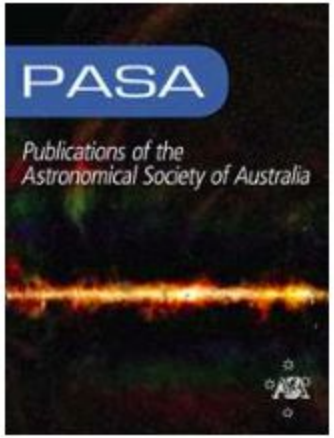
# PINTA:

## *The uGMRT **P**ipeline for **In**dian Pulsar **T**iming **A**rray*

**InPTA Student Week 2023: Phase I**

Debabrata Deb, IMSc

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# pinta: The uGMRT data processing pipeline for the Indian Pulsar Timing Array

Part of: Data Analysis Pipelines and Software

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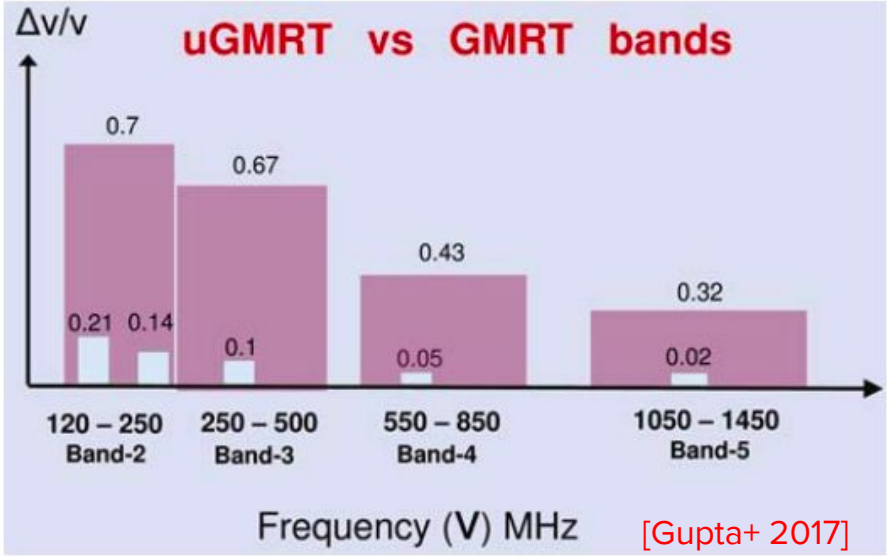
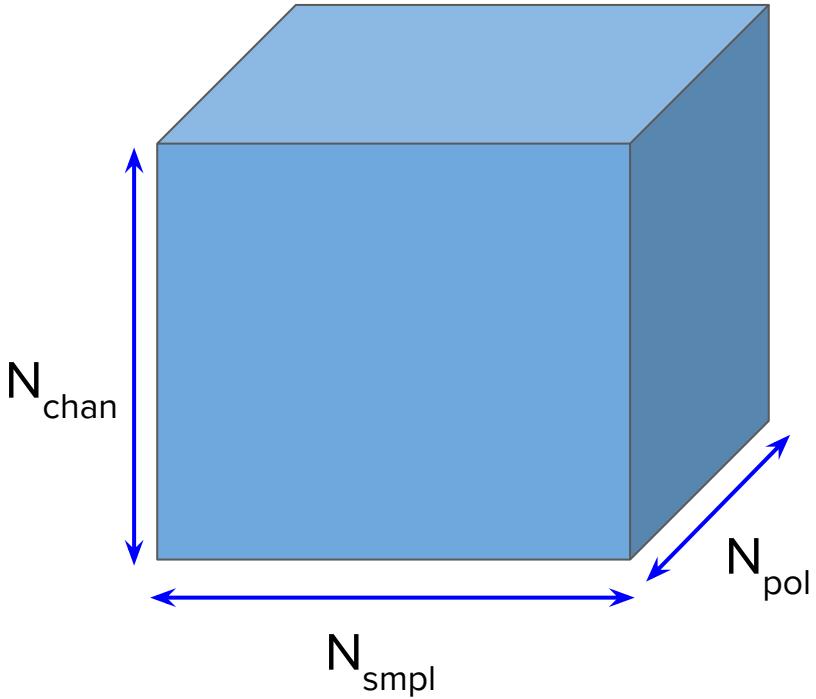
# The upgraded GMRT

- 30-element interferometer
- New wide-band feeds provide seamless frequency coverage between 150-1460 MHz
- 4 phased array beams – simultaneous multi-frequency observations. (IA/PA/CDPA)
- A new GPS-synchronized hydrogen maser for precision timing – 1-10 ns precision timing.



# uGMRT Pulsar Data Format




**Data Volume = $N_{chan}$ * $N_{smpl}$ * $N_{pol}$ * 2 bytes**

- The binary raw data file stores **Npol** polarization products in **Nchan** channels for every time sample as **16-bit integers**.
  - Npol = 1 : Total intensity
  - Npol = 4 : Stokes I,Q,U,V
- The timestamp at the start of observation is stored as an ASCII file.

```
#Start time and date
IST Time: 19:59:57.633098240
Date: 25:08:2018
#Start ACQ SEQ NO = 17
```

# `pinta` Overview

- pinta is a python script which calls various pulsar data processing codes to reduce the GMRT pulsar raw data to a folded Timer archive.
  - Timer format is compatible with packages used for downstream processing.
- Performs RFI mitigation using two different packages.
  - **`RFIClean`**
  - **`gptool`**
- Metadata required for processing is provided as an ASCII input file.

**https://github.com/inpta/pinta**

# Summary

- Inputs
  - uGMRT raw data (.dat)
  - Timestamp (.timestamp)
  - Pulsar ephemeris (.par)
  - Config file (pipeline.in)
- Output
  - Folded profile
    - With RFIClean
    - With gptool
    - Without RFI removal

# Summary

- Inputs
  - **uGMRT raw data (.dat)**
  - Timestamp (.timestamp)
  - Pulsar ephemeris (.par)
  - Config file (pipeline.in)
- Output
  - Folded profile
    - With RFIClean
    - With gptool
    - Without RFI removal

A binary file that contains Npol*Nchan*Nsample values.

# Summary

- Inputs
  - uGMRT raw data (.dat)
  - **Timestamp (.timestamp)**
  - Pulsar ephemeris (.par)
  - Config file (pipeline.in)
- Output
  - Folded profile
    - With RFIClean
    - With gptool
    - Without RFI removal

ASCII file containing the timestamp of start of observation

```
#Start time and date
IST Time: 19:59:57.633098240
Date: 25:08:2018
#Start ACQ SEQ NO = 17
```

# Summary

- Inputs
  - uGMRT raw data (.dat)
  - Timestamp (.timestamp)
  - **Pulsar ephemeris (.par)**
  - Config file (pipeline.in)
- Output
  - Folded profile
    - With RFIClean
    - With gptool
    - Without RFI removal

Pulsar ephemeris in TEMPO2 format.

```
PSRJ            J1857+0943
ELONG           286.86348828                1.000e-08
ELAT            32.32148622                 2.000e-08
DM              13.3140                     2.500e-03
PEPOCH          55367.00000
F0              186.494081249931            3.000e-12
F1              -6.2046E-16                 3.000e-20
POSEPOCH        55367.00
DMEPOCH         56106
BINARY          ELL1
PB              12.32717119157              1.800e-10
A1              9.2307802                   3.000e-07
TASC            55360.513155155             1.900e-08
EPS1            -2.150E-5                   3.000e-08
EPS2            2.440E-6                    1.800e-08
CLK             TT(BIPM2015)
EPHEM           DE436
RM              22.2                        9.000e-01
PX              0.6                         2.000e-01
DM1             0.0017                      2.000e-04
PMELONG         -3.27                       1.000e-02
PMELAT          -5.06                       2.000e-02
STIG            0.966                       5.000e-03
H3              1.07E-6                     4.000e-08
UNITS           TDB
```

# Summary

- Inputs
  - uGMRT raw data (.dat)
  - Timestamp (.timestamp)
  - Pulsar ephemeris (.par)
  - **Config file (pipeline.in)**

```
#JName          RawData                                          Timestamp                                          Freq   Nbin   NChan   BW     TSmpl      SB   NPol TSubint  Cohded
J0437-4715  J0437-4715_bm3_pa_1460_200_8_18mar2023.raw  J0437-4715_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
J0751+1807  J0751+1807_bm3_pa_1460_200_8_18mar2023.raw  J0751+1807_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
J0613-0200  J0613-0200_bm3_pa_1460_200_8_18mar2023.raw  J0613-0200_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
J0740+6620  J0740+6620_bm3_pa_1460_200_8_18mar2023.raw  J0740+6620_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
J0900-3144  J0900-3144_bm3_pa_1460_200_8_18mar2023.raw  J0900-3144_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
J1022+1001  J1022+1001_bm3_pa_1460_200_8_18mar2023.raw  J1022+1001_bm3_pa_1460_200_8_18mar2023.raw.hdr  1460    -1    1024    200  0.00004096  LSB    1   10         0
```

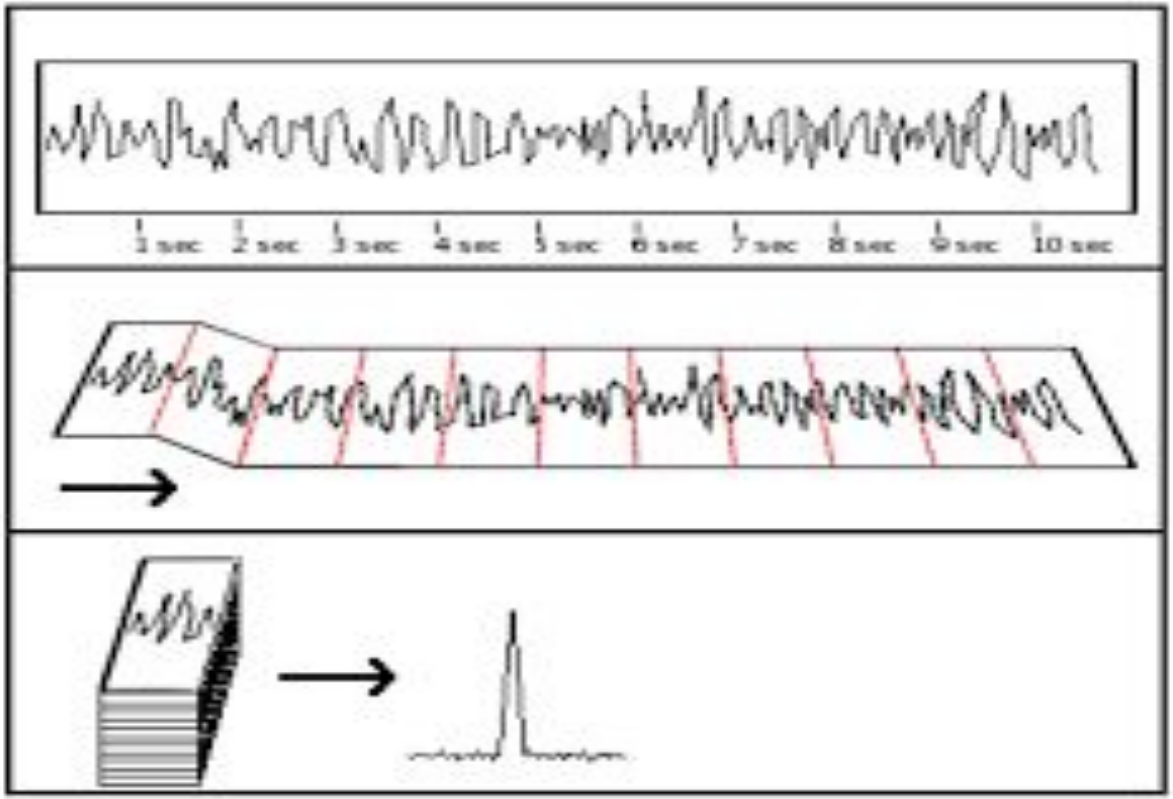
    - With gptool
    - Without RFI removal

# Summary

- Inputs
  - uGMRT raw data (.dat)
  - Timestamp (.timestamp)
  - Pulsar ephemeris (.par)
  - Config file (pipeline.in)
- Output
  - **Folded profile (.fits)**
    - With RFIClean
    - With gptool
    - Without RFI removal

- FITS files containing Nbin*Nsubint*Nchan*Npol entries.
- Can be manipulated using psrchive.

# Folding using dspsr




**Folding** - Add large number of pulses in phase to improve signal to noise ratio.

# What is RFI?

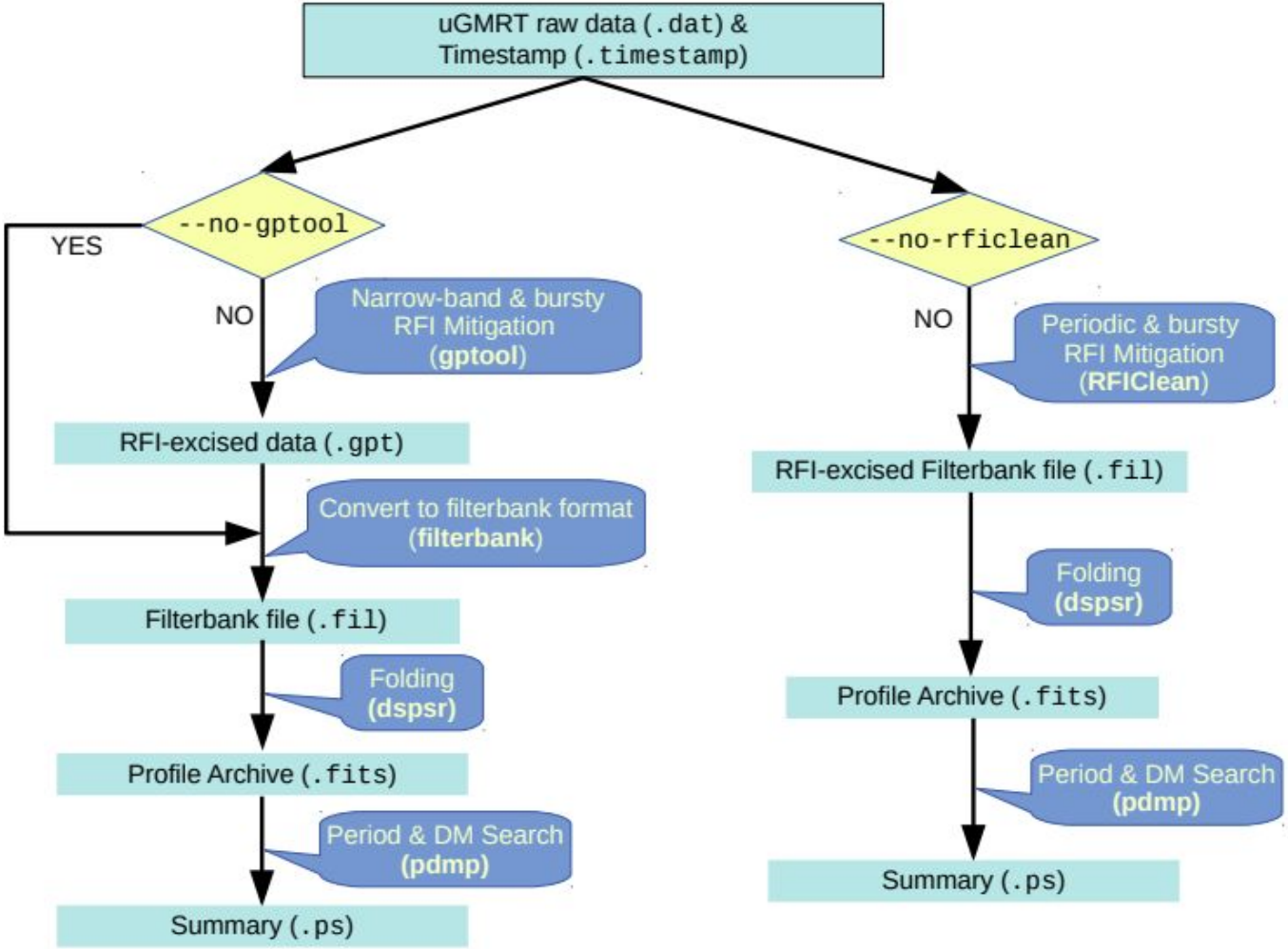
- Unwanted signals picked up by the telescope - mostly human-made
- Strong RFI completely swamps the astrophysical signal.
- Also presence of Weak RFI reduces S/N ratio.
- Broadly three categories of RFI seen at GMRT
  - Periodic RFI
    - Eg: 50 Hz Power lines
  - Spectral line RFI
    - Eg: Satellites, TV signals, mobile phone signals, ...
  - Bursty RFI
    - Eg: Opening your microwave oven before it is done cooking (*google* ***perytones at Parkes***), turning on your water pump, car spark plug, …

**gptool:**

- narrow-band spectral line RFI and broadband bursty time-domain RFI

**rfiClean:**

- periodic RFI in the Fourier domain,
- and then mitigates narrow-band spectral line RFI and broadband bursty time-domain RFI


uGMRT raw data (.dat) &
Timestamp (.timestamp)
--no-gptool
YES
NO
Narrow-band & bursty
RFI Mitigation
(gptool)
RFI-excised data (.gpt)
Convert to filterbank format
(filterbank)
Filterbank file (.fil)
Folding
(dspsr)
Profile Archive (.fits)
Period & DM Search
(pdmp)
Summary (.ps)
--no-rficlean
NO
Periodic & bursty
RFI Mitigation
(RFIClean)
RFI-excised Filterbank file (.fil)
Folding
(dspsr)
Profile Archive (.fits)
Period & DM Search
(pdmp)
Summary (.ps)

# Usage

```
$ pinta [--help] [--test] [--no-gptool] [--no-rficlean]
[--nodel] [--retain-aux] [--log-to-file] [--gptdir <...>]
[--pardir <...>] [--rficconf <...>] <input_dir> <working_dir>
```

- `gptdir` = Folder containing gptool configuration files
- `pardir` = Folder containing pulsar ephemeris files
- `input_dir` = Folder containing raw data and timestamp files.
- `working_dir` = Folder containing pipeline.in file. The output will be written to this location.

# pipeline.in

```
#JName     RawData                          Timestamp                          Freq  Nbin  NChan  BandWidth  TSmpl        SB   NPol  TSubint  Cohded
J1939+2134 J1939+2134.25032019.B3.cdp.dat   J1939+2134.25032019.B3.cdp.timestamp 500   128   1024   100        0.00008192   LSB  1     10.0     1
J1939+2134 J1939+2134.25032019.B4.pa.raw    J1939+2134.25032019.B4.pa.hdr       750   128   1024   100        0.00008192   LSB  1     10.0     0
J1939+2134 J1939+2134.25032019.B5.cdp.dat   J1939+2134.25032019.B5.cdp.timestamp 1460  128   1024   100        0.00008192   LSB  1     10.0     1
```

| Column | Parameter | Description | Data Type | Unit |
|---|---|---|---|---|
| 1 | JName | The name of the pulsar in J2000 epoch. | String | |
| 2 | RawDataFile | Raw data file name. Only the file name is required and not the full path. | String | |
| 3 | TimestampFile | Timestamp file name. Only the file name is required and not the full path. | String | |
| 4 | Frequency ($F_{\rm LO}$) | Local oscillator frequency of the observing band. | Float | MHz |
| 5 | NBins ($N_{\rm bin}$) | Number of phase bins for the folded profile. | Integer | |
| 6 | NChans ($N_{\rm chan}$) | Number of frequency channels. | Integer | |
| 7 | BandWidth ($\Delta F$) | Bandwidth of the observing band. | Float | MHz |
| 8 | TSample ($T_{\rm smpl}$) | The sampling time used for observation. | Float | s |
| 9 | SideBand | The side-band. This should be either LSB (lower side-band) or USB (upper side-band). | String | |
| 10 | NPol ($N_{\rm pol}$) | Number of polarizations (1:=(I), 4:=(I,Q,U,V)) | Integer | |
| 11 | TSubInt ($T_{\rm subint}$) | The duration of individual sub-integrations within which the data will be folded over the pulsar period. | Float | s |
| 12 | Cohded | Whether the data has been coherently dedispersed (De & Gupta, 2016). 1 represents Yes and 0 represents No. | Boolean | |

# Creating pipeline.in

1. File name tells us
    a. The pulsar name
    b. GWB mode : ia/pa/cdp
        Cohded = 1 for cdp
        Cohded = 0 for pa / ia
    c. Observation date

```
-rw-rw-r--. 1 visitor1 svisitor  49G Dec  8 16:00 J2124-3358_300_200_bm2_08Dec2023.raw0
-rw-rw-r--. 1 visitor1 svisitor 1.2K Dec  8 15:42 J2124-3358_300_200_bm2_08Dec2023.raw0.ahdr
-rw-r--r--. 1 visitor1 svisitor  96K Dec  8 15:42 J2124-3358_300_200_bm2_08Dec2023.raw0.bhdr
-rw-rw-r--. 1 visitor1 svisitor   90 Dec  8 15:42 J2124-3358_300_200_bm2_08Dec2023.raw0.hdr
```

# Creating pipeline.in

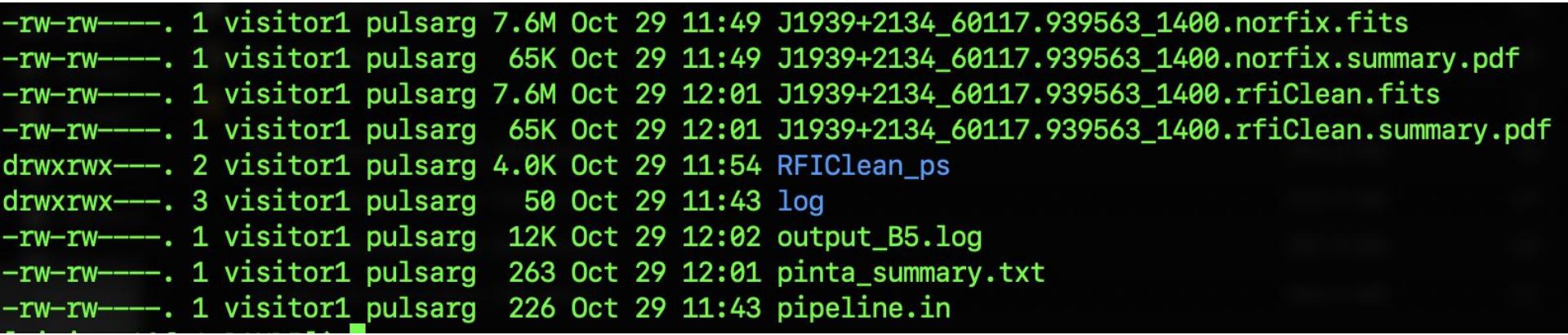
- The observation settings we need are Frequency, Bandwidth, NChan, SideBand, NPol, TSmpl, and Cohded.
- Frequency & Cohded can be found from the file name
- Find the setup file and command file for Bandwidth, NChan, SideBand, NPol, TSmpl.
    - For CDP, TSmpl is not directly given in the setup file.

# Step-by-step

- Copy all the raw data and timestamp files to a directory (This will be the `input_dir`).
  - Make sure that you have read permission to all input files.
- Create your working directory
  - Make sure that this directory has write permissions and has sufficient disk quota.
- Create pipeline.in file
  - Either from a template or from scratch using observation files.
- Run the pipeline.
  - This may take a long time.
  - Use of screen/nohup command is recommended.

# Step-by-step

- Copy all PINTA generated output files at Kaveri
  - Copy PINTA generated pdmp summary output files and fits files at the required directory in Kaveri within the respective pulsar directory BAND wise.
- Copy pipeline.in and pinta_summary.txt file at Kaveri
  - Rename pipeline.in and pinta_summary.txt file based on epoch, BAND and observation date and copy to the required directory at Kaveri



# Step-by-step

- Copy all PINTA generated output files at Kaveri
  - Copy PINTA generated pdmp summary output files and fits files at the required directory in Kaveri within the respective pulsar directory BAND wise.
- Copy pipeline.in and pinta_summary.txt file at Kaveri
  - Rename pipeline.in and pinta_summary.txt file based on epoch, BAND and observation date and copy to the required directory at Kaveri

```
-rwxrwx--- 1 prabu ugmrtpsr  843 Dec  5 00:31 pipeline.in.07Nov2023.60254.BAND3
-rwxrwx--- 1 prabu ugmrtpsr  921 Dec  5 00:21 pipeline.in.07Nov2023.60254.BAND5
```

  - Enter snr values achieved from gptool/norfix and rficlean to the SNR.log file based on the pulsars and BANDs

```
-rwxrwx--- 1 prabu ugmrtpsr 1.6K Dec  5 00:31 pinta_summary.txt.07Nov2023.60254.BAND3
-rwxrwx--- 1 prabu ugmrtpsr 1.6K Dec  5 00:21 pinta_summary.txt.07Nov2023.60254.BAND5
```

  - Rename setup file and observation log based on epoch and observation date and copy to the required directory at Kaveri

# Step-by-step

```
#============J0613-0200/BAND3/CYCL45=========================

#MJD            gptool          norfix          rfiClean

#============================================================
60267.982743      -             342.88            870.50
60274.820178      -              23.82             85.72
60244.951594     --              16.08            53.30
60285.815473     --              52.76            233.55
```

- Enter data to SNR.log files present at Kaveri
  - Enter snr values achieved from gptool/norfix and rficlean to the SNR.log file based on the pulsars and BANDs
- Copy setup file and observation log at Kaveri
  - Rename setup file and observation log based on epoch and observation date and copy to the required directory at Kaveri

# Step-by-step

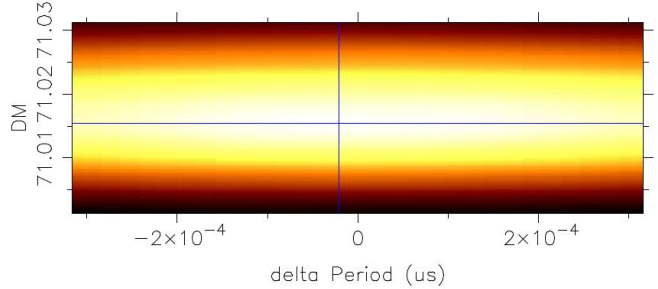
- Copy all PINTA generated output files at Kaveri
  - Copy PINTA generated pdmp summary output files and fits files at the required directory in Kaveri within the respective pulsar directory BAND wise.
- Copy pipeline.in and pinta_summary.txt file at Kaveri
  - Rename pipeline.in and pinta_summary.txt file based on epoch, BAND and observation date and copy to the required directory at Kaveri

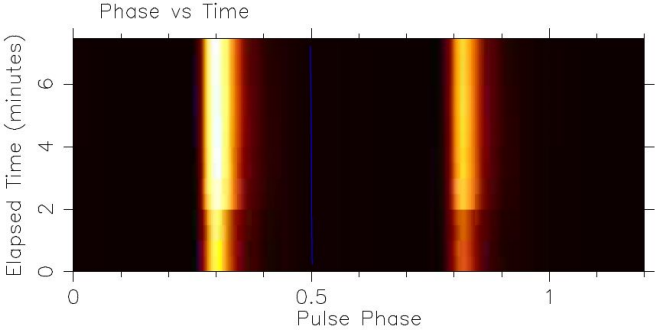
```
-rwxrwx--- 1 aman.srivastava ugmrtpsr 4.8K Nov  8 10:07 45_006_31Oct2023.obslog.txt
-rwxrwx--- 1 aman.srivastava ugmrtpsr 9.2K Nov  8 10:09 gtac_45_006_31Oct2023_1400.txt
-rwxrwx--- 1 ptarafdar       ugmrtpsr 7.0K Nov 11 18:55 45_006_11Nov2023.obslog.txt
-rwxrwx--- 1 ptarafdar       ugmrtpsr 7.9K Nov 11 18:56 gtac_45_006_11Nov2023_1000.txt
```

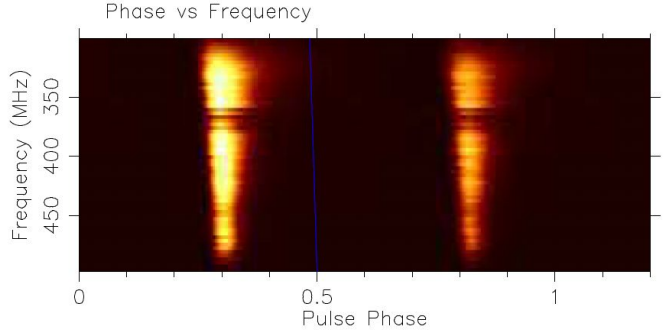
- Copy setup file and observation log at Kaveri
  - Rename setup file and observation log based on epoch and observation date and copy to the required directory at Kaveri

J1939+2134: ./J1939+2134_60259.515851_500.rfiClean.fits

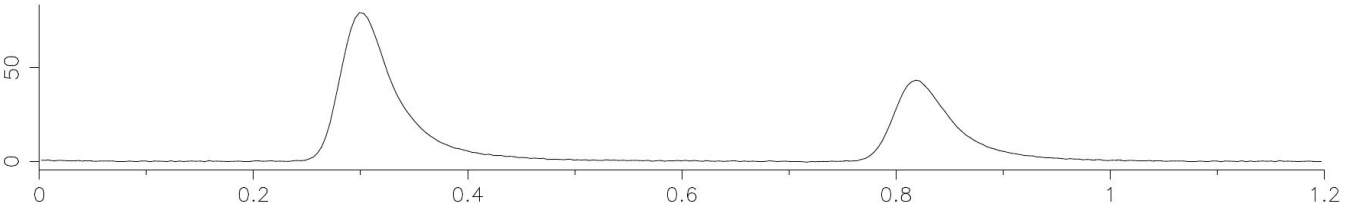
BC P(ms)= 1.557806583 TC P(ms)= 1.557917538 DM= 71.016 RAJ= 19:39:38.56 DecJ= 21:34:59.1
BC MJD = 60259.517962 Centre freq(MHz) = 399.219 Bandwidth(MHz) = −200 l = 57.509 b = −0.290
NBin = 256 NChan = 64 NSub = 15 TBin(ms) = 0.006 TSub(s) = 30.000 TSpan(s) = 446.775
P(us): offset = 0.00000, step = 0.00002, range = 0.00032 DM: offset = 0.000, step = 0.000, range = 0.015



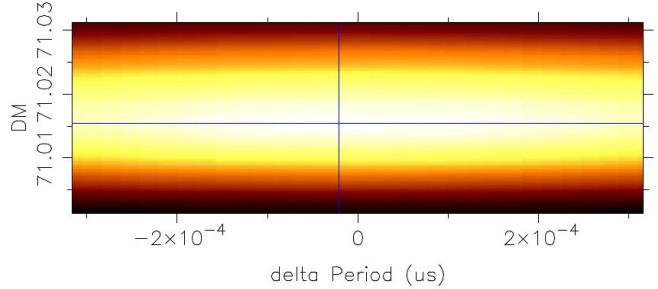



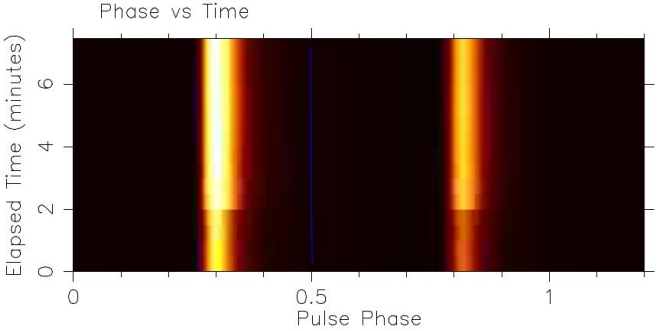

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BC prd (ms): | 1.557806562 | TC prd (ms): | 1.557917516 | DM: | 71.016 | BC freq (Hz): | 641.928224356 |
| Corrn (ms): | −0.000000021 | Corrn (ms): | −0.000000021 | Corrn: | −0.001 | Freq err. (Hz): | 0.000015024 |
| Error (ms): | 0.000000036 | Error (ms): | 0.000000036 | Error: | 0.000 | Width (ms): | 0.116 |
| | | | | | | Best S/N: | 528.68 |

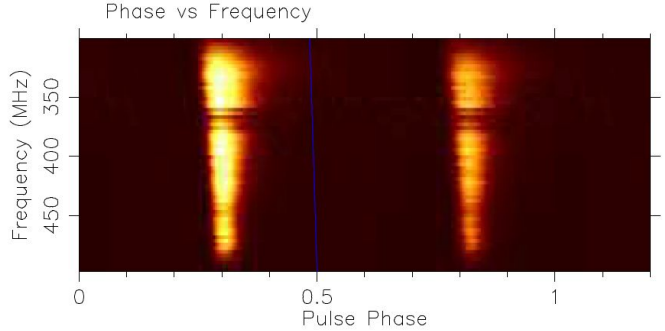


J1939+2134: ./J1939+2134_60259.515851_500.norfix.fits

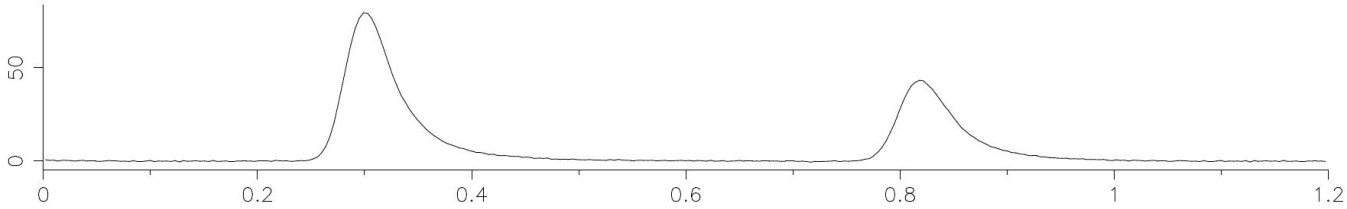
BC P(ms)= 1.557806583 TC P(ms)= 1.557917538 DM= 71.016 RAJ= 19:39:38.56 DecJ= 21:34:59.1
BC MJD = 60259.517962 Centre freq(MHz) = 399.219 Bandwidth(MHz) = −200 l = 57.509 b = −0.290
NBin = 256 NChan = 64 NSub = 15 TBin(ms) = 0.006 TSub(s) = 30.000 TSpan(s) = 446.775
P(us): offset = 0.00000, step = 0.00002, range = 0.00032 DM: offset = 0.000, step = 0.000, range = 0.015




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BC prd (ms): | 1.557806562 | TC prd (ms): | 1.557917516 | DM: | 71.016 | BC freq (Hz): | 641.928224356 |
| Corrn (ms): | −0.000000021 | Corrn (ms): | −0.000000021 | Corrn: | −0.001 | Freq err. (Hz): | 0.000015024 |
| Error (ms): | 0.000000036 | Error (ms): | 0.000000036 | Error: | 0.000 | Width (ms): | 0.116 |
| | | | | | | Best S/N: | 514.54 |



```
[visitor1@fs4 BAND5]$ psredit J1939+2134_60117.939563_1400.rfiClean.fits
file            Name of the file                        J1939+2134_60117.939563_1400.rfiClean.fits
nbin            Number of pulse phase bins              32
nchan           Number of frequency channels            1024
npol            Number of polarizations                 1
nsubint         Number of sub-integrations              91
type            Observation type                        Pulsar
site            Telescope name                          GMRT
name            Source name                             J1939+2134
coord           Source coordinates                      19:39:38.561+21:34:59.12
freq            Centre frequency (MHz)                  1300.09765625
bw              Bandwidth (MHz)                         -200
dm              Dispersion measure (pc/cm^3)            71.0195007324219
rm              Rotation measure (rad/m^2)              0
dmc             Dispersion corrected                    0
rmc             Faraday Rotation corrected              0
polc            Polarization calibrated                 0
scale           Data units                              FluxDensity
state           Data state                              Intensity
length          Observation duration (s)                901.776261120001
int*:@          int:help for attribute list
ext:obs_mode    Observation Mode                        PSR
ext:obsfreq     Centre frequency                        1300.09765625
ext:obsbw       Bandwidth                               -200
ext:obsnchan    Number of channels                      1024
ext:hdrver      Header Version                          6.2
ext:date        File Creation Date                      2023-10-29T06:31:52
ext:coord_md    Coordinate mode                         J2000
ext:equinox     Coordinate equinox                      2000
ext:trk_mode    Tracking mode                           UNSET
ext:bpa         Beam position angle                     0
ext:bmaj        Beam major axis                         0
ext:bmin        Beam minor axis                         0
ext:stt_date    Start UT date                           UNSETTUNSE
ext:stt_time    Start UT
ext:stt_imjd    Start MJD                               60117
ext:stt_smjd    Start second                            81179
ext:stt_offs    Start fractional second                 0.111732318226132
```

| | | |
|---|---|---|
| ext:stt_lst | Start LST | 0 |
| ext:stt_crd1 | Start coord 1 | 00:00:00.000 |
| ext:stt_crd2 | Start coord 2 | +00:00:00.000 |
| ext:stp_crd1 | Stop coord 1 | UNSET |
| ext:stp_crd2 | Stop coord 2 | UNSET |
| ext:ra | Right ascension | 19:39:38.561 |
| ext:dec | Declination | +21:34:59.121 |
| obs:observer | Observer name(s) | |
| obs:projid | Project name | |
| rcvr:name | Receiver name | uGMRT_B5 |
| rcvr:basis | Basis of receptors | lin |
| rcvr:hand | Hand of receptor basis | +1 |
| rcvr:sa | Symmetry angle of receptor basis | 45deg |
| rcvr:rph | Reference source phase | 0deg |
| rcvr:fdc | Receptor basis corrected | 0 |
| rcvr:prc | Receptor projection corrected | 0 |
| rcvr:ta | Tracking angle of feed | 0deg |
| be:name | Name of the backend instrument | GWB |
| be:phase | Phase convention of backend | +1 |
| be:dcc | Downconversion conjugation corrected | 0 |
| be:phc | Phase convention corrected | 0 |
| be:delay | Backend propn delay from digi. input. | -0 |
| be:config | Configuration filename | 1400\|200\|1024\|LSB\|40.96\|0 |
| be:nrcvr | Number of receiver channels | 0 |
| be:tcycle | Correlator cycle time | 0 |
| hist:nrow | Number of rows in history | 2 |
| hist:nbin_prd | Nr of bins per period | 32 |
| hist:tbin | Time per bin or sample | 4.8679660057411e-05 |
| hist:chan_bw | Channel bandwidth | -0.1953125 |
| hist:cal_file | Calibrator filename | NONE |
| aux:dm_model | Auxiliary dispersion model | NONE |
| aux:dmc | Auxiliary dispersion corrected | 0 |
| aux:rm_model | Auxiliary birefringence model | NONE |
| aux:rmc | Auxiliary birefringence corrected | 0 |
| sub:int_type | Time axis (TIME, BINPHSPERI, BINLNGASC, etc) | TIME |
| sub:int_unit | Unit of time axis (SEC, PHS (0-1), DEG) | SEC |
| sub:tsamp | [s] Sample interval for SEARCH-mode data | 0 |
| sub:nbits | Nr of bits/datum (SEARCH mode 'X' data, else 1) | -1 |
| sub:nch_strt | Start channel/sub-band number (0 to NCHAN-1) | -1 |
| sub:nsblk | Samples/row (SEARCH mode, else 1) | -1 |
| sub:nrows | Nr of rows in subint table (search mode) | 91 |
| sub:zero_off | Zero offset for SEARCH-mode data | 0 |
| sub:signint | 1 for signed ints in SEARCH-mode data, else 0 | 0 |

# DATA REDUCTION USING AUTOMATED PINTA IN KAVERI

1. Login to kaveri using ssh
2. Type the following commands:

```
newgrp ugmrtpsr
umask                                                    0007
bash
```

3. Create two directories input directory and working directory.
4. Navigate to BAND3/BAND5 within your working directory and run the following command:

   For BAND3 data:

```
nohup /Data/debabrata/heilpinta/heilpinta_B3.sh 'input_dir' 'output_dir' 'Obs_date'
> output_B3.log
```

   For BAND5 data:

```
nohup /Data/debabrata/heilpinta/heilpinta_B5.sh 'input_dir' 'output_dir' 'Obs_date'
> output_B5.log
```

where

`input_dir` is the full path of the input directory,
`output_dir` is the full path of the output/working directory,
`Obs_date` is the date of the observation in the format: 01Jan2024

# DATA REDUCTION USING AUTOMATED PINTA IN FS4

1. Login to FS4 using ssh.
2. Type the following commands:

```
newgrp pulsarg
umask 0007
Bash
```

3. Create two directories input directory and working directory.
4. Navigate to BAND3/BAND5 within your working directory and run the following command:

   For BAND3 data:

```
nohup /Data/debabrata/heilpinta/heilpinta_B3.sh 'input_dir' 'output_dir' 'Obs_date'
'hostname' 'username'> output_B3.log
```

   For BAND5 data:

```
nohup /Data/debabrata/heilpinta/heilpinta_B5.sh 'input_dir' 'output_dir' 'Obs_date'
'hostname' 'username' > output_B5.log
```

where

`input_dir` is the full path of the input directory,
`output_dir` is the full path of the output/working directory,
`Obs_date` is the date of the observation in the format: 01Jan2024
`hostname` is the hostname of the Kaveri server. Usually, it's kaveri.ncra.tifr.res.in
`username` is the username of your Kaveri account

# Thank you !

InPTA Busy week Feb 2023 (IMSc Chennai)

InPTA Busy week July 2023 (TIFR Hydrabad)