



The Trigger and Localization System of SVOM-GRM

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Abstract

The Space multi-band Variable Objects Monitor (SVOM) is an astronomical satellite jointly developed by China and France, primarily focused on the detection of gamma-ray bursts (GRBs) and transient sources. The SVOM satellite was launched on 2024 June 22, with four payloads installed onboard. As one of payload, Gamma-Ray Monitor (GRM) comprises three gamma-ray detectors (each detector has an effective area of approximately 200 cm²) with distinct pointing directions, enabling the temporal and spectral measurements as well as localization of GRBs in the energy range of 15–5000 keV. This article first introduces the on-board localization algorithm design for GRM and presents preliminary test results. Then, leveraging abundant ground-based computational resources, a joint fitting method for spectral and localization analysis using Monte Carlo Markov Chain (MCMC) is implemented. In contrast to the on-board localization algorithm, the on-ground MCMC method comprehensively considers the influence of spectral characteristics, thereby mitigating systematic biases. Finally, a systematic analysis based on this method is provided, highlighting the localization and spectral measurement capabilities of GRM. The preliminary localization analysis result for the on-board detected GRB 240629A by both GRM and Fermi/GBM shows that the localization result (error $\sim 4.14^\circ$) of GRM is consistent with the Fermi/GBM result.

Key words: (stars:) gamma-ray burst: general – methods: data analysis – instrumentation: detectors

1. Introduction

Since their discovery, gamma-ray bursts (GRBs) have been studied for over five decades (Klebesadel et al. 1973; Gehrels et al. 2009). Research on GRBs holds substantial importance in realms encompassing particle acceleration mechanisms, radiation mechanisms, and constraints on cosmological parameters (Zhang 2011, 2018).

The current operational satellites, such as Swift, Fermi, INTEGRAL, Insight-HXMT and GECAM have generated a wealth of commendable results, including the discovery of the correlation between GRB 170817A and gravitational wave GW170817 (Abbott et al. 2017; Goldstein et al. 2017; Li et al. 2018), the thermal components of GRBs (Guiriec et al. 2011), and the brightest GRB (GRB 221009A) of all time (An et al. 2023; Lesage et al. 2023; Zhang et al. 2024a, 2024b, 2025). The Sino-French collaborative multi-band astronomical observation satellite, Space multi-band Variable Objects Monitor (SVOM), features onboard triggering and localization capabilities. SVOM can transmit trigger and localization information to ground in real-time by using the Very High Frequency (VHF; Lacour 2018) or BeiDou short messages, guiding ground-based telescopes for follow-up observations. The collaborative observation efforts of SVOM with other instruments such as IceCube (IceCube

Collaboration et al. 2006), LIGO (LIGO Scientific Collaboration et al. 2015), will herald an exciting era of multi-messenger observations of GRBs.

The capability to trigger and locate GRBs represents a key scientific requirement for SVOM. SVOM comprises four instruments, among which Eclairs and Gamma-Ray Monitor (GRM) possess on-orbit triggering and localization abilities, operating within the 4–100 keV and 15–5000 keV energy ranges respectively. This article primarily concentrates on the triggering and localization capabilities of GRM (Zhao et al. 2013; He et al. 2025). Given the limited computing resources and the need for rapid trigger and localization results, the primary method for on-orbit localization involves traversing tables to calculate chi-square values, as detailed in Section 3. Compared with on-orbit localization, offline localization using scientific data has a certain time delay, but can achieve better results. In Section 4, a location method based on Bayesian probability is introduced, and the expected localization ability of GRM is demonstrated through simulation.

2. An Introduction of GRM

The GRM consists of three Gamma-Ray Detectors (GRDs), one GRM Particle Monitor (GPM), and one GRM Electronic

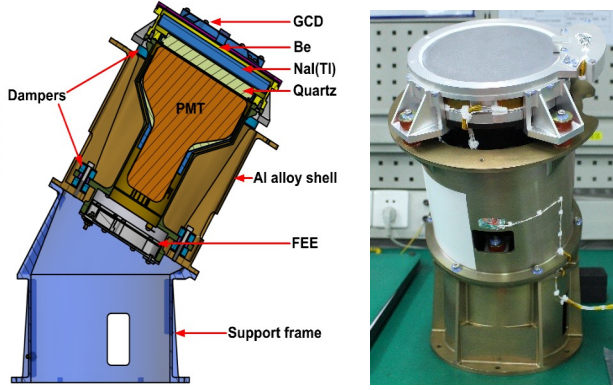


Figure 1. The schematic diagram of the GRD structure of the SVOM satellite.

Box (GEB). The optical axes of the three GRDs are oriented at an angle of 30° relative to the $+Z$ -axis direction, with their projections onto the X - Y plane separated by mutual azimuthal angles of 120° to ensure full-sky coverage. Each GRD detector is equipped with a NaI(Tl) scintillator crystal, 16 cm in diameter and 1.5 cm in thickness, operating over an energy range of 15 keV–5 MeV. Figure 1 is the GRD's structure, for further details on the GRM instrument's design and performance specifications, refer to the corresponding references (Sun et al. 2026).

3. Introduction of On-orbit Triggering and Localization

3.1. Triggering and Localization Process

The GRM employs a count rate trigger algorithm operating across distinct energy bands and time windows. As shown in Figure 2, the onboard software calculates the observed photon counts N_s within a selected energy band (e.g., 15–50 keV) over a specified integration time T_s . Simultaneously, it estimates the background counts N_b using the same energy band from a preceding interval T_b . The signal-to-noise ratio (snr) for each GRD is derived using equation:

$$\text{snr} = \frac{N_s - \frac{N_b \times T_s}{T_b}}{\sqrt{\frac{N_b \times T_s}{T_b}}}, \quad (1)$$

as defined in Equation (1). Trigger conditions are met only when the snr values from at least two GRDs simultaneously exceed predefined thresholds. The algorithm incorporates three configurable timescales (0.1 s, 1 s, and 4 s) and four adjustable energy bands: 15–50 keV, 50–300 keV, 300–1000 keV, and 1000–5000 keV. These parameters can be updated in-flight to optimize sensitivity for different astrophysical transients while minimizing false triggers caused by background fluctuations.

The localization procedure post-triggering is summarized in Figure 3. When only two GRDs exceed the snr threshold, the

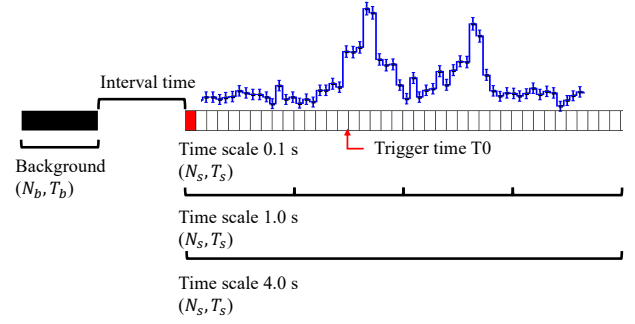


Figure 2. The schematic diagram of trigger calculation, where N_s and N_b correspond to the counts under trigger timescale T_s and background timescale T_b respectively. The T_b timescale and the interval time are adjustable.

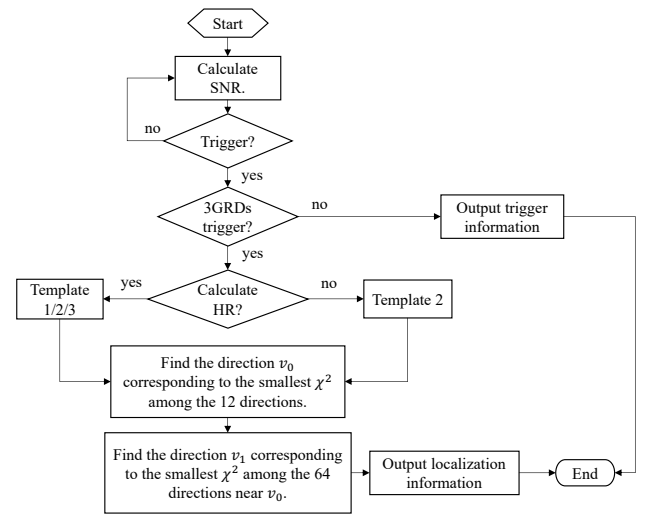


Figure 3. GRM in-orbit triggering and localization workflow.

Table 1
Parameters of Three Typical Hardness Spectra

Template	Model	α	β	E_{peak} (keV)
1	Soft	−1.9	−3.7	70
2	Medium	−1.0	−2.3	230
3	Hard	0	−1.5	1000

system records trigger information (time, energy range, snr) without localization information. Localization are activated only when all three GRDs exceed the threshold. The software supports command-toggled hardness ratio calculations, defined as the count ratio between 15–50 keV and 50–300 keV. If disabled, precomputed reference templates 2 (see Table 1) are used to compute the χ^2 statistic:

$$\chi^2 = \sum_{d=0}^2 \sum_{c=0}^1 \frac{S_{d,c} - f \cdot T_{d,c}}{S_{d,c} + B_{d,c}}, \quad (2)$$

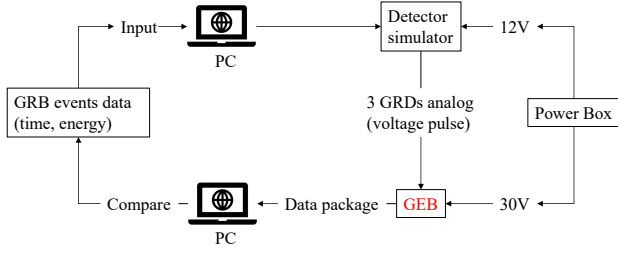


Figure 4. GRM ground test system schematic for validating in-orbit triggering and localization functions.

where the normalization factor f is derived from:

$$f = \frac{\sum_{d=0}^2 \sum_{c=0}^1 S_{d,c}}{\sum_{d=0}^2 \sum_{c=0}^1 T_{d,c}}. \quad (3)$$

The detector index d (0: GRD01, 1: GRD02, 2: GRD03) and energy channel c (0: 15–50 keV, 1: 50–300 keV) jointly define the background counts $B_{d,c}$, background-subtracted observed counts $S_{d,c}$, and simulated template counts $T_{d,c}$ derived from lookup tables.

The template tables contain six columns, corresponding to the two energy channels across three GRDs. Each row represents a distinct incident direction, with 12 coarse (Healpix NSIDE = 1, angular resolution $\sim 60^\circ$) and 768 fine (Healpix NSIDE = 8, resolution $\sim 7^\circ$) directional bins. Templates were generated via Geant4 simulations using three Band function spectral parameter sets (Table 1), corresponding to distinct hardness.

3.2. Results of Triggering and Localization Testing

The GRM triggering and localization algorithms were validated through comprehensive ground-based software testing. As shown in Figure 4, the test framework simulates GRM’s operational pipeline:

1. *Data Generation.* GRB signals and background noise were simulated using Geant4, with each simulated event containing precise timing and energy (15–5000 keV) information.
2. *Signal Emulation.* The simulated events were converted into analog voltage pulses via a detector simulator (Shi et al. 2022).
3. *Onboard Processing.* The GEB electronics digitized these pulses, executed real-time trigger logic, and localization calculations upon three GRD triggers.

Based on different GRB templates and flux, we produced 52 GRB datasets using the Geant4. All 52 GRBs are capable of generating trigger packets, and the triggering moment occurs within 20 s after 100 s (with the GRB starting at 100 s), indicating that the triggering function is normal. Subsequently, we choose one GRB template to simulate data incidence from

Table 2
Localization Results from Different Angles Incident

Azimuth (deg)	Zenith (deg)		
	15	30	45
0	(17.6, 345.0)	(29.6, 351.0)	(48.2, 5.6)
60	(17.6, 75.0)	(35.7, 67.5)	(48.2, 61.6)
120	(11.7, 112.5)	(23.6, 123.7)	(41.9, 109.3)
180	(17.6, 165.0)	(29.6, 171.0)	(48.2, 196.9)
240	(11.7, 247.5)	(29.6, 243.0)	(48.2, 241.9)
300	(17.6, 285.0)	(29.6, 279.0)	(48.2, 309.4)
	60	75	90
0	–	(80.4, 10.3)	(80.4, 28.1)
60	–	–	–
120	(60.0, 129.4)	–	–
180	–	–	–
240	(70.5, 253.1)	–	–
300	–	–	–

Note. The “–” signifies that only two GRDs have been triggered, no localization results.

various directions (36 in total). The localization results are presented in Table 2. It can be seen that the localization function is normal.

4. Ground-based GRB Localization Algorithm

4.1. Methodology

The on-orbit localization method used on GRM satellites is similar to BATSE’s LOCBURST (Pendleton et al. 1999) (the BATSE Burst Location Algorithm) and GBM’s DOL (Connaughton et al. 2015) (Daughter Of Location), which involves using the Band spectral function to simulate the counts from GRBs in different directions on the three GRD detectors and store them in the memory. After the triggering, the chi-square value is computed, and the angle corresponding to the minimum chi-square value is obtained as the in-orbit localization result. This method is resource-efficient and fast in computation. However, GRM performs onboard localization only when all three GRD detectors are triggered, and the localization relies on the count rates from the trigger timescale (0.1, 1, or 4 s), resulting in low photon statistics. Consequently, the onboard localization efficiency is limited and the positional errors are large. Furthermore, the use of fixed spectral parameters in the template-matching approach introduces additional systematic errors (Berlato et al. 2019). To mitigate such biases, the BAYesian Location Reconstruction Of GRBs (BALROG) framework was developed for ground-based localization, which has been shown to effectively reduce systematic uncertainties (Burgess et al. 2018; Liao et al. 2020; Zhao et al. 2023, 2024).

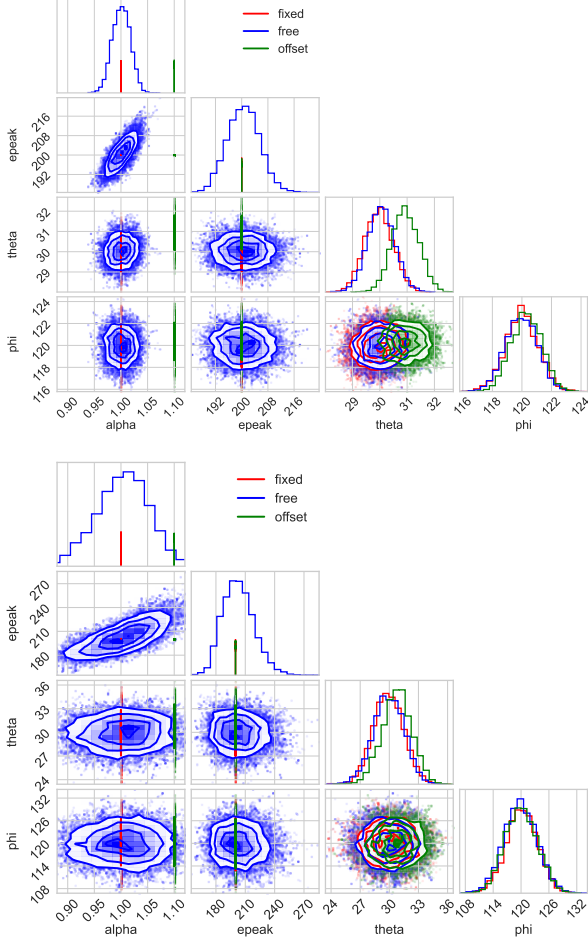


Figure 5. Impact of spectral assumptions on localization for simulated GRBs with fluences of $1 \times 10^{-5} \text{ erg cm}^{-2}$ (top) and $1 \times 10^{-6} \text{ erg cm}^{-2}$ (bottom). Systematic errors are evident for bright GRBs where statistical uncertainties are small, but become negligible for faint GRBs where statistical errors dominate.

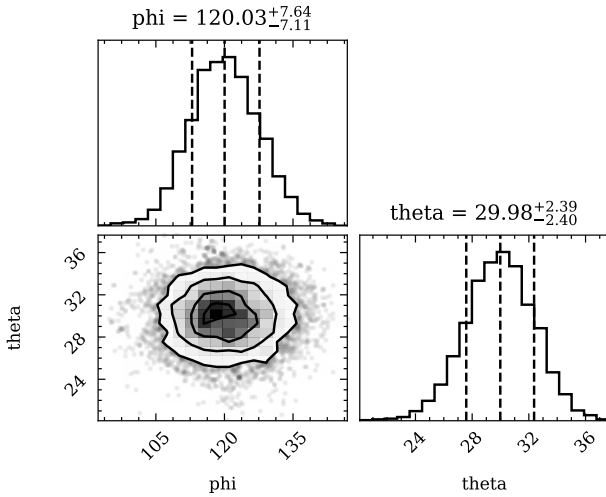


Figure 6. The GRB localization results in the $(30^\circ, 120^\circ)$ direction.

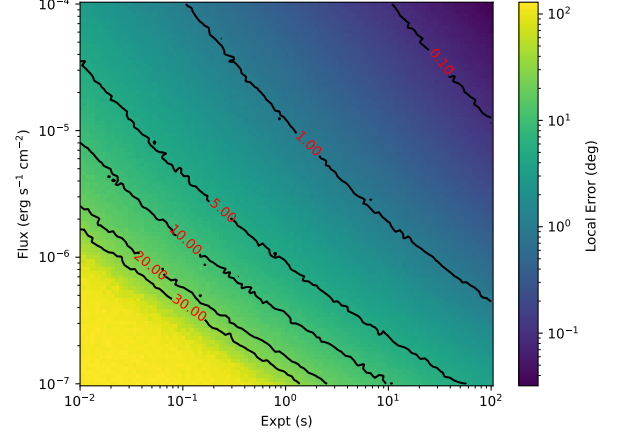


Figure 7. Localization error estimates for different fluxes as a function of burst duration. The black lines from top to bottom correspond to $0.1^\circ, 1^\circ, 5^\circ, 10^\circ, 20^\circ$ and 30° respectively.

The GRM ground-based localization algorithm employs a likelihood-based method similar to BALROG. The first step is to construct the likelihood function. Within a time interval t , the number of photons detected by detector d in energy channel c follows a Poisson distribution. Therefore, the probability of detector d in the direction Ω and spectral parameter Ψ can be expressed as:

$$p_d(\Psi, \Omega) = \prod_{c=1}^{N_c} \frac{(T_{d,c}t)^{\lambda_{d,c}} e^{-T_{d,c}t}}{\lambda_{d,c}!}, \quad (4)$$

When the count is high enough, it can be simplified to Gaussian distribution, as shown below.

$$p_d(\Psi, \Omega) = \prod_{c=1}^{N_c} \frac{1}{\sqrt{2\pi} \sigma_{d,c}} \exp\left(-\frac{(S_{d,c} - T_{d,c})^2}{2\sigma_{d,c}^2}\right), \quad (5)$$

Therefore, the likelihood function $L(\Psi, \Omega)$ can be expressed as Equation 6:

$$L(\Psi, \Omega) = \prod_{d=1}^{N_d} p_d(\Psi, \Omega). \quad (6)$$

By seeking the parameters corresponding to the maximum value of the likelihood function, the optimal direction for localization can be obtained. When there are few parameters, the optimal value can be found by traversing the entire parameter range, but when there are too many parameters, the time and computational resources required for traversal become significant. Here, we employ the method of Markov chain to sample the parameter space and obtain the confidence interval of the parameters. The likelihood function reflects the probability of detecting λ counts when the parameters are (Ψ, Ω) , denoted as $P(\lambda|\Psi, \Omega)$. According to the Bayes' theorem, we can infer the probability distribution of the parameter space

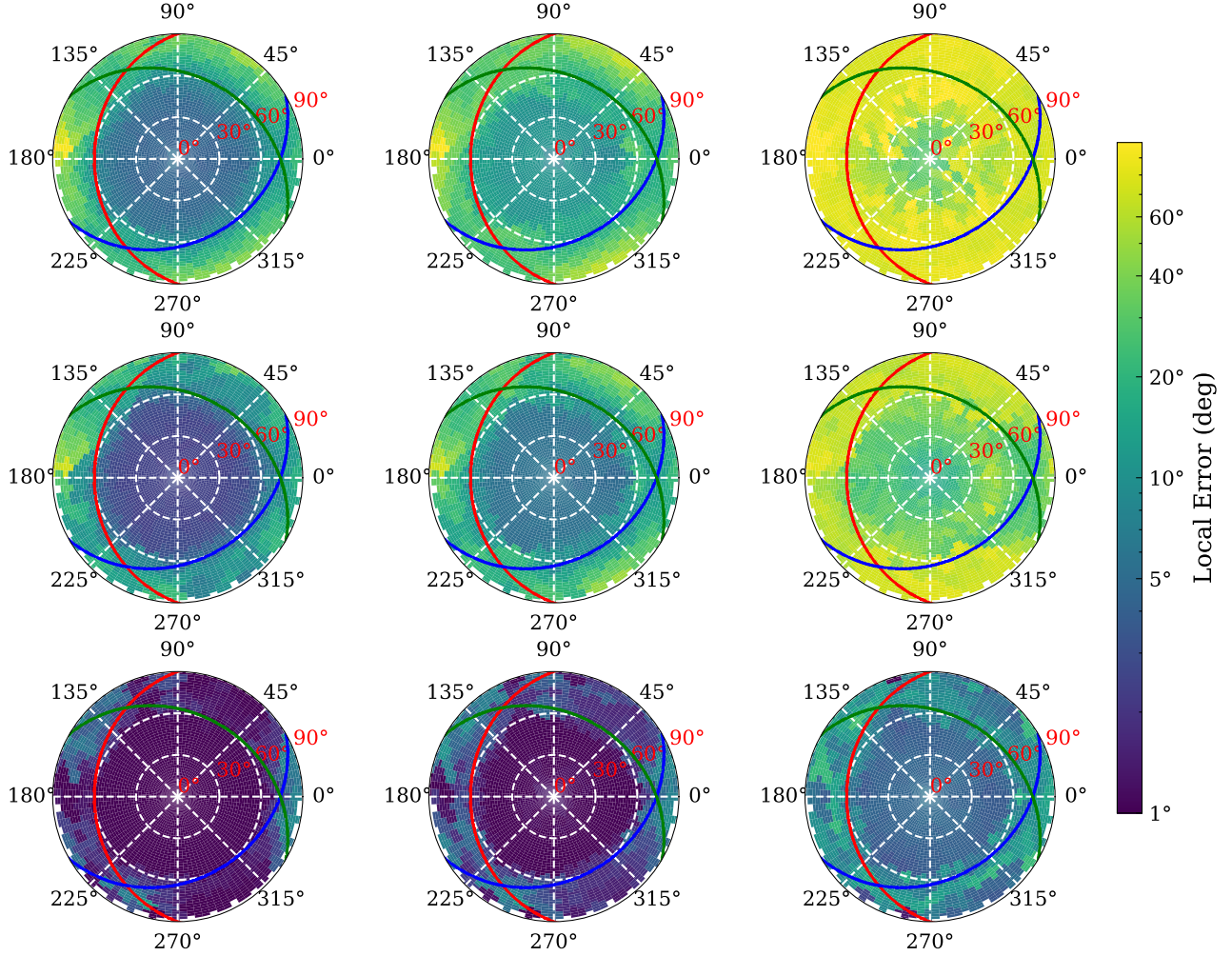


Figure 8. Localization statistical errors for GRBs with different spectral hardness and incident directions. From left to right, the three columns correspond to soft, medium, and hard spectra (see Table 1), respectively. From top to bottom, the three rows represent fluences of 5×10^{-7} , 1×10^{-6} , 1×10^{-5} erg cm $^{-2}$ in 1 s. The red, green, and blue lines indicate the FoV boundaries of the three GRDs.

$P(\Psi, \Omega | \lambda)$ when detecting the count rate λ

$$P(\Psi, \Omega | \lambda) = \frac{P(\lambda | \Psi, \Omega) P(\Psi, \Omega)}{\sum P(\lambda | \Psi, \Omega) P(\Psi, \Omega)}. \quad (7)$$

Assuming that the prior distribution $P(\Psi, \Omega)$ of the parameter space is a uniform distribution, the denominator integral yields a fixed value, so $P(\Psi, \Omega | \lambda) \propto L(\Psi, \Omega)$. Once the form of the probability density function is known, the Monte Carlo Markov Chain (MCMC) method can be employed for sampling. Commonly used MCMC methods include the Metropolis–Hastings (M–H) sampling and Gibbs sampling, as well as some improved methods. In this work, we performed MCMC sampling using the emcee package (Foreman-Mackey et al. 2013). To assess convergence, we first discarded the initial 20% of samples as burn-in. We then computed the autocorrelation time (τ) for the remaining chain and verified that the chain length exceeded $50 \times \tau$. In addition, the chains were visually

inspected to ensure stability. Samples satisfying these criteria were considered effectively independent and used for posterior inference and parameter estimation.

4.2. Validation with Simulated GRBs

To further investigate the impact of spectral assumptions on localization accuracy, we simulated two kinds of GRBs with different fluences of 1×10^{-5} erg cm $^{-2}$ and 1×10^{-6} erg cm $^{-2}$ (integrated over 1 s), respectively. The simulated burst adopts a Comptonized (CPL) spectrum with $\alpha = 1$ and $E_{\text{peak}} = 200$ keV, and is incident from a direction of ($\theta = 30^\circ$, $\phi = 120^\circ$) in GRM coordinates. Using three different approaches—fixed: fixing the spectral parameters to their true values; free: allowing all spectral parameters to vary freely; and offset: fixing the spectral parameters to incorrect values—we sampled the directional parameters.

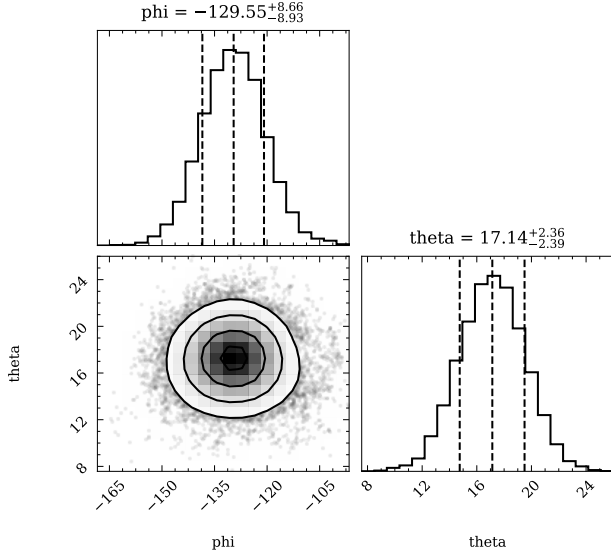


Figure 9. The distribution of theta and phi of GRB 240629A in the GRM's coordinate system.

The results, shown in Figure 5, demonstrate that incorrect spectral assumptions introduce significant systematic errors in localization. The systematic bias is most pronounced when statistical uncertainties are small (i.e., for bright bursts), whereas for faint GRBs where statistical errors dominate, the bias becomes negligible.

The systematic errors introduced by misspecified spectral parameters, while significant for bright GRBs, have a reduced impact on faint bursts. To account for these effects in our analysis, the GRM ground-based localization pipeline adopts a joint sampling approach that simultaneously fits both the spectral and localization parameters. Unless otherwise stated, all ground-based localizations presented in the following sections are obtained using this method.

5. Localization Analysis

5.1. Localization Performance with Simulations

Using the method in Section 4, GRBs incident in the direction of $(30^\circ, 120^\circ)$ were simulated. The location results indicate that for a GRB with a fluence of $1 \times 10^{-6} \text{ erg cm}^{-2} \text{ s}^{-1}$, spectral parameters $\alpha = -1.0$, $\beta = -2.3$, $E_{\text{peak}} = 230 \text{ keV}$, and a duration of 1 s, the 1σ error interval is $\theta = 29.98^{+2.39}_{-2.40}$, $\phi = 120.03^{+7.64}_{-7.11}$, meeting the requirement of less than 5° (see Figure 6). To further evaluate the statistical localization errors for GRBs with different fluences and durations, we present in Figure 7 the localization uncertainties as functions of both flux and burst duration, providing a comprehensive assessment of the expected performance across a wide range of burst fluxes and timescales.

We performed simulations and localization for a grid of 368 incident directions across three different fluence levels (5×10^{-7} , 1×10^{-6} , $1 \times 10^{-5} \text{ erg cm}^{-2}$ in 1 s). The

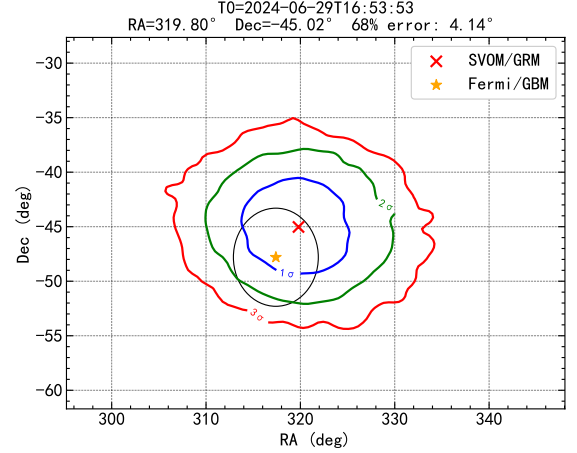


Figure 10. The GRM's localization results for GRB 240629A. The yellow star and black circle represent the GBM localization result and its associated error, respectively.

resulting statistical localization errors are shown in Figure 8. For medium-spectrum GRBs with a typical fluence of $1 \times 10^{-6} \text{ erg cm}^{-2}$, the 1σ localization errors within the common field of view of the three detectors ($\theta < 60^\circ$) are generally below 5° .

5.2. Localization Results with GRB Data

SVOM was successfully launched on 2024 June 22, and the GRM started operating on June 27. Fortunately, the GRM detected the first three GRBs on June 27 (GRB 240627B), June 29 (GRB 240629A), and July 2 (GRB 240702A), respectively (SVOM/GRM Team 2024). GRB 240629A is used to validate the localization algorithm for the GRB (see Figure 9), which is relatively bright.

According to the satellite's attitude quaternion, we transform theta and phi to the J2000 coordinate system. As shown in Figure 10, the three circles represent the 1, 2, and 3 sigma confidence regions, with the maximum probability density position at $(319.80, -45.02)$, which is consistent with the localization result of Fermi/GBM $(317.4, -47.8)$ Fermi GBM Team (2024).

By 2025 December, GRM had detected over 100 GRBs since its commissioning. However, only a limited number of bright bursts have precise independent localizations. Table 3 presents six GRBs with both onboard and ground-based localization results. As shown in Figure 11, the ground-based pipeline significantly improves upon the onboard positions.

Simulations in Section 4.2 demonstrate that fixed spectral parameters can introduce systematic errors. Nevertheless, for real GRBs, the joint fitting approach does not consistently outperform the fixed-spectrum method. In particular, the localization of GRB 240802A deviates from its reference position by more than 3σ , exceeding the expected confidence

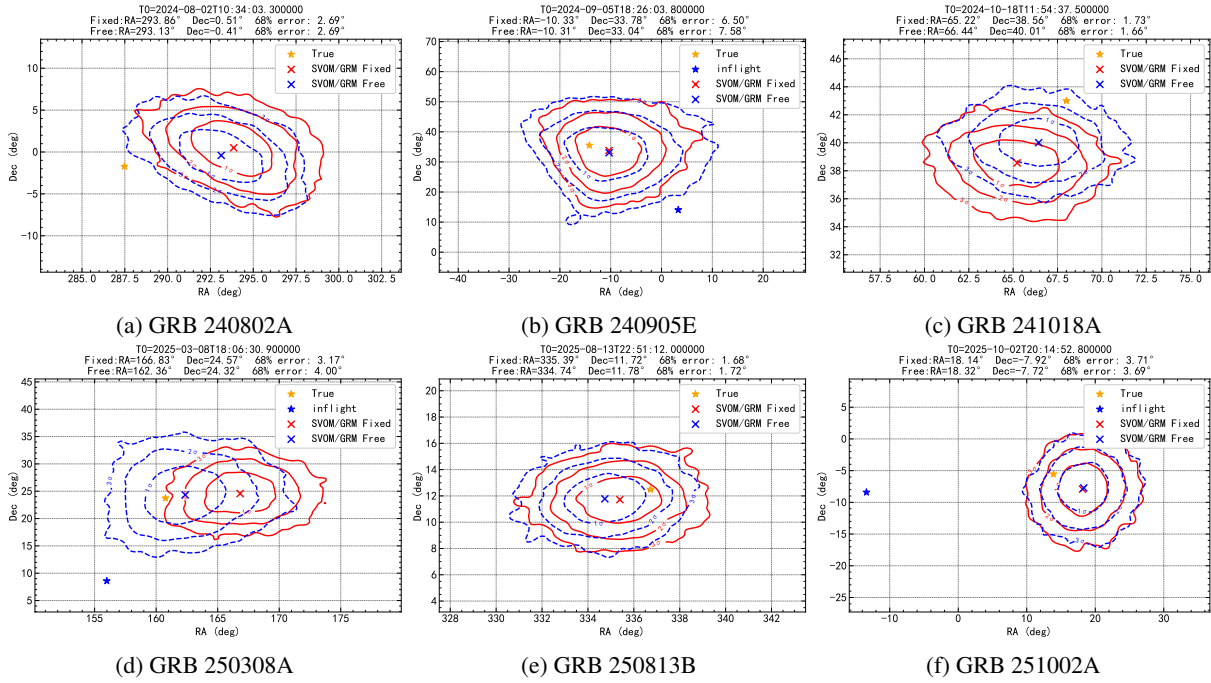


Figure 11. Localization results for six GRBs using different methods. The yellow stars indicate the true (reference) positions of the GRBs. Red crosses with solid lines represent the ground-based localization results obtained with fixed spectral parameters, while blue crosses with dashed lines correspond to the ground-based joint fitting results where both spectral and localization parameters are sampled. For GRB 240905E, GRB 250308A, and GRB 251002A, the onboard real-time localization results are also shown.

Table 3
 Localization Results for GRBs Detected by GRM

GRB Name	Time (UTC)	Position	Local Result		
			Inflight	Fixed	Free
GRB 240802A	2024-08-02T10:34:03.3	(287.5, -1.7)	—	(293.9, 0.5)	(293.1, -0.4)
GRB 240905E	2024-09-05T18:26:03.8	(345.8, 35.5)	(3.3, 14.1)	(-10.4, 33.7)	(-10.5, 33.2)
GRB 241018A	2024-10-18T11:54:37.5	(68.0, 43.0)	—	(65.2, 38.5)	(66.4, 40.0)
GRB 250308A	2025-03-08T18:06:30.9	(160.8, 23.7)	(156.0, 8.6)	(166.9, 24.5)	(162.4, 24.3)
GRB 250813B	2025-08-13T22:51:12.0	(336.7, 12.5)	—	(335.4, 11.7)	(334.7, 11.8)
GRB 251002A	2025-10-02T20:14:52.8	(13.9, -5.5)	(346.6, -8.4)	(18.2, -7.9)	(18.3, -7.7)

Note. The “—” indicates that only two GRDs were triggered, so no onboard localization result is available. The positions are from Swift/BAT, IPN, or SVOM/ECLAIRS and are assumed to be the true GRB locations.

region. This indicates that additional systematic effects—such as detector response uncertainties, atmospheric scattering, among others—may also contribute to the residual errors. A larger sample of well-localized GRBs is required to statistically characterize these biases. Future work will focus on deriving an overall systematic error estimate for GRM.

6. Summary

In this article, we provided a detailed introduction to the on-orbit triggering and localization algorithm of GRM. We tested the triggering and localization functionality using the simulator, and the test results indicated that the triggering and localization

functions of GRM can operate normally. Additionally, addressing the shortcomings of the on-orbit localization algorithm, we designed a ground-based localization algorithm by constructing likelihood functions with energy spectra and directions as variables, and used the MCMC method to compute the posterior distribution of the parameters. Using this method, we simulated the localization statistical errors of GRBs with different hardness spectra and found that softer spectra have higher photon counts which lead to smaller localization statistical errors. The localization results of soft spectra meet the requirement of less than 5° . Finally, we used this algorithm to localize the first relatively bright GRB detected by GRM, and

the localization results demonstrate that this algorithm can local the GRB. Given the challenges in localizing faint or off-axis GRBs, further refinement of the current algorithm is necessary. Future enhancements may incorporate timing-based triangulation using inter-spacecraft delays, as well as joint spectral and positional fits with external instruments such as Fermi/GBM, Swift/BAT, and GECAM. With continued development of the GRM ground pipeline and future multi-satellite collaborative efforts, GRM is expected to play a meaningful role in enabling rapid multi-messenger follow-up observations.

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