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# Enhancing Gamma-ray Burst Detection with Optimized Triggerless Data Analysis in LHAASO WCDA

Gamma-ray bursts (GRBs) are among the most powerful and luminous events in the universe, emitting vast amounts of energy over brief periods. The Large High Altitude Air Shower Observatory (LHAASO) Water Cherenkov Detector Array (WCDA) is instrumental in detecting high-energy gamma-ray emissions from these bursts, providing crucial insights into their underlying mechanisms. This study introduces significant advancements in triggerless data analysis algorithms for the LHAASO WCDA, aimed at enhancing the sensitivity and reliability of GRB detection.

We introduce an improved cell segmentation strategy that employs 49 cells around the source. In this configuration, the central cell and its 8 surrounding background cells are designated as ON cells. Each of these 9 cells is analyzed using two guarding rings: an inner ring of 8 cells (ring1) and an outer ring of 16 cells (ring2). If the noise level in either ring exceeds a specified threshold, the trigger window for that cell is discarded, thereby reducing background noise and enhancing detection accuracy.

To further refine our analysis, we implemented noise filtering techniques that consider the spatial distribution of signals, thereby reducing data volume and improving the signal-to-noise ratio. Bayesian Optimization (BayesOpt) was employed to fine-tune algorithm parameters, ensuring optimal performance and sensitivity. BayesOpt facilitates systematic exploration of the parameter space, identifying the most effective settings for detection enhancement.

Calibration procedures were developed to address variations in detector response and background noise. These procedures include adjusting the acceptance ratio between the central ON cell and surrounding OFF cells, accounting for time offsets using data from later time points of the burst peak, and applying curvature corrections to accommodate the geometric layout of the detector. Additionally, a Fano factor parameter was introduced to further refine the analysis, enhancing sensitivity to faint GRB signals by characterizing statistical fluctuations in the signal.

Our optimized algorithm was evaluated against traditional trigger-based methods using data from the BOAT GRB (GRB221009A) after T0 + 1400 seconds. The triggerless data analysis achieved a significance level of 10.9 sigma, compared to 16.9 sigma for triggered data, which also incorporated a Gamma/proton discrimination algorithm to better identify gamma signals. Despite the lower significance of the triggerless method, the smaller difference compared to the triggered data for the same period indicates considerable potential for further improvement.

These advancements underscore the importance of ongoing algorithmic development and parameter optimization in high-energy astrophysics. By integrating machine learning techniques such as Bayesian Optimization, we aim to achieve more precise and insightful observations of cosmic events. This integration contributes to a deeper understanding of the universe, demonstrating the potential of combining traditional astrophysical analysis with modern computational methods.

In conclusion, the integration of statistical methods, calibration procedures, and machine learning optimization techniques has significantly enhanced the performance of the LHAASO WCDA triggerless data analysis system. Our research highlights the potential of these methods to improve the detection and study of gamma-ray bursts, paving the way for new discoveries in high-energy astrophysics. The continued development of these techniques promises more detailed and accurate observations of GRBs, contributing to the broader field of astrophysics and our understanding of the universe.

Keywords: LHAASO WCDA, Gamma-ray Bursts (GRBs), Triggerless Data Analysis, Algorithm Optimization, Signal-to-Background Noise Separation, Bayesian Optimization, High-Energy Astrophysics

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