A targeted observation for fast radio bursts from a radio source with likely magnetar origin

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Abstract

Fast radio bursts (FRBs) are transient astrophysical events characterized by millisecond-duration, bright radio signals emitted from extragalactic sources. Understanding the origin and nature of FRBs remains a significant challenge in modern astrophysics. Up to now, what we are aware is that at least some of them can be produced from magnetars, which are extremely strong magnetized compact objects in the universe. In this work, we conduct targeted search for fast radio bursts from a radio source, VT 1137−0337, which has exhibited a series of multiwavelength characteristics of magnetar wind nebula similar with the persistent radio sources (PRSes) of some active repeaters, such as FRB 20121102A and FRB 20190520B. Using the FAST and Parkes radio telescopes, we have been monitoring this radio source in 2023-2024 with a total observing time of 28 hours. After the data reduction based on TransientX, we found that two candidate single pulses with signal-to-noise ratios greater than $7.5\,\sigma$ have consistent dispersion measures around 245 $\mathrm{pc\,cm^{-3}}$. If the two events were confirmed as actual detection, it would be the first time that FRBs are discovered from targeted observation from unknown radio sources. The outcome would also reinforce the association between magnetars and FRBs, which can provide us with more insights into the nature of FRBs.

Introduction

Fast radio bursts (FRBs) are bright millisecond-duration radio bursts of unknown physical origin observed at extragalactic distances (Lorimer et al., 2007; Petroff et al., 2019). In the early stage, theory predicted that FRBs could originate from magnetar activity such as large flares (Popov & Postnov, 2013). As evidence of FRBs from multiple observations of magnetars emerged, magnetars began to emerge as top-candidate ancestors of FRBs.

Located at R.A. = 11:37:06.19, Dec = −03:37:37.3 (J2000), VT 1137−0337 was originally discovered and reported by Dong & Hallinan (2023) at a luminosity distance of 121.6 Mpc. VT 1137−0337 exhibits a series of magnetar wind nebula multi-wavelength features similar to active repeaters such as FRB 20121102A (Marcote et al., 2017) and FRB 20190520B (Niu et al., 2022). If VT 1137−0337 were found to be a FRB repeater, it will strengthen the connection between magnetars and FRBs and provide opinions into the origin of FRBs.

Observation and Data Analysis

We have been conducting the targeted observations for VT 1137−0337 using the Five-hundred-meter Aperture Spherical radio Telescope (FAST) and the Parkes 64-m radio telescope with a total observing time of 28 hours during the period of 2023-2024.

Our FRB search is performed using the CPU-based software package TransientX (Men & Barr, 2024). In the pipeline based on TransientX, each data block will be normalized before searching, and then radio frequency interference (RFI) mitigation would be performed. After this, the pipeline would go through de-dispersion, matched filtering, clustering until sifting the candidates. To search for FRB event at any possible dispersion measure (DM), we keep conducting de-dispersion uniformly from 0 to 2000 $\mathrm{pc\,cm^{-3}}$ in our pipeline. This ensures that we would not miss any candidate signals with unconscious bias when searching.

So far, we have completed 80% of observations carried out by FAST and most of the data have been processed. The Parkes observations have been finished but the data reduction is still in progress. From the observations by FAST, we basically selected two interesting candidate single pulses with similar DM values, which are shown in Figure 1. The signal-to-noise ratio of both candidates is greater than $7.5\,\sigma$, and the detailed parameters are shown in Table 1.

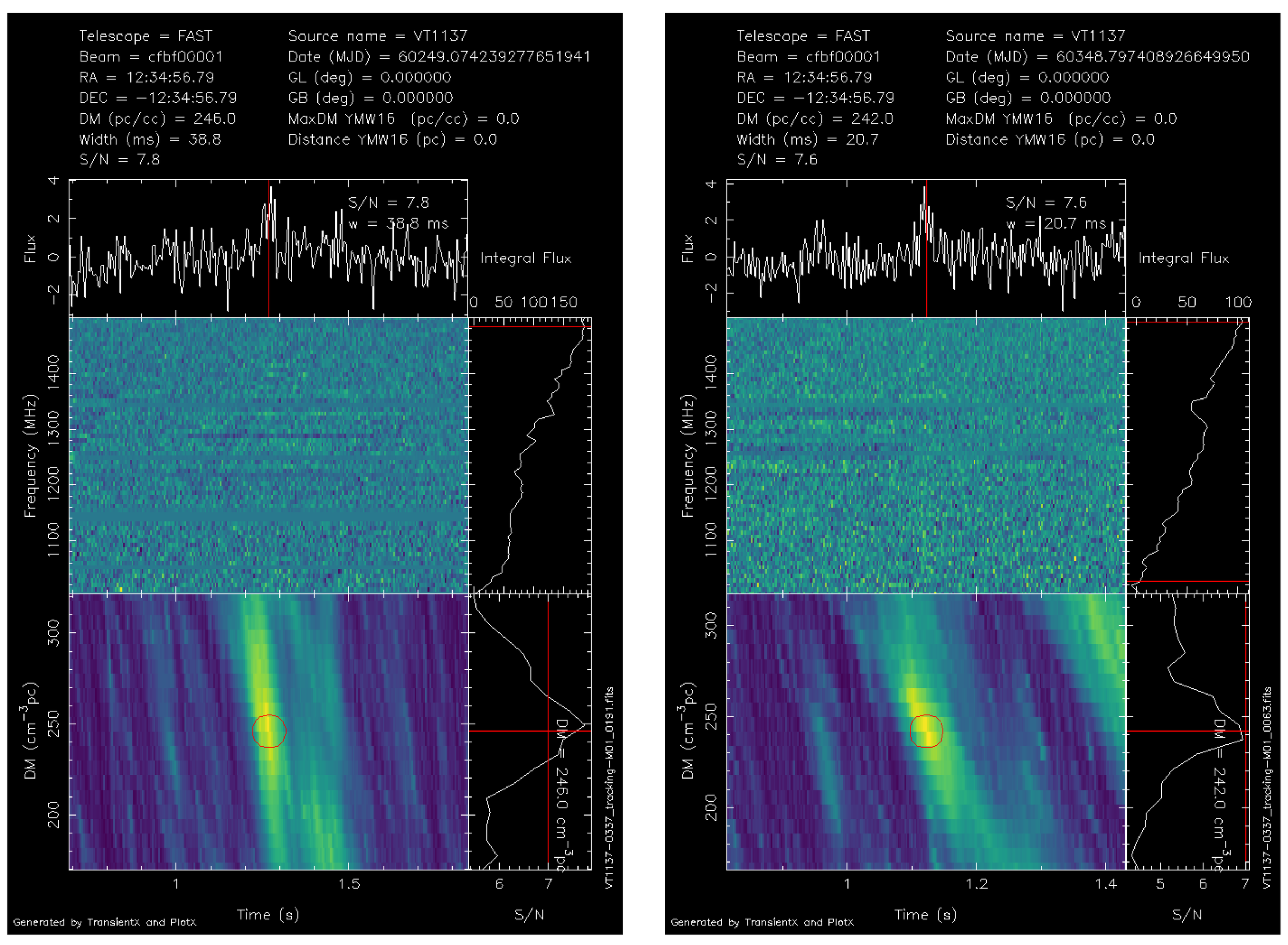

Figure 1. The candidate single pulse signals reported by TransientX[a] from the targeted observation for VT 1137−0337 by FAST. The left panel shows the candidate found on 1 Nov 2023, and the one on 9 Feb 2024 is shown on the right. In each sub-plot, the pulse profile, the dynamic spectrum of the pulse, the optimal DM distribution, and basic meta-information about the pulse are shown.

[a]https://github.com/ypmen/TransientX

Table 1. Candidate single pulses reported from the observations for VT 1137−0337.

Observing Date	2023/11/01	2024/02/09
Arrival time (MJD)	60249.074239	60348.797409
DM ($\mathrm{pc\,cm^{-3}}$)	246.0	242.0
Pulse width (ms)	38.8	20.7
S/N	7.8	7.6

Although no distinct signal signature in its dynamic spectrum (Figure 1), the single pulses with consistent DM make it suspicious enough for further analyses. We analyzed the two selected candidate single pulses through Python in detail. According to the information in Table 1, signal burst localization of observed data prior to de-dispersion to reduce the computational cost. After de-dispersion, we extracted the excess bin numbers to keep the data of two subintegral lengths, masked RFI, and finally obtained the pulse profile and waterfall plot of the candidate. Figure 2 shows the detailed characteristics of the candidate found on 9 Feb 2024. Obviously, the integral profile of this single pulse has a spike higher than the noise level at about 12 ms, but we cannot still determine whether this is caused by fluctuations in noise or a real single pulse from VT 1137−0337.

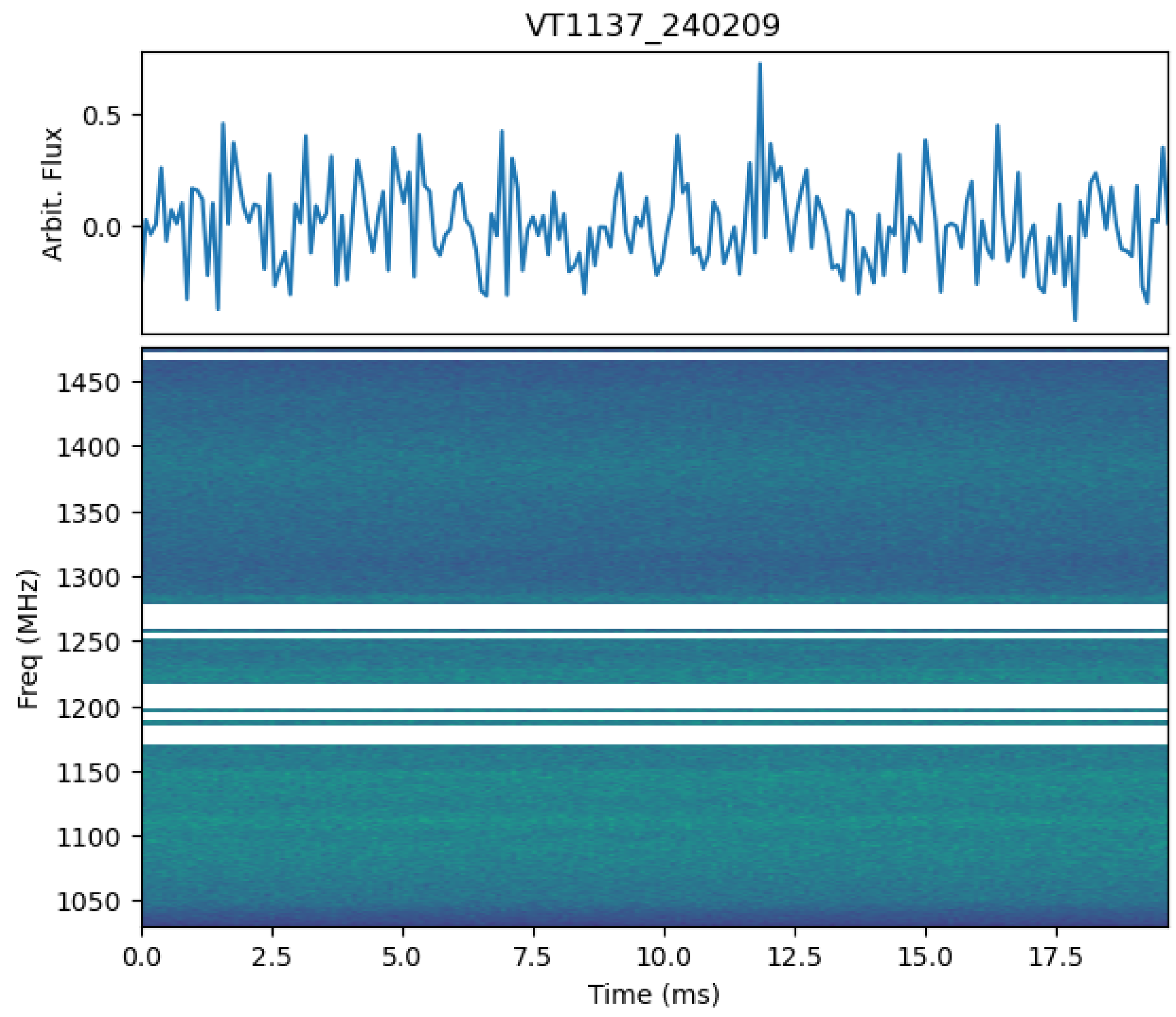

Figure 2. A candidate single pulse from VT 1137−0337. In this plot, the panel above denotes the integrated profile of a de-dispersed single pulse, the horizontal axis represents time in subtle units, and the vertical axis represents arbitrary flux. The panel below shows the dynamical spectrum after a single pulse de-dispersion, with time represented on the horizontal axis and frequency represented on the vertical axis. The white horizontal lines are frequency channels that have been masked because of RFI contamination.

Discussion and Summary

The two candidates with DMs around 245 $\mathrm{pc\,cm^{-3}}$ are both under the estimation on DM budget, which covers a wide range from 167 to 778 $\mathrm{pc\,cm^{-3}}$, using the Hα emission measure observed from VT 1137−0337. In addition, we calculate the coincidence probability by using the simplest statistical model. Statistically, the coincidence probability of detecting two candidates with consistent DM values above a S/N of $7.5\,\sigma$ in a 100-minute data is about 1.9×10^{-6}, yielding a confidence of $4.9\,\sigma$.

In this work, we analyze the candidate single pulses and explore the possibility that they are real signals in terms of coincidence probability. Although no significant single pulses were found, we can discuss about the physical origin of PRSes of some active FRB repeaters. Observationally, the relatively lower radio luminosity of VT 1137−0337 than the PRSes of FRB 20121102A and FRB 20190520B, which was mentioned in Dong & Hallinan (2023), might imply its lower radio efficiency to produce bright FRB events like what have been detected from those two active repeaters.

Regardless of the validity of these two candidates with the same DM, it is absolutely worth monitoring to see if any prominent single pulses would be detected. We expect to find more similar candidates in subsequent observations to examine this point. Further strengthening the connection between magnetars and FRBs will give us a deeper understanding of the nature of FRBs.

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