



# The Gamma-Ray Monitor Onboard the SVOM Satellite

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## Abstract

The Gamma-Ray Monitor (GRM) is a key scientific payload onboard the Space-based multi-band Variable Objects Monitor (SVOM) satellite, designed specifically for the detection and study of gamma-ray bursts (GRBs). Launched into a 625 km low-Earth orbit on 2024 June 22, GRM serves as a large-area, wide-field-of-view instrument capable of observing the hard X-ray and soft gamma-ray emissions in the energy range of 15 keV–5 MeV. Its primary scientific objectives include: promptly triggering and localizing GRBs (with particular sensitivity to short-hard GRBs), measuring spectral and temporal properties of bursts, monitoring charged particle fluxes in orbit. GRM successfully detected its first GRB (GRB 240627B) on 2024 June 27, and has since maintained a detection rate of more than 100 GRBs per year. Cross-instrument comparisons with detectors such as GECAM and Fermi/GBM have validated the performance and data quality of GRM. This paper provides a comprehensive overview of GRM instrument design, reliability verification through ground testing, in-orbit triggering and localization algorithms, performance calibration, and preliminary in-orbit results, demonstrating its capability as a versatile gamma-ray all-sky monitor.

**Key words:** (stars:) gamma-ray burst: general – space vehicles: instruments – instrumentation: detectors – techniques: spectroscopic

## 1. Introduction

Gamma-ray bursts (GRBs) are among the most energetic and enigmatic phenomena in the universe, originating from cataclysmic events such as massive star collapses or neutron star mergers. Since their serendipitous discovery in the 1960s, our understanding of these extreme events has been significantly advanced through observations by successive space missions. Pioneering missions such as BeppoSAX (Boella et al. 1997), Swift (Gehrels et al. 2004), and Fermi (Meegan et al. 2009) have enabled groundbreaking discoveries in GRB localization and afterglow characterization. More recent contributions from missions such as HXMT (Zhang et al. 2020) and GECAM (LI et al. 2020) have further enriched our understanding of GRB prompt emission mechanisms and their connection to multi-messenger astrophysics.

Despite these advances, fundamental questions of GRBs remain unanswered (Zhang 2014; Gill et al. 2021; Lan et al. 2021), especially for short GRBs, such as their connection to gravitational wave events, and the extreme physical conditions in their environments. The SVOM (Space-based multi-band Variable Objects Monitor) satellite (Götz et al. 2009; Paul

et al. 2011; Godet et al. 2012; Wei et al. 2016; Bernardini et al. 2017; Mercier et al. 2018; Wei 2018; Mate et al. 2019; Fan et al. 2020; Wei 2020; Dagoneau & Schanne 2022; Cordier et al. 2026; Li et al. 2026), a Sino-French cooperative mission, represents a significant advancement in GRB research. Launched in 2024 June into a 625 km low-Earth orbit, SVOM carries four scientific instruments covering gamma-ray, X-ray, and optical bands, enabling comprehensive studies of GRB prompt emission and afterglows.

The Gamma-Ray Monitor (GRM; Dong et al. 2010; Zhao et al. 2013; He et al. 2020; Wen et al. 2021; He et al. 2025) serves as a key payload onboard SVOM, designed as a large-area, wide-field detector operating in the 15–5000 keV energy range. GRM’s primary scientific objectives include: triggering gamma-ray transients (including GRBs, soft gamma-ray repeaters (SGRs), with particular emphasis on short-hard GRBs), measuring spectral and temporal properties of bursts, monitoring charged particle fluxes, and providing real-time trigger alerts for follow-up observations. Since its launch, GRM has demonstrated excellent performance, detecting numerous GRBs including the mission’s first triggers GRB 240627B, GRB 240629A, and GRB 240702A (Dong et al. 2024). Cross-instrument comparisons with GECAM and

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Fermi/GBM have validated GRM's detection capabilities and data quality.

Within the SVOM payload suite, GRM works in synergy with the ECLAIRs telescope (Godet et al. 2026), the Microchannel X-ray Telescope (MXT; Götz et al. 2026), and the Visible Telescope (VT; Qiu et al. 2026) to form a complete multi-wavelength observing system. ECLAIRs, a coded-mask imager operating in the 4–250 keV band, provides accurate localization ( $< 10'$ ) of GRBs within its 2 sr field of view (FoV). GRM serves as the high-energy sentinel of the SVOM payload suite, extending the energy coverage up to  $\sim 5$  MeV and enabling studies of the prompt emission, including jet physics and radiation mechanisms. Its large effective area and wide FoV ( $\sim 2\pi$  sr) make it highly sensitive to GRBs falling outside ECLAIRs' coded FoV. With its independent on-board trigger algorithm—particularly effective for short, hard bursts—GRM can detect events that might otherwise be missed, thereby increasing the overall GRB detection rate of the mission. Once a burst is detected and coarsely localized by GRM, or precisely localized by ECLAIRs, MXT and VT perform follow-up observations in X-ray and optical bands to study the afterglow and measure its redshift. This multi-instrument synergy is key to fulfilling SVOM's science goals, especially for multi-messenger follow-up of gravitational wave sources.

This paper provides a comprehensive overview of the GRM instrument, detailing its scientific objectives, instrumental design, ground calibration, preliminary in-orbit performance, and its role in advancing GRB research within the multi-messenger astronomy context.

## 2. Overview of GRM Mission

GRM is designed to significantly advance our understanding of GRBs and related high-energy astrophysical phenomena. Its scientific objectives encompass three primary domains: GRB physics investigation, including progenitor systems, jet mechanisms, energy dissipation processes, and radiation mechanisms; multi-messenger astronomy through complementary studies of gravitational waves, neutrinos, and high-energy cosmic rays; and cosmology and fundamental physics by probing early universe properties and testing physical laws under extreme conditions. Apart from GRB sciences, GRM can also detect other soft gamma-ray transients, including SGRs (Wang et al. 2025; Xie et al. 2025), Solar Flares (SFLs; Zhang et al. 2021; Zhao et al. 2023a), etc. Additionally, GRM's unique capabilities in low Earth orbit, combined with its wide FoV and broad energy coverage extending to several MeV, also make it ideally suited for studying Terrestrial Gamma-ray Flashes (TGFs; Zhao et al. 2023b; Yi et al. 2025a, 2025b), establishing it as a versatile instrument for both astrophysical and terrestrial high-energy phenomena.

The scientific objectives of GRM translate into the following specific requirements (SR):

**[SR1]** Detect diverse GRB populations including short GRBs (5 ms–2 s), long GRBs (up to 1000 s), and X-ray rich GRBs, as well as those outside ECLAIRs' FoV but within GRM's detection range, thereby enhancing ECLAIRs' GRB discovery capability.

**[SR2]** Provide rapid triggering for short GRBs, leveraging GRM's sensitivity to detect events that may not trigger ECLAIRs, similar to Fermi/GBM's enhanced short GRB detection compared to Swift/BAT.

**[SR3]** Observe GRBs across a broad energy band (15–5000 keV) from T0–5 minutes to T0+10 minutes, enabling comprehensive studies of temporal and spectral features including precursors, extended emission, and spectral components, with energy band overlap facilitating cross-calibration with ECLAIRs.

**[SR4]** Support synergistic observations of gravitational wave sources, targeting NS–NS and BH–NS mergers as established progenitors of short GRBs, building on the confirmed association between GRB 170817A and GW170817.

**[SR5]** Detect and characterize TGFs with durations of 50  $\mu$ s to several milliseconds across 10 keV to MeV energies, including potential electron-positron pair observations.

These science requirements lead to the following functional specifications (FR) for GRM:

**[FR1]** Provide spectral observations of GRBs from 15 to 5000 keV.

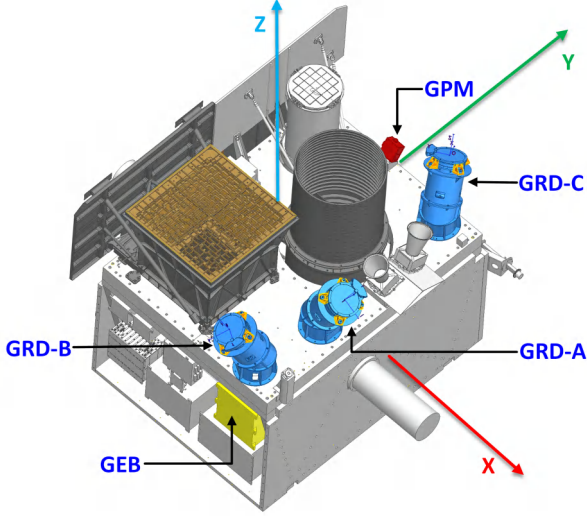
**[FR2]** Implement on-board triggering and duration measurement capabilities, with particular emphasis on short, hard GRBs.

**[FR3]** Measure GRB peak energies in near real-time across hard X-ray and soft gamma-ray bands, with combined analysis capabilities using ECLAIRs data for improved accuracy.

**[FR4]** Monitor and provide alerts for high particle flux regions, particularly the South Atlantic Anomaly (SAA).

**[FR5]** Deliver coarse localization information for detected GRBs.

The GRM subsystem consists of three primary units: the Gamma-Ray Detector (GRD), serving as the main detector for X-ray and soft gamma-ray spectral observations and GRB triggering; the GRM Particle Monitor (GPM), designed to monitor charged particle intensities and provide early warnings for regions like the SAA; and the GRM Electronics Box (GEB), which processes scientific data and manages command transmission and reception. Additionally, each GRD unit incorporates a GRM Calibration Detector (GCD) at the crystal edge for in-orbit gain monitoring and calibration. The physical configuration of GRM aboard SVOM is illustrated in Figure 1, with performance specifications and measured characteristics detailed in Table 1.



**Figure 1.** GRM instrument configuration onboard the SVOM satellite, showing the four primary payloads: GRM, ECLAIRs, MXT and VT. The GRM system comprises GRD-A/GRD01, GRD-B/GRD02, GRD-C/GRD03, GPM, and GEB units.

The complete component hierarchy of GRM is illustrated in Figure 2, with the GEB serving as the central processing unit responsible for detector configuration, data acquisition, and interface management with the SVOM platform.

The GEB performs two primary functions: first, it collects scientific data from the three GRD units, three GCD calibration detectors, and the GPM particle monitor, while simultaneously providing low-voltage power supply (LVPS), high-voltage power supply (HVPS), and high-voltage monitoring for these detectors; second, it manages communication interfaces with the satellite platform, utilizing SpaceWire (SPW) bus for scientific data transmission and Controller Area Network (CAN) bus for telemetry and command exchange.

The platform provides critical timing and control signals to GRM, including the Pulse Per Second (PPS) signal for precise time synchronization and the Low-Level Compatible (LLC) signal for system reset operations. Additionally, the platform supplies primary power and thermal control to the GRM subsystem through the GEB interface.

### 3. Design

#### 3.1. Instruments

##### 3.1.1. Gamma-Ray Detector

The GRD unit employs a NaI(Tl) scintillator to monitor hard X-ray and soft gamma-ray emissions in the 15–5000 keV energy range across a large portion of the sky. GRM incorporates three identical GRD units, each mounted to the payload instrument module (PIM) structure via a dedicated bracket. Similar to Fermi/GBM, the design omits collimators and backside anti-coincidence shielding. The three GRD units

are oriented with elevation angles of  $30^\circ$  relative to the symmetry axis and azimuth angles spaced  $120^\circ$  apart, enabling coarse localization within a wide FoV—a capability particularly valuable for follow-up observations of gravitational wave associated events.

Each GRD unit comprises a Beryllium entrance window, a NaI(Tl) scintillator assembly, a photomultiplier tube (PMT), a shock absorption layer, magnetic shielding, front-end electronics (FEE), protective housing, and eight damping elements. FEE integrates amplifiers, a high-voltage module, a high-voltage control driver, and a high-voltage measurement circuit. A schematic diagram of the GRD assembly is provided in Figure 3.

To cover the full energy range given the limited dynamic range of FEE, each GRD utilizes two signal chains with different amplification factors: a high-gain channel for low-energy photons and a low-gain channel for high-energy events. The high-gain channel is linear over approximately 100–3500 ADC channels, and the low-gain channel also extends up to  $\sim 3500$  ADC channels. During calibration, the actual lower threshold of the high-gain channel was found to be below 100 ADC channels, corresponding to energies of several keV. The gain ratio between the two channels is approximately 9.5:1, with an overlapping energy response between 150 keV and 550 keV.

##### 3.1.2. GRM Calibration Detector

The GCDs are designed to monitor the gain stability of the GRD units and provide in-orbit calibration references. Each GRD is equipped with one GCD module positioned above its entrance window at the edge of the detector’s FoV. The mechanical integration of the GCD on top of a GRD unit is illustrated in Figure 3.

Each GCD comprises an  $^{241}\text{Am}$  radioactive source, a Silicon Photomultiplier (SiPM) device, and associated readout electronics. The  $^{241}\text{Am}$  source emits  $\sim 5$  MeV alpha particles through alpha decay, accompanied by subsequent gamma-ray emissions. The SiPM detects the alpha particles, while the GRD registers the corresponding gamma-rays. By utilizing coincidence signals between the GCD and GRD, gamma photons from  $^{241}\text{Am}$  can be reliably identified for GRD onboard calibration purposes. The  $^{241}\text{Am}$  source has a total alpha activity of approximately 200 Bq, with the GRD detecting approximately 10% of the gamma-rays emitted by the source.

For GRD gain monitoring, the prominent energy line at 59.5 keV from  $^{241}\text{Am}$  is utilized for low-energy calibration, while the in-orbit 511 keV annihilation background line provides a reference for higher energy calibration. With typical count rates of tens of gamma photons per second in the GRD, integration time intervals of 1–5 minutes are required to accumulate sufficient statistics for the calibration spectrum,

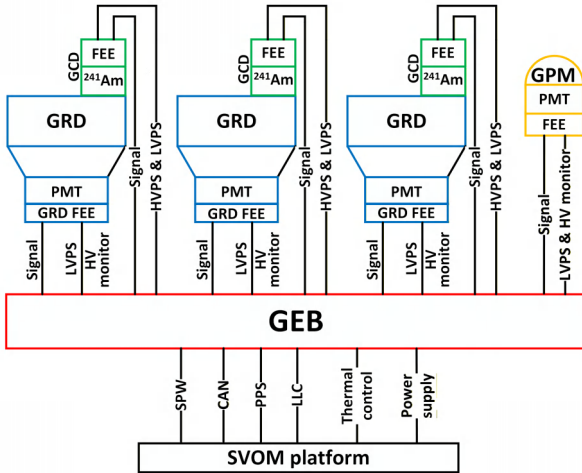
**Table 1**  
GRM Performance Specifications

| Performance Metrics    | Required Value                  | Actual Value                                                                                 | Assessment Method           |
|------------------------|---------------------------------|----------------------------------------------------------------------------------------------|-----------------------------|
| Energy range           | 15–5000 keV                     | GRD-A: 8–5927 keV<br>GRD-B: 8–5675 keV<br>GRD-C: 8–5638 keV                                  | Measurement and calculation |
| Field of view          | $\pm 60^\circ$                  | $\pm 90^\circ$                                                                               | Measurement                 |
| Sensitive area         | $>200 \text{ cm}^2$ (each unit) | GRD-A: $201.31 \text{ cm}^2$<br>GRD-B: $201.06 \text{ cm}^2$<br>GRD-C: $201.31 \text{ cm}^2$ | Measurement and calculation |
| Dead time              | $<8 \mu\text{s}$                | $\sim 4.167 \mu\text{s}$                                                                     | Measurement                 |
| Temporal resolution    | $<20 \mu\text{s}$               | $1 \mu\text{s}$                                                                              | Measurement                 |
| Energy resolution      | $\leq 19\%$ @60 keV             | GRD-A: 16.54% @60 keV<br>GRD-B: 16.53% @60 keV<br>GRD-C: 16.46% @60 keV                      | Measurement                 |
| Burst observation rate | $>90 \text{ yr}^{-1}$           | $>100 \text{ yr}^{-1}$                                                                       | Simulation and measurement  |
| GRB localization error | $<5^\circ$ <sup>a</sup>         | $<5^\circ$ <sup>b</sup>                                                                      | Simulation and measurement  |

**Notes.**

<sup>a</sup> Fluence  $>1 \times 10^{-6} \text{ erg cm}^{-2}$  @1–1000 keV, 1 s.

<sup>b</sup>  $1\sigma$  statistical error, Fluence  $>1 \times 10^{-6} \text{ erg cm}^{-2}$  @1–1000 keV, 1 s. GRB spectral parameters:  $\alpha = -1.9$ ,  $\beta = -3.7$ ,  $E_{\text{peak}} = 70 \text{ keV}$ .



**Figure 2.** GRM system composition and component hierarchy.

and approximately 1 hr for the 511 keV line. Figure 4 shows a typical calibration spectrum measured by the GRD detector unit. The peak on the right of the spectrum corresponds to the 59.5 keV full-energy peak, achieving an energy resolution of better than 17%. The left peak complex contains multiple low-energy full-energy peaks along with the escape peak.

To mitigate temperature-dependent gain variations in the SiPM, the power supply chain incorporates components with negative temperature coefficients that automatically compensate for these effects.

The mechanical design of the GCD minimizes the obstruction of the GRD's effective area. The  $^{241}\text{Am}$  source and SiPM are mounted on a dedicated section of the PCB,

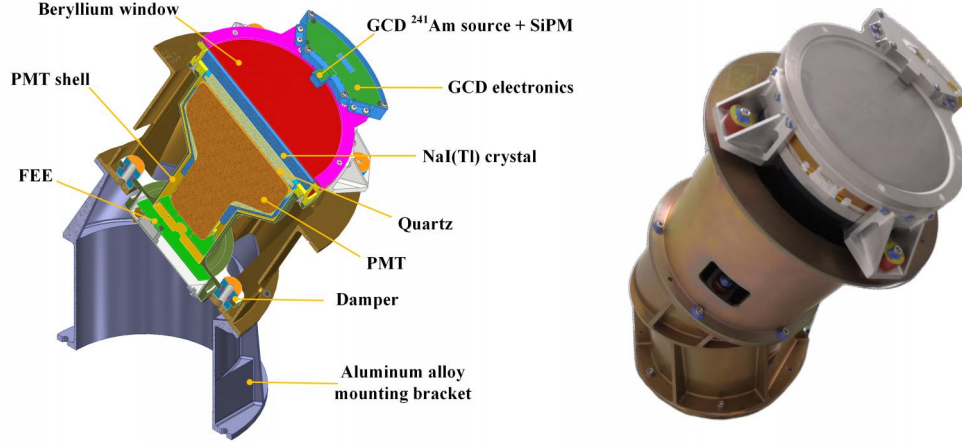
enclosed by a metallic frame that forms a light-tight darkroom. This enclosure is filled with a dark sealant to prevent external photon leakage and enhance mechanical stability, ensuring both optical isolation and shock resistance for safe operation of the radioactive source.

### 3.1.3. GRM Charged Particle Monitor

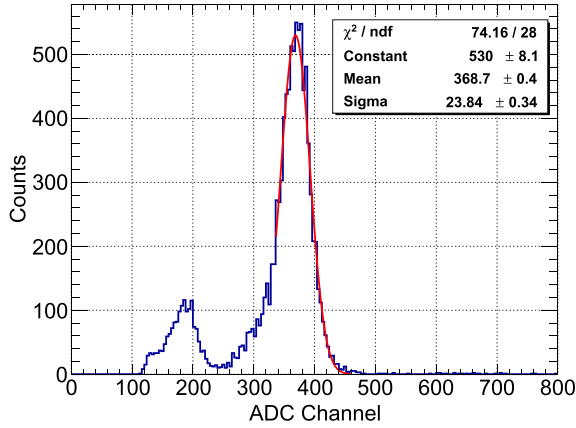
GPM, employing a BC-440M plastic scintillator coupled to a photomultiplier tube (PMT), is installed on the upper surface of the PIM. The cylindrical scintillator measures 10 mm in both diameter and height and is enclosed within a 2 mm thick aluminum housing.

Based on simulation results (as shown in Figure 5), when the incident particle energy is 1 MeV, the detection efficiency of GPM for electrons is approximately 40%, while for photons it is less than 10%. With increasing energy, the detection efficiency for electrons becomes significantly higher than that for photons. Similarly, when the incident particle energy is approximately 10.5 MeV, the detection efficiency for protons approaches 100%, while for photons it remains below 5%. As the energy increases further, the detection efficiency for protons becomes substantially higher than that for photons. Therefore, GPM can effectively distinguish between high-energy charged particle bursts and GRBs. In the actual GPM detector configuration, the energy thresholds for high-energy electrons and protons are set at 1.3 MeV and 20 MeV, respectively, which enhances the detection of GRB photons while reducing false triggers from high-energy charged particles.

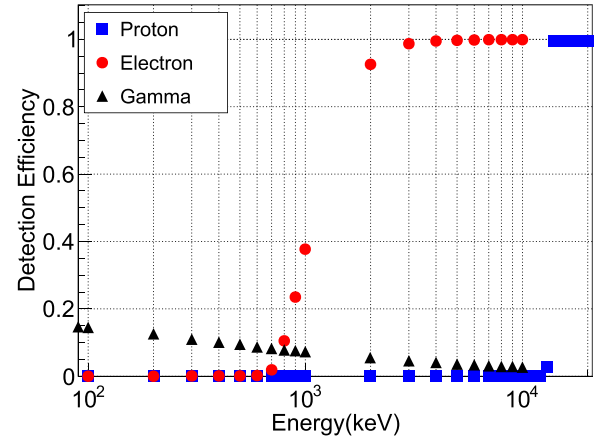
The primary function of GPM is to monitor the in-orbit charged particle fluxes and automatically control the high-



**Figure 3.** Design of the GRD assembly. Left: Exploded schematic view showing key components including a scintillator, photomultiplier tube (PMT), and front-end electronics (FEE). Right: Fully assembled flight model of a GRD unit, illustrating the final mechanical configuration used aboard the SVOM satellite.



**Figure 4.** A typical  $^{241}\text{Am}$  spectrum measured with a GRD detector unit. The prominent photopeak on the right demonstrates the detector's energy response to the 59.5 keV emissions from the GCD, while the feature at lower energies includes both low-energy photoelectric peaks and characteristic escape peak from the detector material.



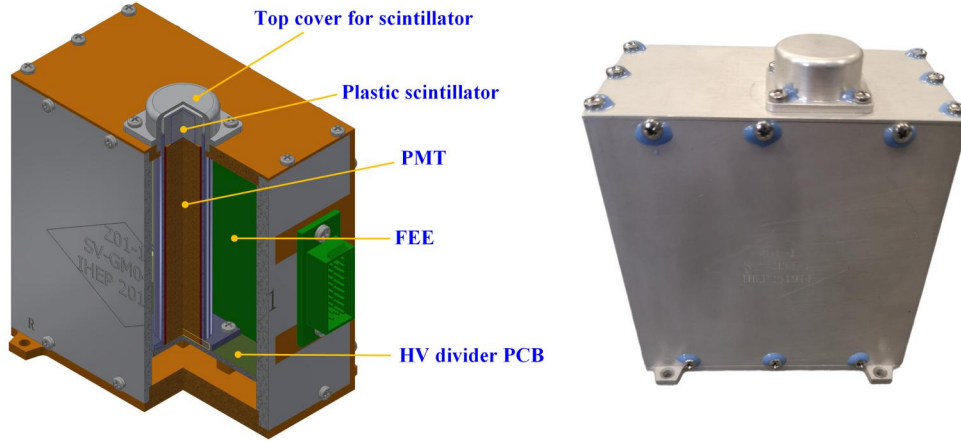
**Figure 5.** Simulated detection efficiency of GPM for electrons, protons, and gamma-ray photons as a function of incident particle energy. The distinct efficiency curves demonstrate the detector's capability to discriminate between charged particles and photons.

voltage supplies to the GRD PMTs. When the measured count rate exceeds a programmable threshold, the GPM triggers the shutdown of GRD high voltages; conversely, when the count rate falls below the threshold, the high voltages are restored. This protection mechanism safeguards the GRD detectors during periods of elevated radiation, such as passages through the SAA region.

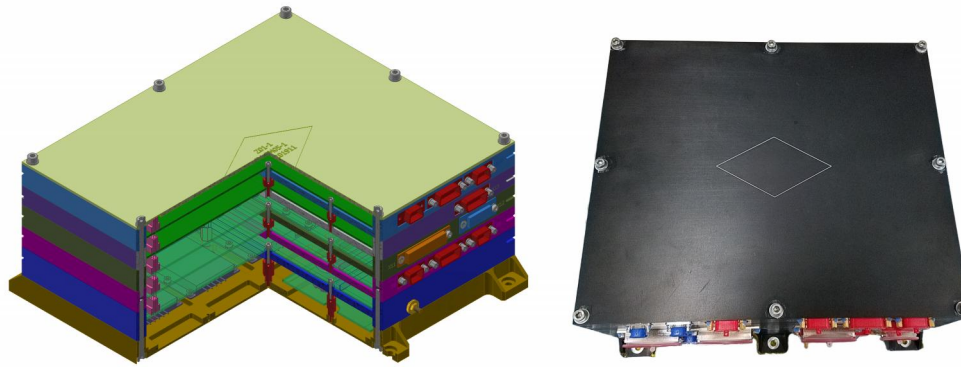
The GPM assembly consists of an encapsulated enclosure, scintillator cover, FEE, high-voltage module, PMT assembly, and scintillator element. The scintillator cover serves dual purposes: establishing the energy threshold for detectable particles while providing mechanical protection for both the scintillator and PMT. The complete GPM design is illustrated in Figure 6.

### 3.1.4. GRM Electronics Box

GEB serves as the central processing and control unit for GRM, integrating multiple critical functions including data acquisition, data management, operational mode transitions, onboard trigger and localization algorithms, DC/DC power conversion, and communication interface management. GEB primarily consists of five electronic module layers: the Power Supply Unit (PSU), the primary data acquisition unit (CEU\_A\_N), the backup data acquisition unit (CEU\_A\_R), the primary data management unit (CEU\_D\_N), and the backup data management unit (CEU\_D\_R). The primary and backup modules feature identical designs and operate in a cold backup configuration. Each electronic module layer is composed of an aluminum frame, PCBs, and electronic



**Figure 6.** Design of the GPM assembly. Left: Exploded schematic view detailing the internal configuration, shielding structure, and detector components. Right: Fully assembled flight unit, demonstrating the compact mechanical design as implemented on the SVOM satellite for charged particle monitoring.



**Figure 7.** Design of the GEB assembly. Left: Exploded schematic view showing the internal organization of electronics. Right: Fully assembled flight unit featuring a black-anodized surface treatment for enhanced thermal and optical properties in the space environment.

components, with interlayer connectors distributed between all five circuit board layers. The complete GEB design configuration is presented in Figure 7.

### 3.2. In-orbit Operation Modes

The GRM instrument operates through seven distinct operational modes, each designed to fulfill specific mission requirements and respond to varying space environment conditions.

**[Off Mode]** In this mode, GRM is completely powered down. Transition from Off mode to other operational states is exclusively controlled by telecommand. This mode is typically activated during SVOM payload self-check procedures or when critical errors are detected in the GRM system.

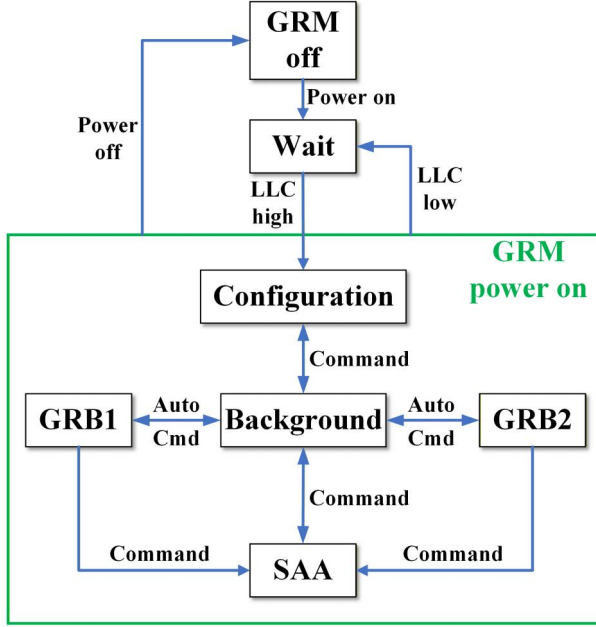
**[Wait Mode]** GRM low-voltage power is enabled while high-voltage systems remain powered off. The GEB awaits the LLC signal rising edge to initiate further operations in this standby state.

**[Configuration Mode]** With low-voltage power active, GRM operates with default parameters. This mode allows configuration of high-voltage settings and other operational parameters via command. Transition to Background mode is exclusively command-initiated.

**[Background Mode]** This is the nominal operational state when no GRBs or transient sources are detected. GRM collects rebinned spectral data at regular intervals and timing profiles across multiple energy bands. Event-by-event data are continuously recorded and transmitted to ground stations.

**[GRB 1 (GRB-G) Mode]** Activated automatically when GEB detects a significant count rate increase in GRD units at time  $T_0$ , indicating a potential GRB. The instrument collects light-curve data from  $T_0 - 2$  minutes to  $T_0 + 7$  minutes for ground transmission. GRM automatically reverts to Background mode after  $T_0 + 7$  minutes. This mode can also be entered via ground command. Event-by-event data collection remains active throughout this mode.

**[GRB 2 (GRB-E) Mode]** Initiated either by ground command or upon trigger notification from the ECLAIRs



**Figure 8.** GRM operational mode transition diagram, illustrating the conditions and pathways between the seven defined operational states.

instrument. Once activated, data collection follows the same temporal pattern as GRB 1 mode ( $T_0 - 2$  minutes to  $T_0 + 7$  minutes) with automatic return to Background mode thereafter. Event-by-event data are preserved and transmitted.

**[SAA Mode]** Activated by ground command when entering the SAA region (with tunable duration parameters). GRD high-voltage systems are disabled to protect the detectors from elevated radiation, while GPM continues monitoring charged particle fluxes. GRM exits SAA mode upon ground command when particle levels normalize, transitioning back to Background mode. SAA region parameters are ground-configurable.

**[Mode Transition]** GRM supports both automatic and command-initiated mode transitions. Automatic transitions occur based on internal instrument data and predefined triggers, while manual transitions are executed via platform commands. The complete mode transition logic is illustrated in Figure 8.

### 3.3. On-board Trigger and Localization Algorithm

GRM employs a count rate trigger algorithm to detect GRBs by identifying significant increases in photon count rates. The trigger significance is calculated using Equation (1):

$$\text{Significance} = \frac{S - B}{\sqrt{B/T}}, \quad (1)$$

where  $T$  is the duration of the burst window searched (in seconds),  $B$  represents the time-normalized background count rate per second (without GRB signals) and  $S$  denotes the

| Table 2<br>Parameters Considered in the GRM On-board Trigger Algorithm |                                                    |
|------------------------------------------------------------------------|----------------------------------------------------|
| Parameter                                                              | Values                                             |
| Energy ranges                                                          | 15–50 keV, 50–300 keV, 300–1000 keV, 1000–5000 keV |
| Timescales                                                             | 0.1 s, 1.0 s, 4.0 s                                |
| GRD combinations                                                       | GRD1+GRD2, GRD1+GRD3, GRD2+GRD3, GRD1+GRD2+GRD3    |

source count rate per second (potentially containing both GRB signals and background events). GRM utilizes background estimates calculated over both short and long timescales: short-timescale backgrounds, calculated as averages immediately preceding the  $S$  interval, are optimized for detecting short GRBs, while long-timescale backgrounds, accumulated over extended periods and fitted for precise characterization, reduce false trigger rates.

The trigger algorithm incorporates adjustable background accumulation periods and considers multiple detection parameters, including energy bands optimized for detector efficiency and GRB spectral characteristics, timescales matching typical GRB temporal features, and various GRD combinations for enhanced sensitivity. The specific parameters used in the trigger algorithm are detailed in Table 2. While the GRD combinations and timescales in Table 2 are fixed in-orbit, the energy ranges and the trigger thresholds (not listed) are adjustable via ground command. Their values were initially set based on pre-launch simulations and are updated occasionally during operations based on observed trigger performance to optimize GRB trigger efficiency and reduce false triggers.

Based on the trigger algorithm, significances for the three GRDs across different energy band-timescale combinations are obtained. These are then compared against predefined thresholds to determine a trigger, according to the following logic: both Trigger Condition A and Trigger Condition B must be satisfied. Trigger Condition A requires that, in at least one energy band, the significances from at least two GRD units exceed their thresholds. Trigger Condition B requires that at least one combination of GRD units (as listed in Table 2) is triggered (significance exceeds the threshold).

For GRB localization, GRM utilizes the differential count rate responses across its three GRD units, which are mounted at  $120^\circ$  azimuthal intervals on the satellite's  $X$ - $Y$  plane, each inclined at  $60^\circ$  to provide complementary sky coverage (Figure 1). Localization calculations are initiated only when all three GRDs are triggered simultaneously.

The on-board localization employs a lookup table approach using chi-squared minimization to match normalized measured count rates from the three GRDs with pre-simulated values. The celestial sphere is divided into 12 coarse regions, each



**Figure 9.** A GRD flight model unit undergoing thermal cycling testing. The unit is shown installed inside the thermal chamber, demonstrating the experimental setup used to verify the detector's performance under simulated space temperature environments ranging from +5°C to +35°C for 12.5 cycles, in accordance with the onboard product environmental testing requirements for the SVOM satellite.

further subdivided into 64 fine regions. The localization procedure involves: (a) identifying the coarse region; (b) refining within the corresponding fine region; and (c) applying chi-squared tests to determine the best match between measured and simulated count rates.

To accommodate different GRB spectral properties, three distinct localization tables (for soft, medium, and hard spectra) are employed based on the measured hardness ratio. Each table provides azimuth ( $\phi$ ) and polar ( $\theta$ ) angle coordinates and is stored in the GEB's EEPROM, with provisions for in-flight updates when necessary. Simulation-based validation confirms that GRM's on-board localization strategy meets the performance requirements outlined in Section 2. A detailed analysis of GRM's trigger and localization performance is characterized in He et al. (2026).

## 4. Ground Test and Validation

### 4.1. Ground-based Qualifications

To verify the environmental adaptability and reliability of the GRM instruments, comprehensive qualification tests were conducted on both qualification and flight models prior to integration with the SVOM satellite platform. Following the satellite test program requirements, these tests included thermal cycling, thermal vacuum, vibration and shock, electromagnetic compatibility, and magnetic tests, all performed under strict quality control protocols. The test regimen comprehensively covered environmental conditions expected

during both launch and in-orbit operations. Post-test review confirmed that the GRM subsystem successfully completed and passed all qualification tests. A photo of a GRD unit during the thermal cycling tests is shown in Figure 9.

GRD performance was characterized using an  $^{241}\text{Am}$  radioactive source before and after each environmental test, with comparative analyses performed to verify the absence of significant performance degradation. Table 3 presents the performance comparison for the three GRD units before and after vibration and shock tests, while Table 4 shows the results for thermal tests (thermal cycling and thermal vacuum) conducted on another GRD unit. The analysis demonstrates that variations in both peak positions and energy resolutions remain below 5%, meeting all specified requirements.

### 4.2. On-ground Test and Calibration

Following the ground calibration plan, comprehensive calibration experiments were conducted on both GRM qualification and flight models using hard X-ray beam facilities and multiple radioactive sources to characterize the instrument's detection performance. The energy response and detection efficiency were systematically measured across various operational configurations, including different high-voltage settings, discrimination thresholds, incident angles, temperature conditions, and beam positions.

#### 4.2.1. Hard X-ray Beam Tests

The GRM hard X-ray beam calibration was conducted at the National Institute of Metrology's Hard X-ray Calibration Facility (HXCF). The facility provides monochromatic X-ray beams through two primary systems: double-crystal monochromators utilizing Si-220 crystals (35–80 keV) and Si-551 crystals (80–160 keV), and single-crystal monochromators employing LiF-220 or LiF-200 crystals (7–40 keV). A lead-shielded collimation system with precisely machined apertures (primary: 9 mm; secondary: 6 mm incident/5 mm exit) ensures well-defined beam geometry.

During calibration, each GRD detector was horizontally mounted on a translation stage within a shielding box, with the front surface exposed to the beam and positioned near the collimator exit. A high-purity germanium (HPGe) reference detector was placed alongside for independent beam monitoring, enabling comprehensive energy response characterization across the specified energy ranges. The complete experimental configuration at HXCF is shown in Figure 10.

#### 4.2.2. Radioactive Source Tests

GRDs operate over an energy range of 15 keV–5 MeV. To calibrate the high-energy response, multiple radioactive sources were employed to cover the entire detectable range and establish an accurate energy–channel (E–C) relationship.

**Table 3**  
GRD Performance Comparison Before and After Vibration and Shock Tests

| GRD   | High Voltage<br>(V) | <sup>241</sup> Am Peak Position <sup>a</sup> |        |           | Energy Resolution |        |           |
|-------|---------------------|----------------------------------------------|--------|-----------|-------------------|--------|-----------|
|       |                     | Before                                       | After  | Variation | Before            | After  | Variation |
| GRD-A | 1175                | 369.90                                       | 372.30 | +0.65%    | 16.40%            | 16.51% | +0.67%    |
| GRD-B | 1205                | 386.10                                       | 376.30 | −2.54%    | 16.55%            | 16.44% | −0.66%    |
| GRD-C | 1185                | 371.30                                       | 379.80 | +2.29%    | 16.82%            | 16.80% | −0.12%    |

**Note.**

<sup>a</sup> The 59.5 keV photon peak position of <sup>241</sup>Am is given in ADC channels.

**Table 4**  
GRD Performance Comparison Before and After Thermal Tests

|                 | <sup>241</sup> Am Peak<br>Position <sup>a</sup> | Energy<br>Resolution | High Gain and<br>Low Gain Ratio |
|-----------------|-------------------------------------------------|----------------------|---------------------------------|
| Before test     | 384.00                                          | 17.76%               | 9.57                            |
| After test      | 373.00                                          | 17.73%               | 9.55                            |
| Variation ratio | −2.86%                                          | −0.17%               | −0.21%                          |

**Note.**

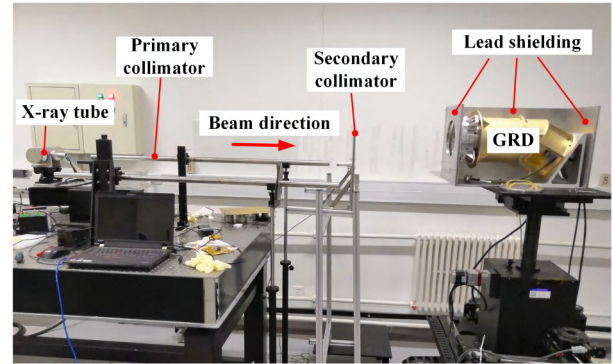
<sup>a</sup> The 59.5 keV photon peak position of <sup>241</sup>Am is given in ADC channels.

The calibration sources include <sup>137</sup>Cs (661.6 keV, 32.2 keV), <sup>113</sup>Sn (391.7 keV), <sup>60</sup>Co (1173.2 keV, 1332.5 keV), <sup>88</sup>Y (14.9 keV, 898.0 keV, 1836.1 keV), <sup>57</sup>Co (14.4 keV, 122.1 keV), <sup>22</sup>Na (511.0 keV, 1274.5 keV), and <sup>241</sup>Am (59.5 keV).

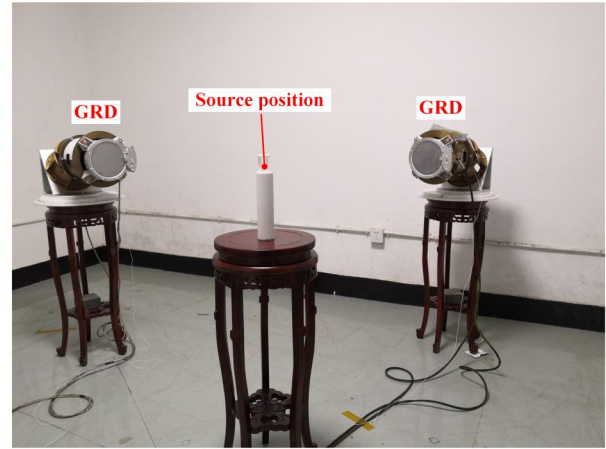
Utilizing the three data acquisition channels of GEB, three GRD units were calibrated simultaneously. To minimize detector non-uniformity effects and approximate parallel beam incidence, radioactive sources were positioned 3 m from the detector surfaces based on prior simulations. The three detector units were adequately spaced to reduce scattered photon interference. The complete source-based calibration setup is shown in Figure 11.

#### 4.2.3. Calibration Results

During calibration tests, the environmental temperature was maintained at  $17 \pm 2^\circ\text{C}$  to minimize temperature-induced variations. Combined analysis of HXCF beam and radioactive source calibration data provides a comprehensive detector performance characterization. Figure 12 presents preliminary results for GRD-A's high-gain channel, showing the energy-channel (E–C) relationship and energy resolution. The E–C relationship was fitted in three energy segments while the energy resolution was fitted in two segments. Results indicate good energy linearity, with both energy range and resolution meeting specifications as indicated in Table 1. A detailed presentation of the complete ground calibration methodology



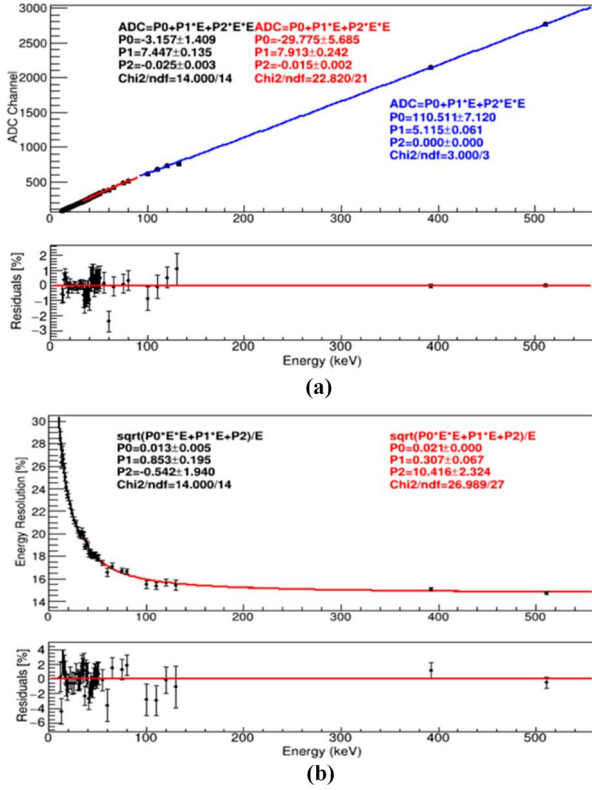
**Figure 10.** Experimental setup for GRM detector calibration at the Hard X-ray Calibration Facility (HXCF).



**Figure 11.** Experimental setup for GRM detector calibration using radioactive sources.

and results will be provided in a dedicated GRM calibration paper currently in preparation.

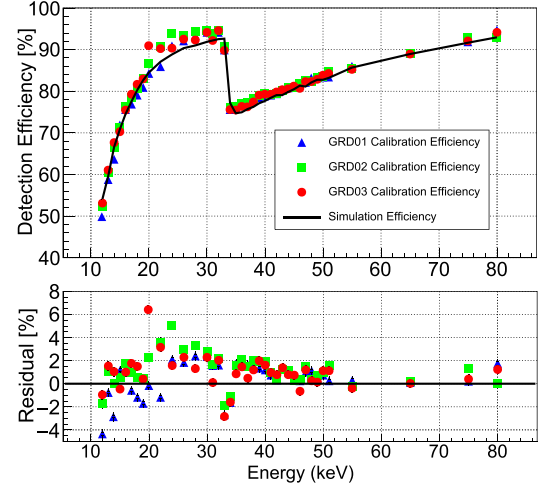
During the HXCF beam tests, by comparing the counting rates of a GRD unit and the HPGe reference detector, we can calculate the detection efficiency of the GRD. Due to the impact of beam flux stability on the calibration results of GRD's detection efficiency, the tests used comparative measurements from the HPGe detector to monitor the count



**Figure 12.** Preliminary calibration results for GRM. (a) Energy–channel relationship of GRD-A high-gain channel. (b) Energy resolution of GRD-A high-gain channel.

rate variations of the beam before and after the GRD test. If the variation between two consecutive HPGe measurements exceeded 3%, the beam was considered unstable, necessitating a recalibration. The detection efficiency measurement results of the three GRD units are shown in Figure 13, along with the simulation result. It indicates that the simulation result is generally consistent with the calibrated detection efficiencies for the three GRD units across the 10–80 keV energy range, demonstrating that the Geant4 simulation mass model and physics interaction processes developed for GRM align well with the actual instrument design. However, a slight overestimation in the measured values is observed within the 20–30 keV energy range, which is likely due to instability in the beam flux during the tests. Despite this minor discrepancy, the deviation between the calibrated efficiencies and simulated values remains within 7%, meeting the calibration accuracy requirements.

The uncertainties obtained during ground calibration provide a first-order estimate of the systematic uncertainties. The energy response residuals translate to a systematic uncertainty of a few percent in photon energy assignment across the energy range. For detection efficiency, the <7% deviation between measured and simulated values implies a



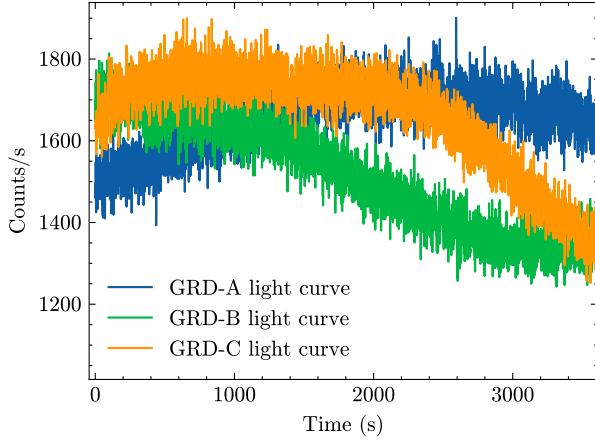
**Figure 13.** Comparison of measured and simulated detection efficiencies for the three GRD units across the 10–80 keV energy range. Experimental data were obtained through calibration measurements at the HXCF beamline, while simulation results were generated using the Geant4-based GRM mass model. The generally good agreement between measurement and simulation validates the accuracy of the detector response modeling, with deviations remaining within the 7% requirement.

similar level of systematic uncertainty in flux determination. These uncertainties may propagate into scientific products such as fluence and peak flux measurements at the level of a few percent, depending on the energy band and spectral shape.

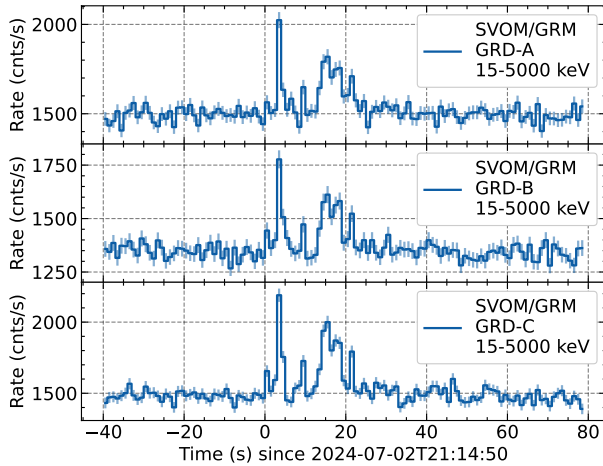
To validate and refine the ground calibration results, GRM performs regular in-orbit calibrations using the onboard  $^{241}\text{Am}$  calibration sources and the 190 keV and 511 keV background spectral lines. Comparisons between in-orbit and ground calibration data allow for monitoring of gain drifts and correction of any residual offsets, ensuring the long-term stability and accuracy of the instrument response. The analysis of the GRM detector energy response is presented in Zhao et al. (2026), and a comprehensive in-orbit calibration performance will be detailed in a dedicated paper currently in preparation.

## 5. Preliminary In-orbit Performance

Since the launch of the SVOM satellite, GRM has maintained a nominal operational status. Throughout the commissioning phase, comprehensive parameter verification confirmed full instrument functionality consistent with ground-based design specifications. The onboard software demonstrates correct operation: GRM automatically disables high-voltage supplies upon entering the SAA area and restores them after exit; the instrument autonomously transitions between GRB 1 (internally triggered) and GRB 2 (externally triggered by ECLAIRs) modes, returning to background mode following burst episodes.



**Figure 14.** In-orbit background light curves for all three GRD units. The curves show one-hour observations in the 15–5000 keV energy band starting from 2025-10-01T22:44:00.



**Figure 15.** Light curves of the bright long-duration GRB 240702A observed by the three GRDs of SVOM/GRM. The emission exhibits a multi-peaked temporal structure.

Preliminary in-orbit calibration confirms that the three GRD units maintain an energy response from several keV to several MeV (extending beyond 5 MeV), consistent with pre-launch calibration results. The energy resolution remains stable at 15%–17% across all units, with a temporal resolution better than 20  $\mu$ s. For bright GRBs (fluence  $> 1 \times 10^{-6}$  erg cm $^{-2}$  in 1–1000 keV, 1 s duration) within its FoV, GRM achieves a statistical localization accuracy better than 5° (He et al. 2026).

Between 2024 June 26 and 2025 January 15 (204 days of operation), GRM detected 78 high-energy transients, including 71 confirmed GRBs. This detection rate corresponds to an annual yield exceeding 100 GRBs, surpassing the design requirement of 90 GRBs per year and in good agreement with pre-launch simulations, which predicted an annual detection rate of approximately 106 GRBs (He et al. 2025).

Figure 14 presents the in-orbit background light curves for all three GRD units over a one-hour period. The count rates fluctuate between approximately 1200–1800 counts s $^{-1}$ , showing excellent agreement with Monte Carlo simulations (He et al. 2020), which predicted an average background rate of  $\sim 1340$  counts s $^{-1}$  for typical orbital conditions. The observed background differences among the three units result from their distinct pointing directions and varying obstruction conditions, as expected from pre-launch analysis. Figure 15 shows a bright GRB (GRB 240702A) detected by the GRM during the early in-orbit phase (Dong et al. 2024), which was also detected by other instruments such as the GBM (Fermi GBM Team 2024). Further analysis of GRM’s in-orbit performance is ongoing, with detailed publications in preparation.

## 6. Summary

The GRM instrument onboard the SVOM satellite has been operating successfully in orbit for more than 1.5 yr, demonstrating excellent stability and reliability. Throughout this period, the instrument has maintained consistent performance while detecting numerous high-energy transient events, particularly GRBs, contributing significantly to time-domain astronomy and multi-messenger astrophysics.

The comprehensive in-orbit verification confirms that all key performance parameters—including the energy range (extending from several keV to beyond 5 MeV), energy resolution (15%–17%), temporal resolution (better than 20  $\mu$ s), and background characteristics—align closely with pre-launch predictions based on extensive ground calibration campaigns and Monte Carlo simulations. All functional and performance requirements specified in the mission design have been successfully fulfilled, validating the instrument’s robust design and implementation. The scientific productivity of GRM is evidenced by the detection of over 100 GRBs annually, exceeding the mission requirement of 90 GRBs per year. These observations have enabled valuable insights into GRB spectral properties, temporal characteristics, and population statistics. The instrument’s capability to provide coarse localization and autonomous mode transitions has proven essential for rapid follow-up observations and multi-wavelength coordination.

The continued operation of GRM promises further contributions to high-energy astrophysics. Ongoing data analysis is yielding new insights into GRB physics and other transient phenomena (Tan et al. 2025). A series of publications detailing the instrument performance, calibration methodology, and scientific discoveries are in preparation and will be submitted to peer-reviewed journals in the coming months.

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