*URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024*

# A multi-beam FRB detection pipeline with real-time injection for the SPOTLIGHT

Ujjwal Panda*[(1)], Kenil Ajudiya[(2)], and SPOTLIGHT team members.
(1) NCRA-TIFR, Pune 411007, India; e-mail: upanda@ncra.tifr.res.in
(2) Indian Institute of Science, Bengaluru-560012, India

## Abstract

The SPOTLIGHT project is a commensal survey for Fast Radio Bursts (FRBs) and pulsars at the GMRT. It aims to leverage the high sensitivity and large frequency coverage of the GMRT to detect and localise hundreds of FRBs. In order to facilitate this, we are developing a multi-beam FRB detection pipeline, which will efficiently utilise SPOTLIGHT's PetaFlops of compute capacity to automatically search through GigaBytes of data per second to search for FRBs in real-time. We are also working on a real-time injection system that can inject simulated FRBs directly into data flowing in from the telescopes. This allows us to test the robustness and completeness of our pipeline, with respect to the FRB parameter space.

## 1. Introduction

Fast radio bursts (FRBs) are transient sources in the radio sky, radiating on timescales of the order of a few milliseconds. Their emission is bright ($T_B = 10^{36}$ K for typical parameters), wideband (110 MHz [1] to 8 GHz [2]) and coherent. Their dispersion measures (DMs; defined as the column density of electrons along the line of sight) indicate that these are extragalactic sources, and this has been confirmed via localisation of these sources to their respective host galaxies [3, 4, 5]. Following the serendipitous discovery of FRBs in 2007 [6], we have detected more than 700 of them (787; as per the **Transient Name Server**). While most of them have been one-off events, a minor fraction (~6%; from the **TNS**) repeats. The first such repeating FRB was detected in 2012, at 1.4 GHz at Arecibo [7]. Now, more than 50 such FRBs are known.

Due to their short timescales, it is well established that an FRB's emission region(s) must be compact. This has led to the suggestion of neutron stars, more specifically magnetars, as their progenitors. The discovery of the first Galactic FRB was associated with a magnetar [8], further bolstering this claim. In order to study the emission environment and progenitors of these sources, it is important to localise them to their host galaxies, which requires an accuracy of a few arcseconds or better. However, telescopes leading the discovery of these sources have low localisation accuracy and wide FoVs; for instance, the CHIME telescope has an FoV of 120° × 2°, but its localisation accuracy is only a few arcminutes. On the other hand, interferometers are good at localising sources up to a few arcseconds, but have very narrow FoVs. Thus, the idea of commensal surveys has gained traction in recent years, wherein one can search for FRBs and other sources any time the telescope is operational. This is done by constructing a dedicated parallel backend that can be used to search for such sources in real time. Examples of such surveys are CRAFT at the ASKAP [9], MeerTRAP at the MeerKAT [10, 11], and realfast at the VLA [12]. In order to further increase their survey speeds, many of these telescopes have come up with ways to increase their FoV, either via hardware (for example, by using phased array feeds at the ASKAP [13]), or via software (for example, by using tiled beams at the MeerKAT [14]).

## 2. The SPOTLIGHT project

Motivated by the above, we started working on the **SPOTLIGHT** project (**S**urvey for s**P**oradic radi**O** burs**T**s via a commensa**L**, mult**I**beam, **G**PU-powered **H**PC at the GMR**T**). This is a commensal survey for FRBs, pulsars, and other sources using the **G**iant **M**etrewave **R**adio **T**elescope (**GMRT**). In order to increase our FoV, we will be forming 2000 beams on the sky, giving us an FoV of ~1 $\text{deg}^2$ at 400 MHz. Each of these beams will be a post-correlation phased array beam [15], which boosts our sensitivity, and makes us more resistant to RFI and systematics. We will cover a frequency range of 300 MHz to 1460 MHz, which covers 96.5% of time allotted at the GMRT, based on data collected since January 2020. A backend consisting of 60 Rudra servers, and 90

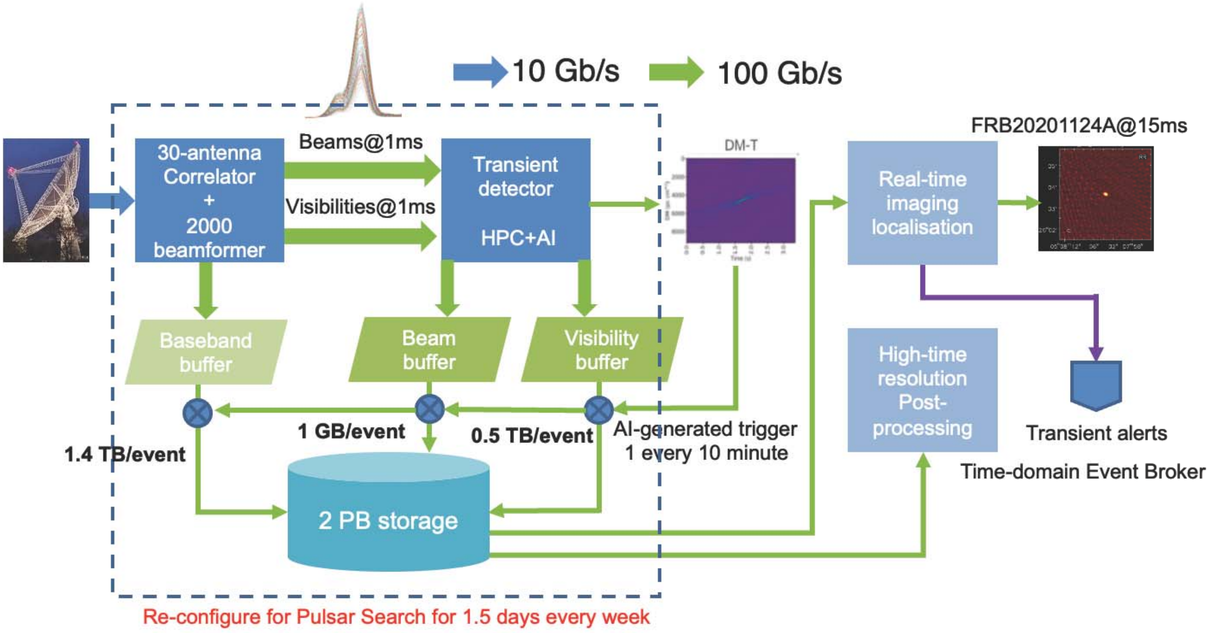

**Figure 1:** Flowchart demonstrating the entire SPOTLIGHT system. It consists of 3 clusters. The second cluster houses the transient detection system discussed in this paper. Upon detection, triggers are generated, which result in the dumping of beamformed data, baseband data,and visibilities, to the 2 PB storage.

NVIDIA A100 GPUs, capable of computing at a rate of ~1 PetaFlops, will be used to search for FRBs in real time. A flowchart of the entire system can be seen in Figure 1.

## 3. SPOTLIGHT's FRB detection pipeline

The multibeam FRB detection pipeline being built for SPOTLIGHT consists of the following stages:

1. **Dedispersion:** As the FRB signal travels through ionised gas (or plasma) present along the line of sight, different frequencies travel at different speeds, which *disperses* the signal. The **dispersion measure** (DM) is a measure of this effect, defined as the column density of electrons along the line-of-sight. The effect this has on the data is undone via a process known as **dedispersion**. However, since the amount the signal is dispersed is not known a priori, dedispersion is done at many different trial DM values. This involves collapsing the frequency-time intensity data, also known as the **dynamic spectrum**, into a time series, taking into account the frequency-dependent delays for each DM value. For dedispersion, we leverage a GPU-optimised algorithm [16] from the `AstroAccelerate` software package.
2. **Single pulse search:** We then search each time series for single pulses by match filtering the signal with boxcars of varying widths. This generates a list of candidates. The `AstroAccelerate` software package also provides a GPU-optimised, single pulse search algorithm [17], which is integrated into our pipeline.
3. **Clustering:** The number of candidates generated can be anything from a few hundreds to a few millions, with many of them being spurious. Thus, we cluster candidates in the DM-time plane as well as in the RA-Dec plane for multiple beams, reducing the number of candidates by a few orders of magnitude.
4. **Feature extraction + classification**: The dedispersed dynamic spectrum and the DM transform (DMT) are characteristic features of FRBs which can be used to distinguish them from RFI. `candies`, a GPU-optimised feature extraction program for FRBs, extracts these features from the beam data around the times of arrival of each of the candidates and their estimated DMs. The extracted features are analysed by `FETCH` - a CNN-based binary classifier - to classify each candidate as an FRB or an RFI. `candies` has been proven to

improve the results of `FETCH` because of certain feature enhancements it does compared to a previously used feature extraction software, `your` (see Figure 2).

Several of the programs used in the SPOTLIGHT pipeline have already contributed to science results from the GMRT; for instance, `candies` has helped in the detection of 135 bursts from FRB 240114A, the analysis of which has been recently submitted to ApJ, and is available as a preprint on the arXiv [19].

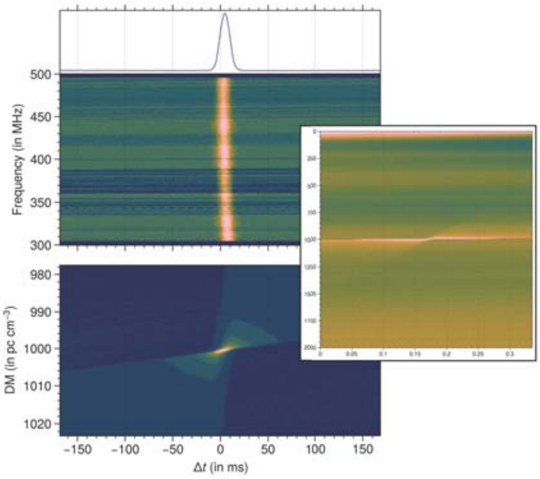

**Figure 2:** A plot generated by `candies` for a simulated FRB injected into GMRT data using `arachne`. The inset shows the plot of the DMT generated by `your`, the software used previously for the same task. `candies` optimises the way the DMT is formed, helping `FETCH` classify FRBs correctly.

## 4. Real-time injection of FRBs at the GMRT

In order to test our pipeline, we have developed a code for injecting simulated FRBs into GMRT data in real time, known as `arachne`. `arachne` reads in data from a ring buffer, injects one or multiple simulated FRBs into it, and writes it out to another identical ring buffer. This is the ring buffer from which the pipeline then reads the data from. This allows us to inject FRBs while precisely varying their parameters, such as their DM, width, emission bandwidth, scattering timescales, number of components, etc. `arachne` also allows injecting an FRB at any point in time, and injecting multiple FRBs at once. An example of an injected FRB can be seen in Figure 2. Injecting a variety of FRBs in such a manner helps in testing both the robustness of the pipeline, as well as its **completeness** with respect to the FRB parameter space. **Completeness** is defined as the fraction of the entire FRB parameter space that can be successfully detected by a survey, and is often estimated via injecting a high number of simulated FRBs, and analysing them using the survey's pipeline [20, 21, 22]. We aim to use `arachne` for carrying out a similar study for SPOTLIGHT's multi-beam pipeline.

## 5. Acknowledgements

We acknowledge the invaluable contribution of colleagues from the Oxford e-Research Centre, and NVIDIA. We also acknowledge the funding of the data centre under NSM Phase 3. We also acknowledge support of the Department of Atomic Energy, Government of India, under project no. 12-R&D-TFR-5.02-0700 for the contributions towards the overhead cost. The GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research, India. The data centre was jointly built by team members from C-DAC and the GMRT backend, electrical, RFI, and mechanical teams. We thank the GMRT telescope operators for supporting the test observations during the software prototyping phase.

## 6. References

[1] Z. Pleunis et al., "LOFAR Detection of 110–188 MHz Emission and Frequency-dependent Activity from FRB 20180916B," ApJL, vol. 911, no. 1, p. L3, Apr. 2021, doi: 10.3847/2041-8213/abec72.

[2] V. Gajjar et al., "Highest Frequency Detection of FRB 121102 at 4–8 GHz Using the Breakthrough Listen Digital Backend at the Green Bank Telescope," ApJ, vol. 863, no. 1, p. 2, Aug. 2018, doi: 10.3847/1538-4357/aad005.

[3] S. Chatterjee et al., "A direct localization of a fast radio burst and its host," Nature, vol. 541, no. 7635, Art. no. 7635, Jan. 2017, doi: 10.1038/nature20797.

[4] K. W. Bannister et al., "A single fast radio burst localized to a massive galaxy at cosmological distance," Science, vol. 365, no. 6453, pp. 565–570, Aug. 2019, doi: 10.1126/science.aaw5903.

[5] H. Xu et al., "A fast radio burst source at a complex magnetized site in a barred galaxy," Nature, vol. 609, no. 7928, Art. no. 7928, Sep. 2022, doi: 10.1038/s41586-022-05071-8.

[6] D. R. Lorimer, M. Bailes, M. A. McLaughlin, D. J. Narkevic, and F. Crawford, "A Bright Millisecond Radio Burst of Extragalactic Origin," Science, vol. 318, no.

5851, pp. 777–780, Nov. 2007, doi: 10.1126/science.1147532.

[7] L. G. Spitler et al., “A repeating fast radio burst,” Nature, vol. 531, no. 7593, Art. no. 7593, Mar. 2016, doi: 10.1038/nature17168.

[8] C. D. Bochenek et al., “A fast radio burst associated with a Galactic magnetar,” Nature, vol. 587, no. 7832, Art. no. 7832, Nov. 2020, doi: 10.1038/s41586-020-2872-x.

[9] J.-P. Macquart et al., “The Commensal Real-Time ASKAP Fast-Transients (CRAFT) Survey,” Publications of the Astronomical Society of Australia, vol. 27, pp. 272–282, Jun. 2010, doi: 10.1071/AS09082.

[10] S. Sanidas, M. Caleb, L. Driessen, V. Morello, K. Rajwade, and B. W. Stappers, “MeerTRAP: A pulsar and fast transients survey with MeerKAT,” Proceedings of the International Astronomical Union, vol. 13, no. S337, pp. 406–407, Sep. 2017, doi: 10.1017/S1743921317009310.

[11] K. M. Rajwade et al., “First discoveries and localizations of Fast Radio Bursts with MeerTRAP: real-time, commensal MeerKAT survey,” Monthly Notices of the Royal Astronomical Society, vol. 514, no. 2, pp. 1961–1974, Aug. 2022, doi: 10.1093/mnras/stac1450.

[12] K. Aggarwal et al., “VLA/Realfast Detection of a Burst from FRB 180916.J0158+65 and Tests for Periodic Activity,” Research Notes of the American Astronomical Society, vol. 4, p. 94, Jun. 2020, doi: 10.3847/2515-5172/ab9f33.

[13] A. Chippendale, J. O’Sullivan, J. Reynolds, R. Gough, D. Hayman, and S. Hay, “Phased array feed testing for astronomy with ASKAP,” in 2010 IEEE International Symposium on Phased Array Systems and Technology, Oct. 2010, pp. 648–652. doi: 10.1109/ARRAY.2010.5613298.

[14] W. Chen, E. Barr, R. Karuppusamy, M. Kramer, and B. Stappers, “Wide field beamformed observation with MeerKAT,” J. Astron. Instrum., vol. 10, no. 03, p. 2150013, Sep. 2021, doi: 10.1142/S2251171721500136.

[15] J. Roy, J. N. Chengalur, and U.-L. Pen, “Post-correlation beamformer for time-domain studies of pulsars and transients,” ApJ, vol. 864, no. 2, p. 160, Sep. 2018, doi: 10.3847/1538-4357/aad815.

[16] J. Novotný, K. Adámek, M. A. Clark, M. Giles, and W. Armour, “Accelerating Dedispersion Using Many-core Architectures,” ApJS, vol. 269, no. 1, p. 29, Nov. 2023, doi: 10.3847/1538-4365/acfef6.

[17] K. Adámek and W. Armour, “Single-pulse Detection Algorithms for Real-time Fast Radio Burst Searches Using GPUs,” The Astrophysical Journal Supplement Series, vol. 247, p. 56, Apr. 2020, doi: 10.3847/1538-4365/ab7994.

[18] D. Agarwal, K. Aggarwal, S. Burke-Spolaor, D. R. Lorimer, and N. Garver-Daniels, “FETCH: A deep-learning based classifier for fast transient classification,” Monthly Notices of the Royal Astronomical Society, vol. 497, no. 2, pp. 1661–1674, Sep. 2020, doi: 10.1093/mnras/staa1856.

[19] U. Panda, J. Roy, S. Bhattacharyya, C. Dudeja, and S. Kudale, “Low-frequency, wideband study of an active repeater, FRB 20240114A, with the GMRT,” May 18, 2024, arXiv: arXiv:2405.09749. doi: 10.48550/arXiv.2405.09749.

[20] V. Gupta et al., “Estimating fast transient detection pipeline efficiencies at UTMOST via real-time injection of mock FRBs,” Monthly Notices of the Royal Astronomical Society, vol. 501, no. 2, pp. 2316–2326, Feb. 2021, doi: 10.1093/mnras/staa3683.

[21] C. F. Zhang et al., “Fast radio burst detection in the presence of coloured noise,” Monthly Notices of the Royal Astronomical Society, vol. 503, no. 4, pp. 5223–5231, Apr. 2021, doi: 10.1093/mnras/stab823.

[22] H. Qiu, E. F. Keane, K. W. Bannister, C. W. James, and R. M. Shannon, “Systematic performance of the ASKAP Fast Radio Burst search algorithm,” Jun. 06, 2023, arXiv: arXiv:2306.03886. doi: 10.48550/arXiv.2306.03886.