Using metronomes & microphones to model a pulsar timing array
Pulsar Timing Array

pulsars are Nature’s most stable clocks

radio telescope (pulse detector)

pulsar (pulse emitter)

pulsar (pulse emitter)
gravitational waves cause pulses to arrive ahead or behind schedule, correlated across pulsars (pulse perturber)
Metronome Timing Array

microphone motion causes pulses to arrive ahead or behind schedule, correlated across metronomes (pulse perturber)

microphone (pulse detector)

metronome (pulse emitter)

metronome (pulse emitter)
Key quantities to calculate

- pulse period $T_p$
- pulse shape (profile)
- measured times of arrival (TOAs)
- expected TOAs
- residuals = measured − expected
- correlations between pairs of residuals
Some numbers to keep in mind

\[ v_{\text{sound}} = 340 \text{ m/s (in air)} \]

amplitude \( \approx 10 \text{ cm} \)

amplitude / \( v_{\text{sound}} = 3 \times 10^{-4} \text{ sec} \)

120 bpm: \( T_p = 0.5 \text{ sec} \)

200 bpm: \( T_p = 0.3 \text{ sec} \)
PTAdemo0GUI.py
m200a.txt
m120b.txt
Data folding to determine pulse period and pulse profile

- break data into chunks of duration $T$
- fold (stack) chunks, then add together
- get maximum sum when $T$ is the period of the signal (noise cancels, signal combines coherently)
Metronome pulse profiles

[Graphs of metronome pulse profiles for metronome 1 and metronome 2, showing time (sec) on the x-axis and profile on the y-axis.]
Estimating TOAs by correlating data with the pulse profile

![Graphs showing data, profile, and correlation with time and time shift axes.](image)
PTAdemo2GUI.py

m200a120b0.txt
Expected residuals for circular microphone motion

-1.0 \[ \rightarrow \] 0.0 \[ \rightarrow \] 1.0

residual (normalized)

time (sec)

-1.0 \[ \rightarrow \] 0.0 \[ \rightarrow \] 1.0

residual (normalized)

time (sec)
PTAdemo2GUI.py

m200a120b180.txt
m200a120b90.txt
m200a120b45.txt
m200a120b135.txt
Metronome timing array illustrates several techniques from pulsar timing

1. Estimate pulse period and pulse shape (profile) by folding data

2. Estimate pulse times of arrival (TOAs) by correlating data with pulse profile

3. Calculate timing residuals by subtracting expected TOAs (based on a model) from the measured TOAs

4. Improve estimate of pulse period by removing a linear trend from residuals

5. Timing residuals for a pair of pulsars are correlated as a function of their angular separation