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In-field phasing for the GMRT and its application for time domain astronomy

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For time domain radio astronomical observations the signals from the individual antennas in an interferometric array are usually combined together to synthesize a single dish. To maximize the sensitivity towards a celestial source like pulsar, the antenna signals are added in phase (phased array). For a phased array with N identical antennas, the signal to noise ratio (SNR) improves by a factor of N with respect to single antenna. In a conventional phased array like the one used in the Giant Metrewave Radio Telescope (GMRT), the antenna based phases (ionospheric and instrumental) are derived from phase calibrator observations interleaved with the target scans. This approach of using external field at regular intervals for deriving antenna gains is not optimal, particularly for the longer baselines and introduces significant reduction in SNR (reducing the usable array size maximum up to 70% for time domain astronomy), along with adding observing overheads. In this talk we will present a new approach of using in-field phasing with the upgraded GMRT (uGMRT), where the antenna phases are determined in real-time using a model for the intensity distribution in the target field. This method is very useful for time domain astronomy e.g. timing studies of pulsar, studies of eclipsing binaries, studies of repeating fast radio bursts (FRBs) where in-field phased array allows uninterrupted long observation of target field with the full sensitivity. In contrast, conventional phasing would lead to periodic breaks in the target observation, and also the possibility of missing events of interest which occur during the break for phasing. In in-field phasing, the antennas are kept in phase throughout the observation for arbitrarily large duration by applying antenna based phase corrections derived from visibilities that are obtained in parallel with the phased array beam data, and which are flagged and calibrated in real-time using a model for the continuum emission in the target field. We have demonstrated for GMRT discovered millisecond pulsar (MSP) J1120-3618, the sensitivity is enhanced from using a full GMRT array with in-field phasing compared to < 70% of array phased using external calibrator, thereby improvising the precision of dispersion measure (DM) and scaled time-of-arrival (ToA) measurements (Figure 1). With full GMRT array, we achieved median DM precision of 2.97 x 10^{-4} pc/cc with in-field phasing observations which is about 3.6 times better than conventional phasing (using ~70% GMRT array), DM precision reported by Sharma et. al., 2022 [1] for J1120-3618. Corresponding median scaled ToA precision also has shown improvement by factor of 2.75 reaching to 2.59 micro-seconds from what is reported in Sharma et. al., 2022 [1]. With in-field phasing, we achieve and maintain around 74% of theoretical sensitivity as compared to 62% (in start and dropping down below 50% during active ionospheric conditions) with conventional phasing both using 90% of the GMRT array. This enhances the prospects of using newly discovered MSPs in pulsar timing array (PTA) experiments aiming to detection of the low frequency gravitational waves. Our findings from various observations and the possible applications of in-field phasing in the study of pulsars with the GMRT will also be discussed.

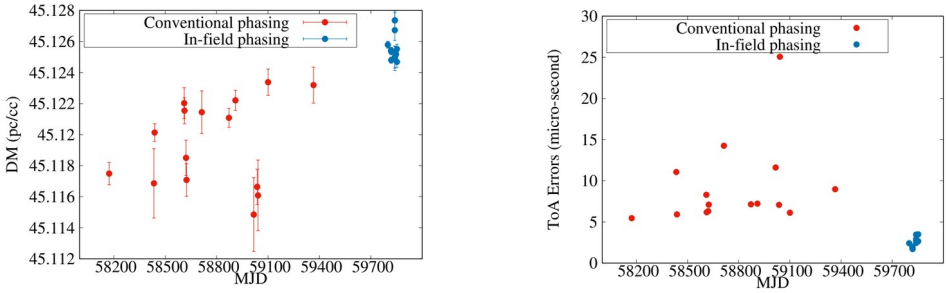

Figure 1. Comparison of the DM (left panel) and scaled ToA precision (right panel) achieved from in-field phasing observations (blue) for J1120-3618 with the previous measurements (Sharma et. al., 2022 [1]) obtained from conventional phasing (red).

References :

[1] Sharma et. al., "Wide-band Timing of GMRT- discovered Millisecond Pulsars", The Astrophysical Journal, 936:86 (17pp), 2022 September 1