

Introduction

Over the 14 years, GBM has produced the largest database of all-sky observations in gamma rays with high time resolution continuous data which contain a wealth of relatively weaker short transient events that did not trigger the detectors. These short gamma-ray transient events can arise from several different astrophysical origins and scenarios such as GRBs, thermonuclear bursts from accreting neutron star systems, bursts from magnetars.

Identification and investigation of untriggered events is crucial towards fully understanding the physical mechanisms responsible for the observed bursts. To this end, we performed a deep search for gamma ray transients in the *Fermi* GBM database, identification of the detected transient events, and investigations of statistical properties of the identified events, especially magnetar outbursts.

Search Methods and Modes

The search in the GBM CTTE database was done using three independent methods:

1. Poisson statistics based ($\leq 10^{-4}$),
2. Signal-to-noise-ratio based ($\geq 4.5\sigma$),
3. Bayesian statistics based.

Each method has four different modes with different time and energy resolution, targeting different types of events.

Mode	Targeted Class	Time Resolution (ms)	Energy Range (keV)
1	SGR	8	10-100
2	LGRB & Transients (<10 s)	512	10-300
3	SGRB & TGF	16	50-1000
4	SFL & Transients (>10 s)	2048	10-25

Filtering

We filtered out false event identifications caused by the spacecraft's orbits (before and after the SAA passages) as well as known triggered events or Solar flares (SFL).

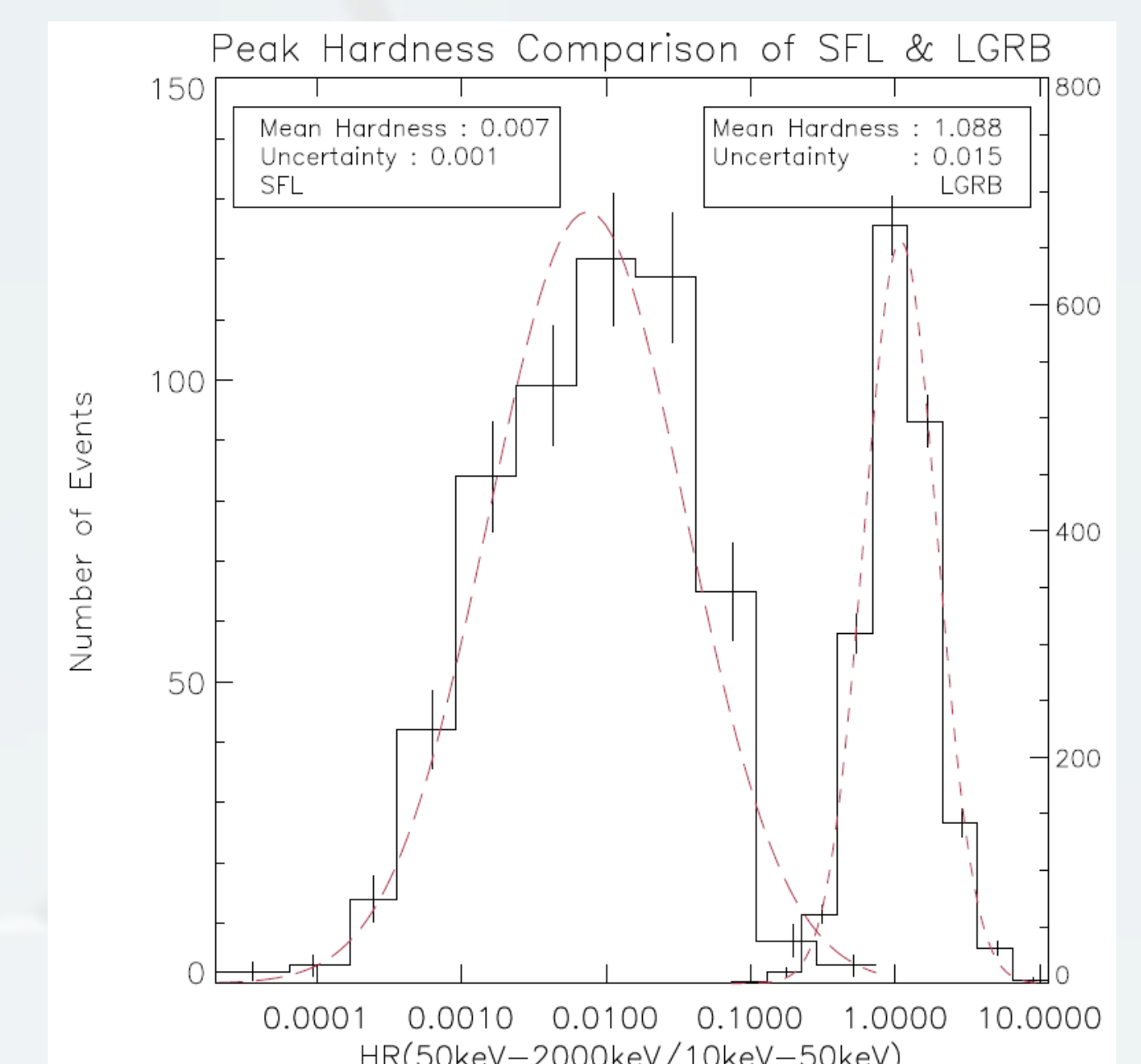
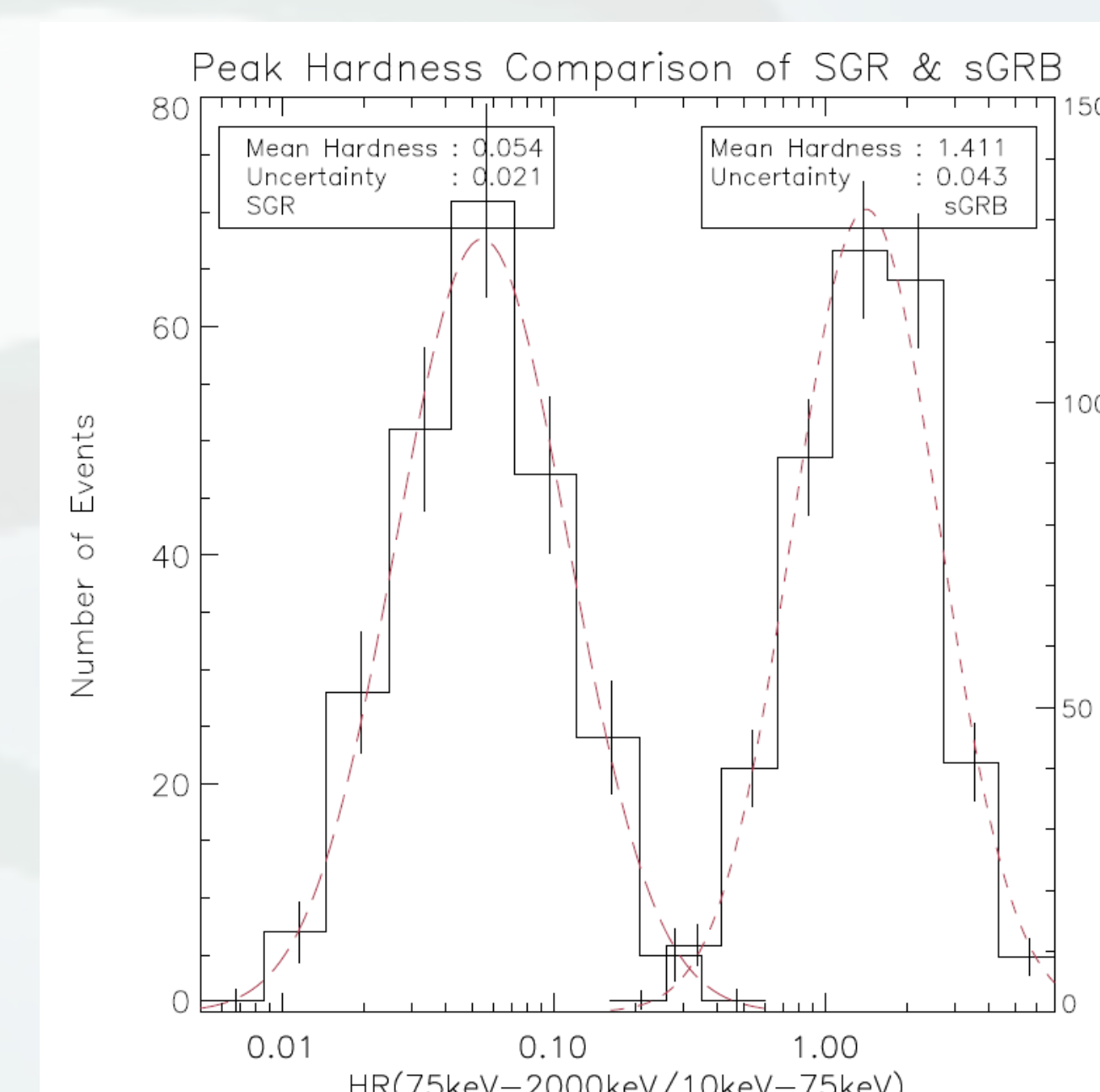
- False Detections: Identification of false detections that occurred within ± 60 s of SAA passages
- Known Events: The search event must coincide both in time and space (direction) with the known event.

Duration and Spectral Hardness for Classification Properties

The durations of *Fermi*/GBM triggered events were calculated via Bayesian Block (BB) method, and the duration distribution of each class was obtained. Then, burst types were divided into two categories:

- Short ($\lesssim 2$ s; SGRB, SGR, TGF) events and
- Long ($\gtrsim 2$ s; LGRB, SFL, TRANSNT) events.

Spectral hardness was calculated at the peak of each trigger in the energy range of 10-2000 keV as simply the ratio of background subtracted counts in hard and soft different energy bands.



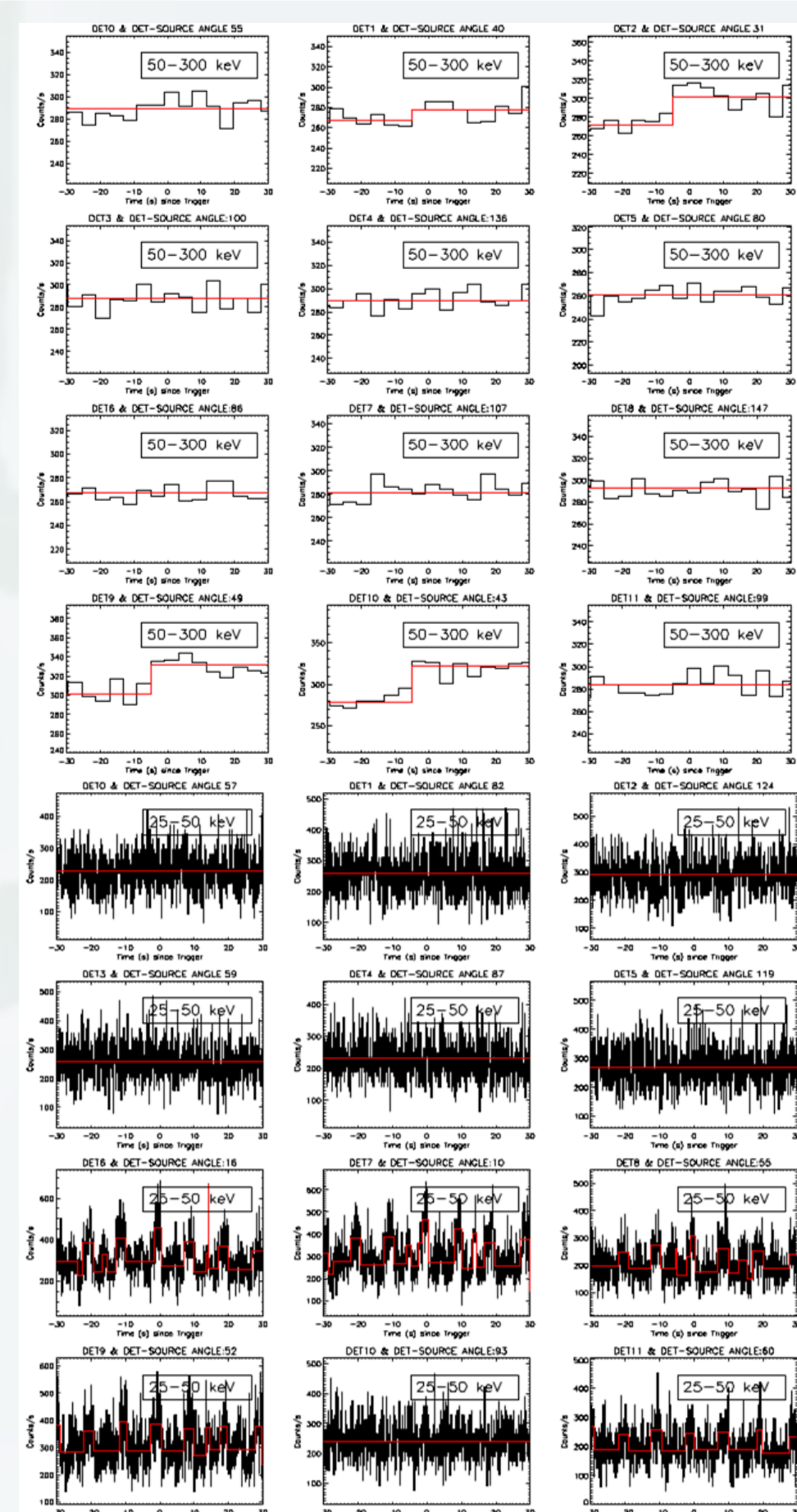
The least overlap in the hardness distributions of different event classes was obtained when we used 50 keV and 75 keV as breaking (pivot) points between the soft and hard energy bands for short- and long-lasting events, respectively.

Detections due to Pulsations and Earth Occultations of Astronomical Sources

We studied *Fermi*/GBM triggers due to pulsations and Earth occultations of known sources and found a way to distinguish these detections in untriggered-event searches.

[TOP]: TRANSNT18040755 from IGRJ 18245-2452. Red lines represent BBs. The detectors that observe the source with the smallest angles show an increase in the count rates and the change point of BB representations coincides with the rise time of the source.

[BOTTOM]: TRANSNT171102658 from the outburst of Swift J0243.6+6124. Red lines represent BBs. Trigger time falls under the outburst period of the source and detectors (6&7) that observe pulses from source with the smallest angles are triggered.

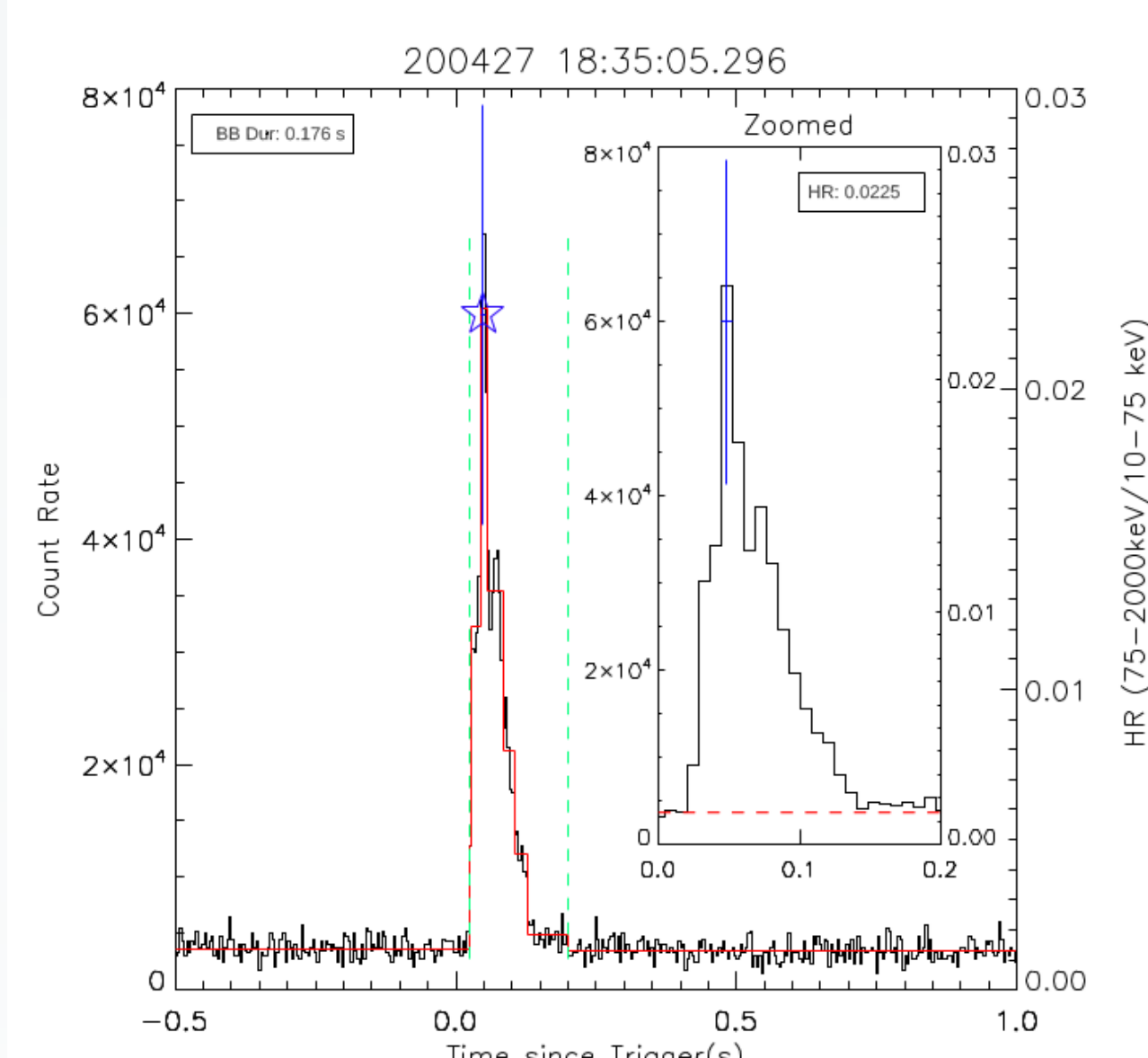


Bayesian Probability for Classification of Unidentified Events

- Prior Probability: We listed the events that were triggered the *Fermi*/GBM by the algorithms similar to our search modes and found the number of events in each class.
- Posterior Probability: We determined BB duration and hardness ratio of each of the events in our search, then used the distributions of duration and hardness ratio of *Fermi*/GBM triggered events for each class to calculate the likelihood and determined the posterior probability for the event belonging to a specific class.

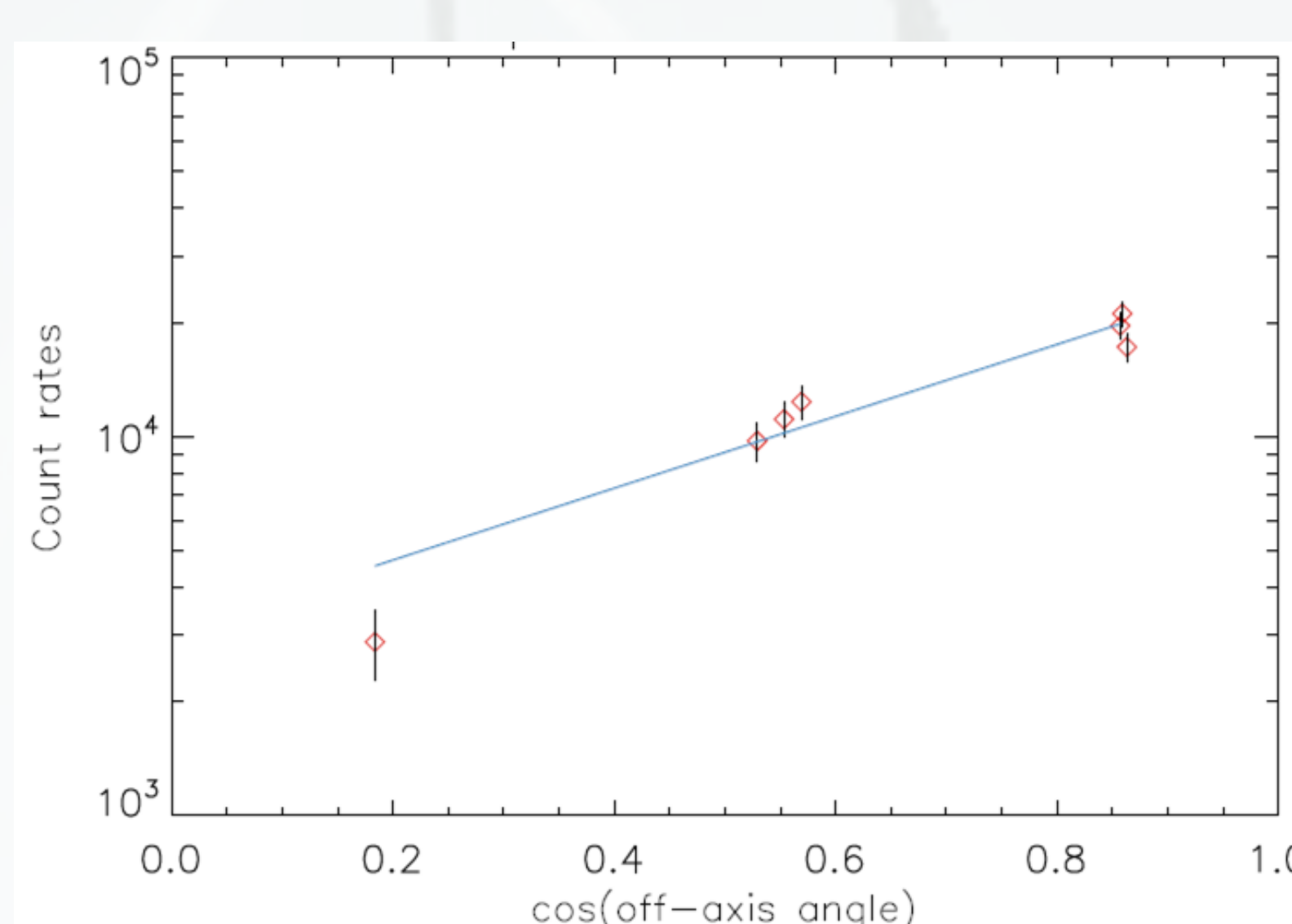
Localization and Source Identification of Events

We looked for a positive correlation between the cosines of the detector-to-source angles and the corresponding peak count rates (in log scale) of all detectors with $\theta < 90^\circ$ with linear fits to make a rough localization.



An example of untriggered burst that we detected with the first mode of all methods, classified as SGR with Bayesian probability algorithm and localized in the direction of SGR 1935:

The red solid lines indicate BBs. The blue star shows the peak hardness. The green vertical dashed lines show the duration interval. Inside panel zooms into the duration interval and shows the peak hardness value with its error. The red dashed lines show the background level.



X-axis shows the cosines of det-to-source angles (angles between the detector's zenith and SGR 1935) less than 90° . Y-axis shows the peak count rates of corresponding detectors in log scale. Linear fit results indicate that the burst is in the direction of SGR 1935.

Our extensive search results, identification and classification of the untriggered events, and their temporal/spectral characteristics are available at:

magnetars.sabanciuniv.edu

- [1] Jeffrey D. Scargle 1998 *ApJ* **504** 405
- [2] Jeffrey D. Scargle *et al* 2013 *ApJ* **764** 167
- [3] A. von Kienlin *et al* 2020 *ApJ* **893** 46
- [4] P. A. Jenke *et al* 2016 *ApJ* **826** 228
- [5] A. C. Collazzi *et al* 2015 *ApJS* **218** 11
- [6] O.J. Roberts *et al* 2018 *JGR Space Physics*, 123 5

