The Absence of Periodicity in Repeating FRB

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ABSTRACT

Popular Fast Radio Burst models involve rotating magnetized neutron stars, yet no rotational periodicities have been found. Small datasets exclude exact periodicity in FRB 121102. Recent observations of over 1500 bursts from each of FRB 121102 and FRB 20201124A have also not found periodicity. Periodograms of events with cosine-distributed random offsets as large as ±0.6P from a strict period P would still reveal the underlying periodicity. The sensitivity of periodograms of long data series, such as bursts observed on multiple days, to slow frequency drifts is mitigated by considering individual observing sessions, and results are shown for FRB 121102. Models of repeating FRB without intrinsic periodicity are considered, as are models of apparently non-repeating FRB.

Key words: radio continuum, transients: fast radio bursts, accretion, accretion discs, stars: black holes, stars: magnetars

1 INTRODUCTION

The sources of Fast Radio Bursts (FRB) remain mysterious. Strongly magnetized neutron stars ("magnetars") have long been proposed because their great magnetostatic energy is believed to be released in Soft Gamma Repeater (SGR) outbursts (Katz 1982), and because neutron stars have the short characteristic time scales (manifested in the sub-ms rise times of SGR and in pulsar pulse widths and substructure) required to explain FRB. As radio pulsars, magnetic neutron stars radiate coherently with extraordinarily high brightness temperatures, another property of FRB. Although the giant outburst of the Galactic SGR 1806–20 did not produce a FRB (Tendulkar, Kaspi & Patel 2016), setting an upper bound on its isotropic-equivalent FRB energy about 11 orders of magnitude lower than that of FRB at redshifts z ∼ 1, related objects, perhaps with different values of their parameters, are popular models of FRB sources (Platts 2018).

The magnetically mediated or powered emission of any rotating magnetized object must be periodic at its rotational frequency, unless the magnetic field is (implausibly) accurately dipolar and accurately aligned with the rotational axis. Radio pulsars are the classic example, and the pulses of RRAT (radio pulsars most of whose pulses are nulled) are separated by integer multiples of their underlying (rotational) periods. This applies even if the radiation is produced by a collimated relativistic beam far from the neutron star (Metzger, Margalit & Sironi 2019) because the direction of the beam and its radiation are tied to the orientation of the rotating neutron star. Even the thermal emission of Anomalous X-ray Pulsars (AXP; the quiescent counterparts of SGR) is periodic with their rotational period, as is the emission of accreting binary neutron stars.

Two types of periodicity may be considered: bursts separated by integer multiples of a stable underlying period (as in radio PSR and RRAT) and near-periodic modulation of activity. The latter describes a process that has irregular, perhaps random, scatter about the underlying stable period; an example is observed Solar activity that is modulated at the underlying more stable Solar rotation period. Either would produce a narrow spike in a periodogram and in the distribution of burst intervals.

Despite the expectation of rotational periodicity in the activity of repeating FRB, no such periodicity has been found. Long period modulation of the activity of two FRB has been observed (16.35 d of FRB 180916 (CHIME/FRB 2020) and 160 d of FRB 121102 (Rajwade et al. 2020)), but these periods are too long to be plausibly identified as neutron star rotational periods. Many repetitions of repeating FRB have recently been reported, including 1652 bursts of FRB 121102 (Li et al. 2021) and 1863 bursts of FRB 20201124A (Xu et al. 2021), in both cases without a spike in periodograms extending over the approximately two months of observation or other evidence of periodicity. Are these results consistent with an underlying periodicity, as required in a magnetic neutron star model because neutron stars rotate, or do they point to entirely different models?

Orbital motion and spindown may interfere with a search for periodic behavior in a rotating neutron star model by introducing large phase offsets. Popular neutron star models of FRB assume them to resemble Soft Gamma Repeaters (SGR; “magnetars”), none of which are binary. For this reason and because of the difficulty of searching the large phase space of possible binary orbits and time-dependence of the resulting phase shifts, this paper assumes a single object.

I first describe an unsuccessful search for exact periodicity in a small sample of bursts so closely spaced in time that period changes are unlikely to be significant. Next, I consider
the effects of frequency drifts, such as would be produced by neutron star spin-down (or spin-up). These effects are mitigated by analyzing each comparatively brief observing session independently; no periodicity is found. Then I calculate the periodogram of a simple model in which an underlying clock is stable, but bursts are randomly distributed in phase about its period. The periodogram reveals the presence of the clock even when the random phase deviations, distributed by a cosine probability function, may equal or slightly exceed ± a half cycle. The absence of significant peaks in the periodograms calculated here using the data of Li et al. (2021) (unfortunately, Xu et al. (2021) have not yet published or made available their data) is evidence that there is no such clock in FRB 121102, and supports arguments (Katz 2020) against magnetic neutron star models. Alternative models of repeating and non-repeating FRB are considered in Sec. 7.

2 EXACTLY PERIODIC BURSTS

Gajjar et al. (2018) observed five bursts (11B–F) of FRB 121102 within 0.001072338 d (93 s). For a neutron star spinning down by emission of magnetic dipole radiation (a similar rate is expected for an aligned rotor) the rate of change of spin frequency at age $A$

$$\dot{\omega} = \frac{-\omega}{2A}$$

where $\omega < 2 \times 10^8 \text{s}^{-2}$, and $A > 5 \text{y}$ have been assumed (this bound on $A$ is applicable to the data of Gajjar et al. (2018)) and it is assumed the present spin period is much longer than the spin period at birth (if this is not true, then a yet stricter bound results). This result is more generally applicable if $A$ is taken as the spin-down age, that might greatly exceed the actual age.

The resulting phase drift, measured from the middle of the observing interval of length $T = 93 \text{s}$, is

$$\Delta \phi = \frac{1}{8} \omega T^2 \lesssim 0.02 \text{ radian.}$$

Even for the fastest and youngest possible rotating neutron star, spindown cannot interfere with detecting exact periodicity in this 93 s interval, were it present.

Combining Eqs. 1, 2 yields the maximum useful data span if $\omega$ is constant:

$$T < \sqrt{\frac{16 \Delta \phi A}{\omega}} \approx 1.6 \times 10^5 \sqrt{\frac{A}{10^5 \text{y}}} \frac{2 \pi \times 10^8 \text{s}^{-1}}{\omega} s,$$

where $\Delta \phi \approx \pi$ is the maximum phase drift consistent with finding a significant peak in the periodogram. It is possible to generalize the periodogram and increase its power by adding an $\dot{\omega}$ term like that in Eq. 2 to the phase $\phi$, but that would increase the dimensionality of the parameter space that must be searched.

An exercise in Diophantine arithmetic shows that the four independent intervals between bursts 11B, 11C, 11D, 11E and 11F are not consistent with integer multiples of a constant underlying period. Alternatively, the space of possible rotational frequencies from $20/d$ to $2 \times 10^8/d$ (231 $\mu$Hz to 2.31 kHz) is evenly sampled, corresponding to periods of 0.432 ms to 1.2 hours. A figure of merit may be defined:

$$\text{FOM}(P) = \sum_{i=C,D,E,F} \left( \frac{(t_i - t_B) - \text{NINT}[(t_i - t_B)/P]}{P} \right)^2,$$

Figure 1. Distribution of r.m.s. deviations of times of bursts 11B–F of Gajjar et al. (2018) from integer multiples of exact periods, for $10^7$ periods evenly spaced in frequency from 231 $\mu$Hz to 2.31 kHz (periods 0.432 ms to 1.2 hr). Error bars are 1σ. A smooth curve, as observed, is expected for uncorrelated aperiodic bursts. Exact periodicity would appear as a period showing zero (except for measurement and roundoff errors) deviation; none is found.

where NINT is the nearest integer function, the quantity in large parentheses is the deviation in units of $P$ of $t_i - t_B$ ($t_B$ functions as a reference time) from an integer multiple of $P$ and FOM measures the deviation of the four independent intervals from exact periodicity.

The resulting distribution of FOM is shown in Fig. 1. Some values of $P$ will, entirely fortuitously, provide a good fit to the observed intervals even if there is no underlying periodicity. Because the frequency resolution is greater than the maximum physically possible frequency (the limiting rotation rate of a neutron star), and orders of magnitude greater than likely frequencies (SGR rotation rates), a true periodicity would appear as multiple occurrences of very small r.m.s. deviations from the smooth curve expected for uncorrelated pulses. No such excess is observed.
3 THE PROBLEM OF FREQUENCY DRIFT

Unfortunately, calculating periodograms of entire datasets extending over months, as was done by Li et al. (2021); Xu et al. (2021), may not reveal a periodicity because even tiny period derivatives can dephase bursts months apart. This is a particular problem for fast (ms) rotation periods, but would be less so for the multi-second periods of known SGR/AXP. For example, Eq. 2 shows that for $T \approx 2$ months, as in the datasets of Li et al. (2021); Xu et al. (2021), $|\omega| = 2 \times 10^{-12} \text{s}^{-2}$ is sufficient to dephase by $2\pi$ radians. For comparison, most SGR/AXP have $|\omega| \gtrsim 10^{-11} \text{s}^{-2}$. If repeating FRB are made by SGR-like objects, periodograms of months-long datasets, as computed by Li et al. (2021); Xu et al. (2021), may not reveal their periodicity.

This problem may be mitigated by computing the periodograms of individual observing sessions. The long datasets consist of many shorter observing sessions as the sources pass through the field of view of FAST, a transit instrument. For example, most of the observing sessions of Li et al. (2021) are one hour long, although a few are as long as five hours. These may be considered individually, and their average may reveal low-amplitude modulation not apparent in data from individual sessions (although frequency drift may move the signal to different periodogram bins in different sessions).

For $T = 1$ hour, dephasing by $\Delta \phi = \pi$ radians only occurs if

$$|\omega| \geq \frac{8 \Delta \phi}{T^2} \approx 2 \times 10^{-6} \text{s}^{-2}. \quad (5)$$

Such large values of $|\omega|$ are possible if $\omega = 2\pi \times 10^3 \text{s}^{-1}$ and $A = 10 \text{y}$, but only at these extremes of both parameter ranges.

Li et al. (2021) detected bursts in 39 distinct observing sessions, spread over about two months. The number of bursts in a single session ranged from one to 122 (an additional eight sessions detected no bursts). Of those 39 sessions, the 17 with at least 50 bursts (to ensure good statistics in the periodograms) were analyzed; these comprise 78% of the total 1652 bursts. The 17 individual periodograms, evaluated at the $3.6 \times 10^6$ evenly spaced frequencies from 1/h to $10^3$/s, were then averaged.

There was no evidence of a periodicity in any of the individual periodograms or in their average. Because it is difficult to display graphically the $3.6 \times 10^6$ elements of an individual periodogram, the distribution of averages of the amplitudes of the 17 single-session periodograms is shown in Fig. 2. Examination of the highest averages also shows no evidence for periodicity (which might occur at slightly different periods in the individual sessions, and be smoothed in the average):

The greatest amplitude is only 3% greater than the second-highest, and they are at very different periods, not indicating a smoothed or broadened periodicity.

The 17 individual single-session periodograms, that would not be expected to be significantly affected by period drift, also show no evidence of periodicity. None of the highest amplitudes exceed the second-highest by more than 11%, and in each periodogram the highest amplitudes are at very different periods, unlike a broadened peak. The top ten are shown for each session and for the average in the Appendix.

The amplitudes of the largest values of the average periodogram are smaller than those of the individual session periodograms because extremes are reduced by averaging with

![Figure 2. Distribution of the the $3.6 \times 10^6$ averages of the amplitudes of 17 single-session (sessions with $\geq 50$ bursts) periodograms of the bursts of FRB 121102 for periods from 1 ms to 1 hour; data from Li et al. (2021). The amplitude normalization is arbitrary. The distribution is close to the Gaussian expected for “shot noise” burst times, somewhat broadened and skewed by the slow variations in activity of FRB 121102. The largest average amplitude in the data is 1.706; there is no evidence of periodicity.](image)

(smaller) values of the other periodograms at the same frequencies. The highest values of the averaged periodogram are at comparatively low frequencies (the frequencies are equally spaced from 1/h to $10^3$/s = $3.6 \times 10^6$/h) because of slow variations in the activity of the source.

4 PERIODIC BURSTS WITH RANDOM PHASE SCATTER

The massive datasets of Li et al. (2021); Xu et al. (2021) permit consideration of the hypothesis that there are underlying stable clocks but that bursts occur with random phase offsets from exact periodicity. This would be consistent with the failure to find exact periodicity in small datasets (Sec. 2).

The differential probability distribution $\text{Prob}(\delta t)$ of an offset $\delta t$ from an integer number of periods $P$ is taken as

$$\frac{d\text{Prob}(\delta t)}{d\delta t} = \frac{1}{2\alpha P} \cos \left( \frac{\delta t}{\alpha P} \right); \quad |\delta t| \leq \pi \alpha P/2 \quad (6)$$

and zero otherwise. The parameter $\alpha$ is a measure of the
scatter of the actual burst times from exact periodicity. This assumed functional form is arbitrary, but has the desirable property of being an even function of $\delta t$, peaking smoothly at $\delta t = 0$.

The $n$-th burst occurs at a time

$$T_n = PN + P\alpha \sin^{-1} (2R' - 1); \quad 1 \leq n \leq 1500,$$

where $N = \text{NINT}(RL/P)$ is the integer closest to $RL/P$, $R$ is a random number uniformly distributed on $[0, 1)$, $P$ is taken to be 1, $L$ (taken as $50P$) is the total duration of the hypothesized dataset and $R'$ is another random number uniformly distributed on $[0, 1)$. The deviations from the underlying period lie in the range $(-P\alpha\pi/2, P\alpha\pi/2)$ with the cosine distribution Eq. 6. The full range of scatter is $\pm \alpha\pi P/2$ and its r.m.s. value is $\alpha P/\sqrt{2}$.

The periodogram amplitude is defined by

$$A(P) = \sqrt{C^2(P) + S^2(P)},$$

where

$$C(P) = \sum_n \cos 2\pi T_n / P$$

and

$$S(P) = \sum_n \sin 2\pi T_n / P. \quad (9)$$

The resulting periodograms are shown for several values of $\alpha$ in Fig. 3. Fig. 4 shows realizations of the periodogram at the underlying period $P$ as a function of $\alpha$, normalized to the mean periodogram for periods from 0.01$P$ to 5$P$, linearly spaced in frequency. The periodicity is evident for $\alpha \leq 0.4$.

The absence of a peak at the underlying period excludes this model for $\alpha < 0.4$. Somewhat larger $\alpha$ may produce a peak at that period, although it may not be compellingly distinguished from the level of random fluctuations. In Fig. 3 the true period is known a priori while in a real dataset any true peak must be distinguished in a statistically significant manner from random fluctuations, requiring an amplitude greater than that shown for $\alpha = 0.6$ and possibly even that for $\alpha = 0.4$.

5 BURSTS WITH PERIODIC VISIBILITY MODULATION

A rotating emitter with anisotropic emission intensity produces a peak in the periodogram at its rotational period, because a burst is more likely to rise above the observational threshold at certain rotational phases, and less likely at other phases, even if the energy emitted in the bursts has no intrinsic periodicity (as would be expected for magnetic flares). This is simulated using the observed burst catalogue of Li et al. (2021) by discarding a burst with probability

$$P_{\text{discard}} = \beta \cos^2 \left(\frac{\pi\delta t}{P}\right),$$

where $P$ is the period, $T_n$ is the observed epoch of the $n$-th burst and

$$\delta t = T_n - \text{PNINT}(T_n / P) \quad (11)$$

is the deviation of $T_n$ from exact periodicity. Note that $|\delta t| \leq P/2$.

Discarding these bursts at assumed unfavorable phases, the maximum values of the periodogram for all periods corresponding to evenly spaced frequencies from 1/hour to $10^4$/s

![Figure 3. Periodograms for several values of $\alpha$. If $\alpha \leq 0.6$ there is an evident peak at the underlying period.](image)

![Figure 4. Values of the periodogram at period $P$, normalized by its mean, as a function of $\alpha$.](image)
Acceleration of energetic particles is nearly ubiquitous in as-
neutron stars, should be considered. Emission angles is not demonstrably impossible. Despite this, the angle between the disc axis. Neither has been modeled in detail, but might be found for a Gaussian, although then there would be an large modulation that would be expected for radiation by an oblique dipole or a more complex field distribution is not found; the data are consistent with no periodic modulation.

6 IMPLICATIONS

The absence of a peak in the observed periodograms, if inter-
preted as a consequence of random phase scattering, implies \( \alpha \gtrsim 0.4 \), or a half-range of scatter \( \pm 0.6P \); the scatter from the \( N \)-th peak slightly overlaps those of the \( (N - 1) \)-th and \( (N + 1) \)-th. The quantitative result depends somewhat on the assumed cosine distribution Eq. 6. It depends chiefly on the width of the scattering rather than on the specific func-
tional form assumed, which must necessarily be arbitrary. The raised cosine distribution (Hann function) used here is widely used in statistics (Nuttall 1981). A similar result could be found for a Gaussian, although then there would be an exponentially small (but not zero) probability of bursts im-
plausibly displaced by arbitrarily large amounts from integer multiples of \( P \).

The question of whether a scatter of \( \pm 0.4P \) (about \( \pm 2.5 \) radians) is consistent with a rotating neutron star model de-
pends on a detailed model of FRB emission, which does not exist. Emission along a bundle of field lines emerging from a magnetic pole implies narrow collimation along the magnetic axis (as is apparently the case in radio PSR and RRAT, as inferred from their pulse widths), but closed field lines are typically bent by \( \sim \pi \) radians (\( 2\pi \) radians for the polar field lines of a dipole) before returning to the star. The location of the emission region is not known, so large scatter of the emission angles is not demonstrably impossible. Despite this caveat, the absence of periodicity in the observed burst arrival times suggests that aperiodic models, not based on rotating neutron stars, should be considered.

7 APERIODIC MODELS

Acceleration of energetic particles is nearly ubiquitous in as-
trophysics (Katz 1991). It is described phenomenologically, but there is no fundamental understanding of why it takes place. For example, much of the energy output of active galac-
tic nuclei (AGN) takes the form of particle acceleration and the (incoherent) emission of highly relativistic particles. Yet it is not obvious why this is so: why does accretion onto a supermassive black hole convert so much of the accretional power to these nonthermal processes? If this were not an empirical fact, we would likely expect only the thermal emission of hot disc gas.

7.1 Repeaters

FRB are not emitted by AGN (although we cannot exclude the possibility of some analogous phenomenon). They are not emitted by stellar mass black holes, of which there are many in our Galaxy; if they were, the Galactic sources would dominate the FRB sky because of their proximity. FRB sources must be rare, and (with the possible exception of FRB 200428) no active FRB source appears to be present in the Galaxy. In the zoo of astronomical objects, this suggests accreting intermediate mass black holes and their accretion discs (Katz 2017a, 2019, 2020). They are rare in the Universe, like FRB sources, and analogy to AGN suggests the possibility of nonthermal processes. That analogy is also consistent with the persistent radio sources associated with FRB 121102 (Marcote et al. 2017), FRB 190520B (Nui et al. 2021) and FRB 20201124A (Ravi et al. 2021), and discussed more generally by Law et al. (2021).

In such a model, long-period modulation (CHIME/FRB 2020; Rajwade et al. 2020) of the activity of a repeating FRB is readily explained as the result of precession of the plane of the accretion disc, and hence of the direction of emission emerging from its central funnel. Precession is a familiar, perhaps ubiquitous, feature of accretion discs; the original examples are Her X-1, whose disc surrounds a neutron star (Katz 1973), and SS 433, whose disc surrounds a stellar-mass black hole (Katz 1980). Neither of these has been observed to emit anything like a FRB, but their disc axes are never close to the direction to the observer so emission close to that axis cannot be excluded. The rarity of similar objects (there is no known analogue of SS 433 in either our Galaxy or in any other, nor have intermediate mass black holes been compellingly identified) is consistent with the low space density of sources of repeating FRB, and motivates consideration of analogous systems as their sources.

Precession of the disc axis around the orbital angular mo-
momentum axis is a fundamental mode of oscillation of an ac-
cretion disc in a binary system, that can be excited by irreg-
ularity or turbulence in the accretion flow, with the compan-
ion’s gravity providing the restoring force. In addition, jitter about the mean precession is observed (Katz & Piran 1982) and may contribute to the aperiodicity of repeating FRB. If FRB are emitted along the disc axis, like the thermal plasma jets of SS 433 and the relativistic jets of AGN, the rate at which such collimated activity will be observed depends on both the angle between the disc axis and the direction to the observer and the angular scatter of FRB emission about the disc axis. Neither has been modeled in detail, but might provide a natural explanation of the periodic modulation of burst activity of FRB 121102 and FRB 180916 as the effect of precession of the disc axis.

| \( \beta \) | Peak Periodogram |
|---|---|
| 0.00 | 1.706 |
| 0.05 | 1.720 |
| 0.10 | 1.722 |
| 0.15 | 1.736 |
| 0.20 | 1.798 |
| 0.25 | 1.760 |
| 0.30 | 1.813 |

Table 1. Peak values of the mean over 17 observing sessions of the periodogram when the observed bursts of FRB 121102 (Li et al. 2021) are discarded with a periodic probability, according to Eq. 10. The peak is a noisy function of \( \beta \) because the data have temporal structure, partly random (with 1652 bursts randomness does not completely average out) and partly systematic (the activity level of FRB 121102 varies systematically with time). Compari-
oson to the peak amplitude of 1.706 for the actual data (see also Fig. 2) shows that the probability modulation amplitude \( \beta \lesssim 0.20 \).
7.2 Non-Repeaters

Several lines of evidence indicate that non-repeating FRB differ qualitatively from repeating FRB; they are distinguished by more than a repetition rate. One is the “sad trombone” phenomenon characteristic of repeating FRB: within a burst the frequency of emission drifts downward, distinguished from the effects of dispersive propagation (Hessels et al. 2019; Josephy et al. 2019; Rajabi et al. 2020). Its origin is not understood, but it may be a useful phenomenological tool for distinguishing the two classes of sources even if only one burst has been observed. Other distinguishing characteristics have been reported by Amiri et al. (2021); Pleunis et al. (2021).

Another argument is the bimodality of the duty factors, defined by

\[ D \equiv \frac{\langle F \rangle^2}{\langle F^2 \rangle}, \]

where \( F \) is the flux. For repeaters \( D \) is typically \( \sim 10^{-5} \) while for non-repeaters (where only an upper limit can be found) \( D \lesssim 10^{-8} - 10^{-10} \) for the best observed non-repeating FRB (Katz 2017b, 2018, 2019). If repeating and non-repeating FRB differed only quantitatively, a monotonic, rather than bimodal, distribution of \( D \) would be expected.

Arguments derived from the periodograms of repeating FRB are inapplicable to non-repeaters. But arguments based on the space density of FRB sources do apply to non-repeaters, and have been considered by Hashimoto et al. (2020). The volumetric rate of observed non-repeating FRB in the local (\( z \lesssim 1 \)) universe approaches or exceeds that of known or plausibly inferred classes of catastrophic events, such as stellar collapses or mergers. The observed volumetric FRB rate is surely an underestimate of its true value, that is much larger if their emission is beamed, if there is a population of FRB below instrumental detection thresholds. It is a priori implausible that the distribution of burst fluxes or fluences cuts off just below instrumental sensitivities (this would be inconsistent with the observation that both cosmologically distant and cosmologically local FRB have fluxes and fluences ranging down to detection thresholds; they are not standard candles), or if FRB distances are overestimated because of non-intergalactic contributions to their dispersion measures (Nui et al. 2021). The observed rate of apparently non-repeating FRB can only set a lower bound on the rate of catastrophic events to which they are attributed because it is not determinable how many FRB-like events fall below the detection threshold. Almost any downward extrapolation of the flux or fluence distribution would indicate that the “true” rate must be much higher than the observed rate.

Unless there is a completely unanticipated class of catastrophic events, appeal must be made to less catastrophic events that might, in principle, repeat, but at a much lower rate than those of known repeating FRB. The giant outbursts of SGR are not extrapolations of their smaller eruptions, but are qualitatively different outliers (Katz 2021a). This is attributed to a global rearrangement of the magnetic geometry, analogous to a crack that propagates through the entire neutron star crust, while the smaller eruptions are attributed to localized reconnection and flares. The giant outburst of SGR 1806–20 did not make a FRB (Tendulkar, Kaspi & Patel 2016), likely because it filled the magnetosphere with opaque and electrically conducting equilibrium pair plasma (Katz 1996). Beaming is an unsatisfactory explanation because it would require 11 orders of magnitude difference between in-beam and out-of-beam emission, inconsistent with even a tiny amount of scattering or extension of the emission region along a field line.

A less energetic but global rearrangement, perhaps of a magnetosphere with lower field, might similarly be a statistical outlier (not the high energy tail of a smooth distribution of smaller eruptions) without creating a dense pair plasma that would suppress FRB emission. It is impossible to estimate the recurrence time of such bursts (the recurrence time of SGR is at least a few decades), but it might well be \( > 1 \) y, making it difficult to observe repetitions, but \( \leq 10^{16} \) y, permitting an event rate orders of magnitude greater than the birth rate of FRB sources and the rates of stellar collapse, merger or similar catastrophic events (Hashimoto et al. 2020). The development of instruments capable of large angular acceptance angle or all-sky monitoring of FRB will offer the possibility of observing repetition rates \( < 1 / y \).

8 DISCUSSION

The failure to detect periodicity in repeating FRB casts doubt on popular models that attribute them to rotating magnetic neutron stars. The data exclude not only strict, PSR-like or RRAT-like periodicity, but even models with substantial scatter of burst times around rotations of a presumed neutron star source. Aperiodic models, such as accretion discs around black holes should be considered, even though there is no understood mechanism by which they might produce FRB (a problem also with neutron star models).

Black hole accretion disc models must address the absence of FRB from known black holes, both stellar mass black holes in binaries and supermassive holes in AGN. This might be related to the mass of the black hole, which is why intermediate mass black holes are suggested, although no mechanism for this is evident.

There may be large observational selection effects. The inner regions of the accretion discs and funnels of luminous stellar mass and AGN black holes are in the intense radiation fields that make these objects observable; such radiation fields are hostile environments for the acceleration of energetic electrons because of Compton scattering. If only a small fraction of black hole accretion discs are favorably oriented for observation of FRB, and FRB are preferentially (or only) emitted by low luminosity black hole accretion then observational selection mitigates against the identification of FRB sources with identified black holes.

The related environments of FRB 121102 and SGR/PSR J1745–2900 (Katz 2021b) suggests this latter object as a candidate repeating FRB. No FRB has been observed from it, but its Galactic location means that even micro-FRB would be detectable. It might repay monitoring.

Non-repeating FRB pose a different problem because the rate of catastrophic events is insufficient, even if each catastrophic event produces an observable FRB. This suggests appealing to intrinsically infrequent but repeating events that are not accompanied by a larger number of weaker events, such as would be implied by a power law distribution of their fluxes or fluences, in analogy to the giant outbursts of SGR.
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DATA AVAILABILITY

This theoretical study did not generate any new data. Codes and their output will be provided upon request.

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APPENDIX A: HIGHEST AMPLITUDES IN PERIODOGRAMS

| Session | MJD   | Duration | # Bursts |
|---------|-------|----------|----------|
| 1       | 58724 | 3 h      | 87       |
| 2       | 58725 | 3 h      | 121      |
| 3       | 58726 | 4 h      | 110      |
| 4       | 58727 | 5 h      | 91       |
| 5       | 58728 | 3 h      | 65       |
| 6       | 58730 | 1 h      | 122      |
| 7       | 58733 | 1 h      | 81       |
| 8       | 58738 | 1 h      | 58       |
| 9       | 58746 | 1 h      | 52       |
| 10      | 58748 | 1 h      | 53       |
| 11      | 58749 | 1 h      | 50       |
| 12      | 58752 | 1 h      | 54       |
| 13      | 58753 | 1 h      | 53       |
| 14      | 58754 | 1 h      | 60       |
| 15      | 58756 | 1 h      | 117      |
| 16      | 58757 | 1 h      | 64       |
| 17      | 58758 | 1 h      | 53       |

Table A1. Observing sessions from Li et al. (2021) used in the analysis. MJD are truncated to whole days and refer to the beginning of the session; some extend into the next MJD. Durations are rounded to the closest whole hour.
Table A2. Amplitudes $A$ (arbitrary units) of largest ten elements of the average (top row, left) and 17 individual session periodograms, with periods from 1 ms to 1 h, of FRB 121102 bursts, from data of Li et al. (2021). The extreme values of the averaged periodogram are less than those of the individual session periodograms because at a frequency at which one periodogram has an extreme value, others generally will not.