Glitch Identification Method for the HXMT High Energy Telescope (Postprint)

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Abstract

The HXMT satellite' s high-energy telescope data exhibits clustering of spurious photon events, prominently manifested as numerous glitches in the light curves. This has a certain impact on the study of light curves and energy spectra. This paper analyzes the properties of a large number of glitch events and identifies glitches based on these properties through the adjacent event time interval method. We find that this method can identify glitches at the event level, which offers significant advantages over methods utilizing some characteristic functions, such as the signal-to-noise ratio method. The identification of glitch events has a very minimal impact on normal photon events, and glitch events do not produce periodic or quasi-periodic signals in light curves.

Full Text

Spike Identification Methods for the High Energy Telescope onboard HXMT

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Abstract

The High Energy Telescope (HE) onboard the Hard X-ray Modulation Telescope (HXMT) satellite exhibits clustering of non-photon events that manifest as prominent spikes in light curves. These artifacts significantly impact studies of temporal variability and energy spectra. Through analysis of extensive spike event data, we have characterized their properties and developed an event time interval neighborhood method for spike identification. This approach enables spike recognition at the individual event level, offering substantial advantages over feature-function-based methods such as signal-to-noise ratio techniques. The identification process minimally affects genuine photon events, and spike events do not generate periodic or quasi-periodic signals in timing analysis.

Keywords: Spike, time interval, signal-to-noise ratio, data analysis

0 Introduction

The Hard X-ray Modulation Telescope (HXMT) satellite, launched on June 15, 2017 from Jiuquan, marked China' s entry into X-ray astronomy observations. Covering the 1–250 keV energy band, HXMT combines large field-of-view scanning capabilities with high-precision pointed observations while monitoring high-energy X-ray and gamma-ray burst phenomena. The High Energy Telescope (HE) serves as the mission' s key scientific payload, employing a slat-collimator design with NaI(Tl)/CsI(Na) composite crystal detectors comprising 18 main detector units. The NaI crystals enable high-sensitivity observations of hard X-rays from 20–250 keV, while the CsI crystals monitor gamma-ray bursts in the 0.2–3 MeV range, with both crystals providing spectral and timing capabilities. Each detector unit consists of a composite crystal detector, photomultiplier tube (PMT), front-end electronics, and back-end electronics. When X-ray photons deposit their full energy in the NaI crystal, the CsI crystal functions as an active shield to monitor particle backgrounds and gamma photons. Pulse shape discrimination (pulse width) distinguishes signals from the two crystals. The PMT collects scintillation light, and signals undergo shaping and amplification in the front-end electronics. When signals exceed the trigger threshold, the back-end electronics records photon energy, pulse width, and timing information. However, signals exceeding the upper threshold ("large signals") are discarded without analog-to-digital conversion. With energy resolution approaching 19% at 60 keV, timing resolution of approximately 8 microseconds, timing accuracy of 2–4 microseconds, and dead time of only 3–5%, the rapid data processing unfortunately generates spurious photon-like signals present in both crystal types, appearing as sharp spikes in light curves.

These spikes severely impact both timing and spectral analyses. In light curves, spikes appear as sharp peaks that could be misinterpreted as genuine astrophysical variability. During small-field scanning and gamma-ray burst searches, spikes can be confused with sources and bursts, particularly for soft-spectrum, low-flux short bursts. Spikes also alter the power spectrum structure of source light curves and introduce noise fluctuations in direct demodulation imaging that interfere with source detection. Spectrally, spikes concentrate in low-energy channels, introducing uncertainties in model selection and parameter constraints. While low-energy events could simply be discarded, this would reduce source significance given the large effective area and high photon count rates at low energies. Therefore, removing these instrument-induced spike signals is essential.

Current literature contains limited discussion of this phenomenon. This paper systematically characterizes spike properties and identification methods to support HXMT HE data analysis and inform future fast electronics design and data processing pipelines. Although HE comprises 18 detector units with identical electronics designs and similar spike distributions, this study focuses on Detector Unit 2 as a representative example.

1 Properties of Spikes

Spike generation correlates with large energy deposition events in the crystals. Ground experiments demonstrate that spikes predominantly occur after large signals, which may induce space charge effects in the PMT and trigger numerous random threshold-crossing events. During low-gain observations with reduced high voltage (and consequently lower output signals for equivalent energies), spikes decrease significantly, confirming their close relationship with large signals.

Spikes also strongly depend on HE' s electronic architecture. Increasing data processing time (which increases dead time) or reducing high voltage both substantially suppress spikes. However, the fundamental origin remains unclear, potentially involving crystal scintillation, photoelectron production, and front-end electronics. Current experimental evidence favors large-signal-induced spikes over electronic noise, suggesting that normal photon events (20–250 keV) should not produce spikes. Rather than investigating root causes, this work focuses on minimizing spike impact through data processing.

[Figure 1: see original paper] shows a raw light curve segment from Detector Unit 2, with only in-flight calibration source events removed. Panel (a) displays the raw light curve with 0.01 s time resolution, panel (b) shows identified spike events, and panel (c) presents the light curve after spike removal. The Crab Nebula observation began at 13:40:26 on November 20, 2018. While the source signal remains relatively stable and the background primarily consists of orbital particles (with elevated counts at high latitudes), spikes exhibit rapid count increases and decreases within extremely short time intervals. Using the HXMT data analysis software module *hepical* with adjusted parameters, we isolated individual spikes as shown in panel (b). Panel (c) reveals the cleaned light curve, though some potential spikes remain.

[Figure 2: see original paper] presents statistical distributions from approximately 60 ks of Crab observations, yielding 762 isolated spikes containing 45,807 events. Panel (a) shows the electronic channel distribution: channels 0–10 correspond to above-threshold signals primarily from backgrounds, while spike events concentrate in channels 18–35 near the electronic threshold. HE' s automatic gain control maintains consistent electronic gain through in-flight calibration source peak tracking. Panel (b) displays pulse width distribution, where values below 80 correspond to NaI events and above 80 to CsI events. Spike pulse widths span a broad range covering both crystals' typical values. Panel (c) shows the time interval distribution between consecutive spike events, with most intervals below 100 microseconds following an exponential distribution. Panel (d) illustrates single-spike duration distribution, with most lasting 1-2 ms, though this depends on software parameters.

2 Spike Identification

Spike identification targets prominent spikes—clusters of numerous trigger events within brief time intervals. Treating spikes as signal and photon events as background enables detection via signal-to-noise ratio (SNR) criteria (the "function-based method").

Since most spikes last less than 5 ms, we bin light curves at 10 ms resolution. Background estimation uses either averaging or linear fitting over time intervals, with counts expanded by 1-3 standard deviations to cover normal photon variations. A 200-second (or shorter) background calculation step ensures essentially constant background counts. The SNR method employs SNR = S/(S+B)^(1/2). [Figure 3: see original paper] shows spikes selected with SNR > 3, consistent with Figure 1: see original paper. This method requires two parameters: background count and SNR threshold. While background parameters derive from measurements, SNR thresholds of 3 or 5 are typical. Alternative formulations like the incomplete gamma function IG(x,a) can replace the SNR formula:

$$IG(x,a) = \frac{\int_0^x t^{a-1}e^{-t}dt}{\Gamma(a)} = \frac{\int_0^x t^{a-1}e^{-t}dt}{\int_0^\infty t^{a-1}e^{-t}dt}, \quad x > 0, a > 0$$

where a represents background and x denotes data points. Points with IG(x,a) exceeding a threshold (e.g., 0.999999) are identified as spikes.

The HXMT data analysis software currently uses the neighborhood method, which identifies spikes by examining adjacent event time intervals: if the interval between consecutive events falls below TIMEDEL, a counter increments; when multiple consecutive events satisfy this condition and the total exceeds EVTNUM, the cluster is classified as a spike. Figure 1: see original paper shows spikes identified with TIMEDEL = 250 µs and EVTNUM = 25. Parameter selection requires careful balance: larger TIMEDEL demands larger EVTNUM to avoid misclassifying genuine photons, but excessively large EVTNUM misses some spikes. This introduces subjectivity in EVTNUM selection. The method imposes no restrictions on electronic channel or pulse width—avoiding channel cuts prevents spectral truncation, while omitting pulse width constraints maximizes utilization of spike counts that exceed both NaI and CsI signal levels.

The key distinction lies in identification granularity: the neighborhood method operates at the event level, while function-based methods identify spike time bins. Both require two parameters (TIMEDEL/EVTNUM versus background/threshold), but function-based methods like SNR offer simpler parameterization. If spikes originate from random threshold crossings due to electronic noise, normal photons could also induce variations. The neighborhood method addresses this by removing closely spaced events (either low-channel events or all events), which time-binning cannot achieve. For instance, setting EVTNUM = 2 and TIMEDEL = 120 µs enables event-level removal. Bin-based identification can split spikes across adjacent bins, causing missed detections and filtering genuine events, though smaller bin sizes improve detection while reducing false removals. Both methods yield similar results with proper parameters, but the neighborhood method holds clear advantages.

Parameter selection for the neighborhood method considers that most spike intervals fall within 250 µs, and during spike durations (milliseconds), background and source photons are negligible. For prominent spikes, achieving SNR = 5 requires approximately 25 events ($\mathrm{SNR} = 25/\sqrt{25} = 5$). Figure 4: see original paper shows the photon event count distribution within spikes when TIMEDEL = 250 µs and EVTNUM = 5, revealing rapid increase in spike counts as event numbers decrease. Figure 5: see original paper presents Monte Carlo simulations of 1000 counts/s data processed identically, showing identified spikes capped at 10 events. This result depends on count rate; actual Crab data (600-1400 counts/s from source plus background) justifies EVTNUM = 25 to avoid misclassifying photons. Figure 4: see original paper and Figure 5: see original paper show duration distributions, which shrink from milliseconds (EVTNUM = 25) to hundreds of microseconds (EVTNUM = 5).

3 Impact on Data Analysis

The HXMT data analysis software employs the neighborhood method to maximize spike identification while preserving genuine events, though some impact on spectra and light curves remains inevitable.

In spectral analysis, spikes primarily affect low-energy channels (18–35), but quantifying unidentified spikes proves difficult due to multiple uncertainties: fluctuations in crystal fluorescence efficiency and PMT photoelectron production complicate detection efficiency determination, while electronic noise and particle backgrounds hinder accurate background estimation. These factors are coupled, further complicating analysis. All methods inevitably misidentify some source photons as spikes through two mechanisms: (1) normal photons occurring during spike intervals are classified as spikes, and (2) photons temporally near spike boundaries are misidentified. The neighborhood method primarily suffers from the first case. Analyzing 3000 s of Crab data with ~800 counts/s (source plus background) and using in-flight calibration source events (17 counts/s, concentrated near channel 50) to estimate misidentification rates, only 7 of 52,384 calibration events were flagged as spikes (0.2%). The method also affects normal photon spectra through exposure time discontinuities: spikes create millisecond-to-microsecond gaps in continuous observations, but with minimal total impact –spike durations totaled only 0.11 s in the 3000 s exposure. A critical question for timing analysis is whether spikes induce periodic or quasi-periodic signals. [Figure 6: see original paper] shows the power spectrum of identified spike events from Crab observations, revealing no significant periodic or quasi-periodic features. The absence of Crab's ~33 ms pulsation signal in the spike power spectrum confirms that very few normal events are misidentified.

4 Summary and Discussion

The HXMT High Energy Telescope data contain clusters of non-photon events manifesting as spikes in light curves. These spikes typically last less than 2 ms, with inter-event intervals mostly below 100 µs. Energetically, they concentrate in low-energy channels (18–35), while their pulse width distribution spans the characteristic ranges of both NaI and CsI crystals.

Based on these properties, we employ the neighborhood method for spike identification, which operates at the event level and offers significant advantages over feature-function methods like SNR. Spike identification minimally impacts genuine photon events and does not generate periodic or quasi-periodic timing signals. However, the fundamental origin remains unclear beyond its association with large signals, and the completeness of spike identification is uncertain. Nevertheless, nearly all prominent spikes are removed from light curves. The impact on low-energy spectra couples with calibration and background estimation challenges. Notably, HXMT' s background estimation relies on blind detector counts and spectral shapes; since blind detectors share identical crystal and electronic designs with other units, unidentified spikes are suppressed through background subtraction.

While this work removes spikes across all energy channels, the HXMT analysis software also provides energy-selective spike removal to avoid affecting other bands. Spikes differ fundamentally from genuine gamma-ray bursts in their extremely short durations and absence across multiple detector units—characteristics that enable discrimination between bursts and spikes.

Although spikes correlate with large signals, the properties of these large signals, such as their dependence on geographic coordinates, require further investigation.

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