One-and Repeating Fast Radio Bursts: A Statistical Analysis

Hao-Yan Chen, Wei-Min Gu, Mouyuan Sun, and Tuan Yi

Abstract

According to the number of detected bursts, fast radio bursts (FRBs) can be classified into two categories, i.e., one-off FRBs and repeating ones. We make a statistical comparison of these two categories based on the first FRB catalog of the Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst Project. Using the Anderson–Darling, Kolmogorov–Smirnov, and Energy statistic tests, we find significant statistical differences (p-value < 0.001) in the burst properties between the one-off FRBs and the repeating ones. More specifically, after controlling for distance, we find that the peak luminosities of one-off FRBs are, on average, higher than the repeating ones; the pulse temporal widths of repeating FRBs are, on average, longer than the one-off ones. The differences indicate that these two categories could have distinct physical origins. Moreover, we discuss the subpopulations of FRBs and provide statistical evidence to support the existence of subpopulations in one-off FRBs and in repeating ones.

1. Introduction

Fast radio bursts (hereafter FRBs) are extragalactic millisecond-duration radio bursts and have been detected in frequencies from 118 MHz to 8 GHz (e.g., Cordes & Chatterjee 2019; Petroff et al. 2019; Pleunis et al. 2021). The host galaxies of 19 FRBs have been identified (Heintz et al. 2020).1 The origins of FRBs remain mysteries. According to the number of detected bursts, FRBs can be classified into two categories, i.e., repeating FRBs and observational one-off (hereafter one-off) ones. For repeating FRBs, models involve young rapidly rotating pulsars (Lyutikov et al. 2016), a wandering jet in an intermediate-mass black hole (BH) binary with chaotic accretion (Katz 2017), a pulsar passing through the asteroid belt (Dai et al. 2016; Dai & Zhong 2020), a neutron star (NS)–white dwarf (WD) binary with strong dipolar magnetic fields (Gu et al. 2016, 2020), the precession of a jet in an NS/BH–WD binary with a super-Eddington accretion rate (Chen et al. 2021), and the intermittent collapses of the crust of a strange star (Geng et al. 2021). For one-off FRBs, models often invoke the collapse of a spinning supramassive NS forming a BH (Zhang 2014), and the merger of a charged Kerr–Newman BH binary (Liu et al. 2016; Zhang 2016). Therefore, we would expect that the repeating FRBs and one-off ones have different temporal and spectral properties (e.g., CHIME/FRB Collaboration et al. 2019; Fonseca et al. 2020).

Recently, the Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst (hereafter CHIME/FRB) Project released the first CHIME/FRB catalog (hereafter Catalog 1); the catalog consists of FRBs that were detected between 400 and 800 MHz and from 2018 July 25 to 2019 July 1, (Amiri et al. 2021). Catalog 1 contains 492 unique sources, i.e., 474 one-off FRBs and 18 repeaters.2 With the same search pipeline, the burst properties can be measured with uniform selection effects. Therefore, this sample is ideal for exploring the statistical properties of FRBs.

Some studies aim to explore the possible differences between one-off FRBs and repeating ones based on Catalog 1. For example, Josephy et al. (2021) studied the Galactic latitudes of one-off FRBs and repeating ones and found that the distribution of FRBs is isotropic. Meanwhile, Amiri et al. (2021) found that the distributions of the dispersion measures (DMs) and extragalactic DMs (DM_E) of one-off FRBs and the first-detected repeater events are statistically consistent with originating from the same underlying sample. For the distribution of fluences, Amiri et al. (2021) showed that one-off FRBs and repeaters are statistically similar. On the other hand, Amiri et al. (2021) found that two distinct FRB populations could be inferred from the distribution of the peak fluxes. Moreover, Pleunis et al. (2021a) showed that the “downward-drifting” of frequency and multiple spectral-temporal components, which are absent in one-off FRBs, seem to be common in repeaters. Compared to the distributions of pulse temporal widths and spectral bandwidths, Pleunis et al. (2021a) showed that the repeating FRBs (for the first-detected events) have larger temporal widths and narrower bandwidths than one-off ones. Zhong et al. (2022) showed that the distribution distinctions for one-off FRBs and repeaters in the spectral index and the peak frequency cannot be explained by the selection effect due to a beamed emission. These differences all indicate that FRBs might have different populations.

Amiri et al. (2021) only compared 205 one-off FRBs and 18 of the first-detected repeater events to explore the differences between the two types of FRBs. The differences in the physical mechanisms of the burst features between repeaters and one-off FRBs could not be found only by analyzing the first-detected repeater events. Moreover, some burst parameters used in Pleunis et al. (2021a), e.g., spectral bandwidth, might be

1 http://frbhosts.org

2 https://www.chime-frb.ca/catalog
inappropriate to compare the one-off FRBs with the repeating ones. The reason is that, due to the limited instrumental bandwidth, the spectral bandwidth reported in Catalog 1 might be significantly biased and is not an excellent tracer of the FRB intrinsic bandwidth. In addition, some previous works (e.g., Cui et al. 2021; Zhong et al. 2022) did not control for distance when comparing the peak-luminosity and energy distributions of the two types of FRBs. Thus, the distinctions of comparisons might be biased. In this work, we demonstrate that one-off FRBs and repeating ones should be two physically distinct populations based on Catalog 1 by investigating several different burst parameters with similar distances, i.e., the fluxes, the pulse temporal widths, and the estimated isotropic peak luminosity $L_p$.

The remainder of this manuscript is organized as follows. In Section 2, we calculate the peak luminosities of one-off FRBs and repeating ones and build up the mock samples for repeaters and the control samples for one-off FRBs with matched DM$_E$ to present the differences between the two types of FRBs. In Section 3, we demonstrate statistically that FRBs could be divided into two categories, i.e., one-off FRBs and repeaters. Then, we further discuss whether one-off FRBs and repeaters have subpopulations. Conclusions and discussion are presented in Section 4.

2. The Samples

Our study utilizes the largest FRB sample to date (i.e., Catalog 1). Catalog 1 consists of 474 one-off FRBs and 18 repeating FRBs (62 bursts). We exclude six one-off sources that have bad gains (Amiri et al. 2021). Thus, our sample contains 468 one-off sources plus 18 repeating sources.

2.1. Isotropic Peak Luminosity

To estimate the FRB isotropic peak luminosity (denoted as $L_p$), we use FRB DMs to estimate their redshifts $z$ and luminosity distances $D_L$ since only three host galaxies of FRBs in Catalog 1 (i.e., FRBs 20121102A, 20180916B, and 20181030A) have been identified (e.g., Zhang 2018; Macquart et al. 2020). The methodology is as follows.

The extragalactic dispersion measure DM$_E$ of an FRB, which takes away the contributions from our Galactic interstellar medium (ISM) (DM$_{ISM}$), is based on the Galactic electron density model NE2001 (Cordes & Lazio 2002) or YMW16 (Yao et al. 2017) and halos (DM$_{halo}$), where DM$_{ISM}$, $\Delta z \approx 0.05$ pc cm$^{-3}$ (Macquart et al. 2020), can be written as

$$\text{DM}_E = \text{DM}_{IGM} + \text{DM}_{host},$$

where DM$_{IGM}$ is the contribution from the intergalactic medium (IGM), and DM$_{host}$ is the contribution from the host galaxy of FRB. Amiri et al. (2021) mainly compared the distribution of DM$_E$ based on the NE2001 model. Thus, we only consider the NE2001 model. The DM$_{host}$ can be estimated as DM$_{host} = 50/(1 + z)$ pc cm$^{-3}$ (Macquart et al. 2020). The contribution from IGM is roughly proportional to the redshift $z$ of the source through (Deng & Zhang 2014)

$$\text{DM}_{IGM} = \frac{3 \pi c H_0 \Omega_b f_{IGM}}{8 \pi G m_p} \int_0^z \frac{\chi(z)(1 + z)^2}{[\Omega_m(1 + z)^3 + \Omega_k]^{1/2}} dz,$$

where $G$ is the gravitational constant, $f_{IGM}$ is the fraction of baryons in the IGM with the average value $f_{IGM} \approx 0.83$ (Fukugita et al. 1998), $m_p$ is the mass of proton, $\chi(z) = (3/4)\chi_{eH}(z) + (1/8)\chi_{eHe}(z)$ expresses the free electron number per baryon in the universe, $\chi_{eH} \sim 1$ are the hydrogen and helium mass fractions normalized to 3/4 and 1/4, respectively, and $\chi_{eHe}$ are the ionization fractions for hydrogen and helium, respectively. For FRBs at $z < 3$, both hydrogen and helium are fully ionized (e.g., Yang & Zhang 2016). Thus, $\chi_{eH} = \chi_{eHe} = 1$ and $\chi(z) \approx 7/8$. The values of cosmological parameters are adopted from the latest Planck results (Planck Collaboration et al. 2016), i.e., the Hubble constant $H_0 \approx 67.74$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m \approx 0.0486$, $\Omega_b \approx 0.3089$, and $\Omega_L \approx 0.6911$. Based on the result of Zhang (2018), the DM$_{IGM}$ can be roughly estimated when $z < 3$

$$\text{DM}_{IGM} \approx z \frac{855}{3} \text{ pc cm}^{-3}.$$ (3)

In summary, we can use Equations (1)–(3) to estimate DM$_{IGM}$ and redshift $z$ (and the corresponding luminosity distance $D_L$).

The isotropic peak luminosity $L_p$ of each one-off FRB or every burst of each repeating one is (Zhang 2018)

$$L_p \approx 4\pi \left( \frac{D_L}{10^{28} \text{ cm}} \right)^2 \left( \frac{S_v}{\text{ Jy}} \right) \left( \frac{\nu_c}{\text{ GHz}} \right) \times 10^{42} \text{ erg s}^{-1},$$

where $S_v$ is the observed peak flux density of an FRB, and $\nu_c$ is the central frequency of the telescope, i.e., for CHIME, $\nu_c = 600$ MHz.

We present in Figure 1, the distributions of DM$_E$ and $L_p$ (and their joint distribution) for one-off FRBs (red) and repeating ones (gray). We compare the distributions of DM$_E$ and $L_p$...
under the same upper limit of $\text{DM}_E$. The peaks of the $\text{DM}_E$ and $L_p$ distributions of repeaters tend to be smaller and lower than that of one-off ones, respectively. Using the two-dimensional Kolmogorov–Smirnov (2DKS) test\(^3\) (Peacock 1983; Fasano & Franceschini 1987), we compare the joint distribution of $\text{DM}_E$ and $L_p$ for one-off FRBs with that for repeating ones; we find that the differences between the two joint distributions are statistically significant since the corresponding $p$-value is $\sim 1.18 \times 10^{-16}$. In addition to the 2DKS test, we use the Energy statistic\(^4\) (E-statistic; e.g., Gábor & Rizzo 2013) for two-dimensional data to verify the differences in the two joint distributions of one-off FRBs and repeating ones. The E-statistic test compares the energy distance between the distributions of the different samples. The energy distance is zero if and only if the distributions are identical. The energy distance of two joint distributions for one-off FRBs and repeating ones is $\sim 75$ ($p_{\text{energy}} \sim 5 \times 10^{-4}$), implying that the two joint distributions of $\text{DM}_E$ and $L_p$ are significantly different. The observed differences suffer from strong statistical biases since the two types of FRBs have different $\text{DM}_E$ distributions. Below, we explore this point in detail.

### 2.2. The Mock Samples

As shown in Figure 1, one-off FRBs and repeating ones have different distributions of $L_p$. The differences might be intrinsic, i.e., one-off FRBs and repeaters have distinct bursting energy-generation mechanisms or are caused by the differences in redshift $z$ (or $D_L$). Hence, we perform the following Monte Carlo experiment to build the mock samples of repeaters and one-off FRBs with the matched $\text{DM}_E$ to verify whether the differences are intrinsic. Unlike previous works, which only chose the physical properties of the first-detected burst for each repeater to explore the differences between the two types of FRBs (e.g., Pleunis et al. 2021a; Amiri et al. 2021), we consider each repeating burst as an independent mock FRB source. The reason is that, as shown in Figure 1, the peak luminosities of different bursts from the same repeater vary greatly (e.g., $\sim 1.5$ magnitudes for FRB 20180916B). The burst features of the repeaters could not be revealed only by analyzing the first-detected bursts. We expect that, if the physical mechanisms for one-off FRBs and repeating ones are the same, the peak-luminosity distribution of all bursts in repeating FRBs is statistically similar to bursts in one-off ones after controlling $\text{DM}_E$. We conduct Monte Carlo experiments to test the expectation. In the Monte Carlo experiments, we need to ensure that each burst of repeaters has a corresponding one-off FRB with a similar $\text{DM}_E$, i.e., $|\text{DM}_{\text{repeating}} - \text{DM}_{\text{one-off}}| / \text{DM}_{\text{repeating}} \lesssim 0.05$. For the repeaters, the minimum value of the $\text{DM}_E$ is $62.5\, \text{pc}\, \text{cm}^{-3}$ of FRB 20181030A. None of the one-off FRBs has a similar $\text{DM}_E$ to FRB 20181030A since the minimum value of the one-off FRB $\text{DM}_E$ is $78.8\, \text{pc}\, \text{cm}^{-3}$. Thus, for the Monte Carlo experiments, we reject the repeater FRB 20181030A and consider the remaining 17 repeaters, which have a total number of 60 bursts.

The steps to conducting the Monte Carlo experiments are as follows. First, we randomly select (with replacement) 60 mock repeating FRBs from the 17 repeaters. Hence, each repeater can be selected multiple times ($n_i$), and the statistical expectation of $n_i$ is the same for all repeaters. Second, for each mock repeating FRB, we randomly select (with replacement) one burst, whose DM is the same as the mock repeating FRB. That is, we eventually obtain 60 bursts (hereafter the repeating mock sample) from the repeating FRBs, and the contribution of each repeater to the mock sample is statistically the same. The DM distribution of the repeating mock sample is different from that of the original 60 bursts mentioned in Section 2.1 and Figure 1 but resembles the DM distribution of the 17 repeaters. Third, for each repeating mock burst, we randomly select a one-off FRB with a similar $\text{DM}_E$ (hereafter the one-off control sample). Hence, the repeating mock sample and the one-off control sample share identical $\text{DM}_E$ distributions (see the left panel of Figure 2). Then, we compare the peak-luminosity distributions of the repeating mock sample and the one-off control sample (see the right panel of Figure 2). We repeat this experiment 10,000 times. The mean distributions (and their $2\sigma$ uncertainties) of the peak luminosities $L_p$ of bursts from the repeating mock samples and one-off control samples are calculated.

We use the Kolmogorov–Smirnov (KS) test to assess whether there are statistical differences between the repeating mock samples and the one-off control samples. The two samples are statistically different if the $p$-values of the KS tests are smaller than 0.05. The probability density distributions of the $\text{DM}_E$ and $L_p$ for a realization of the repeating mock and the one-off control samples are shown in Figure 2. For the distributions of $\text{DM}_E$ (the left panel of Figure 2), the $p$-value of the KS test is $\sim 0.95$. For the distributions of $L_p$ (the right panel of Figure 2), the $p$-value of the K-S test is $\sim 4.16 \times 10^{-6}$, indicating that two mock samples could originate from different underlying peak-luminosity distributions after controlling for $\text{DM}_E$. For the 10,000 simulations, while the $p$-value of the K-S test for the $\text{DM}_E$ distributions (the left panel of Figure 3) is always larger than 0.05, the $p$-value for the $L_p$ distributions (the right panel of Figure 3) is smaller than 0.05 in 90% of simulations. We also use the E-statistic test to check the statistical differences in the distributions of $\text{DM}_E$ and $L_p$ and obtain the same conclusions.

Some studies have found differences in the temporal widths between repeating FRBs and one-off ones (e.g., Pleunis et al. 2021a; Amiri et al. 2021). Therefore, in addition to the comparison of the luminosity distributions, we follow the above procedures to compare the distributions of the pulse temporal widths of repeating FRBs and one-off ones. The mean distributions and the corresponding $2\sigma$ statistical uncertainties are evaluated. In our comparisons, after controlling for $\text{DM}_E$, the pulse temporal widths of two types of FRBs would have similar dispersive delays (e.g., Equation (4) in Petroff et al. 2019), which could help to compare the distribution distinctions for the intrinsic pulse temporal widths between one-off FRBs and repeaters. For the peak flux density $S_v$, there is a correlation between $L_p$ and $S_v$ (see Equation (4)). Hence, we mainly compare the differences in $L_p$ and the burst temporal widths between repeating FRBs and one-off ones. For the distributions of the temporal widths, there are statistical differences between the repeating mock samples and the one-off control samples since the $p$-values of the KS and E-statistic tests are always less than 0.001 in all simulations.

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3. https://github.com/syrte/ndtest/blob/master/ndtest.py
4. The E-statistic can be available for R on the Comprehensive R Archive Network (CRAN) under a general public license, i.e., the energy package (https://cran.r-project.org/web/packages/energy/index.html).
3. The Populations of FRBs

3.1. Repeating and One-off FRBs

Figure 4 shows the mean distributions of $L_p$ (the left panel) and the pulse temporal widths (the right panel) for the bursts of repeating FRBs and one-off ones with similar DM$_E$. Their corresponding 2σ statistical uncertainties are shown as the shaded regions. We use the Anderson–Darling (AD) and KS tests to assess the statistical differences in the two FRB samples in terms of $L_p$ and temporal width. The null hypotheses of the AD and KS tests are that the two samples are drawn from the same population. If the $p$-values of the AD and KS tests are smaller than 5%, we reject the null hypothesis and conclude that the two samples are statistically different. For the distributions of $L_p$ (the left panel of Figure 4), we find that the $p$-values of the KS and AD tests are less than 0.001. That is, the bursts of the two FRB samples have intrinsically different luminosity distributions (the mean $L_p$ for repeaters is log $(L_{pcr}/\text{erg s}^{-1}) \approx 40.14 \pm 0.71$; for one-off FRBs, it is log $(L_{pcr}/\text{erg s}^{-1}) \approx 41.41 \pm 0.65$) and the difference is more evident at the low-luminosity end (log $(L_{pcr}/\text{erg s}^{-1}) \leq 39$). Moreover, for the distributions of temporal widths (the right panel of Figure 4), we find that the $p$-values of the KS and AD tests are smaller than 0.001. That is, the bursts of the two FRB
samples have distinct distributions of the temporal width (the mean temporal width for repeaters is 13.08 ± 2.38 ms; for one-off ones, it is 3.14 ± 0.74 ms) and the difference is more evident at the long temporal width end (>7 ms). These differences support the speculation that the emission mechanisms of the bursts in the two types of FRBs should be distinct.

3.2. Subpopulations

As mentioned in Section 3.1, repeating FRBs and one-off ones should have distinct emission mechanisms. Do one-off FRBs and repeating FRBs have subpopulations (e.g., Li et al. 2021a)?

For one-off FRBs, the single-pulse bursts are commonly detected (e.g., CHIME/FRB Collaboration et al. 2019), whereas CHIME/FRB Collaboration et al. (2022) detected the multicomponent pulse profiles of three one-off FRBs, i.e., FRBs 20191221A, 20210206A, and 20210213A, and identified the periodic separations of these components. The complex and periodic profiles indicate that there could exist a subgroup of one-off FRBs that have similar physical processes or host environments to some repeaters.

For periodicity, repeating sources have been found to have periodic activities, i.e., FRBs 20180916B (16.35 day activity period; see CHIME/FRB Collaboration et al. 2020) and 20121102A (~157 day activity period; see Cruces et al. 2021). Some repeaters with more than 20 bursts recorded by CHIME were not found to have any periodic activity, e.g., FRBs 20180814A (22 bursts), 20190303A (27 bursts), and 20201124A (34 bursts). The differences in periodicity of repeating FRBs might indicate that the repeaters could have different groups, i.e., the periodic repeaters and the aperiodic repeaters (e.g., Katz 2017; Lin et al. 2022).

For active repeaters, we can study the waiting time (WT) distributions to understand the physical mechanism of repeating FRBs (e.g., Wang & Yu 2017; Zhang et al. 2021). The WTs are the time intervals between two adjacent (detected) bursts measured during periods of continuous observation. Up until now, the most active repeaters are FRBs 20121102A (e.g., Li et al. 2021b, 20180916B (e.g., CHIME/FRB Collaboration et al. 2020), and 20201124A (e.g., Xu et al. 2022). As shown in the top three panels of Figure 5, the distributions of WTs for three active repeating FRBs have different features, i.e., a bimodal structure for FRB 20121102A, and unimodal structures for FRBs 20180916B and 20201124A. We can infer some progenitor models for repeaters from the cumulative distribution functions (CDFs) of WTs. Three models are proposed to fit the CDFs of WTs, i.e., simple power law (SPL), e.g., the soft gamma repeaters (SGRs)-like model for FRB 121102; Wang & Yu 2017), bent power law (BPL) (e.g., SGR J1550–5418; Chang et al. 2017), and Weibull function (e.g., Oppermann et al. 2018). The SPL model is expressed as (Sang & Lin 2022)

\[ N(>\delta t) = A (\delta t^{-\alpha} - \tau_{c}^{-\alpha}) \]

where \(\delta t\) is the waiting time and \(\tau_{c}\) is the cutoff value with \(N(>\tau_{c}) = 0\). The BPL model is taken the form (Sang & Lin 2022)

\[ N(>\delta t) = B \left[ 1 + \left( \frac{\delta t}{t_{m}} \right)^{\beta} \right]^{-1} \]

where \(t_{m}\) is the median value, i.e., the number of bursts with \(\delta t > t_{m}\) is equal to the number of bursts with \(\delta t < t_{m}\). The Weibull function is described as (e.g., Oppermann et al. 2018)

\[ N(>\delta t) = e^{-(\delta t r)^{(1+1/k)}} \]

where \(k\) is the shape parameter, \(r\) is the event rate, and \(\Gamma\) is the gamma function. The Weibull distribution is equivalent to a
Poisson distribution when \( k = 1 \), while \( k \approx 1 \) implies that the bursts are clustered, with more clustering implied for lower \( k \). The fitting results are shown in the bottom three panels of Figure 5. The best-fitting parameters and their 1\( \sigma \) uncertainties for three fitting models are shown in Table 1. The \( \chi^2 \), defined as \( \chi^2 = \sum(N_i - N_{i, \text{model}})^2/N_i \), where \( N_i \) and \( N_{i, \text{model}} \) are the data of the WT distributions and the fitting models, respectively, can be used to evaluate the goodness of fit of the fitting models for the CDFs of WTs. The minimum value of \( \chi^2 \) corresponds to the best-fitting models. We find that the CDFs of WTs for FRBs 20121102A and 20201124A can be well fitted by the Weibull function; the WT distribution of FRB 20180916B is well fitted by the BPL model. That is, the central engine of these active repeating FRBs could be magnetars, while the physical mechanisms should be distinct.

Using the KS test (and the AD test), we compare the correlations of the distributions of WTs for three active repeating FRBs. There is evidence that three active repeaters should come from different groups, i.e., for FRBs 20121102A and 20180916B, \( p_{KS} = 0 \); for FRBs 20121102A and 20201124A, \( p_{KS} \approx 1.67 \times 10^{-10} \); and for FRBs 20180916B and 20201124A, \( p_{KS} \approx 7.77 \times 10^{-16} \).

In addition to comparing differences in the CDFs of WTs, we would like to compare the differences between the active repeating FRBs in the joint distributions of \( L_p \) and WTs. As shown in Figure 6, \( \Delta L_p \) represents the luminosity differences between two adjacent (detected) bursts, i.e., \( \Delta L_p = \log(L_{p,i+1}) - \log(L_{p,i}) \), where \( L_{p,i} \) represents the peak luminosity of the \( i \)th burst. We use the E-statistic test to verify the differences in the joint distributions of three active repeaters in terms of WTs and \( \Delta L_p \). There is significant

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**Figure 5.** Top: the distributions of waiting times (WTs) of three active repeating FRBs. The WT distributions of FRB 20121102A show a bimodal structure, whereas other FRBs, i.e., FRBs 20180916B and 20201124A, have unimodal structures. Bottom: the CDFs of WTs of three FRBs. Three distribution models, i.e., the bent power law (BPL; red line), the simple power law (SPL; dashed red line), and the Weibull model (black line), are considered to fit the CDFs of WTs. The data for FRB 20121102A is taken from Li et al. (2020); the data for FRB 20180916B are taken from Chawla et al. (2020), CHIME/FRB Collaboration et al. (2020), Martí et al. (2020), Pastor-Marazuela et al. (2021), and Pleunis et al. (2021b); and the data for FRB 20201124A are taken from Hilmarsen et al. (2021) and Martí et al. (2022).

**Table 1**

| FRB             | \( \alpha \) | \( t_c \) | \( \chi^2 \) | \( \beta \) | \( t_m \) | \( \chi^2 \) | \( \epsilon \) | \( k \) | \( \chi^2 \) |
|-----------------|--------------|-----------|-------------|------------|---------|-------------|-------------|-------|------------|
| FRB 20121102A   | -0.25±0.01   | 534.9±200.67 | 416.85      | 1.14±0.29  | 51.54±11.40 | 8.99        | 864.25±239.23 | 0.59±0.11 | 7.94       |
| FRB 20180916B   | -0.16±0.01   | 5060.89±1832.79 | 4.86        | 1.21±0.53  | 684.99±142.98 | 0.34       | 86.43±23.84  | 0.78±0.15  | 0.39       |
| FRB 20201124A   | -0.22±0.06   | 1926.37±716.62 | 1.28        | 1.48±0.33  | 264.02±105.77 | 0.52       | 241.92±35.64 | 0.83±0.10  | 0.14       |
evidence that three active repeaters should originate from distinct populations, i.e., for FRBs 20121102A and 20180916B, the energy distance is \( \sim 26,128 \) \( \left( \rho_{\text{energy}} \sim 1 \times 10^{-4} \right) \); for FRBs 20121102A and 20201124A, the energy distance is \( \sim 8562 \) \( \left( \rho_{\text{energy}} \sim 7 \times 10^{-5} \right) \); and for FRBs 20180916B and 20201124A, the energy distance is \( \sim 5719 \) \( \left( \rho_{\text{energy}} \sim 5 \times 10^{-4} \right) \).

Moreover, the polarization of repeating FRBs is also a significant feature that suggests the diversity of repeaters. FRB 20121102A was found to be \( \sim 100\% \) linearly polarized and had a rotation measure (RM) of about \( 10^2 \) rad m\(^{-2} \), which implies an extreme magneto-ionic environment (e.g., Michilli et al. 2018). FRB 20180916B was also found to be \( \sim 100\% \) linearly polarized yet is not surrounded by a dense supernova remnant since [RM] \( \sim 10^2 \) rad m\(^{-2} \) (Pastor-Marazuela et al. 2021). In addition, some bursts of FRB 20201124A showed signs of circular polarization, which were first found in repeating FRBs (e.g., Hilmursson et al. 2021). The discrepancies between the distributions of the energy distance distribution and the polarization characteristics suggest that the central engine of repeating FRBs could be magnets, while the emission mechanisms (e.g., pulsar-like or GRB-like mechanisms; see the review of Zhang 2020) and host environments (e.g., the magnetic field strengths; Zhong et al. 2022) should be distinct.

4. Conclusions and Discussion

In this paper, we have statistically studied the differences in the burst properties between one-off FRBs and repeaters in Catalog 1. We found that one-off FRBs and repeating ones have different burst \( L_p \) and temporal width distributions, indicating that the two samples have distinct physical origins (see Figure 4; Section 3.1). Moreover, we discuss the subpopulations of one-off FRBs and repeating ones and provide evidence to support the existence of subpopulations in both types of FRBs (see Figures 5 and 6; Section 3.2).

Our work can be advanced in terms of the sample size. Chen et al. (2022) used unsupervised machine learning to classify repeaters and one-off FRBs from Catalog 1 and identified 188 repeating FRB candidates from 474 one-off sources, suggesting a large fraction of repeating FRBs could be missed due to the lack of monitoring observations. Recently, Li et al. (2021b) detected 1652 independent burst events from FRB 20121102A by FAST. The flux limit of this sample is at least three times lower than those of previously observed samples for FRB 20121102A. Therefore, sensitive radio telescopes, e.g., FAST, can detect many faint bursts to help reveal the physical nature of FRBs and to determine whether distinct populations of FRBs are present.

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**ORCID iDs**

Hao-Yan Chen [https://orcid.org/0000-0003-3410-0002](https://orcid.org/0000-0003-3410-0002)

Wei-Min Gu [https://orcid.org/0000-0003-1377-1851](https://orcid.org/0000-0003-1377-1851)

Mouyuan Sun [https://orcid.org/0000-0002-0771-2153](https://orcid.org/0000-0002-0771-2153)

Tuan Yi [https://orcid.org/0000-0002-5839-6744](https://orcid.org/0000-0002-5839-6744)

**References**

Amiri, M., Andersen, B. C., Bandura, K., et al. 2021, *ApJS*, 257, 59

Chang, Z., Lin, H.-N., Sang, Y., et al. 2017, *ChPhC*, 41, 065104

Chawla, P., Andersen, B. C., Bhardwaj, M., et al. 2020, *ApJL*, 896, L41

Chen, B. H., Hashimoto, T., Goto, T., et al. 2022, *MNRAS*, 509, 1227

Chawla, P., Andersen, B. C., Bhardwaj, M., et al. 2020, *ApJL*, 896, L41

Chang, Z., Lin, H.-N., Sang, Y., et al. 2017, *ChPhC*, 41, 065104

Cruces, M., Spitler, L. G., Scholz, P., et al. 2021, *MNRAS*, 500, 448

Cui, X.-H., Zhang, C.-M., Wang, S.-Q., et al. 2021, *MNRAS*, 500, 3275

Cordes, J. M., & Lazio, T. J. W. 2002, *arXiv:astro-ph/0207156*

Cordes, J. M., & Lazio, T. J. W. 2002, *arXiv:astro-ph/0207156*

Cui, X.-H., Zhang, C.-M., Wang, S.-Q., et al. 2021, *MNRAS*, 500, 3275

Dai, Z. G., & Zhong, S. Q. 2020, *ApJL*, 895, L1

Deng, W., & Zhong, B. 2014, *ApJL*, 783, L35

Fasano, G., & Franceschini, A. 1987, *MNRAS*, 225, 155

Fonseca, E., Andersen, B. C., Bhardwaj, M., et al. 2020, *ApJL*, 891, L6

Fukugita, M., Hogan, C. J., & Peebles, P. J. E. 1998, *ApJ*, 503, 518

Gábor, J., & Rizzo, M. 2013, *J. Stat. Plan.,* 143, 1249

Geng, J., Li, B., & Huang, Y. 2021, *Innov.,* 2, 100152

Gu, W.-M., Dong, Y.-Z., Liu, T., et al. 2016, *ApJL*, 823, L28

Gu, W.-M., Yi, T., & Liu, T. 2020, *MNRAS*, 497, 1543

Hao-Yan Chen [https://orcid.org/0000-0003-3410-0002](https://orcid.org/0000-0003-3410-0002)

Wei-Min Gu [https://orcid.org/0000-0003-1377-1851](https://orcid.org/0000-0003-1377-1851)

Mouyuan Sun [https://orcid.org/0000-0002-0771-2153](https://orcid.org/0000-0002-0771-2153)

Tuan Yi [https://orcid.org/0000-0002-5839-6744](https://orcid.org/0000-0002-5839-6744)
