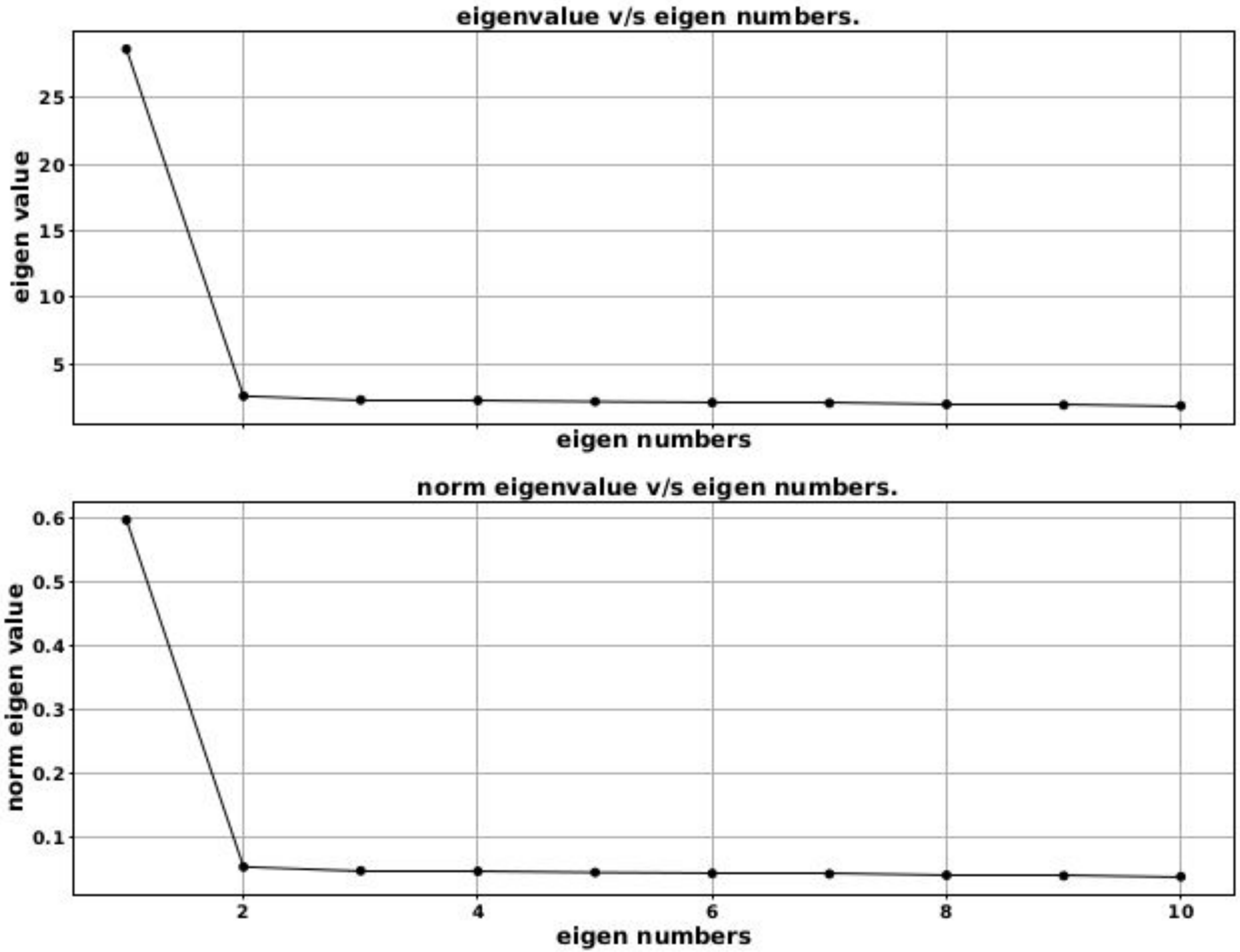
$$T(\nu) = \sum_{i=1}^{n_{\rm eig}} B_i(\nu)\, \hat{e}_i \; + \; \widetilde{p}.$$

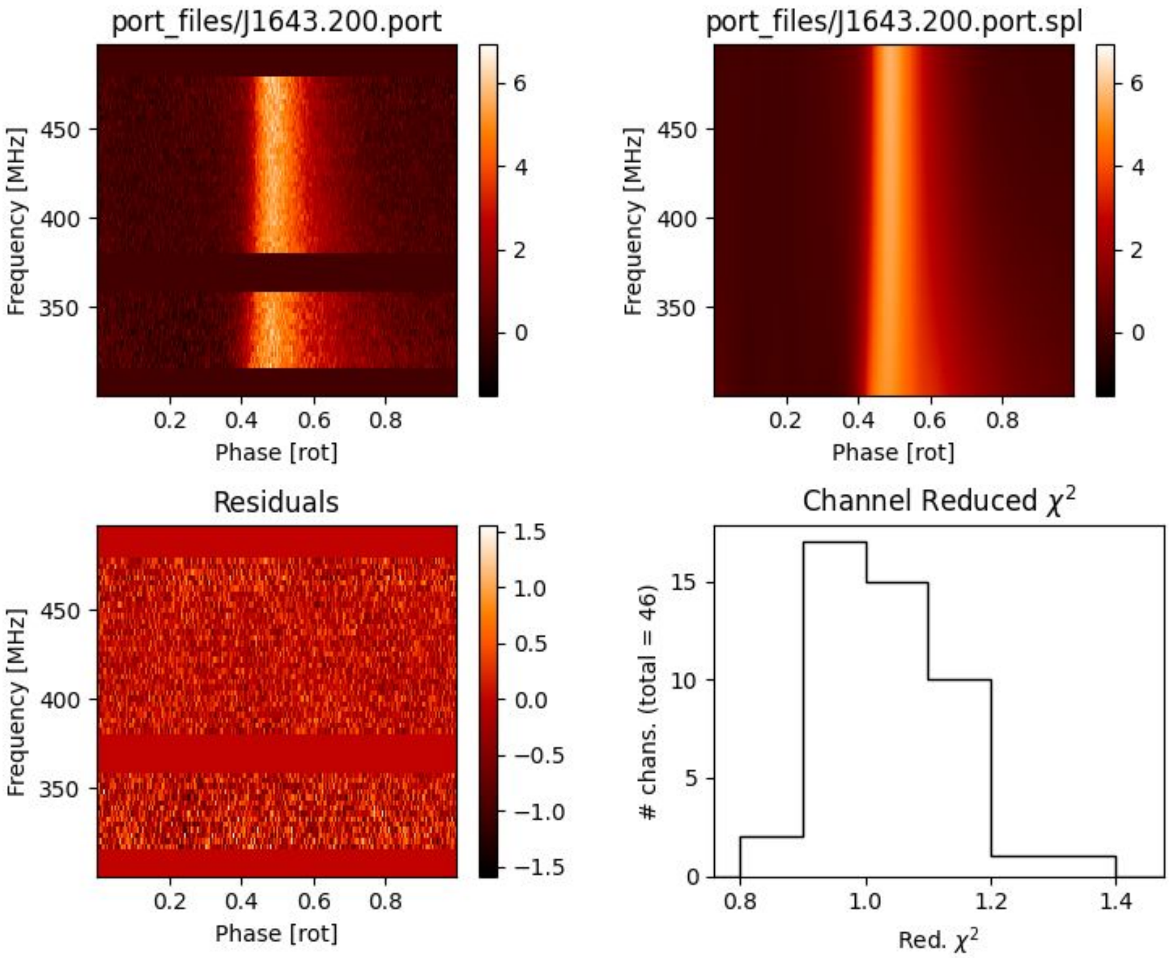

port_files/J1643.200.port.spl
Mean profile
Eigenprofile 1
Eigenprofile 2
Eigenprofile 3
Eigenprofile 4
Eigenprofile 5
Eigenprofile 6
Eigenprofile 7
Eigenprofile 8
Phase [rot]


Coordinate 1
Coordinate 2
Coordinate 3
Coordinate 4
Coordinate 5
Coordinate 6
Coordinate 7
Coordinate 8
Frequency [MHz]


port_files/J1643.200.port.spl
Mean profile
Eigenprofile 1
Eigenprofile 2
Eigenprofile 3
Eigenprofile 4


Coordinate 1
Coordinate 2
Coordinate 3
Coordinate 4


eigenvalue v/s eigen numbers.
eigen value
25
20
15
10
5
eigen numbers
norm eigenvalue v/s eigen numbers.
norm eigen value
0.6
0.5
0.4
0.3
0.2
0.1
2
4
6
8
10
eigen numbers



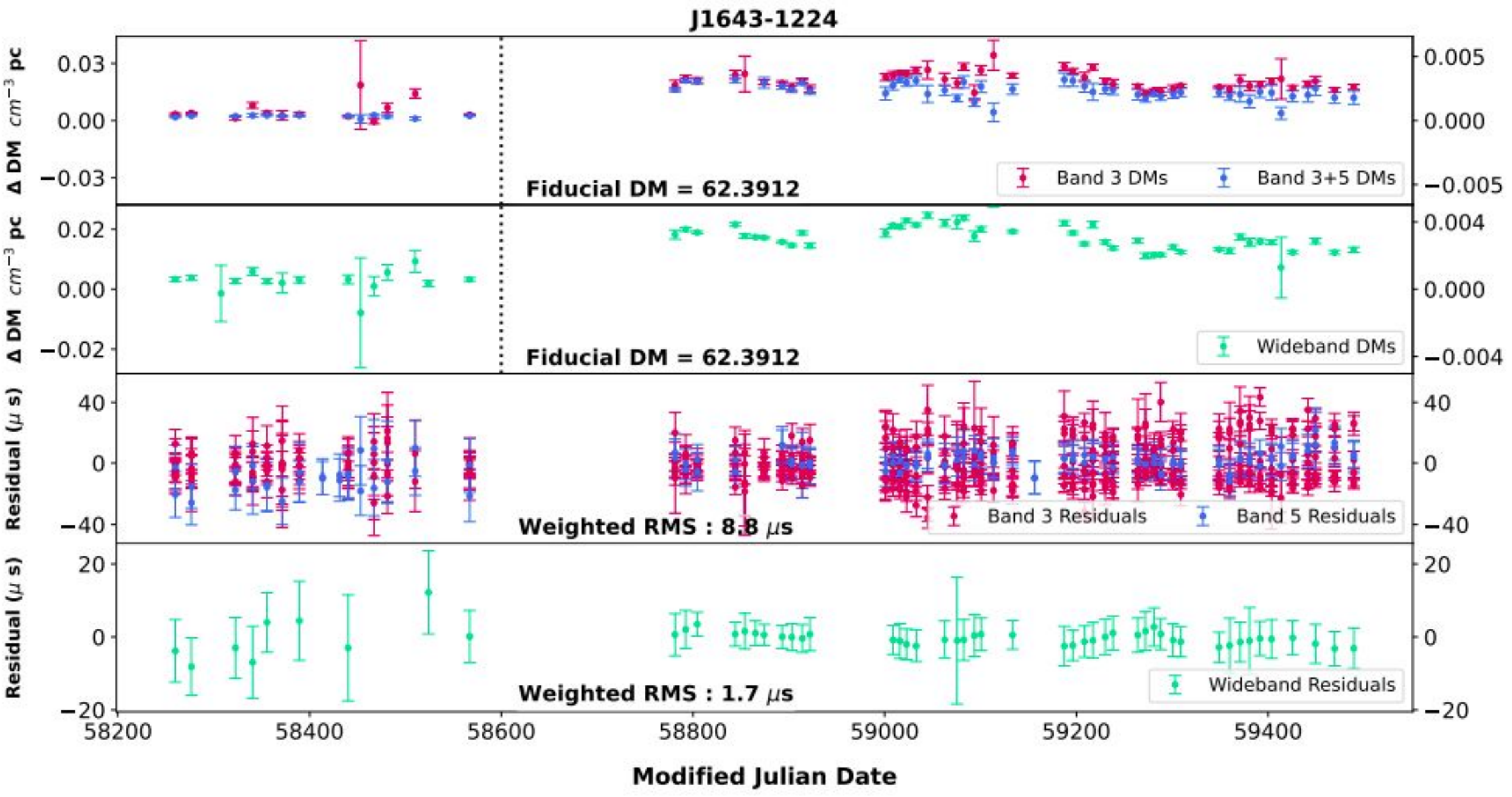
port_files/J1643.200.port
port_files/J1643.200.port.spl
Residuals
Channel Reduced χ^2
Frequency [MHz]
Phase [rot]
chans. (total = 46)
Red. χ^2

pptoas

- Pptoas cross correlate the analytic template with data in fourier domain
- It does global fit for dm and TOA i.e. only one TOA per epoch
- It creates a tim file which provides all the TOA and DM for each epoch

$$\chi^2(\phi_n, a_n) = \sum_{n,k} \frac{|d_{nk} - a_n p_{nk} e^{-2\pi i k \phi_n}|^2}{\sigma_n'^2}. \qquad \phi_n = \phi_{\mathrm{ref}}^{\circ} + \frac{K \times \mathrm{DM}}{P_s}\left(\nu_n^{-2} - \nu_{\mathrm{ref}}^{-2}\right),$$

```
J1643/data_200bw/J1643-1224_58781.324655_500.rfiClean.fits 428.09437203 58781.341990540106443   0.816  gmrt -pp_dm 62.3951239 -pp_dme 0.000267
2 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 2999.766 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 431.523 -gof 1.238
J1643/data_200bw/J1643-1224_58792.348162_500.rfiClean.fits 397.31820864 58792.365543652314069   0.720  gmrt -pp_dm 62.3946182 -pp_dme 0.000113
0 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3000.102 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 510.192 -gof 1.281
J1643/data_200bw/J1643-1224_58804.373146_500.rfiClean.fits 398.49711261 58804.392222071303465   0.458  gmrt -pp_dm 62.3945001 -pp_dme 0.000073
4 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3299.869 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 797.579 -gof 1.600
J1643/data_200bw/J1643-1224_58844.132989_500.rfiClean.fits 416.08135893 58844.152060024433903   0.457  gmrt -pp_dm 62.3952944 -pp_dme 0.000106
5 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3299.743 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 795.120 -gof 1.452
J1643/data_200bw/J1643-1224_58854.082932_500.rfiClean.fits 405.21036374 58854.102002187797505   0.699  gmrt -pp_dm 62.3943889 -pp_dme 0.000124
5 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 526.203 -gof 1.183
J1643/data_200bw/J1643-1224_58865.093237_500.rfiClean.fits 399.19541931 58865.112303067275387   0.449  gmrt -pp_dm 62.3942252 -pp_dme 0.000066
7 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 831.882 -gof 1.508
J1643/data_200bw/J1643-1224_58874.115917_500.rfiClean.fits 404.41422605 58874.134988242305923   0.403  gmrt -pp_dm 62.3941762 -pp_dme 0.000063
6 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 922.495 -gof 1.679
J1643/data_200bw/J1643-1224_58892.978470_500.rfiClean.fits 405.38369070 58892.997546148065198   0.432  gmrt -pp_dm 62.3940923 -pp_dme 0.000070
6 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3299.900 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 862.922 -gof 1.498
J1643/data_200bw/J1643-1224_58902.966306_500.rfiClean.fits 407.54657278 58902.985335611681608   0.505  gmrt -pp_dm 62.3939665 -pp_dme 0.000086
3 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 728.747 -gof 1.412
J1643/data_200bw/J1643-1224_58914.070684_500.rfiClean.fits 411.52190429 58914.089733709751200   0.530  gmrt -pp_dm 62.3947409 -pp_dme 0.000101
0 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 694.112 -gof 1.396
J1643/data_200bw/J1643-1224_58922.075766_500.rfiClean.fits 422.08171780 58922.094826193050086   0.602  gmrt -pp_dm 62.3939586 -pp_dme 0.000128
2 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3300.078 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 600.564 -gof 1.277
J1643/data_200bw/J1643-1224_59000.868037_500.rfiClean.fits 414.12801749 59000.886979284932955   1.263  gmrt -pp_dm 62.3944144 -pp_dme 0.000230
2 -be GWB -fe uGMRT_B3 -f uGMRT_B3_GWB -nbin 128 -nch 64 -nchx 64 -bw 196.875 -chbw 3.125 -subint 0 -tobs 3281.569 -fratio 1.653 -tmplt J1643/
port_files/J1643.spl -snr 285.097 -gof 1.173
```


J1643-1224
Δ DM cm^{-3} pc
Fiducial DM = 62.3912
Band 3 DMs
Band 3+5 DMs
Wideband DMs
Residual (μ s)
Weighted RMS : 8.8 μs
Band 3 Residuals
Band 5 Residuals
Weighted RMS : 1.7 μs
Wideband Residuals
Modified Julian Date

Summary

- **Wideband technique** (Pennucci et. al. 2014, Pennucci 2019, Nobleson et. al. 2022)

2D template creation: Frequency and phase

A high SNR epoch is used.

→

Principal component analysis (PCA) decomposition of 2D portrait.

Extract frequency information

→

Frequency dependent template

$$T(\nu) = \sum_{i=1}^{n_{eig}} B_i(\nu)\hat{e}_i + \tilde{p}$$

↓

Minimizing χ^2 where phase offset follows:

$$\phi_n(\nu_n) = \phi_0 + \frac{K \times DM}{P_s}(\nu_n^{-2} - \nu_{\phi 0}^{-2})$$

←

Obtain TOA (ϕ_0) and DM simultaneously

Thank You