MONITORING A REPEATING FRB SOURCE — A POSSIBLE MAGNETAR/BE STAR BINARY

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1 Introduction

Fast radio bursts (FRBs) are enigmatic astrophysical phenomena. FRBs are radio transients characterized by very bright millisecond-bursts of radio photons and extragalactic origins. These bursts can be repeating or bursts that has been observed repeatedly in a certain period of time and non-repeating or bursts that have never been observed more than once. The Canadian Hydrogen Intensity Mapping Experiment (CHIME), with its FRB search backend, has opened up a new era of FRB detection. With this instrument, the CHIME/FRB collaboration has published its first catalog of more than 500 FRBs, both from repeating and non-repeating sources. Only 18 sources are found to be repeating. Despite this number, fast radio bursts remain to be a puzzling occurrence. Currently, there are over 40 theories attempting to explain the origins and nature of these radio flashes. Some theories suggest that they originate from interactions or mergers of compact objects such as black holes, neutron stars or white dwarfs. Others theories argue that they are collapsed offspring such as when a neutron star becomes a quark star. There are proponents of active galactic nuclei as source e.g. when it interacts with a Kerr Black hole. Some suggest that supernova remnants can be sources of FRBs. There are FRB theories proposed by a minority. Observations of FRBs indicate that their progenitors are of extragalactic or cosmological origin which compounded the difficulty of ascertaining its nature (Platts et al 2018).

In theories suggesting FRBs orginating from neutron stars, we have been on the look out for observations associating FRB events with X-ray emissions. In these observations, the X-ray emission comes from magnetars—neutron stars with extremely strong magnetic field (Kaspi 2010). One such observation is the Galactic FRB 20200428A recorded on the 28th April 2020 with an X–ray counterpart from a magnetar SGR 1935+2154 (The CHIME/FRB Collaboration; Andersen et al. 2020, Li et al. 2021, Ridnala et al. 2021). SGR 1935+2154 is a magnetar classified as a soft-gamma repeaters (SGR) and has been known to have numerous outburst of x-ray and gamma energy (Lin et al. 2020, Younes et al. 2017, Israel et al. 2016). Figures 1 and 2 show two peaks of fast radio bursts (FRB 20200428A) coinciding the two peaks of x-ray bursts from SGR 1935+2154. Hence, magnetars are good candidates for FRB progenitors. However, there has not been another event similar to SGR 1935+2154 fast radio bursts and X-ray bursts that has been observed. This motivates to look into other repeating FRBs. FRB 20201124A is a repeating FRB and the third closest among the repeaters. The energy budget consideration with the observing campaign with Five-hundred-meter Aperture Spherical Radio Array (FAST) suggests a magnetar with a Be star company (Wang et al. 2022). **We propose two follow-up observations with *Chandra* at 60 ks each for a total time of 120 ks to monitor the evolution of the x-ray emission of FRB 20201124A after a highly active of FRB episode.**

2 Scientific Justification

FRB 20201124A is a burst observed on 2020 November 24 at UTC 08:50:41.885952 with a dispersion measure, DM= 415.31 ± 0.63 pc cm^3. Since its first detection by CHIME, FRB 20201124A has been observed by several radio telescopes including FAST. It entered a highly active state towards the

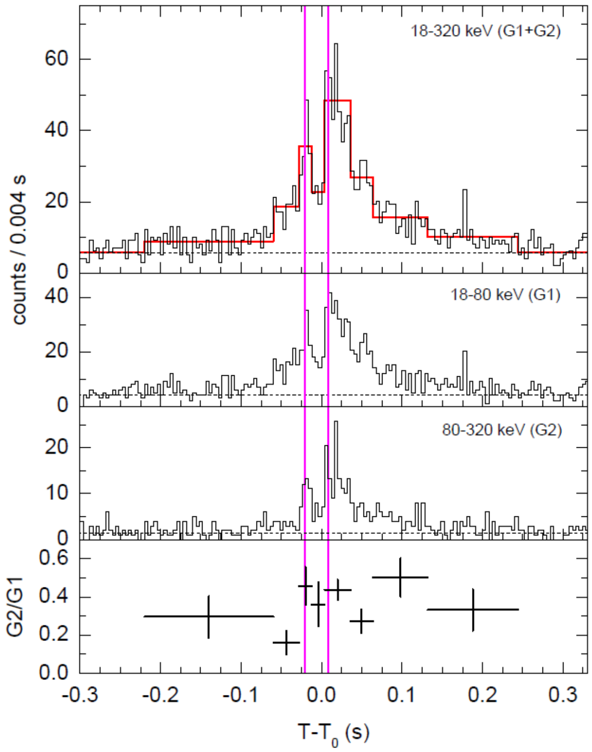

Figure 1: X-ray light curve of FRB 20200428/SGR 1935+2154 event from Konus-*Wind* in three energy bands: 18-320 keV, 18-80 keV, 80-320 keV. The magenta vertical lines correspond to the two FRB peaks which coincide the x-ray peaks. (Adapted from Ridnala et al. 2021)

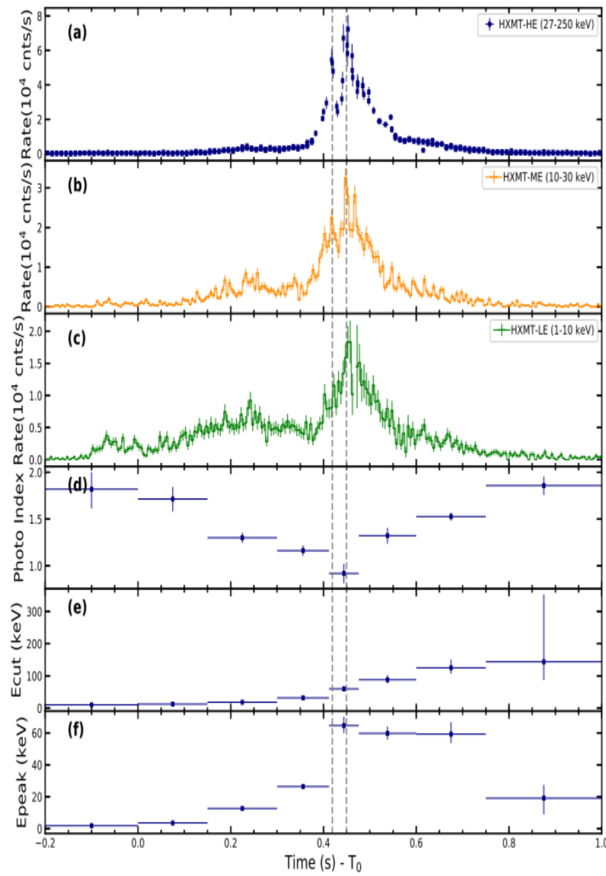

Figure 2: *Insight*-HXMT-HE X-ray light curve of the FFRB 20200428/SGR 1935+2154 event. (a) through (c) show the count rate with decreasing energy 27-250 keV, 10-30 keV and 1-10 keV. (d) through (f) indicate the CPL model parameters, photon index, E_{cut} and E_{peak}, respectively. The vertical dashed line correspond to the two FRB peaks coinciding the x-ray peaks. (Adapted from Li et al. 2021)

end of March 2021 (Lanman et al. 2021). FAST observed a total of 1863 independent bursts between April 1-June 11, 2021 covering frequencies 1 GHz to 1.5 GHz. These bursts adds up to a sum of 88 hours (Wang et al. 2022). In this time span, the total energy emitted by radio bursts is about 3×10^{41} erg. For a neutron star with magnetic field $B_d = 10^{13}$ G, total magnetic energy is $E_{mag} = 3 \times 10^{43}$ erg. This radio energy is physically impossible. But assuming an event similar to the SGR 1935+2154 which has five order of magnitude higher energy budget for X-ray emission, $E_X = 3 \times 10^{41}/10^5\ 10^{46}$ erg. For $E_{mag} > E_X$ the magnetic field B_d has to be larger than 10^{15} G, suggest FRB 20201124A to be magnetar scenario. Furthermore, the observed orbital period and eccentricity has a strong similarity to a magnetar/Be star binary LS I+61° 303 which also suggests the magnetar to accompanied by a Be star binary (Wang et al. 2022).

Magnetars as FRB progenitors. FRB models of magnetar can be can be classified into two categories. The first group of models proposes that transient emission originates from the relativistic outflow which interacts with the surrounding medium. In Ridnala et al 2021, scenarios such as relativistic outflow with internal shocks or magnetospheric flares in the magnetar wind driving the collision of magnetized shells may be observed and characterized by a single power spectrum from radio extending to hard x-rays. On the other hand, the second group suggests that FRBs are hyperflares from non-thermal particles generated by magnetosphere reconnection. The radio emission produced immediately after reconnection with x-ray emission from electron-positron pair production.

In figures 1 and 2, CHIME/FRB recorded a two-peak event which lasted about 0.6 ms and 0.3 ms, respectively and were separated by 29 ms. The FRB outbursts and the double-peaked X-ray burst coincided with each other, suggesting a common origin (The CHIME/FRB Collaboration; Andersen et al. 2020, Ridnala et al. 2021, Li et al. 2021). **This has pushed magnetars as the leading candidate for an FRB progenitor.** Consequently, this prompts to search for FRB signals from magnetars. Due to FRB 20201124A closer proximity, we will have an opportunity to understand the nature of FRB when it is decaying into quiescence.

Magnetar Outbursts and its Environment. The FRB associated with SGR 1935+2154 was detected at an active phase of the magnetar and hundreds of bursts were detected since its confirmation as magnetar in 2014 (Lin et al. 2020, Younes et al. 2017, Israel et al. 2016). After the magnetar's flaring activity, its x-ray emission enters a period of decay toward a quiescent state. Although, it may also become active before actually reaching the quiescent state. In most magnetars, the cooling process may be explained by neutron star crustal cooling but when the decay is extremely slow, the model fails and favors a different model known as untwisting bundle theory such as the observation of magnetar SGR 1745-2900 (Zelati et al. 2017). In the internal crustal cooling, the star cools exponentially and this rapid cooling is related to the neutron star achieving thermal equilibrium with itself (Cackett et al 2006). The untwisting bundle theory, on the other hand, asserts that the twisted bundle of current-carrying closed field lines in the magnetosphere controls the evolution of magnetar outbursts (Beloborodov 2009). In addition, harder x-ray emission may be explained resonant Compton scattering by plasma in the magnetosphere (Younes et al. 2017).

3 Technical Feasibility

The FRB-like emission of SGR 1935+2154 is a rare event according to estimates, occuring only at 7 to 40 events per millennium per magnetar (The CHIME/FRB Collaboration; Andersen et al. 2020, Ridnala et al. 2021). Moreover, *Chandra* has only made a single observation of the FRB source. It is paramount to launch an observation campaign and with its sub-arcsecond angular resolution, confirmation of the existence of magnetar behind FRB 20201124A and accurate investigation on its evolution with a detected FRB emission will be achieved. **This is a great opportunity of appending Chandra's already illustrious legacy considering the rarity of the event and little understanding we have of the nature of FRBs**.

FRB 20201124A is localized at J050803.48+260338.0 at z = 0.098. Using PRoVis, FRB 20201124A can be observed in the upcoming cycle except for a forbidden period from April 22 to August 01, 2023. To estimate the PIMMS predicted counted rate, the parameters N_H, redshift and photon index were taken from Piro et al. 2021. The PIMMS predicted count rate is 4.157×10^{-4}

cts / s in order to achieve a signal-to-noise ratio (SNR) ~ 5 per observation. With this count rate and SNR, we are requesting 60 ks per observing run. **Thus, we propose to observe FRB 20201124A for a total time of 120 ks before and after the forbidden period in the upcoming cycle using the ACIS-S3 operating in TE mode in Faint format**. This will allow us to study the temporal and spectral evolution of FRB 20201124A. ACIS-S3 in TE mode provides high resolution imaging in two dimensions.

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