The Advanced Particle-astrophysics Telescope: Simulation of the Instrument Performance for Gamma-Ray Detection

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We present simulations of the instrument performance of the Advanced Particle-astrophysics Telescope (APT) and the Antarctic Demonstrator for APT (ADAPT).

The APT is a high-energy gamma-ray and cosmic-ray mission concept. The instrument design is aimed at maximizing effective area and field of view for MeV-TeV gamma-ray and cosmic-ray measurements. Considering the limit payload mass and instrument cost, we propose a detector design based on 3-meter scintillating fibers read out by Silicon photomultipliers (SiPMs). The APT detector includes a multiple-layer tracker composed of scintillating fibers and an imaging calorimeter composed of thin layers of sodium-doped CsI (CsI:Na) scintillators and wavelength-shifting (WLS) fibers. The CsI:Na crystals are coupled to crossed planes of wavelength shifting fibers to localize energy deposition to ~ mm accuracy. With about half of the number of electronic readout channels of the Fermi Gamma-ray Space Telescope (FGST) Large Area Detector (LAT) and a relatively shallow (< 6 radiation length) calorimeter, our simulations show that the critical performance requirements can be met within a reasonable payload mass for available launch vehicles. The ADAPT is a balloon experiment using a small portion ~ 1% of the APT detector. The ADAPT experiment will demonstrate the potential of our instrument concept and test our gamma-ray and cosmic-ray reconstruction algorithms.

The major scientific goals of the APT experiment include fast, all-sky, and large effective area detection and localization of gamma-ray bursts (GRBs) and other gamma-ray transients such as gravitational wave counterparts and searches for thermal dark-matter particles over the entire natural range of masses and total annihilation cross section. We developed a simulation package called APTsoft that includes scripts to generate geometry configuration files, Geant4 simulation code to simulate gamma-ray and cosmic-ray interactions with the detector, optical simulation code of light collection and electronics detection, and gamma- and cosmic-ray event analysis tools to calculate instrument performance. The specifications of the detector response for the simulations are derived from measured performance parameters from prototype tracker fibers and a prototype of the CsI detector. At energies above 30 MeV, pair production is the dominant photon interaction in most materials, by which an electron-positron pair is created as the cosmic gamma-ray interacts in the electric fields of atoms in the detector. At lower energies (< 10 MeV), incident gamma-rays experience multiple Compton scatterings. The APT instrument will function both as a pair telescope for 30 MeV to 1 TeV gamma-rays and as a Compton telescope with excellent sensitivity down to ~ 0.3 MeV. Our simulations show that the APT could provide an order of magnitude improvement in effective area and sensitivity for gamma-ray detections compared with the Fermi-LAT. At MeV energies, the APT could achieve sensitive detection of faint GRBs and other gamma-ray transients down to ∼ 0.01 MeV/cm^2 with degree-level to sub-degree-level localization accuracy. The sensitivity of the polarization measurement in terms of degree of polarization for ∼ 1 MeV/cm^2 GRBs is below 20%, making the APT a very powerful polarimeter for measuring both the degree of polarization and polarization angles for GRBs at MeV energies.

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