The 2021 Activity of the FRB-Emitting Galactic Magnetar SGR 1935+2154 as Observed by Fermi-GBM

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Introduction

Magnetars, a special isolated neutron star (INS) class, have ultra-high decaying magnetic fields in NS family. These magnetic fields power the burst emission only distinct to magnetars.

SGR 1935+2154 is a distinguished magnetar due to its frequent burst emission, with active episodes in 2014, 2015, 2016, 2019, 2020, and 2021 (Younes et al. 2017, Lin et al. 2020a, Lin et al. 2020b, Palmer 2020, Ridnaia et al. 2021a, Ridnaia et al. 2021b). 2020 activity contains a discovery of a fast radio burst (~ millisecond long, very bright burst) from the source with an x-ray counterpart.

A more unique feature of SGR 1935+2154 is the emission of the first galactic fast radio burst (FRB, see Petroff et al. 2022 for recent review) on 2020 April 28 detected by the CHIME and STARE2 radio observatories (CHIME/FRB Collaboration et al. 2020; Bochenek et al. 2020). This FRB was accompanied by a counterpart x-ray burst, detected by INTEGRAL, AGILE, Insight-HXMT, and Konus-Wind (Mereghetti et al. 2020; Tavani et al. 2021; Li et al. 2021; Ridnaia et al. 2021).

Studying each activity in detail is important for a coherent picture of the class of magnetars and their diverse behavior. Here we present the Fermi GBM observations of the source during the 2021 September activity. We study the burst temporal and spectral properties, and their correlations. We compare the burst properties to those of the previous activities of the source during the past 6 years (2014 2020).

Observations and Analysis

The Gamma-ray Burst Monitor (GBM) onboard the Fermi γ–ray space observatory is an un-occulted, large FOV, all-sky monitor. It detected bursts in 2021-09 from $9^{th} \rightarrow 30^{th}$ from SGR 1935+2154.

- ➔ Select NaI detectors (8 keV – 1 MeV) from the GBM, placed on all four corners of GBM as triads (Meegan et al. 2009).
- ➔ Select *tte* files (Δt=2μs, 128 pha channels) from the GBM data types as suitable for the magnetar burst analysis (Collazzi et al. 2015).

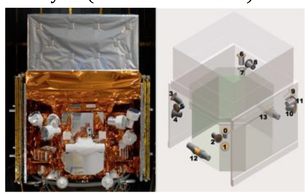


Figure 1: (*left*) Fermi GBM. (*right*) NaI detector positioning on GBM illustration

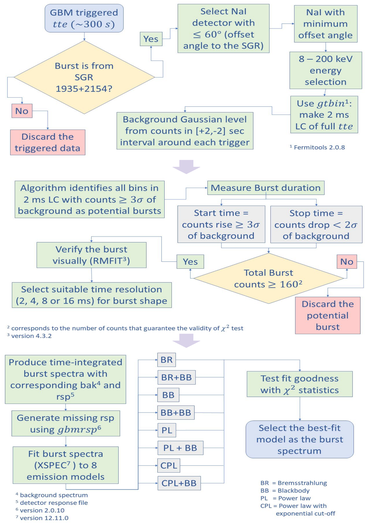


Figure 2: Flowchart of Analysis method followed to analyze SGR 1935+2154 2021-09 burst activity.

Results

- 79 bursts in the 2021 September Activity
- Most bursts are short (Avg. T_{100} = 149.80 ms) and single peaked (~ 84%).

- Burst Duration (T_{100})
  - ranges between 22 – 1424 ms
  - fits to log-Gaussian function
  - has mean of 77.34 ± 1.03 ms.

- CPL and 2BB models are best-fit models. CPL photon index (Γ_{CPL}), CPL peak energy (E_{peak}), 2BB hard and soft temperatures (kT_{BBh}, kT_{BBs}) and 2BB hard and soft region radii[1] (R_{BBh}, R_{BBs}) fit with Gaussian function. Their Gaussian mean are given in Table 1.

- Γ_{CPL} range: -1.27 → +3.16
  E_{peak} range: 12.96 → 63.05 keV.
- kT_{BBh} range: 5.26 → 18.32 keV
  kT_{BBs} range: 1.79 → 9.25 keV
- R_{BBh} range: 0.31 → 15.57 km
  R_{BBs} range: 2.91 → 77.01 km.

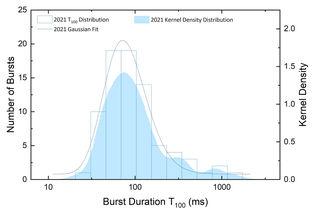
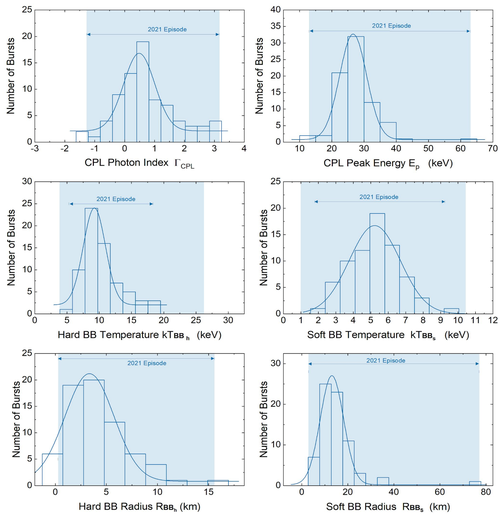


Figure 3: Burst duration (T_{100}) distribution with its Kernel density distribution.

Figure 4: Distributions of CPL and 2BB parameters with their Gaussian fit in 2021-09 activity.



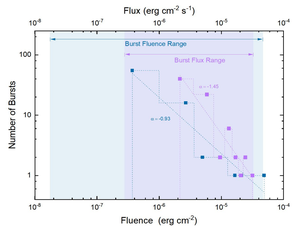


Figure 5: Burst flux and fluence distributions with their ranges in 2021 September activity.

Burst flux and fluence distributions follow power-law behaviour

1. Flux PL index: -1.45 ± 0.27
   range: $2.77 \times 10^{-7} \rightarrow 3.27 \times 10^{-5}$ erg cm^{-2} s^{-1}
2. Fluence PL index: -0.93 ± 0.15
   range: $1.76 \times 10^{-8} \rightarrow 4.66 \times 10^{-5}$ erg cm^{-2}

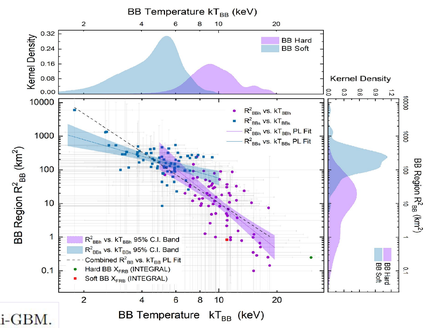


Figure 6: R^2_{BB} vs. kT_{BB} relation of 2021-09 activity with the R^2_{BB} and kT_{BB} kernel density distributions in marginal plots.

There is an anti- correlation between BB areas R^2_{BB} and BB temperatures kT_{BB} in both hard and soft components in 2BB scenario fitted to a PL. The Spearman correlation rank for hard, soft and combined R^2_{BB}- kT_{BB} is r_s = - 0.61 (P = 2.50×10^{-8}), and r_s = - 0.39 (P = 7.39×10^{-4}), and r_s = - 0.81 (P = 1.02×10^{-33}), respectively.

Table 1. Comparison of the SGR 1935+2154 burst episodes over seven years since its discovery, as observed by Fermi-GBM. Results of the first four activities (2014 to 2016) are obtained from Lin et al. (2020b). The two burst episodes during 2016 are denoted 2016a and 2016b. Results of the 2019 – 2020 activities are obtained from Lin et al. (2020c).

SGR 1935+2154 Burst Activities							
	2014 (Jul)	2015 (Feb–Mar)	2016a (May–Jun)	2016b (Jun–Jul)	2019 (Nov)	2020 (Apr–May)	2021 (Sep)
No. of Bursts	3	24	42	54	22	125	79
Duration (log-Gaussian mean)	···	$78.00^{+17.00}_{-14.00}$	$72.00^{+7.00}_{-6.00}$	$128.00^{+11.00}_{-10.00}$	$121.00^{+45.00}_{-33.00}$	$182.00^{+22.00}_{-19.00}$	77.34 ± 1.03
Γ_{CPL} (Gaussian mean)	···	0.18 ± 0.10	0.07 ± 0.05	-0.02 ± 0.26	-0.31 ± 0.89	-0.10 ± 0.12	0.49 ± 0.07
E_{peak} (Gaussian mean)	···	30.00 ± 0.40	33.80 ± 1.30	30.40 ± 0.20	27.00 ± 1.00	26.30 ± 0.70	26.62 ± 0.26
kT_{BBh} (Gaussian mean)	···	11.20 ± 0.30	13.30 ± 0.90	12.10 ± 0.40	13.60 ± 1.30	9.40 ± 2.80	9.24 ± 0.19
kT_{BBs} (Gaussian mean)	···	4.10 ± 0.10	5.40 ± 0.20	5.10 ± 0.10	4.00 ± 0.70	4.50 ± 0.10	5.23 ± 0.11
Average Flux ($\times 10^{-7}$erg cm^{-2} s^{-1})	6.09 ± 1.04	19.84 ± 0.84	23.56 ± 0.75	31.30 ± 0.92	21.40 ± 1.40	18.36 ± 0.22	48.78 ± 0.84
Average Fluence ($\times 10^{-7}$erg cm^{-2})	0.36 ± 0.03	1.73 ± 0.09	3.02 ± 0.13	9.93 ± 0.56	5.82 ± 0.79	6.51 ± 0.16	16.46 ± 0.77
Total Fluence (sum) (erg cm^{-2})	1.10×10^{-7}	4.14×10^{-6}	1.20×10^{-5}	4.56×10^{-5}	1.27×10^{-5}	8.13×10^{-5}	1.28×10^{-4}
Fluence range ($\times 10^{-7}$erg cm^{-2})	$0.15 - 0.62$	$0.13 - 9.48$	$0.02 - 28.84$	$0.06 - 213.12$	$0.17 - 80.40$	$0.17 - 190.00$	$0.18 - 465.65$
Power-law Index:							
Fluence Distribution	···	-0.78 ± 0.01			-0.77 ± 0.01		-0.93 ± 0.15
R^2_{BBh} vs. kT_{BBh}	···	-10.60 ± 1.80			-7.20 ± 1.30		-4.56 ± 0.60
R^2_{BBs} vs. kT_{BBs}	···	···			0.30 ± 1.10		-1.63 ± 0.33
R^2_{BB} vs. kT_{BB}	···	-4.20 ± 0.30			-3.60 ± 0.20		-3.80 ± 0.23

Discussion

The 2021 September activity of SGR 1935+2154 offered a rich burst sample to study both the temporal and spectral properties and comparison with previous activities. No radio emission was observed. Properties of bursts from SGR 1935+2154 observed by Fermi GBM over 7 years offer an opportunity to examine evolution or trends, thanks to the SGR frequent activities and large FOV of Fermi-GBM.

The 2021-09 activity was the most energetic activity since 2014 with a total burst energy release of 1.24×10^{42} erg within ~ 20 days including seven intermediate flares. Examining the evolution of the burst fluence during the past 7 years, a gradual increase is observed during 2014–2020. The burst mean E_{peak} also shows a slight softening during 2014–2021 (see Table 1).

Beloborodov (2009) proposed that a strong global twist on the magnetar surface would have a higher energy release. Such a release could power nonthermal emissions in the magnetosphere and radio emission near the polar regions. We look at the 2021 episode in this scenario and suggest that a strong twist occurred in a small region far from the polar caps, with no radio emission. While the 2020 activity might have a strong twist near the polar cap (Younes et al. 2020), followed by a sudden release of energy in the form of the observed x-ray burst forest and the radio bursts.

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