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Research in Astronomy and Astrophysics

A GPU based single-pulse search pipeline (GSP) with database and its application to the Commensal Radio Astronomy FAST Survey (CRAFTS)

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Abstract We developed a GPU based single-pulse search pipeline (GSP) with a candidate-archiving database. Largely based upon the infrastructure of the open source PulsaR Exploration and Search Toolkit (PRESTO), GSP implements GPU acceleration of the de-dispersion and integrates a candidate-archiving database. We applied GSP to the data streams from the Commensal Radio Astronomy FAST Survey (CRAFTS), which resulted in quasi-real-time processing. The integrated candidate database facilitates synergistic usage of multiple machine-learning tools and thus improves efficient identification of radio pulsars such as rotating radio transients (RRATs) and fast radio bursts (FRBs). We first tested GSP on pilot CRAFTS observations with the FAST Ultra-Wide Band (UWB) receiver. GSP detected all pulsars known from the the Parkes multibeam pulsar survey in the corresponding sky area covered by the FAST-UWB. GSP also discovered 13 new pulsars. We measured the computational efficiency of GSP to be ∼120 times faster than the original PRESTO and ∼60 times faster than an MPI-parallelized version of PRESTO.

Key words: methods: data analysis — pulsars: general — surveys: astronomical databases

1 INTRODUCTION

Pulsars are rapidly rotating, highly magnetized neutron stars. Since the first pulsar was discovered in 1967, more than 2800 pulsars (Manchester et al. 2005) have been detected. Pulsar detection mainly relies on Fast Fourier Transform (FFT) to search in the time-frequency domain and Fast Folding Algorithm (FFA) (Staelin 1969) to search in the time domain. These two methods are very efficient for periodic pulsar searches. However, some pulsars have sporadic pulse trains, such as nulling pulsars and intermittent pulsars, and rotating radio transients (RRATs), which are better dealt with through single pulse detection. A fast radio burst (FRB) (Lorimer et al. 2007) is a radio pulse with extremely high dispersion measure (DM) and a duration of milliseconds, presumably from outside the Milky Way. FRBs can only be searched through single pulse search at present.

With faster sampling and more simultaneous beams, the data volume of pulsar search surveys has reached petabytes. Commensal Radio Astronomy FAST Survey (CRAFTS) (Li et al. 2018), for example, generates 6 GB s^{-1} pulsar search data streams. It is paramount to accelerate the data processing and prioritization of resulting pulse candidates. Due to its superior parallel processing capability and memory bandwidth, graphics processing units (GPUs) have been widely utilized in pulsar search. The AstroAccelerate software package[1] has GPU implemented Fourier domain acceleration search, GPU accelerated harmonic sum of periodicity search and also a GPU implementation of single pulse detection algorithms for real-time FRB searches (Adámek & Armour 2020). Jameson and Barsdell developed the GPU accelerated transient detection pipeline Heimdall[2]. Yu et al. (2020)

[1] `https://gitlab.com/ska-telescope/astro-accelerate`

[2] `https://sourceforge.net/p/heimdall-astro/`

developed a CPU-based parallel pipeline based on PulsaR Exploration and Search TOolkit (PRESTO, `https://www.cv.nrao.edu/~sransom/presto/`) to shorten the data processing time.

Since millions of candidates or diagnostic plots are generated by pulsar survey data processing, inspecting all of them by eye is time-consuming as well as a laborious task in which it is easy to make mistakes. Machine learning, particulary deep learning, has been shown to be effective in ranking the candidates (Zhu et al. 2014; Wang et al. 2019). There are many tools to realize single pulse search identification. Karako-Argaman presented a single pulse sifting algorithm named RRATtrap, which first groups the detected single pulse events of nearby DMs and times, then ranks and scores the grouped candidates according to some specified rules (Karako-Argaman et al. 2015). Devine presented a machine learning approach to identify and classify dispersed pulse groups (DPGs), which contain two-stages, first identifying DPGs in signal to noise ratio (S/N) versus DM domain by a peak identification algorithm, then using supervised machine learning for automatic DPG classification (Devine et al. 2016). Michilli developed a machine learning classifier, called Single-Pulse Searcher (SPS), to discriminate astrophysical signals from a strong RFI environment (Michilli & Hessels 2018). Pang et al. (2018) developed a two-stage single pulse search method, called Single Pulse Event Group IDentification (SPEGID), which first identifies single pulse candidates as single pulse event groups (SPEGs) within DMs versus time span, then automatically classifies unlabelled SPEGs as astrophysical (pulsars, RRATs or FRB) or nonastrophysical (RFI or noise) cases through supervised machine learning.

Pulsar search is one of the primary science objectives for FAST. We designed a GPU-based single-pulse search pipeline with candidate-archiving database (GSP) to realize a quasi-real-time processing of the CRAFTS data. GSP implements the PulsaR Exploration and Search TOolkit (PRESTO) de-dispersion algorithm 'prepsubband' on NVIDIA GPUs using CUDA, which performs 120 times faster than the original program and 60 times faster than MPI on an NVIDIA GTX 1080 GPU. GSP incorporates a pulsar-search database, through which astronomers can retrieve data analysis results, and achieve centralized management of the data processing.

We describe GSP in Section 2. In Section 3, we benchmark the GSP in test runs. In Section 4 we briefly present the processing that resulted in 13 new pulsars from CRAFTS. We provide our conclusions in Section 5.

Table 1 Frequency Bands of FAST UWB Drift Scan Data in the Single Pulse Search Pipeline

	Band1	Band2
Frequency range (MHz)	271 to 398	291 to 802
Bandwidth (MHz)	128	512
Channels across the band	512	2048
Central frequency (MHz)	334	546
Drifting time (s)	52	52

Table 2 Subband De-dispersion Survey Plan for Band1

No.	Low DM (pc cm^{-3})	High DM (pc cm^{-3})	dDM (pc cm^{-3})	DownSamp	Number of DMs
1	0	11.34	0.01	1	1134
2	11.34	22.2	0.03	2	362
3	22.2	39.05	0.05	4	337
4	39.05	77.15	0.1	8	381
5	77.15	153.75	0.2	16	383
6	153.75	343.75	0.5	32	380
7	343.75	687.75	1	64	344
8	687.75	969.75	2	128	141

Table 3 Subband De-dispersion Survey Plan for Band2

No.	Low DM (pc cm^{-3})	High DM (pc cm^{-3})	dDM (pc cm^{-3})	DownSamp	Number of DMs
1	0	48.77	0.01	1	4877
2	48.77	93.14	0.03	2	1479
3	93.14	164.74	0.05	4	1432
4	164.74	325.04	0.1	8	1603
5	325.04	485.04	0.2	16	800
6	485.04	592.84	0.2	16	539

2 SINGLE PULSE SEARCH PIPELINE

2.1 Overview of the Search Pipeline

We first tested GSP on pilot CRAFTS observations with the FAST-Ultra-Wide-Band (UWB) receiver (270 – 1620 MHz) from August 2017 to May 2018. A series of original fits files with a fixed size separately recorded two frequency bands of 0–1 GHz and 1–2 GHz in PSRFITS format (Hotan et al. 2004) with two polarization channels of XX and YY with 8 bit sampling, including ∼1800 hours of observation time (about 500 TB) in 2017, and ∼960 hours of observation time (about 260 TB) in 2018, stored in the cluster disk array and tape library of the FAST early scientific data center.

The GSP implements GPU acceleration of the de-dispersion and integrates a candidate-archiving database. We applied GSP to the data streams from the CRAFTS survey, and the data processing is performed in the FAST early scientific data center. For the single-pulse pulsar search, there are five major steps involved in processing the data: data preparing, pulsar search (RFI mitigation, de-dispersion and single-pulse search) and results evaluation. See Figure 1 for a schematic of data processing.

In data preparation, we first merged every two adjacent fits files for each actual pointing, and the data stream overlapped half of the time for the Nyquist sampling. For pulsar search, as illustrated in Algorithm 1, under the premise that the channels and samples are determined, the number of DMs determines the calculation load of the dedispersion. In GSP, we mainly use PRESTO's 'DDplan.py' to generate the optimized DM trails. For two different frequency bands (Table 1), the parameters of de-dispersion trails are displayed in Tables 2 and 3.

For the single pulse search of CRAFTS, there are two challenges to be solved in data processing. First, the de-dispersion accounts for a large proportion of the data processing, and secondly, it needs to identify a large number of single pulse candidates. In order to improve the search efficiency, we implemented a parallel acceleration policy to the search process, in which the most time-consuming de-dispersion part is accelerated by a GPU (see in the next section), and the single-pulse search, single pulse identification and data folding steps were executed in parallel on CPUs, which saved a lot of data processing time. The entire processing flow starts with data processing. We manage with the help of a database, and save some intermediate results to the database to facilitate the later single pulse identification and diagnosis. For the single pulse candidates that failed to find periods, we used the SPS software package[3] as an identification tool to generate single pulse diagnostic plots to determine whether it is an astronomical signal from the universe.

2.2 Single Pulse Candidate-archiving Database

In order to facilitate the storage, management and query of single-pulse candidates, we implemented a database based on the framework of MariaDB[4]. As displayed in Figure 2, the database consists of six tables, mainly recording the single pulse candidates identified by single pulse sifting algorithm. The database stores the psrfits file to be processed in the T_FITS_INFO table. For the single pulse results identified by RRATtrap, we save the overall information of each file in T_SINGLEPULSE_GROUPS, and store the information about each single pulse candidate, including the maximum DM, minimum DM, number of events of single pulse candidates, maximum sigma, pulse appearance time, pulse duration and other information, in T_SINGLEPULSE_CANDIDATES. We saved the pulsars in the latest ATNF Pulsar Catalogue in T_PULSAR, and compared them with DM according to the direction of the observation file, saved the results of the comparison in T_FILE_PULSAR and the path of pictures generated by the pipeline was saved in T_SINGLEPULSE_PIC.

Table 4 Basic Parameters of CPU and GPU

Processor type	CPU	GPU
Version	AMD Ryzen 7 2700X	NVIDIA GeForce GTX 1080
Core number	8 cores, 16 threads	2560 cores
Clock rate	3.7 GHz	1.6/1.7 GHz
Memory	64 GB	8 GB
Compute ability	—	6.1

2.3 GPU Accelerated De-dispertion

For performing the blind search, we do not know the DM of pulsars, so we must make an optimized dedispersion plan and search over a wide range of trial DMs. Computing the dedispersion transform is a computationally intensive task. There are three algorithms: brute force dedispersion, tree dedispersion algorithm (Taylor 1974), and sub-band dedispersion algorithm (Barsdell et al. 2012). We analyzed acceleration of the parallel dedispersion algorithm on GPU, and developed a C language GPU dedispersion library. We implemented the sub-band dedispersion algorithm based on PRESTO's 'prepsubband'. This article examines the acceleration and designs an accelerated program that supports multiple GPUs.

In PRESTO prepsubband, the input of dedispersion was stored in two preprocessed channelized time-series matrixes with $numpts \times numchan$, where $numpts$ is the number of time samples per read and $numchan$ is the frequency channels. The delay of each channel was pre-calculated and stored in a $numdm \times numchan$ matrix, where $numdm$ is the number of DMs to dedisperse. The results after dedispersion were stored in a matrix with $numdm \times numpts$. The algorithm is illustrated in Algorithm 1.

Algorithm 1 Pseudocode of the dedispersion algorithm of PRESTO prepsubband

Require: data array with $numpts \times numchan$, delays array with $numdm \times numchan, numpts, numchan$
Ensure: result array with $numpts$
  for $ii = 0 \rightarrow numpts$ **do**
    result[ii]=0
  end for
  for $ii = 0 \rightarrow numchan$ **do**
    $jj = ii + delays[ii] \times numchan$
    for $kk = 0 \rightarrow numpts - delays[ii]$ **do**
      result[kk] += lastdata[jj]
    end for
    $jj = ii$
    for $kk = numpts - delays[ii] \rightarrow numpts$ **do**
      result [kk] += data[jj]
    end for
  end for

[3] https://github.com/danielemichilli/SpS
[4] https://mariadb.org/

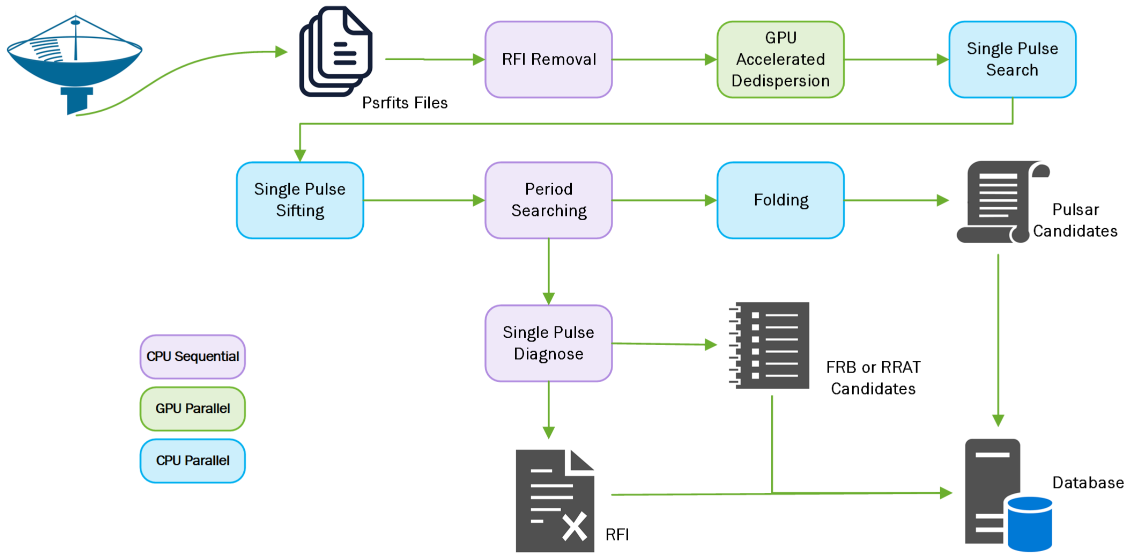


Fig. 1 Schematic of the CRAFTS pulsar single pulse search pipeline (GSP).

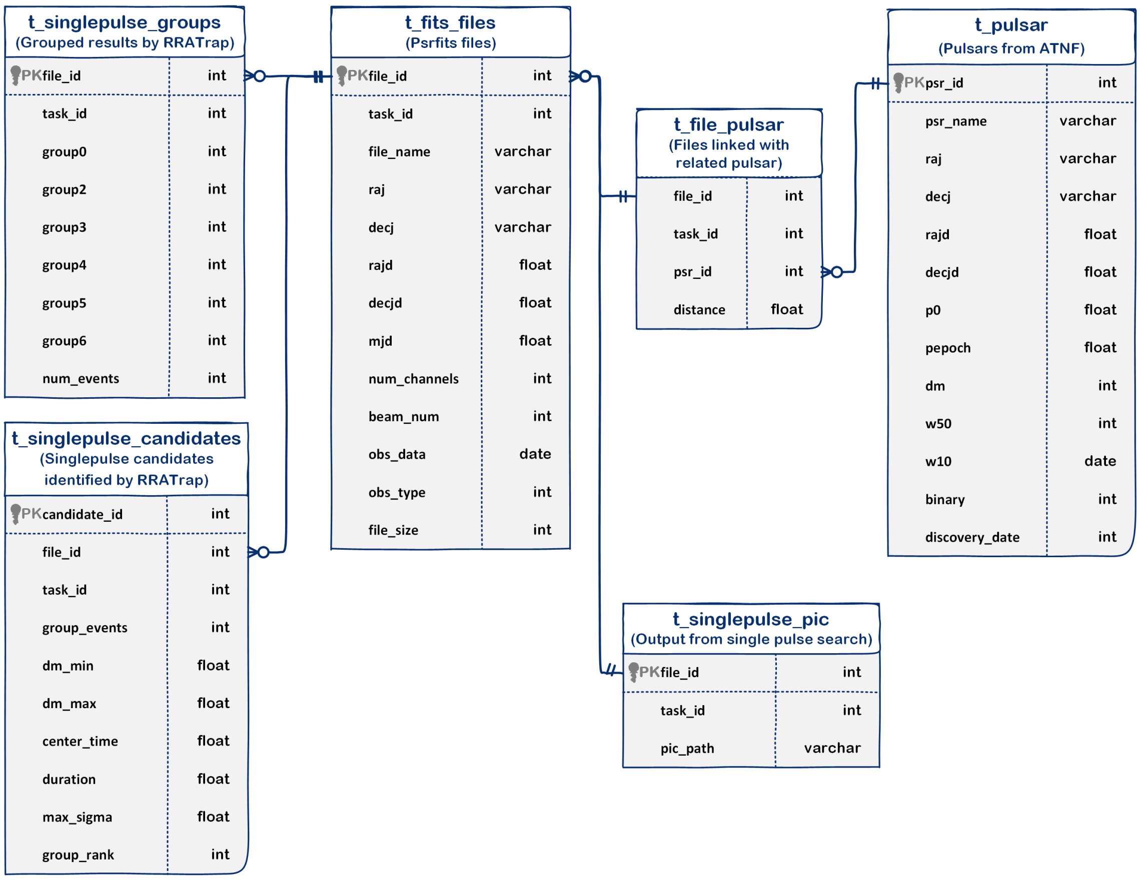


Fig. 2 Framework of the GSP pulsar single-pulse database.

Since PRESTO was originally developed based on CPU serial programs, the code was gradually optimized to support parallel programs with OPENMP and MPICH, but the overall program was based on CPU implementation. Therefore, to achieve GPU accelerated prepsubband calculation, it is necessary to redesign the de-dispersion acceleration algorithm based on the GPU programming model. From Algorithm 1, the loop of time sampling is divided into two parts by the delay matrix, the part with delay less than $numpts$ minus $delays$ gets data

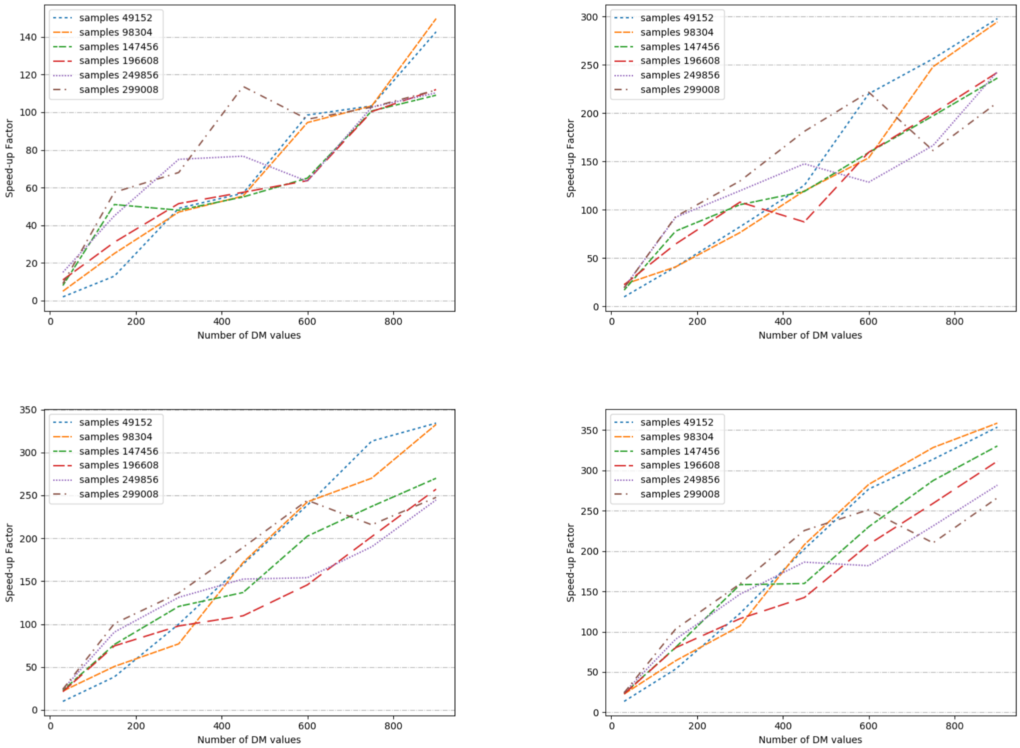


Fig. 3 When the number of channels is 256, 512, 1024, and 2048 the gpuprepsubband is compared with the acceleration effect of prepsubband running 1 process. It can be seen from the figure that as the number of tested DMs increases, the acceleration effect becomes better and better; when the number of DMs is relatively large, the acceleration effect of short files is better than that of long files.

from lastdata matrix, and the rest gets data from the data matrix. This type of design will result in divergence on the GPU, thereby reducing the performance of dedispersion. To eliminate the divergence, we merge the two matrices and produce a new matrix with $2 \times numpts \times numchan$. As displayed in Algorithm 2, we revised the dedispersion algorithm with $numpts \times numdm$ threads. Each thread computes the sum of a single time sample over every channel sequentially. Unlike Algorithm 1, for each thread, we add the sum of samples over channels to a variable which is stored in the GPU registers, thus reducing the number of accesses to global memory.

For input data preparation, in order to be compatible with the original PRESTO, the original code has not been changed, which can ensure that the parameters of the dedispersion input are consistent with the original parameters, thereby ensuring that the result of the GPU computation is the same as that of the original CPU.

3 PIPELINE TESTS

In this section, we present the test of GSP to the data streams from the CRAFTS survey.

Algorithm 2 Pseudocode of the parallel dedispersion algorithm on GPU

Require: data array with $2 \times numpts \times numchan$, delays array with $numdm \times numchan, numpts, numchan$
Ensure: result array with $numpts$
tid = blockIdx.x * blockDim.x + threadIdx.x
if $tid < numpts \times numdm$ **then**
resultvar = 0
for $ii = 0 \rightarrow numchan$ **do**
jj=ii*2*numput+(tid mod numpts)+delays[$\lfloor tid/numpts \rfloor$ * numchan + ii]
resultvar += data[jj]
end for
result[tid] = resultvar
end if

3.1 Experiments of GPU Accelerated De-dispertion

The FAST UWB receiver achieves a better than 60 K receiver temperature covering 270 MHz–1.62 GHz. The beam-passing time of a drift scan equals approximately 52 s at frequency of Bands in Table 1. With proper weighting, the equivalent integration time per beam will be around 65 s. The recorded FAST data stream for pulsar observations is a time series of total power per frequency channel, stored in PSRFITS format (Hotan et al. 2004)

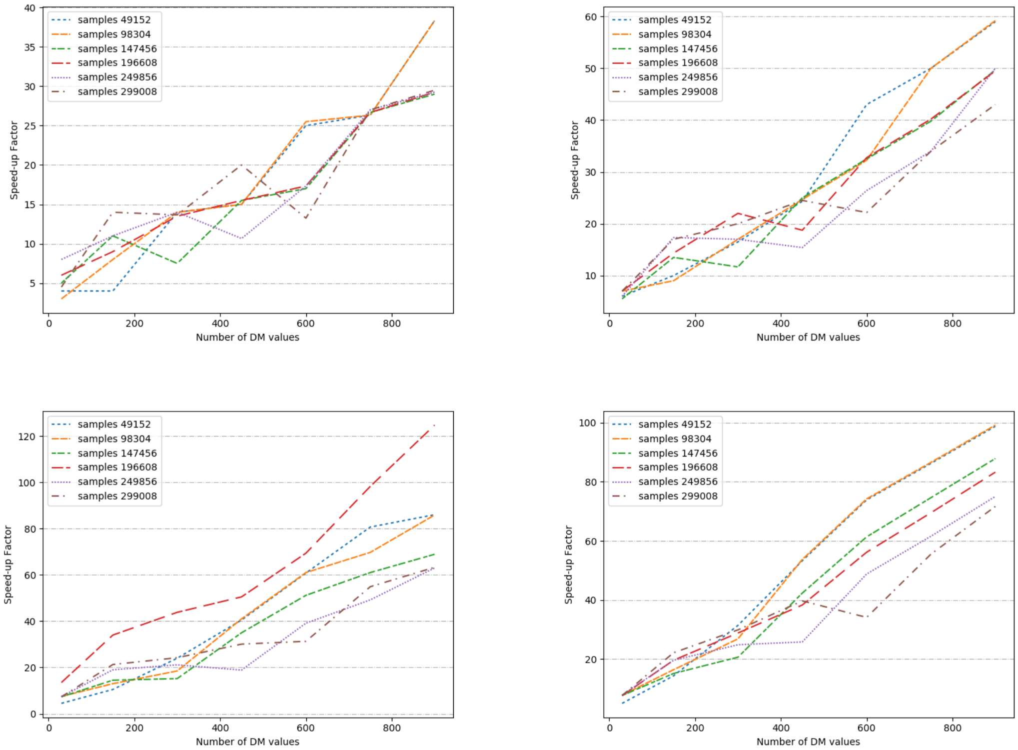


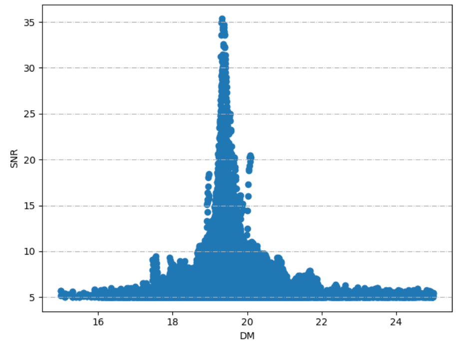
Fig. 4 When the number of channels is 256, 512, 1024 and 2048, the gpuprepsubband is compared with the acceleration effect of mpiprepsubband running 15 processes. It can be seen from the figure that as the number of tested DMs increases, the acceleration effect becomes better and better; when the number of DMs is relatively large, the acceleration effect of short files is better than that of long files.

Table 5 Comparison of Eight Pulsars both Detected by FAST and Parkes

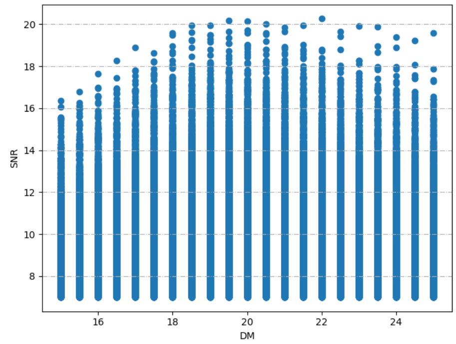
No.	Name	P0	DM	Number of pulses detected by FAST	Number of pulses detected by Parkes	Max S/N of pulses detected by FAST	Max S/N of pulses detected by Parkes
1	B1822-09	0.769006	19.38	83714	76403	35.35	20.26
2	B1839+09	0.381319	49.16	101928	296	53.86	9.28
3	B1845-01	0.659432	159.53	13431	168190	12.42	22.17
4	B1846-06	1.451319	148.17	345565	11054	79.3	30.38
5	J1823-0154	0.759777	135.87	3421	70	17.66	8.97
6	J1824-0127	2.499468	58	14235	109	78.22	11.36
7	J1852-0635	0.524151	171	24782	3711	58.6	17.33
8	J2005-0020	2.279661	35.93	5077	27	11.8	9.06

from a ROACH-2[5] based backend, which produces 8-bit sampled data over 256 – 4k frequency channels at 98 µs cadence. For the GPU de-dispersion test in this work, we carried out an experiment by adding simulated pulses into real data. The injected pulses were generated assuming various DMs and then sampled in time and frequency in exactly the same fashion as those of the FAST data. Since the DM of a pulsar is not known a priori, we created de-dispersed time series for each pseudo-pointing over a range of DMs, from 0 to ∼1000 $\mathrm{pc\,cm^{-3}}$, which is a factor of three to four larger than the maximum DMs predicted by the NE2001 model (Cordes & Lazio 2002) and YMW16 model (Yao et al. 2017) in the low Galactic latitude regions of the survey. The step size between subsequent trial DMs (ΔDM) was chosen such that over the entire band $t_{\_\Delta DM}$ = $t_{\_chan}$. This ensures that the maximum extra smearing caused by any trial DM deviating from the source DM by ΔDM is less than the intra-channel smearing. The set of trial values is chosen using the 'DDplan.py' tool from PRESTO and is shown in Tables 2 and 3. We tested a total of 48 test files, and the number of DMs start from 30 steps and test to 900 steps. Each test process tests CPU single-

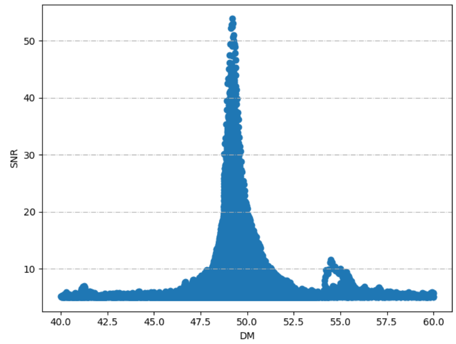
[5] *https://casper.ssl.berkeley.edu/wiki/ROACH-2_Revision_2*



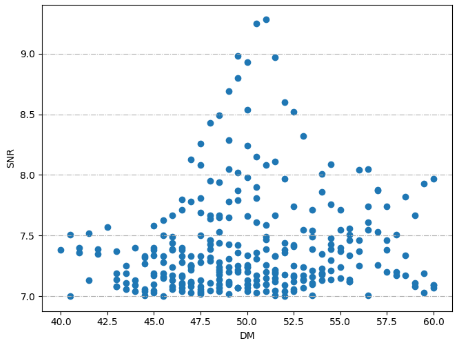
B1822-09 detected by FAST



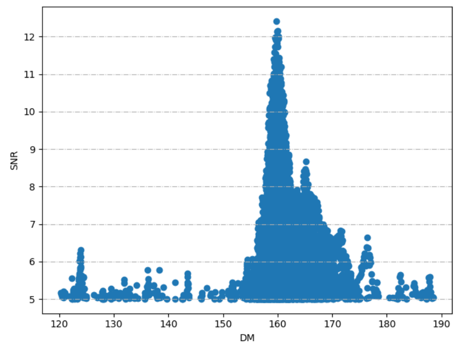
B1822-09 detected by Parkes



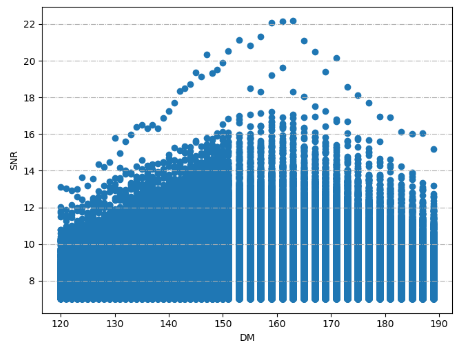
B1839+09 detected by FAST



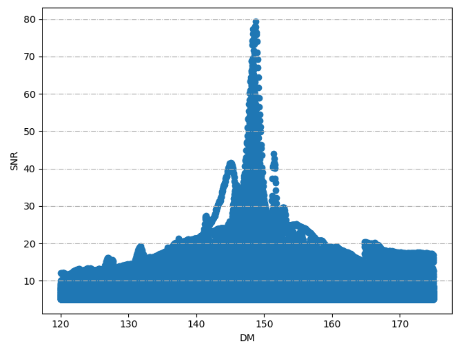
B1839+09 detected by Parkes



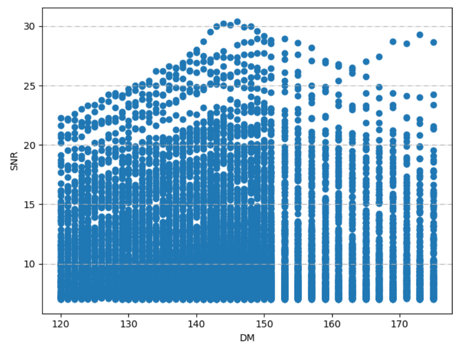
B1845-01 detected by FAST



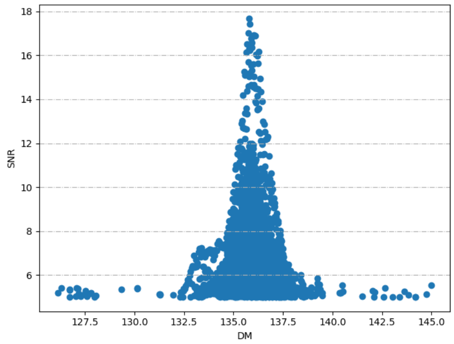
B1845-01 detected by Parkes



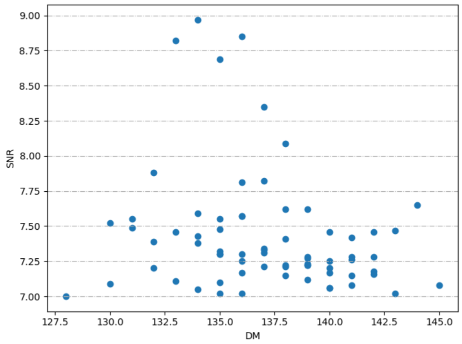
B1846-06 detected by FAST



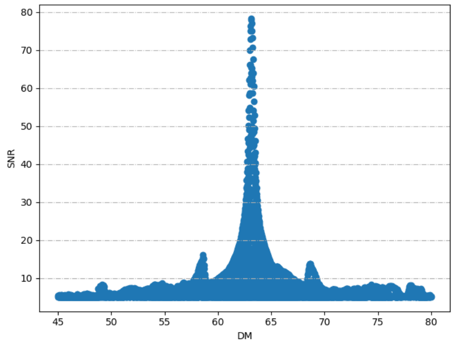
B1846-06 detected by Parkes



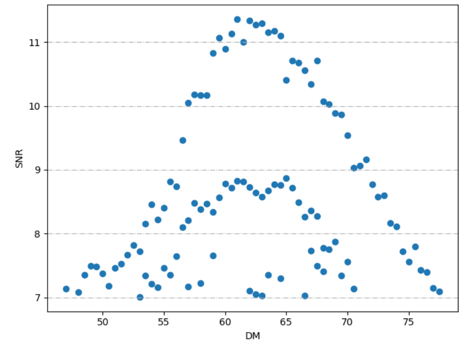
J1823-0154 detected by FAST



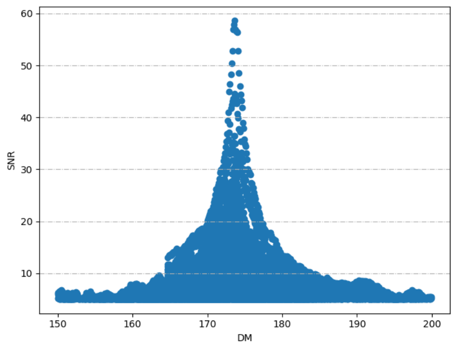
J1823-0154 detected by Parkes



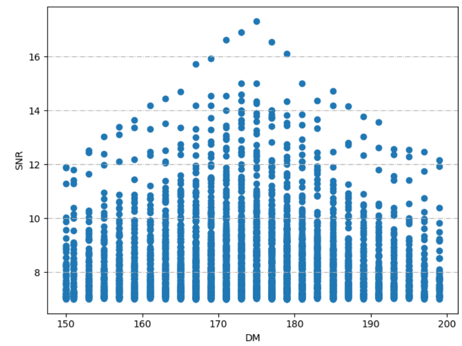
J1824-0127 detected by FAST



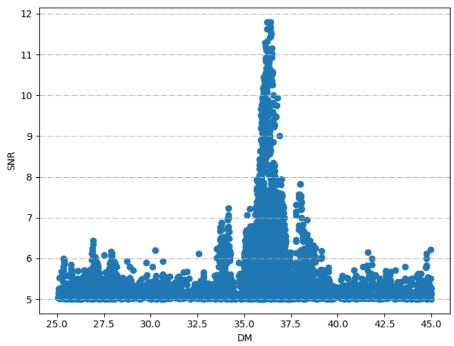
J1824-0127 detected by Parkes



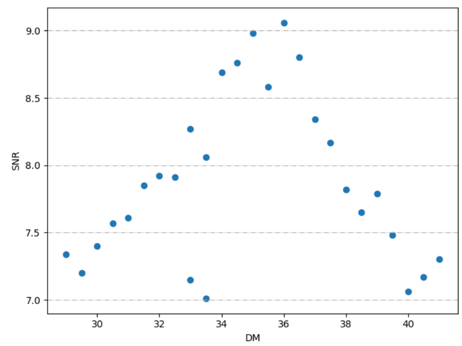
J1852-0635 detected by FAST



J1852-0635 detected by Parkes



J2005-0020 detected by FAST



J2005-0020 detected by Parkes

Fig. 5 Comparisons of DM vs. S/N plots of the eight pulsars that were detected by both FAST and Parkes.

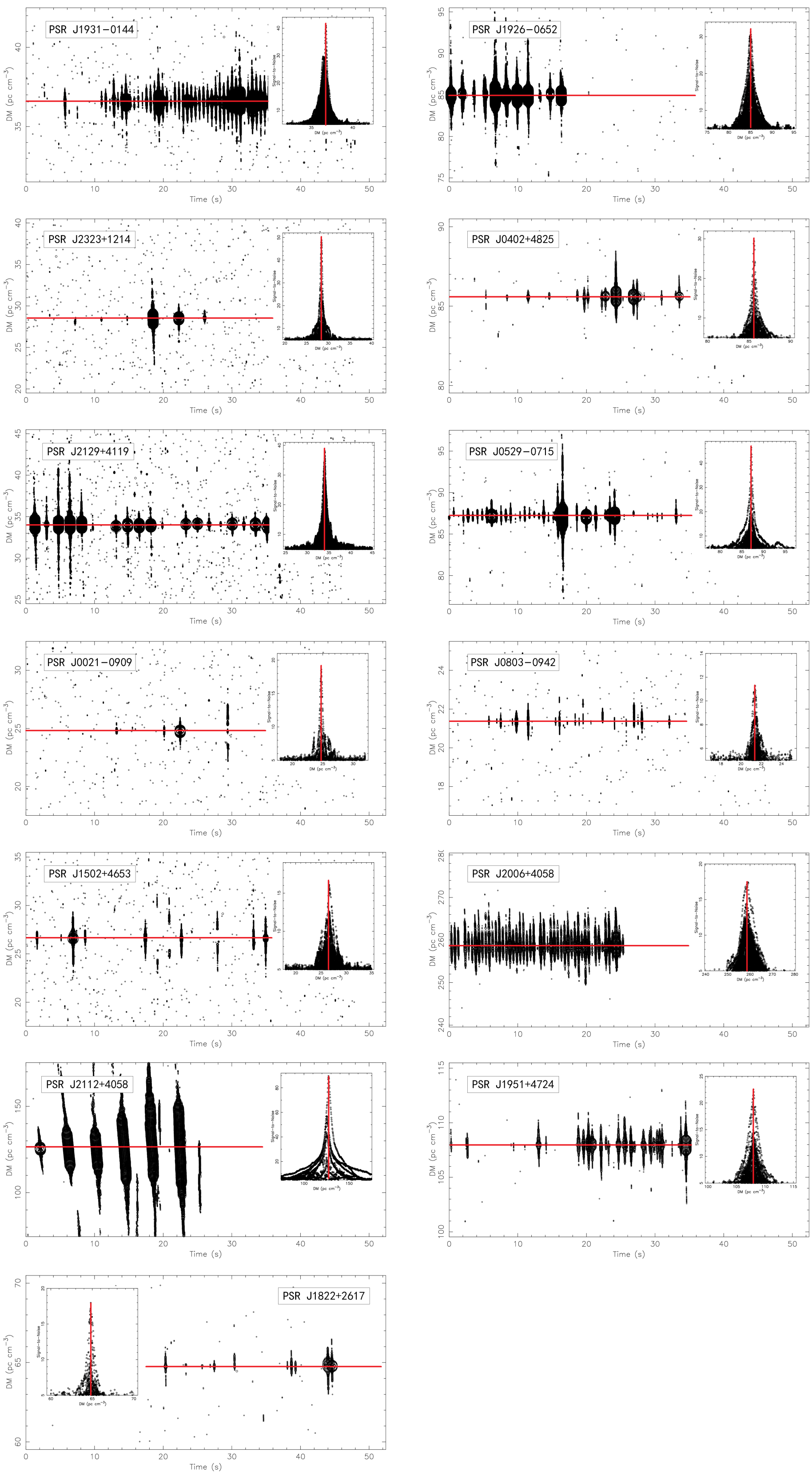


Fig. 6 Single pulse search of 13 FAST pulsars discovered by GSP. The subplots are scatterplots of the DM versus time for each single-pulse event which is proportional to its S/N. The *horizontal red line* signifies the DM value corresponding to the maximum S/N. Subplots are scatterplots of S/N versus DM. The *vertical red line* signifies the DM value corresponding to the maximum S/N.

Table 6 13 New Pulsars Discovered by GSP

No.	Name	P0 (s)	DM (cm^{-3} pc)	RA(2000) (h:m:s)	Dec(2000) (±d:m:s)	GL (°)	GB (°)	D_{NE2001} (kpc)	D_{YMW16} (kpc)
1	J1931-0144	0.593661359782(12)	38.3(13)	19:31:32.025(9)	–01:44:22.5(4)	35.974	–9.711	1.7	1.4
2	J1926-0652	1.608816302697(18)	85.3(7)	19:26:37.041(6)	–06:52:42.7(4)	30.751	–10.936	2.9	5.3
3	J2323+1214	3.75949148736(8)	29.0(3)	23:23:21.619(7)	+12:14:12.70(16)	91.595	–45.209	1.7	>25
4	J0402+4825	0.512194448728(3)	85.7(3)	04:02:40.633(9)	+48:25:57.51(7)	152.4276	–3.1772	2.3	1.8
5	J2129+4119	1.68741829528(1)	32(1)	21:29:21.46(4)	+41:19:55(1)	87.1948	–7.1093	2.3	1.9
6	J0529-0715	0.689223601359(8)	87.3(4)	05:29:08.973(2)	–07:15:26.43(10)	210.065	–21.582	>46	7.0
7	J0021-0909	2.31413082912(16)	25.2(10)	00:21:51.47(3)	–09:09:58.7(11)	100.290	–70.726	1.3	>25
8	J0803-0942	0.571256559156(14)	21.1(3)	08:03:26.848(13)	–09:42:50.81(14)	230.070	11.197	1.3	0.8
9	J1502+4653	1.75250806373(3)	26.6(5)	15:02:19.83(1)	+46:53:27.4(1)	79.3056	57.6263	1.5	25.0
10	J2112+4058	4.0607548114(5)	129(8)	21:12:51.76(6)	+40:58:04(1)	84.7385	–5.1570	5.4	5.2
11	J2006+4058	0.499694912119(2)	259.5(2)	20:06:39.098(3)	+40:58:53.48(3)	77.1185	4.7313	>50	12.6
12	J1951+4724	0.18192759882(1)	104.35(8)	19:51:07.45(3)	+47:24:35.1(2)	81.1828	10.3473	6.0	9.0
13	J1822+2617	0.591417585722(1)	64.7(1)	18:22:44.819(2)	+26:17:26.83(4)	54.0268	17.5535	3.6	7.8

Notes: The parameter are obtained from the timing solutions utilizing the 64-m Parkes radio telescope (Cameron et al. 2020) and the 100-m Effelsberg radio telescope (Cruces 2021 MNRAS accepted, Wang Shen 2021 RAA accepted).

thread, CPU 16-thread OMP acceleration (implemented with -ncpus 16) and 15-process mpiprepsubband (because mpiprepsubband must meet the number of processes $n-1$ times the number of cpu cores), and gpuprepsubband acceleration tests.

The testing process was conducted on an AMD Ryzen 7 Threadripper 2700X with an NVIDIA GTX 1080 GPU. Table 4 lists the basic parameters of CPU and GPU. The operating system was Ubuntu 18.04 with CUDA Version 10.0, and the testing data were stored on the SSD. Figure 3 demonstrates the speed-up effect of GPU relative to CPU single thread when the number of channels is 256, 512, 1024 and 2048. As the number of tested DMs increases, the acceleration effect gets better and better. When the number of DMs is large enough, the acceleration effect of short files is better than that of long files. Figure 4 shows the speed-up effect of GPU relative to mpiprepsubband with the same parameters of CPU single thread testing. The general tendency of mpiprepsubband with GPU test was similar to the CPU single thread with GPU results.

The results of prepsubband are single-precision floating-point numbers recorded in dat files of binary format, within the allowable range of calculation accuracy. We checked the results by the linux 'diff' command, and it was confirmed that the GPU results are the same as those of the CPU.

In the early analysis and testing process of prepsubband, we found that Algorithm 1 takes up the largest proportion of calculation time, and the optimization of this part will not affect the various options of prepsubband. We have also tested the 'mask', 'clip' and 'nobary' options, where the results of running on the CPU and GPU are consistent.

3.2 Confirmation of Eight Known Pulsars with Cross-matching in GSP & Parkes Database

We used the servers of the FAST early scientific data center to perform a single pulse search on the data of Band1 and Band2. After single pulse identification with RRATtrap.py in PRESTO, 2 244 298 single pulse candidates were classified and recorded into the database. Of the classified candidates, 1 469 415 were classified as being RFI or noise, 100 791 as excellent astrophysical candidates (with group rank 6), and 674 092 candidates with group rank in 3, 4 or 5. In these candidates, we compared the records of FAST UWB single pulse database with Parkes database and found eight known pulsars both detected by FAST and Parkes (Zhang et al. 2020), as affirmed in Table 5 and Figure 5. For pulsar B1845-01, since the FAST drifting scan is far from the pulsar's position, the S/N detected by FAST was weaker than that of Parkes.

4 DISCOVERY OF 13 PULSARS FROM THE CRAFTS SURVEY

Using the GSP pipeline, we discovered 13 new pulsars[6] as listed in Table 6, and applied FFA (Staelin 1969) for periodical search. For the single pulses adjacent to the DM, the maximum range of the FFA search is 1.5 times the time interval of the two single pulses adjacent to the DM; the follow-up timing observation has been completed by Parkes and Effelsberg Radio Telescope. These pulsars were reported upon (Cameron et al. 2020; Qian et al. 2019; Cruces et al. 2021; Wang et al. 2021a; Zhang et al. 2019; Wang et al. 2021b) and the discovery plots of GSP for each of the 13 pulsars are displayed in Figure 6.

[6] *https://crafts.bao.ac.cn/pulsar/*

5 CONCLUSIONS

We described a new, more efficient single pulse search pipeline, namely GSP, to search for pulsars, RRATs and FRBs. The pipeline relies on GPUs to accelerate dedispersion, and utilizes CPU parallel threading to implement single pulse search, single pulse identification and folding processes. Our main results are as follows:

- GSP integrates data preparation, dedispersion, single pulse search, candidate ranking and candidate archiving.
- GSP implements the PRESTO dedispersion package 'prepsubband' with CUDA, which was shown to be $\sim$120 times faster than the original 'prepsubband' and $\sim$60 times faster than the MPI version for processing CRAFTS data.
- We detected all known pulsars in the overlapping sky of the FAST-UWB observation and Parkes Multibeam surveys.
- GSP discovered 13 new FAST pulsars in the pilot CRAFTS survey with the FAST-UWB.

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