Searching Local Universe Fast Radio Bursts

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Abstract

Fast Radio Bursts (FRBs) are short, millisecond-scale bursts of radio emission whose origins are currently unknown. Magnetars are considered to be a source of FRBs since FRB-like bursts have been detected coming from known magnetars, but it is still unknown what fraction of FRBs are generated by magnetars. Data analysis of FRBs is very similar to that of examining giant pulses from Pulsars, though given the distance they have travelled, FRBs have a spectral luminosity several orders of magnitude higher than Pulsar pulses. Unlike pulsars, FRBs do not always repeat so consistently: most FRB sources have not been observed to repeat, though around 4% of them are known repeaters. FRB sources labelled as "non-repeating" have the potential to be repeating sources whose successive FRBs have not been detected, motivating us to re-observe both repeating and non-repeating FRB sources to search for more bursts. The mysteries behind FRBs' origins and the dichotomy between repeating and non-repeating sources makes FRBs an exciting frontier with great progress to be made. We analyzed data from a 20-hour survey composed of various repeating and non-repeating FRB sources on the Five-hundred-meter Aperture Spherical Telescope (FAST), which gives us unprecedented sensitivity to resolve fainter FRBs than we have previously been able to observe. We processed just over 8 hours of this data to search for bursts using the software PRESTO—which helps us de-disperse the incoming signal according to the Dispersion Measure (DM) and remove Radio Frequency Interference (RFI) from man-made sources—and were able to identify two bursts from one of our repeating targets. We were unable to identify bursts in the other repeating targets and did not discover that any of our non-repeating bursts were actually repeating; however, our ability to find and identify FRBs from FAST data bodes well. In the future, we can continue to search for more bursts with FAST and discover more from repeating sources while possibly establishing non-repeating sources as repeaters.

This paper represents my work in accordance with University regulations.

/s/ Xander Jenkin

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1 Introduction

Fast Radio Bursts (FRBs) are short (millisecond-scale), broadband radio emissions which come from unknown, usually extragalactic sources (though, excitingly, we have recently discovered one residing within the Milky Way). The origins of FRBs are still largely unknown, and the variety of sources make them even more difficult to pin down. Some FRB sources do repeat, but repeating sources are rare, further adding to the puzzle of the mechanics behind FRBs. FRBs are similar to pulses from Pulsars, though they do not always repeat so consistently, and operate in much smaller windows on the millisecond scale with significantly larger (10^{10} times larger) flux density, with wildly different spectra [Cordes & Chatterjee(2019)].

As of 2019, we have found bursts from around 60 confirmed unique sources, but this number grew to over 600 by 2022, and 19 of them have localization precise enough to associate them with specific galaxies [Petroff et al.(2022)Petroff, Hessels, & Lorimer]. Most of these are not apparent repeating sources, but some are, as around 4% of the FRB sources are known repeaters. All our current identifications of non-repeating FRB sources are simply sources that have produced an FRB which we have not found another, so they all could potentially be repeating sources which we have failed to confirm—a symptom of the current mysteries behind the origins of FRBs.

1.1 FRB Origins

As mentioned, the origin of FRBs is largely unknown. Previously, they were classified as being only extragalactic, but in 2020, FRB 200428 was found coming from the Galactic magnetar SGR 1935+2154, which is about 100 pc above the Milky Way disk's plane [Bochenek et al.(2020)Bochenek, Ravi, Belov, Hallinan, Kocz, Kulkarni, & McKenna]. Magnetars are young, highly magnetized neutron stars that are active in the X-ray [Kaspi & Beloborodov(2017)], and are theorized to be an explanation for how FRBs form. Many FRBs have been localized to areas associating them with magnetars (like FRB 200428), but as a whole, the question of which objects originate FRBs remains unanswered, and magnetars remain a theory among other objects. FRBs have also come from both highly star forming regions and regions of galaxies at least 200 pc away from a peak of local star formation [Petroff et al.(2022)Petroff, Hessels, & Lorimer].

The mystery behind their origins, the discrepancies between repeating/non-repeating sources, the variety of environments from which they can form, and the recent rapid growth in detections make FRBs an enticing field to study at the moment, as there is much progress to be made which can come by discovering and analyzing new bursts.

1.2 Dispersion Measure

As FRBs propagate through space, the higher frequencies penetrate dust more quickly than lower frequencies do, resulting in a dispersion in the arrival times of different portions of the radio signal, as each frequency is delayed differently [Keane et al.(2012)Keane, Stappers, Kramer, & Lyne]. The amount of delay dispersion of a particular FRB corresponds to the amount of dust the FRB travelled through by the time we receive it, so if we want to view the original signal, we should de-disperse it by an amount corresponding to how much dust we think the FRB has travelled through (which also relates to how far away the FRB originated from us). This amount is referred to as the Dispersion Measure (DM). We can both use physical knowledge of the environment of an FRB to guess a good value for its DM and try searching for FRBs at a range of DM values to learn more about the properties of its environment by seeing which DM values give the clearest burst.

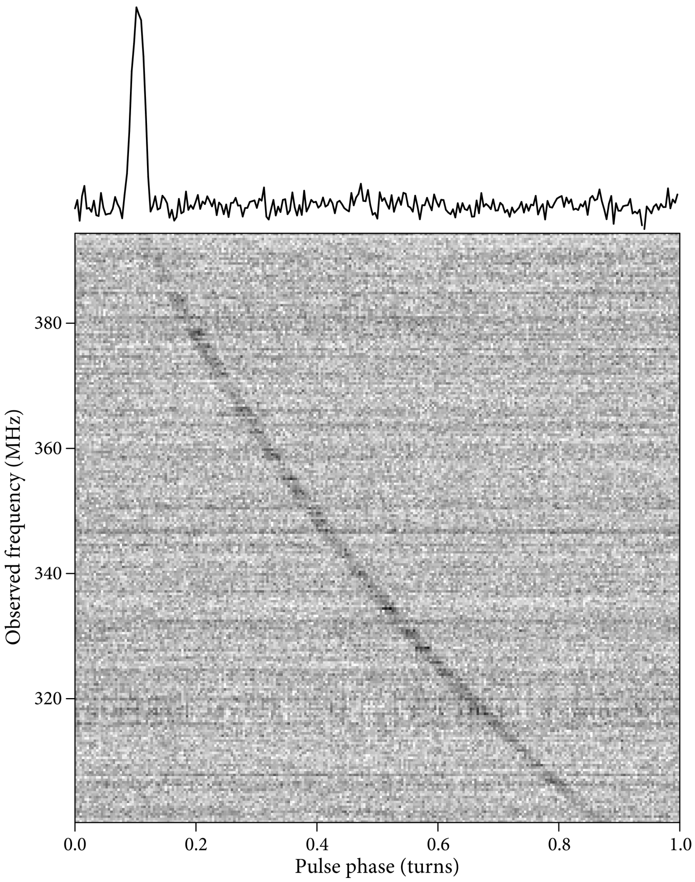


Figure 1: Example of a pulse from Pulsar J1800+5034, which is dispersed in frequency over time, resulting in a distinct "ribbon" diagonal shape in Frequency v. Time (as Pulsar pulses also experience dispersion in the same way as FRBs). When de-dispersed according to the dispersion measure, we get the re-formed pulse above [Condon & Ransom(2018)].

The contribution to the time delay caused by the dispersion measure is

$$t_{DM}(\nu) = 4.15\text{ms}\left(\frac{\text{DM}}{\nu^2}\right) \tag{1}$$

Where DM is a column density (in pc cm^{-3}) integrated over all of the electrons along the distance d from the source to the observer [Cordes & Chatterjee(2019)].

$$\text{DM} \equiv \int_0^d n_e dl \tag{2}$$

There are other contributions to the time delay which come from the Faraday rotation measure and emission measure, which each scale as ν^{-3} and ν^{-4} respectively, where ν is the frequency in GHz (the full equation of time delay $t(\nu)$ with these two terms included will be shown later when we show how to de-disperse an incoming FRB).

Because the dispersion measure corresponds to both the time delay and physical distance of the burst, when we first get a detection that is dispersed over time and frequency indicative of an FRB, we can de-disperse that by the amount which would "straighten" it to recover the single burst. This DM value that was found experimentally can be used to estimate the distance d (Eq. 4), though this is influenced by the density of the environments the FRB has travelled through, so it becomes difficult to get a precise distance without knowledge of the source's local environment. However, lower-DM FRBs will still generally have closer sources than sources whose FRBs have much higher DM. This means that if we want to find far FRB sources, we should look for ones with high DM; likewise, to find nearby sources, we should look for low DM bursts—which will motivate our choice of targets for this survey.

2 Data Selection

2.1 FAST

We used data from the Five-hundred-meter Aperture Spherical Telescope (FAST) located in Guizhou, southwest China. This massive telescope is the largest single-dish telescope ever made—even larger than the 300-meter Arecibo Telescope in Puerto Rico—which gives us unprecedented sensitivity to resolve faint radio bursts, making FAST a great way to observe both repeating FRB sources and search non-repeating FRB sources for new bursts to possibly discover a new repeating source. Here, we conducted a survey with FAST that spans a total of 20 hours over all 12 targets.

The goal of using FAST data is to find nearby ($\sim 50Mpc$), lower-energy FRBs. This regime of FRBs currently has the highest potential for multi-wavelength follow-up surveys, and FAST's unparalleled sensitivity will allow us to discover these fainter, lower-energy bursts than other radio surveys. As previously mentioned, the gap between the energies of most FRBs and Pulsar pulses is on the scale of $\sim 10^{10}$. FAST's sensitivity allows it to be used to explore this by looking at the differences between the lowest-energy FRBs and some of the most energetic Pulsar pulses, which also further motivates the need to find fainter FRBs that can only be spotted by something as sensitive as FAST. The environments around nearby FRBs can also be much more easily observed in the X-ray and optical, allowing for us to use detailed non-radio observations to analyze where the FRB came from, furthering our understanding as to the mystery behind their origins.

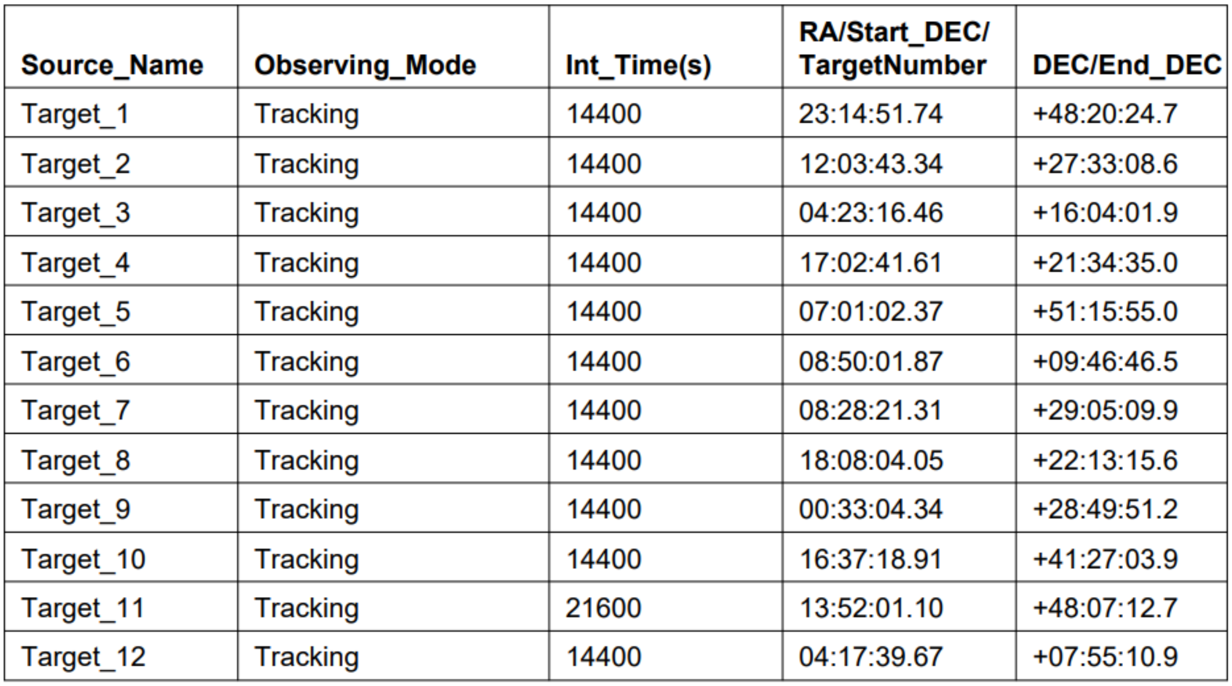
2.2 FAST and CHIME Telescopes

Our particular target selection is a set of FRBs that were discovered (yet unpublished) from the Canadian Hydrogen Intensity Mapping Experiment (CHIME) radio telescope at the Dominion Radio Astrophysical Observatory in British Columbia, Canada. CHIME is a much broader survey with no moving parts that can monitor FRBs on a large scale, though with much less sensitivity than FAST. This makes CHIME perfect for taking large-scale surveys to search for possible new burst sources that can then be observed with much more sensitivity through FAST to possibly find new repeaters, which is what we've done here.

2.3 Target Selection

In total, the data from this survey has 12 targets. Targets 1-7 are known low-DM non-repeating FRB sources; however, they could potentially be repeating FRB sources which repeat faintly [Ravi(2019)], and FAST's sensitivity may allow for us to discover faint bursts which may have been previously thought not to repeat. This already happened with the source of FRB 20180301A, which was thought to be a non-repeating source after the

FRB was observed by the Parkes observations, but another FRB was found from the same source using FAST [Luo et al.(2020)Luo, Men, Lee, Wang, Lorimer, & Zhang]. Targets 8-12 are known low-DM repeating FRB sources, which were selected to both increase the likelihood of detecting bursts with this survey (in case none of the non-repeating sources are found to repeat) and to compare their properties to the previous FRBs that came from the non-repeaters. Targets 11 and 12 in particular are found to be some of the most active FRB repeaters observed with CHIME, so targeting them with such increased sensitivity provided by FAST could provide deep insight into the bursts' structure, morphology, and polarization.



Source_Name	Observing_Mode	Int_Time(s)	RA/Start_DEC/ TargetNumber	DEC/End_DEC
Target_1	Tracking	14400	23:14:51.74	+48:20:24.7
Target_2	Tracking	14400	12:03:43.34	+27:33:08.6
Target_3	Tracking	14400	04:23:16.46	+16:04:01.9
Target_4	Tracking	14400	17:02:41.61	+21:34:35.0
Target_5	Tracking	14400	07:01:02.37	+51:15:55.0
Target_6	Tracking	14400	08:50:01.87	+09:46:46.5
Target_7	Tracking	14400	08:28:21.31	+29:05:09.9
Target_8	Tracking	14400	18:08:04.05	+22:13:15.6
Target_9	Tracking	14400	00:33:04.34	+28:49:51.2
Target_10	Tracking	14400	16:37:18.91	+41:27:03.9
Target_11	Tracking	21600	13:52:01.10	+48:07:12.7
Target_12	Tracking	14400	04:17:39.67	+07:55:10.9

Table 1: List of FRB sources requested for this FAST survey (pulled from our proposal). Not all of the hours requested were observed, so the total time of our survey is less than the sum of the times listed above, and not all of the data surveyed was analyzed (see Table 4 for hours and sources which were scanned for bursts).

Target	R.A deg.	$\sigma_{R.A}$ deg.	Dec deg.	σ_{Dec} deg.	S/N	DM pc cm^{-3}	DM$_{ex}$ pc cm^{-3}	R$_{FAST}$ /h
1	348.72	0.01	48.340	0.006	44	208.6	45.8	0.3
2	180.931	0.007	27.552	0.007	28	111.6	51.6	0.4
3	65.818	0.007	16.067	0.009	27	182.7	56.8	0.5
4	255.673	0.003	21.576	0.003	64	127.7	37.8	0.5
5	105.259	0.006	51.265	0.004	57	147.1	32.3	0.3
6	132.51	0.01	9.77	0.01	19	150.4	57.5	0.5
7	127.088	0.009	29.086	0.006	35	141.9	43.9	0.4

Repeaters

Target	R.A deg.	$\sigma_{R.A}$ deg.	Dec deg.	σ_{Dec} deg.	DM pc cm^{-3}	DM$_{ex}$ pc cm^{-3}	N_{bursts}	RM	active	R$_{FAST}$ /h
8	272.0169	0.0075	22.221	0.0082	218.1	103.1	2	L		0.9
9	8.2681	0.0038	28.8309	0.0034	201.7	125.9	5		Y	2.3
10	249.3288	0.0104	41.4511	0.0086	222.2	156.4	2	vary		0.7
11	208.0046	0.0037	48.1202	0.0024	221.6	161.7	24	vary/L	Y	8.2
12	64.4153	0.0127	7.9197	0.0174	287.1	200.7	12		Y	6.1

Table 2: Full list of parameters for the proposed FRB sources. In this project, Targets 2, 3, 4, 11, and 12 were scanned for FRBs (more details in Table 4 The $DM_{ex} = DM - DM_{ISM} - DM_{MWhalo}$, while assuming that the Milky Way halo contribution is $DM_{MWhalo} = 30$ pc cm^{-3}. If the FRB from the source has $||RM|| > 400$ rad m^{-2}, the RM (Faraday rotation measure) column is labelled with 'L'. Definitions for RM and EM (emission measure) are included later on with the full time-delay $t(\nu)$ (Eq. 3).

3 Searching for Bursts

Fortunately, the similarities between FRBs and pulsar pulses means that pulsar processing software can work well for finding FRBs—with some modifications, of course. We search the data for bursts by first attempting to identify and remove Radio Frequency Interference (RFI) coming from man-made sources, which can interfere with bursts that can be many orders of magnitude smaller than the interference.

Here we used the software PRESTO (PulsaR Exploration and Search TOolkit) from the pulsar software41 suite to search our data for FRBs, which conveniently has built-in functions which allow us to use it for FRB search [Amiri et al.(2020)Amiri, Andersen, Bandura, & The CHIME/FRB Collaboration*]. There are many portions of the Pulsar search process and various tools in PRESTO which we will not do, and others which will be done differently to account for the shorter time window, vastly larger intensity, etc.

We processed our FAST data through PRESTO by first searching for prominent RFI peaks using the `rfifind` command, then searching for low-level, persistent RFI using `prepdata` (which uses a DM $= 0$ time series). Those two RFI commands result in a `.mask` file which is an RFI mask that will attempt to suppress RFI during the de-dispersion. During the first time when running this process on a target, we create a Fast Fourier Transform (FFT) of the `.dat` timeseries file which was made from `prepdata`: we ran `realfft` with the `.dat` file, and feed it into one of PRESTO's python scripts, `DDplan.py`, which creates a de-dispersion plan which outputs various parameters to be used in when de-dispersing. Finally, we take those parameters and use them with `prepsubband`, which de-dispersed our FAST data according to the parameters from both `DDplan.py` and our proposal. This gives us data that is ready to be looked through for FRBs. We searched through these with another included python script, `single_pulse_search.py`, which will search the modified data for strong bursts above a given threshold of Signal/Noise ratio—we used a threshold of $> 10\sigma$. After that, we took the outputted list of detected bursts, created plots for each one of them, and visually looked through to see if any of them had clear signs of being FRBs. More details on the concepts behind each of these steps are included in the various subsections below.

PRESTO can read in many `.fits` files for searching by clipping them together to search the whole survey for bursts at once. This allows us to also find bursts that may be between or at the edges of files, we then use this to mask RFI and de-disperse across the whole survey—which is quite useful when we have hundreds of `.fits` files across all of the surveys that total to many terabytes of data. PRESTO loads them in sequentially and handles them by generating an info file based on the parameters of the first .fits file and appending the rest of them based on the number of samples and the starting MJD (modified Julian date) for each file, allowing for us to recover a continuous survey for each target.

We started by loading in all of the `.fits` files for a single continuous survey of a target (which could be as many as 1025 files at once) to do the search with PRESTO once, then we would re-search individual .fits files whose times were detected as containing bursts when we processed many files.

3.1 Radio Frequency Interference (RFI)

RFI can be difficult to detect and even harder to remove, but we can attempt to remove much of it by looking for very large single value spikes or elevated shifts that range across large frequencies, both of which we account for by creating a mask that replaces them with median values.

A strong strategy to get rid of RFI is to make a $\mathrm{DM} = 0$ time series for a target and clip out strong signals. This is usually quite effective, since FRBs will be dispersed smoothly according to our DM, and anything that appears to be a strong burst at $\mathrm{DM} = 0$ is likely RFI, so this technique is less prone to false positives than other methods than can be problematic and occasionally remove bursts that are mistaken for RFI.

Still, much of the RFI remains, and we expect that most of the "bursts" which will be reported by the software will just be RFI, so we will have to manually look through them. Visually a clear FRB is generally obvious to distinguish from RFI, but the attempt to mask the RFI still helps to narrow down the candidates that we must sift through.

FRBs (again, like Pulsar pulses) are Gaussian-shaped, so what we are looking for is a continuous increase in intensity that is broad on about the millisecond scale—which peaks and somewhat smoothly falls (at least, it should be more gradual than a single data point, which would likely be RFI which we mask out in software).

PRESTO will (as a part of its default RFI removal procedure), identify portions of data as "bad blocks" if it detects particularly strong RFI: masking those blocks entirely so they won't trigger burst detections. This feature is great for reducing the amount of RFI detections that the software flags as bursts. Unfortunately, particularly strong bursts (which is what we are looking for) can have sharp peaks that become masked as "bad blocks" and are not detected.

When searching for FRBs, it can be a tough balancing act to try and cut out as much RFI as possible so you get fewer falsely flagged bursts while at the same time trying not to have any real bursts be masked out of the data so you can actually find them. Fortunately, while the RFI masking process varies, running it on survey data that contains a burst means that the burst can persist when scanning different sets of files; if bursts are "disappearing" when you scan individual files that were detected throughout a larger set of files, it could be being falsely masked out as RFI (which we will talk about later in the Results and Conclusion sections). We fortunately can re-enable the "bad blocks" in PRESTO to recover these bursts, so during this process we frequently changed the software parameters as we searched to find FRBs.

3.2 Dispersion Measure (DM)

3.2.1 Our Choice of DM

The full time delay for arriving FRBs (Eq. 3) is inversely proportional to each frequency, with the first of the leading terms being proportional to the DM. The next two leading terms come from the Faraday rotation measure (RM) (which scales as ν^{-3} and can be polarized, hence the $\pm$) and the emission measure (EM) (which scales as ν^{-4}), where ν is again in GHz [Cordes & Chatterjee(2019)].

$$t(\nu) = 4.15\text{ms}\left(\frac{\text{DM}}{\nu^2}\right) \pm 28.6\text{ps}\left(\frac{\text{RM}}{\nu^3}\right) + 0.251\text{ps}\left(\frac{\text{EM}}{\nu^4}\right) \tag{3}$$

where

$$\text{RM} \equiv \int n_e B_{||} ds \quad , \quad \text{EM} \equiv \int n_e^2 ds \tag{4}$$

The RM is in units of rad m^{-2} and the EM is in units of pc cm^{-6}.

For an FRB search, we are primarily concerned with the delay from the first term from the dispersion measure. During general FRB analysis, however, we could take these other terms into account and use the third and fourth order changes in delay to inform more about the FRB source. The EM term is not taken into account in this project, but the regime of the RM is listed for each target in Table 2, so we could take that into account if it might have an effect on our bursts' time of arrival (which will have a much greater impact than the EM which is fourth-order in ν). For this project, neither term is needed exactly to confirm an FRB, but for the parameters of the targets it could prove helpful to see if RM may noticeably affect the time delay in relation to our fixed DM values. In our testing, we used our initial DM values as fixed values for the targets from the results of the CHIME observations, so we did not vary our DM when initially searching for bursts with PRESTO.

3.3 De-Dispersion

The physical dispersion of bursts according to the DM is a continuous process across the EM spectrum—to de-disperse an incoming signal, we have to shift each individual channel, which is inefficient and can be computationally intensive for a large survey. To make this process quicker, we can break up the channels into groups called "subbands" and shift each subband by a nominal DM value around the target DM, as visualized in Figure 2.

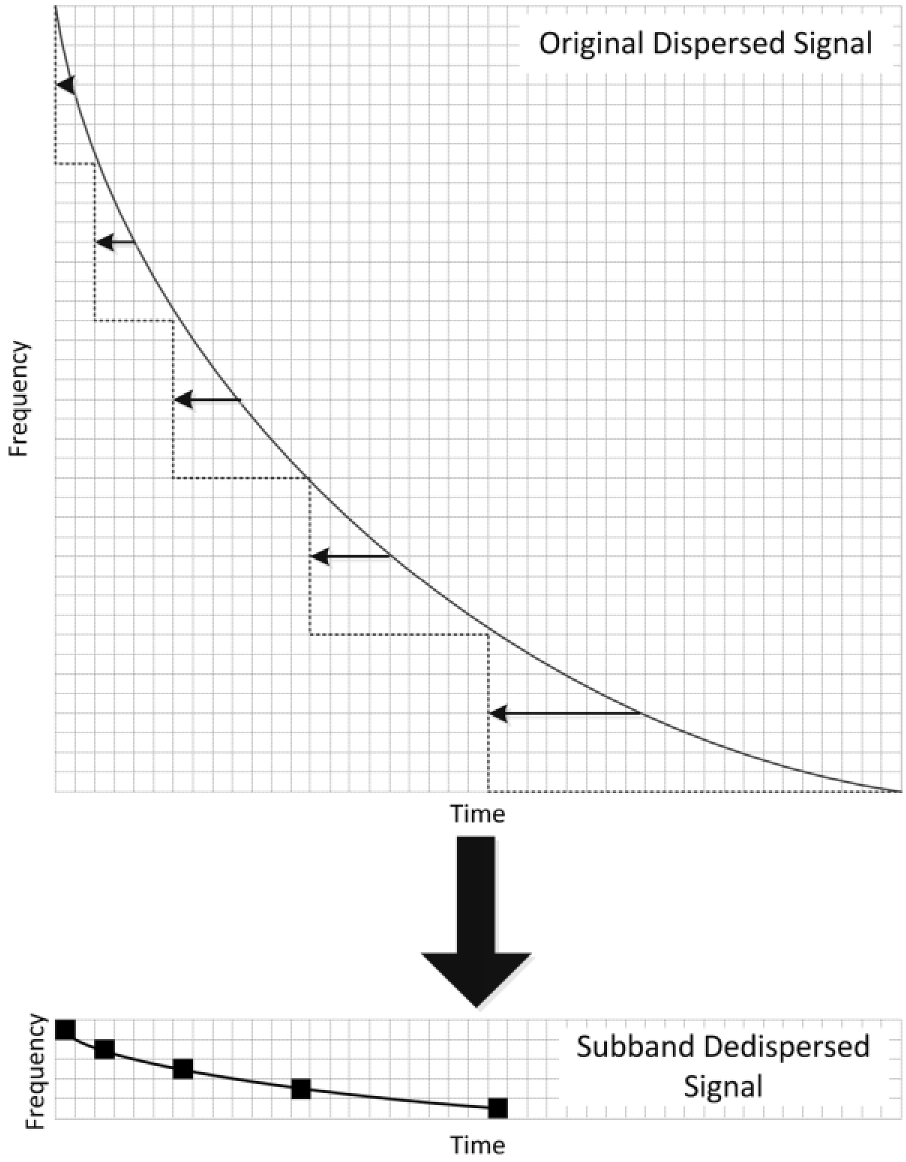


Figure 2: Visual depiction of how we attempt to de-disperse the subbands of our incoming radio data to try and look for originally structured bursts. The data is split up into different subbands that are all shifted according to our chosen DM [Magro et al.(2011)Magro, Karastergiou, Salvini, Mort, Dulwich, & Zarb Adami].

3.4 Searching through the Bursts

Practically speaking, one of the most obvious signs to confirm an FRB is to look for a diagonal “ribbon” shape when plotting the not de-dispersed frequency v. time across DM—which shows that it is a radio burst that is dispersed as we expect it to be, per the previous de-dispersion figure—as well as a very high (yet still wide enough as to not just be a single point which could be RFI) spike in flux v. time. Both of these are true with these examples. When the data is de-dispersed, we should see that this “straightens out”, resulting in a vertical set of marks that follow the structure of the burst. If we see all three of these, it is a strong indication that we are looking at an FRB. [Cordes & Chatterjee(2019)].

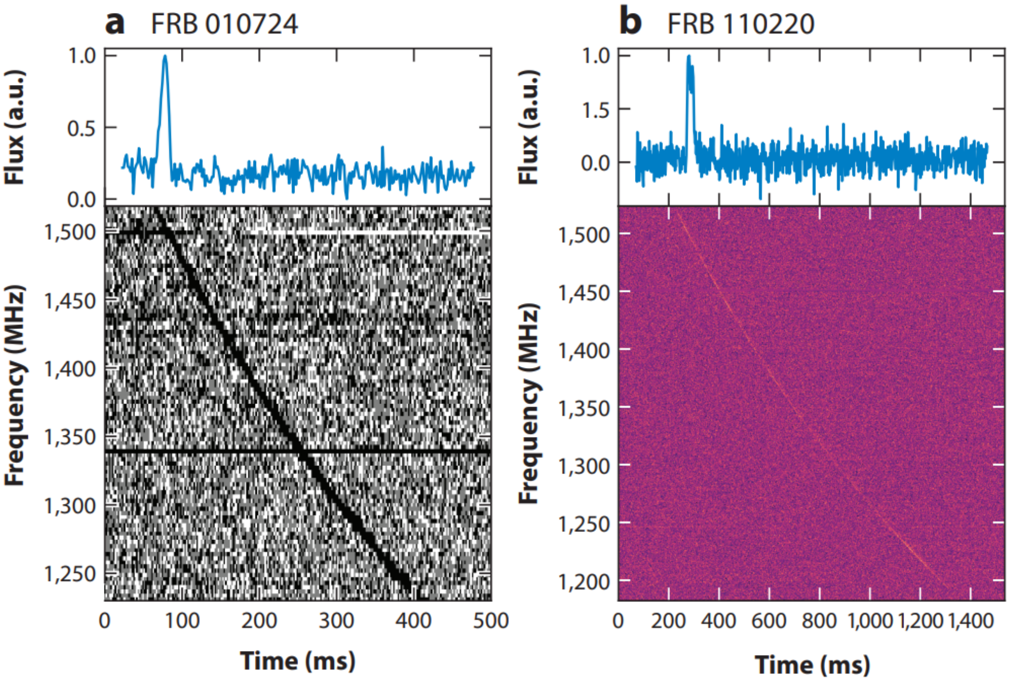


Figure 3: Examples of the “ribbon” across DM before de-dispersion present in FRBs 010724 and 110220 [Cordes & Chatterjee(2019)].

3.4.1 Searching for Significance

After we de-disperse the data, PRESTO can search for single pulses (which in this case are our FRBs), and it looks for any elevated pulses in the spectra that have at least a window of a few milliseconds, and returns the times at which they occurred. We can then filter this large list by a threshold sigma which the peak occurred. For one of our FAST observations which spans over 22 hours, we can get hundreds of pulses in the list, most of which aren’t nearly high enough to be bursts. We can filter it by pulses whose peaks are higher than a

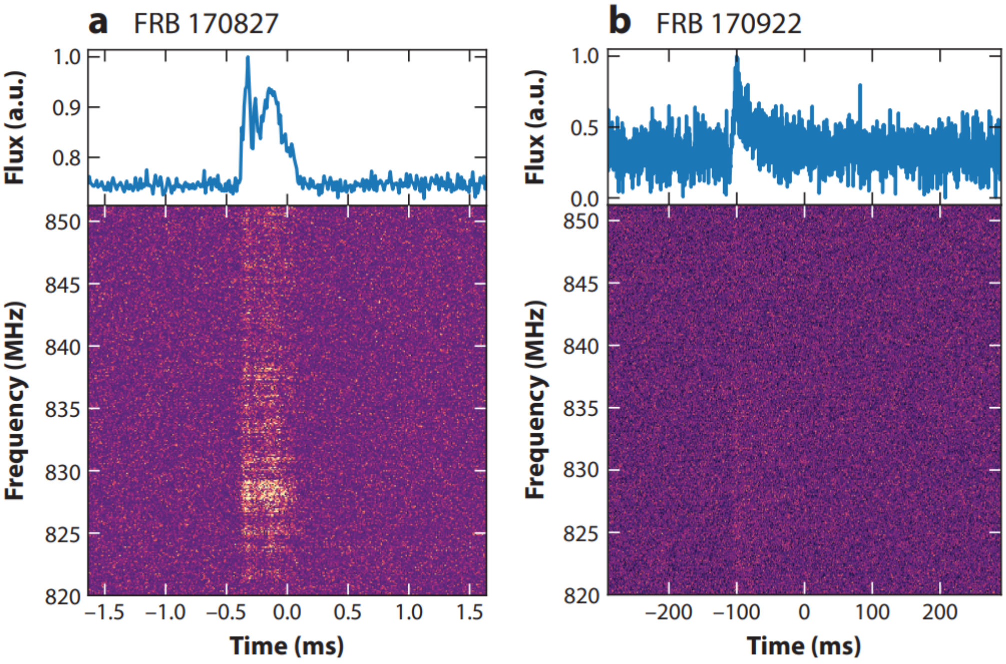


Figure 4: Examples of the vertical marks along the burst after de-dispersion for FRBs 170827 and 170922 [Cordes & Chatterjee(2019)].

certain threshold over the average value: in our testing we found that any obvious FRBs would be greater than about $\sim 10\sigma$, (where σ is the standard deviation of each spectra from its mean value) this brings the amount of possible bursts down to around a dozen per observation, which is much easier to manually look through.

3.4.2 Examining Each Pulse

From here, we must manually examine each pulse to see if any of our possible "bursts" are clearly FRBs. Unfortunately, most of the pulses don't show the clear "ribbon" across DMs or clear vertical marks after de-dispersion, and many of them don't even appear to show a clear, defined peak with a window of at least a few milliseconds.

The hardest part of searching for FRBs is finding a detection that is not just RFI, and any pulses that are too weak without any of the aforementioned defined features are likely to be RFI instead of a burst. The RFI masking method does eliminate much of the RFI when searching, but nearly all of the single pulses flagged by PRESTO will have no clear bursts that are not likely RFI.

Thus, to actually identify the burst, we need to take the list of the single pulses found by PRESTO and visually inspect the pulses (starting with the highest sigma pulses, typically $> 10\sigma$) until we find one that has signs that it could be an FRB: the clear, broad structure in intensity, “ribbon” diagonal shape across DM, and vertical marks outlining the burst structure in frequency v. time. While many potential candidates may have some of these features, all should be clearly present in order for us to call it an FRB.

4 Results

4.1 Bursts found from Target 11

We found two potential bursts in Target 11, both of which happen to have quite high peaks ($> 20\sigma$ and $> 30\sigma$ respectively), and each of them have clear vertical marks in frequency that match their structures and very distinct “ribbon” shapes across DM.

Burst #	Target	Date	Time (UT)	Signal/Noise (σ)	Peak Flux	Fluency
1	11	2021-10-20	03:12:10.824	22.38	0.034 Jy	0.27 Jy ms
2	11	2022-01-08	22:28:02.530	31.33	0.047 Jy	0.38 Jy ms

Table 3: List of found bursts from Target 11 with locations, times, and parameters. Peak Flux ($\sim 0.0015\sigma$ Jy) and Fluency ($\sim 0.012\sigma$ Jy ms) are statistical estimates given the average results of FAST (not directly measured) which can have up to an order of magnitude of undertainty).

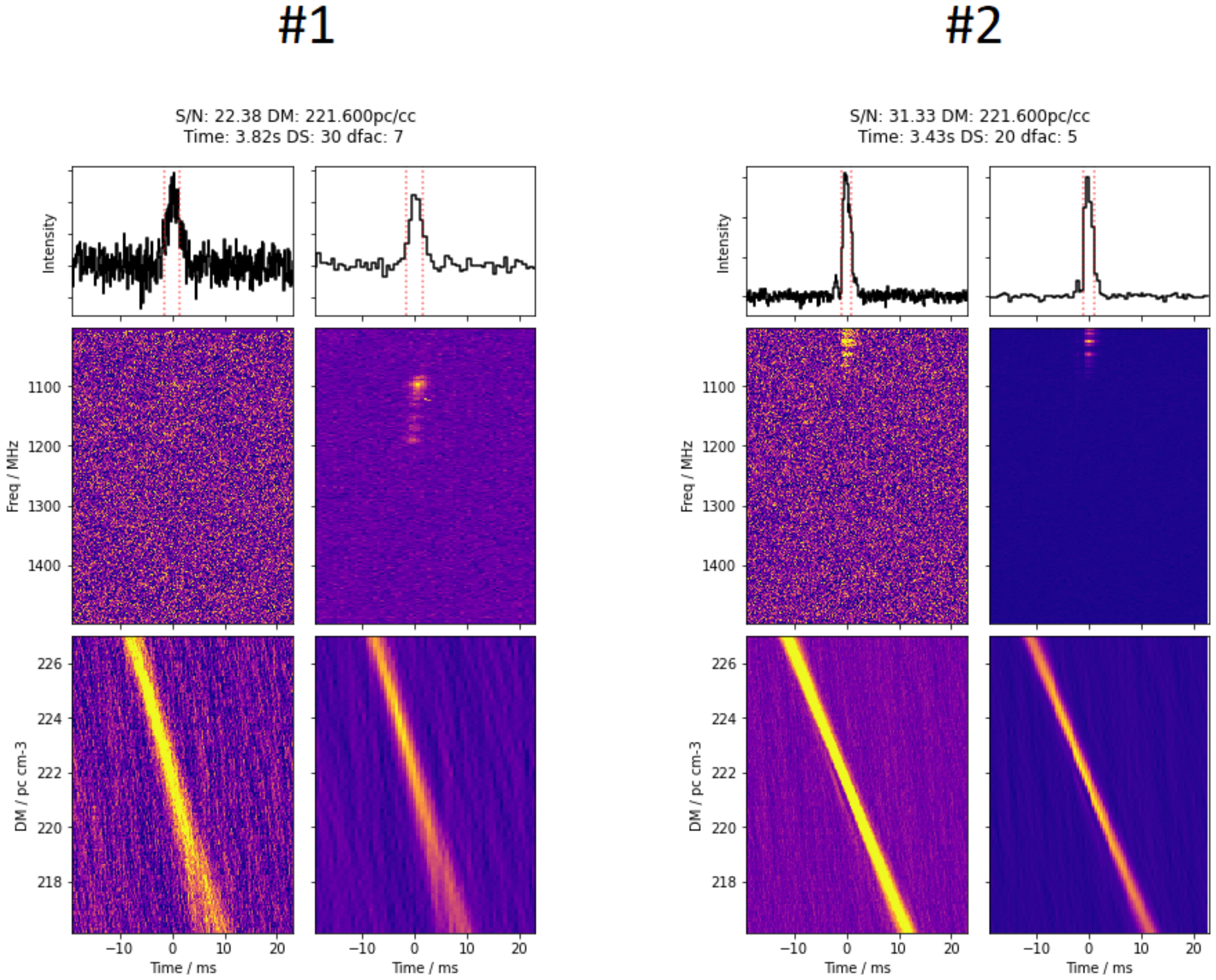


Figure 5: First and second bursts found from Target 11

Burst #1 reached FAST on October 20th, 2021 with a significance of 22.38σ and a peak flux of 3.4×10^{-2} Jy, and burst #2 reached FAST 80 days later on January 8th, 2022 with a significance of 31.33σ and a peak brightness of 4.7×10^{-2} Jy.

While burst #2 is sharper with a much higher peak and burst #1 is more broad, both potential bursts are more than bright and wide enough to be clearly the Gaussian-like shape of an FRB. When comparing these with the known FRB examples, they each clearly exhibit both the “ribbon” seen in the bursts of Figure 3 and the vertical marks that are along the shape of the bursts in Figure 4. This gives us a strong indication that we have, indeed, found not one, but two FRBs.

Target Scanned	DM	Repeating?	Hours Scanned	Bursts Found
2	111.6	Not yet repeating	0.832	0
3	182.7	Not yet repeating	0.788	0
4	127.7	Not yet repeating	0.299	0
11	221.6	Repeater	5.503	2
12	287.1	Repeater	0.834	0

Table 4: Results for all the targets scanned for bursts.

5 Conclusion

Unfortunately, we were unable to find bursts using this same process on the other FRB targets. We were certainly not expecting to immediately find bursts in all of them (especially the non-repeaters), and looking for FRBs can be a bit like finding a “needle in a haystack”, even for the other repeating sources which should be producing more FRBs. Even with all of the software filtering and searching, we must still visually verify a burst, and out of thousands of software detections, nearly all of them will just be RFI and not an FRB.

We did, however, find multiple bursts that are very likely to be real FRBs. We also confirmed the accuracy of our CHIME DM value for an FRB source detected with FAST, and we know that we can use PRESTO to find FRBs with FAST data—where we now have a refined process for doing so.

5.1 Future Steps

In the future, the next steps to continue this work would be to continue searching for FRBs in the other sources. When searching through these, PRESTO did actually detect several bursts at $> 10\sigma$ throughout the other repeating and non-repeating sources. The problems arose when we checked the individual files, where no burst was detected at all. Previously this also occurred with Target 11: We were initially unable to find any of the bursts, but after we turned off PRESTO's masking of "bad blocks" that mistook the peaks of the FRBs as RFI, they suddenly appeared, and we were able to de-disperse and plot them. This was not the case with the surveys from the other targets, and no matter how conservatively we turned down the RFI masking, we could not recover any bursts.

There could be many things causing these issues, and while many of them were tried, none were successful as of the writing of this paper. Should this project continue, there is certainly promising hope that if these surveys of the other targets do contain FRBs, we might be able to find them.

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