Luminosity distribution of fast radio bursts from CHIME/FRB Catalog 1 by means of the updated Macquart relation

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Abstract

Fast radio bursts (FRBs) are extremely strong radio flares lasting several micro- to milliseconds and come from unidentified objects at cosmological distances, most of which are only seen once. Based on recently published data in the CHIME/FRB Catalog 1 in the frequency bands 400–800 MHz, we analyze 125 apparently singular FRBs with low dispersion measure (DM) and find that the distribution of their luminosity follows a lognormal form according to statistical tests. In our luminosity measurement, the FRB distance is estimated by using the Macquart relation that was obtained for 8 localized FRBs, and we find it still applicable for 18 sources after adding the latest 10 new localized FRBs. In addition, we test the validity of the luminosity distribution up to the Macquart relation and find that the lognormal-form feature decreases as the uncertainty increases. Moreover, we compare the luminosity of these apparent nonrepeaters with that of the previously observed 10 repeating FRBs also at low DM, noting that they belong to different lognormal distributions with the mean luminosity of nonrepeaters being two times greater than that of repeaters. Therefore, from the two different lognormal distributions, different mechanisms for FRBs can be implied.

Keywords

Transients · Fast radio burst - methods · Statistical - stars · Magnetars

1 Introduction

Fast radio bursts (FRBs) are very strong radio sparks lasting micro- to milliseconds in duration, which are mostly confirmed to be from objects at cosmic distances, which were perhaps noted in 1980 (Linscott and Erkes 1980). The FRB phenomenon was systematically studied by Lorimer et al. (2007), and then Thornton et al. (2013) discovered several more sources in 2013. Subsequently, this field developed rapidly (Lorimer 2018; Zhang 2020; Petroff et al. 2021), including the first localized repeating FRB 121102 (Spitler et al. 2016; Chatterjee et al. 2017), the first FRB-like signal-FRB 200428 from the Galactic soft gamma repeater (SGR) 1935+2154 (Bochenek et al. 2020; CHIME/FRB Collaboration 2020b; Lin et al. 2020; Lie et al. 2021) and FRB 20200120E in M81 (Bhardwaj et al. 2021). In addition, with further study, several research efforts showed...
that FRBs may be periodically active (FRB 180916: 16 day and FRB 121102: 157 day) (Chime/Frb Collaboration 2020a; Rajwade et al. 2020) and emit periodic signals (FRB 20191221A: 216.8 ms, FRB 20210206A: 2.8 ms, and FRB 20210213A: 10.7 ms) (The CHIME/FRB Collaboration 2021b). Meanwhile, thanks to the completion of advanced radio instruments like the Canadian Hydrogen Intensity Mapping Experiment (CHIME) (CHIME/FRB Collaboration 2019a,b, 2020b; Chime/Frb Collaboration 2020a; The CHIME/FRB Collaboration 2021a,b), the Australian Square Kilometre Array Pathfinder (ASKAP) (Shannon et al. 2018; Chime/Frb Collaboration 2020a; The CHIME/FRB Collaboration 2021a), the Five-hundred-meter Aperture Spherical radio Telescope (FAST) (Li et al. 2018; Zhu et al. 2018; Hashimoto et al. 2020; Luo et al. 2020). Among the evidence and results, the luminosity distribution of FRBs is likely preferred to follow a power-law form or Schechter function on the whole (Li et al. 2017; Luo et al. 2018; Lu and Piro 2019; Luo et al. 2020; Hashimoto et al. 2022), but this is still an open question because there exists the possibility of a lognormal distribution (Cui et al. 2021a). Moreover, Li et al. (2021) recently found that the burst-energy distribution of a repeating FRB 121102 is not a single power law but a bimodal distribution, which may contain a lognormal component. Besides these, whether the repeaters and nonrepeaters share the same origin or physical properties is also a controversial issue (Connor 2019; Caleb et al. 2019). Some statistical analyses suggested that the different distributions for repeating and nonrepeating FRBs may imply multiple origins or physical processes of FRBs (Palaniswamy et al. 2018; Petroff et al. 2019; Fonseca et al. 2020; Cui et al. 2021b; The CHIME/FRB Collaboration 2021a), while others believed that the difference is not so obvious or caused by the selection effects (Connor et al. 2020; Gardener et al. 2021). Therefore, according to these unsettled questions (Kulkarni et al. 2014; Petroff et al. 2019; Cordes and Chatterjee 2019), by means of the new CHIME database, the statistical explorations with various physical parameters between repeaters and nonrepeaters can proceed.

For the study of FRB luminosity, the distance estimation is a key step, where the Macquart relation between the dispersion measure and redshift (DM–z) (Macquart et al. 2020) is most useful, which is acquired by the 8 localized FRBs. Here, as the first step, to test the validity of the Macquart relation with the updated 18 localized FRBs, by adding the 10 new ones (Heintz et al. 2020), we showed that the Macquart relation is still applicable (see the details in Appendix A). Therefore, we employed the Macquart DM–z relation and analyzed the new CHIME data to estimate the FRB luminosity, processing the statistics that include the goodness of fit (Cui et al. 2021b), the Kolmogorov–Smirnov (K–S) test (Smirnov 1948), the Mann–Whitney–Wilcoxon (M–W–W) test (Mann and Whitney 1947), the Anderson–Darling (A–D) test (Anderson and Darling 1952), and the Lilliefors test (Lilliefors 1967).

The structure of our paper is as follows. In Sect. 2, we describe the data selection and luminosity estimation. In Sect. 3, the FRB luminosity distribution is fitted by the different types of functions, and the results of statistical tests are given. In Sect. 4, we discuss the selection effects, the error of the Macquart DM–z relation, the applicability of the lognormal distribution, and the implications of statistical results. Finally, a brief summary is given at the end of the paper.
2 Data selection and estimation

In this section, we elaborate on the data selection of CHIME/FRB Catalog 1 and the estimation of FRB distance, based on which the FRB luminosity is obtained.

2.1 Data selection

Our data are taken from the first release of CHIME/FRB Catalog 1 (The CHIME/FRB Collaboration 2021a) and its website. This catalog contains 474 nonrepeaters and 18 repeaters, of which 462 nonrepeaters are published for the first time. However, due to instrument responses, processing methods, and other potential effects, these data need selection for nonrepeaters for the later analyses, which were mentioned in The CHIME/FRB Collaboration (2021a) and illustrated as follows.

- Events with the tab of “excluded_flag = 1” should be removed, considering that these data may be influenced by nonnominal telescope operation.
- Signal-to-noise ratio (SNR) should be larger than 12, because events with SNR < 12 are sensitive to human bias and are more likely to be misclassified as noise or radio-frequency interference (RFI).
- DM needs to meet the conditions that DM > 1.5DMMW and DM > 100 pc cm\(^{-3}\), to ensure these events are truly extragalactic sources, and where DMMW we used is DMYW16 model (Yao et al. 2017).
- The scattering timescale for events needs to be less than 10 ms, due to the selection effects bias against wide bursts.
- Events detected in far side lobes (indicated by the tab “Flux note” of Catalog 1) were rejected, as reliable flux or position measurements are not yet available for these events.
- Some sources have subbursts, so we only consider the first burst to avoid repetitive counting.

After these criteria, 255 nonrepeaters were reserved. However, the direct distance data have not been given for sources. If we assume that the Macquart relation (Macquart et al. 2020) of DM and redshift (DM-z) correlation is correct, we can derive an empirical formula to roughly estimate the FRBs distance. In addition, we also reexamine the Macquart DM-z relation by the latest updated 18 localized FRBs and find that it still follows the previous results, the detail of which is shown in Appendix A. Then, another problem arises that the Macquart relation can only estimate the distance at low redshift or DM (James et al. 2022). Meanwhile, in Catalog 1, the inferred power-law index for the cumulative fluence distribution of low DM (ranges in 100–500 pc cm\(^{-3}\)) and high DM (DM > 500 pc cm\(^{-3}\)) is different (The CHIME/FRB Collaboration 2021a), where DM is the data that removes the Milky Way galaxy contribution. Besides that, for high-DM data, bright bursts are more likely to be recorded by receivers, which means that the distant faint burst is incomplete for the full sample. Therefore, finally 125 nonrepeaters with low DM are selected in our sample, as well as 10 repeaters at low DM.

2.2 FRB Luminosity estimation

We employed the Macquart relation to estimate the distance of FRB, so the first step is to clarify the DM we used. FRB’s DM consists of 4 parts (Cordes and Chatterjee 2019), originating from the Milky Way galaxy and halo (DMMW), intergalactic medium in cosmic distance (DMIGM), host galaxy (DHOST), and surrounding medium (DMsur), respectively. As only 19 FRBs were localized, we know little information about other host galaxies and their DMexcess (DMIGM, DHOST, and DMsur), where DMexcess is used to estimate the upper limit of redshift and distance and DMMW is subtracted according to the YMW model (Yao et al. 2017) but not NE2001 (Cordes and Lazio 2002). Here, we do not estimate the DM contribution of the Milky Way galaxy halo, because they are not well constrained by current observations so far (Rafiei-Ravandi et al. 2021), which have a rough range of ∼ 10 – 100 pc cm\(^{-3}\). Since our DMs are all larger than 100 pc cm\(^{-3}\) after the above selections, we can ensure that these sources are from extragalactic distances. Thus, based on our method, the luminosity we calculate is the upper limit of the intrinsic value.

By using the basic knowledge of distance measures in cosmology (Hogg 1999), the proper distance (dp) can be roughly estimated as dp = cz/H0, where c is speed of light and H0 is the Hubble constant cited from Planck Collaboration (2016) and Macquart et al. (2020) (H0 = 67.74 km s\(^{-1}\) Mpc\(^{-1}\)). Based on the simplest assumption of a flat universe (Ωk = 0) and the definition of comoving distance (dc), the luminosity distance (dL) is written as dL = (1 + z)dc = (1 + z)dp/(1 + z) = dp. Meanwhile, the data of Catalog 1 are only from CHIME in the frequency band of 400–800 MHz, so we do not need to consider the impact of the different telescope calibrations on the data. Thus, combined with the FRB flux (S), the upper limit of luminosity of nonrepeaters can be calculated as L ≈ SdL\(^2\)/(1 + z). For the 10 repeaters, we also estimated their distances by the above method, and the first flux values of multiple observations are taken to represent this source.

3 Analysis and results

In our former work about the luminosity distribution of FRBs, we elucidated that the lognormal distribution is better
than the power-law type based on the FRB data by CHIME and other telescopes (Cui et al. 2021a). However, our conclusion was weakened due to the small amount of data and the difficulty of calibrating between the different telescopes. Nowadays, thanks to the CHIME Catalog 1, we can employ sufficient and more uniform data to do the further statistical tests, where the 125 nonrepeaters mentioned above are applied and the histogram of their luminosity is plotted in Fig. 1. Meanwhile, 5 statistical methods are used to judge our results, including goodness of fit, the K–S test, the M–W–W test, the A–D test, and the Lilliefors test. The analyses of the full sample (255 nonrepeaters) are shown in Appendix B.

To start our statistics, the test criteria need to be briefly introduced. The test results are represented by the parameters of the coefficient of determination \( R^2 \) and p-values that are given under a 5% significance level, and the procedures are as follows:

- For the goodness of fit, the closer \( R^2 \) is to 1, the better the fit, otherwise the fit is worse.
- For the K–S test, the M–W–W test, and the Lilliefors test, the lower the p-value, the greater the difference from the null hypothesis. If the p-value is less than 0.05, it indicates that this test rejects the null hypothesis.
- For the A–D test, when the value of the statistic is larger than the critical value, the null hypothesis can be rejected.

First, we directly test the lognormal distribution by applying the K–S test, the Lilliefors test, and the A–D test, and the null hypothesis is that the sample is consistent with a lognormal form. The results are shown in Table 1. Meanwhile, all p-values and statistics are larger than 0.05 and critical values, respectively, which indicate that the lognormal form is consistent with both repeaters and nonrepeaters under these three tests.

Then, we use the lognormal and power-law types to fit the luminosity distribution (in Fig. 1) and utilize the statistical methods to test the fitting closeness, including the goodness of fit, the K–S test, and the M–W–W test. To avoid deviations caused by different coefficients, we normalized the data and fitted curves and performed statistical analysis on them. From Fig. 1, we can see that the lognormal curve is closer to the data histogram compared with the power-law curve, and the fitting residuals of lognormal are also smaller than that of the power law, where the power-law form is mentioned as the Schechter function (Luo et al. 2018). From Table 2, the goodness of fit of the lognormal \( (R_{log}^2 = 0.99989) \) is higher than that of the power law \( (R_{power}^2 = 0.820) \). Moreover, further tests of the K–S and M–W–W on the fitting property also show that the lognormal conforms better than the power law. Although the goodness of fit of the power law is high, it is still smaller than that of the lognormal, and the p-values of the power law are all smaller than 0.05 in Table 2. Therefore, from the distribution pattern and the above statistical test results, a prelimi-
Statistical test results (p-values) of luminosity distribution with various error shapes and error percentages

| Statistical tests | Error shapes | Error percentages |
|-------------------|--------------|-------------------|
|                   |              | 10%    | 20%    | 30%    | 40%    | 50%    | 60%    | 70%    | 80%    | 90%    | 100%   |
| K–S test          | Uniform      | 0.748  | 0.746  | 0.780  | 0.800  | 0.796  | 0.762  | 0.697  | 0.499  | 0.241  | 0.0128 |
|                   | Normal       | 0.794  | 0.811  | 0.637  | 0.204  | 0.168  | 0.225  | 0.0422 | 0.0416 | 0.0334 | 0.0782 |
| M–W–W test        | Uniform      | 0.889  | 0.878  | 0.870  | 0.868  | 0.855  | 0.848  | 0.839  | 0.784  | 0.651  | 0.303  |
|                   | Normal       | 0.884  | 0.873  | 0.804  | 0.602  | 0.528  | 0.539  | 0.434  | 0.402  | 0.411  | 0.447  |
| Lilliefors test   | Uniform      | 0.363  | 0.323  | 0.391  | 0.374  | 0.421  | 0.340  | 0.235  | 0.0509 | 0.00949| 0.00144|
|                   | Normal       | 0.416  | 0.448  | 0.108  | 0.00975| 0.00683| 0.00967| 0.00328| 0.00247| 0.00255| 0.00334|

4 Discussions and conclusions

Four aspects will be discussed in this section: selection effects, the applicability of the lognormal for FRB luminosity, the magnetar origin for FRBs, and the difference between the repeaters and nonrepeaters. To begin with, we need to clarify the possible selection effect in our sample, discussing whether the lognormal distribution will be varied as the error percentage of DM-z relation changes. Then, we discuss what kinds of magnetars can produce the FRB luminosity as obtained, and the models for the repeaters and nonrepeaters.

4.1 Selection effects

The detection position from far side lobes and off-axis beams will affect the performance of the telescope. Although most of these data have been removed after selection,
Fig. 2  Luminosity histogram of nonrepeaters at low dispersion measure (DM) in uniform error shape with changing error percentages from 10% to 100%, from subfigure a to subfigure j. In each subfigure, the crosshatched histogram is the maximum deviation and the empty one means the minimum deviation of 300 times sampling in the corresponding error percentage. The line represents the best-fitting curve without considering the error of the Macquart relation, which is an unnormalized fitting curve in Fig. 1.
Fig. 3 Luminosity histogram of nonrepeaters at low dispersion measure (DM) in normal error shape with changing error percentages from 10% to 100%, from subfigure a to subfigure j. Other annotations are consistent with those in Fig. 2.
we cannot guarantee that all flux data are under the same instrument response due to the current positional uncertainties of the CHIME/FRB Catalog 1 events. However, we believe that this may be a minority case and has less impact on the conclusions. Besides that, we should note that the data of burst flux in CHIME/FRB Catalog 1 are biased, such as in high-DM and wide bursts with long scattering time, hence the CHIME/FRB Collaboration (2021a) injected simulate bursts to quantify this effect. However, we do not use this method but apply the data selection of low-DM and short scattering events to study the FRBs population. Therefore, it should be remarked that our analyses are only applicable to the current selection method.

Due to repeaters having been observed several times, they may obtain better measured DM data and estimated fluence. These effects probably cause differences in selection functions compared with nonrepeater samples, we cannot use this statistical result to determine whether a particular source will be repeated in the future. Thus, the difference between them may stem from selection effects like beaming and propagation, or the intrinsic characteristics of FRBs are various (Pleunis et al. 2021), and our following discussion mainly focuses on the possibility of intrinsic features.

4.2 Applicability of the lognormal distribution

As our study on the FRB luminosity depends on the distance estimation by the Macquart DM-z relation, this needs further discussions, as seen below. To verify the Macquart relation, we first use the new data of 18 localized FRBs to confirm its validity as previously noted (as shown in Fig. 5 in Appendix A). We obtain that the slope (k) by using a linear function for fitting ($k_{18} \sim 1028$) is almost parallel with the value of Macquart relation ($k_m \sim 973$), and the difference between the two slopes is no more than 6%. Under the constraints of 10 new data of localized FRBs, the Macquart relation does not change significantly, and the further analysis is listed in Appendix A. Therefore, it is reasonable that we employ this DM-z relation to estimate the distance to calculate the FRB luminosity. Then, the approximated isotropic luminosity data of FRBs based on the CHIME/FRB Catalog 1 are acquired under the Macquart relation, which follows the lognormal distribution and rejects the power-law type.

However, considering that the Macquart relation is not a strict one-to-one conversion from DM to z (distance), the lognormal distribution of FRB luminosity perhaps needs to be deformed with the increase of error for DM-z correlation. Here, with the different error shapes (uniform and normal type) and error percentages (from 10% to 100%), the variations of the lognormal characteristics are represented by statistical test results ($p_{ks}$, $p_{mww}$, and $p_{lilliefors}$), which means that the lognormal distribution may be constrained with a certain scope of application. According to Table 3, for the different error percentages, the lognormal characteristics are gradually decreasing under K–S, M–W–W, and Lilliefors test results. Although the majority of p-values are greater than 0.05, this clear downward trend indicates a weakening of the lognormal feature.

Specifically, for the uniform error shape, when the percentages reach 100% in the K–S test and 90% in the Lilliefors test, the corresponding p-values are lower than 0.05. For the normal error shape, the p-values smaller than 0.05 have appeared, while the percentages go to 70% and 40% in K–S and Lilliefors test, respectively. Therefore, the lognormal feature is threatened in the above situations. The reason for the different p-values under multiple tests lies in the different emphasis of each method. For example, the K–S tests the maximum distance between an empirical distribution function and a cumulative distribution function, while the M–W–W analyzes by the median. The Lilliefors test is an improved K–S test, which is appropriate when the test distribution must be specified by parameters estimated from the data (Lilliefors 1967). This also explains why $p_{lilliefors}$ always precedes $p_{ks}$ by less than 0.05. If we give the criterion that they pass all three tests in both error shapes, they will meet the lognormal distribution. Thus, it can be inferred that when the estimation error of the Macquart relation between DM and z is less than 40%, the lognormal luminosity distribution is credible. On the contrary, the lognormal feature is not obvious.

It should be clarified that the errors we are discussing here do not come from a particular uncertainty, but represent all possible aspects in DM-z transition. This is intended
to simulate and test whether the form of luminosity distribution changes when uncertainty is introduced, rather than to describe and discuss the type and cause of specific error. Indeed, the selective effect and the observational bias may significantly affect DM-z conversion, hence James et al. (2022) gave the detailed analysis for possible errors and concluded that works may produce erroneous results when assuming a 1:1 DM-z relation, which is consistent with our original intention to add errors in DM-z conversion. Meanwhile, since our curve fitting is only for the situation when the error is not considered, the fitting result may have a slight change after the error is introduced, but this will not affect our final conclusion, because the statistical test values are given for the different errors.

4.3 Magnetar origin of FRBs

Next, we discuss the upper limit of the intrinsic luminosity that we obtained in Fig. 1. As concluded in our former work (Cui et al. 2021a) and combined with new CHIME data, the lognormal distribution is more supportive of the magnitude changes when uncertainty is introduced, rather than to describe and discuss the type and cause of specific error. Indeed, the selective effect and the observational bias may significantly affect DM-z conversion, hence James et al. (2022) gave the detailed analysis for possible errors and concluded that works may produce erroneous results when assuming a 1:1 DM-z relation, which is consistent with our original intention to add errors in DM-z conversion. Meanwhile, since our curve fitting is only for the situation when the error is not considered, the fitting result may have a slight change after the error is introduced, but this will not affect our final conclusion, because the statistical test values are given for the different errors.

4.4 Difference between repeaters and nonrepeaters

The possible distinction between the repeaters and nonrepeaters is briefly discussed in this subsection. Although the luminosity distribution of repeaters is also lognormal (Cui et al. 2021a), the two groups have different statistical distributions. The average luminosity of repeaters (3.85 × 10^{47} \text{ erg s}^{-1}) is about three times lower than that of nonrepeaters (1.31 × 10^{44} \text{ erg s}^{-1}). This implies that they may come from a similar origin but different environments or emission mechanisms, such as the magnetars with the mediate magnetic field strengths or special structures. For example, the magnetic-field strength of a repeater source is about 10^{14–15} \text{ G}, while that of a nonrepeater may be higher than 10^{15} \text{ G}. In terms of the FRB origin models, there are two promising candidate forms: violent outburst from a magnetar and supergiant pulse from a strong magnetic neutron star (Popov et al. 2018; Katz 2020; Zhang 2020).

Specifically, the huge giant flares from an ultrastrong magnetar (∼10^{16} \text{ G}) (Lyubarsky 2014; Murase et al. 2016; Beloborodov 2017) may be one of the explanations for a single burst of nonrepeaters, and extremely high luminosity (∼10^{47} \text{ erg s}^{-1}) could lead to the long burst interval that it is considered as a nonrepeater. On the other hand, the supergiant pulses from the extragalactic neutron stars (Cordes and Wasserman 2016; Connor et al. 2016) may be a good description for repeaters. Consequently, our results further support the opinion of multiple origins of FRBs, which is also implied in previous studies based on CHIME/FRB Catalog 1 in different parameters (Pleunis et al. 2021) and another database (Cui et al. 2021b).

Finally, we need to clarify that the luminosity of two samples may have an overlap part, which means that some nonrepeaters may be repeated in the future, like FRB 171019 (Kumar et al. 2019). In other words, the merger of the binary system (Totani 2013; Kashiya et al. 2013; Mingarelli et al. 2015) and catastrophic collision events (Geng and Huang 2015; Dai et al. 2016) may also be mixed in the nonrepeater sample. However, the proportion of these one-time collision events should be a small part, because the luminosity distribution of nonrepeaters shows a single log-normal distribution. Therefore, the nonrepeater samples can also be divided into two groups: the true nonrepeaters and repeaters as a single observed burst. Finally, because of the statement in Sect. 4.1 and fewer data of only 10 repeaters, the low p-values need to be treated carefully, and its statistical conclusion might be tentative. Thus, we look forward to having more such data to uncover the mysteries of FRBs.
Table 4 Statistical test results of lognormal distribution for repeaters and nonrepeaters for full DM

| FRBs        | Number | K–S test | Lilliefors test | A–D test$^a$ |
|-------------|--------|----------|-----------------|--------------|
| Nonrepeaters| 255    | 0.452    | 0.111           | (0.481, 0.775) |
| Repeaters   | 18     | 0.716    | 0.238           | (0.397, 0.687) |

$^a$The results of the A–D test are shown in the form of statistic and critical values (statistic, critical values).

Table 5 Statistical test results of different luminosity distribution for all nonrepeaters

| Different types | Goodness of fit | K–S test | M–W–W test |
|-----------------|-----------------|----------|------------|
| Lognormal       | 0.99994         | 0.851    | 0.670      |
| Power-law       | 0.614           | $4.57 \times 10^{-4}$ | $3.29 \times 10^{-3}$ |

A brief summary of conclusions:

- We added the latest 10 localized FRBs to reconfirm the Macquart relation, indicating that this relation is still credible for the known 18 localized FRBs.
- The luminosity of repeaters and nonrepeaters are calculated based on the distance estimated by the Macquart relation, and their distribution conforms with the lognormal with the different mean values and derivations. However, the lognormal features decrease as the transition error of DM-z increases until the error reaches 40%, at where the lognormal features are weakened.
- These implies that the two samples possibly come from similar origins, such as magnetars or strong magnetic NS.

Appendix A: Verification of the Macquart relation with updated 18 localized FRBs

When the Macquart relation was given, only 8 localized FRBs were considered. Now, we add the newly localized 10 FRBs, and a total of 18 data points are taken into account to verify the Macquart relation. Since the M81 is too close to us (Bhardwaj et al. 2021), FRB 20200120E is not listed in the above 18 data. The fitted line of 18 data is given, with the goodness of fit as 0.75. As shown in Fig. 5, our fitted line (solid) is almost parallel to that of the Macquart relation (dashed), and the deviation of two slopes is less than 6%. This indicates that the DM-z relation is still valid, at least for the case that z is less than 0.7. While the obvious difference between the two lines is reflected as a fact that our fitting has an intercept value of $84.43 \text{ pc cm}^{-3}$ with the vertical axis. A possible reason for this gap is that the different DM data have been used. Our $\text{DM}_{\text{excess}}$ contains the $\text{DM}_{\text{host}}$ and $\text{DM}_{\text{sur}}$, but the $\text{DM}_{\text{cosmic}}$ in the Macquart relation does not. Meanwhile, the contribution of the Milk Way galaxy halo is not considered in our analysis either. Therefore, the gap value of $84.43 \text{ pc cm}^{-3}$ may infer the DM in the host galaxy, surrounding medium, halo, or both of them.

Appendix B: Analysis of full DM data

Under our data selection, we only analyze the repeaters and nonrepeaters at low DM in the main text, so we discuss the full data here, including FRBs at both high and low DM. Same as the above, we test lognormal feature for these data under K–S, Lilliefors, and A–D tests in Table 4. The results are consistent with the low DM data. Meanwhile, the goodness of fit, K–S, and M–W–W tests are also applied on the fitted curves, and the results are shown in Table 5 that further support the lognormal distribution of luminosity for nonrepeaters.

Besides that, we plot full DM data in Fig. 6 to compare whether repeaters and nonrepeaters have the same distribution with mean values of the two samples (repeaters: $1.23 \times 10^{44} \text{ erg s}^{-1}$, nonrepeater: $5.48 \times 10^{44} \text{ erg s}^{-1}$). Although the repeaters and nonrepeaters still show the different distributions ($p_{kl} = 6.17 \times 10^{-4}$ and $p_{mw} = 5.70 \times 10^{-5}$) as in the case of low DM selection, the mean values of all data are inconsistent with the data at low DM, indicating that the high and low DM may be different. Furthermore,
Fig. 6 The distinction for all repeaters and nonrepeaters (both low- and high-dispersion measure (DM)) in the aspect of luminosity. The top panel (subfigure a) is the CDF of repeaters and nonrepeaters for luminosity. The dashed (solid) line is for repeaters (nonrepeaters). The bottom panel (subfigure b) is the histogram of luminosity for two samples. The crosshatched (empty) histogram means the repeaters (nonrepeaters). The dashed (solid) line represents the mean value of repeaters (nonrepeaters)

the maximum and minimum luminosity of nonrepeaters is $8.00 \times 10^{45}$ erg s$^{-1}$ and $6.83 \times 10^{42}$ erg s$^{-1}$, respectively, which has a wider distribution range than the sample at low DM. Therefore, these imply that the reasons for these differences are possibly the observational effects, data-processing methods, or even their intrinsic physical properties, and we need further study to answer these puzzles.

Overall, no matter whether we use the low DM or full DM data, it does not impact our main conclusions on the luminosity distribution form of nonrepeaters, which is that the lognormal type is better for describing them.

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Data Availability The dataset of repeaters and nonrepeaters is available in the CHIME/FRB Catalog 1 repository, https://www.chime-frb.ca/home. The dataset of localized FRBs is available in the FRB HOST DATABASE, http://frbhosts.org/.

Declarations

Competing Interests The authors have no relevant financial or nonfinancial interests to disclose.

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