

Research Article

GBD-DART-I: Pulsars and transient source observation between 130 and 350 MHz at Gauribidanur

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Abstract

Gauribidanur Diamond Array Radio Telescope (GBD-DART) is a new, low-frequency radio antenna array with 64 log-periodic dipole array (LPDA) and associated receivers, developed and deployed at the Gauribidanur observatory (13.604 N, 77.427 E). It studies bright pulsars and solar transients in the frequency range of 130–350 MHz. The LPDAs are arranged in a checkerboard pattern. The orthogonal polarisation feeds are formed using pairs of opposite LPDAs. A diamond-shaped (tilted square) array configuration was chosen for high sidelobe suppression in the East–West and North–South directions. The tile measures 5.9 by 5.9 m, with diagonals along North–South and East–West directions, each about 8.3 m. The tile operates as a phased array in transit-observing mode and has been successfully detecting strong pulsars and solar flares for eleven months. The current instantaneous observation bandwidth is 16 MHz, limited by the present digital backend. Array operations are streamlined for remote use. In addition to its scientific role, the system serves as a training platform for radio astronomy using a simple, low-cost telescope. This paper presents details of the array and antenna studies, brief descriptions of the front-end and backend instrumentation, and illustrative results from pulsar and solar flare observations. It also briefly discusses future upgrade plans, focusing on tile sensitivity and backend bandwidth, to extend observation capabilities.

Keywords: Astronomical instrumentation; methods and techniques; telescopes; pulsars; Sun

(Received 9 November 2025 UTC; revised 22 May 2026 UTC; accepted 18 June 2026 UTC)

1. Introduction

Our understanding of the universe has significantly expanded due to radio astronomy, which has changed our perspectives. There are several important benefits to low-frequency radio observation, which detects radio waves at longer wavelengths. Numerous celestial objects are coherent continuum sources, such as pulsars, which emit synchrotron radio with a steep spectrum that intensifies substantially at low frequencies. The desire to investigate the distant Universe using the highly redshifted 21 cm line of neutral hydrogen (HI) at the epoch of reionisation (Morales & Hewitt 2004; Benson et al. 2006), cosmic microwave background radiation (Penzias & Wilson 1965), the study of the dark halo with the galactic rotation curve (Sofue 2020), The Sun (Ramesh et al. 1998), neutron stars and pulsars (Hewish et al. 1969), an understanding of the interstellar medium propagation effect with fast radio bursts (Petroff et al. 2019), study enabled by plasma dispersion (Cordes et al. 2016), magnetic field strength with faraday rotation (Lyne & Smith 1989). Low-frequency radio observations of pulsar emissions and their timing measurements are crucial for understanding and characterising the effects of the interstellar medium (Backer & Hellings 1986; Tarafdar et al. 2022). In particular, these

observations enable the investigation of phenomena such as chromatic dispersion, scintillation, and pulsar emission spectra. As a result, the information gained helps determine the timing of pulsar signals more accurately, thereby supporting advanced investigations of gravitational wave detection (Singha et al. 2021; Srivastava et al. 2023; Bhat et al. 2018).

Several large and modern aperture array radio telescopes, such as the Low-Frequency Array (LOFAR) (Van Haarlem et al. 2013), the Long Wavelength Array (LWA) (Ellingson et al. 2009), the Murchison Widefield Array (MWA) (Tingay et al. 2013), the Canadian Hydrogen Intensity Mapping Experiment (CHIME) (Amiri et al. 2018), the Hydrogen Epoch of Reionisation Array (HERA) (DeBoer et al. 2017), and the upcoming Square Kilometre Array (SKA) (Dewdney et al. 2016), are designed to probe the low/mid radio frequency universe. The radio observatory at Gauribidanur facilitated pulsar observations at 34.5 MHz using a fat-dipole array (Sastry 1989; Deshpande & Radhakrishnan 1992; Maan 2015), and between 50 and 80 MHz using a log periodic dipole array (LPDA) (Bane et al. 2022).

The new LPDA antenna array presented in this paper is designed to observe pulsars and solar transients between 130 and 350 MHz from the Gauribidanur Observatory. It provides a cost-effective, simple radio telescope design for educational purposes, enabling more university students to gain hands-on experience in radio astronomy, particularly in pulsar and solar studies. This work is also focused on encouraging early-career students to pursue careers in radio astronomy instrumentation (Pandian B et al. 2022; Mhaske et al. 2022; Fung et al. 2023).

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Cite this article: Pandian B A, Bagchi J, Thiagaraj P, Rao KBR, Chandrashekar V, Abhishek R, Sathyamurthy A, Sandhya S, Bhatramakki S, S K and Sethi SK. (2026) GBD-DART-I: Pulsars and transient source observation between 130 and 350 MHz at Gauribidanur. *Publications of the Astronomical Society of Australia* 43, e095, 1–10. <https://doi.org/10.1017/pasa.2026.10231>

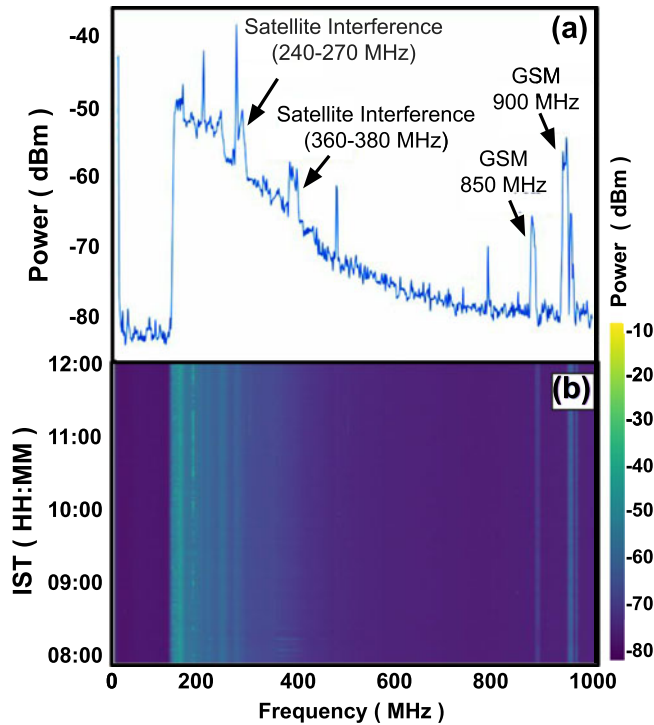


Figure 1. Typical of (a) radio spectrum and (b) spectrogram observed during the RFI measurements at the Gauribidanur observatory (recorded on 29 April 2022).

The use of an LPDA-based aperture array in the design achieved cost-effectiveness and broadband frequency coverage (Isbell 2003). To realise these advantages, significant investigation was necessary to find radio-frequency interference (RFI) free zones and to determine a suitable array configuration that would maximise the required array gain (Pandian B 2025). After completing these investigations, the functionality of the antenna, signal conditioning, and signal transport components was first verified in a two-element interferometer setup (Likhit *et al.* 2025). Subsequent to this verification, an array with 64 LPDAs, phased to observe transiting sources nominally for about an hour at the zenith, was subsequently commissioned at the observatory site. Currently, the instantaneous observing bandwidth is 16 MHz per polarisation, limited by the data recorder. Furthermore, the array observations can be remotely scheduled and monitored, and work is also in progress to implement a second tile to enhance observations.

2. Array design considerations

An important constraint for the array design comes from pulsar observations. Pulsars are point-like sources, and their signals are very weak. Hence, the array must have good sensitivity from 100 to 200 MHz, where pulsars are brightest and show interesting spectral features (Sieber 1973; Cai *et al.* 2025). Also, the array should be able to measure over a broadband without grating or side-lobe contamination.

We assessed the site's RFI conditions over several days using a custom-built receiver chain and a commercial spectrum analyser. The Figure 1(a) and (b) illustrate a typical spectrum, highlighting the spectral regions where periodic interference was observed.

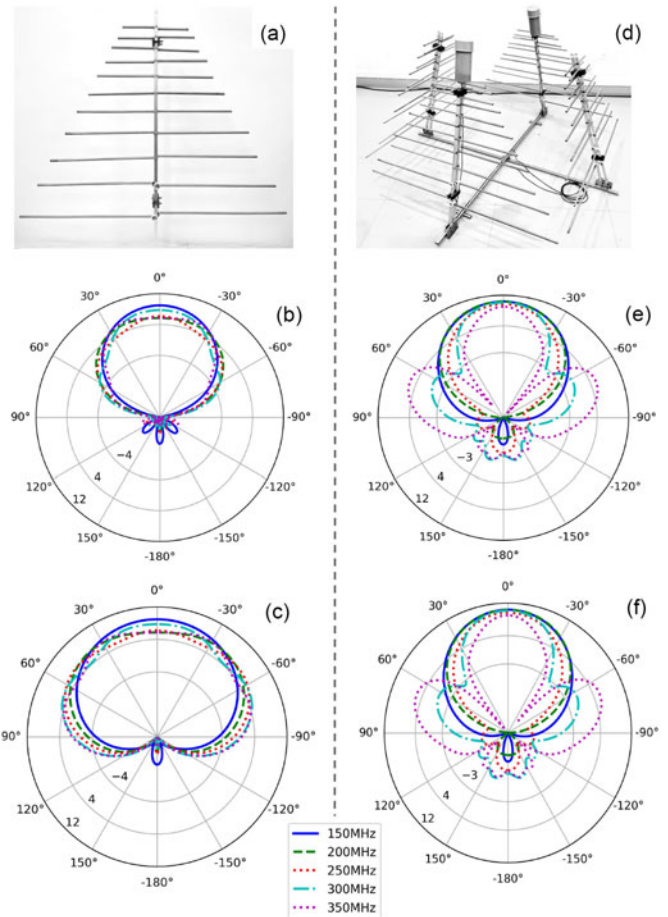


Figure 2. (a) Single LPDA Antenna with 11-dipoles. The responses obtained at 150, 200, 250, 300, and 350 MHz are overlaid for E-plane in (b) and H-plane in (c). (d) Pyramid antenna element (e) Pyramid antenna element E-plane gain (f) Pyramid antenna element H-plane gain. The simulations carried out using the CST[®] software package.

Strong RFI was observed between 80 and 129 MHz, and moderate levels of RFI were detected between 250 and 270 MHz, as illustrated in the Figure 1(a). Given that strong low-frequency RFI typically saturates the measurement system's front-end amplifiers, we used a high-pass filter to study the band above 130 MHz. Furthermore, the highest frequency for the new antenna array was also limited to 350 MHz due to interference seen beyond this frequency.

3. LPDAs in a diamond configuration

We designed an aperture-array tile using 64 custom-designed short LPDAs. Each LPDA shown in Figure 2(a) is optimised for operation in the 130–350 MHz range, has 11 dipoles, made from 9 mm diameter, 1 mm thick aluminium alloy tubes. The booms consist of 12 mm aluminium alloy square tubes having a wall thickness of 1 mm, and the dipoles are welded to the booms.

The LPDA performance is verified by beam-pattern simulations (Figure 2(b), (c), (e), and (f)) and by S11 field measurements (Figure 3).

To enable observations in X and Y orthogonal polarisations, we examined arranging two pairs of LPDAs in an off-axis configuration (see Figure 2(d)) (Shankar *et al.* 2009; Maan *et al.* 2013).

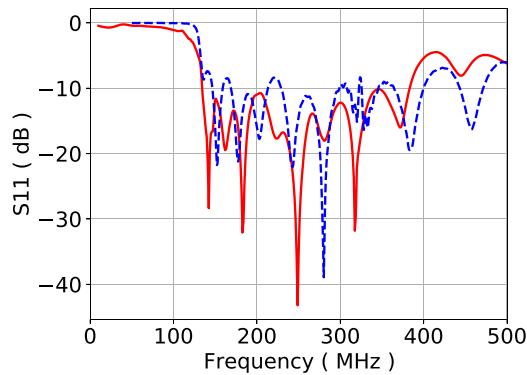


Figure 3. Simulated S11 (blue dashed line) of the LPDA from CST software is compared with measured S11 (solid red line) by N9916B microwave analyser.

In this setup, voltages from each orthogonal pair are combined to form the two polarisation feeds. There are 16 LPDA pairs, each for the X-polarisations and Y-polarisations, with their electrical centres at each pair's baseline centre. Simulations show a gain of around ≈ 11 dBi across the broadband. The nominal half-power beam widths range from 60° and $\approx 30^\circ$, as shown in Figure 2(e) and (f).

Our investigation into arrays identified a novel diamond (45° rotated square) configuration (Kraus & Moffet 1967; Kraus & Fleisch 1999). A simple model of it was first studied using both Python-based and CST[®] (CST Microwave Studio 2008) designs. We enhanced the diamond configuration with two additional features. First, we arranged the dual-polarised LPDA pairs in a checkerboard layout within the diamond shape (Kawano & Nakano 2016, 2017; Hotan et al. 2021). Next, we positioned the LPDA pairs at an inclined angle of 23° from the zenith (67° from the ground), with the tilt towards each other within the pair, as shown in Figure 2(d). The resulting array exhibited near-flat gain across the band and significant sidelobe suppression in the East-West and North-South directions, both highly desirable. The far-field orthographic responses (obtained using CST) of the array with 1, 2, 8, and 32 LPDAs at 150, 250, and 350 MHz are shown in Figure 4.

The array's responses for three illustrative directions at three frequencies (150, 250, and 350 MHz) were simulated in CST, with the results displayed in Figure 5. To obtain these steered-beam responses, we first defined the antenna array element positions in CST, exported them to a custom-developed computer code, and calculated the phases required to steer the beam of each primary element. These phases were then applied to the excitation ports in CST. Figure 5 presents the orthographic plots of the array's responses, showing beam formation at the middle and the two extreme frequencies for three representative sky directions.

4. Tile signal flow

This section provides an overview of array signal conditioning and data processing. A detailed discussion appears in Pandian B et al. (2026).

4.1. Overview

The array is located about 250 m from the observatory's receiver room. To support this arrangement, comprehensive analogue front-end radio-frequency signal-conditioning electronics were

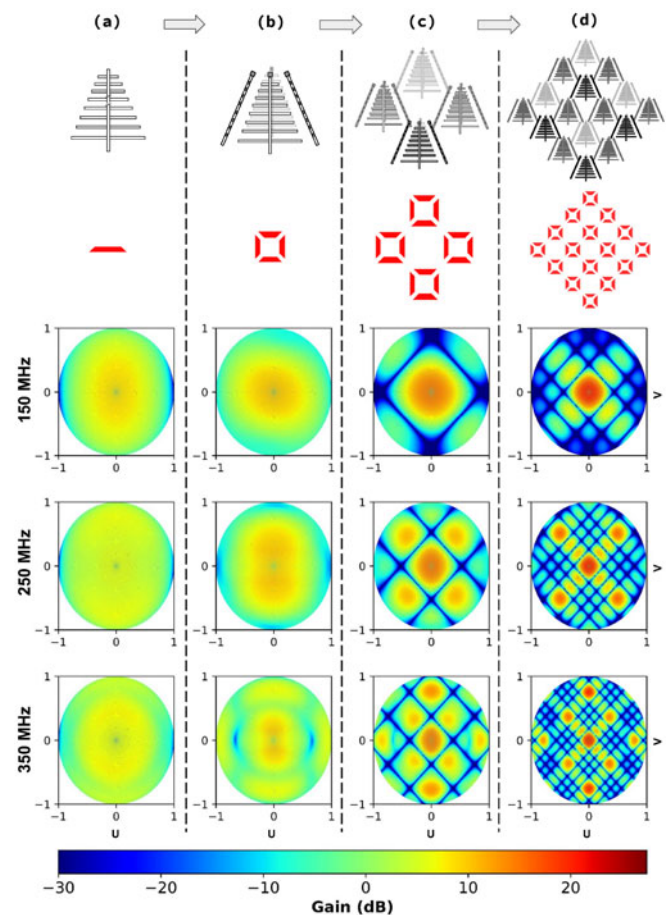


Figure 4. Far-field orthographic responses of (a) single LPDA, (b) a pyramid configuration formed by four LPDAs, (c) four pyramids (a subgroup) formed by 16 LPDAs, and (d) the full array formed by 16 pyramids (with all 64 LPDAs). The far-field responses are shown for 150, 250, and 350 MHz. Full array (d), Steered beam responses obtained through CST simulation shown in Figure 5.

specifically developed. These include low-noise amplifiers (LNAs), high-gain amplifiers, 8-way and 4-way power combiners, and fibre transmission/reception (RfOF) modules.

Data recording used the existing back-end digital receiver and the portable dual receiver (PDR). In addition, a new set of software utilities was created for real-time data capture, processing, and archiving. These utilities were executed as pipelines across Intel i7 and AMD Ryzen 9 desktops. This setup coordinated the processing and storage of acquired data.

4.2. Signal conditioning and transport

As outlined in Figure 6, the tile analogue signal chain begins with low-noise amplifiers (LNAs) fitted at the boom feed points of the 64 LPDAs (corresponding to 32 X polarisation and 32 Y polarisation) through a BALUN arrangement. The LNAs have a 20 dB gain and a bias-tee arrangement to obtain the DC power. The amplified signal leaves the LNAs via a 3-m long RG174 RF cable. The voltage signals from the X-polarisation and Y-polarisation LPDAs are combined independently using equal-length wires to produce the tile's phased-array voltage outputs for the two polarisations by combining them in two stages: eight 8-way combiners in the first stage and two 4-way combiners in the second. The first-stage

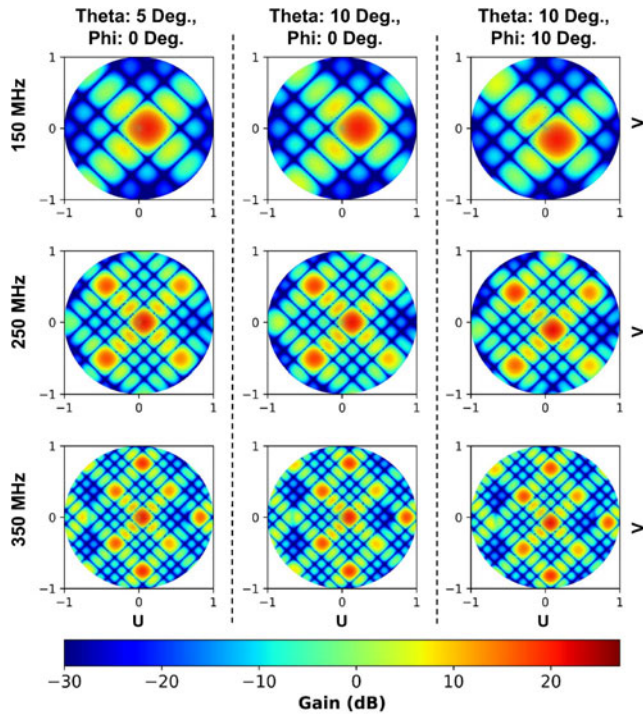


Figure 5. Illustration of beam steering for full array (Figure 4(d)) by applying suitable phases at the different frequencies.

combiners incorporate a bias-tee network for distributing the DC supply to the LNAs.

The tile's voltage outputs are further amplified by a high-gain amplifier chain (Tubular-Rx) module. It consists of multiple stage amplifiers and filters arranged in the following sequence: a first stage amplifier, a high-pass filter allowing signals above 130 MHz, a second amplifier, a low-pass filter to stop signals above 350 MHz, and a third amplifier. The Tubular-Rx has a noise figure of 1.2 dB and a gain of 52 dB across the 220 MHz wide band from 130 to 350 MHz. The amplified RF signals from the Tubular-Rx are routed to an RFoF transmitter (RFoF-Tx) module via a short RF cable.

The RFoF-Tx module is fitted with a pre-amplifier to bias the laser diode, and it has a dynamic range of 40 dB with an operating midpoint at -40 dBm. The RFoF-Tx converts the RF signal amplitudes to a 1 310 nm laser output. The transmission is by the intensity modulation of the laser output. A commercial 12-core (only 2-cores used), 250 m single-mode fibre cable carries the laser signals to the observatory receiver room. The electronics located in the observatory room, as shown on the bottom side of Figure 6, receive the optical signals from the field in an RF over fibre receiver (RFoF-Rx) module that converts the laser signal to analog RF signal, which is then fed to the analogue section of the PDR, using a short semi-flex cable having high shield attenuation (about 40 dB). At the PDR, each of the two polarisation signals is subsequently filtered into a selected 16 MHz band, digitised, and transmitted out for recording.

4.3. Data-processing

The PDR is a dual-channel, 16 MHz-wide heterodyne receiver and digitiser. It operates by using the externally fed mixer's local-oscillator frequency and a set of filter configurations; as a result,

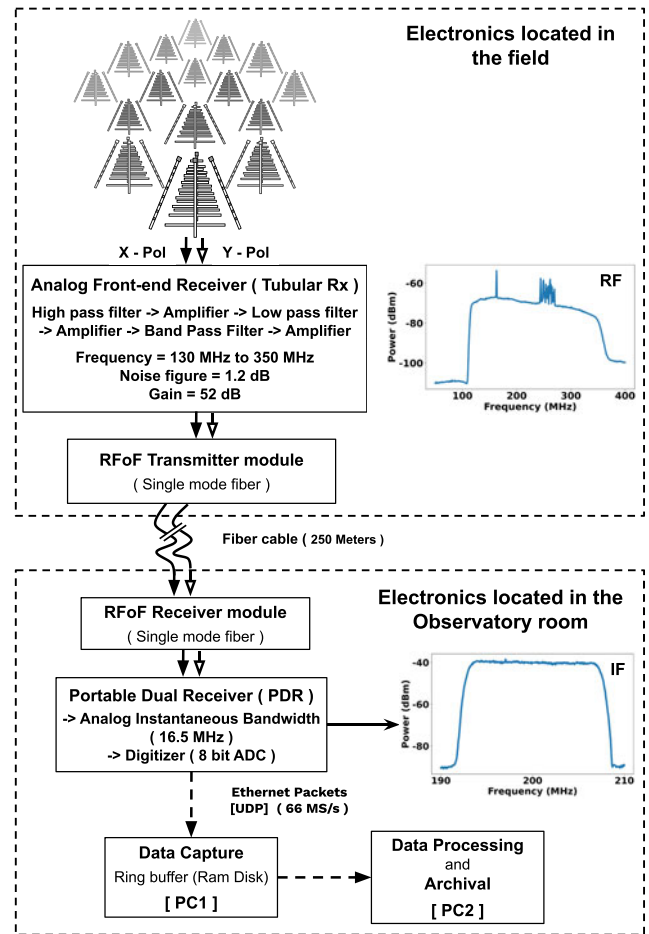


Figure 6. Array signal chain consists of 64 LPDAs in a dual polarised configuration with LNAs, voltage combiner network, high gain amplifiers with 130–350 MHz band-pass filters, RF to optical converters, 250 m, 1 310 nm single mode optical fibres, optical to RF converters, amplifiers, 16 MHz portable analogue and digital receiver, and computers for data recording, processing, and archival.

the PDR can select any of the 16 MHz bands between 130 and 350 MHz received from the array. The dual 8-bit digitisers in the PDR, each sampling at 33 MSPS, digitise the selected 16 MHz bands for X- and Y-polarisation. The PDR also timestamp the digitised data (referenced to a GPS 1-s pulse), arrange the data into UDP packets, and transmit them over Ethernet to the recording computer. A *Virtex-5* FPGA is used in the PDR for time-stamping and packetisation.

The PDR's UDP packets are first captured by the data recording computer (PC-1). Here, they are written to a RAM-based circular buffer using the GULP utilities (Satten 2008). The GULP utility writes the captured data in the packet capture (PCAP) format and fills the circular buffer at a nominal rate of 66 MBPS. From this point, the system establishes two simultaneous data flow paths. The first path is dedicated to pulsar observations. It transfers the full-time-resolution (33 MSPS) voltage data from the ring buffers via a transient buffer to hard discs for later, specific to pulsars and transient signals post-processing. (Pandian B *et al.* 2026). Meanwhile, in parallel, the second path focuses on system health and radio spectrum monitoring: here, a dedicated process in PC-1 uses data from the circular buffer to compute a Fast Fourier Transform (FFT), average spectral power, and archives the

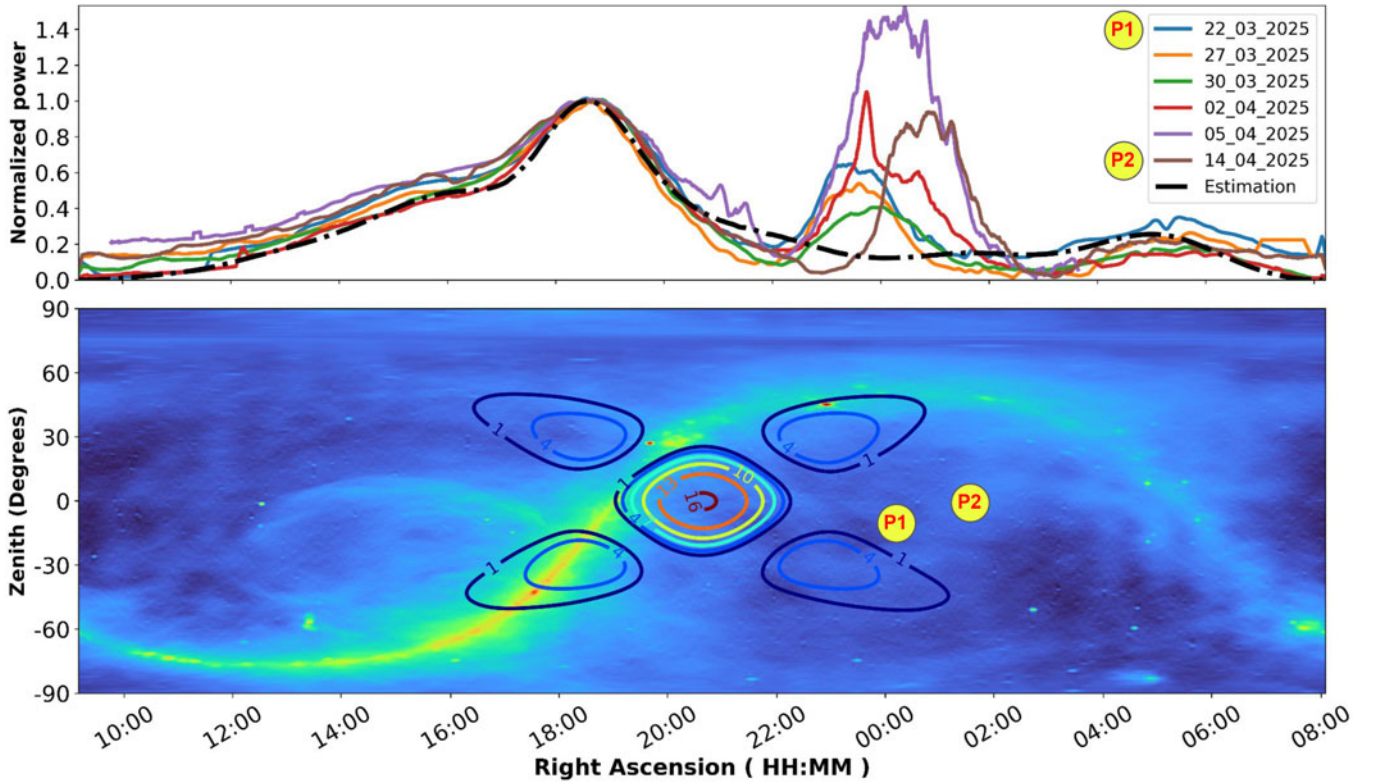


Figure 7. The upper plot shows an overlay of results from six days' drift mode observation by the array subgroup Figure 4(c). High intensities correspond to the Galactic plane, which appears at RA 18:30 h. The plane is obscured by the Sun between 23:00 and 02:00 h. The plots correspond to observations made over three weeks. The lower subplot shows the radio sky visible to the array's subgroup in the (Remazeilles et al. 2015) 408 MHz sky map. An orthographic beam pattern of the array subgroup at 200 MHz is overlaid on the sky map. This orthographic pattern was convolved with the sky map to estimate the expected total power deflections from the subgroups (shown as a black dot-dashed line in the upper plot). The total power observed was normalised to the peak power in the galactic plane at 18:30 h. The positions of the Sun (yellow – colour circles) at the beginning (P1) of this set of observations on 22 March 2025 and at the end (P2) of the observation on 14 April 2025 are marked as P1 and P2, respectively, on the map. For illustration, the tile beam is overlaid at RA 20:30 h sky map position in the bottom plot.

results with timestamps. This monitor archive is then written in the hierarchical data format version 5 (HDF5).

5. Results from the array

We present four different results from commissioning the array to illustrate its end-to-end operation:

- Drift observation over days
- Satellite and Sun transit
- Solar transient detection
- Pulsar signal detection

5.1. Drift observation over days

Drift mode observations in the sub-array configuration of Figure 4(c) for a 16 MHz band around 200 MHz were made on multiple days. These were conducted to study the receiver performance both over the course of a day and in relation to sky temperature variations. For this, the measured power throughout each day was then evaluated against the power expected for the sub-array's beam at the corresponding sky positions.

For a radiometer pointing at a fixed azimuth ϕ and elevation θ , the observed power changes with time t as the sky drifts zenith

angle of the antenna. The apparent sky brightness distribution T_A , weighted by the antenna beam pattern,

$$T_A(\theta, \phi, t) = \frac{\int_0^{2\pi} \int_0^\pi T_{\text{sky}}(\theta, \phi, t) G(\theta, \phi) \sin \theta d\theta d\phi}{\int_0^{2\pi} \int_0^\pi G(\theta, \phi) \sin \theta d\theta d\phi} \quad (1)$$

G is the antenna beam power pattern over azimuth ϕ , and elevation θ . T_{sky} is the brightness temperature of the sky towards any azimuth and elevation, which varies over time as the sky drifts (Kraus & Moffet 1967; Singh et al. 2018). The 408 MHz radio sky map (Remazeilles et al. 2015), was centred at +13.6° north (Antenna zenith) was convolved with the subgroup beam of Figure 4(c). A spectral index of -2.55 used to estimate sky temperature at 200 MHz (Mozdzen et al. 2019) from the 408 MHz sky map. The estimate thus-obtained is plotted as a black dot-dashed line in the upper subplot of Figure 7.

The different days measurements were normalised to the galactic plane's peak power at 18:30 h and overlaid in various colours. The estimate matches the power observed by the array, with minor deviations. The Sun (a $\approx 96\,000$ Jy source) positions shown as the yellow dots (P1 and P2) in figure, drifts to the right during the observed epochs between 22 March 2025 and 14 April 2025. We have also investigated the array's responses to a few radio sources: Cygnus-A (8 100 Jy), Taurus-A (1 420 Jy), Virgo-A (970 Jy) at 178 MHz (Kraus & Moffet 1967) and infer the full array sensitivity to

be around 4 Jy for 1 s integration with 16 MHz bandwidth. We observed ORBCOMM FM113 satellite 137.8 MHz beacon (Schoen & Locke 1993) between AOS: 2025/01/17 00:13:02 UTC, LOS: 2025/01/17 00:28:01 UTC (orbit 48416).

5.2. Satellite and Sun transit

For this study, the PDR was configured to select the 130–146 MHz (the lowest 16 MHz) band of the array, and a subgroup configuration with 8 LPDAs, as shown in Figure 4(c), was used. The data were recorded as the satellite beam traversed the array. The satellite pass positions and velocities were analysed using the *gpredict* (Csete 2023) FM113 polar map, azimuth/elevation, and velocity information by feeding the satellite TLE information (Prabu 2026). The collected data was normalised to the satellite's position and velocity at the timestamp of each data point. Then the expected orthographic beam response for the 8 LPDA subgroup at 138 MHz was obtained from the CST simulation. During the satellite transit, time-stamped readings of the satellite's azimuth, elevation, altitude, and signal attenuation at different positions were obtained from Gpredict software. To obtain the estimated gain, we used the satellite's azimuth and elevation and obtained the corresponding array's gain values from the 138 MHz CST simulation data. The gain values obtained were gain-corrected using the signal attenuation reported for the different positions to obtain the estimated gains. Then the peak intensities of the estimated gain and the satellite signal recorded by the array are overlaid in Figure 8(a). It can be noticed that the satellite pass is faster during our zenith transit and only seven discrete polar map positions available for the subgroup's main beam from the *gpredict* tool. Subsequently, a drift observation of the Sun was also made, using a band centred around 200 MHz, with the same subgroup of 8 LPDAs, and the beam shape obtained from the observation overlaid with expected ones from simulation is presented in Figure 8(b).

5.3. Solar flare detection

During system commissioning, the array was monitored in continuous drift mode for system monitoring and pipeline development.

Over several months, digitised data were recorded for a few hours each day during solar transit. In Figure 9(a), we present an intense *Type III* Solar event (solar flare) of 27 July 2024 detected from the archive data of the array. The data have a temporal resolution of 0.5 s and a spectral resolution of 64 kHz. The observation was carried out at 200 MHz with a 16.5 MHz bandwidth from 10:00 AM to 3:00 PM local time. The time series of solar event intensity across the observed band is shown in Figure 9(a) and the corresponding dynamic spectrum shown in Figure 9(b), while the Figure 9(c) shows the spectrum obtained during the event. Our detection time and event morphologies closely match those recorded by the *e-CALLISTO* solar radio spectrograph at the Udaipur Solar Observatory (Upadhyay et al. 2019).

5.4. Pulsar signal detection

The primary goal of the array was to observe a set of bright pulsars. To achieve this, we continually developed strategies and tools for observations and data processing (Pandian B et al. 2026). On 14 April 2025, the array achieved its 'first light' by detecting pulsar B1919+21 with a signal-to-noise ratio (SNR) of 7, using only 16 LPDAs in two Y-polarisation subgroups. Building on this, we then activated all 64 LPDAs, as outlined in the paper, using both

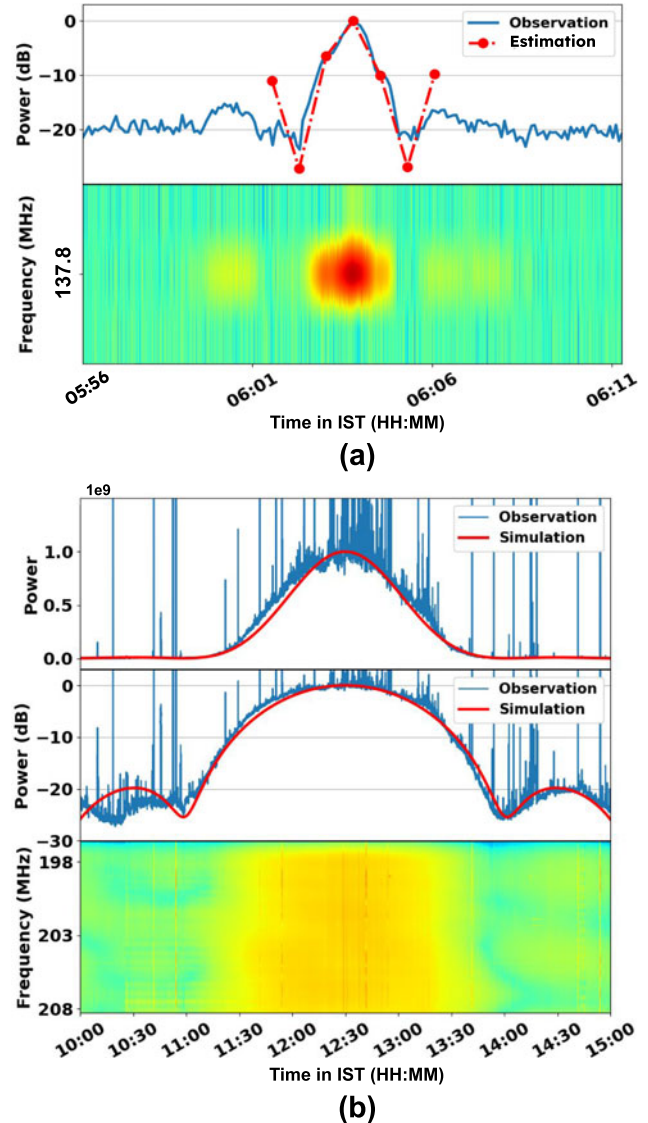


Figure 8. The array's subgroup (eight LPDAs) of Figure 4(c) beam response verified in the field using a satellite and Sun transit observations. (a) A transit observation of the ORBCOMM – FM113 (orbit 48416) satellite beacon at 137.8 MHz on 17 January 2025 is shown in the top subplot. The simulated antenna beam at 137.8 MHz correspond to the satellite path (obtained from the *gpredict*) is shown as a red trace. (b) Transit observation of the Sun at 200 MHz on 14 March 2025. From the simulated beam pattern, a -15° from zenith angle beam position traced by the Sun for this epoch is plotted in red. See also Figure 7 for a multiple-day transit observation.

X-polarisation and Y-polarisation. The commissioned array layout in the field is shown in Figure 12. In this enhanced setup, we detected four additional bright known pulsars.

The pulsars J0534+2200, J0837+0610, and J1136+1551 were detected with SNRs varying between 5 and 25, depending on the RFI situation, while the pulsar J0953+0755 was detected with SNRs varying between 10 and 100. This pulsar is known to be affected by diffractive interstellar scintillation at low frequency (Bell et al. 2016). Figure 11 illustrates the sky coverage accessible for the selected configurations of the array shown in Figure 4(b), (c) and (d).

A dedicated pulsar data processing pipeline was built with the standard software packages such as *DSPSR* (van Straten & Bailes 2011) and *PSRCHIVE* (Hotan et al. 2004). The continuous raw

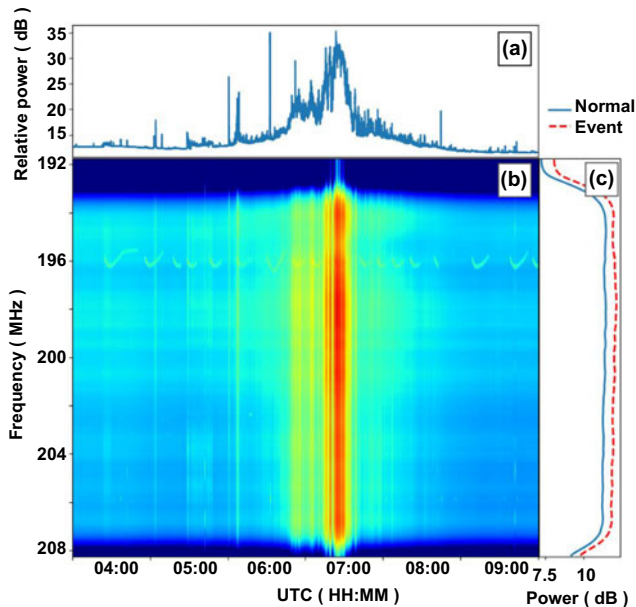


Figure 9. An intense solar event was recorded on 27 July 2024. The total power observed between 192 and 208 MHz band with time is shown in subplot (a). The spectrogram of a six-hour observation at the Sun transit is shown in the subplot (b). Band-pass power corresponding to event and non-event (normal) time is shown for comparison in the subplot (c).

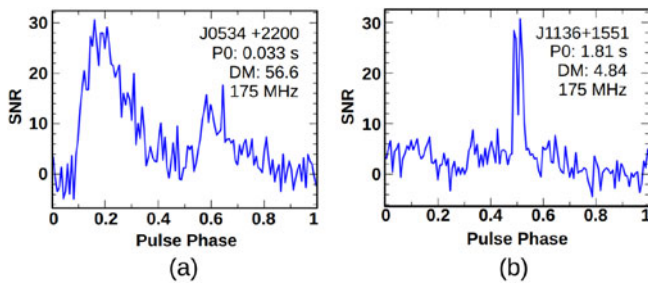


Figure 10. Pulsars detected at 175 MHz with 1 800 s integration. (a) J0534+2200 (MJD 60945) (b) J1136+1551 (MJD 60939).

ADC data was recorded with the PDR system (Figure 6). The data were reduced to a time resolution of 128 μ s and a spectral resolution of 64 kHz, with all Stokes products in *PSRFITS* format (Hotan et al. 2004). We present in Figure 10, a folded total intensity pulse profile for two pulsars, J0534+2200 (CRAB pulsar) and J1136+1551. These pulsars represent the extremes in dispersion measure and period in our sample of five currently detected pulsars. These pulsars were observed with the full array in the dual-polarised LPDA arrangement described in the paper, over a 16 MHz band centred at 175 MHz and with an integration time of 1 800 s. The intensities from the X and Y polarisations were added in the total-intensity mode during post-processing.

6. Future scopes

The array consists of 16 dual-polarised elements, each with a typical gain of 10.5 dBi throughout the band. This configuration results in an effective aperture area of 30 m², an array gain of 22 dBi, and a system equivalent flux density (SEFD) of about 15 kJy at 200 MHz, since the sky noise dominates the receiver temperature

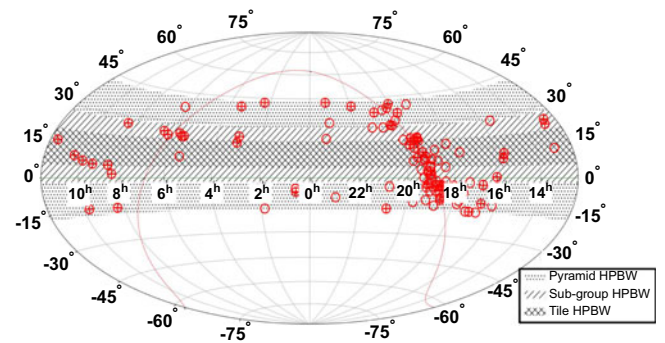


Figure 11. The sky portion visible to the sub-elements of the GBD-DART tile from the observatory site and detectable known pulsars. The hatched region depicts the HPBW of the individual pyramids (four LPDAs). A narrower inner shaded-sky area is the portion of the zenith visible for a Tile beam. The '+' symbols on the map indicate the locations of the 65 pulsars detectable with a reasonable SNR (10) in an hour of observation in a 16 MHz band around 200 MHz, if the beams are formed by combining the time-delay corrected pyramid signals. The 'o' symbols indicate the locations of 114 pulsars that can be detected if the collecting area is doubled by using two tiles.

at this frequency. For comparison, the SEFD reported for a single MWA tile at 200 MHz is between 20 and 22 kJy (Tingay et al. 2013).

Pulsar flux density at our frequency of interest typically ranges between a few milli-Jansky to a few Jansky (Stappers et al. 2011). Considering a 16 MHz band observation over an hour with a nominal HPBW of 15° at 200 MHz, this new array will be sensitive enough to detect sources with a flux density of 50 mJy. Figure 11 displays the regions of sky observable in three beam-forming modes and the known bright pulsars within those regions with flux density above 50 mJy at 200 MHz. In the figure, the central patch represents the area seen by the tile's zenith beam (current mode) with all LPDAs combined. The adjoining patch shows additional sky accessible with beams formed by combining time-delay corrected subgroup signals. The outer patch indicates the sky observable when forming beams by combining time-delay corrected signals of the orthogonal pairs of LPDAs (pyramids). The number of detectable bright pulsars in each corresponding sky region is based on estimated sensitivity limits for the tile (Lorimer & Kramer 2015).

We would also investigate forming multiple simultaneous beams for transient search applications. In such a case, an FFT-based beamforming option would be more suited for this array (Sahana 2025). Multiple beams are beneficial for transient searches, such as investigations into Fast Radio Bursts (FRBs) at low frequency (Pleunis et al. 2021). The sensitivity can also be improved by increasing the number of tiles and enhancing the associated signal conditioning and processing. Our current digital back-ends record only a 16 MHz band, and we will also consider recording and processing larger bands up to 200 MHz. These efforts would involve upgrading the digital receivers to higher-capability FPGA-based receivers, such as those recently being developed in the laboratory (Girish et al. 2023).

7. Summary and conclusion

We have designed and implemented an LPDA in a diamond configuration (measuring 5.9 m by 5.9 m, with its diagonals aligned along both the North-South and East-West directions) at the Gauribidanur observatory (GBD-DART). It is a small array with

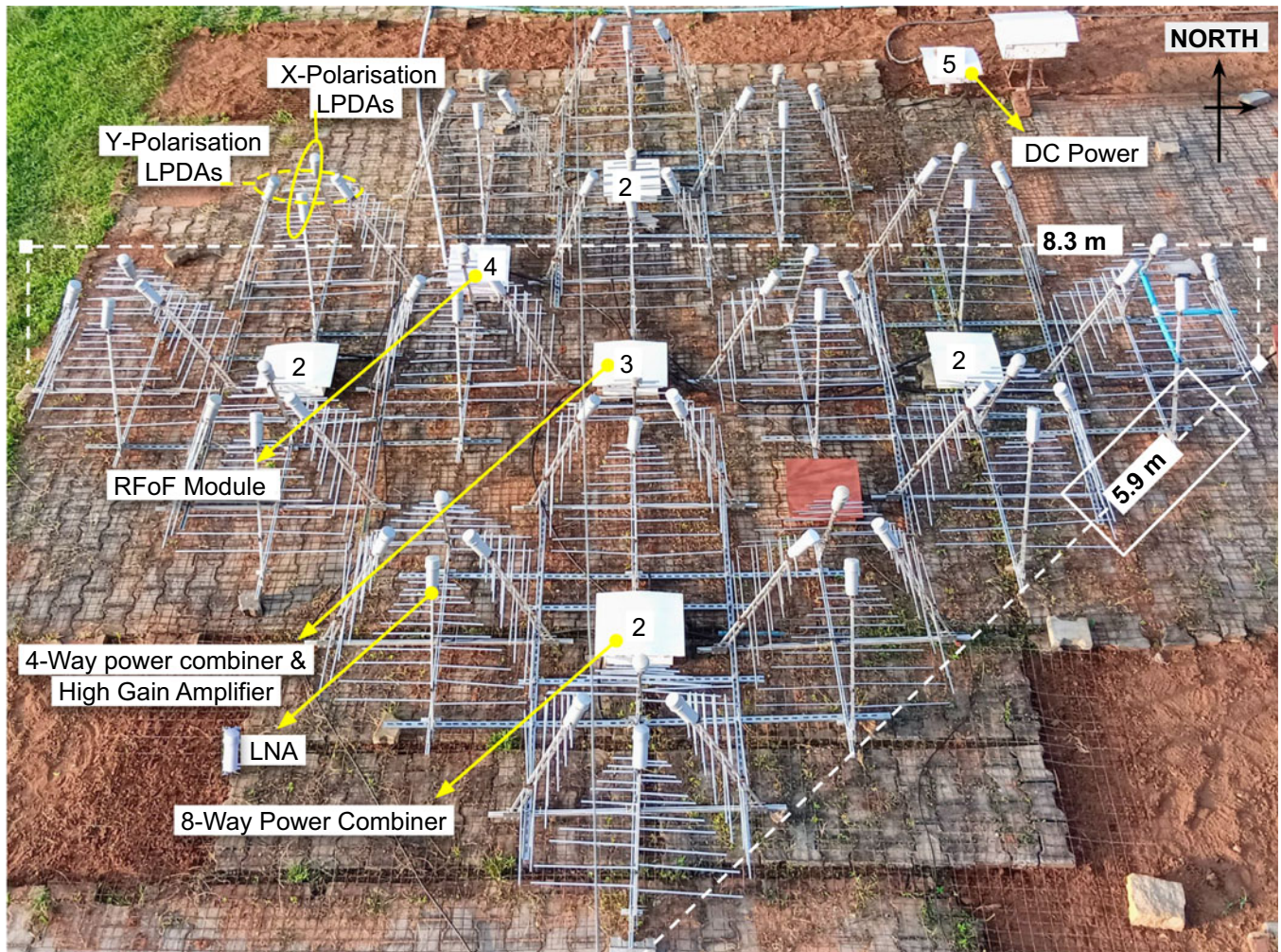


Figure 12. Diamond antenna array deployment in the field. White boxes seen house first stage analogue electronic components. A metal mesh with gap of $1/16$ th wavelength of the highest operating frequency isolates the array form ground.

64 LPDAs arranged in a checkerboard layout, forming orthogonal polarisation with dual-tilted LPDAs. This array is primarily employed to study bright Pulsars and Solar transients in the frequency range of 130–350 MHz. The diamond-shaped (tilted-square) array configuration helped suppress side-lobes. It enabled pulsar observations, often without being affected by strong signals from the Sun or other bright radio objects in the sky, or by any low-level RFI from the horizon. All associated electronics for the array have been custom-developed and commissioned on-site. The antennas, RF front-end, fibre transmission system, back-end RF and digital systems, as well as the data-gathering and processing pipelines, are all developed in-house, and their salient features are outlined in this paper and a detailed discussion about the specialised signal processing pipeline developed to perform astronomical data analysis, particularly for pulsar data processing in Pandian B *et al.* (2026). The array beam formations were studied through simulations and verified by observing satellite signals and strong celestial sources.

Building on this foundation, the array continuously collects pulsar data at a daily cadence and records spectra at 1-s time resolution 24/7. Using the archived data, we detected a strong

solar flare. The event time and morphology of the detected flare were verified against standard observatory results. The array could detect weak radio sources, as demonstrated by the successful observation of five bright pulsars with varying periods, flux densities, and dispersion measures. These pulsar parameters, including profile and dispersion measure, detected by the array match with the standard catalogues, confirming that our frequency and timing standards are well understood and meet the standards for such time-domain astronomy. Currently, we can observe pulsars with flux densities above 700 mJy and that transit our nominal zenith beam between $+8^\circ$ and $+21^\circ$ declination for about an hour. However, we discussed schemes to enhance the array's sensitivity and detect sources about 10 times weaker.

Furthermore, one of the primary focuses of this array building effort is to illustrate how a small radio telescope can be built to observe radio transients such as pulsars and to leverage duplication of such designs to enhance the number of student participants both in the instrumentation and in understanding the radio pulsar observations, data analysis, and develop interest in pulsar astrophysics. The entire DART development was done from scratch, with a focus on keeping the costs moderate. The DART

array 2025 cost estimate breakdown: (a) Antennas, 1 000 Euros; (b) Front-end Electronics and cables, 2 000 Euros (Ragavendra 2025); (c) fibre transmission modules and receiver, 500 Euros; (d) digitiser and recorder, whose cost depends on the digitisation bandwidth selected, with higher bandwidth choices resulting in higher costs; our in-house developed dual 16 MHz receiver-side analogue conditioning, mixer, digitisation, FPGA-based packetiser (PDR) costed about 3 500 Euros; and (e) backend real-time processing systems, consisting of two *Intel i9* or *Ryzen-9* equivalent systems, each with 128 GB RAM and 4 TB storage. The costs of the local-oscillator clock and GPS systems are not included here, as they were available in the observatory. Alternate low-cost options for the digitisation, an FPGA-based packetiser based on RetPitaya boards, are being investigated for future systems.

To support the educational objectives, this new small pulsar array is now open for student training, offering hands-on experience in observations, data analysis, and signal processing for astrophysics (Adithya 2025; Mahek 2025).

Acknowledgements. We acknowledge the multiple technical consultations with R. Somashekar. We also value Keerthipriya Sathish for guiding the development of the RF over fibre transmission links. We acknowledge the involvement of our colleagues at the Gauribidanur Observatory team for their support during the commissioning of the LPDA array, particularly Srinath and Janardhanan, and for their contributions to making all of the 64 LPDAs and in making the RF module enclosures at the observatory workshop and Ibrahim for the access to the RRI workshop. Additionally, we thank the undergraduate interns at Gauribidanur AES National College for their help in transporting and mounting the array of elements from the Bangalore lab to the observatory. We are also grateful to our EEG colleagues for their various forms of support and valuable conversations that aided this work. We thank the Raman Research Institute for supporting this development work. We also thank the Christ University for recognising the research aspect of this effort. Also, we acknowledge the use of the RRI library, which provided access to the Grammarly (Fitria 2021b) tool and the publicly available QuillBot (Fitria 2021a) to correct grammar in the manuscript.

Data availability statement. The data presented in this article are publicly available in https://github.com/Arul16psp05/supplementary_materials.git at <https://doi.org/10.5281/zenodo.15709357>.

Financial statement. The authors declared there are no financial interests.

Competing interest. None.

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