



Rutger van Haasteren
rutger@vhaasteren.com



MetaPulsar



Wang-Wei Yu
wangwei.yu@aei.mpg.de

Quick Start

```
from metapulsar import (
    create_all_metapulsars,
    discover_layout,
    discover_files,
    combine_layouts)

# Load data of two PTAs (automatic pattern discovery and matching)
file_data = discover_files(combine_layouts(
    discover_layout('./ipta-dr2/EPTA_v2.2', name='EPTA dr2'),
    discover_layout('./ipta-dr2/NANOGrav_9y', name='NANOGrav 9y')
))

# Create all Enterprise pulsars
metapulsars = create_all_metapulsars(file_data,
                                     combination_strategy='consistent')

# B-name and J-name pulsars are matched by coordinates automatically
psr = metapulsars['B1855+09'] # Internally both PINT and libstempo

# Update parameter values and re-form residuals
# Same API as Vela.jl uses
psr.update_parameters({'PX': 0.01})
psr.form_residuals() # Calls PINT and libstempo

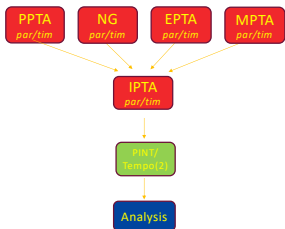
# Can use the regular Enterprise tools
psr.residuals, psr.toas, psr.freqs

# Model parameters look like:
psr.fitpars
# Output: ['RAJ', 'PB', 'FD1_NANOGrav 9y', 'JUMP1_EPTA dr2', ...]
```

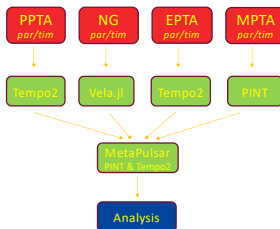
Overview

Data Combination:

create a new par/tim files for the data combination. Create a single Tempo2/PINT/Vela.jl instance.



MetaPulsar: keep data releases. Use separate Tempo2/PINT/Vela.jl instances, and only combine the astrophysical models

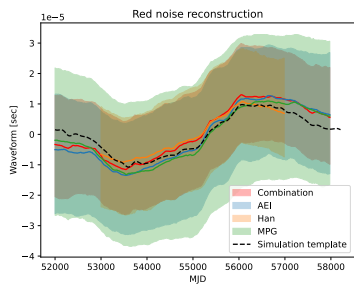


Results

Data quality check

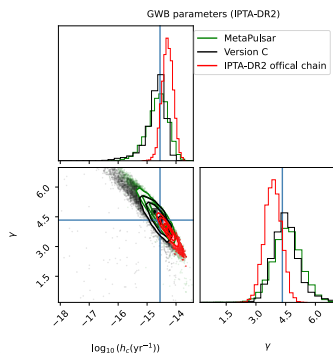
Compare waveforms between data of a pulsar from different PTAs using the FFT-Int model.

(Christostomi et al., 2025)



Compare with IPTA-DR2

Official IPTA-DR2 chain had extra data. Remove it (Version C) and compare with MetaPulsar
→ Exact Match in GWB analysis!



Manual combination



- Takes years of research time/work
- Duplicated work: data already published
- Static combination, cannot be modified
- Whole dataset in PINT or Tempo2
- Delays scientific output of IPTA

MetaPulsar



- Instantaneous
- Consistent astrophysical model
- Combining PINT and Tempo2
- Do *all* science of full combination

How?

Core principle:

The pulsar arrival times (TOAs) are the data. The timing residuals are just *latent model variables*. We (should) marginalize over all physical model parameters. Their exact value in the PAR file is not important.

Consistent timing model:

$$t_{\text{arr}} = \underbrace{t_{\text{em}} + \Delta_B + \Delta_{\text{DM}} + \Delta_{\odot} + \Delta_{\text{GW}} + \dots}_{\text{(astro)physical}} + \underbrace{\Delta_{\text{JUMP}} + \Delta_{\text{FD}} + \dots}_{\text{observatory dependent}}$$

Delays implemented in timing packages are deterministic, well-understood, and consistent up to nanosecond level between packages (Tempo, LALBarycenter, Tempo2, PINT, Vela.jl). Basic principle: identical parameters = identical delays.

PINT for parameter parsing:

MetaPulsar uses PINT to parse all timing models to make them consistent. Bookkeeping is done by PINT, underlying timing packages calculate delays.

What about fitting?

Yes, we can! Anything you can do with an ordinary pulsar, you can do with a MetaPulsar, even nonlinear timing model analysis. Interestingly: we get fully consistent results with the official IPTA-DR2 analysis without doing a single fit.

Going forward

Recommendation:

- No more official IPTA Data Releases after DR3
- Delegate data prep. (outliers, S/N cuts, etc.) to individual PTAs (pre-release)
- Delegate noise analysis to separate projects (post-release)

Workflow when new PTA dataset is released:

- MetaPulsar objects are created for full new data combination (same day)
- Run 'standard noise model', use PTA-released white noise parameters
- Basic data quality checks (e.g. waveform matching with FFT-Int)
- Maximum likelihood optimization and Bayesian inference (few days)
- Post results online/paper/living document

Note: Everything automated to prevent p-hacking! (At most delete PTA-pulsar)

Acknowledgements

We thank the following individuals and groups

David Wright for MetaPulsar development help

The **IPTA Data combination working group** for valuable discussions

Kalista Wayt, David Wright, Xavier Siemens, Jeff Hazboun (FrankenStat team) for collaboration

