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Multi-wavelength Study of Gamma-Ray Burst Afterglows: from X-rays to GeV / TeV

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Observations of the early X-ray afterglow phases of Gamma-Ray Bursts (GRBs) using the Swift X-ray Telescope (XRT), which operates in the 0.3 to 10 keV energy range, have revealed distinct temporal features beyond those predicted by the standard forward shock afterglow model. Components in the XRT light curve, such as steep decay, flares, and plateaus, suggest more complex afterglow physics. These observations highlight the need for a systematic, multi-wavelength investigation into the temporal and spectral evolution of GRB afterglows. In this work, we perform a comprehensive analysis of GRB afterglow emissions spanning a broad energy interval, from soft X-rays (0.3 keV) to high-energy gamma rays (˜ 100 GeV). Our dataset combines observations from Swift/XRT, Swift's Burst Alert Telescope (BAT; 15- 150 keV), and the Fermi Large Area Telescope (LAT), which detects photons in the 30 MeV to 300 GeV range. The selected GRBs in our sample exhibit prominent high-energy gamma-ray components, allowing us to probe the full spectral behavior across this wide range. Our results indicate that the broadband spectra of these GRBs often show a double-peaked structure in their spectral energy distributions. This characteristic provides new insights into the physical processes at play in the emission regions, particularly regarding the emission of X-ray and GeV photons. We interpret these findings in the context of synchrotron self-Compton (SSC) models, discussing how they inform our understanding of the microphysics driving forward shock emissions. Furthermore, our analysis highlights the crucial role of very high energy (VHE) gamma-ray observations (>100 GeV) in uncovering the mechanisms responsible for these complex behaviors. We also explore the future potential of observatories such as the Cherenkov Telescope Array Observatory (CTAO) to enhance our understanding of GRB spectral evolution in the VHE domain. By synthesizing observations across multiple energy bands and emphasizing the contributions from VHE instruments, our work advances the broader goal of understanding the physical processes underlying GRB phenomena.

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