

A Galactic Plane Monitor at 200 MHz

N. Hurley-Walker,¹ S. McSweeney,^{2,1} T. J. Galvin,^{3,1} C. Horváth,¹ J. Morgan,^{3,1} and A. Tilly^{4,1}

¹International Centre for Radio Astronomy Research, Curtin University, Bentley, WA6102, Australia

²SKA Observatory, SKA-Low Science Operations Centre, 26 Dick Perry Avenue, Kensington, WA 6151, Australia

³CSIRO, Space and Astronomy, P.O. Box 1130, Bentley, WA 6102, Australia

⁴Centre for Astrophysics, University of Southern Queensland, West Street, Toowoomba, QLD 4350, Australia

Author for correspondence: N. Hurley-Walker, Email: nhw@icrar.org.

Abstract

We present the Galactic Plane Monitor (GPM), a dedicated low-frequency radio transient survey conducted with the Murchison Widefield Array at 200 MHz. The GPM targets an underexplored region of transient parameter space spanning timescales from seconds to weeks, where recent discoveries of unusual Galactic radio sources—including long-period transients and other coherent emitters—suggest a rich and largely uncharted population. Leveraging the MWA’s wide field of view, we carried out 72 observing epochs between June 2022 and March 2025, searching $\sim 5,000$ sq. deg. of the Southern Galactic plane. We developed a multi-stage processing pipeline to search for variability across a broad range of timescales, from intra-snapshot (4 s to minutes), to inter-snapshot (minutes to hours), and inter-epoch (days to years). This approach combines image differencing, statistical variability metrics, and visual inspection to robustly identify transient candidates while mitigating the effects of ionospheric variability and imaging artefacts. In parallel, we produced deep mosaics using a “lucky imaging” strategy to maximise sensitivity to faint persistent sources. We present the detections of five long-period radio transients, seven eclipsing binary millisecond pulsars, seven intrinsically variable pulsars, and the detection of refractive interstellar scintillation and night-time interplanetary scintillation. The GPM represents a key step toward fully mapping the dynamic low-frequency radio sky and informs the design of next-generation transient surveys with the SKA Observatory.

Keywords: astronomical databases: surveys – techniques: interferometric – stars: pulsars – radiation mechanisms: non-thermal – Galaxy: general

1. INTRODUCTION

Radio transients are indicators of high-energy astrophysical processes in our Universe, and as such can probe extreme physics (e.g. Frail et al., 1997; Kramer et al., 2021). Coherent emitters such as pulsars and Fast Radio Bursts can be used to probe the interplanetary (Smirnov et al., 2024), interstellar (Ocker & Cordes, 2026) and intergalactic (Macquart et al., 2020) media, yielding information about otherwise invisible matter, and indeed the cosmology of the Universe.

In recent decades, observations of the radio transient sky have moved from following up objects detected at high energies (e.g. Gehrels et al., 2004) or wide-area optical surveys (e.g. Bellm et al., 2019), to blind surveys that select objects of interest in the radio (Murphy & Kaplan, 2026). This builds on decades of work searching the fast (<seconds) time domain for radio pulsars (e.g. Lorimer et al., 2006) and Fast Radio Bursts (CHIME/FRB Collaboration et al., 2018), and epoch-to-epoch ($\sim$ years) comparisons of large radio surveys (e.g. Somalwar et al., 2023). Historically, these searches have been insensitive to “medium” timescales of a few seconds to a few hours. This has left a relatively unexplored space in the radio transient parameter space (Fig. 1) which recent searches are beginning to fill.

Within this region lie recent serendipitous discoveries of unusual objects, such as the Galactic “burper” (Hyman et al., 2005), extremely slowly rotating pulsars (Caleb et al., 2022), magnetic white-dwarf/M-dwarf binaries (Pelisoli et al., 2023),

Main-sequence Radio Pulse emitters (Das & Chandra, 2021), the “Galactic Radio Transients” (Anumalapudi et al., 2026), and the “long-period radio transients” (LPTs; Rea et al., 2026). For the most part, these objects are coherent emitters that produce polarised radio waves and tend to be brighter at low to mid (100–1000 MHz) radio frequencies. So far, these discoveries are confined to our own Milky Way galaxy.

It is thus timely to perform dedicated radio searches for transients in the image plane. Consistent and repeated observations are more valuable in placing meaningful limits on the activity and brightnesses of sources than heterogeneous searches (such as commensal use of other data, or archival searches). As the recently discovered sources are Galactic, observations over the Galactic plane could yield higher numbers of detected sources. The widest-area effort at mid frequencies is the Australian SKA Pathfinder (ASKAP; Hotan et al., 2021) Variables And Slow Transients survey, (VAST; Murphy et al., 2021), at 888 MHz. While most mid-frequency transient surveys (such as ThunderKAT; Fender et al., 2016), suffer from the small fields-of-view that follow from using single-pixel feeds on dish-based telescopes (field-of-view $\theta \propto \frac{\lambda}{D}$, where λ is the observing wavelength and D is the dish diameter), ASKAP employs phased-array feeds to essentially widen the field-of-view by a factor of 36. To increase the field-of-view further, one can only decrease D (reducing sensitivity, only countered by increasing the number of dishes, leading to new computational challenges; see e.g. the Deep Synoptic Array

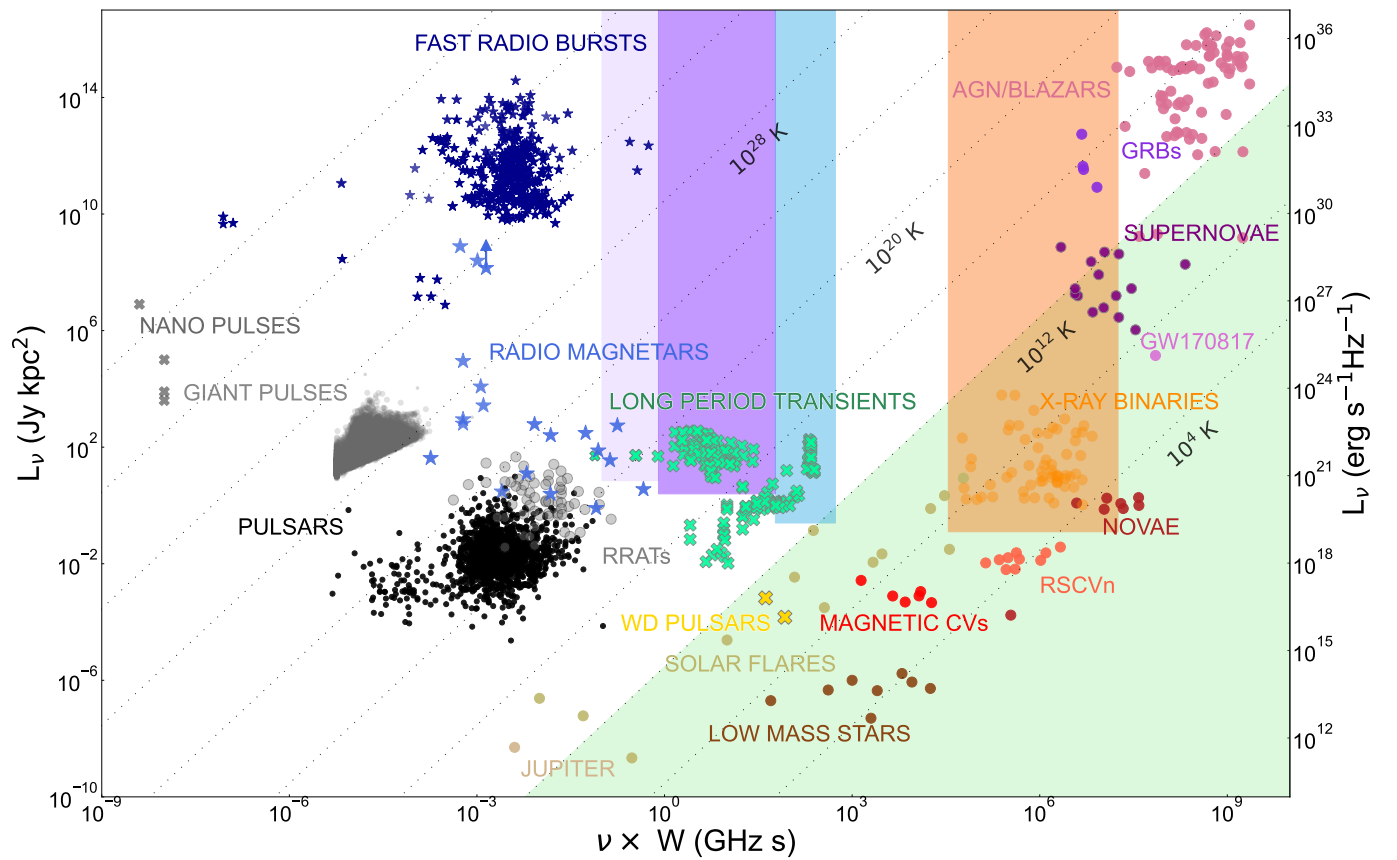


Figure 1. Transient parameter space diagram of pseudo-luminosity against timescale. A representative distance of 5 kpc has been used to calculate the sensitivity of the survey (as the approximate distance of GPM J1839–10, the first new transient detected by this survey). Shaded regions indicate those which this work explores via searches within 5-minute observations (purple), 30–45-minute pointings (cyan) and via images made several nights apart (orange). The lavender region indicates the parameter space that *would* be explored by processing the GPM data at full time resolution (0.5 s; see Section 4.4.2 for a discussion). Figure adapted from Rea *et al.* (2026).

Hallinan et al., 2019), or increase λ .

Thus, low-frequency telescopes offer an effective view of the transient radio sky. For example, the LOw-Frequency ARray (LOFAR; van Haarlem et al., 2013) has been carrying out the LOFAR Two-metre Sky Survey (LOTSS; Shimwell et al., 2017) of the Northern Sky; a search of just 2% of this data for transients revealed a new LPT (de Ruiter et al., 2024, 2025). The Murchison Widefield Array (Tingay et al., 2013) is a low-frequency aperture array operating at Ilyarrimanha Ilgari Bundara, the CSIRO Murchison Radio Astronomy Observatory. It is a precursor to the low-frequency component of the SKA Observatory and has been operating since 2013. Its flagship all-sky radio surveys, the GaLactic and Extragalactic All-sky MWA (GLEAM; Wayth et al., 2015) and GLEAM-eXtended (Hurley-Walker et al., 2022b) surveys have offered opportunities to search for radio transients across the entire Southern sky (Murphy et al., 2017; Hurley-Walker et al., 2022a; Horváth et al., 2025), but with only a limited number of epochs.

In this work, we describe a new radio transient survey that leverages the wide field-of-view and Southern location of the MWA to regularly observe the Galactic Plane over 72 epochs in three campaigns spanning June 2022 to March 2025: the Galactic Plane Monitor (GPM). Section 2 describes the instrumental set-up and processing pipeline and resulting data products, Section 3 presents the detected transient objects, Section 4 discusses the effectiveness, limitations, and potential future utility of reprocessing the GPM, and Section 5 concludes with a summary and outlook.

Throughout, we use J2000 co-ordinates, and the convention that σ refers to the local root-mean-square (RMS) noise of the dataset under discussion.

2. OBSERVATIONS AND DATA PROCESSING

2.1 Observations

The Galactic Plane Monitoring survey was performed using the Phase II “extended” configuration of the MWA, under project code G0080. The GPM was conducted over three observing semesters, described in Table 1.

The MWA is capable of observing 30.72 MHz of instantaneous bandwidth placed within 72–300 MHz, with optimum instrumental sensitivity over 100–185 MHz. However, sky noise is dominant over the system temperature and is proportional to $\nu^{-2.7}$ (Rybicki & Lightman, 1979), so similar noise levels are observed across 154–231 MHz when imaging (Hurley-Walker et al., 2017). The dispersive and scattering effects of the interstellar medium scale as ν^{-2} and $\nu^{-\frac{11}{3}}$ respectively (Taylor & Cordes, 1993), and ionospheric phase shifts scale as ν^{-2} (Thompson et al., 2001), with amplitude scintillation sometimes inducing extreme flux density fluctuations at the lowest frequencies (Waszewski et al., 2022). These considerations might argue for as high an observing frequency as possible. However, the frequency range above 231 MHz is often contaminated with military satellites, and has a complex primary beam response with strong sidelobes (Cook et al., 2021). To compromise between these competing effects, the GPM was performed using 185–215 MHz.

Galactic radio transients may produce time-variant emission on a range of timescales from less than a second (e.g. pulsars; Hewish et al., 1968) to many years (e.g. X-ray binaries; Markoff et al., 2001). Detecting fast transients such as canonical pulsars and Fast Radio Bursts requires very high sampling rates such as provided by the Voltage Capture System (Tremblay et al., 2015), as employed, for example, by the Southern-sky MWA Rapid Two-metre (SMART) pulsar survey (Bhat et al., 2023). High time and frequency resolution avoids smearing the short-duration ($\lesssim 10$ ms) pulses and enables coherent correction of dispersive effects. This is impossible with standard correlator data, although some fast (~ 0.5 s) signals can be recovered, such as interplanetary scintillation of compact radio sources (Morgan et al., 2018a). Processing such fast timescales induces a large computational and data-handling challenge. The goal of the GPM is to detect long-period radio transients and other Galactic radio transients, so to compromise between time-resolution and computational cost, while still retaining the highest-resolution data in case of a detection, we perform the observations at 0.5 s resolution, but average them to 4 s for onward processing.

Formed by an analogue beamformer, the MWA primary beam is fixed on the sky for each observation, and the sky drifts through it, slowly changing the apparent flux density of radio sources. To minimise this effect, while still making each observation useful for detecting sources with pulses 30–60 s across, we integrate for 296 s per observation. The MWA-X correlator upgrade has enabled seamless transition between observations such that there are no flagged time-steps between observations (Morrison et al., 2023).

Ten pointings were selected to cover the largest fraction of Galactic volume visible to the MWA at night-time in semesters 2022-A and 2024-A. The centres of the pointings are set to $b = 0^\circ$, and span $300^\circ < l < 57^\circ$ in 13° intervals. Each pointing has an approximate full-width-half-maximum (FWHM) of $16\text{--}20^\circ$, varying somewhat with pointing position. This yields an overall coverage of $|b| < 15^\circ$ and $284^\circ < l < 73^\circ$, with reduced sensitivity toward the edges. At $l > 50^\circ$, imaging artefacts from Cygnus A result in decreased sensitivity; close to the Galactic centre, the sky temperature is higher, and at lower Declinations, the primary beam sensitivity is decreased. For 2024-B, we scanned the rest of the Southern Galactic plane (despite the lower Galactic volume). Here we attempted a closer longitude spacing of 7° , but some pointings could not be included in the schedule, leading to somewhat unequal spacing of the 11 successful pointings. Fig. 2 shows the layout of the pointings as well as the detected transients (Section 3).

We found that at low elevations, strong ionospheric phase scintillation induced a large number of false positive detections on short (Section 2.3) to medium (Section 2.4) timescales, either by causing sources themselves to appear and disappear, or by affecting bright sources nearby, causing their sidelobes to appear as transients. In combination with the scheduling requirement to fit as many pointings as possible in the night-time available, in a sequential order in Galactic longitude, this effectively placed further longitude limits on the searchability of each semester, shown in Table 1.

Table 1. Observation details for the three conducted epochs of the GPM. Not all observations could be searched for transients on all timescales due to ionospheric phase scintillation at low elevations (see Section 2). $\tilde{N}_{\text{tiles}}$ indicates the median number of functioning tiles in the array during each epoch.

Semester	Dates	M_{nights}	Observed l	Searched l	$\tilde{N}_{\text{tiles}}$	Dwell time / min	Calibrator
2022-A	2022-06-02 – 2022-09-22	18	285° – 65°	320° – 40°	115	30	Hercules A
2024-A	2024-06-02 – 2024-09-16	24	285° – 65°	300° – 40°	94	45	Hercules A
2024-B	2024-12-01 – 2025-03-31	30	185° – 310°	220° – 305°	110	30	In-field (GLEAM)

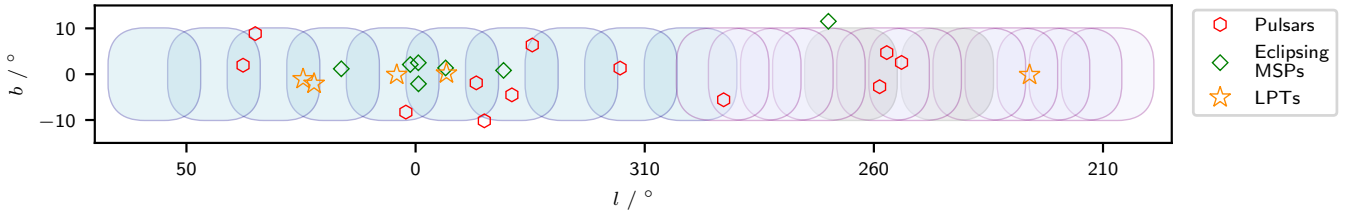


Figure 2. Pointing centres of the GPM over semesters 2022-A and 2024-A (blue), and 2024-B (lavender). Two pointings could not be scheduled and are shown in grey. The $20^\circ \times 20^\circ$ boxes shown are at the $\sim 50\%$ level of the MWA primary beam, relative to the maximum of each pointing centre. Detected transients described in Section 3 are overlaid with markers.

Fig. 3 shows an overview of the main stages of the processing described in the subsequent sections.

2.2 Imaging and calibration

The data were downloaded from the All-Sky Virtual Observatory^a without calibration solutions applied, with RFI flagging performed by AOFLAGGER (Offringa *et al.*, 2012). We performed (phase and amplitude) calibration on dedicated pointings toward Hercules A, which at 200 MHz is ~ 377 Jy (Hurley-Walker *et al.*, 2017), sufficient to dominate the visibilities and produce good calibration solutions. We used the GLEAM-X pipeline (Hurley-Walker *et al.*, 2022b) which incorporates this and other sources in the field to produce a sky model, then MITHCAL (Offringa *et al.*, 2016) to form complex antenna gains for each antenna, frequency, and polarisation. These were applied to all data for each night. Imaging was also performed with the GLEAM-X pipeline, using WSCLEAN (Offringa *et al.*, 2014) to create a continuum image of each 5-minute snapshot (top-right panel of Fig. 4). For speed, we decreased the CLEAN thresholds to $5\text{-}\sigma$ (peak detection) and $3\text{-}\sigma$ (masked clean), as well as reducing the maximum number of major iterations to 3. Subtracting the deep visibility model formed in this process, the data are re-imaged at 4-s time resolution to produce a series of near-empty snapshots in which only transient and variable sources are visible (Hurley-Walker *et al.*, 2022b; Horváth *et al.*, 2025), which are thence combined into a cube in 16-bit HDF5 format for compact storage and onward analysis, as described in Appendix 2 of Morgan *et al.* (2018b). An example slice of such a cube is shown in Fig. 4, demonstrating that diffuse emission and point sources are subtracted well by the initial imaging process, despite reasonably significant ionospheric blurring effects in the displayed observation. Fig. 5 shows the typical RMS as a function of Galactic longitude.

^a<https://asvo.mwatelescope.org/>

2.3 Intra-snapshot search

Individual observations are sensitive to transients on timescales between the imaged time resolution (4 s), to approximately half of the observation duration (0.5×5 min). To extract transients on these timescales from within five-minute snapshots we used filter methods developed by Horváth *et al.* (2025) in their search of a subset of GLEAM-X data. Briefly, these consist of:

1. A sum of Gaussian matched-filters of 4, 8, 16, and 32s widths;
2. A search for any pixel that has brightness $> 7 \times$ the local RMS of that voxel along the time axis;
3. A search for any voxel that has an RMS along the time axis larger than $5 \times$ the median value of other voxels in the image.

The ionosphere induces phase scintillation of radio sources over timescales of ~ 30 s, and this can produce a large number of false positives. To combat this, we excluded any candidate with a peak brightness equal to or less than a known radio source in the GLEAM catalogues (Hurley-Walker *et al.*, 2017, 2019), cross-matched within a $2'$ radius. The detection sensitivity of the latter catalogue, which covers $|b| < 10^\circ$, is similar to the per-snapshot sensitivity of the GPM data, and thus this cross-match performs efficiently.

Some observations still produced large volumes of candidates due to instrumental or calibration errors. Any observation that produced more than 10 candidate transients after the above ionospheric filtering was excluded from onward processing.

After selecting candidates that passed any of the three filters in acceptable observations, we produced light curves and animations of the surrounding 200×200 pixel ($45' \times 45'$) regions for visual inspection.

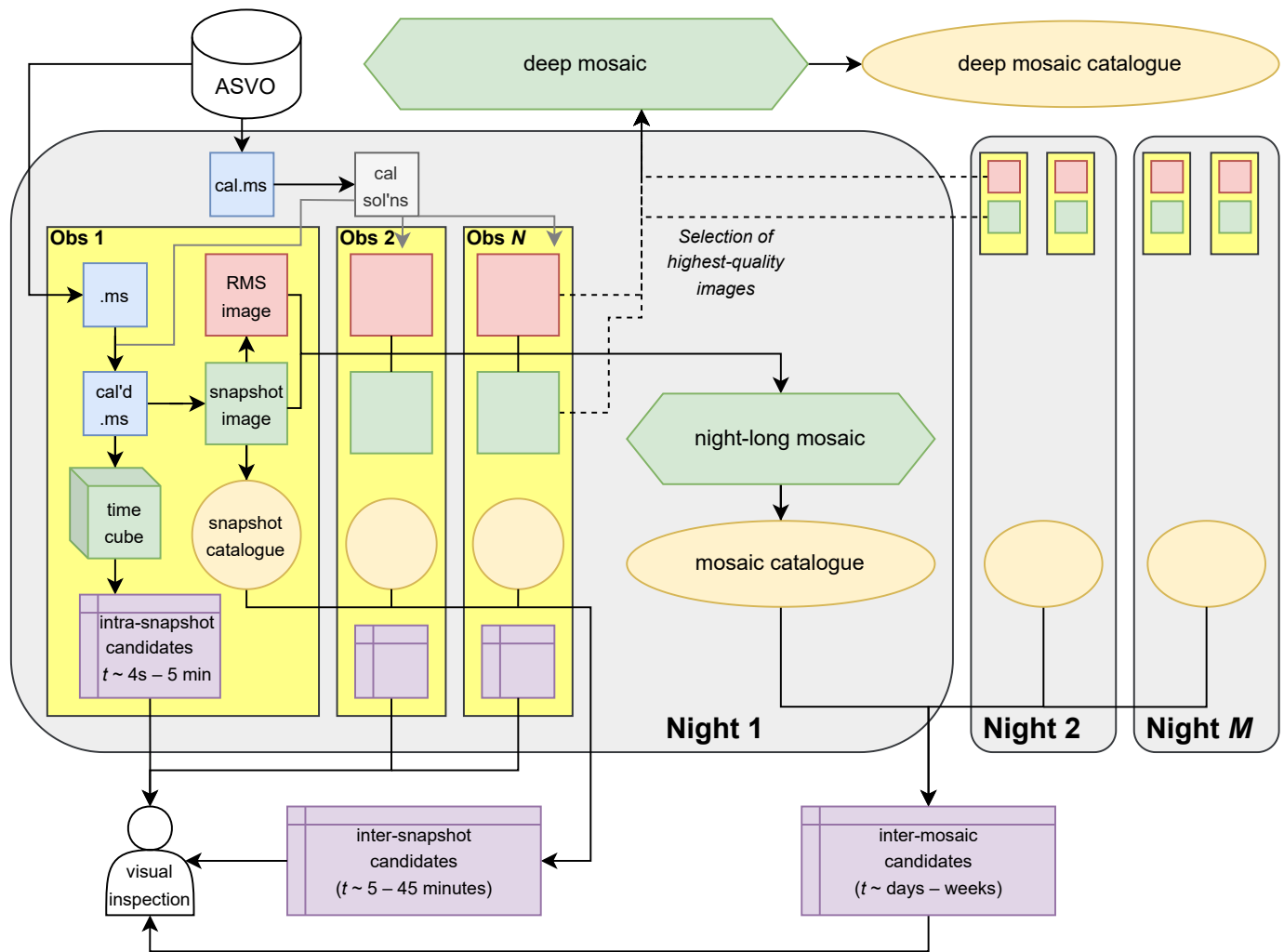


Figure 3. Diagram showing the data flow through the Galactic Plane Monitor transient search and deep mosaic creation. In each of the three epochs (2022-A, 2024-A, and 2024-B, there are M nights of observing (grey oblongs), each of which is internally composed of N snapshot observations (yellow boxes labelled “Obs” in the diagram). M for each epoch is given in Table 1. Individual observations are searched for candidates (Section 2.3), catalogues from multiple observations pointed at a single location in a night are searched for transients (Section 2.4), and mosaics formed from a night of observations are also searched (Section 2.5). A subset of the highest-quality images from all three epochs is formed into a deep mosaic covering the entire GPM region (Section 2.6).

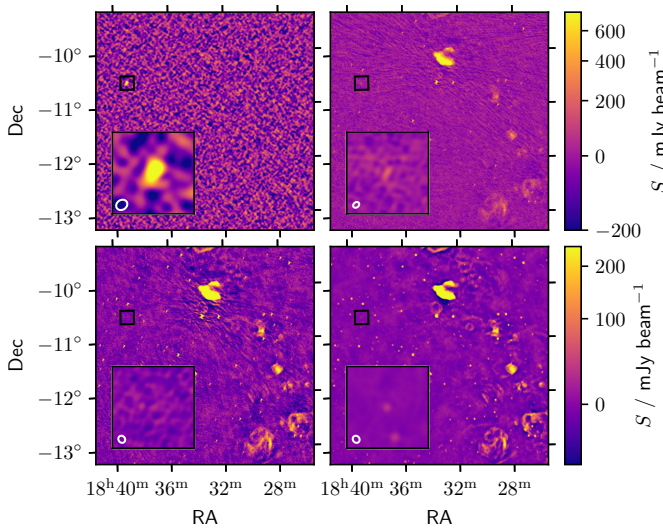


Figure 4. Examples of the four imaging products generated in this work, using the same region for reference. Top-left: a single slice from a continuum-subtracted time-step cube (Section 2.3); top-right: a single five-minute snapshot (Section 2.4); bottom-left: a night-long mosaic (effective integration time ~ 30 min: see Section 2.5); bottom-right: the deep mosaic formed with the “lucky imaging” approach (Section 2.6). The RMS noise of each image is, respectively, 110, 26, 14, and 5 mJy beam $^{-1}$. All images except the bottom-right were generated from observations on 2022-06-30 at ~ 16 h UTC. In each panel, a 15' square region around the LPT GPM J1839-10 is highlighted, and displayed in the bottom-left insets. Within these, the PSF of each image is shown as white ellipse in the bottom-left corner.

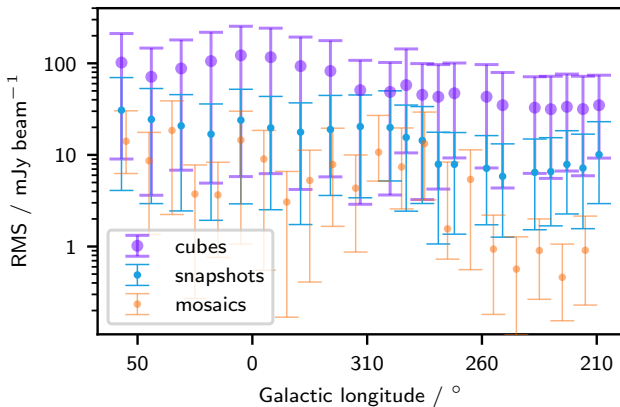


Figure 5. Noise levels of the various data products formed in this work, as a function of Galactic longitude. The points show median values while the error bars indicate the 1st (lower) and 3rd (upper) quartiles. The formation of the cubes and snapshots is described in Section 2.2, and the mosaics in Section 2.5. The change in spacing of the observations over longitude is due to a combination of a change in pointing separation between 2022-A/2024-A (13°) and 2024-B (7°), with gaps resulting from unforeseen limitations in the scheduling (see Section 2.1 for details). The relatively high RMS of the mosaics at $l = 285^\circ$ is due to this region lying on the edges of both the GC and SP regions.

2.4 Inter-snapshot search

Each 30- or 45-minute integration points within a few degrees of the same location in the Galactic plane (limited by the analogue beamformer), divided into 6–9 snapshot observations. Transients on timescales of the snapshot time (5 minutes) to the total integration time (30 to 45 minutes) can be detected by performing cross-matches of the source catalogues detected in these snapshots and performing some statistical tests.

We use *AEGEAN* v2.2.5^b (Hancock *et al.*, 2012, 2018) and its companion tools such as the Background and Noise Estimator (BANE) to perform source-finding, with the default settings. We use the *FLUX_WARP*^c package (Duchesne *et al.*, 2020) applying a set of radial basis functions to bring the source flux densities into agreement with the GLEAM-X GP catalogue of Mantovanini *et al.* (2025c), for $|b| < 10^\circ$ and $233^\circ < l < 44^\circ$, and GLEAM outside of this region (Hurley-Walker *et al.*, 2022b). We use the fitted 200-MHz flux densities from these catalogues to best-match the observing frequency of the GPM.

We also apply *FITS_WARP* (Hurley-Walker & Hancock, 2018) to shift the radio source positions into agreement with higher-resolution radio catalogues. We used the Rapid ASKAP Continuum Survey (RACS; McConnell *et al.*, 2020; Hale *et al.*, 2021) Low Data Release 1. These position shifts are typically ~ 1 – $10''$.

Using the Starlink Tables Infrastructure Library ToolSet (STILTS; Taylor, 2006), we perform a cross-match between all snapshot catalogues within a given pointing, using a $25''$ cross-matching radius and keeping all matches, which allows us to retain non-detections (i.e. transients). This relatively large cross-matching radius is necessary due to residual ionospheric errors caused by small ($\sim$ degree-size patches) scale ionospheric defocussing, which cannot be corrected by *FITS_WARP*.

We then exclude from our catalogues:

- sources with extent (integrated to peak flux density ratio) > 1.5 in any image;
- sources where *AEGEAN* failed to fit a shape in any image (usually artefacts or parts of extended structures such as supernova remnants);
- sources more than 9.5 from the center of the combined pointings, where the coverage of the combined pointings is low and has high noise;
- sources which are decomposed in any image into components lying within $2'$ of each other.

Where a source is not detected in an image, we perform a forced photometric measurement at the location of the mean position obtained from images where the source was detected. We set the uncertainty on this flux density measurement to the local RMS noise measured by BANE at the same position.

Due to the limited number N of data points (6–9), we use the simplest transient search variability metrics: the significance of variability η and the coefficient of variation V (McKay, 1932):

^b<https://github.com/PaulHancock/Aegean>

^chttps://gitlab.com/Sunmish/flux_warp

$$\eta = \chi^2_{N-1} = \frac{1}{N-1} \sum_{i=1}^N \frac{(S_i - \bar{S}^*)^2}{\sigma_i^2} \quad (1)$$

and

$$V = \frac{1}{\bar{S}} \sqrt{\frac{N}{N-1} (\bar{S}^2 - \bar{S}^{*2})}, \quad (2)$$

where $\bar{S}$ is the mean flux density, and $\bar{S}^*$ is the weighted average flux density, respectively. The standard error σ_i on the i th flux density measurement S_i is calculated as the quadrature sum of the local RMS noise and a 10% flux density calibration error.

For sources which meet the following criteria:

- $\eta > 5$;
- $V > 0.5$;
- mean $S/\sigma > 6$, calculated using images in which the detection was made (i.e. not including forced measurements),

we generate a light curve and an animation of a 200×200 pixel ($45' \times 45'$) region around the source for visual inspection.

2.5 Mosaic search

Observing the same sky across multiple epochs also enables a search for radio transients that change between epochs, i.e. timescales of days to weeks. We use the flux-density calibrated primary-beam-corrected images where ionospheric position shifts have been removed, generated in Section 2.4. We then form weight images based on the inverse of the square of the RMS maps calculated by BANE. We noted that the primary beam correction had occasionally introduced artefacts into the edges of the images, so also cropped the outer 800 pixels (3.3°) of both the images and RMS maps. The RMS in these regions is typically $\sim 100\times$ that of the centre part of the image, so very little useful data is lost.

We use the mosaicking software SWARP (Bertin et al., 2002) to form a Cartesian FITS image in Galactic coordinates, weighting each 5-minute snapshot by the weight images. The resulting images have RMS noise $7\text{--}25$ mJy beam $^{-1}$, largely depending on proximity to bright sources, around which calibration artefacts can be significant.

Night-time observations generally form good-quality images following this procedure, but daytime observations suffer significant direction-dependent time-dependent ionospheric effects, with the net effect producing significant smearing of the sources beyond the nominal point spread function. We therefore restricted our mosaicking to night-time observations. An example of the imaging quality obtained is shown in the bottom-left panel of Fig. 4. Fig. 5 shows the typical RMS of the mosaics within $|b| < 10^\circ$ as a function of Galactic longitude.

To search for radio transients and variables, we performed a similar process to that described in Section 2.4. Several changes were made to the process to accommodate the large mosaics:

- due to their similar sky coverage, we searched all data from semesters 2022-A and 2024-A in one analysis;

- to account for point spread function (PSF) projection and ionospheric blurring without expending unnecessary effort in determining it exactly, we relaxed the extent constraint to > 3 ;
- instead of a pointing centre distance cut, we cut 150 pixels ($36'$) from the edges of mosaics and any areas where the local RMS noise exceeded 200 mJy beam $^{-1}$ (typically on the Northern edge where Cygnus A is a strong source in the primary beam sidelobes);
- the source density in the mosaics is sufficiently high that imposing a $2'$ “isolation” cut (as performed for the snapshots) can result in the exclusion of real transients, so we adjusted this to best recover transients while not including too many false positives from sources decomposing into multiple objects:
 - within the GC region, the calibration and imaging quality motivated a $112''$ radius and exclusion of groups size 2 or more;
 - the SP region had higher imaging and calibration quality enabling a $60''$ radius and the exclusion of groups of size 3 or more;
- as the image quality was generally higher in the mosaics than the snapshots, we reduced the cuts to select variable sources to:

- $\eta > 2$;
- $V > 0.3$;
- mean “on” $S/\sigma > 5.5$,

then inspected the candidates visually using light curves and animations, as per Section 2.4.

2.6 Deep mosaic

By combining our accumulated $\sim 19,000$ 5-minute snapshots with inverse-variance weighting, we can form a deep image of the Galactic plane at 200 MHz. Since in 2022-A and 2024-A a single calibration solution is applied for each night, and all individual snapshots are only relatively lightly-cleaned (Section 2.2), relative to the large amount of total integration time (~ 320 hours), the resulting mosaics become dominated not by thermal noise, but by a combination of sidelobe and classical confusion, as well as calibration and imaging artefacts. Ionospheric blurring can occasionally be significant, which would increase confusion and decrease image quality if strongly affected snapshots were included in a mosaic.

We can therefore create the cleanest and deepest mosaic by taking a “lucky imaging” approach, selecting only the most high-quality observations to be included. We determine this quality by cross-matching the source-finding results of each snapshot to a catalogue of unresolved sources as determined from the SUMSS and NVSS catalogues; from this subset we calculate the mean integrated to peak flux density ratio; we retain only snapshots where this ratio is < 1.25 . This yields 2,953 snapshots to be mosaicked ($\sim 15\%$ of the total). We then perform the cropping, weighting, and mosaicking steps identically to Section 2.5, with a template covering the full

spatial range of data taken from 2022–2025. A section of this image is shown in the bottom-right panel of Fig. 4.

The mosaic does not have a well-defined PSF as it is formed from such a large range of snapshots, each of which has a unique PSF. This is in contrast to the GLEAM and GLEAM-X surveys, which were deliberately conducted in drift scan modes so that the PSF would be well-defined, and any residual difference between the measured PSF and expected PSF could be attributed to ionospheric blurring, measured, and corrected.

Since the GPM visibilities lack short baselines, and there exists already a deep 200-MHz mosaic specifically produced to reconstruct the multiple spatial scales of the Galactic plane (Mantovanini et al., 2025c), the utility of the mosaic formed in this work is mainly in measuring a slightly ($\sim 2\text{--}3\times$) fainter point source population, as well as qualitatively revealing some of the fainter $\sim 1'$ -scale filamentary structures in Galactic objects such as supernova remnants. This motivates a simplistic approach to characterising the PSF, wherein we simply measure it using unresolved sources, and do not attempt to correct for any ionospheric blurring. This is further supported by our “lucky imaging” approach which should minimise the inclusion of ionospherically distorted data.

Following Hurley-Walker et al. (2017) and Hurley-Walker et al. (2022b) we perform (5σ) source-finding on this mosaic to produce an initial catalogue of 200-MHz sources. We use the RACS-Low 1 survey (Hale et al., 2021) to determine which of these sources are unresolved and are therefore representative of the PSF. We concatenate the two Gaussian component RACS catalogues available from Vizier and select sources at $|b| < 16^\circ$ to match our sky coverage. We then perform internal cross-match on this catalogue to remove all sources that have one or more neighbours within $45''$ (the resolution of the GPM). We also apply Hale et al.’s criteria to select unresolved sources (see their Section 5.2.1), furthermore selecting only sources that are well-fit by one Gaussian ($N_g = 1$), and brighter than 15 mJy (equivalent to 50 mJy at 200 MHz, for a typical spectral index $\alpha = -0.8$). We crossmatch this subset of the RACS catalogue with the initial GPM catalogue, further downselecting to sources in the GPM with $S_{200\text{ MHz}}/\sigma_{200\text{ MHz}} > 10$.

From this combined catalogue of isolated, compact sources, we create a PSF map following previously established methods (Hurley-Walker et al., 2017, 2019, 2022b). We average and interpolate the sources’ major axis θ_{maj} , minor axis θ_{min} , and position angle (PA) measurements, using Healpix (order= 5, i.e. pixels $\sim 1.5^\circ$ on each side) as a natural frame in which to accumulate and average source measurements. These are projected on to a Galactic Cartesian grid for re-use. Fig. 6 shows the final mosaic as well as the associated background, RMS noise, and PSF maps.

We then use the PSF map as an input to a final source-find using AEGEAN, this time using a seed-clip of 4σ and a flood-clip of 3σ , subsequently discarding any source with a signal-to-noise of less than 4.5σ . We discuss the characteristics of the resulting catalogue in Section 3.4.

3. RESULTS

A summary of the detection results for each timescale is shown in Table 2. Here we examine each timescale in more detail.

Table 2. Detection statistics for the different timescale searches performed in this work. The final row does not include the edges of supernova remnants, as these should not be considered real transients or variables.

method	intra-snapshot	inter-snapshot	mosaic
timescale	4s–5 min	5–45 min	hours to days
sources	—	1,227,183	147,329
candidates	1,952	1,206	1,685
detections	119	88	16
transients/variables	6	10	16

3.1 Intra-snapshot search: short-duration transients

By searching the model-subtracted timestep imaging cubes (described in Section 2.3), we detected 1,952 candidate transients across the three epochs of the GPM. All were visually inspected, and most originated from sidelobes around bright sources, the occasional bad frame in an observation, and aliasing from sources from outside of the field-of-view. Since the search covers a large number of ($\sim 19,000$ observations $\times$ 4000 $\times$ 4000 quasi-independent pixels $\simeq 3 \times 10^{11}$) samples, and the noise is not completely Gaussian, we also detected 7–8- σ candidates purely due to noise peaks.

Fig. 7 shows all of the candidate transient pulses, with real transients identified and marked. Table 3 summarises the identified transients; all confirmed sources were detected at least three times. Two bright (> 30 Jy) supernova remnants, SNR G21.8–0.6 and SNR G326.3–1.8, have sharp, distinct shell edges, that tended to ionospherically scintillate depending on the observing conditions. One compact (peaked-spectrum) radio source, NVSS J183537+033151 demonstrated extreme variability in three adjacent observations in 2022-A (Fig. 15f), with an (undersampled) variability timescale consistent with an episode of night-time interplanetary scintillation (not unknown at low frequencies; see e.g. Kaplan et al., 2015). Two pulsars demonstrated detectable variability in 2024-B: and PSR J0820–4114 and PSR J0828–3417. The former has been observed to null for about 30 s every few minutes (Johnston et al., 2021) while the latter is known to switch between “strong” and “weak” emission states (Esamdin et al., 2005).

The main goal of the GPM was to detect LPTs, and in this respect each epoch successfully discovered a unique LPT. In 2022-A we discovered the LPT GPM J1839–10 (Hurley-Walker et al., 2023), that has been active for at least 33 years. Recent work by Horváth et al. (2026) indicates that is likely to be a binary M-dwarf / white dwarf system, although the exact emission mechanism of the radio pulsations remains unknown.

In 2024-A we detected multiple pulses from ASKAP J175534.9–252749 originally discovered by Dobie et al. (2024) as a single bright 2-minute duration burst. Alongside dedicated follow-up, the GPM data confirmed this source as an LPT with a periodicity of 1.16 h (McSweeney et al., 2025).

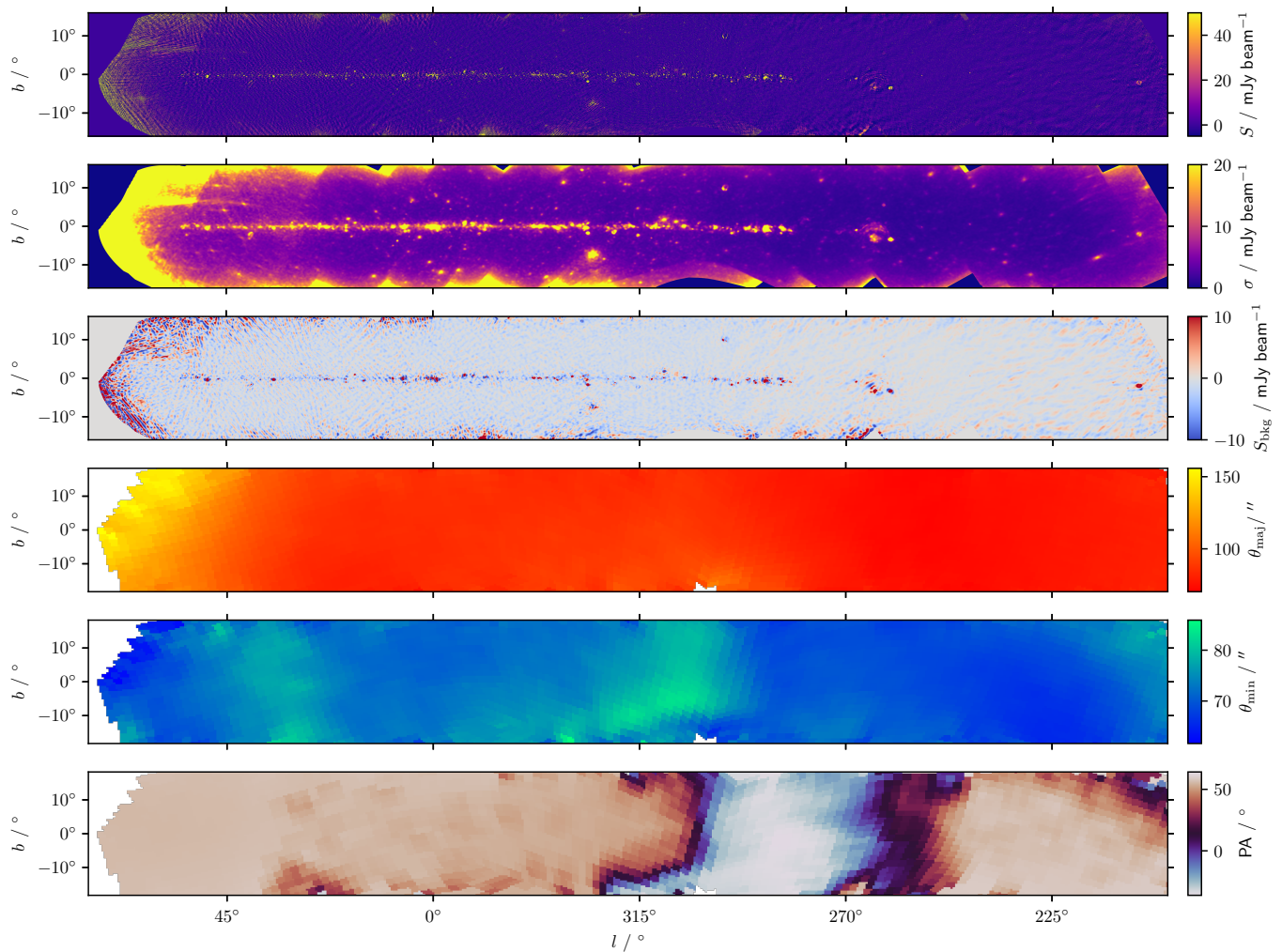


Figure 6. Deep mosaic and its ancillary data. From top to bottom: the deep mosaic, the RMS sensitivity map, the background map, the PSF major and minor axes, and the PSF position angle.

In 2024-B we discovered the LPT GPMJ0715–11 (McSweeney et al. in review), an LPT with a periodicity of ~ 8 min, modulated by a 32.5-hour activity window. The pulses from this LPT are sufficiently short (<1 s) that Romer delay can be measured; combining this with optical observations, McSweeney et al. find that the system is consistent with a white dwarf pulsar in a 32.5-hour orbit around a G-type star.

3.2 Inter-snapshot search: medium-duration transients

Fig. 8 shows the variability metrics η and V for the isolated, compact sources identified as described in Section 2.4. 1,206 candidates passed the $\eta > 5$, $V > 0.5$, and $S/\sigma > 6$ thresholds for visual inspection. Through this process we identified 10 real transient or variable sources, shown in Table 4. The remaining candidates were largely caused by ionospheric phase scintillation and sidelobes from bright sources.

Five of the real transients are known pulsars, with relatively low dispersion measures ($DM < 300 \text{ pc cm}^{-3}$) and typical periodicities $0.25 < P < 1.5$ s. Their light curves display variability without strong patterns, which is intrinsic and due to changes in their emission patterns. PSRJ1853+0505 and PSRJ1717–4054 in particular are well-studied nulling pulsars with multiple modes (Young et al., 2015). PSRJ1703–4851 has demonstrated two emission modes (Johnston et al., 2021), as has PSRJ1107–5907 (Wang et al., 2020), while PSRJ0846–3533 demonstrates three (Wang et al., 2007).

Mantovanini et al. (2025b) recently measured the 72–231 MHz flux densities of 199 Galactic pulsars via mosaics integrating several hours of observing across two years. Their average flux densities at 204 MHz (the closest matching frequency to the GPM) are factors of $\sim 2\text{--}8\times$ lower than the maximum 200-MHz flux densities of the pulsars we measure in our analysis, consistent with the pulsars varying in their emission states. The detections of these pulsars are shown as red hexagons in Fig. 8.

One of the detected transients is a candidate eclipsing binary millisecond pulsar. In the Evolutionary Map of the Universe pilot survey with the Australian SKA Pathfinder (Norris et al., 2021), Zic et al. (2024) discovered ASKAP J164622–440540, and the flux density measurements made with the GPM are analysed and published therein. They demonstrate that the absorption in the eclipsing phase is broader at low frequencies (as is expected for most eclipse mechanisms), and that the spectral index of the source ($\alpha = -2.7$) is consistent with the millisecond pulsar population. The detections of this source are shown as green diamonds in Fig. 8.

The remaining four sources detected in this search were long-period radio transients, shown as gold stars in Fig. 8. Three are published sources; for ASKAP J175534.9–252749.1 and GPMJ1839–10, the GPM was critical for determining the periodicity and other properties such as spectral index, scattering, and polarisation (Hurley-Walker et al., 2023; Dobie et al., 2024; McSweeney et al., 2025, see also Section 3.1). ASKAP J183950.5–075635.0 has not previously been detected at 200-MHz; indeed, only three days after this blind detec-

tion, follow-up observations with the MWA failed to reveal the source, despite a contemporaneous detection at GHz frequencies (Lee et al., 2025). Unfortunately, there were no GHz measurements contemporaneous to this detection in the GPM, so it is not clear whether it is the spectrum or the brightness of the source that varied to the point where it changed its detectability between these two measurements.

ASKAP J172755–343116 was detected blindly by the GPM as a double-peaked pulse across a 45-minute integration at 2024-07-15 at 12:35 UTC (Fig. 17a). It was also independently discovered by the VAST Collaboration using ASKAP. To date, only seven detections of this source have been made (including the one described here), yielding a preliminary periodicity estimate of 4.3 hours (priv. comm. VAST collaboration). A forthcoming publication will investigate this source in further detail.

3.3 Mosaic search: long-duration transients

Searching the mosaics via the methods described in Section 2.5 yielded 1,685 candidates; within these we detected 16 significantly variable astronomical objects: eight known pulsars, seven candidate or confirmed eclipsing binary millisecond pulsars, and the LPT GPMJ1839–10, which has been described in Section 3.1 and Section 3.2. Table 5 summarises the sources detected via the mosaics and Fig. 10 illustrates their variability statistics in context with the other sources. In the following sections, we discuss the two types of pulsars selected by this search and their variability characteristics.

3.3.1 Eclipsing binary millisecond pulsars

Four of these sources were blindly discovered by the GPM: PSRJ1723–3342, GPMJ1734–28, GPMJ1752–30, and GPMJ1815–14. These sources were followed up by Petrou et al. (2025) with a range of observations, determining that the sources have negative spectral indices ($\alpha \sim -2.5$) and γ -ray source associations in the *Fermi*-LAT fourth source catalog data release 2 (4FGL; Abdollahi et al., 2020; Ballet et al., 2020). After phase-folding the data, orbital periods of $\sim 5\text{--}20$ hours are obtained; taken together, these attributes are consistent with newly-discovered eclipsing binary millisecond pulsars (MSPs). PSRJ1723–3342 has been successfully detected as an MSP with MeerKAT, and the other sources are subjects of an ongoing search for pulsations.

PSRJ1740–2650 was identified by Frail et al. (2016) as a strong candidate binary MSP; phase-folding the GPM data resulted in the detection of an orbital period of 9.77 hr, motivating follow-up observations with MeerKAT at inferior conjunction, resulting in the detection of a $P = 1.83$ ms pulsar (Hyman et al., 2025). As discussed in Section 3.2, ASKAP J164622–440540 was also blindly detected in the GPM, independently discovered with ASKAP, and the GPM measurements for that source are published by Zic et al. (2024).

PSRJ0955–3947 was confirmed as a pulsar using MeerKAT observations by the TRAPUM project, who are carrying out a progressive campaign to search for radio pulsations from unassociated *Fermi* sources (Thongmeekom et al., 2024). Folding

Table 3. Compact objects blindly detected as variables or transients within the 5-minute snapshots; see Fig. 7 for their locations and Section 3.1 for discussion. Where possible, references for the sources' original discovery and their most recent accurate position are given in the references column (in that order). The flux density at 200 MHz is calculated from its brightest appearance in all of the snapshots (Section 2.3; see Appendix 1 for plots). Uncertainties are dominated by the flux density scale error (10 %) but as these are all variable sources, the flux density is only indicative. The top part of the table shows known intrinsically-variable pulsars; the bottom section shows detections of long-period radio transients. Example light curves for each of these sources are shown in Appendix 2.

Name	Max $S_{200\text{ MHz}}$ mJy	Number of detections	Refs.
PSR J0820–4114	300	26	Manchester et al. (1978); Lower et al. (2020)
PSR J0828–3417	1,300	57	Manchester et al. (1978); Hobbs et al. (2004a)
GPM J0715–11	430	9	McSweeney et al. submitted
ASKAP J175534.9–252749.1	880	10	Dobie et al. (2024); McSweeney et al. (2025)
GPM J1839–10	1,800	14	Hurley-Walker et al. (2023)
NVSS J183537+033151	980	3	Large et al. (1981); Condon et al. (1998)

Table 4. Sources detected as variables in the 5–45-minute searches. Where possible, references for the sources' original discovery and their most recent accurate position are given in the references column (in that order). The flux density at 200 MHz is calculated from its brightest appearance in all of the snapshots (Section 2.4). Uncertainties are dominated by the flux density scale error (10 %) but as these are all variable sources, the flux density is only indicative. The top part of the table shows known intrinsically-variable pulsars; the second section shows a candidate eclipsing binary MSP where clear eclipsing behaviour is noted. The bottom section shows detections of long-period radio transients.

Name	Max $S_{200\text{ MHz}}$ mJy	Number of detections	Refs.
PSR J0846–3533	130	2	Manchester et al. (1978); Keith et al. (2024)
PSR J1107–5907	175	2	Lorimer et al. (2006)
PSR J1703–4851	100	1	Manchester et al. (1996); Keith et al. (2024)
PSR J1717–4054	230	11	Johnston et al. (1992)
PSR J1853+0505	150	2	Hobbs et al. (2004b)
ASKAP J164622–440540	220	4	Zic et al. (2024)
ASKAP J172755–343116	330	1	VAST Collaboration, in prep.
ASKAP J175534.9–252749.1	250	7	Dobie et al. (2024); McSweeney et al. (2025)
GPM J1839–10	900	16	Hurley-Walker et al. (2023)
ASKAP J183950.5–075635.0	160	1	Lee et al. (2025)

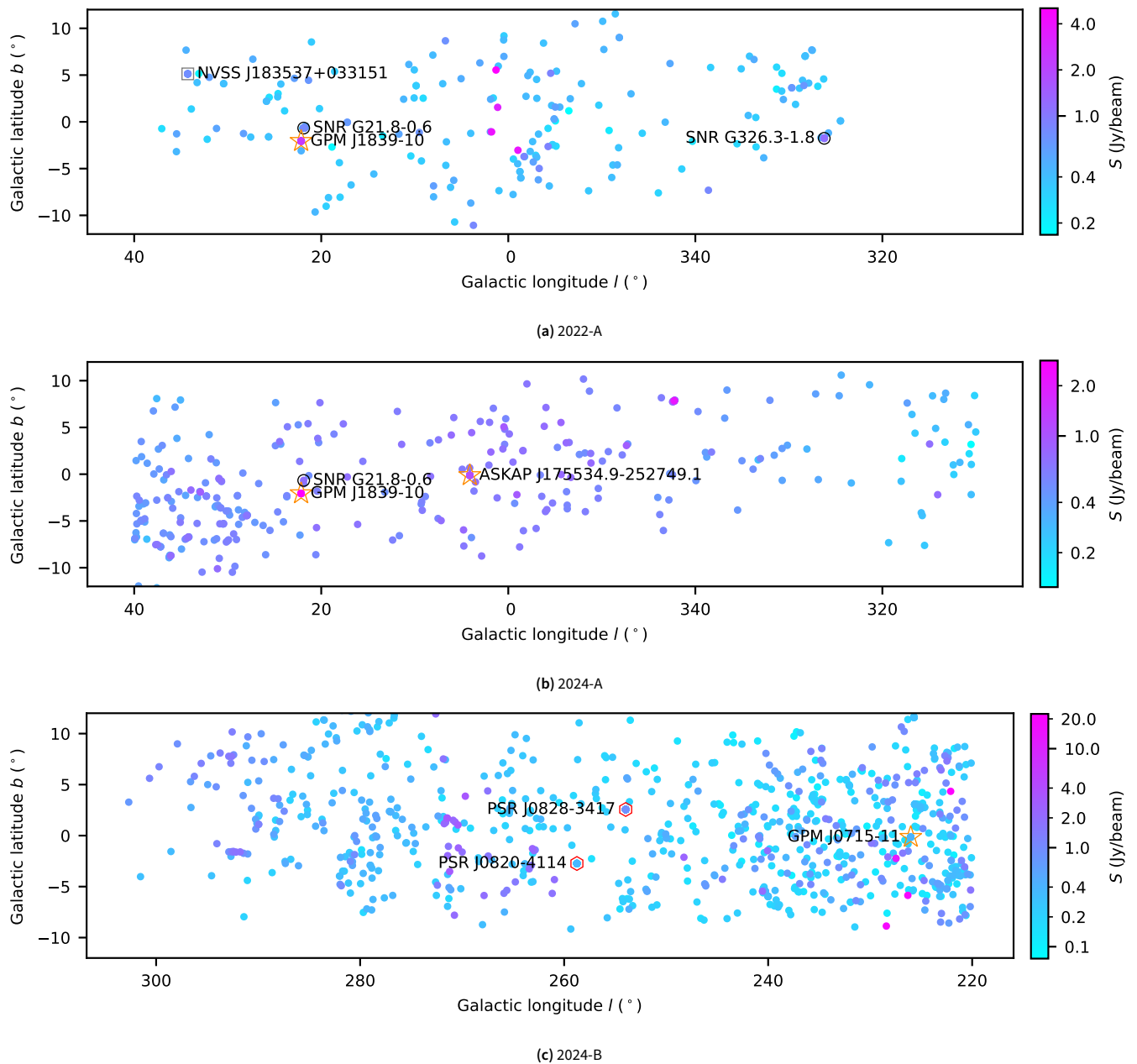


Figure 7. Candidates detected within 5-minute observations in each epoch of the GPM, using the techniques described in Section 2.3. Real transients and variables, or the edges of supernova remnants that contaminate the results are marked and labelled, and are discussed in Section 3.1. LPTs are highlighted with gold stars, variable pulsars with red hexagons, and the single night-time IPS source with a grey square.

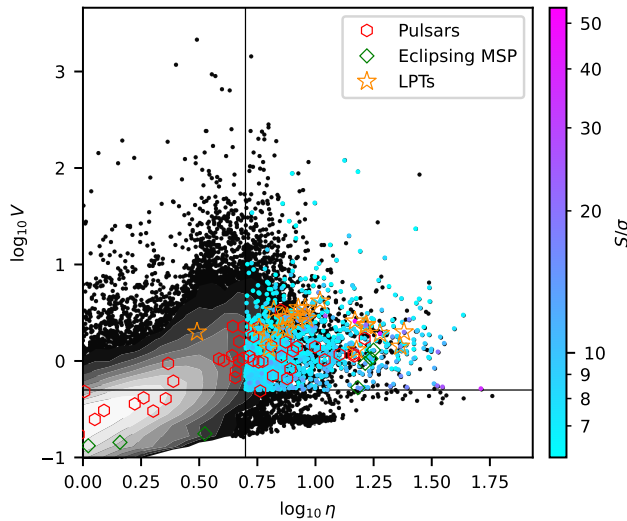


Figure 8. Variability analysis for the 5–45-minute timescale probed by comparing sources found in 5-minute snapshots within a 30–45-minute pointing (Section 2.4), using the metrics η (Equation 1) and V (Equation 2). The grey contours are in log density, in order to indicate the location of the majority of non-variable sources ($\sim 10^6$ objects). The coloured points indicate the 1,206 candidates that passed the $\eta > 5$ (vertical line), $V > 0.5$ (horizontal line), and $S/\sigma > 6$ threshold for visual inspection. Red hexagons highlight pulsars, gold stars highlight LPTs, and the eclipsing binary MSP candidate is marked with a green diamond. Sources are detected multiple times, so these markers include both the detections of significant variability (within the top right region) and all other detections (elsewhere). Source details are shown in Table 4.

the GPM detections on Thongmeeakom et al.’s published orbital period and phase-referencing to their time of ascending node yields a clear eclipsing pattern (Fig. 9) similar to the pulsars seen in GPM data published by Petrou et al. and Zic et al..

3.3.2 Variable pulsars

Three of the pulsars identified as variable in the mosaics are known nulling pulsars: PSR J0828–3417 is well-known to enter phases of producing bright bursts, followed by long windows of much fainter, more intermittent and bursty activity (Esamdin et al., 2005; Burke-Spolaor et al., 2012); PSR J1717–4054 intermittently nulls on various timescales (Kerr et al., 2014); and PSR J1853+0505 switches between three different emission states (Young et al., 2015). While the variability identified by our transient pipeline is consistent with the known behaviour of these pulsars, it offers little additional insight due to the long integration times of the data relative to the nulling timescales of the pulsars (as short as minutes) or indeed their spin periodicities ($\sim$ seconds).

The remaining five pulsars are not known to have changing emission states. The flux density variability measured by the GPM is more smoothly-varying and less stochastic, typified by small (~ 10 –30%) variations on timescales of weeks and sometimes larger (~ 80 –90%) variations on timescales of years (see Fig. 19 for plots). Since these are all bright, relatively well-studied pulsars with no reported nulling behaviour,

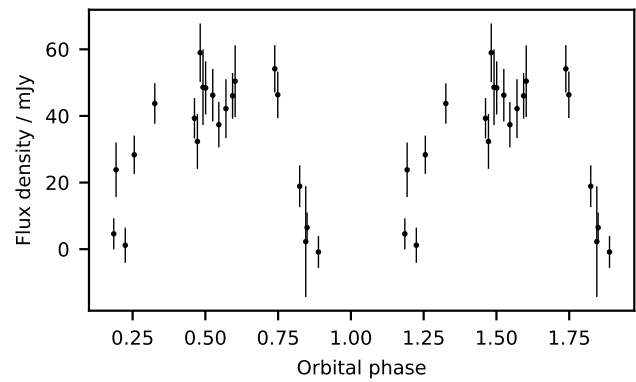


Figure 9. Flux density measurements of PSR J0955–3947 using night-long mosaics of GPM data, folded on the orbital period $P_{\text{orb}} = 0.387339$ days and time of ascending node $T_{\text{asc}} = 58097.44433$ (MJD) derived from MeerKAT timing data (Thongmeeakom et al., 2024). Orbit-dependent eclipses typical of absorption of radio pulses by material from an ablated companion are clearly visible. The unfolded data are shown in Fig. 18a.

the observed variability in our data is likely to be caused by scintillation by the intervening interstellar medium.

Diffractional interstellar scintillation (DISS) has been measured for two pulsars in this group: PSR J1430–6623 was measured by Johnston et al. (1998) to scintillate on 93-s timescales at 660 MHz, and PSR J1559–4438 was measured by Deller et al. (2009b) to scintillate on 77-s timescales at 600 MHz. Observations at lower frequencies should result in faster timescales of DISS (see e.g. Bhat et al., 2014), and this is therefore ruled out as the cause of the flux density variation on the observed long timescales for these two objects, and most likely for the other sources.

On the other hand, refractive interstellar scintillation (RISS) should produce flux density variations on timescales of 1–20 years at these positions (Hancock et al., 2019), purely from the Earth’s relative motion. However, pulsars typically have velocities $O(100) \text{ km s}^{-1}$ (Hobbs et al., 2005), a factor of a few greater than Earth’s relative velocity. This decreases the expected timescale of RISS to several weeks – a few years. This is consistent with the observed flux density variations of these pulsars (see Table 5 for a summary).

3.4 200-MHz catalogue

Source-finding on the mosaic yields a catalogue of 206894 sources with a peak flux density to local RMS noise (signal-to-noise) value greater than 4.5. However, this includes some areas with poor-quality imaging, largely due to the sidelobes of bright sources. The 175906 sources that lie within $210^\circ < l < 50^\circ$ and $|b| < 13^\circ$ are used for onward analysis in this section; the other 30988 sources are made available, but marked in the catalogue (Table 9) as having low data quality and should be used with caution.

3.4.1 Astrometry

We cross-match the (high-quality subset of the) catalogue sources with the compact, isolated RACS catalogue used in Sec-

Table 5. Sources detected as variables in the mosaic searches. Where possible, references for the sources’ original discovery and their most recent accurate position are given in the references column (in that order). For all objects excepting the RISS detections, the timescale of variability ($= P_{\text{orb}}$ for eclipsing binary MSPs) is sourced from the referenced papers. The flux density at 200 MHz is the average flux density of the source when it is blindly detectable in the mosaics, i.e. not including forced photometric measurements (Section 2.5). Uncertainties are dominated by the flux density scale error (10 %) but as these are all variable sources, the flux density is only indicative. The top part of the table shows non-eclipsing pulsars; the second section shows confirmed (prefixed by “PSR”) and candidate eclipsing binary millisecond pulsars; the bottom section shows detections of a long-period radio transient. Light curves for individual sources are shown in Fig. Appendix 3.

Name	$\bar{S}_{200 \text{ MHz}}$ mJy	Cause of variability	Timescale	Refs.
PSR J0828–3417	410	nulling	hours	Manchester et al. (1978); Hobbs et al. (2004a)
PSR J1430–6623	150	RISS	months	Large et al. (1968); Jankowski et al. (2019)
PSR J1559–4438	70	RISS	months	Vaughan & Large (1972); Deller et al. (2009a)
PSR J1717–4054	100	nulling	hours	Johnston et al. (1992)
PSR J1751–4657	200	RISS	weeks	Vaughan et al. (1969); Keith et al. (2024)
PSR J1823+0550	110	RISS	months	Manchester et al. (1978); Keith et al. (2024)
PSR J1823–3106	110	RISS	years	Manchester et al. (1978); Keith et al. (2024)
PSR J1853+0505	70	nulling	minutes	Hobbs et al. (2004b)
PSR J0955–3947	45	eclipsing	9.30 hr	Thongmeeakom et al. (2024)
ASKAP J164622–440540	220	eclipsing	5.3 hr	Zic et al. (2024)
PSR J1723–3342	60	eclipsing	5.15 hr	Petrou et al. (2025)
GPM J1734–28	40	eclipsing	20.11 hr	Petrou et al. (2025)
PSR J1740–2650	30	eclipsing	9.77 hr	Hyman et al. (2025)
GPM J1752–30	40	eclipsing	17.86 hr	Petrou et al. (2025)
GPM J1815–14	110	eclipsing	9.82 hr	Petrou et al. (2025)
GPM J1839–10	70	pulsations	22 min	Hurley-Walker et al. (2023)

tion 2.6 to correct the astrometry on a snapshot basis. Fig. 11 shows the results, with the median offsets between the catalogues $\Delta\text{RA} = -17 \pm 830 \text{ mas}$ and $\Delta\text{Dec} = 9 \pm 854 \text{ mas}$; the uncertainties are $1-\sigma$ (unweighted standard deviation) of the offsets in each direction. This is a lower uncertainty than the typical astrometric uncertainty of the RACS catalogue itself ($\sim 2''$), which is currently being updated to better-match the International Celestial Reference Frame (Duchesne et al., priv. comm.).

3.4.2 Flux density scale, PSF, and noise properties

As discussed in Section 2.6, the flux density scale was matched to that of GLEAM-X: GP (Mantovanini et al., 2025c); to test whether this was successfully preserved through the mosaicking and source-finding, we cross-match again to the GLEAM-X: GP catalogue and present the measured flux density ratio as a function of signal-to-noise in Fig. 12. We also test whether the PSF determination was successful by plotting the ratio of the integrated to peak flux densities as a function of signal-to-noise. There are no unusual trends and we conclude that the flux density scale is correctly matched, and the PSF is well measured.

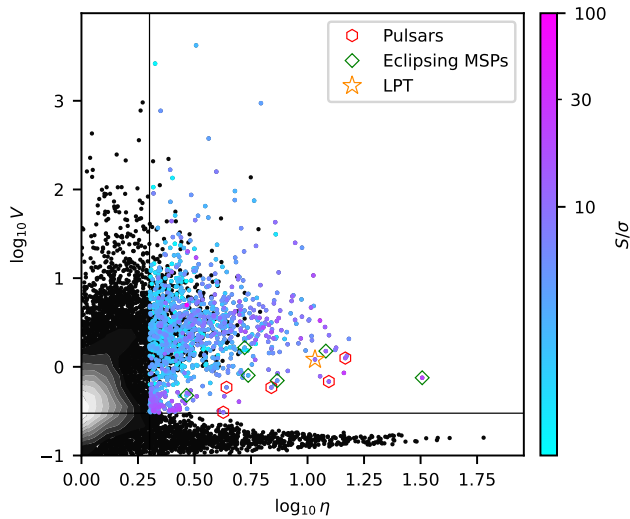
In Fig. 13 we show the median and inter-quartile ranges of the RMS noise as a function of Galactic longitude. In general the noise is slightly lower than that of the GLEAM-X: GP catalogue, particularly around the Galactic Centre. However, this comes at the cost of poor recovery of diffuse emission (angular scales $\gtrsim 2'$).

4. DISCUSSION

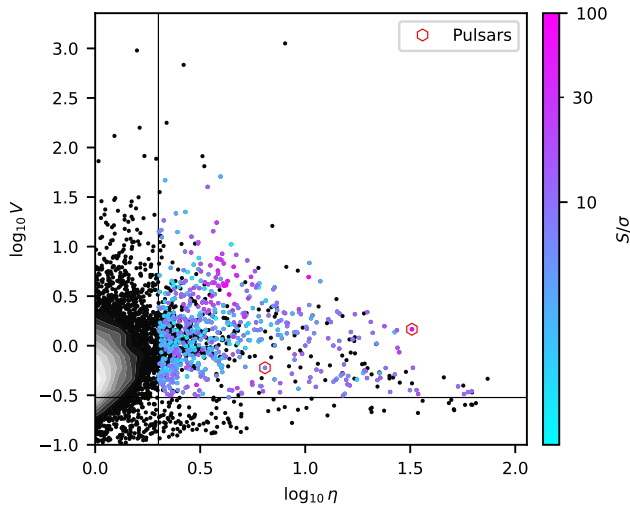
4.1 Effectiveness of survey strategy

The original survey strategy of the GPM (epoch 2022–A) was formulated shortly after the discovery of the first LPT with the MWA (Hurley-Walker et al., 2022a). The goal was to survey the largest Galactic volume observable at night in that semester, with dwell times sufficient to find sources of that periodicity (18 min). At that time, the only other object that could guide the survey strategy was the Galactic “Burper” (Hyman et al., 2005); their unifying feature being a transient activity window of order weeks to months, motivating continuous monitoring on at least a weekly cadence. Subsequently-discovered LPTs have periodicities *longer* than 18 min, and at least a handful of (mostly unpublished) examples have been seen to be active for less than two weeks (Rea et al., 2026).

These factors potentially motivate a future survey strategy of integrating for longer (to pick up longer-period sources) and more frequently (to catch sources with a transient activity window). Of course, for a real telescope, there is only so much time available per night, and the only way to increase both of these terms is to increase the field-of-view of the instrument. This is difficult, as the MWA is already almost as wide-field as is practical at these frequencies; any wider and the deleterious effects of bright sources on the (chromatic) edges of the main lobe, and the computational cost of imaging extremely large fields-of-view, would become challenging. Forming multiple beams that avoid (null) bright sources and tiling a large area, potentially targeting areas of lower scattering, will be possible with the SKA-Low, and may be an effective way of increasing



(a) 2022-A & 2024-A (Galactic Centre region)



(b) 2024-B (Southern Plane region)

Figure 10. Variability analysis for the days to months timescale probed by comparing sources found in integrated mosaics over several semesters of observing (Section 2.5), using the metrics η (Equation 1) and V (Equation 2). The top panel shows the analysis for the mosaics in the semesters 2022-A and 2024-A, covering the Galactic Centre region; the bottom panel shows the analysis for the mosaics in semester 2024-B, covering the Southern Galactic Plane. The grey contours are in log density, in order to indicate the location of the majority of non-variable sources ($\sim 10^5$ objects per panel). The coloured points indicate the 1,080 (top) and 605 (bottom) candidates that passed the $\eta > 2$ (vertical line), $V > 0.3$ (horizontal line), and $S/\sigma > 5.5$ threshold for visual inspection. Red hexagons highlight variable pulsars, green diamonds highlight (candidate and confirmed) eclipsing binary MSPs, and the gold star highlights the single detected LPT. Source details are shown in Table 5.

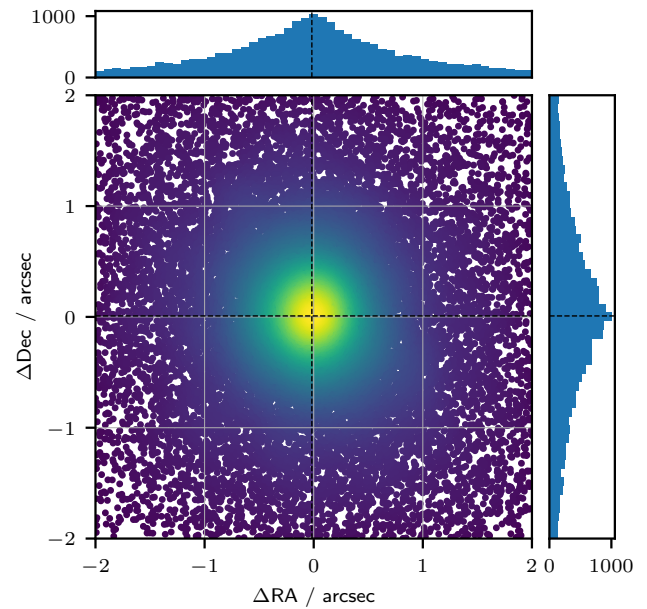


Figure 11. Astrometric offsets of the final deep 200-MHz GPM catalogue from the RACS DR-1 catalogue in RA and Dec. Source density is shown as an arbitrary colour axis. The upper and right histograms show the (unweighted) distributions of offsets in RA and Dec, respectively. The dashed lines show the median offsets in each direction ($\Delta\text{RA} = -17$ mas; $\Delta\text{Dec} = 9$ mas).

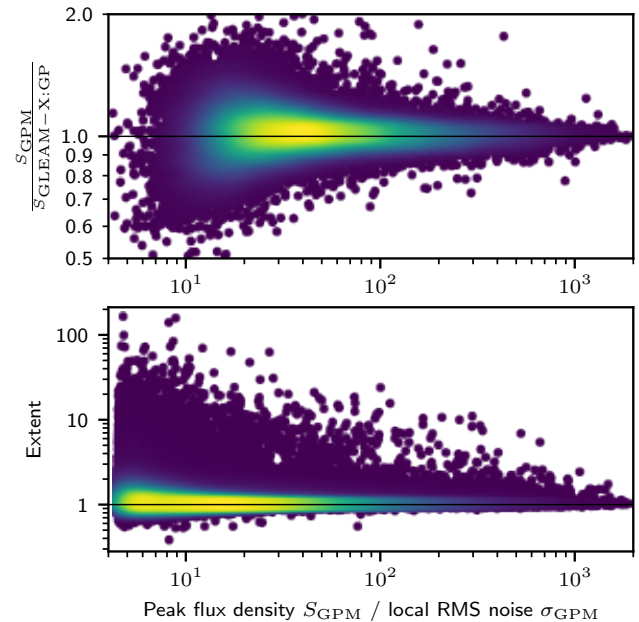


Figure 12. Flux density ratio of the GPM catalogue to the fitted 200-MHz flux densities from GLEAM-X: GP (Mantovanini et al., 2025c), and the ratio of the integrated to peak flux densities (“extent”) of the GPM catalogue, both plotted as a function of signal-to-noise in the GPM. The density of points is shown with an arbitrary linear colour scale. The horizontal line is drawn at a ratio of unity, where the source density is highest, as expected.

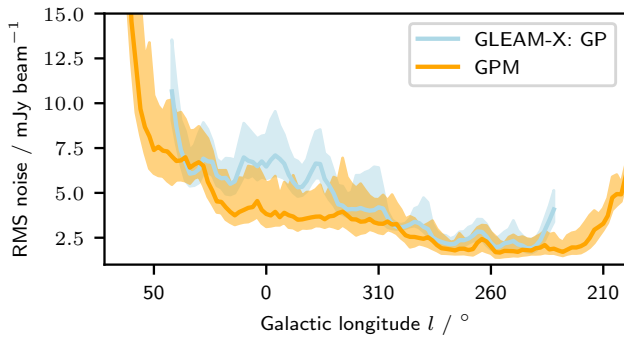


Figure 13. Local RMS noise levels of the deep mosaic, compared to those of the 170–231 MHz source-finding image from GLEAM-X: GP (Mantovanini *et al.*, 2025c). For each survey, the solid lines show the median values and the filled region spans the 25th and 75th percentiles (the 1st and 3rd inter-quartile ranges).

the yield of transient detections.

In the meantime, a complementary survey strategy in a future epoch of the GPM could be to perform longer tracks (~ 4 h) on particular Galactic longitude pointings, and iterate over the Galactic plane over the course of a week. This would start to fill in the unprobed parameter space indicated by the gap between the grey and red shaded regions in Fig. 1. It would have the added advantage of being more likely to clearly detect ingress and egress of eclipsing binary millisecond pulsars, which are otherwise only selected by having highly variable light curves. The orbital periods derived therefrom would be far more accurate; the 2022–A GPM epoch enabled the detection of several new eclipsing binary MSPs (Table 5) but the initial periodicities determined from those initial 18 epochs were incorrect, and only converged on consistent periodicities once follow-up was performed (Petrone *et al.*, 2025) and more samples were obtained in 2024–A.

Northern ($l > 40^\circ$) pointings were not effective uses of observing time due to the low primary beam sensitivity and the challenge of Cygnus A, and could be dropped from future observing. The spacing of 13° in longitude was sufficient and easier to schedule than 7° so would be a good choice to maintain over the Galactic plane.

Reflecting on the spatial distribution of the detected transient and variable objects (Fig. 2), it is clear that despite the higher Galactic scattering expected at low Galactic latitudes, the yield of new eclipsing binary MSPs and LPTs was highest towards low Galactic latitudes, and especially around the Galactic centre. This is perhaps surprising since these areas are some of the most intensively surveyed by existing pulsar and transient surveys, but clearly the low-frequency image-domain searches pursued in this work have accessed a new population that is not well-selected by other searches: these sources are faint at high frequencies, and produce emission on long timescales which are selected against by the short dwell times and fast-transient oriented processing backends of most Galactic surveys.

Nevertheless, the GPM is very unlikely to detect any further eclipsing binary MSPs (or other well-known objects such

as nulling pulsars, or “persistent” LPTs Hurley-Walker *et al.*, 2023) at its current sensitivity levels. Potentially, the MWA Phase III upgrade, with a full 256 tiles correlated (Tingay *et al.* in review), could more than double the sensitivity^d since only ~ 100 tiles were functioning during the GPM observing (Table 1). Given most of the “new” tiles in Phase III are in a centrally-condensed core that would generate mostly relatively short baselines, care would need to be taken to select the correct imaging parameters in order to remove or properly-deconvolve the diffuse emission in the Galactic plane, that could otherwise complicate onward source association and transient detection. Indeed, doubling the sensitivity would reveal more than double the number of sources, exponentially increasing the challenge of source association, perhaps requiring better calibration, and better treatment of ionospheric effects, than undertaken in this work.

Regarding “transient transients” such as LPTs, further epochs are of course potentially able to find further examples, should they become active. This would need to be weighed against the processing costs of running such searches, as well as the potential of exploring other areas of sky. As shown by Fig. 1 of Rea *et al.* (2026), several LPTs lie at relatively high Galactic latitudes, so even if the yield is low, a comprehensive search of both the MWA archive, and a new survey exploring a wide area of high-latitude sky, could be effective methods for finding new LPTs. Potentially, LPTs (or transients on similar timescales) could exist and be detectable at extragalactic distances (e.g. Anpilov & Tyul’bashev, 2026); if so, they will be rare, and will require the search of large volumes of (preferably high-latitude) data. Efforts in these directions are currently underway.

4.2 Effectiveness of detection methods

Unusually for most transient surveys (Murphy & Kaplan, 2026), the GPM explores a very large range of timescales, ranging from 4 s all the way up to several years, in a relatively well-distributed way (Fig. 1). This descends from the employment of three different detection methods that sample multiple timescales. Since, effectively, “single-pulse” searches were employed, this naturally leads to lower noise (better sensitivity) on the longer timescales (Fig. 13).

Importantly, this leads to the question: *could we make better use of our data?* For example, every transient imaging cube is searched in isolation. However, periodicity (folding) searches for LPTs could stack the data over relatively long integrations per phase bin, potentially revealing faint, periodic sources, below the “single-pulse” threshold. Such searches could be computationally expensive and would require barycentring, but are not infeasible. For a typical cube RMS noise level of $100 \text{ mJy beam}^{-1}$ at 4 s resolution (Table 1), the RMS noise from using all ~ 27 hours of integration per pointing in 2022–A and

^dThis improvement in sensitivity would likely only apply to the intra- and inter-snapshot searches, since the mosaics are largely sidelobe-confused. The integration time is difficult to increase due to the analogue beamformers, and joint deconvolution of multiple integrations is computationally complex (Mantovanini *et al.*, 2025c).

2024-A would be $20\sqrt{\frac{P_{\text{fold}}}{1 \text{ hour}}} \text{ mJy beam}^{-1}$; modulo, this only applies if the LPT is persistently active over the duration of the folded data. Potentially, returning to the visibilities may be even more effective, albeit computationally more challenging (Zic et al., in preparation).

On the longer timescales, we currently treat every pointing separately in the inter-snapshot searches, leading to very sparse light curves, particularly for the 2022-A and 2024-B epochs (30-min integrations). Combining the data across multiple pointings and employing more sophisticated statistics than η and V may yield further transients. Andersson et al. (2025) compared the use of these simplistic metrics with both citizen-science and generic feature classification approaches and found the latter were far more effective in finding real transients. Similar approaches here, necessarily dealing with the large gaps in sampling, may be effective.

4.3 Detections of radio transients

In this section we discuss the selection biases of the GPM in detecting objects of different classes. Fig. 14 shows a Venn diagram of intrinsically variable objects (i.e. not due to scintillation) detected by the GPM, as a function of the three different detection methods employed.

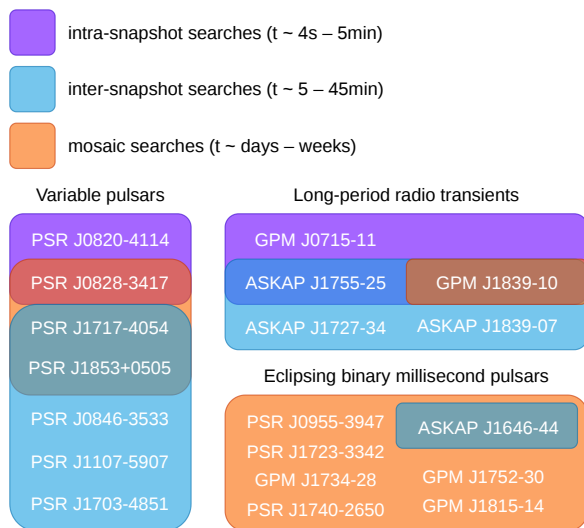


Figure 14. Venn diagram of the different transients and variables detected in this work depending on their detection method.

4.3.1 Eclipsing binary MSPs

The eclipsing binary MSPs are unsurprisingly most easy to discover via the mosaic searches; only ASKAP J1646–44 is bright enough, with a sharp enough ingress/egress, to detect within a single 30–45-minute pointing (Fig. 17e). What is perhaps most surprising is the lack of detections of any *known* eclipsing binary MSPs; PSR J0955–3947 is the only exception to this and was only recently-discovered (Thongmearkom et al., 2024). This indicates that the GPM survey is sampling a

very different population than that sampled by traditional blind pulsar timing searches. The detected systems are likely more highly absorbed (i.e. in closer orbits, with more vigorous ablation of the companion star leading to higher material density), potentially in shorter-period orbits (high acceleration can be challenging for traditional pulsation searches), and will likely have high orbital inclination angles with respect to our line of sight. However, the non-detection of these systems may also point to at least some of them having eclipse durations and depths that are so long at low frequencies, they are rendered entirely invisible to our survey. A careful cross-match of all of our sources (not just those detected as variable) with existing pulsar catalogues could separate these different populations and effects.

The GPM is a blind survey, but after discovery, all of these sources were found to have γ -ray associations. For several decades, various groups have observed the unassociated *Fermi*-LAT sources to search for pulsations, including these objects (e.g. Camilo et al., 2015; Clark et al., 2023). That none were previously detected likely indicates that either the dwell times of these searches were too low, resulting in too low a chance of catching the sources out of eclipse, or the frequency of the observations was too low, such that the ablated companion material dispersed or absorbed the pulsations to the point of undetectability (both effects are stronger at low frequencies; Thompson et al., 1994). A further complicating factor is the poor localisation of the *Fermi* sources; for example, the nearest *Fermi* source to GPM J1734–28 is 4FGL J1734.5–2818, 11' away (c/f the $\sim 5'$ *Fermi* localisation; Petrou et al., 2025). It seems more likely that the current γ -ray localisation is incorrect than there be an even fainter γ -ray source closer by. A radio timing campaign for the GPM-discovered MSPs is currently underway; constrained radio timing will enable γ -ray timing which could conclusively determine an association. In the meantime, our results may motivate longer-dwell-time pulsation searches toward more spatially-separated radio source associations (ideally in combination with other metrics, e.g. compactness and spectral index; Frail et al., 2018). This can require a challenging amount of observing time due to the small fields-of-view of radio telescopes operating at higher frequencies, which are necessary to defeat scattering and absorption effects.

4.3.2 Variable pulsars

Seven intrinsically variable pulsars were detected by the GPM, across all search methods employed. Perhaps surprisingly, the intra- and inter-snapshot searches found no sources in common, whereas the mosaic searches detected pulsars in common with the other two methods. This is particularly noticeable for PSR J0828–3417, which displays very high variability on timescales of seconds (Fig. 15b) when active, but also nulls for hours to days (Fig. 19a). It was observed by 30 different pointings of the GPM but none caught a transition from the null state to active state. This underscores the importance of exploring multiple timescales of variability for maximum return.

Image-plane variance searches for pulsars are an emerging method; e.g. Ahmad *et al.* (2025) imaged multiple timesteps of the EMU survey and looked for high-variance sources, likely compact and scintillating and thus potentially previously undiscovered pulsars. This is a similar approach to the cube analysis performed here, but without the initial field subtraction step. At the current sensitivity levels (~ 100 mJy beam $^{-1}$) of the GPM, such searches are exceedingly unlikely to find pulsars that have not previously been discovered by traditional time-domain searches, particularly at these low and well-searched Galactic latitudes. However, higher latitudes offer more potential; the image-plane search over ~ 1 hr of integration and 10,000 sq deg of GLEAM-X data performed by Horváth *et al.* (2025) discovered a very bright Rotating Radio Transient (RRAT), described in full by Mcsweeney *et al.* (2025). Deeper and longer-integration searches may yet yield results, although widefield beamforming searches such as the SMART survey (Bhat *et al.*, 2023) are more likely to be more successful in finding standard pulsars due to the large sensitivity boost of pulsar gating.

We also blindly detected five known pulsars via their RISS (Section 3.3, Table 5). This is not an efficient search method for new pulsars at low frequencies due to the very long timescales that need to be monitored. However, the GPM mosaic measurements could be used to constrain RISS from other pulsars. For example, cross-matching the GPM mosaic candidates (before any selection on η or V) with the ATNF pulsar catalogue (Manchester *et al.*, 2005)^e, for those pulsars with measured 400-MHz flux densities (as a proxy for being visible at low frequencies) yields 136 matched objects. In combination with other measurements, the degree of RISS in the GPM may help constrain the turbulent electron content of our Galaxy.

Additionally, traditional pulsation searches often ignore the total flux density of pulsars on timescales longer than the observation, with a focus usually only on distinguishing between various emission states identified by changes in pulse profile shape. Potentially, examination of the GPM data toward the cross-matched pulsars might identify mode-switching pulsars via sharp changes in flux density, which could motivate further pulsation observations to determine what those states are.

4.3.3 Long-period radio transients

The science motivation of the survey was to detect new long-period radio transients, in particular to employ the intra-snapshot search methods developed by Horváth *et al.* (2025) specifically on the Galactic plane, where in theory the source density should be highest. All three methods successfully recovered LPTs, with the mosaic search being (unsurprisingly) least sensitive and only capable of detecting the brightest source, GPM J1839–10.

The two longest-period sources, ASKAP J1727–34 ($P \sim 4$ hr) and ASKAP J1839–07 ($P \sim 6$ hr), were only detected once each, in the inter-snapshot search, and both have become dimmer since discovery (priv. comm. VAST collaboration). This is similar behaviour to the first LPT discovered with the

MWA, GLEAM-X J1627–52, which was only detectable for three months in 2018. However, this source had a much faster period of 18 minutes, rendering it much more likely to be detected. As discussed in Section 4.1, this “transient transient” behaviour motivates continuous, repeated monitoring of the Galactic plane, with dwell times longer than those accomplished by the GPM and better-matched to this long-period population.

One hope for monitoring the Galaxy in a consistent and homogeneous way was the possibility of producing population-level measurements or limits on such sources, even if the detection rate was low. However, over the time that the GPM has been running, various new LPTs have been discovered, several of which are not visible at 200 MHz, potentially due to absorption along the line-of-sight, but also potentially due to intrinsic emission properties. The detection of ASKAP J183950.5–075635.0 in this work, yet its non-detection a few days later during contemporaneous monitoring (and detection) at higher frequencies, demonstrates that either the brightness or spectral index of these sources can change dramatically. Coupling that with extremely variable windows of emission (from weeks to decades) and a wide range of periodicities, and the detection of further modulating periodicities in some sources (e.g. Horváth *et al.*, 2026), there are too many possible variable parameters for the non-detections in the GPM to be particularly constraining. At best, we can suggest a rate of ~ 0.1 LPTs per month per 1,000 sq. deg. of Galactic plane monitoring using the strategies pursued here, with avenues for improvement in survey strategy largely discussed in Sections 4.1 and 4.2.

4.4 Future processing

4.4.1 Polarisation

The searches described in this work were carried out in Stokes I, but the MWA observes in full polarisation, has been used to measure the polarisation properties of both LPTs (Hurley-Walker *et al.*, 2022a) and flare stars (Lynch *et al.*, 2017). Blind linear polarisation searches are (currently) computationally infeasible as the effects of Faraday Rotation from the magnetic interstellar medium would need to be corrected, necessitating costly frequency-domain imaging and Rotation Measure (RM) trials. Circular polarisation (Stokes V) is a viable search method, resulting in decreased sky noise and much-reduced CLEANING requirements due to the dearth of circularly-polarised sources casting sidelobes across the imaged field-of-view. For instance, Lenc *et al.* (2018) reprocessed the 170–231 MHz part of the GLEAM survey over 30,900 sq. deg. to produce a southern-sky Stokes V survey, blindly detecting 14 pulsars and 6 artificial satellites. At mid-frequencies, circular polarisation searches are revealing new populations of highly scattered and faint pulsars (Sengar *et al.*, 2025a,b). Stokes V can also detect novel transients (Wang *et al.*, 2021). This motivates testing the utility of reprocessing the GPM data in Stokes V.

A brief initial investigation of the GPM data found that Stokes V imaging reduces noise levels in the resulting mosaics by 30%, and the snapshots by 50%, while the noise levels of

^eVersion 2.7.0: <https://www.atnf.csiro.au/research/pulsar/psrcat/>

the cubes are largely unaffected (Y. Low, Hons thesis, Curtin University). This implies that the continuum subtraction is already very effective at reducing the noise to approximately thermal limits in the transient cubes, but that the snapshots are highly dominated by imaging and calibration artefacts, and the mosaics somewhat less so (consistent with what is seen in Fig. 4).

For 100% circularly-polarised sources, these sensitivity improvements would directly result in improved detection statistics. However, most pulsars and LPTs have only fractional (~ 1 –50%) circular polarisation, which would decrease the utility of such searches. Stellar bursts can be very highly circularly-polarised, but are also likely to be much fainter than the noise levels achieved by the GPM, the noise budget of which is dominated by the high sky temperature towards the Galactic plane and (relatively) low number of functioning tiles. Localisation of such bursts would also be extremely challenging given the arcminute spatial resolution of the survey and the high stellar density at low Galactic latitudes. For serendipitous novel transients, there is still potential in reprocessing the data. However, these polarisation search techniques may be better employed at higher latitudes in other upcoming MWA surveys.

4.4.2 Full time resolution

To make the computation of the GPM feasible, and to quickly achieve our primary goal of detecting LPTs with 30–60-s long pulses, the processing described in this work was undertaken at 4-s time resolution (Section 2.2). The discovery of GPMJ0715–1142, the pulses of which are only ~ 1 s long, potentially motivates a reprocessing of the data at full time resolution (0.5 s). Obviously, this would impose a factor of 8 increase in the cost of most processing tasks, particularly imaging. The noise levels of the individual time-steps would also increase by a factor of $\sqrt{8} \sim 2.8$ which would need consideration as to whether it is worth the increased cost. A search for short-duration pulses could also motivate de-dispersion of the data, and we briefly examine the main considerations here.

We consider a pulse of duration 0.5 s observed across the 185–215 MHz bandwidth, and calculate that at a DM of 44 pc cm^{-3} , it would be reduced in S/N by the above factor of 2.8 (i.e., would not be any more detectable without dedispersion at 0.5-s time resolution than in our current 4-s search). Sources of higher DM would be commensurately more affected. However, interstellar scattering is strong at low frequencies and could still render such sources undetectable even with de-dispersion. Bhat et al. (2004) determined an empirical correlation between DM and scattering timescale which we use as a model (their Equation 7). At $\text{DM}=245 \text{ pc cm}^{-3}$, the scattering timescale reaches 0.5 s. Thus, if image-plane dedispersion techniques are used, they would only improve the signal-to-noise of a subset of sources with narrow ($\lesssim 4$ -s) pulses, within a DM range of ~ 44 – 245 pc cm^{-3} .

Implementations of such techniques exist (e.g. Anderson et al., 2021; Di Pietrantonio et al., 2026, or the LOfar Ra-

dio Dedispersion Software^f) and typically utilise GPUs for rapid computation. Potentially, the more expensive stage of the processing would be generating the multi-channel images required to perform the dedispersion. For a 0.5 s pulse at $\text{DM}=245 \text{ pc cm}^{-3}$, the 24 MWA “coarse” channels of 1.28-MHz would need to be imaged to avoid significant in-channel DM smearing, which would increase the imaging computational and storage costs by a further factor of 24; i.e. the total costs would increase by a factor of nearly 200, even before the cost of running the dedispersion trials and ensuing transient searches. In future, if further LPTs with narrow pulse widths are found by dedicated fast-transient searches such as CRACO and SMART, it will be possible to make a more informed cost/benefit analysis of a full-time resolution reprocessing, including dedispersion.

5. Conclusions

We have presented the Galactic Plane Monitor, a widefield image-plane transient survey at 200 MHz. The survey has blindly detected several new transients: four candidate eclipsing millisecond pulsars (all discussed and one confirmed by Petrou et al., 2025), and two new LPTs (Hurley-Walker et al., 2023, McSweeney et al. in review). Additionally it has co-discovered one as-yet unpublished LPT (ASKAPJ1727–34, VAST Collab. in prep), determined the periodicity of a newly-discovered LPT (McSweeney et al., 2025), and contributed measurements to two further co-discovered eclipsing binary millisecond pulsars (Zic et al., 2024; Hyman et al., 2025). We have blindly re-detected 13 known pulsars: one eclipsing binary millisecond pulsar, seven mode-switching/nulling pulsars, and five pulsars through high variability induced by RISS. We also note that the deep mosaic has been used to find new supernova remnants (Mantovanini et al., 2025a) and offers a complementary, slightly deeper view of the Galactic plane to the GLEAM-X: GP data release (Mantovanini et al., 2025c).

We suggest several possible uses for the data products of the GPM, such as analysis of the RISS across the Galactic plane via the ~ 136 pulsars detected in the GPM, folding the data to search for fainter LPTs, and blind transient searches using improved algorithms and statistical methods. We also note that non-detections in the GPM can also be useful in constraining the activity window of future discoveries, especially the elusive LPTs (e.g. Pritchard et al., 2026), and the emerging population of image-plane-selected eclipsing binary millisecond pulsars (Wang et al. in prep).

We have motivated possible future improvements or complementary directions to the GPM: longer integrations to find longer-period LPTs, exploitation of the larger number of tiles of the Phase III MWA for better instantaneous sensitivity, and searches at higher Galactic latitudes. We have also discussed potential reprocessing options such as finer-timescale searches including dedispersion, and uses of Stokes V searches, particularly on the 5-minute “snapshot” timescale, which would be synergistic with searches for the most likely generators of highly-

^f<https://gitlab.com/kmrajwade/lordss>

circularly-polarised emission, stellar bursts over timescales of ~ 10 min to several hours.

With the current timeline of SKAO indicating that image-plane transient searches with SKA-Low will only be possible from 2032[§], the MWA continues to offer the best low-frequency time-domain view of the Southern radio sky. This work demonstrates the strength of the MWA in searches for new radio transients in the image plane, and we expect high-latitude searches, as well as a thorough examination of the archive, to yield many more discoveries.

Acknowledgement

We thank the anonymous referee for their constructive feedback, which improved the quality of this research article. We thank Ramesh Bhat for discussions on the nature of pulsar scintillation at low frequencies, Stefan Duchesne and Kathryn Ross for discussions on radio survey processing, and Andrew Williams for his tireless scheduling of our “appallingly complicated” observations.

N.H.-W. is the recipient of an Australian Research Council Future Fellowship (project number FT190100231).

This scientific work uses data obtained from Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory. We acknowledge the Wajarri Yamaji People as the Traditional Owners and Native Title Holders of the observatory site. Support for the operation of the MWA is provided by the Australian Government (NCRIS), under a contract to Curtin University administered by Astronomy Australia Limited. We acknowledge the Pawsey Supercomputing Centre which is supported by the Western Australian and Australian Governments.

A range of python packages were used for this work including *Astropy*, a community-developed core Python package for Astronomy (Astropy Collaboration *et al.*, 2018, 2013); *matplotlib*, a Python library for publication quality graphics (Hunter, 2007) and *NumPy* (Harris *et al.*, 2020).

This research made use of *ds9*, a tool for data visualization supported by the Chandra X-ray Science Center (CXC) and the High Energy Astrophysics Science Archive Center (HEASARC) with support from the JWST Mission office at the Space Telescope Science Institute for 3D visualization and TOPCAT, an interactive graphical viewer and editor for tabular data (Taylor, 2005).

References

- Abdollahi, S., Acero, F., Ackermann, M., *et al.* 2020, *ApJS*, 247, 33
- Ahmad, A., Dai, S., Lenc, E., *et al.* 2025, arXiv e-prints, arXiv:2511.10886
- Anderson, G. E., Hancock, P. J., Rowlinson, A., *et al.* 2021, *PASA*, 38, e026
- Andersson, A., Lintott, C., Fender, R., *et al.* 2025, *MNRAS*, 538, 1397
- Anpilogov, A. M., & Tyul'bashev, S. A. 2026, arXiv e-prints, arXiv:2601.11950
- Anumarlapudi, A., Kaplan, D. L., Hurley Walker, N., *et al.* 2026, arXiv e-prints, arXiv:2604.11881
- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., *et al.* 2013, *A&A*, 558, A33
- Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., *et al.* 2018, *AJ*, 156, 123
- Ballet, J., Burnett, T. H., Digel, S. W., & Lott, B. 2020, arXiv e-prints, arXiv:2005.11208
- Bellm, E. C., Kulkarni, S. R., Graham, M. J., *et al.* 2019, *PASP*, 131, 018002
- Bertin, E., Mellier, Y., Radovich, M., *et al.* 2002, in *Astronomical Society of the Pacific Conference Series*, Vol. 281, *Astronomical Data Analysis Software and Systems XI*, ed. D. A. Bohlender, D. Durand, & T. H. Handley, 228
- Bhat, N. D. R., Cordes, J. M., Camilo, F., Nice, D. J., & Lorimer, D. R. 2004, *ApJ*, 605, 759
- Bhat, N. D. R., Ord, S. M., Tremblay, S. E., *et al.* 2014, *ApJ*, 791, L32
- Bhat, N. D. R., Swainston, N. A., McSweeney, S. J., *et al.* 2023, *PASA*, 40, e021
- Burke-Spolaor, S., Johnston, S., Bailes, M., *et al.* 2012, *MNRAS*, 423, 1351
- Caleb, M., Heywood, I., Rajwade, K., *et al.* 2022, *Nature Astronomy*, 6, 828
- Camilo, F., Kerr, M., Ray, P. S., *et al.* 2015, *ApJ*, 810, 85
- CHIME/FRB Collaboration, Amiri, M., Bandura, K., *et al.* 2018, *ApJ*, 863, 48
- Clark, C. J., Breton, R. P., Barr, E. D., *et al.* 2023, *MNRAS*, 519, 5590
- Condon, J. J., Cotton, W. D., Greisen, E. W., *et al.* 1998, *AJ*, 115, 1693
- Cook, J. H., Seymour, N., & Sokolowski, M. 2021, *PASA*, 38, e063
- Das, B., & Chandra, P. 2021, *ApJ*, 921, 9
- de Ruiter, I., Meyers, Z. S., Rowlinson, A., *et al.* 2024, *MNRAS*, 531, 4805
- de Ruiter, I., Rajwade, K. M., Bassa, C. G., *et al.* 2025, *Nature Astronomy*, 9, 672
- Deller, A. T., Tingay, S. J., Bailes, M., & Reynolds, J. E. 2009a, *ApJ*, 701, 1243
- Deller, A. T., Tingay, S. J., & Brisken, W. 2009b, *ApJ*, 690, 198
- Di Pietrantonio, C., Sokolowski, M., Harris, C., Price, D. C., & Wayth, R. 2026, arXiv e-prints, arXiv:2603.02931
- Dobie, D., Zic, A., Oswald, L. S., *et al.* 2024, *MNRAS*, 535, 909
- Duchesne, S. W., Johnston-Hollitt, M., Zhu, Z., Wayth, R. B., & Line, J. L. B. 2020, *PASA*, 37, e037
- Esamdin, A., Lyne, A. G., Graham-Smith, F., *et al.* 2005, *MNRAS*, 356, 59
- Fender, R., Woudt, P. A., Corbel, S., *et al.* 2016, in *MeerKAT Science: On the Pathway to the SKA*, 13
- Frail, D. A., Kulkarni, S. R., Nicastro, L., Feroci, M., & Taylor, G. B. 1997, *Nature*, 389, 261
- Frail, D. A., Mooley, K. P., Jagannathan, P., & Intema, H. T. 2016, *MNRAS*, 461, 1062
- Frail, D. A., Ray, P. S., Mooley, K. P., *et al.* 2018, *MNRAS*, 475, 942
- Gehrels, N., Chincarini, G., Giommi, P., *et al.* 2004, *ApJ*, 611, 1005
- Hale, C. L., McConnell, D., Thomson, A. J. M., *et al.* 2021, *PASA*, 38, e058
- Hallinan, G., Ravi, V., Weinreb, S., *et al.* 2019, in *Bulletin of the American Astronomical Society*, Vol. 51, 255
- Hancock, P. J., Charlton, E. G., Macquart, J.-P., & Hurley-Walker, N. 2019, arXiv e-prints, arXiv:1907.08395
- Hancock, P. J., Murphy, T., Gaensler, B. M., Hopkins, A., & Curran, J. R. 2012, *MNRAS*, 422, 1812
- Hancock, P. J., Trott, C. M., & Hurley-Walker, N. 2018, *PASA*, 35, e011
- Harris, C. R., Millman, K. J., van der Walt, S. J., *et al.* 2020, *Nature*, 585, 357
- Hewish, A., Bell, S. J., Pilkington, J. D. H., Scott, P. F., & Collins, R. A. 1968, *Nature*, 217, 709
- Hobbs, G., Lorimer, D. R., Lyne, A. G., & Kramer, M. 2005, *MNRAS*, 360, 974
- Hobbs, G., Lyne, A. G., Kramer, M., Martin, C. E., & Jordan, C. 2004a, *MNRAS*, 353, 1311
- Hobbs, G., Faulkner, A., Stairs, I. H., *et al.* 2004b, *MNRAS*, 352, 1439
- Horváth, C., Hurley-Walker, N., McSweeney, S., Galvin, T. J., & Morgan, J. 2025, *PASA*, 42, e129
- Horváth, C., Rea, N., Hurley-Walker, N., *et al.* 2026, *Nature Astronomy*, arXiv:2507.15352
- Hotan, A. W., Bunton, J. D., Chippendale, A. P., *et al.* 2021, *PASA*, 38, e009
- Hunter, J. D. 2007, *Computing In Science & Engineering*, 9, 90
- Hurley-Walker, N., & Hancock, P. J. 2018, *Astronomy and Computing*, 25, 94

[§]<https://www.skao.int/en/science-users/timeline-science>

- Hurley-Walker, N., Callingham, J. R., Hancock, P. J., et al. 2017, *MNRAS*, 464, 1146
- Hurley-Walker, N., Hancock, P. J., Franzen, T. M. O., et al. 2019, *PASA*, 36, e047
- Hurley-Walker, N., Zhang, X., Bahramian, A., et al. 2022a, *Nature*, 601, 526
- Hurley-Walker, N., Galvin, T. J., Duchesne, S. W., et al. 2022b, *PASA*, 39, e035
- Hurley-Walker, N., Rea, N., McSweeney, S. J., et al. 2023, *Nature*, 619, 487
- Hyman, S. D., Lazio, T. J. W., Kassim, N. E., et al. 2005, *Nature*, 434, 50
- Hyman, S. D., Hurley-Walker, N., Joyner, I., et al. 2025, *The Astronomer's Telegram*, 17189, 1
- Jankowski, F., Bailes, M., van Straten, W., et al. 2019, *MNRAS*, 484, 3691
- Johnston, S., Lyne, A. G., Manchester, R. N., et al. 1992, *MNRAS*, 255, 401
- Johnston, S., Nicastro, L., & Koribalski, B. 1998, *MNRAS*, 297, 108
- Johnston, S., Sobey, C., Dai, S., et al. 2021, *MNRAS*, 502, 1253
- Kaplan, D. L., Tingay, S. J., Manoharan, P. K., et al. 2015, *ApJ*, 809, L12
- Keith, M. J., Johnston, S., Karastergiou, A., et al. 2024, *MNRAS*, 530, 1581
- Kerr, M., Hobbs, G., Shannon, R. M., et al. 2014, *MNRAS*, 445, 320
- Kramer, M., Stairs, I. H., Manchester, R. N., et al. 2021, *Physical Review X*, 11, 041050
- Large, M. I., Mills, B. Y., Little, A. G., Crawford, D. F., & Sutton, J. M. 1981, *MNRAS*, 194, 693
- Large, M. I., Vaughan, A. E., & Wielebinski, R. 1968, *Nature*, 220, 753
- Lee, Y. W. J., Caleb, M., Murphy, T., et al. 2025, *Nature Astronomy*, 9, 393
- Lenc, E., Murphy, T., Lynch, C. R., Kaplan, D. L., & Zhang, S. N. 2018, *MNRAS*, 478, 2835
- Lorimer, D. R., Faulkner, A. J., Lyne, A. G., et al. 2006, *MNRAS*, 372, 777
- Lower, M. E., Bailes, M., Shannon, R. M., et al. 2020, *MNRAS*, 494, 228
- Lynch, C. R., Lenc, E., Kaplan, D. L., Murphy, T., & Anderson, G. E. 2017, *ApJ*, 836, L30
- Macquart, J. P., Prochaska, J. X., McQuinn, M., et al. 2020, *Nature*, 581, 391
- Manchester, R. N., Hobbs, G. B., Teoh, A., & Hobbs, M. 2005, *AJ*, 129, 1993
- Manchester, R. N., Lyne, A. G., Taylor, J. H., et al. 1978, *MNRAS*, 185, 409
- Manchester, R. N., Lyne, A. G., D'Amico, N., et al. 1996, *MNRAS*, 279, 1235
- Mantovanini, S., Hurley-Walker, N., & Anderson, G. 2025a, *PASA*, 42, e021
- Mantovanini, S., Hurley-Walker, N., Anderson, G., et al. 2025b, *MNRAS*, 542, 2925
- Mantovanini, S., Hurley-Walker, N., Ross, K., et al. 2025c, *PASA*, 42, e137
- Markoff, S., Falcke, H., & Fender, R. 2001, *A&A*, 372, L25
- McConnell, D., Hale, C. L., Lenc, E., et al. 2020, *PASA*, 37, e048
- McKay, A. T. 1932, *Journal of the Royal Statistical Society*, 95, 695
- McSweeney, S. J., Moseley, J., Hurley-Walker, N., et al. 2025, *ApJ*, 981, 143
- McSweeney, S. J., Hurley-Walker, N., Horváth, C., et al. 2025, *MNRAS*, 542, 203
- Morgan, J. S., Macquart, J.-P., Ekers, R., et al. 2018a, *MNRAS*, 473, 2965
- . 2018b, *MNRAS*, 473, 2965
- Morrison, I. S., Crosse, B., Sleep, G., et al. 2023, *PASA*, 40, e019
- Murphy, T., & Kaplan, D. L. 2026, *PASA*, 43, e006
- Murphy, T., Kaplan, D. L., Croft, S., et al. 2017, *MNRAS*, 466, 1944
- Murphy, T., Kaplan, D. L., Stewart, A. J., et al. 2021, *PASA*, 38, e054
- Norris, R. P., Marvil, J., Collier, J. D., et al. 2021, *PASA*, 38, e046
- Ocker, S. K., & Cordes, J. M. 2026, *arXiv e-prints*, arXiv:2602.11838
- Offringa, A. R., van de Gronde, J. J., & Roerdink, J. B. T. M. 2012, *A&A*, 539, A95
- Offringa, A. R., McKinley, B., Hurley-Walker, N., et al. 2014, *MNRAS*, 444, 606
- Offringa, A. R., Trott, C. M., Hurley-Walker, N., et al. 2016, *MNRAS*, 458, 1057
- Pelisoli, I., Marsh, T. R., Buckley, D. A. H., et al. 2023, *Nature Astronomy*, 7, 931
- Petrou, F., Hurley-Walker, N., McSweeney, S., et al. 2025, *PASA*, 42, e139
- Pritchard, J., Murphy, T., Dobie, D., et al. 2026, *arXiv e-prints*, arXiv:2603.07857
- Rea, N., Hurley-Walker, N., & Caleb, M. 2026, *Journal of High Energy Astrophysics*, 52, 100566
- Rybicki, G. B., & Lightman, A. P. 1979, *Radiative processes in astrophysics* (Wiley)
- Sengar, R., Anumarlapudi, A., Kaplan, D. L., et al. 2025a, *arXiv e-prints*, arXiv:2509.20614
- Sengar, R., Kaplan, D. L., Lenc, E., et al. 2025b, *arXiv e-prints*, arXiv:2509.20611
- Shimwell, T. W., Röttgering, H. J. A., Best, P. N., et al. 2017, *A&A*, 598, A104
- Smirnov, O. M., Stappers, B. W., Tasse, C., et al. 2024, *MNRAS*, 528, 6517
- Somalwar, J. J., Ravi, V., Dong, D. Z., et al. 2023, *ApJ*, 945, 142
- Taylor, J. H., & Cordes, J. M. 1993, *ApJ*, 411, 674
- Taylor, M. B. 2005, in *Astronomical Society of the Pacific Conference Series*, Vol. 347, *Astronomical Data Analysis Software and Systems XIV*, ed. P. Shopbell, M. Britton, & R. Ebert, 29
- Taylor, M. B. 2006, in *Astronomical Society of the Pacific Conference Series*, Vol. 351, *Astronomical Data Analysis Software and Systems XV*, ed. C. Gabriel, C. Arviset, D. Ponz, & S. Enrique, 666
- Thompson, A. R., Moran, J. M., & Swenson, Jr., G. W. 2001, *Interferometry and Synthesis in Radio Astronomy*, 2nd Edition
- Thompson, C., Blandford, R. D., Evans, C. R., & Phinney, E. S. 1994, *ApJ*, 422, 304
- Thongmearkom, T., Clark, C. J., Breton, R. P., et al. 2024, *MNRAS*, 530, 4676
- Tingay, S. J., Goeke, R., Bowman, J. D., et al. 2013, *PASA*, 30, 7
- Tremblay, S. E., Ord, S. M., Bhat, N. D. R., et al. 2015, *PASA*, 32, e005
- van Haarlem, M. P., Wise, M. W., Gunst, A. W., et al. 2013, *A&A*, 556, A2
- Vaughan, A. E., & Large, M. I. 1972, *MNRAS*, 156, 27P
- Vaughan, A. E., Large, M. I., & Wielebinski, R. 1969, *Nature*, 222, 963
- Wang, J., Hobbs, G., Kerr, M., et al. 2020, *ApJ*, 889, 6
- Wang, N., Manchester, R. N., & Johnston, S. 2007, *MNRAS*, 377, 1383
- Wang, Z., Kaplan, D. L., Murphy, T., et al. 2021, *ApJ*, 920, 45
- Waszewski, A., Morgan, J., & Jordan, C. H. 2022, *PASA*, 39, e036
- Wayth, R. B., Lenc, E., Bell, M. E., et al. 2015, *PASA*, 32, e025
- Young, N. J., Weltevrede, P., Stappers, B. W., Lyne, A. G., & Kramer, M. 2015, *MNRAS*, 449, 1495
- Zic, A., Wang, Z., Lenc, E., et al. 2024, *MNRAS*, 528, 5730

Appendix 1. Light curves for transients detected within transient cubes generated from individual snapshot observations

Appendix 2. Light curves for transients detected in groups of snapshots

Appendix 3. Light curves for transients detected in mosaics

Appendix 4. Table descriptions

Table 6. Column descriptions for the table containing the candidates found in the intra-snapshot searches (Section 3.1). There are three tables, one for each semester of observing (2022-A, 2024-A, 2024-B).

Column name	Unit	Description
ID	–	Arbitrary candidate identification number
gpstime	–	GPS Time of start of observation (= MWA observation ID)
MJD	–	Modified Julian Date of epoch
pointing_lon	°	Galactic longitude / of pointing
can_ra	°	RA of candidate
can_dec	°	Dec of candidate
can_peak_flux	Jy beam ^{−1}	Maximum peak flux density of candidate
can_det_stat	–	Unitless “detection statistic” of candidate, defined by Horváth et al. (2025)
can_beam	–	Sensitivity of the MWA primary beam at the candidate’s location, normalised to zenith
nks_name	–	Name of nearest known source in GLEAM
nks_ra	°	RA of nearest known source
nks_dec	°	Dec of nearest known source
nks_peak_flux	Jy beam ^{−1}	Maximum peak flux density of nearest known source
nks_det_stat	–	Unitless “detection statistic” of nearest known source

Table 7. Column descriptions for the table containing the candidates found in the inter-snapshot searches (Section 3.2).

Column name	Unit	Description
Name	hh:mm:ss+dd:mm:ss	International Astronomical Union name
MJD	–	Modified Julian Date of epoch
pointing_lon	°	Galactic longitude / of pointing
gpstime	–	GPS Time of first snapshot observation in pointing (= MWA observation ID)
mean_ra	°	Mean RA from snapshots in which source was detected
mean_dec	°	Mean Dec from snapshots in which source was detected
mean_on_peak_flux	Jy beam ^{−1}	Mean peak flux density from snapshots in which source was detected
mean_on_local_rms	Jy beam ^{−1}	Mean RMS local noise from snapshots in which source was detected
weighted_avg_peak_flux	Jy beam ^{−1}	Average peak flux density from snapshots in which source was detected, weighted by (local RMS noise) ^{−2}
mean_peak_flux	Jy beam ^{−1}	Mean peak flux density from all snapshots, including forced photometry
eta	–	Unitless “significance” statistic η , defined by Eq 1
var	–	Unitless “variability” statistic V , defined by Eq 2

Table 8. Column descriptions for the table containing the candidates found in the mosaic searches (Section 3.3). There are two tables, one for the Galactic Centre region (2022-A and 2024-A; 42 epochs), and the other for the Southern Plane region (2024-B; 30 epochs).

Column name	Unit	Description
Name	hh:mm:ss+dd:mm:ss	International Astronomical Union name
mean_lon	°	Mean Galactic longitude l from epochs in which source was detected
mean_lat	°	Mean Galactic latitude b from epochs in which source was detected
mean_on_peak_flux	Jy beam ⁻¹	Mean peak flux density from epochs in which source was detected
mean_on_local_rms	Jy beam ⁻¹	Mean RMS local noise from epochs in which source was detected
weighted_avg_peak_flux	Jy beam ⁻¹	Average peak flux density from epochs in which source was detected, weighted by (local RMS noise) ⁻²
mean_peak_flux	Jy beam ⁻¹	Mean peak flux density from all epochs, including forced photometry
eta	–	Unitless “significance” statistic η , defined by Eq 1
var	–	Unitless “variability” statistic V , defined by Eq 2
GroupID	–	Identification number of the group of associated objects
GroupSize	–	Number of members in group
<i>Additionally, for each epoch:</i>		
MJD	–	Modified Julian Date of first observation in epoch
lon	°	Galactic longitude l
lat	°	Galactic latitude b
peak_flux	Jy beam ⁻¹	Peak flux density
int_flux	Jy	Integrated flux density
local_rms	Jy beam ⁻¹	Local RMS noise

Table 9. Column descriptions for the table containing sources detected in the 200-MHz deep mosaic. The low-quality flag is set if AEGERAN could not fit the source, or it lies outside of the high-quality imaging region discussed in Section 3.4.

Column name	Unit	Description
Name	hh:mm:ss+dd:mm:ss	International Astronomical Union name
lon	°	Galactic longitude l
err_lon	°	Error on Galactic longitude l
lat	°	Galactic latitude b
err_lat	°	Error on Galactic latitude b
background	Jy beam ⁻¹	Background measured by BANE
local_rms	Jy beam ⁻¹	Local RMS noise measured by BANE
peak_flux	Jy beam ⁻¹	Peak flux density
err_peak_flux	Jy beam ⁻¹	Error on peak flux density
int_flux	Jy	Integrated flux density
err_int_flux	Jy	Error on integrated flux density
a	°	Major axis
err_a	°	Error on major axis
b	°	Minor axis
err_b	°	Error on minor axis
pa	°	Position angle
err_pa	°	Error on position angle
psf_a	°	Estimated PSF major axis at source location
psf_b	°	Estimated PSF minor axis at source location
psf_pa	°	Estimated PSF position angle at source location
q	—	Low-quality flag

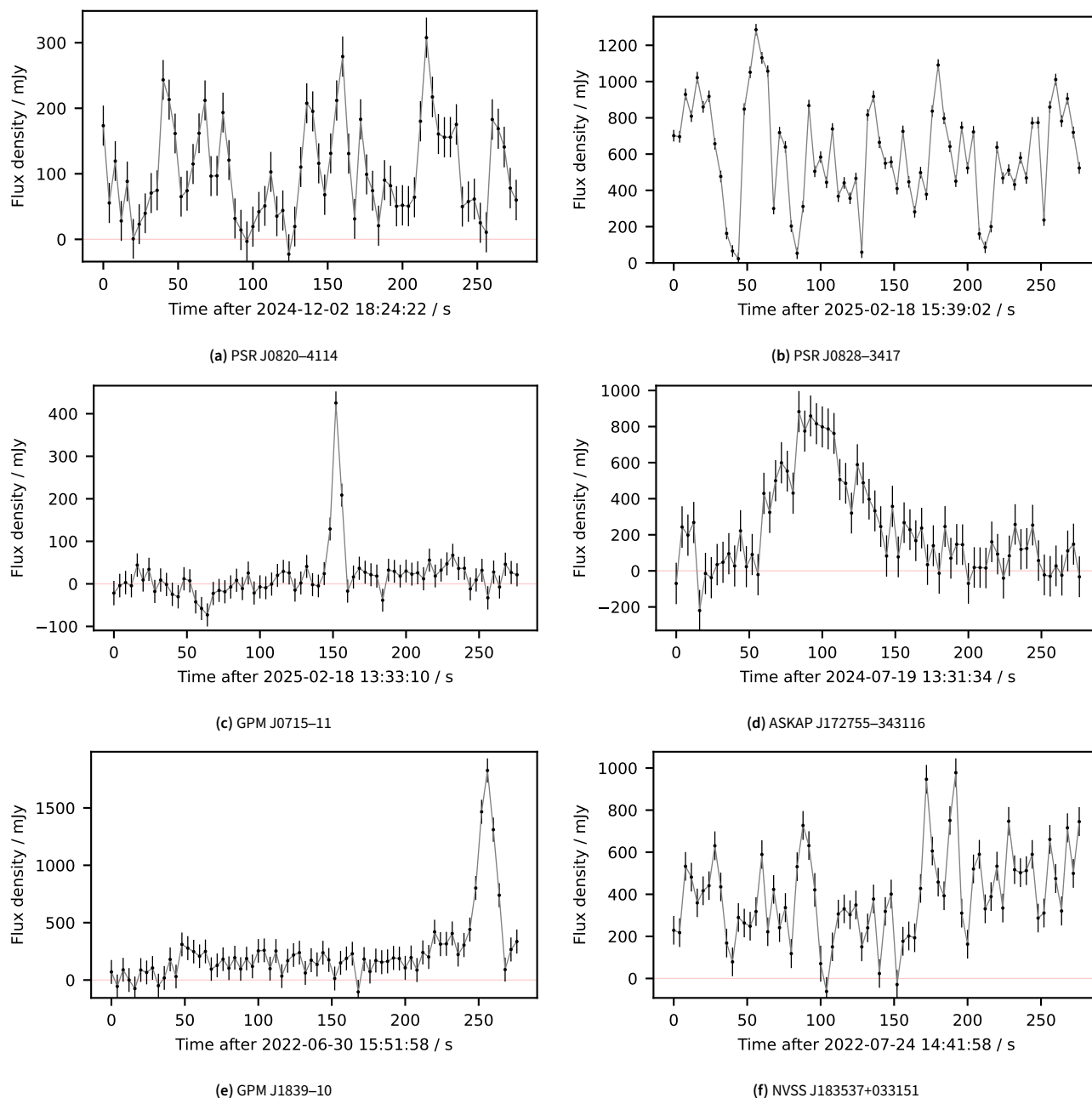


Figure 15. An example light curve for the brightest detections of each of the six transients/variables detected in the intra-snapshot search. The mean flux density that was subtracted away during pipeline imaging has been added back to the flux density measurements displayed here. The locations of these sources are shown in Fig. 7 and the source details are presented in Table 3.

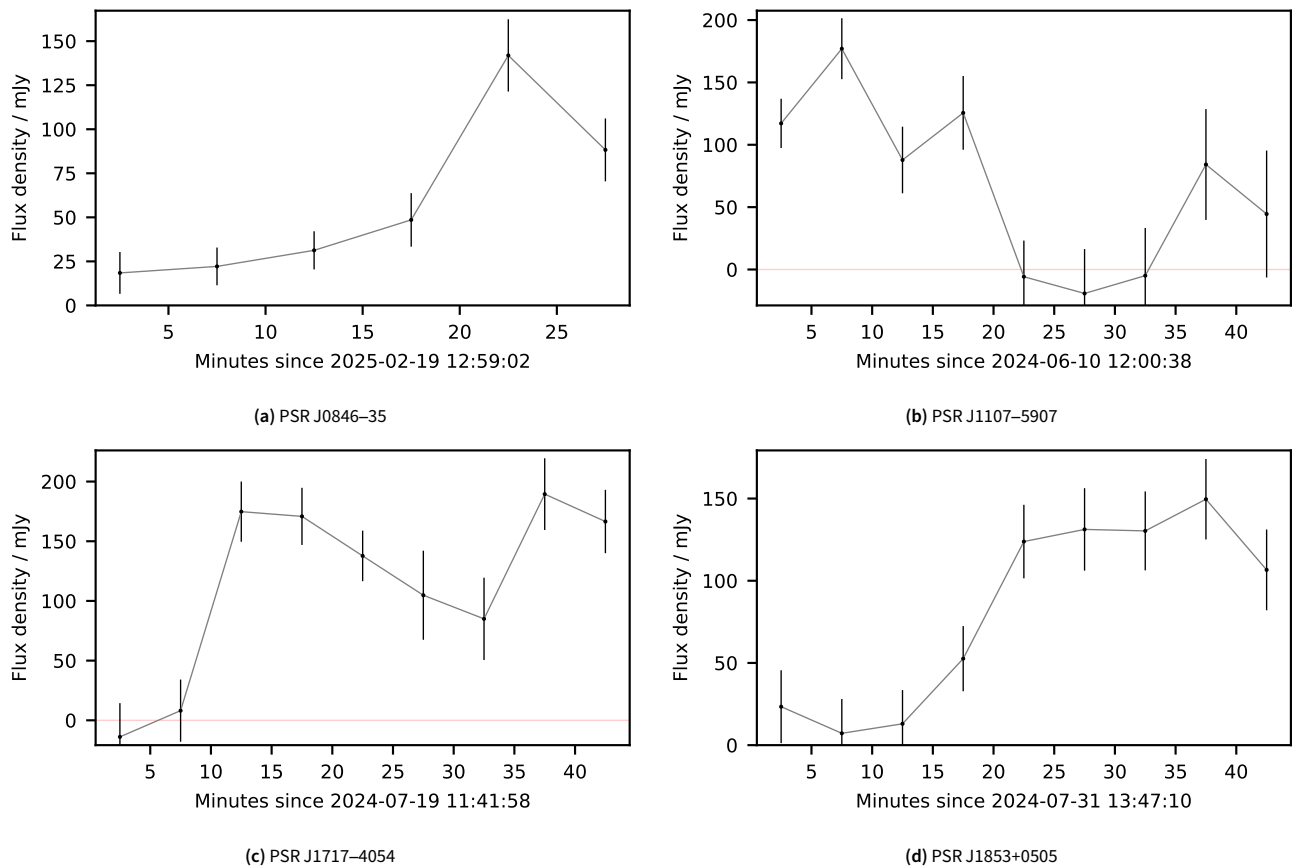


Figure 16. An example light curve for each variable pulsar detected in the inter-snapshot search. The variability statistics of these sources are shown in Fig. 8 and the source details are presented in Table 4.

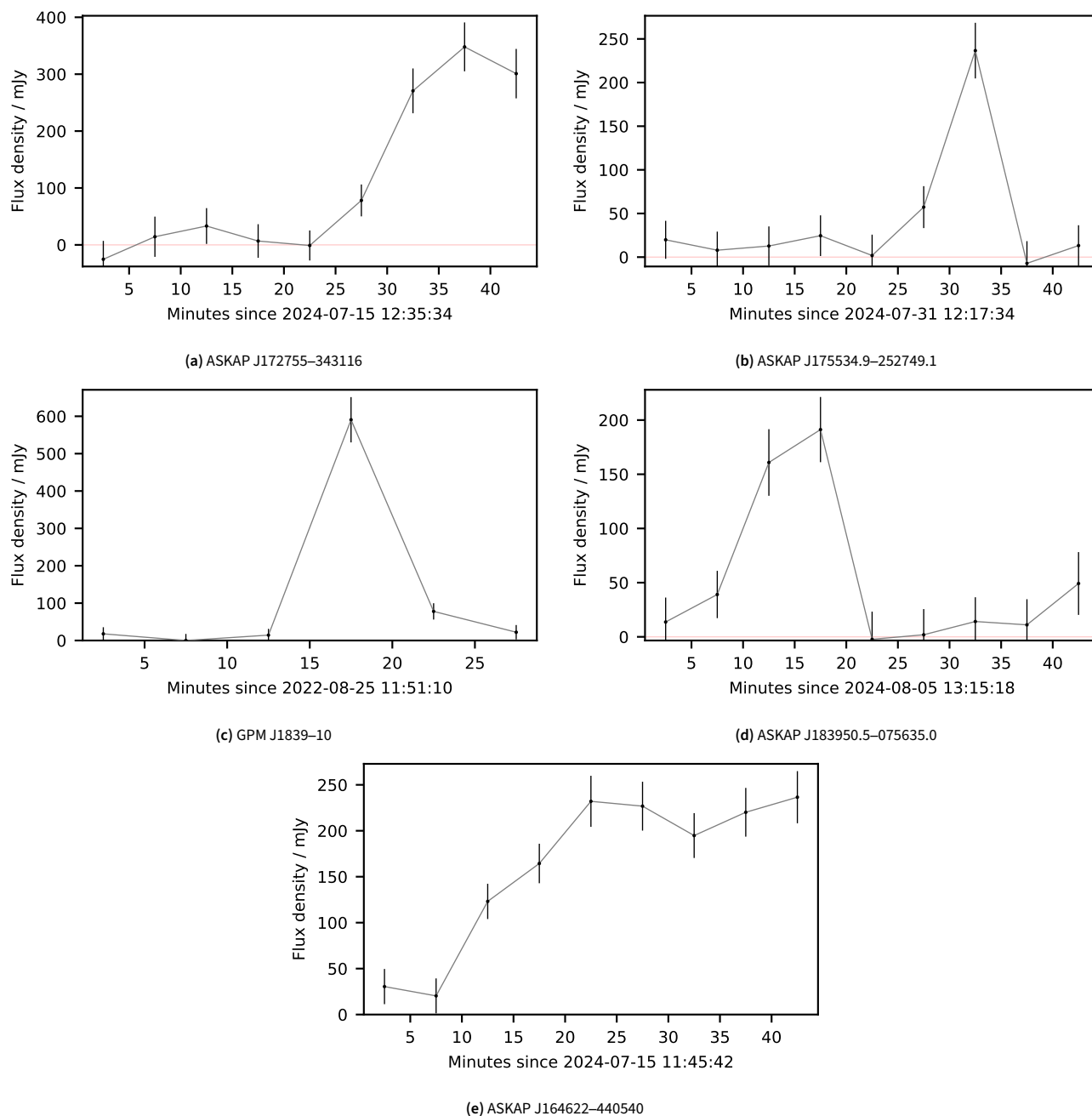


Figure 17. An example light curve for each transient detected in the inter-snapshot search: long-period radio transients, and one candidate eclipsing binary MSP (panel e). The variability statistics of these sources are shown in Fig. 8 and the source details are presented in Table 4.

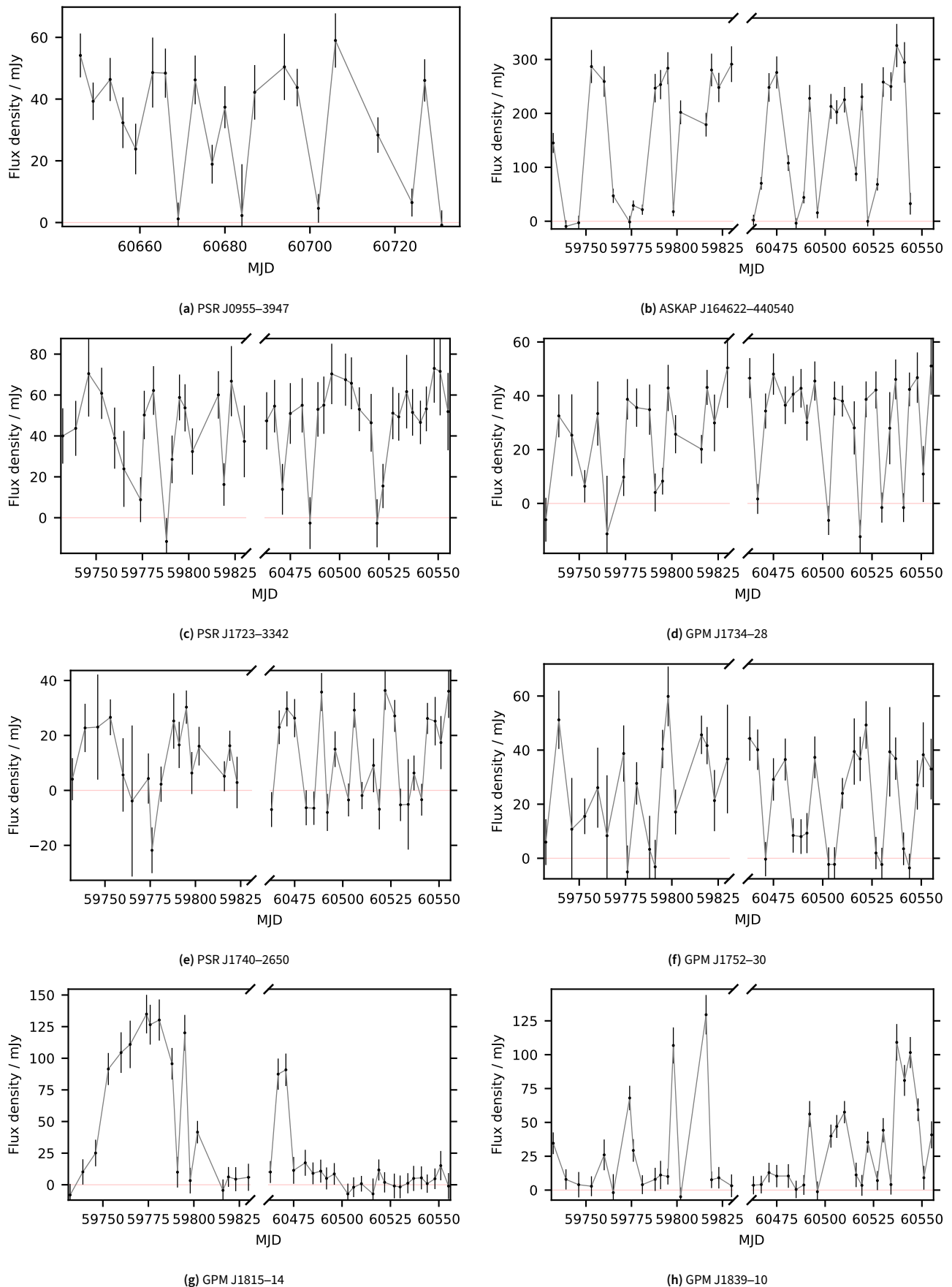


Figure 18. Light curves of transients detected in the mosaic search: confirmed (prefixed by “PSR”) and candidate eclipsing binary MSPs, and one LPT (panel h). The variability statistics of these sources are shown in Fig. 10 and the source details are presented in Table 5.

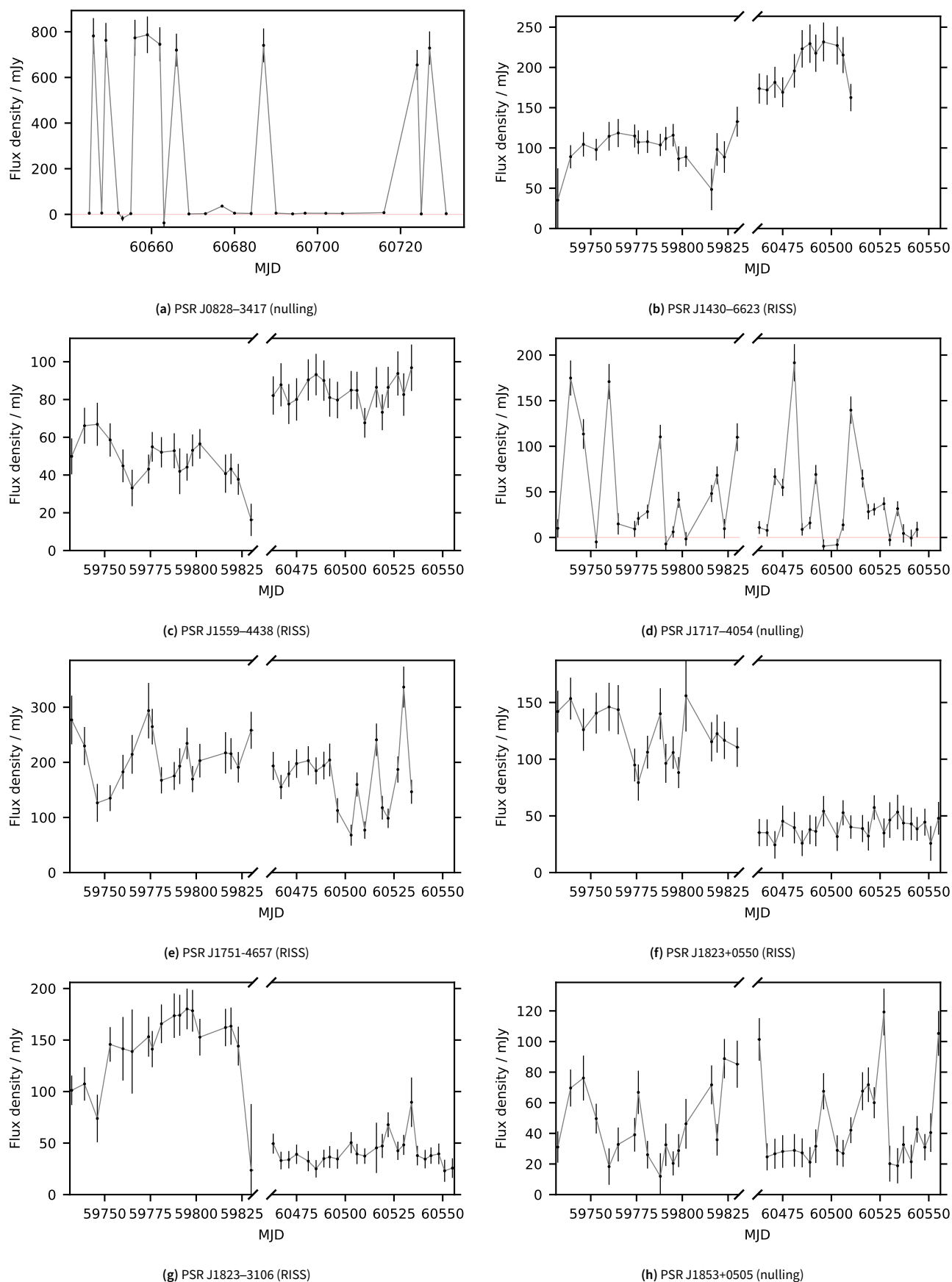


Figure 19. Light curves of variable (but not eclipsing) pulsars detected in the mosaic search. The variability statistics of these sources are shown in Fig. 10 and the source details are presented in Table 5.