Possible Periodictity of Two Fast Radio Bursts (FRB) Repeaters with Limited Detections: FRB20190915D and FRB20191106C

Murthadza Aznam   Zamri Zainal Abidin   Norsiah Hashim

Muhammad Hassan Zakie Yussoff

Matdhesh Kummar Jayaganthan

Abstract

Fast radio burst (FRB) is a class of transients characterized by its miliseconds scale duration with a relatively high dispersion measure. Some of them show repetition and among those, only some of them seem to repeat regularly. This paper tries to characterize the periodicity of FRBs whose repetition seems to be limited within a certain timeframe – FRB20190915D and FRB20191106C as the chosen examples – from a 3 year dataset provided by the CHIME/FRB 2023 Catalog. This paper found that the periodicity can be characterized with more than 50% certainty despite the limited samples given that the waiting time is bimodally distributed.

1 Introduction

Fast Radio Burst (FRB) is a class of transients first discovered by Lorimer et al. (2007) with currently unknown origin. It is characterized as a radio pulse with durations in the order of milliseconds and a relatively high dispersion measure. Its high dispersion measure suggests an extragalactic origin consistent with observation of identified hosts such as in Bannister et al. (2019), Chatterjee et al. (2017), and Ravi et al. (2019).

With increasing interests in FRBs, progress have been made in detections (especially with the commisioning of the CHIME/FRB telescope (The CHIME/FRB Collaboration et al. 2018) and in the future, BURSTT (Lin et al. 2022)), theoretical models (a list of theories can be found in Platts et al. (2019)), and analyses (especially on regularly repeating bursts such as FRB20121102A and FRB20180916B). For an in-depth review of the growth of FRB research, readers are suggested to read Petroff, Hessels, and Lorimer (2019) and their follow-up review Petroff, Hessels, and Lorimer (2022).

Currently, FRBs can be categorized as repeating or non-repeating. The population seem to favor non-repeating FRBs over repeating FRBs as The CHIME/FRB Collaboration et al. (2018) reports on 18 (3.7%) repeating sources are among 492 FRB sources detected [1]. A recent paper (Andersen et al. 2023) estimates that repeating sources constitutes about 2.6% of known FRBs. However, it is important to note that there is no guarantee that one-off FRBs will not repeat. Following this assumption, the term 'apparently non-repeating FRB' have been used in various papers, such as in Cui, Zhang, Wang, Zhang, Li, Peng, Zhu, Wang, et al. (2021), Cui, Zhang, Wang, Zhang, Li, Peng, Zhu, Strom, et al. (2021), and Katz (2022).

Multiple statistical analyses seem to support the idea that they are truly two different population of FRBs with consistent differences between repeating and non-repeating FRB in various properties (Cui, Zhang, Wang, Zhang, Li, Peng, Zhu, Wang, et al. 2021; Chen et al. 2022; Zhang et al. 2022). This consistency does not prevent some authors in assuming that a small part of the non-repeating FRBs might repeat in the future dubbed as 'potentially repeating' or 'repeater candidates', as was done by Bo Han Chen et al. (2021), Luo, Zhu-Ge, and Zhang (2022), Zhu-Ge, Luo, and Zhang (2022), and Pleunis et al. (2021).

Regularly repeating FRBs such as FRB20121102A and FRB20180916B are rare. Most of the repeaters currently identified has a limited sample which makes it hard to study its individual property. As such, many repeaters are understudied as its low number of samples provide limited certainty. This paper tries to study the property of individual sources with limited samples.

Since periodicity generally requires many data points, this paper examines whether it is possible to determine the periodicity of a source with at least 50% confidence using samples with more than 3 and less than 20 event counts. If so, what are the criteria to differentiate between determinable and non-determinable periodicity? Having this criteria can help anticipate new detections.

2 Methodology

This paper will examine the periodicity of FRB20190915D (10 detections) and FRB20191106C (7 detections) from the CHIME/FRB Catalog 2023[2] (Andersen et al. 2023). This paper will also include FRB20180916B (77 detections) from CHIME/FRB Catalog 1 [3] (The CHIME/FRB Collaboration et al. 2021) to compare the validity of methods since its periodicity value is well quantified to be around 16 days (The CHIME/FRB Collaboration et al. 2020; Sand et al. 2023).

---

[1]https://www.chime-frb.ca/catalog
[2]https://www.chime-frb.ca/repeater_catalog
[3]https://www.chime-frb.ca/catalog

2.1 Periodogram

A periodogram is a function of cost versus periods which quantifies the strength of the fit between the given period and the time series data. The cost function depends on the method of choice. The best period is chosen based on the period with the maximum or minimum cost. While most periodogram methods choose the best period via the maximum cost, the phase dispersion minimization method chooses the minimum cost. VanderPlas (2018) includes four types of periodograms: (1) Fourier Method, based on Fourier transforms; (2) Phase-Folding Method, which calculates cost by trying to fold phases at multiple trial periods; (3) Least-Square Method, which fits a model time series; and (4) Bayesian Approaches, which applies Bayesian probability to the problem.

2.1.1 Method: Lomb–Scargle Periodogram

The Lomb–Scargle periodogram Scargle (1982) is the most commonly used in astronomy. The cost function for this periodogram is the Fourier power which is to be maximized. As such, it is a periodogram based on Fourier transform but it can also be approached as a least square optimization (VanderPlas 2018). The widespread use of this method warrants its place in the `astropy` package[4], an astronomy package for the Python programming language.

2.1.2 Method: Duty Cycle

The Duty Cycle method is a phase–folding periodogram which measures the trial period with the longest continuous inactivity per cycle of a given FRB. This method was introduced by Rajwade et al. (2020) to measure the periodicity of FRB20121102A because of the nature of repeaters to be active within a certain period per cycle. A duty cycle of 56% means that there is a continuous inactivity for 44% of the cycle.

2.1.3 Method: Phase Dispersion Minimization

Phase Dispersion Minimization (PDM) is a phase–folding method to determine the periodicity of non–sinusoidal time variation introduced by Stellingwerf (1978). This method computes the variances, `theta`, of the data with respect to mean light curve at each trial periods and minimizes it. It is suitable for small dataset with irregularly sampled observations, such as the repeaters sampled in the CHIME/FRB 2023 Catalog. This paper will use the Python wrapper of this algorithm written in C using the `py-pdm`[5] package.

---

[4]https://docs.astropy.org/en/stable/api/astropy.timeseries.LombScargle.html
[5]https://github.com/ckm3/Py-PDM

2.1.4 Parameter: Frequency Grid

For this study, we chose a frequency grid of $f_{\max} = (3 \text{ days})^{-1}$ to $f_{\min} = 0.5 * (T_{\text{obs}} \text{ days})^{-1}$, where T_{obs} is the length of observation (1,007 days). The maximum frequency is chosen such that if the period of FRBs is less than 3 days, we would see it much more often at a daily or bidaily rate. On the other hand, the minimum frequency is chosen such that to minimize the windowing effect near the length of observation. Following the advice of VanderPlas (2018), the frequency grid is chosen such that $N_{\text{eval}} = n_0 T_{\text{obs}} f_{\max}$ where n_0 is chosen to be 7.

2.2 Uncertainty Estimation

Periodograms do not usually have an associated uncertainty, especially non-Bayesian periodograms. As such, the Lomb–Scargle periodogram is equipped with a False Alarm Probability (FAP) associated at each power level to avoid false positives. However, the same cannot be said about other periodograms. It is treated with a case by case basis. For example, Rajwade et al. (2020) approached the problem by calculating the full width at half maximum of the peak.

This paper will try to estimate uncertainty by employing the leave-one-out strategy. For each event, k detections of said event are used to find the best period for the chosen periodogram method. Then, k samples of $k-1$ detections are run through the same method and twice the standard deviation of best periods between these $k-1$ detections are used as the uncertainty. The idea is that the uncertainty in the periodicity is tied to the fact that some observation might be missed.

3 Result

Table 1: The periods obtained from the specified methods in days and its uncertainty. The percentage in brackets for the 'Duty Cycle' column is the active fraction of the cycle.

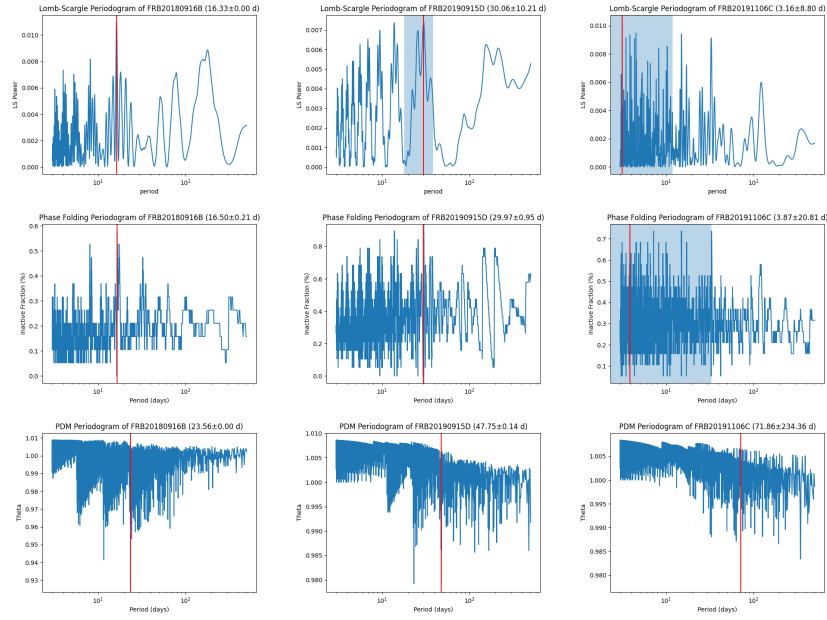| burst name	Lomb–Scargle	Duty Cycle	Phase Dispersion Minimization
FRB20180916B	16.33±0.00	16.30±0.21 (36.8%)	23.56±0.00
FRB20190915D	30.06±10.21	29.97±0.95 (10.5%)	47.75±0.14
FRB20191106C	3.16±8.80	3.87±20.81 (26.3%)	71.86±234.36

Figure 1: The periodograms of FRB20180916B (left), FRB20190915D (middle column) and FRB20191106C (right) using Lomb–Scargle method (top), Duty Cycle method (middle row) and Phase Dispersion Minimization (bottom).

The results shown in Table 1 accompanied by Figure 1 for FRB20180916B using Lomb–Scargle and Duty Cycle methods are consistent with the periodicities from The CHIME/FRB Collaboration et al. (2020) of 16.35±0.15 days and Sand et al. (2023) of 16.34±0.07 days. This consistency indicates that the methodology is reliable in determining periodicity using the available data. The Phase Dispersion Minimization method, however, offshoots by about ~1.4 times the obtained periodicity from the previous two methods.

This pattern also emerges in the results for FRB20190915D with Lomb–Scargle and Duty Cycle methods showing a periodicity of 30.06±10.21 days and 29.97±0.95 days respectively, with Phase Dispersion Minimization offshooting to 1.5~1.6 times the two values. This hints that these values might point to the real periodicity of the newly discovered FRB20190915D even though the available data is limited. The Phase Dispersion Minimization seems to consistently obtain 1.5 ×period days which is somewhat like a harmonic, equivalent to the second harmonic equivalent to $1.5 \times \lambda$ standing wave.

The same could not be said for FRB20191106C for two reasons. First, although it has consistent values for the first two methods, the Phase Dispersion Minimzation period is 18.5~22.7 times the previous two values. This does not follow the pattern of the previous FRBs. Secondly, we have to be careful in interpreting periodogram values. While it is true that the first two values are consistent, it is imperative to understand that 3 days is the minimum period chosen for this analysis and periodograms tend to spike at high frequency limit, which explains the high uncertainty.
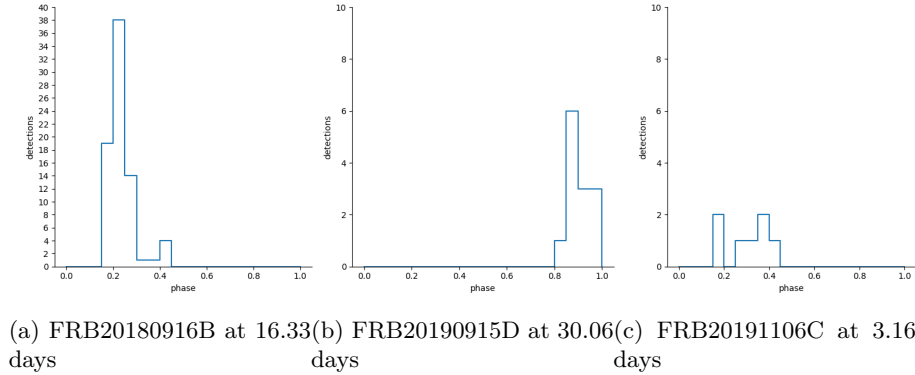

(a) FRB20180916B at 16.33 days (b) FRB20190915D at 30.06 days (c) FRB20191106C at 3.16 days

Figure 2: Phase folded detection count of FRB at their selected periods.

4 Discussion

4.1 False Alarm Probability

It is useful to quantify the false alarm probability (FAP) as a proxy of confidence. The FAP is computed using the 'bootstrap' method implemented in astropy's `LombScargle` class. It is found that each FRBs has a FAP of 13.3% (FRB20180916B), 57.0% (FRB20190915D) and 66.0% (FRB20191106C). These values are consistent with the heuristics in the preceding paragraphs that the value for FRB20180916B has a higher confidence than for FRB20190915D while values obtained for FRB20191106C has the least confidence. The fact that the FAP for FRB20190915D is slightly above 50% but not any higher might be due to the fact that its detection only happens in a small time frame compared to the observation window. Fixing the window to be between 20 Jun 2019 and 15 May 2020 reduces the FAP to 44.2% – suggesting that there is more than 50% confidence that it has a periodicity if treated as a time-limited event. Further discussion on this property is in Section 4.3.

4.2 Waiting time distribution

One might wonder what distinguishes FRB20190915D from FRB20191106C which allowed one to have periodicity despite limited samples? Looking at the waiting time distribution in Figure 3, FRB20190915D clearly shows bimodal distribution consistent with FRB20180916B (shown here) and FRB20121102A (shown in Hewitt et al. (2022) and Jahns et al. (2022)). Additionally, the waiting time of FRB20191106C is concentrated in the longer timescale compared to the bimodal distribution. It seems that a bimodal distribution is required for an FRB to have a well-defined periodicity.

4.3 Where is the rest of the detections?

If it is indeed that FRB20190915D has a 30 day periodicity, why is there no additional detections within the 3 year window of the catalogue? It might be the case that this FRB has a multi-term periodicity with this value representing it's short-term periodicity. If that is the case, it's long-term periodicity is expected to be more than 2 years which is yet to be seen. However, this is the same as hypothesizing that repeaters are possible repeaters with not-yet-observed repetition.

Another hypothesis that might explain this seemingly lack of regular detection is that FRB20190915D is a cataclysmic event with a periodic pulse and stopping at a certain point, such as the inspiraling of two magnetic bodies whose interaction releases some radio bursts. This might explain the ever increasing detection count as it reaches peak and then no longer bursting.
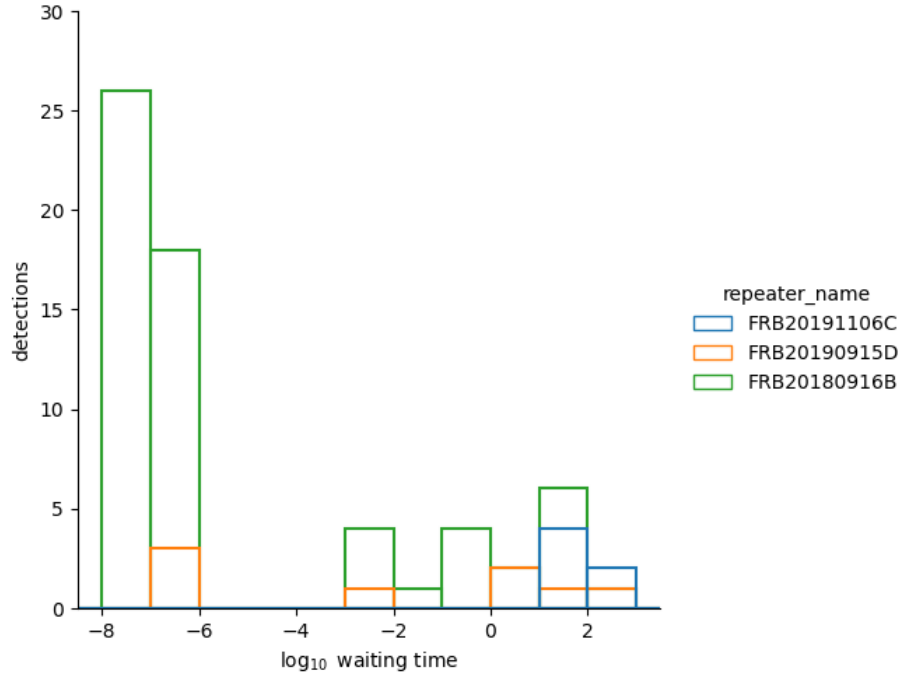
Figure 3: The waiting time distribution of FRB20191106C, FRB20191106C, and FRB20190916B in the $\log_{10}$ scale.
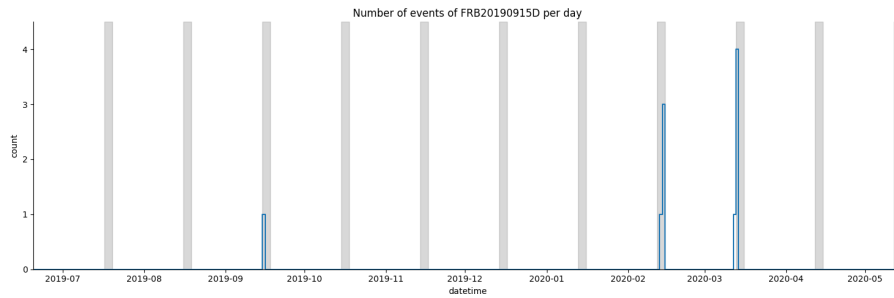

Figure 4: The number of detections per day of FRB20190915D between 20th Jun 2019 between 15th May 2020. The gray coloured regions indicate the active fractions (10%) in a 30 day cycle from 25th Jul 2018. Note that this graph focuses on this small timeframe because the datasets spans from 25th Jul 2018 to 26th Apr 2021 but is empty throughout the beginning and end for the specified FRB.

5 Conclusion

This paper determines that it is possible to evaluate the periodicity of FRBs despite small event counts. The choice of periodogram seems to matter as the Phase Dispersion Minimization method seems to offshoot for FRBs, but using multiple periodogram methods help find a consistent pattern. The bimodal distribution of waiting times seems crucial in the determinability of its periodicity. This paper also hints that there might a new class of FRB whose repeatability seems limited – such as an inspiraling collision – suggesting that FRBs might be divided into three classes: (i) continuously repeating, (ii) limited repeating, or (iii) one-off.

6 Acknowledgement

References

Andersen, B. C., K. Bandura, M. Bhardwaj, P. J. Boyle, C. Brar, T. Cassanelli, S. Chatterjee, et al. 2023. "CHIME/FRB Discovery of 25 Repeating Fast Radio Burst Sources." *The Astrophysical Journal* 947 (January): 83. https://doi.org/10.3847/1538-4357/acc6c1.

Bannister, K. W., A. T. Deller, C. Phillips, J. -P. Macquart, J. X. Prochaska, N. Tejos, S. D. Ryder, et al. 2019. "A Single Fast Radio Burst Localized to a Massive Galaxy at Cosmological Distance." *Science* 365 (August): 565–70. https://doi.org/10.1126/science.aaw5903.

Bo Han Chen, Tetsuya Hashimoto, Tomotsugu Goto, Seong Jin Kim, Daryl Joe D. Santos, Alvina Y. L. On, Ting-Yi Lu, and Tiger Y. -Y. Hsiao. 2021. "Uncloaking Hidden Repeating Fast Radio Bursts with Unsupervised Machine Learning." *Monthly Notices of the Royal Astronomical Society* 509 (1): 1227–36. https://doi.org/10.1093/mnras/stab2994.

Chatterjee, S., C. J. Law, R. S. Wharton, S. Burke-Spolaor, J. W. T. Hessels, G. C. Bower, J. M. Cordes, et al. 2017. "A Direct Localization of a Fast Radio Burst and Its Host." *Nature* 541 (January): 58–61. https://doi.org/10.1038/nature20797.

Chen, Hao-Yan, Wei-Min Gu, Mouyuan Sun, and Tuan Yi. 2022. "One-Off and Repeating Fast Radio Bursts: A Statistical Analysis." *The Astrophysical Journal* 939 (November): 27. https://doi.org/10.3847/1538-4357/ac958a.

Cui, Xiang-Han, Cheng-Min Zhang, Shuang-Qiang Wang, Jian-Wei Zhang, Di Li, Bo Peng, Wei-Wei Zhu, Na Wang, et al. 2021. "Fast Radio Bursts: Do Repeaters and Non-Repeaters Originate in Statistically Similar Ensembles?" *Monthly Notices of the Royal Astronomical Society* 500 (January): 3275–80. https://doi.org/10.1093/mnras/staa3351.

Cui, Xiang-Han, Cheng-Min Zhang, Shuang-Qiang Wang, Jian-Wei Zhang, Di Li, Bo Peng, Wei-Wei Zhu, Richard Strom, et al. 2021. "Statistical Properties of Fast Radio Bursts Elucidate Their Origins: Magnetars Are Favored over Gamma-Ray Bursts." *Research in Astronomy and Astrophysics* 21 (8): 211. https://doi.org/10.1088/1674-4527/21/8/211.

Hewitt, D. M., M. P. Snelders, J. W. T. Hessels, K. Nimmo, J. N. Jahns, L. G. Spitler, K. Gourdji, et al. 2022. "Arecibo Observations of a Burst Storm from FRB 20121102A in 2016." *Monthly Notices of the Royal Astronomical Society* 515 (September): 3577–96. https://doi.org/10.1093/mnras/stac1960.

Jahns, J. N., L. G. Spitler, K. Nimmo, D. M. Hewitt, M. P. Snelders, A. Seymour, J. W. T. Hessels, K. Gourdji, D. Michilli, and G. H. Hilmarsson. 2022. "The FRB 20121102A November Rain in 2018 Observed with the Arecibo Telescope." *Monthly Notices of the Royal Astronomical Society* 519 (November): 666–87. https://doi.org/10.1093/mnras/stac3446.

Katz, J. I. 2022. "The Absence of Periodicity in Repeating FRB." *Monthly Notices of the Royal Astronomical Society* 513 (June): 1925–31. https://doi.org/10.1093/mnras/stac1059.

Lin, Hsiu-Hsien, Kai-yang Lin, Chao-Te Li, Yao-Huan Tseng, Homin Jiang, Jen-Hung Wang, Jen-Chieh Cheng, et al. 2022. "BURSTT: Bustling Universe Radio Survey Telescope in Taiwan." *Publications of the Astronomical Society of the Pacific* 134 (September): 094106. https://doi.org/10.1088/1538-3873/ac8f71.

Lomb, N. R. 1976. "Least-Squares Frequency Analysis of Unequally Spaced Data." *Astrophysics and Space Science* 39 (February): 447–62. https://doi.org/10.1007/BF00648343.

Lorimer, D. R., M. Bailes, M. A. McLaughlin, D. J. Narkevic, and F. Crawford. 2007. "A Bright Millisecond Radio Burst of Extragalactic Origin." *Science* 318 (5851): 777–80. https://doi.org/10.1126/science.1147532.

Luo, Jia-Wei, Jia-Ming Zhu-Ge, and Bing Zhang. 2022. "Machine Learning Classification of CHIME Fast Radio Bursts: I. Supervised Methods." *Monthly Notices of the Royal Astronomical Society*, November, stac3206. https://doi.org/10.1093/mnras/stac3206.

Petroff, E., J. W. T. Hessels, and D. R. Lorimer. 2019. "Fast Radio Bursts." *The Astronomy and Astrophysics Review* 27 (1): 75. https://doi.org/10.1007/s00159-019-0116-6.

———. 2022. "Fast Radio Bursts at the Dawn of the 2020s." *The Astronomy and Astrophysics Review* 30 (1): 49. https://doi.org/10.1007/s00159-022-00139-w.

Platts, E., A. Weltman, A. Walters, S. P. Tendulkar, J. E. B. Gordin, and S. Kandhai. 2019. "A Living Theory Catalogue for Fast Radio Bursts." *Physics*

Reports 821 (August): 1–27. https://doi.org/10.1016/j.physrep.2019.06.003.

Pleunis, Ziggy, Deborah C. Good, Victoria M. Kaspi, Ryan Mckinven, Scott M. Ransom, Paul Scholz, Kevin Bandura, et al. 2021. "Fast Radio Burst Morphology in the First CHIME/FRB Catalog." *The Astrophysical Journal* 923 (1): 1. https://doi.org/10.3847/1538-4357/ac33ac.

Rajwade, K M, M B Mickaliger, B W Stappers, V Morello, D Agarwal, C G Bassa, R P Breton, et al. 2020. "Possible Periodic Activity in the Repeating FRB 121102." *Monthly Notices of the Royal Astronomical Society* 495 (4): 3551–58. https://doi.org/10.1093/mnras/staa1237.

Ravi, V., M. Catha, L. D'Addario, S. G. Djorgovski, G. Hallinan, R. Hobbs, J. Kocz, et al. 2019. "A Fast Radio Burst Localized to a Massive Galaxy." *Nature* 572 (August): 352–54. https://doi.org/10.1038/s41586-019-1389-7.

Sand, Ketan R., Daniela Breitman, Daniele Michilli, Victoria M. Kaspi, Pragya Chawla, Emmanuel Fonseca, Ryan Mckinven, et al. 2023. "A CHIME/FRB Study of Burst Rate and Morphological Evolution of the Periodically Repeating FRB 20180916B." *arXiv e-Prints.* https://doi.org/10.48550/arXiv.2307.05839.

Scargle, J. D. 1982. "Studies in Astronomical Time Series Analysis. II. Statistical Aspects of Spectral Analysis of Unevenly Spaced Data." *The Astrophysical Journal* 263 (December): 835–53. https://doi.org/10.1086/160554.

Stellingwerf, R. F. 1978. "Period Determination Using Phase Dispersion Minimization." *The Astrophysical Journal* 224 (September): 953–60. https://doi.org/10.1086/156444.

The CHIME/FRB Collaboration, Mandana Amiri, Bridget C. Andersen, Kevin Bandura, Sabrina Berger, Mohit Bhardwaj, Michelle M. Boyce, et al. 2021. "The First CHIME/FRB Fast Radio Burst Catalog." *The Astrophysical Journal Supplement Series* 257 (2): 59. https://doi.org/10.3847/1538-4365/ac33ab.

The CHIME/FRB Collaboration, M. Amiri, B. C. Andersen, K. M. Bandura, M. Bhardwaj, P. J. Boyle, C. Brar, et al. 2020. "Periodic Activity from a Fast Radio Burst Source." *Nature* 582 (7812): 351–55. https://doi.org/10.1038/s41586-020-2398-2.

The CHIME/FRB Collaboration, M. Amiri, K. Bandura, P. Berger, M. Bhardwaj, M. M. Boyce, P. J. Boyle, et al. 2018. "The CHIME Fast Radio Burst Project: System Overview." *The Astrophysical Journal* 863 (1): 48. https://doi.org/10.3847/1538-4357/aad188.

VanderPlas, Jacob T. 2018. "Understanding the Lomb–Scargle Periodogram." *The Astrophysical Journal Supplement Series* 236 (1): 16. https://doi.org/10.3847/1538-4365/aab766.

Zhang, Kongjun, Longbiao Li, Zhibin Zhang, Qinmei Li, Juanjuan Luo, and Min Jiang. 2022. "The Statistical Similarity of Repeating and Non-Repeating Fast Radio Bursts." *Universe* 8 (7): 355. https://doi.org/10.3390/universe8070355.

Zhu-Ge, Jia-Ming, Jia-Wei Luo, and Bing Zhang. 2022. "Machine Learning Classification of Fast Radio Bursts: II. Unsupervised Methods." arXiv. https://doi.org/10.48550/arXiv.2210.02471.