**Advanced Particle-astrophysics Telescope (APT)**

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The *Advanced Particle-astrophysics Telescope* (APT) is a concept for a future space-based $\gamma$-ray mission that would provide an order of magnitude improvement in sensitivity in the 1 MeV to 50 GeV range compared with Fermi or any existing (or proposed) Compton telescope. The straw-man concept makes use of multiple layers of long scintillating fibers and thin CsI tiles covering a large passive area of 3m$\times$6m. With a thickness of $< 4$ radiation lengths, the concept trades energy resolution and high-energy reach for a very large effective area and nearly all-sky coverage. This trade-off would result in an optimal design for the primary science drivers: identifying dark matter and revealing the nature of gravitational wave sources and short $\gamma$-ray bursts. By replacing the passive converter layers (e.g., the tungsten foils employed in pair-production telescopes) with imaging CsI detectors, the instrument will function both as a pair telescope for 100 MeV to $\sim$50 GeV $\gamma$-rays and as a Compton telescope with excellent sensitivity down to MeV energies. At GeV energies where effective area begins to become the dominant factor determining sensitivity, the much larger geometry factor of the instrument would result in an order of magnitude improvement in sensitivity compared with Fermi. While the Compton angular and energy resolution would be somewhat limited, the enormous effective area would result in an improvement in sensitivity in the $\sim$MeV to 100 MeV regime by orders of magnitude compared to any extant instrument. In the Compton regime, the higher detection statistics would more than compensate for a degradation in angular resolution for localization of short transients. Another unique feature of the instrument concept is incorporation of transition radiation detectors (TR) by adding passive multi-layer radiators as part of the fiber support structure. While the idea lacks an experimental demonstration, preliminary calculations and past studies (for cosmic-ray experiments) indicate that with the use of high-energy TR detectors (with thick TR converter layers and CsI detectors for $>$100 keV X-rays) the instrument could potentially extend energy measurements up to electron energies of 50 GeV [3][4] but with only 3 radiation lengths of CsI (see Fig. 1). The up-down symmetry of the detector layers would also allow particles to enter from the top or bottom of the instrument, providing close to a $4\pi$ sr field of view for a high orbit.

The primary science goals for the mission are to conduct a definitive search for dark matter, and to provide instantaneous nearly all-sky coverage (with a $\sim 10 i\mathrm{m}^2$ effective area) to search for the signals from short $\gamma$-ray bursts and gravitational wave sources. Analysis of Fermi LAT data on dwarf galaxies results in some of the most powerful constraints on generic models of WIMP dark matter up to $>$100 GeV masses [1] and underscores the important role of indirect detection on solving the dark matter problem. With more than an order of magnitude improvement in the exposure factor for dwarf galaxies in the GeV range and with extended coverage of the continuum spectrum down to MeV energies, APT will be able to rule out the entire natural parameter space for a thermal WIMP up to TeV mass scales. At mass scales above $\sim$1 TeV the continuum spectrum will reach hundreds of GeV where ground-based instruments like CTA can be used more effectively to detect the continuum $\gamma$-ray emission. Moreover, annihilation line features are more effectively probed by ground-based experiments like CTA down to even lower masses (down to $\sim$100 GeV). Acknowledging the important role of ground based experiments, the philosophy of trading maximum energy and energy resolution for a larger geometry factor is likely to lead to the optimum DM search strategy. While the design is driven by dark matter science, this design also makes a number of secondary scientific objectives possible.

The recent discovery of gravitational waves by the LIGO collaboration [2] points to the importance of instantaneous all-sky coverage to detect electromagnetic counterparts needed to localize these events. The $\gamma$-ray band is one of the few wavebands (over the entire electromagnetic spectrum) in which true instantaneous all-sky coverage is possible. The very large effective area of APT in the MeV to multi-GeV regime would be ideal for detecting GeV emission from short $\gamma$-ray bursts or the MeV to GeV counterparts from gravity wave sources. A larger GeV FoV and larger MeV effective area could offer a great improvement in the capability of APT compared to Fermi. For GRBs, Fermi has only seen the brightest events near the high end of the fluence distribution; thus the dramatic improvement in effective area is as (or more) important as the larger instantaneous field of view.

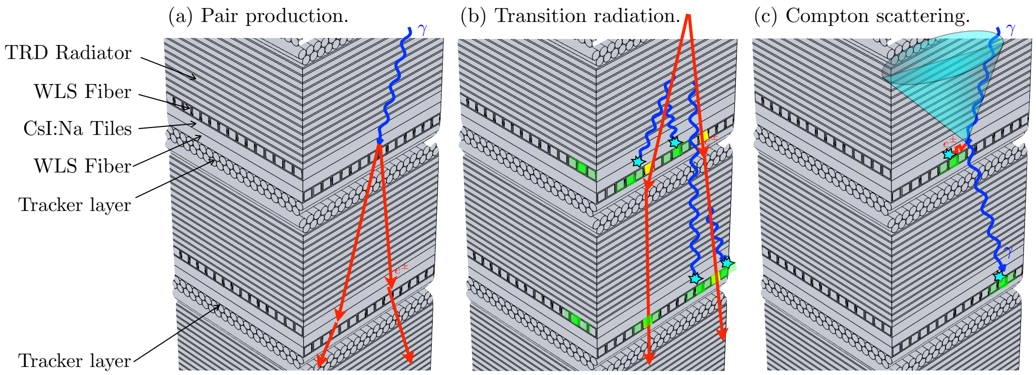


**Figure 1:** Cross section of APT showing 2 of the 20 layers, and demonstrating: (a) Pair telescope mode where a primary $\gamma$-ray pair produces and the $e^- + e^+$ pair are tracked in subsequent hodoscope layers; (b) Transition radiation mode where Lorentz-factor measurements of the electron and positron from a pair or a primary cosmic-ray are provided by the TR radiator and CsI hard X-ray detector; and (c) Compton telescope mode where one or more Compton scatters is followed by total absorption of the Compton gamma. Dark blue indicates photons ($\gamma$-rays or X-rays), red indicates charged particles (e.g., electrons and positrons, blue stars indicate energy deposition in the CsI, and green indicates light collected by the WLS fibers. The blue cone in figure (c) represents the reconstructed arrival direction for a Compton telescope measurement.

Another, secondary capability of the instrument also has a bearing on the primary dark-matter science driver, but through the detection of charged cosmic rays rather than $\gamma$-rays. The use of a transition radiation detector to reduce the instrument mass for $\gamma$-ray measurements will also provide measurements of cosmic-rays with energies approaching the knee in the all-particle spectrum. In particular, this capability could result in the measurement of the secondary to primary ratio of cosmic rays up to $\sim$100 TeV energies providing a critical data needed to understand cosmic-ray propagation, and to properly interpret cosmic-ray positron and antiproton measurements.

We describe a straw-man technical approach for APT that could achieve the order of magnitude improvement in sensitivity compared with Fermi at about the same total mission cost. The key to making this possible is the use of long scintillating fibers, and new solid-state high-QE photodetectors. The tracker layers would be formed of interleaved layers of round scintillating fibers for high detection efficiency (>30 photoelectrons for a minimum ionizing particle in a 1.5mm fiber). Limited pulse-height information from two layers could be used to centroid much better than the fiber pitch reaching an RMS resolution of around 250$\mu$m. The larger area of the instrument translates to a larger separation in the fiber planes for a given geometry factor, reducing the geometric contribution to angular resolution. In place of passive converter layers, CsI detectors would be used. Green wavelength shifting fibers covering thin sodium-doped CsI tiles could be used to shift the blue emission from the CsI:Na and pipe a fraction of the isotropically re-emitted light to the SiPM photodetectors. The relatively fast signals from ionization in the plastic WLS fibers could be discriminated from the relatively slow signal from ionization or X-ray absorption in the CsI:Na. Centroiding the light collected by the fibers would provide the $x - y$ coordinates of the interaction, and the spread of the light could be used to determine the depth of interaction. The use of long scintillating fibers read out at the edges of the instrument with solid-state photosensors (SiPMs) allows the large passive volume to be read-out by a similar number of electronic channels to the Fermi instrument ($\sim$800,000). This approach also allows for a doubling of the number of tracker layers compared with Fermi, and effectively eliminates gaps or embedded electronics in the detector volume. A $3 \times 6\text{m}^2$ instrument would fit inside the shroud of a number of existing launch vehicles. With 3 to 4 radiation lengths of CsI, the instrument and would fit within the mass budget of a heavy lift launch vehicle for a low earth orbit or even a Lagrange-point orbit. Either orbit would limit the total radiation exposure of the fibers to acceptable levels for a 10 year mission, but only the higher orbit would allow the realization of the full potential of the very wide field-of-view. The instrument would achieve an effective area of $\sim 10\text{m}^2$ and an etendu (or geometry factor) (in a high orbit) of $60\text{m}^2\text{sr}$. Based on a rough preliminary cost estimate, the proposed instrument could fit in the budget of a probe-class mission. Such a mission, optimized to address a central scientific question (the nature of dark matter) and addressing critical secondary science (the nature of short GRBs or gravity wave sources) could warrant prioritization in the next decadal survey.

## References


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