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New materials advance gamma-ray telescopes

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Advanced detector materials such as lanthanum bromide enable the design of a highly sensitive, low-background Compton telescope for a future gamma-ray astronomy mission.

There is a need for a new mission in the medium-energy band of gamma-ray astronomy (0.4-10MeV). This part of the cosmic electromagnetic spectrum encompasses a variety of high-energy physical processes occurring in the universe, that cannot be replicated in the laboratory. Medium-energy gamma-ray astrophysics addresses the acceleration of electrons, protons, and heavier ions to relativistic energies (as in, for example, solar flares, pulsars, and black holes) and the nuclear reactions that occur when these particles interact with matter (as in the formation of heavy elements in supernovae). Gamma rays hold clues to understanding nature under extreme physical conditions.

Satellite-based observations at these energies, however, are difficult due to the weak fluxes of the cosmic sources compared to the high background generated by cosmic-ray interactions with the spacecraft and instrument. The only practical instrument for all-sky spectroscopic imaging is the Compton telescope, due to its wide field of view and its background rejection properties. The classical Compton telescope was the COMPTEL instrument on NASA's Compton Gamma-Ray Observatory (CGRO).[1] It consisted of two layers of scintillator detectors separated by 1.6m. A good event required near simultaneous interactions in both layers (see Figure 1). Incoming gamma rays would Compton scatter in an organic liquid scintillator, and ideally be fully absorbed in a NaI crystal. From the positions and energy deposits in the two detector layers, the source of the incident photon could be constrained, using the Compton-scatter formula, to lie on the so-called Compton cone.[1] A critical feature of COMPTEL was its ability to measure the 5ns time-of-flight (TOF) of the scattered photon between the detector layers. Any event not showing the expected 5ns TOF delay would be rejected.

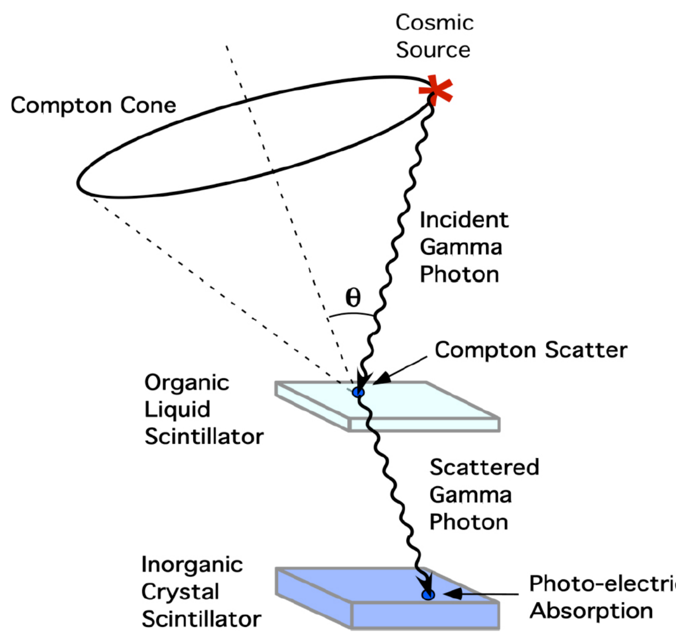

Figure 1. *Principle of a Compton telescope, such as COMPTEL. From the energy deposits of the Compton scatter and photo-electric absorption, the angle θ can be calculated, and the source of the incident photon is then constrained to lie on the Compton cone.*

There has been recent interest in using semiconductor materials, such as germanium, in the design of new Compton telescopes due to their excellent energy resolution.[2] Semiconductors, however, are expensive, and their timing resolution is too poor for TOF discrimination of background. At the same time, new scintillator materials, such as cerium-doped lanthanum bromide ($LaBr_3$:Ce), offer higher density, better energy resolution, and much faster response time than NaI.[3] With the philosophy that as much background as possible should be rejected before data analysis, we believe that a straightforward, cost-effective road to progress in this field is to develop a scintillator-based Compton telescope using material such as $LaBr_3$:Ce. This approach builds directly on the experience gained from the COMPTEL experiment, while taking advantage of new technology to

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confidently improve performance and reduce background. The tangible benefit would be sharper images (and thus a many-fold increase in detectable objects), far better spectral measurements of them, and the ability to study how they vary.

As a starting point in the design, we modeled detector planes 1m × 1m in size and 75cm apart.[4] This more compact envelope is made possible by the 400ps time resolution.[3] Based on the published properties of $LaBr_3$:Ce,[3] and compared to COMPTEL, we find that such an instrument would have comparable detection efficiency with much improved angular and energy resolution. Combining these factors with the reduced TOF acceptance window (400ps vs. 4ns), we estimate that the instrumental background would be reduced by at least a factor of twenty.[4]

A Compton telescope based on advanced scintillator technology could fit within the constraints of a NASA Medium Explorer mission and still improve on the sensitivity of the COMPTEL experiment by at least a factor of ten. We hope in the next year to expand our simulations to advance the design, and begin laboratory prototyping of this new instrument.

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