Simultaneous multiwavelength observation of active FRB 220912A with GBT and CHIME

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Abstract

Despite happening all the time in all parts of the sky, fast radio bursts are still a mystery for modern astronomy. More multiwavelength observations are desperately needed in order to better constrain their emission mechanism, especially at higher frequencies above 8 GHz, where data is completely lacking. We propose to observe a newly-discovered, highly active and bright FRB 220912A with the 100-meter Green Bank Telescope in the K_a band (28 GHz), which provides a unique opportunity for the first time ever detection of an FRB at such a high frequency. Provided the detection is carried out in sync with CHIME, a fluence spectral index measurement of up to $\alpha = -1.76$ is attainable for bright bursts.

1 Scientific Motivation

Introduction Fast radio bursts (FRBs) are mysterious extragalactic radio pulses of very high energy, typically lasting for about a millisecond. They mostly peak in the L-band, reaching flux densities in the order of a couple Jy. Usually, we like to report their intensity in the units of *fluence* (the time integral of received flux density), which is in the ballpark of $\sim$ 1 Jyms for an average burst. What's interesting with their detection is that lower frequencies tend to arrive slightly later than higher frequencies because of the dispersion of radio waves in the ionized interstellar medium between the source and the Earth. The time delay is expressed as

$$\begin{gathered}\Delta t = 4.149\,\mathrm{ms} \cdot DM \frac{\mathrm{cm}^3}{\mathrm{pc}} \cdot \left(\frac{1}{f_{lo}^2} - \frac{1}{f_{hi}^2} \right) \mathrm{GHz}^2, \\ DM = \int n_e \cdot dl, \end{gathered} \tag{1}$$

where the *dispersion measure* DM, expressed in the units of $\mathrm{pc/cm^3}$, is related to the number of free electrons encountered along the line of sight. Since the charged particle number density is approximately constant at large scales, we can often infer the distance to the source from the measurement of its DM.

FRBs are ubiquitous. The CHIME/FRB collaboration detected 536 fast radio bursts in a single year between 2018 and 2019, inferring a total sky rate of $\sim$ 1000 *per day* above a fluence of 5 Jyms at 600 MHz [1]. They seem to occur in all parts of the sky, independent of the Galactic Plane. This, together with their very high DM values of >100 pc/cm^3, clearly points to sources from well beyond the Milky Way.

Although more than a decade has passed since FRBs were first discovered by Lorimer and Narkevic back in 2007 [2], their origin remains a puzzle. There are many theories trying to explain FRBs, and the most likely scenario seems to point to neutron stars, especially young magnetars. Another mystery is the fact that some FRBs repeat, while others don't. In the catalog released by the CHIME/FRB collaboration [1], 18 of 536 detected FRBs are repeaters. Their pulse shapes seem to differ from one-offs (they are longer and have a narrower bandwidth), so there are still a lot of debates whether repeating and non-repeating FRBs belong to two different populations of sources. Repeaters typically pulse sporadically, without any apparent order, however, two periodic repeaters have been discovered so far - FRB 121102 with an activity period of 157 days and FRB 180916 with a period of 16.35 days [3] (naming convention goes as YYMMDD of first discovery). Both are believed to be magnetars. Periodic repeaters are very appealing to study, because astronomers can predict the window of their highest activity and schedule observations accordingly.

If we want to better understand the true nature of FRBs, it is essential to perform observations at multiple wavelengths. X/gamma-ray follow-ups have been made, for example of FRB 121102 by Scholz et al. [4]. However, very little is known about FRBs in the high-frequency RF range, like 10's of GHz. The highest frequency observations so far went up to 8 GHz and were performed for both periodic repeaters, FRB 121102 [5, 6, 7] and FRB 180916 [7, 8]. The authors of these studies found something remarkable: the radio emission from these two sources is not instantaneously broadband - in other words, the activity of the source strongly depends on the observed frequency. Not only that, FRB 180916 appears to exhibit *chromaticity*, i.e. different frequencies are active at different times within the period of the FRB (see Figure 1 below). It is unclear whether chromaticity is a feature of only this particular source, of all periodic repeaters, or repeaters in general.

FRB 220912A FRB 220912A is a newly discovered repeater first picked up by CHIME on 12 September 2022 [9] and later localized to RA = 23h09m04.9s, DEC = $+48°42'25.4''$ by the Deep Synoptic Array (DSA-110) [10]. The DM of the source is $\sim$ 220 pc/cm^3 with an estimated redshift of $z = 0.0771$. Recent observations by Zhang et al. [11] with the FAST telescope in China point to very high activity of the source; the team reported 180 bursts in the L-band in 30 minutes, suggesting an event rate close to 400/hr. Very bright pulses were also detected by Sheihk et al. in the beginning of November [12], surpassing fluences of 10 Jyms in the L-band. Considering the fact that this source was found in September and is still so active months later suggests that this might be one of the most active FRBs on record.

While FRB 220912A is still active, we propose a high-frequency follow-up with GBT in the K$_a$ band (28 GHz) when crossing CHIME's field of view at 400-800 MHz. To our knowledge, no attempts have been made to observe FRBs at such high frequencies before. A simultaneous detection at 600 MHz and 28 GHz would place direct limits on the type of emission mechanism and therefore the nature of the source, marking a new era in FRB astronomy. On the other hand, not seeing anything in the K$_a$ band would imply that FRB 220912A

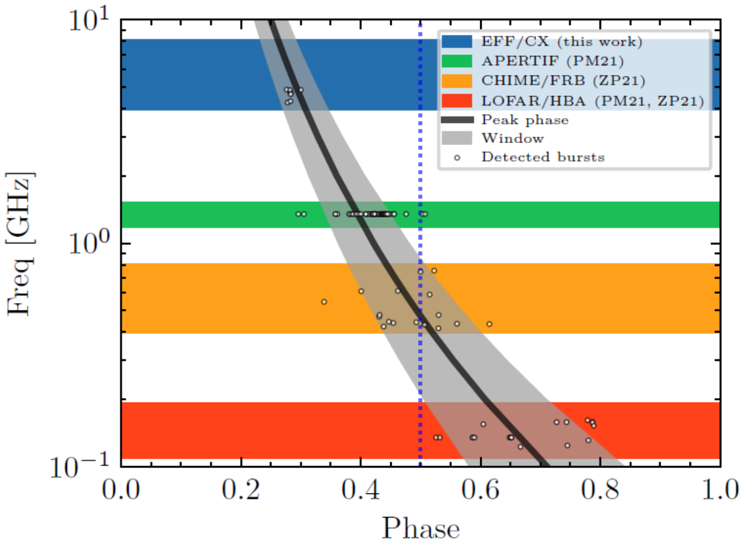

Figure 1: Chromaticity of FRB 180916. The active window moves up in time and becomes wider as frequencies go down. The x-axis ("phase") corresponds to the period of 16.35 days. Figure from [8].

might be chromatic, which is equally exciting and would provide us with valued information for possible future studies of chromaticity in non-periodic repeaters.

2 Technical Justification

All evidence suggests that FRBs have falling spectral indices above the L-band, meaning that the possible signal in the K_a band will be extremely weak. Consequently, a large radio telescope with a very high antenna gain is needed for detection. Together with its rich set of receivers, the 100-meter Robert C. Byrd Green Bank Telescope (GBT) presents itself as the perfect telescope for this job.

We propose to observe in the first band (F1) of the K_a receiver using both beams (polarizations), paired with the VEGAS backend in Pulsar mode which is most suitable for fast transients. This setup gives us a center frequency of 28.5 GHz and a maximum instantaneous bandwidth of 4 GHz [13]. Looking further at the specs, we can see that the gain of the telescope in the K_a band is 1.8 K/Jy with a maximum system temperature of $T_{sys} \approx 40$ K. Using the radiometer equation, this gives us the thermal noise sensitivity of 11 mJy or 0.011 Jyms for 1 ms pulses. Since the signal is very short, we don't expect any significant contribution from $1/f$ noise and the confusion noise at 28.5 GHz reads about 5.9 μJy, which is negligible.

Assuming 1 ms pulses, we therefore infer a 1σ fluence sensitivity of 0.011 Jyms in the 28.5 GHz band with GBT. If we define the spectral index α of FRBs in terms of fluence, $F_\nu \propto \nu^\alpha$, we expect to be sensitive to spectral indices up to (in absolute value) -1.76 for bright 10 Jyms bursts in CHIME's 600 MHz band or up to -1.17 for weaker 1 Jyms bursts. Detection by CHIME is anticipated $1.4 - 5.7$ seconds after the GBT K_a signal due to dispersion (see equation 1).

Figure 2 shows the field of view of the CHIME telescope. It's $1.3°-2.5°$ wide in the E-W direction, which translates to about 10-15 minutes of daily exposure to a source at $+45°$ declination [1]. At the time of first detection by CHIME, FRB 220912A had an estimated activity of 200-300 bursts per day at $\sim$ Jyms fluence thresholds [9] and as recent reports show [11, 12], the source is still very active. If we assume an activity of 100 bursts per day, we expect approximately 1 event on average when crossing CHIME's beam. Assuming the bursts are Poisson distributed, we need 3 exposures in order to detect at least one burst with 95% confidence. **Therefore, we propose to schedule 3 one-hour GBT observing sessions, coincident with the 15-min window when the source is within CHIME's beam.** Each 1-hour session consists of 30 mins for telescope setup, pointing and calibration [13] and 30 minutes on the source. Any detection of events in the K_a band, coincident with CHIME or not, would represent a groundbreaking discovery in FRB science.

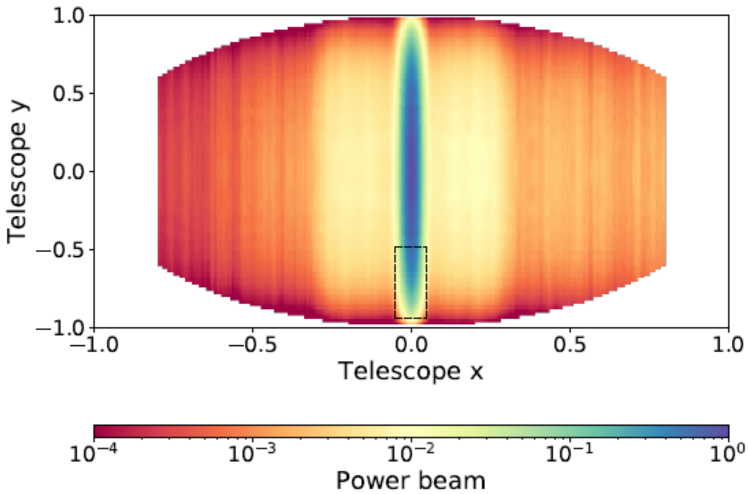

Figure 2: CHIME's cigar-shaped primary beam. As the Earth rotates, the telescope scans across the sky. Figure from [1].

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