Frequency-Resolved Template Timing for Precision Pulsar Timing Array Science

Project level: Honours

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Background

Pulsars are extremely dense, rapidly spinning remnants of dead stars that emit beams of radio waves like cosmic lighthouses. Because these pulses arrive at Earth with extraordinary regularity, pulsars act as some of the most precise natural clocks in the Universe. Astronomers use networks of such pulsars, called Pulsar Timing Arrays (PTAs), to search for ultra-low-frequency gravitational waves produced by merging supermassive black holes across the cosmos.

One of the biggest challenges in modern pulsar timing is that pulsar signals change shape across different radio frequencies. These subtle changes in pulse shape can affect how accurately we measure the arrival time of pulses. Most current timing methods attempt to correct these effects using empirical mathematical corrections called frequency-dependent (FD) parameters. However, these corrections are often not physically motivated and may accidentally absorb other important astrophysical signals.

In this project, we explore a different and more physically motivated approach using frequency-resolved templates and optimal frequency subbanding. Instead of correcting the timing data afterwards, this method attempts to directly model how the pulsar signal evolves across the observing band itself.

The project uses realistic simulated pulsar observations and forms part of ongoing efforts to develop next-generation pulsar timing techniques for future gravitational-wave astronomy.

Project statement

In this project, the student will investigate intrinsic pulse profile evolution in wideband pulsar observations using simulated pulsar datasets.

The student will:

- analyse frequency-resolved pulsar profiles across wide radio bands,
- generate and study frequency-resolved templates,
- investigate the effect of different numbers of frequency subbands on pulsar timing precision,
- compare timing performance with and without FD parameter fitting,
- and develop statistical methods to identify the optimal number of subbands for pulsar timing analysis.

The project will involve pulse profile analysis, signal processing, statistical analysis, and pulsar timing using modern radio astronomy software packages such as `PSRCHIVE`, `TEMPO2`, and Python-based analysis tools. The student will contribute to an active research problem in pulsar timing and gravitational-wave astronomy, with opportunities for participation in conference presentations and scientific publications depending on project progress.

Recommended skills and interests

The project is suitable for students interested in:

- radio astronomy,
- pulsars and neutron stars,
- gravitational-wave astronomy,
- signal processing,
- computational astrophysics,
- and scientific programming.

The analysis will primarily be performed using Python and Linux-based astronomy software tools. Prior experience in programming is helpful but not mandatory, as training will be provided during the project.

Students will gain experience in:

- pulsar timing techniques,
- radio astronomical data analysis,
- statistical signal analysis,
- scientific programming in Python,
- and modern computational research workflows used in astronomy.