An explanation for the repetition/pulse width relation in FRBs

Abstract

It is not currently known if repeating fast radio bursts (FRBs) are fundamentally different from those that have not been seen to repeat. One striking difference between repeaters and apparent non-repeaters in the CHIME sample is that the once-off events are typically shorter in duration than sources that have been detected multiple times. We offer a simple explanation for this discrepancy based on a selection effect due to beamed emission, in which highly-beamed FRBs are less easily observed to repeat, but are abundant enough to detect as once-off events. The explanation predicts that there ought to be a continuous distribution of burst duration—not a bimodal one—with a correlation between repetition rate and width. Pulse width and beaming angle may be related by relativistic beaming and the Doppler effect, which lead to short-duration bursts with small solid angles. Alternatively, the relationship could be geometric as with pulsars, such that short pulses correspond to narrow opening angles or high rotation frequency. Our model has implications for the FRB emission mechanism, volumetric event rates, and energetics.

1 Introduction

Fast radio bursts (FRBs) are short-duration (μs-ms) extragalactic radio transients whose origins remain a mystery. To date, 20 FRBs have been found to repeat out of approximately 800 total detections (Spitler, Fonseca20, FRBcat, etc.). All but two repeaters were discovered by an FRB survey on the Canadian Hydrogen Intensity Mapping Experiment (CHIME/FRB), as well as the majority of non-repeaters (Fonseca20).

2 Model

In our picture, most or all FRBs repeat. The distribution of repetition rates is currently unknown, and our model remains agnostic to its shape. Instead, the key distinction between observed repeaters and FRBs that have only been detected once is their beaming angle. If sources with beaming angle, Ω, emit repeat bursts in different directions $\hat{k}$, then on average the probability of detecting a burst from a given source is $\frac{\Omega}{4\pi}$.

Suppose there exists a relationship between beaming angle, Ω, and pulse width, t, in the observer frame and that there is a positive correlation between the two. If the differential number counts of the *intrinsic* beaming angles is $n_i(\Omega) \equiv \frac{dn}{d\Omega_i}$, then the open angles of the *observed* FRBs will be distributed as,

$$n_{\rm obs}(\Omega) = n_i(\Omega)\frac{\Omega}{4\pi}, \tag{1}$$

because an anisotropic source with solid angle $\Omega << 4\pi$ can easily be missed. If the mapping between Ω and t is trivial, such that $\Omega(t) \propto t$, then clearly the observed pulse width distribution will favour broader bursts.

In the CHIME data, there appear to be many more FRBs near the instrumental smearing threshold ($\sim 1.3\,$ms at DM=$1000\,{\rm pc\,cm^{-3}}$) than at $\sim 10\,$ms. There are also many more apparent

non-repeaters than repeaters in the CHIME data taken between 28 August 2018 and 30 September 2019. Therefore, our model requires that there is an abundance of highly-beamed FRB-emitting sources. Due to this abundance, the majority of FRB detections will come from preferentially short-duration, beamed sources. But once an FRB has been detected, that source's repeat bursts will be more easily detectable if it has large Ω.

2.1 Monte Carlo simulation

3 Discussion

3.1 Origin of the Ω/t relationship

Either relativistic beaming (https://arxiv.org/pdf/1908.07743.pdf, https://arxiv.org/pdf/1908.07743.pdf) or opening angle effects, like with pulsars.

3.2 Predictions

1. Continuous distribution of widths, not bimodal as with two-class model for repeaters and non-repeaters
2. If the opening angle is due to relativistic beaming and the short-duration bursts due to the Doppler effect, then maybe there will be a width/brightness correlation?
3. Narrow bursts should have similar dynamic spectra when coherently dedispersed.
4. What should we expect about the bandedness? Repeaters may be more banded in frequency than non-repeaters...

3.3 Implications

Beaming alleviates issues with FRB energetics but exacerbates the volumetric rates. Interesting implications for emission mechanism.