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Overview of the Indian Pulsar Timing Array

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Abstract

The Indian Pulsar Timing Array (InPTA) is a self-sustaining experiment, leveraging and analyzing its own observational data from the upgraded Giant Metrewave Radio Telescope (uGMRT). This has helped the International Pulsar Timing Array (IPTA) consortium to inaugurate the nano-Hertz gravitational wave astronomy era through precise pulsar timing. In this paper, we provide a concise overview of the InPTA, detailing its objectives, observational strategies, recent results, and future plans.

1. Introduction

Millisecond pulsars (MSPs) are highly stable rotating neutron stars with a beamed radio frequency emission originating from a few hundreds of kilometers above its magnetic pole, co-rotating with the stellar surface. These beams arrive on earth as pulses with extreme time precision. However, there lies the vast space-time in between the MSP and the earth, and any changes to the space-time fabric due to gravitational waves can lead to a change in the expected arrival time of these pulses. A Pulsar Timing Array (PTA) experiment is a scientific initiative aimed at detecting and studying low-frequency (nano-Hertz) gravitational waves (GWs) by observing an ensemble of MSPs. These low frequency gravitational waves are either sourced from a stochastic gravitational wave background (SGWB) or from isolated supermassive black hole binaries.

Building on the overarching goals of PTA experiments, the InPTA [1] stands out as a significant contributor to this global effort. InPTA leverages the unique capability of the uGMRT to observe in multiple frequency bands simultaneously and analyze an array of millisecond pulsars with unprecedented precision through meticulous data analysis. InPTA aims to detect and study nano-Hertz GWs contributing valuable data to the IPTA community. Since becoming a full member of the IPTA in 2021, InPTA, in conjunction with the European Pulsar Timing Array (EPTA), announced evidence for a nano-Hertz gravitational wave background at 3 sigma significance in 2023 [2].

2. Observational strategy

In our initial data release (InPTA-DR1) [3] in 2023, we observed and analyzed 14 MSPs. For our second data release effort (DR2) we are presently studying 29 MSPs which includes pulsars observed in the early stages of InPTA and the ones included in DR1. Fig. 1 shows the distribution of pulsars monitored by InPTA. The sample of InPTA pulsars have been selected from a larger sample of more than 120 pulsars monitored by IPTA regularly. These pulsars are selected such that they have significant signal-to-noise ratio when observed with uGMRT and to improve sampling of the sky for detecting quadrupolar spatial correlation, in addition to having high drop-out factors reported in the IPTA GW analysis [4].

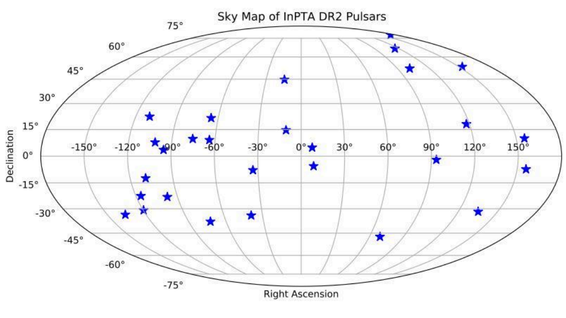

Figure 1. SkyMap of the 29 InPTA-DR2 pulsars

InPTA observations are done with a cadence of around 15-20 days using the uGMRT, at frequencies which range from 300 MHz to 1460 MHz simultaneously at two different frequency bands. The raw data from the telescope is reduced using pinta [5], a pipeline developed by InPTA.

3. Summary of recent results

InPTA distinguishes itself from the other Pulsar Timing Arrays with its unique and innovative observational techniques. Precise times of arrival (ToAs) and dispersion measures (DMs) are obtained using two different approaches : narrowband [6] and wideband [7] methods. InPTA has further improved the wideband method to incorporate data from simultaneous observations at different bands to measure single ToA and DM accurately [8]. The multiband simultaneous observations of InPTA also enabled us to study changes of pulse profile in PSR J1713+0747, one of the best timed MSPs in the PTA sample [9]. The timing precision of pulsars can be limited due to pulse jitter. InPTA has successfully characterized jitter noise amplitude in PSR J0437-4715, which is one of the brightest MSPs, and have studied their implications on DM estimates [10]. InPTA has devised a technique that uses low frequency observations to correct for pulsar scatter broadening and obtain DMs by reconstructing pulse profiles without scatter broadening in them [11]. InPTA-DR1 demonstrates the high timing precision achievable using InPTA observations and how careful selection of frequency sub-bands can account for any changes in the profile with frequency [3]. Further detailed noise analysis of the InPTA sample of pulsars shows the importance of low frequency data to characterize the interstellar medium (ISM) [12].

Recently, the InPTA data was combined with the EPTA dataset. It was seen that for some pulsars the addition of high sensitive low frequency data improved the noise modeling significantly, demonstrating the capabilities of InPTA [13]. Presently InPTA has been working towards InPTA-DR2 where high precision ToAs and DMs of a sample of 29 MSPs will be released. These will also include the timing solutions, advanced noise analysis and GWB search with our dataset. Various members of InPTA are also involved in the ongoing international efforts of IPTA-DR3.

4. Future directions

The future data release of IPTA (DR3) ought to increase the significance of the presence of a common GWB in the PTA datasets. InPTA will play a major role in these endeavors. As uGMRT is a pathfinder for the future Square Kilometre Array (SKA), InPTA’s observation strategies and analysis techniques are relevant for future observations with SKA [14]. The detection of nano-Hertz GWs opens a new window in gravitational wave astronomy, enabling us to probe the universe in a different way.

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