On Detecting Repetition from Fast Radio Bursts

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Abstract

Fast radio bursts (FRBs) are bright, millisecond-duration radio pulses of unknown origin. To date, only one (FRB 121102) out of several dozen has been seen to repeat, though the extent to which it is exceptional remains unclear. We discuss detecting repetition from FRBs, which will be very important for understanding their physical origin, and which also allows for host galaxy localization. We show how the combination of instrument sensitivity, beam shapes, and individual FRB luminosity functions affect the detection of sources with repetition that is not necessarily described by a homogeneous Poisson process. We demonstrate that the Canadian Hydrogen Intensity Mapping Experiment (CHIME) could detect many new repeating FRBs for which host galaxies could be subsequently localized using other interferometers, but it will not be an ideal instrument for monitoring FRB 121102. If the luminosity distributions of repeating FRBs are given by power laws with significantly more dim than bright bursts, CHIME’s repetition discoveries could preferentially come not from its own discoveries, but from sources first detected with lower-sensitivity instruments like the Australian Square Kilometer Array Pathfinder in fly’s eye mode. We then discuss observing strategies for upcoming surveys, and advocate following up sources at approximately regular intervals and with telescopes of higher sensitivity when possible. Finally, we discuss doing pulsar-like periodicity searching on FRB follow-up data, based on the idea that while most pulses are undetectable, folding on an underlying rotation period could reveal the hidden signal.

Key words: methods: observational – methods: statistical – pulsars: general

1. Introduction

Fast radio bursts (FRBs) are a new class of extragalactic radio transient. They are characterized by their large dispersion measures (DMs; 175–2600 pc cm⁻³) and short durations (30 μs–30 ms). All FRB detections to date have been one-off events, except for FRB 121102. It was first detected with Arecibo (Spitler et al. 2014), but follow-up observations by Spitler et al. (2016) found 10 repeat bursts at the same DM as the initial detection. This repetition allowed for sub-arcsecond precision localization by the Very Large Array (VLA) and the European VLBI Network (EVN) and provided the first direct host galaxy identification (Chatterjee et al. 2017; Marcote et al. 2017; Tendulkar et al. 2017). Eventually, FRBs will be localized in real-time by interferometers like the Australian Square Kilometer Array Pathfinder (ASKAP; Bannister et al. 2017) and realfast (Law et al. 2018), but no FRB has yet been successfully localized to a host galaxy through its discovery pulse. Finding repeating FRBs and carrying out high time resolution VLBI follow-up is still a viable avenue for localizing host galaxies.

Beyond allowing for localization, repetition also offers valuable clues about FRB progenitor models. Before the detection of FRB 121102’s repetition, most theories postulated a cataclysmic origin (Kashiyama et al. 2013; Totani 2013; Falcke & Rezzolla 2014; Zhang 2014). The local environment of FRB 121102 could play a role in the nature of its repetition. Michilli et al. (2018) found that it resides in an extreme magneto-ionic environment that contributes a Faraday rotation measure (RM) of ~1.4 × 10⁵ rad m⁻². Burst arrival times are clustered, individual bursts that exhibit considerable time and frequency structure, and strong pulse-to-pulse brightness fluctuations are seen (Scholz et al. 2016; Spitler et al. 2016; Michilli et al. 2018). While the sporadic repetition and pulse structure may be intrinsic, it is possible that they are coupled to the extreme plasma environment around the source. Cordes et al. (2017) argued that FRB 121102 might be behind a plasma lens that would magnify burst intensity and imprint time and frequency variations that are characteristic of caustics. Depending on the relationship between the resultant luminosity function of this amplification and the source’s intrinsic luminosity function, magnification bias may mean that we preferentially see repeating FRBs that are associated with extreme environments.

It remains unclear how many FRBs repeat and if their repetition is similar to FRB 121102. Of the more than 30 FRBs found so far,³ no others have been seen to repeat. Most of these bursts have had very little later follow-up, but some have been re-observed for tens and even hundreds of hours (Lorimer et al. 2007; Petroff et al. 2015a; Ravi et al. 2016). However, meaningful constraints are difficult to achieve in the presence of clustered repetition (Connor et al. 2016b; Oppermann et al. 2018).

In this Letter we consider detecting repetition from FRBs with current and future surveys. In order to address questions of optimal observing strategy, we simulate repeating FRBs with arrival times that are not described by a homogeneous Poisson process, and with pulse intensities that are drawn from power-law luminosity functions. We consider the extent to which FRB 121102 may be unusual in the frequency and statistics of its repetition. We also discuss the possibility of repetition with an underlying period and show that for many brightness distributions, periodicity searches could offer a higher signal-to-noise ratio (S/N) than single-pulse searching.

³ All publicly released FRBs are available on the FRB Catalog: www.frbcat.org.
2. Repetition Model

Before discussing the statistics of repetition it is important to
distinguish the luminosity function of a single repeating source,
which we will call \( N(\mathcal{L}) \), from both the global luminosity function of FRBs, \( N_s(\mathcal{L}) \), and their detected brightness distribution, \( N(\mathcal{F}) \). The brightness distribution usually refers to the source counts in a given flux, flux, or \( S/N \) bin (in the case of flux this is \( \log N - \log \mathcal{F} \)). The \( \log N - \log \mathcal{F} \) statistic encodes information about the volumetric distribution of FRBs, not just their intrinsic luminosities. It has important implications for survey design and the nature of the FRB population, and has been subject to considerable debate in the literature (Oppermann et al. 2016; Vedantham et al. 2016; Amiri et al. 2017; Macquart & Ekers 2018). The ensemble luminosity function, \( N_s(\mathcal{L}) \), with which we are not concerned here, refers to the number of bursts with a certain luminosity across all FRBs; unlike \( N(\mathcal{L}) \), it would be meaningful even if all FRBs were one-off events.

To describe the arrival times of repeat bursts, we follow the
formalism of Oppermann et al. (2018) and use a generalization
of Poissonian statistics known as the Weibull distribution. If
repetition were well described by a homogeneous Poisson
process, then the probability of seeing \( n \) repeats in some time
interval \( t \) given a rate \( r \) would be

\[
p(n|t, r) = \frac{(rt)^n e^{-rt}}{n!}.
\]

This can also be written as an expected wait time, \( \delta \), between bursts. It will have the exponential distribution

\[
p(\delta|r) = re^{-br},
\]

where \( r = (\delta)^{-1} \). This can be expanded to include a shape
parameter, \( k \), which describes the clustering (or lack thereof) of events in time. The probability density function (PDF) of time
intervals for the Weibull distribution is

\[
\mathcal{N}(\delta|k, r) = \frac{k}{\delta} (\delta r \Gamma(1+k^{-1})) e^{-[\delta r \Gamma(1+k^{-1})]^k}.
\]

where \( \Gamma(m) \) is the gamma function of some positive input, \( m \). Equation (3) reduces to an exponential when \( k = 1 \), so \( k \approx 1 \)
implies what we will call non-Poissonian statistics. For \( k < 1 \)
the probability of a new event decreases with time, whereas \( k > 1 \) indicates a monotonically increasing chance of an event.
In other words, when the shape parameter is less than unity,
events are clustered in time; when the shape parameter is large,
event spacing tends toward uniformity.

Interestingly, neutron stars span a large range of \((k, r)\) pairs.
A typical radio pulsar is a good example of a \( k \gg 1 \) source,
because as the shape parameter approaches infinity, the signal
asymptotes to perfect periodicity. In that case, \( 1/r \) would simply be the spin period. The brightest giant pulses (GPs) from the Crab seem to follow Poissonian statistics, with \( k \approx 1 \) (Lundgren et al. 1995). They are neither clustered in time, nor
do they have predictable arrival times. If FRB 121102 does indeed come from a rotating neutron star (Popov & Postnov 2013; Pen & Connor 2015; Connor et al. 2016; Cordes & Wasserman 2016; Lyutikov et al. 2016; Spitler et al. 2016), then this would be an example of a temporally clustered \( k < 1 \) source. Oppermann et al. (2018) fit available data from FRB 121102 to a Weibull distribution and found best-fit parameters of \( k = 0.34^{+0.06}_{-0.05}, r = 5.7^{+3.0}_{-2.0} \) repeats per day,
strongly disfavoring homogeneous Poissonian repetition. They
used data from 80 observations during which 17 pulses were
found in a subset of just seven pointings.

Repetition rates for an FRB must be treated in a similar way to
FRB all-sky rates in general. It is not useful to give an all-sky event
rate of FRBs on its own. It must be accompanied by a complete
brightness threshold, for example, \( 1.7^{+0.9}_{-1.0} \times 10^{-3} \text{sky}^{-1} \text{day}^{-1} \)
above 2 Jy ms for widths between 0.13 and 32 ms (Bhandari et al. 2018). Forecasting detection rates of surveys with different
sensitivities requires further information about \( \log N - \log \mathcal{F} \).
In the same way, repetition rates must be quoted not only
with clustering parameters and an average interval, but also with a
minimum brightness threshold. Again, forecasting expected
repetition detection in different surveys will require knowledge
about the particular source’s \( N(\mathcal{L}) \). Thus, the best-fit values for FRB 121102 in Oppermann et al. (2018) could be expanded to \( k = 0.34^{+0.06}_{-0.05}, r = 5.7^{+3.0}_{-2.0} \) per day above 20 mJy.

We parametrize the luminosity function in the following way:

\[
dN \propto \mathcal{L}^{-\gamma} d\mathcal{L}
\]

\[
N(>\mathcal{L}) \propto \mathcal{L}^{-\gamma} \ \gamma = 0.
\]

This equation gives the number of repeat bursts from the same
FRB-emitting source that are greater than luminosity, \( \mathcal{L} \). Our
power-law assumption is partly motivated by the brightness
distributions of FRBs from Galactic pulsars, like the Crab (Cordes et al. 2004; Zhuravlev et al. 2011; Mickaliger et al. 2012; Oronsaye et al. 2015) or PSR B1937+21 (Zhuravlev et al. 2013), but also the distribution of burst energies and \( S/N \) from FRB 121102 (Spitler et al. 2016; Law et al. 2017).

A boost in the observed repeat rate can be achieved during
follow-up observations. For example, because the original
detection was necessarily made in a blind search over a large
number of DM trials, the phase space that must be searched by
a dedispersion back-end in follow-up will shrink by a factor of \( N_{\text{DM}} \). This allows for a reduction in the \( S/N \) cutoff from the
blind threshold, \( \sigma_B \), to the targeted threshold, \( \sigma_T \). Similarly, a boost can be achieved if the initial detection was found in an instrument’s sidelobe, or if it was found with a lower-sensitivity telescope than the one searching for repetition.

Assuming that the initial detection was found with a system-
equivalent flux density (SEFD) of \( S_B \) then followed up with \( S_T \),
we can combine these with Equation (4) to get the transformed
rate

\[
r \rightarrow r \left( \frac{\sigma_B S_B}{\sigma_T S_T} \sqrt{B_T / B_B} \right)^\gamma,
\]

where \( B_B \) and \( B_T \) are the bandwidths of the blind observation
and the targeted one, respectively.

If either the individual FRB’s brightness function is steep
(i.e., \( \gamma \) is large) or the ratio of SEFDs is large, the observed
repeat rate of the source will change drastically. As an example,
suppose \( \gamma = 2 \), as with Crab GPs, and the source was initially
detected in an instrument’s sidelobe but can be localized to less
than a primary beam width. If the forward gain of the sidelobe
is 15 dB below that of on-axis, and a significance threshold
was lowered from \( 10\sigma \) to \( 5\sigma \), then the detectable repeat rate of the
FRB will increase by a factor of 400— an example that may
be significant for FRB 121102, as discussed in Section 3.1. The
same is true for follow-up observing with a more sensitive
telescope. Assuming the same luminosity distribution, an FRB
found with ASKAP in fly’s eye mode will have an average detectable repeat rate that is ~10^4 times larger when observed with Parkes, if the power-law continues over at least a couple of decades in L.

3. Considerations for Specific Cases

3.1. FRB 121102

The extent to which FRB 121102 is exceptional remains unclear. Some of its ostensibly unusual properties could, in principle, be explained by observational selection effects, and others no longer appear to be unique to that source. For example, the non-power-law spectral behavior found by Spitler et al. (2016) and Scholz et al. (2016) seemed to set FRB 121102 apart from other FRBs, but recently more events have been discovered that have a clumpy frequency structure (Bannister et al. 2017; Farah et al. 2018). The temporal structure that emerged after coherent dedispersion seemed different from other FRBs, many of which are unresolved (Ravi 2017). However, Farah et al. (2018) showed that FRB 170827, initially unresolved after being detected with incoherent dedispersion, also exhibits rich time and frequency structure when coherently dedispersed. The large RM of FRB 121102, ~10^5 rad m^-2 (Michilli et al. 2018), may also have been present in previous FRBs with polarization measurements, but intra-channel Faraday rotation would have smeared out their linear polarization (Petroff et al. 2015b; Keane et al. 2016).

The most salient difference between FRB 121102 and other FRBs is that it is known to repeat. All other detected FRBs have been one-off events, despite, in some cases, considerable follow-up observations (Lorimer et al. 2007; Petroff et al. 2015a; Ravi et al. 2016). However, as shown by Connor et al. (2016b), when repeat pulses are clustered in time strong constraints on repeat rate are difficult to achieve. Still, there are reasons to think that FRB 121102 is particularly special in its repeatability. One is discovery bias, which refers to the fact that initial detections of phenomena tend to be outliers themselves. Macquart & Ekers (2018) argued that the ultra-bright first FRB discovery, the Lorimer burst (Lorimer et al. 2007), should not be included in calculating population statistics for this reason. Indeed, there may already be evidence that FRB 121102 is exceptional in at least its frequency of repetition (Palaniswamy et al. 2018). Another reason why FRB 121102 may have been found to repeat before others is that the initial detection (Spitler et al. 2014) was in the Arecibo L-band Feed Array (ALFA) sidelobe, where the forward gain was less than 1.7 K Jy^-1 (Spitler et al. 2016). With the seven-beam ALFA receiver, they used a grid of six pointings and found 10 repeat bursts (Spitler et al. 2016), all of which were in primary beams with forward gains that are between 8 and 10 K Jy^-1. With Equation (5), the rate of FRB 121102 increased by a factor of approximately 8^7 for the on-axis observing.

Law et al. (2017) analyzed the repetition rate of FRB 121102 as a function of burst energetics. They found that its luminosity function is described by a power law continuing over at least 2.5 orders of magnitude, with γ = 0.7±0.3. In Figure 1 we show the expected wait time for a given telescope to see an FRB 121102 burst, plotted as a function of power-law index γ. We have highlighted the region of the 1–2 GHz Crab GP’s power-law index in blue, as well as the fit by Law et al. (2017) in red. There is still significant uncertainty on the average repeat rate of FRB 121102, which could result in a re-scaling of the γ-axis, but the purpose of the figure is to demonstrate the significance of γ on repetition detection.

3.2. The Canadian Hydrogen Intensity Mapping Experiment (CHIME)

CHIME is a transit instrument with no moving parts, observing between 400 and 800 MHz (Bandura et al. 2014; Ng et al. 2017; The CHIME/FRB Collaboration et al. 2018). It is expected to have the highest FRB detection rate of any upcoming survey due to its large collecting area and ability to search continuously 10^3 beams (Chawla et al. 2017; The CHIME/FRB Collaboration et al. 2018). Even if the FRB rate were diminished at low frequencies due to scattering, free–free absorption, or spectral index, Connor et al. (2016a) showed that using only the top quarter of CHIME’s band between 700 and 800 MHz—where the rate is known to be non-zero—would still result in 2–40 detections per day.

In Section 4 we prescribe observing strategies for detecting repeating FRB sources in the presence of non-Poissonian repetition and negative-power-law brightness distributions. For CHIME, which is not steerable and which records data continuously, scheduling does not have many degrees of freedom. Fortunately, transit instruments with north–south primary beams naturally apply the optimal observing strategy for clustered repetition, per unit time on source. With an east–west primary beam of i°–2°, CHIME will have 0.3%–0.6% of the sky visible at any given time. This means that once it has discovered a few hundred FRBs, CHIME will be performing repetition follow-up at almost all times because there will be a known source at most right ascensions. Therefore, even if the probability of seeing a single source repeat over the course of a year is low, CHIME will automatically follow up large numbers of FRBs, and will either produce a catalog of repeaters or establish the uniqueness of FRB 121102. If it does
find repeaters, they can be followed up with longer-baseline interferometers like the VLA for localization.

One interesting implication of the effect of sensitivity on repetition rate is that CHIME may see more repeat pulses from FRBs originally detected at other, less sensitive instruments than from FRBs found with CHIME itself. Suppose that each individual FRB repeats with a luminosity distribution \( N(\gtrsim \mathcal{L}) \propto \mathcal{L}^{-\gamma} \). Suppose also that CHIME, with SEFD \( S_{CH} \) has detected \( N_{CH} \) FRBs, which it can follow up daily. Then if some other survey \( X \), with SEFD \( S_X \) has detected \( N_X \) bursts that are visible to CHIME, the condition

\[
\left( \frac{S_X}{S_{CH}} \right) \frac{B_{CH}}{B_X} \frac{N_{CH}}{N_X} > 1 ,
\]

implies that CHIME will find more repeaters that were initially detected in survey \( X \) than detected at CHIME.

As a simple example, if ASKAP in fly’s eye mode were to find 50 bursts at declinations, \( \delta \gtrsim 10^\circ \), and CHIME amassed a set of 500 FRBs, we can calculate the values of \( \gamma \) above which the relation in Equation (6) hold. Taking \( S_{CH} \approx 50 \text{ K}/1.3 \text{ K Jy}^{-1} \approx 38 \text { Jy} \) and \( S_{ASKAP} = 1800 \text{ Jy} \) (Bannister et al. 2017), then if \( \gamma > 0.6 \) CHIME will detect more repeaters from the ASKAP collection than from its own. This could also be true for Apertif (van Leeuwen 2014) incoherent-mode detections. And in general, if \( \frac{N_{CH}}{N_X} \) is also the ratio of detection rates, then the inequality will always be true. Therefore, when possible, surveys like CHIME ought to search for repetition from known FRBs discovered by less sensitive instruments, potentially with a decreased \( S/N \) threshold at the initial detection’s DM.

Though it sees the whole Northern sky each day, a given source is only in CHIME’s primary beam for \( \sim 10 \) minutes, totaling roughly 60 hr per year. This fact, combined with the brightness function arguments in Section 2, means that it may not be a good tool for monitoring FRB 121102. If FRB 121102’s mean repeat rate with ALFA is 5.7 events per day, then one would expect roughly a dozen pulses per year if the source had a perfectly flat brightness distribution. But FRB 121102’s luminosity function is not flat, and almost all of the bursts detected from FRB 121102 would not have been detected by CHIME, (or Apertif, Parkes, ASKAP). We have assumed that FRB 121102’s repetition rate and brightness is the same at 400–800 MHz as it is at higher frequencies. The behavior of FRB 121102 is not well constrained below 1 GHz. Out of the 80 observations in Scholz et al. (2016), 11 were taken with GBT’s 820 MHz receiver with 200 MHz bandwidth and no bursts were seen. However, given the highly non-Poissonian behavior of FRB 121102 and the lower sensitivity at 820 MHz due to less bandwidth, it is unsurprising that none was detected.

We have built a simple Monte Carlo simulation in which pulse arrival times are given by a Weibull distribution and each burst’s energy is randomly drawn from some input luminosity function. In Figure 2 we show the number of expected FRB 121102 bursts detected per year with CHIME, assuming three different power laws. This figure shows that unless FRB 121102’s repeat rate turns out to be considerably larger than the value used here, or \( \gamma \) is smaller than \( \sim 0.5 \), CHIME may see at most a few FRB 121102 bursts per year.

![Figure 2](image-url) Distribution of the number of FRB 121102 burst detections in one year of observing with CHIME. We simulate events with the repetition statistics found by Oppermann et al. (2018) and use three different power luminosity distributions. One (pink, dashed) does not account for 121102’s luminosity distribution and assumes that Arecibo and CHIME would see the same mean event rate. The other two use power laws such that \( N(\gtrsim \mathcal{L}) \propto \mathcal{L}^{-0.5} \) (blue, solid), and \( N(\gtrsim \mathcal{L}) \propto \mathcal{L}^{-1.5} \) (orange, dotted).

### 4. Survey Strategy

We advocate doing follow-up observations with more sensitive instruments than the detection survey, if possible. The Five-hundred-meter Aperture Spherical Radio Telescope (FAST) will have extraordinary sensitivity at 1.4 GHz, with an expected forward gain of 18 K Jy to 1 and system temperature of 20 K (Li & Pan 2016). Therefore, with an SEFD that is almost 2000 times lower than that of ASKAP in “fly’s eye” mode, FAST would see an effective repeat rate that is \((2 \times 10^3)^2 \) times higher than ASKAP, assuming that the power law holds beyond those brightnesses. For single-pixel instruments, the field-of-view mismatch between large and smaller dishes would make this program difficult, because follow-up observations would have to be tiled. However, even in the extreme example of ASKAP fly’s eye and FAST, the tiling problem is softened by their multi-pixel receivers. ASKAP’s phased-array feed (PAF) allowed it to localize FRB 170107 to an \( 8 \times 8 \text{ arcmin} \) region, despite its nominal \( \sim 1^\circ \) beams (Bannister et al. 2017). FAST will initially have 12.5 arcmin beams in its 1.4 GHz multi-beam receiver, meaning that the error region of FRB 170107 could be covered with between one and seven pointings, depending on the angular separation of FAST’s on-sky beams.

In the case of non-Poissonian repetition, the distribution of observing time has implications for detectability. If repetition is Poissonian, then detection statistics are affected only by total time on source. But if FRBs are significantly clustered in time, then the worst observing strategy is to point at a source for a single long integration. Connor et al. (2016b) calculated this effect for 1/f noise, or a “pink distribution” of arrival times in which bursts are significantly temporally correlated. Oppermann et al. (2018) quantified it for a Weibull distribution with \( k = 0.35 \) and \( r = 5.7 \) per day, showing that the chance of not seeing a burst during a single observation was four times larger than if observations were at approximately regular intervals and separated by roughly days, holding total time on source equal. The improvement becomes more extreme for lower values of \( k \), i.e., higher clustering.
As discussed, transit telescopes like CHIME automatically apply this periodic sampling function. However, for studies of a single FRB of particular interest, one may want more than 10 minutes per source per day. For steerable surveys like Apertif, follow-up should be spread out over multiple observing sessions, switching between sources. For a clustered source, detection of a burst implies a higher probability of a subsequent burst. Therefore, telescopes that detect an FRB in real-time should stay on that source. In Figure 3 we show detection distributions from a simulated repeater. The results show that a single long observation of a clustered repeater (green, solid), the probability of seeing zero events is large despite an expected value of \( \sim 14 \); if the time is spaced out with daily 2 hr observations for four weeks (blue, dashed), a clustered repeater’s statistics become near-Poissonian.

4.1. Galactic FRBs

An FRB from our own Galaxy would be extremely bright, and might be detected by a low-sensitivity, all-sky instrument, e.g., STARE\(^5\) or in other telescope’s sidelobes (Tendulkar et al. 2016).

This is because a Galactic FRB would be very rare, but would not require much forward gain to detect, so beam solid angle wins over sensitivity. It also means surveys that when preserving such signals one should take measures not to throw them out as RFI, as they may show up as moderate-DM multi-beam detections.

Here we consider a Galactic FRB to be a short-duration radio pulse with energetics that are close to those of known extragalactic FRBs; we do not include in this category the Crab GP that have been measured to date. The probability of ever seeing such an event depends strongly on the statistics of FRB repetition. Suppose that there are 5000 FRBs across the sky each day above some brightness threshold. If we imagine the extreme case, where all 5000 of those come from a single repeater, then every Galaxy in the observable Universe except for one has zero FRB-emitting sources in it over the timescale of the typical emitting window. Even if the average repeat rate of FRBs is once per day—lower than FRB 121102—then there are still only a few thousand galaxies in the Universe containing FRBs during an emitting window. Conversely, in the non-repeating case one simply has to wait long enough to see an FRB locally. Therefore, an observer in a random location sees either many ultra-bright Galactic FRBs, or none. In reality, there exists a continuum of FRB brightnesses, such that there are many more events below our surveys’ detection thresholds than, in this example, a few thousand. This argument also depends on repeating sources being the dominant sub-class of FRBs. Still, the statistics of repetition strongly affect the implied spatial distribution of burst-emitting sources.

4.2. Non-power-law \( N(L) \)

FRB 121102 and GPs have power law \( N(L) \), but there is no guarantee that other repeating sources will have such a functional form; brightness fluctuations in regular pulsars have been modeled with log-normal and Chi-squared distributions. However, even if the brightness function flattens out for very faint events, or decays exponentially, follow-up with higher sensitivity will significantly improve detectability so long as there are more dim repeat bursts than bright ones.

4.3. FRB Periodicity Search

Though no underlying periodicity has been found in FRB 121102’s repetition, it is possible that other repeating sources will have a more easily detectable periodic signal. Therefore, it may be useful to do a periodicity search for one-off FRBs. This could be done either with an fast Fourier transform (FFT) search or a fast folding algorithm (FFA) to protect against missing long-period or low-duty cycle repeating sources (Staelin 1969; Cameron et al. 2017). If other sources have luminosity distributions like FRB 121102 in which there are more dim pulses than bright ones, de-dispersing to the known DM and folding on a range of rotation periods might pull the underlying signal out of the noise. The periodicity search could either be done during follow-up with a more sensitive instrument, or in data around the detection. The latter may help for intermittent sources; the former would allow a hidden underlying signal to emerge more easily. Periodicity in rotating radio transients (RRATs) was initially found using single-pulse time differencing (McLaughlin et al. 2006), but folding searches like the one that we discuss here have been

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\(^5\) http://www.astronomerstelegram.org/?read=11385

\(^6\) http://www.caastro.org/files/64/3383921601/bochenek_frb2018presentation_upload.pdf
The $S/N$ optimality of periodicity searching versus single-pulse detection depends primarily on the number of pulses in an observation, $N_p$, and the luminosity distribution of those pulses, $\mathcal{L}(\mathcal{L})$ (McLaughlin & Cordes 2003). Periodicity searches tend to achieve higher $S/N$ if there are a large number of pulses in an observation, which is why they are often used for millisecond pulsars. For a perfectly flat brightness distribution between some minimum brightness, $F_{\text{min}}$, and maximum $F_{\text{max}}$, McLaughlin & Cordes (2003) show that FFT-periodicity searching is preferred over single-pulse search for $N_p \geq 11$. For another power-law index, or indeed different functional forms like an exponential distribution, the values of $N_p$ for which periodicity searching results in higher $S/N$ may be larger.

It may also be that repeating FRBs do not have any underlying periodicity. If this is the case, an excess of events that are below the single-pulse threshold but above, say, 3$\sigma$ could be looked for in the dispersed time-stream at the FRB detection DM. The cumulative $S/N$ distribution of all samples (binned to the width of the initial burst) could be compared to the same data dispersed to other DMs in order to look for statistically significant differences in their tails. While there is no guarantee that these techniques would uncover periodicity, periodicity searching a small range of DMs or making a histogram of $S/N$ has a relatively low cost, whereas demonstrating repetition with a folded spectrum would be highly informative.

5. Conclusions

In this Letter we have investigated the interplay between instrumental effects, survey strategy, and the detectability of FRB repetition from sources with burst arrival times that are not necessarily described by a homogeneous Poisson process. We summarize our findings as follows.

1. If other repeating FRBs have luminosity functions similar to FRB 121102 or the Crab’s GPs, in that there are many more dim bursts than bright ones, observed repeat rates can be greatly boosted by doing follow-up observations with higher sensitivity instruments than the original detection telescope. The same is true for sidelobe contributions to it being the first repeater discovered.
2. North–South transit telescopes like CHIME are well suited to search for repetition in FRBs with bursts that are clustered in time, allowing for arcsecond localization by longer-baseline interferometers. However, CHIME will not be an ideal instrument for monitoring the one known repeater, FRB 121102.
3. Repetition found by CHIME may preferentially come from FRBs initially detected at other, lower-sensitivity instruments like ASKAP or AperT coherent mode.
4. The probability of ever detecting an ultra-bright Galactic FRB depends strongly on the statistics of repetition.
5. Periodicity searches at the known DM of one-off FRBs could reveal repetition in their folded spectra, ideally carried out with more sensitive instruments than the detection telescope. Such searches could also be done in pre-existing data around the initial detection.

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