Fast Gamma-Ray Variability in Solar Flares

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Abstract

Fast Radio Bursts (FRBs) are fast, bright, extragalactic transients, typically associated with magnetars. In early 2021, a very sensitive radio array observed a unique FRB-like event which localized to the Sun. This solar-FRB (sFRB) lasted for only a few milliseconds at 1.4 GHz and had a flux density of 9.1 Mega-Janskys (910 solar flux). This millisecond long sFRB was seen as a "spike" in the radio data, which raises the question, can sFRBs be detected in other wavelengths? Fermi-GBM has a 4 pi steradian field of view of the sky and measures gamma-rays down to 2 microseconds temporal resolution, which makes it the perfect instrument for detecting sFRBs. If such variability were to be found in the Fermi-GBM data, it would provide evidence that this unique energetic process spans multiple 9 orders of magnitude in energy. We performed a blind search of Solar Flares in the Fermi-GBM time-tagged event (TTE) data, binned at 10, 20, and 50 milliseconds in the 5 keV to 20 keV range starting from November 27th, 2012, and ending on April 23rd, 2021. Of the ~3500 solar flares that were examined, no statistically significant gamma-ray emission were detected. We derive upper limit density flux range for the gamma-ray emission to be 0.2 to 0.9 Janskys.

Motivation:

Many FRBs may be associated with magnetars, which are highly magnetized neutron stars. A radio array recently observed a unique Fast Radio Burst (FRB)-like solar event at the frequency of 1.4 GHz. This sFRB was only a few milliseconds long and it had a flux density of 9.1 mega Janskys (910 solar flux). Two flares were also recently studied which seemed to have strong variability in the higher energies. Not many of these solar events have been observed because there are few instruments with such high resolution in the x-ray and gamma-ray energy range. Finding fast time variability in the gamma-ray data of solar flares would prove that this unique energetic processes spans over 9 orders of magnitude in energy.

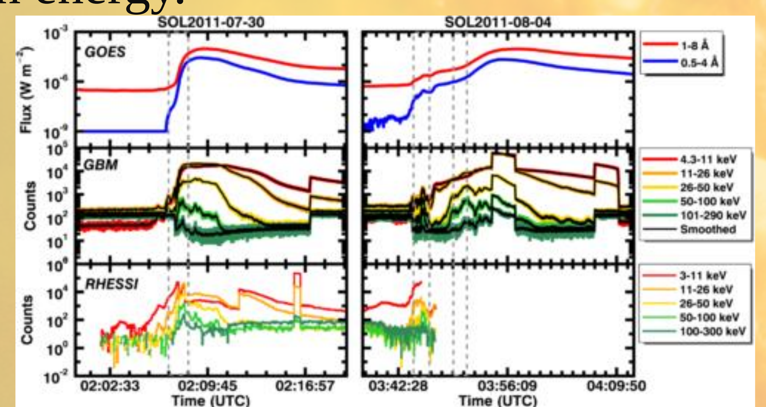

Figure 1.X-ray time profiles of 2 M9.3 solar flares. The dashed gray boxes presents where spikes were observed.

Instrument

The Fermi Gamma-ray Space Telescope is an international and multi-agency space mission launched on June 11th, 2008 that studies the cosmos in the energy range 10 KeV - 300 GeV. It orbits Earth every 96 minutes in a 26° inclination orbit at an altitude of 535 km. The data we used is time tagged events data from the fermi Gamma-ray Burst Monitor (GBM) which has 2 sets of detectors: 12 sodium iodide (NaI) scintillators and 2 cylindrical bismuth germanate (BGO) scintillators. The NaI detectors are sensitive in the lower end of the energy range, from a few KeV to about 1 MeV and provide burst triggers and locations.

Methods:

Individual photon data from Fermi GBM was used with resolution of 2, for the 6 sunward-facing Fermi-GBM detectors were summed together to carry out this analysis. The data was binned to 10, 20, and 50 milliseconds and averaged over 50 bins. We looked at solar flares in the 5.0 KeV to 20 KeV energy range. The solar flare residuals were then plotted to look for statistically significant "spikes". We calculated a moving standard deviation using Poisson statistics and only kept candidates with a significance above 4 sigma. To test if a spike is real, and not just a detector artifact, a second test of plotting each detector individually was conducted. Finally, we calculated upper limits on the energy flux of our solar flare data. The data was then fitted with a Poisson distribution module to calculate the statistical significance.

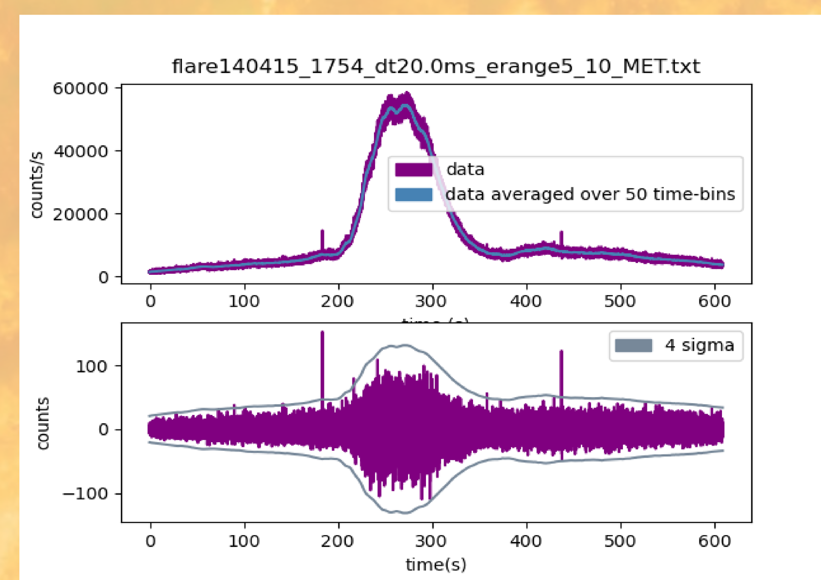

Figure 2. Solar Flare data binned to 20 ms in the energy range 5.0-10.0 KeV and the residual. The gray line showes the 4 sigma detection.

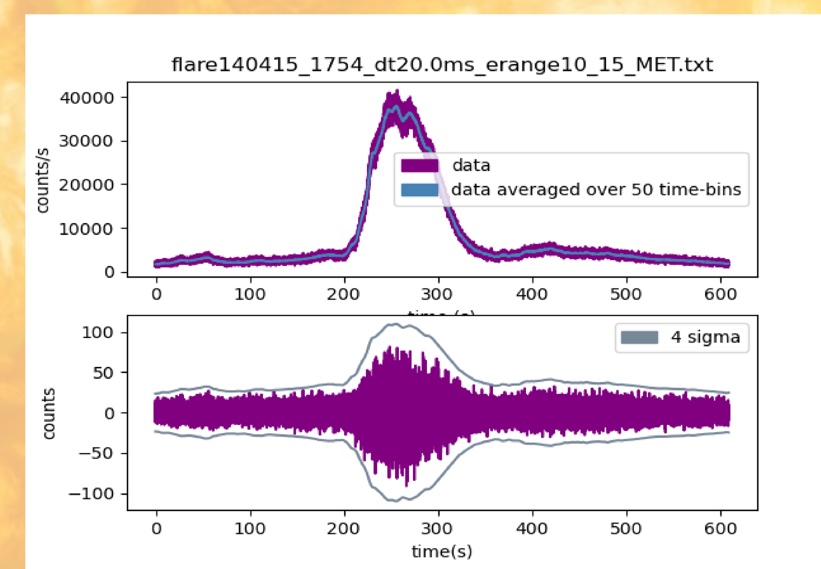

Figure 3. Solar Flare data binned to 20 ms in the energy range 10.0-15.0 KeV and the residual. The gray line shows the 4 sigma detection.

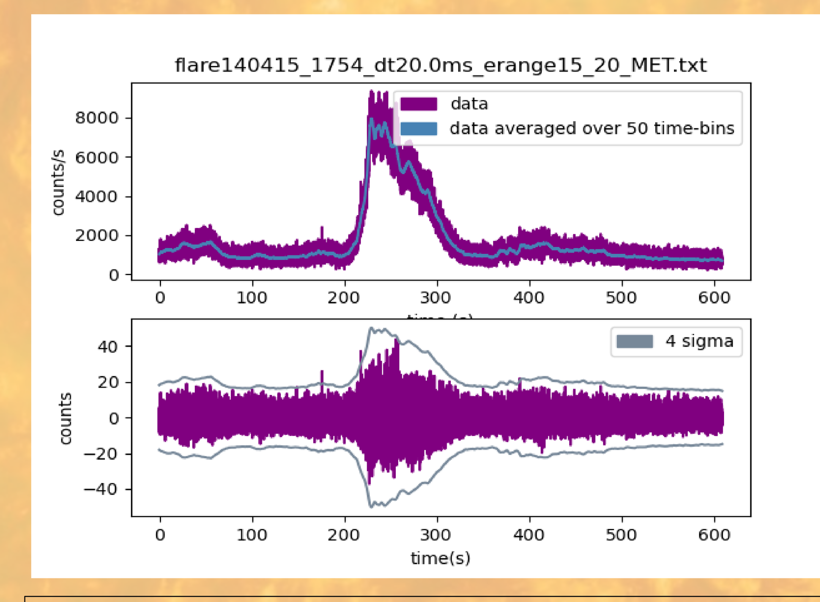

Figure 4. Solar Flare data binned to 20 ms in the energy range 15-20.0 KeV and the residual. The gray line shows the 4 sigma detection.

Results:

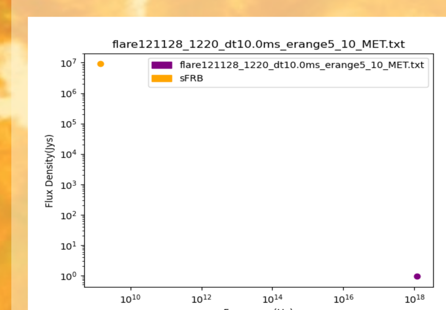

Figure 6. Flux density over frequency of gamma-ray emission data and the sFRB.

Potential spikes were found in 48 solar flares, all in the 5 to 10 keV energy range. Further examination showed that these spikes were present only in the data of single detectors, which is not consistent with a solar origin. This could be due to the excited long-lived glow caused by high-energy cosmic rays hitting the NaI detectors causing radioactive- decay and thus producing gamma-rays. Although, a true gamma-ray flare could be concentrated in one detector because the detectors are directional. We derived an upper limit of energy flux ranging from 0.2 to 0.9 Jansky.

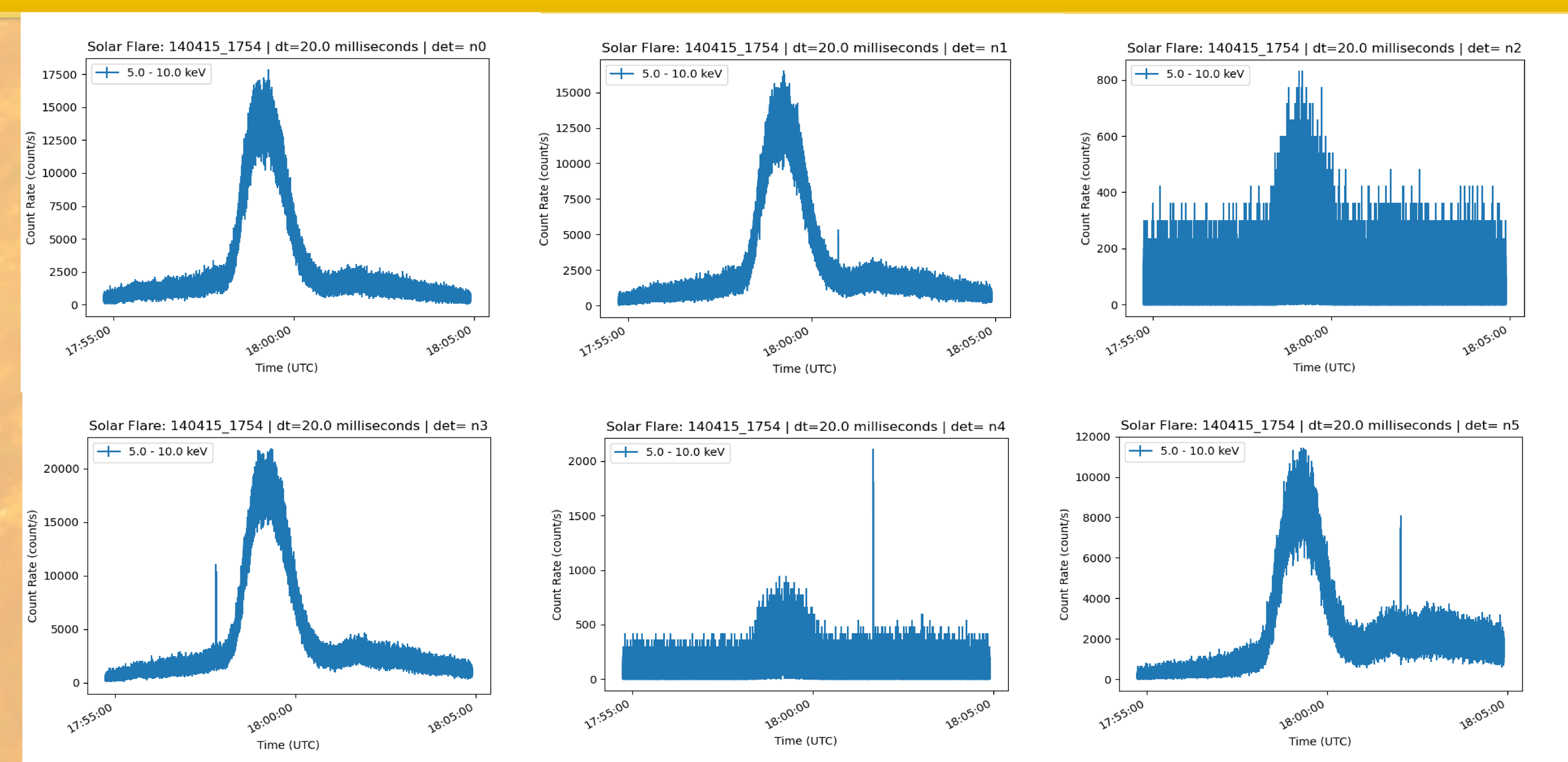

Figure 5. Solar Flare data binned to 20 ms in the energy range 5.0-10.0 KeV from 4 different NaI detectors.

Future work:

Analyze data in the radio band to find FRBs. Get reference time of solar flares that have anything interesting in them(potential spike). Then, go back to the gamma ray data to analyze it during the reference time and search for fast variability.

References:

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