A Fast GRB Source Localization Pipeline for the Advanced Particle-astrophysics Telescope

Marion Sudvarg Jeremy Buhler James Buckley Wenlei Chen Zachary Hughes
Emily Ramey Michael Cherry Samer Alnussirat Ryan Larm
Cristofer Berruz Chungata For the ADAPT Collaboration

July 3, 2021

The Advanced Particle-astrophysics Telescope (APT) is a space-based observatory, currently in development, to survey the entire sky for gamma-ray sources in the MeV to 100 GeV range. APT's goals include prompt detection of energetic transient events in the distant universe, such as gamma-ray bursts (GRBs), and rapid communication of these events to narrow-band instruments that can conduct follow-up observations in other spectral bands. Pursuant to this goal, we are developing analytical methods to perform real-time detection and localization of events, which will run on computing hardware on the orbiting APT platform.

In this work, we focus on detecting events for which most incident photons have energies in the Compton regime (511 keV to a few MeV). For such events, the photons of interest Compton-scatter one or more times within the detector, depositing energy with each scattering, until they are eventually photoabsorbed. All scatterings for one photon appear simultaneous at the time resolution of the detector. Our analytical tasks are twofold: first, to identify the first two scatterings for each photon in order of occurrence, which localizes the source's direction to an annulus centered on the line connecting these scatterings; and second, to combine the annuli from all detected photons to estimate the most likely direction in the sky for a distant point source (the GRB) that emitted them.

Several computational challenges arise in building a robust pipeline of algorithms for event detection and localization. The pipeline must accurately localize even low-fluence events (at most a few thousand total incident photons) while being efficient enough to keep up with high-fluence events (around 10^5 photons/sec) involving many photons that might scatter 5 or more times within the detector. It must yield results quickly enough to permit rapid retargeting of narrow-band instruments to the event – ideally in well under a second. And it must deliver this performance using a low-power processor of the type feasible for a space-based platform. All of these criteria must be met while also dealing robustly with the measurement limitations of the APT detector.

This work describes a computational pipeline for Compton-regime reconstruction and event localization. We build on the basic approach of Boggs and Jean[1] to reconstruct photon trajectories within the instrument by minimizing disagreement between the reconstructed angle of each scattering and the energy it deposited. To eliminate redundant computation and ensure rapid analysis even of photons with multiple scatterings, we implement a tree search with pruning over possible photon trajectories to find one with the best agreement. Event localization from reconstructed photons then follows a maximum-likelihood approach, with random sampling of reconstructed photons to guess a plausible source direction, followed by iterative refinement. We demonstrate that our pipeline can reliably localize events to within 2.53 degrees (68% containment) for low-fluence events and 0.42 degrees for high-fluence events while delivering results within 200 ms even on a low-power ARM Cortex-A53 processor.

[1]S. Boggs and P. Jean, "Event reconstruction in high resolution Compton telescopes," *Astronomy and Astrophys. Supp. Series* **145** (2000) 311.