

# A Proposal to Localize Fermi GBM GRBs Through Coordinated Scanning of the GBM Error Circle via Optical Telescopes

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We investigate the feasibility of implementing a system that will coordinate ground-based optical telescopes to cover the Fermi GBM Error Circle (EC). The aim of the system is to localize GBM detected GRBs and facilitate multi-wavelength follow-up from space and ground. This system will optimize the observing locations in the GBM EC based on individual telescope location, Field of View (FoV) and sensitivity. The proposed system will coordinate GBM EC scanning by professional as well as amateur astronomers around the world. The results of a Monte Carlo simulation to investigate the feasibility of the project are presented.

## 1. Introduction

Gamma-ray bursts (GRB) are bursts of gamma-rays that arguably signal the birth of a black hole somewhere in the universe. Based on the duration and spectrum, two classes of bursts have been observed [Kouveliotou et al. 1993]: those that last less than two seconds and have on the average hard spectra (short GRBs), and those that last longer than two seconds and are spectrally softer (long GRBs). The exact nature of the GRB progenitors is unknown, although it is possible that long GRBs come from the collapse of massive, rapidly rotating stars [Woosley et al. 2006, Woosley & Bloom 2006] and short GRBs result from the merger of compact objects [Eichler et al. 1989, Narayan et al. 1992]. Regardless of the progenitor system, accretion onto the resulting compact object is thought to create a highly relativistic jet. The prompt gamma-ray emission from the GRBs may arise from the internal shocks due to collisions of faster shells with slower ones ejected earlier by the central engine. The subsequent softer multi-wavelength emission, referred to as the afterglow, may be due to the collision of the fireball with the extra-stellar material [Piran et al. 1999, Rees & Meszaros 1994].

Our understanding of GRBs progressed very rapidly after the detection of multi-wavelength afterglows. Well localized, favorably positioned GRBs get fairly good multi-wavelength afterglow coverage. Currently, the leading GRB afterglow detection mission is *Swift* which detects 90–100 GRBs annually. Most of the *Swift* GRBs get observed by various instruments around the world because of its rapid arc-minute localization capability. Compared to *Swift*, *Fermi* Gamma-ray Burst Monitor (GBM) detects about 250 burst per year but with poor localization. The Error Circle (EC) of *Fermi* GBM detected bursts is

too large for a single telescope to observe effectively. The typical statistical uncertainty of the GBM burst location is about 3.3 degrees. However, when combined with the systematic uncertainty of 3.8 degrees [Briggs et al. 2009], the total burst location uncertainty is  $\sim 5.0$  degrees (i.e., 5.0 degree error radius). Naturally, a brighter burst will have a smaller GBM EC than a weaker burst.

Even though the localization is poor, GBM detected bursts have very good timing and spectral information including crucial  $E_{\text{peak}}$  measurements ( $E_{\text{peak}}$  is the peak energy of the GRB  $\nu F_{\nu}$  spectrum). If there is a method to localize GBM detected GRBs to a few arc-seconds uncertainty, then large telescopes can do deeper follow-up observations to determine the redshift of the burst and also potentially identify any emerging supernova. In addition, *Swift* can also slew quickly to the GBM burst in order to observe the X-ray afterglow and obtain its light curve in X-ray wavelengths.

Based on *Swift* observations about  $\sim 60\%$  of GRBs have optical counterparts [Gehrels et al. 2009]. These optical counterparts are detected by various observatories with R magnitudes ranging from 14 to 22 within few hours after the burst [Fiore et al. 2007]. Thus, it is reasonable to assume about 60% of the GBM detected GRBs also have optical counterparts with similar brightness distribution. If we were able to cover the entire GBM EC within about 24 hours after the burst it is conceivable that we would be able to find optical afterglows of  $\sim 150$  GRBs per year, which is more than the total number of burst *Swift* detects per year.

Due to the small energy range (15-150 keV) of the *Swift* Burst Alert Telescope (BAT), *Swift* measurements alone cannot constrain the  $E_{\text{peak}}$  of all BAT detected bursts [Sakamoto et al. 2009]. In contrast, due

to the wide energy range (8 keV - 40 MeV) of GBM, all GRBs detected by GBM have fairly good  $E_{\text{peak}}$  measurements. Hence, addition of possibly another  $\sim 100$  bursts per year with good  $E_{\text{peak}}$  and redshift measurements may allow us to explore the validity of various GRB luminosity relations and to conduct detailed GRB Hubble diagram studies.

We have investigated the feasibility of using a system to do coordinated monitoring of the BAT field-of-view (FoV) for prompt optical emission from GRBs [Ukwatta et al. 2011]. The study showed that with the current instrumentation, performing such a coordinated monitoring is not practical mainly due to the BAT's very large FoV. However, a similar coordinated observing campaign can be used to find the optical afterglow of GBM detected bursts. The GBM EC is much smaller than the BAT FoV and observers do not need to continuously monitor the field to detect the optical afterglow. This enables a given observatory to perform multiple observations inside the GBM EC and thereby increase the chance of an afterglow detection.

## 2. Method and Feasibility

The basic proposal is to design a system to facilitate scanning of the GBM EC for optical emission from GRB afterglows. This observing program will be specially aimed at amateur astronomers around the world. Proliferation of amateur telescopes with high quality CCD cameras has opened a new avenue to study optical emission from GRBs. The basic objective of the system is to coordinate a significant number of ground based telescopes to scan different patches of the GBM EC in order to find the location of the optical afterglow. Unlike the GCN system [Barthelmy et al. 1998] which sends notices to large number of recipients, this system will send customized targeted messages to individual registered telescopes. These individual messages will be sent via email or socket connections and they will have one or more assigned pointing locations for each telescope. The target telescopes can be either robotic or non-robotic. The selection of various patches in the GBM EC will be done based on the number of available telescopes, individual telescopes' physical location, Field of View (FoV) and sensitivity. It is also reasonable to assume that these telescopes can observe multiple patches of the GBM EC, which will increase the chances of detection significantly.

Some of the important impacts of the proposed project are:

1. The project will significantly enhance the value of GBM as a GRB discovery instrument.
2. Potentially increase the number of burst with

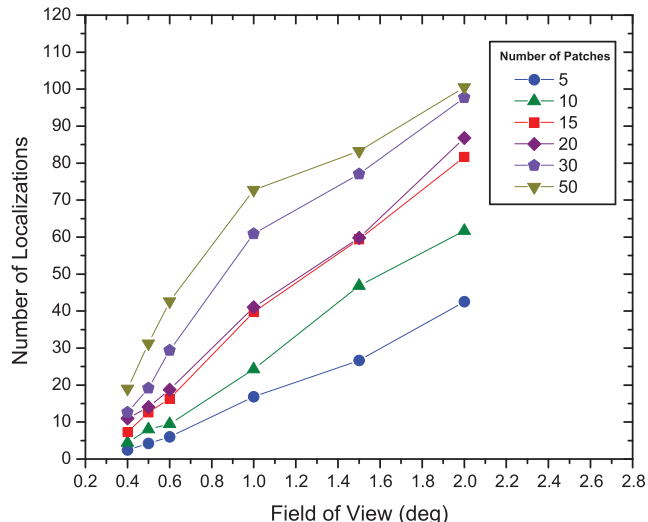


Figure 1: The number of localized bursts as a function of the FoV for 25 participating telescopes. Various curves corresponds to different number of observations (or number of patches) a given telescope can perform.

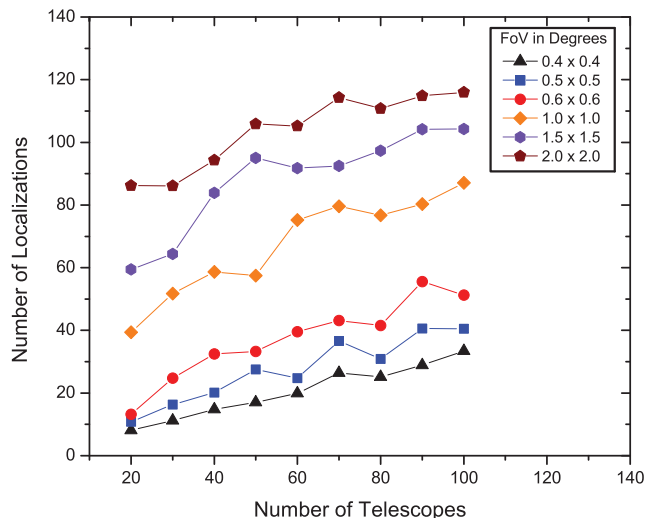


Figure 2: The number of localized bursts as a function of number of participating telescopes in the program assuming each telescope can observe 20 patches.

good timing, spectral and redshift measurements.

3. The project will allow and attract the participation of amateur astronomers and their telescopes.

In order to investigate the feasibility of the project, we performed a Monte Carlo simulation to study the probability of detection of optical afterglows from *Fermi* GBM GRBs. We assumed that GBM detects about 150 GRBs with optical afterglows (total rate is 250 per year) per year distributed isotropically in the sky and throughout the year. We have distributed

telescopes in such a way that they roughly trace the major cities in the world. Then for each burst we tracked the path of the Sun and selected a set of telescopes away from the Sun and within few hours from the burst location to scan the GBM EC. We also calculated the illuminated fraction of the Moon's disk ( $f_{\text{moon}}$ ) at the time of each burst. The probability,  $P$ , of finding a GRB was estimated by

$$P = 1 - (1 - p)^n. \quad (1)$$

Here  $n$  is the total number of independent attempts to observe, with probability of success,  $p$ . In this case  $n$  is equal to the product of number of available telescopes and number of patches each telescope can observe. We calculated the probability of success, i.e., the probability of detecting a given burst afterglow per observation using the following equation.

$$p = \frac{\text{Tel. FoV Solid Angle}}{\text{GBM EC Solid Angle}} \times (1.0 - f_{\text{moon}}) \times 68\%. \quad (2)$$

Note that typically the one  $\sigma$  GBM EC is  $10.0^0 \times 10.0^0$ . We repeated this procedure for every simulated burst, while changing the total number of telescopes participating in the program, the FoV of telescopes, and total number of patches a given telescope can cover.

The results of our simulation are shown in Figure 1 and Figure 2. For these particular simulations we have assumed that all the telescopes have the same FoV and all telescopes can cover some constant number of patches in the GBM EC. Furthermore, we assumed that these telescopes will be able to observe assigned sky patches within a few hours after the burst. Hence, in the simulation we used only telescopes which are within a few hours ( $\sim 6$  hours) of the burst location. The number of participating telescopes in the observing program was varied from 20 to 100.

Figure 1 shows the number of localized bursts ( $P \times$  Total Number of Bursts) as a function of the FoV of participating telescopes. Here we have fixed the number of participating telescopes to 25. Various curves correspond to different number of patches that each telescopes can observe. Figure 2 shows the number of localized bursts as a function of number of participating telescopes in the program assuming that each telescope can observe 20 patches. The six curves shown in the plot correspond to various field of views. According to the simulation, with 60 telescopes participating it is possible to detect about 40 GRB optical afterglows per year using telescopes with FoV of  $0.6^0 \times 0.6^0$ . This value is close to the value of a typical FoV of an amateur telescope. It is also interesting to note that if we have about 10 telescopes participating with FoV of  $1.0^0 \times 1.0^0$ , then it is possible to detect about 25 GRB afterglows per year. In order to put these values into perspective we point out that thus far, no one has managed to observe optical afterglow of a GRB based only on a GBM localization (the GBM has been detecting GRBs for more than three years).

It is also worth noting that not all the GBM locations will have a statistical error of 3.3 degrees. About a third of the GRBs will have a statistical error less than this value. About 10% will have error of 1 degree or less. In such cases the GBM EC radius will be less than 5 degrees and may be as small as 4 degrees. Obviously, for those cases we have a much higher chance of detecting the afterglow.

A schematic block diagram of a potential software system is shown in the Figure 3. The system has two components: 1) a Scheduling System that will assign various observing patches to participating telescopes, and 2) a Online System that will let observers to upload their images and search for candidate transients.

The algorithms in the Scheduling System will check the GBM EC observability of each participating telescope and assign them to different parts of the GBM EC. In doing this the algorithm will consider individual telescopes' FoV, sensitivity and local weather conditions. In addition, it will also assign more than one patch for each astronomer. On average an amateur astronomer may receive about 40 notices per year. The exposure time for each patch depends on many factors such as aperture, seeing, type of CCD camera etc and typically may vary from 1 to 30 mins. The probability of success depends on the telescope configuration (FoV, sensitivity), local weather and sky conditions, and the number of patches observed. However, every amateur observer who submits an observation to the system will get credit for their effort by being a co-author of the subsequent GCN notice that results from a successful detection.

The Online System is envisioned to have a web interface where the participants can submit their observations. It will also have online tools that will compare the submitted observations with existing catalogs and search for the optical afterglow of the GRB. If one of the observations has a positive detection then the system will initiate a follow-up observation to establish whether the candidate source is fading. If the candidate is found to be fading (telltale signature of a GRB afterglow) then the magnitudes of the two images will be determined and a GCN circular will be sent.

### 3. Summary and Conclusions

We investigate the feasibility of implementing a system that will coordinate ground based telescopes (both amateur and professional) to scan the GBM EC in order to localize GBM bursts. Unlike the GCN system, proposed system will send individual customized messages to telescopes to observe certain patches in the GBM EC. The scientific objective of the system is by localizing GBM detected burst, we will be able to increase the number of GBM bursts with multi-wavelength followups potentially with redshifts measurements. These measurements are scientifically very

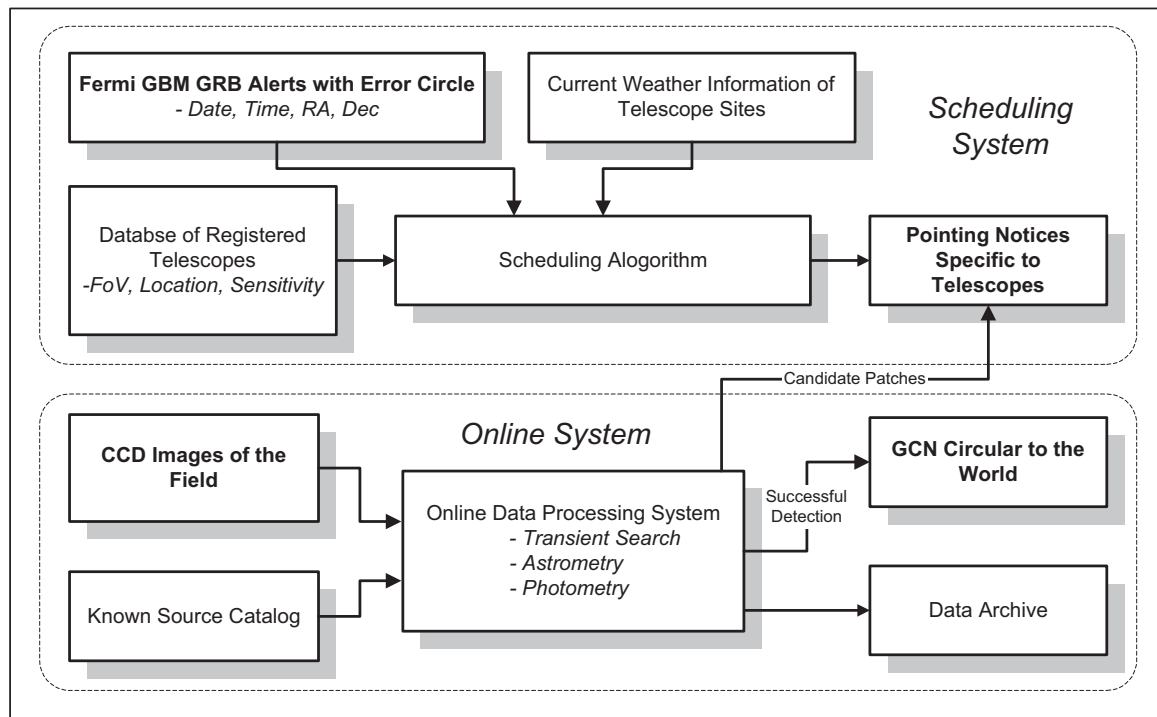


Figure 3: Schematic block diagram of a potential system to localize GRB bursts.

important because there are hints that GBM bursts may represent significantly different burst population. Based on our simulation, we can detect about 25 GRB afterglows per year using just 10 telescopes with  $1.0^0 \times 1.0^0$  field-of-view. With more telescopes participating in the program, we should be able to detect many more afterglows and study a potentially interesting burst population that is currently inaccessible to the GRB community.

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