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Searching for Fast Radio Transients with FAST

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Abstract

This paper summarizes our efforts on the fast radio transient searches by the Five-hundred-meter Aperture Spherical radio Telescope (FAST), which was realized by an efficient GPU-based single-pulse searching pipeline and the artificial intelligence detection technology. We discovered more than 100 Galactic rotating radio transients (RRATs) and 5 extragalactic fast radio bursts (FRBs) in the survey data from FAST. We have also observed known RRATs with the FAST, obtained many high signal-to-noise ratio pulses, and confirmed that RRATs are typically weak or nulling pulsars. In addition, thousands of bursts of some repeating FRBs have been detected with our newly developed pipeline, and we did statistics on the parameters of these sources. Our supersensitive observations contribute to a deeper understanding of RRATs and FRBs.

1 Introduction

Rotating radio transients (RRATs) are a type of neutron star within the Milky Way discovered through single-pulse search techniques [1]. Their rotational periods, obtained by solving for the arrival times of detected sporadic pulses, are comparable to those of typical pulsars, classifying them as a subtype of pulsars. Before our observations by the FAST, only a limited number, around 160, of RRATs had been found. The sporadic nature of their radiated pulses has restricted our in-depth understanding of these objects.

Fast radio bursts (FRBs) represent another significant class of radio transient sources discovered through single-pulse search techniques [2]. Their large dispersion measures (DM), much excessing than the possible contributions from the Milky Way, indicate their extragalactic origin. The exact emission sources of FRBs and radiation mechanisms remain unknown. They are categorized into one-off sources and repeaters based on the presence of already-detected repeated bursts. Furthermore, FRB bursts exhibit the complexity of pulse characteristics, including narrow-band radiation, frequency drifting of radio emission, and large periodic radiation windows in some FRBs.

The search for millisecond-duration fast radio transients and the subsequent monitoring using high-sensitivity telescopes are crucial steps to understand the occurrences and possible physical laws governing the emission of RRATs and FRBs. The supersensitive Five-hundred-meter Aperture Spherical radio Telescope (FAST)[3], with a 19-beam L-band receiver, is a great tool to study the transient universe in radio waves, including the discovery and monitoring of weak pulsars[1] [4, 5], RRATs [6], FRBs [7–9]. In the following sections, we briefly introduce the pipeline for searching fast radio transients (Section 2), the discovered new transients by the pipeline (Section 3), the observation results of known transients by FAST (Section 4). Conclusions are given in the Section 5.

2 Singlepulse Search Pipline

To promptly and efficiently process the extensive data from the FAST sky survey observations, we developed a code to do de-dispersion and generate DM-time images in GPU. The main de-dispersion range is from 3 $\mathrm{pc\,cm^{-3}}$ to 1000 $\mathrm{pc\,cm^{-3}}$ with a step of 1.0 $\mathrm{pc\,cm^{-3}}$, and plotting DM-time images for every 4 s, that processes one image in only about 0.25 s in one node of the FAST computing cluster. This fast search strategy is suitable for searching Galactic fast radio transients, like RRATs, but for a source with a larger DM, we expend the de-dispersion range of 900 – 10000 $\mathrm{pc\,cm^{-3}}$. To enhance the detection of narrowband bursts, or bursts with a steep-spectrum or scintillation, we apply frequency-dependent de-dispersion strategies. Down-sampling data and median filtering have been applied to create the images, which accelerate the computation and also improve the signal detection.

For searching the distinctive features of real transients in the DM-time images, we use the `YOLO` object detection technology, which is developed in the `Darknet`[2] neural network framework. The features of all detected bursts are outstanding in the waterfall plots, and it is relatively easy to identify a real transient. Comparisons with known pulsars or

[1] Pulsar lists of GPPS survey: http://zmtt.bao.ac.cn/GPPS/ and CRAFTS: http://groups.bao.ac.cn/ism/CRAFTS/202203/t20220310_683697.html.

[2] https://pjreddie.com/darknet/

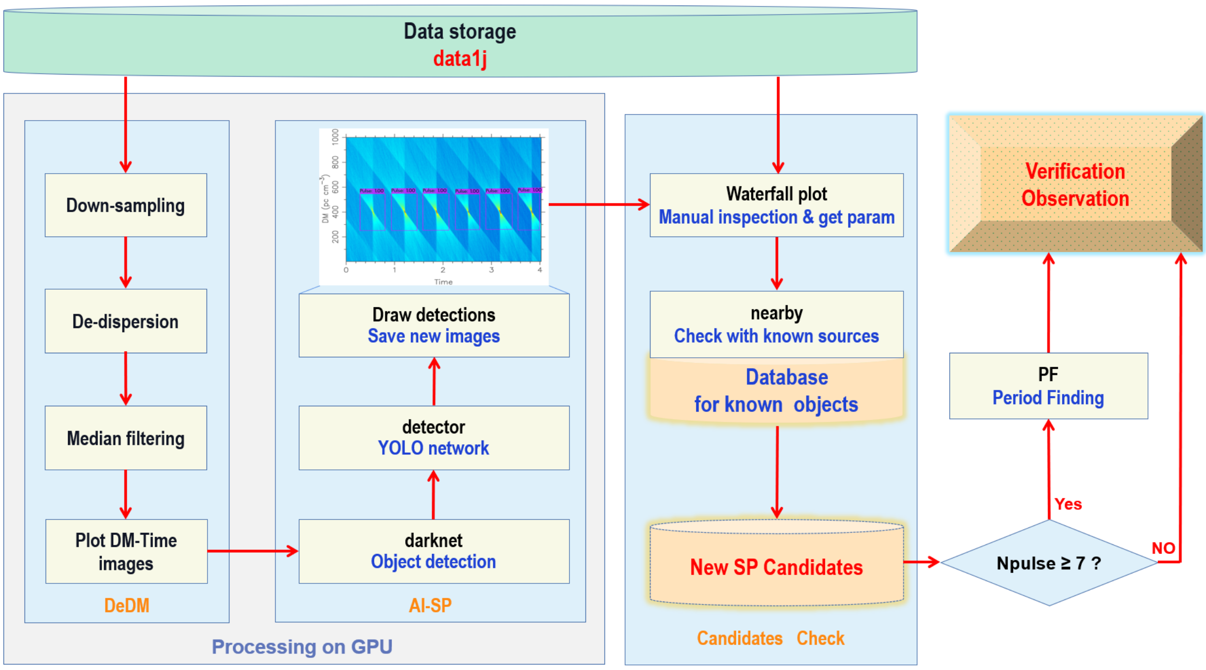

Figure 1. The flowchart for our single pulse search pipeline [6].

RRATs helped on the classification of all kinds of sources. For the newly detected sources, we always attempt to determine the possible periods of bursts.

Figure 1 shows the flowchart for our single pulse search pipeline. Compared to other methods, our approach excels in speed and also accuracy. It efficiently filters false signals, produces minimal intermediate files, and is versatile for both targeted observations and large surveys.

3 New Discoveries

3.1 New RRATs

We utilized our search pipeline to the FAST data of the Galactic Plane Pulsar Snapshot (GPPS) survey and discovered over 100 RRATs. [5, 6]. They have been classified into three groups: standard RRATs exhibiting discrete single-pulse radiation, extreme nulling pulsars, and weak pulsars with sporadic bright pulses. Due to limited observation time and a relatively low burst rate, over one-third of the sources have not yet found the periods.

3.2 New FRBs

Five new FRBs were also discovered from the GPPS survey data via our search pipeline[9], no repeating bursts from these FRB sources have been detected in the many follow-up monitoring observations, leading to their classification as potential one-off events. All FAST one-off FRBs, including those reported by other FAST projects such as the CRAFTS project [7, 8], have remarkably low peak flux densities and fluences. However, they have substantial excessing DMs (DM_E) (see Figure 2).

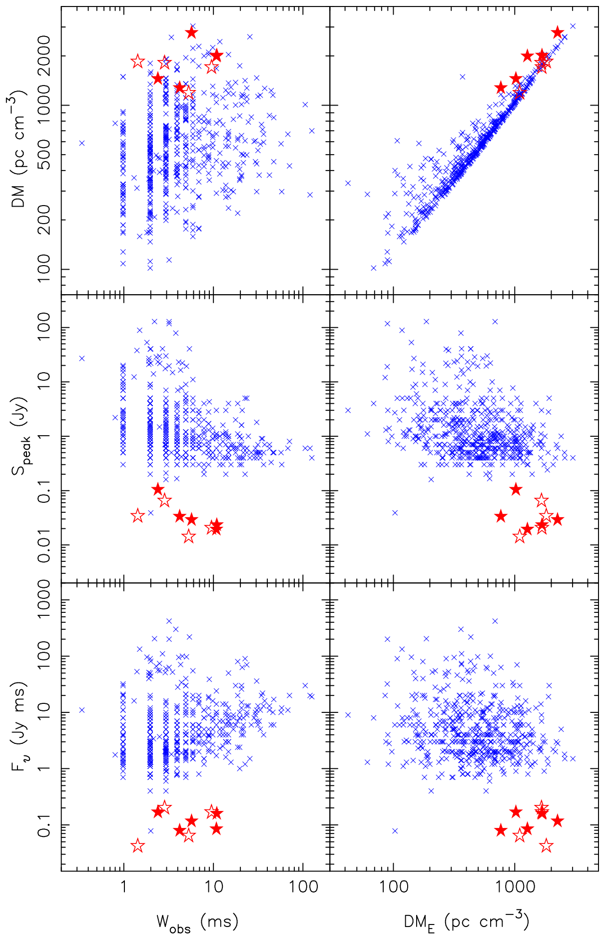

Figure 2. Basic parameters for FRBs discovered by FAST in the GPPS survey (solid star) and the CRAFTS (hollow star) [7–9] and for other known one-off events (cross), those mostly searched by CHIME [10].

4 FAST Observation of Known Sources

4.1 Known RRATs

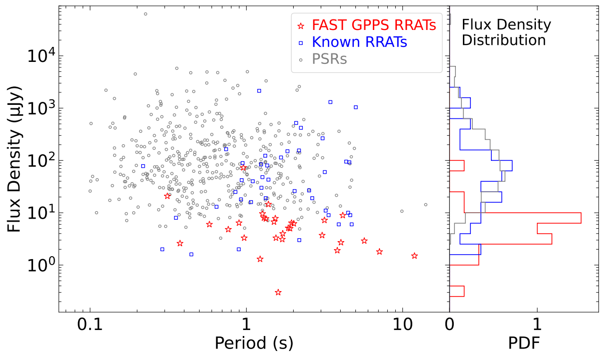

Figure 3. The distribution for the period and mean flux density of the newly discovered transients in GPPS survey (red), compared with the known RRATs (blue) and the other pulsars in the GPPS survey (gray)[5]. The right panel is the probability density function (PDF) for the mean flux density.

Sensitive observations of known RRATs can help to understand the enigma of RRATs. We observed 59 known RRATs using the FAST [6], detecting signals from 48 of them, improved the parameters of 28 RRATs. Importantly, a comprehensive analysis of folded single pulse shapes, energy distributions, and polarization reveals that these known RRATs either exhibit characteristics typical of weak pulsars or are nulling pulsars.

Comparing the periods and mean flux densities of newly discovered RRATs with those of known RRATs (Figure 3), the mean flux densities of these new sources are much lower than those of the known RRATs and even the GPPS pulsars, and there is no significant difference in period distribution between the new RRATs and the known RRATs.

4.2 Known FRBs

Our search pipeline has also been applied to process FAST's FRB data, resulting in the detection of thousands of bursts of repeating FRBs. Our program identifies numerous weak bursts that were overlooked by other search algorithms. Utilizing this sample of bursts observed by FAST, we conducted in-depth studies on repeating FRBs, measured the parameters of all bursts and explored morphology classifications [11]. Our colleagues have also analyzed the periodicity, polarization, and energy distribution, as well as investigating the correlation between FRB-like bursts and radio pulse from SGR J1935+2154 [12–19].

5 Discussions

Through systematic searches for radio transients from observational data by the super-sensitive FAST telescope, many known RRATs are confirmed as being typical weak or nulling pulsars [6]. We also discovered a large number of faint RRATs. Simply looking at the fraction of such RRATs, that is about 5% of previously known pulsars, we have found many more RRATs than expected, roughly about 15% in the GPPS survey products. This large increase in the fraction indicates that many radio transient radio sources in our Galaxy have been missed in previous surveys. The new approach and the telescope sensitivity are key to reveal this hide population of neutron stars.

About the unknown origin and radiation mechanisms of FRBs, the sensitive polarization of repeated FRBs and the discovery of faint FRBs by the FAST will improve our understanding of the burst features and FRB population.

We will continue our work by using our pipeline to process data of FAST observations and will have more discovery of radio transients.

6 Acknowledgements

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