Fermi Large Area Telescope locates unexpected gamma-ray outbursts

Elizabeth Hays

A high-efficiency, high-precision, space-based particle tracker maps the sky in gamma rays, locating new and unexpected gamma-ray sources.

Ever since researchers learned a century ago that Earth is bombarded by gamma rays from space, scientists have searched for the sources of this high-energy radiation. The hot gases of stars do not generate light at the wavelengths of gamma rays, which each carry more than a million times the energy of an optical photon. Only the extreme conditions prevalent in phenomena such as jets of relativistic particles driven by accreting black holes, blast waves from supernova explosions, and strong electromagnetic fields around rotating neutron stars can accelerate particles to the energies required to produce gamma rays.

The Fermi Gamma-ray Space Telescope, launched in 2008, maps and monitors the high-energy gamma-ray sky in much greater detail than previous space-based gamma-ray missions. The Large Area Telescope (LAT) views 20% of the sky instantaneously and the entire sky every three hours at energies from ~20MeV to >300GeV. The first year of observations has revealed 1451 distinct gamma-ray sources, five times more than previously known. Many are associated with galaxies that contain an active, central black hole or with pulsars and supernova remnants in our galaxy. However, approximately 40% have no obvious relation to catalogued objects at other wavelengths, suggesting that some may be new types of gamma-ray emitters. More than 30% of the sources are variable, changing in brightness over days, weeks, or months. A new outburst may appear at any time.

The LAT (see Figure 1) detects gamma rays by converting them into electron/positron pairs that are tracked through the instrument. The design of the tracker balances efficient detection of gamma rays with precise measurement of their arrival directions. Each tower contains layers of tungsten—to convert gamma rays—alternating with silicon-strip detectors to track their electron/positron pairs. Figure 2 shows a single flight tray. Although the electron and positron pass through multiple planes (see Figure 3), position measurements close to conversion
A standard tray contains two layers of single-sided silicon-strip detectors, a single layer of tungsten foil, and readout electronics. The silicon detectors provide very high efficiency for detecting charged particles. Tungsten has a high atomic number, which is favorable for the pair-conversion process.

Critically impact the reconstructed direction. This consideration invites the use of thin tungsten layers placed near the silicon strips to minimize multiple scattering of the electron and positron before they pass through the silicon. However, to successfully convert gamma rays, the tungsten cannot be too thin. The LAT records many gamma rays from the same object over time to locate a typical source in the sky to an accuracy of hundredths of a degree.

In early 2010, scientists analyzing LAT data discovered a new gamma-ray transient source with the detection of V407 Cygni, a white dwarf star and a red giant star orbiting each other. The wind of the red giant transfers material away from the star at a high rate (up to 0.1 Earth masses per year). Matter accumulates on the white dwarf surface until it undergoes a thermonuclear explosion, producing a nova but leaving the white dwarf intact. Scientists were not sifting the LAT data specifically for such a discovery, but the presence of a new source was unmistakable (see Figure 4). The consistency with the optical location and the appearance of gamma rays within a day of the optical discovery confirm that the nova is the origin of the outburst. The total energy emitted in gamma rays implies that approximately 9% of the kinetic energy went into accelerating protons, a percentage comparable to that for supernova explosions.

V407 Cygni is a rare system because of the presence of the red giant and its accompanying high-density wind, which primes the white dwarf and enhances the gamma rays produced by the nova’s shock wave. Novae require decades—and, more commonly, millennia—between outbursts. It is, therefore, unlikely that another detectable gamma-ray nova will occur during the Fermi mission. Without the frequent monitoring, excellent sensitivity, and accurate source localization of the LAT, this remarkable event would have been missed.

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The first detection of a nova in gamma rays is one of many diverse results obtained in the past two years from LAT data. Fermi will continue to survey the sky in the coming years, catching new and unanticipated gamma-ray sources as they appear. This effort will continuously increase our knowledge of high-energy processes and the systems that contain them.

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**Author Information**

Elizabeth Hays  
NASA Goddard Space Flight Center  
Greenbelt, MD

Astrophysicist Elizabeth Hays serves as deputy project scientist for the Fermi Gamma-ray Space Telescope. Her research interests include searches for steady and transient sources of gamma rays in the Milky Way galaxy using a variety of gamma-ray telescopes.

**References**