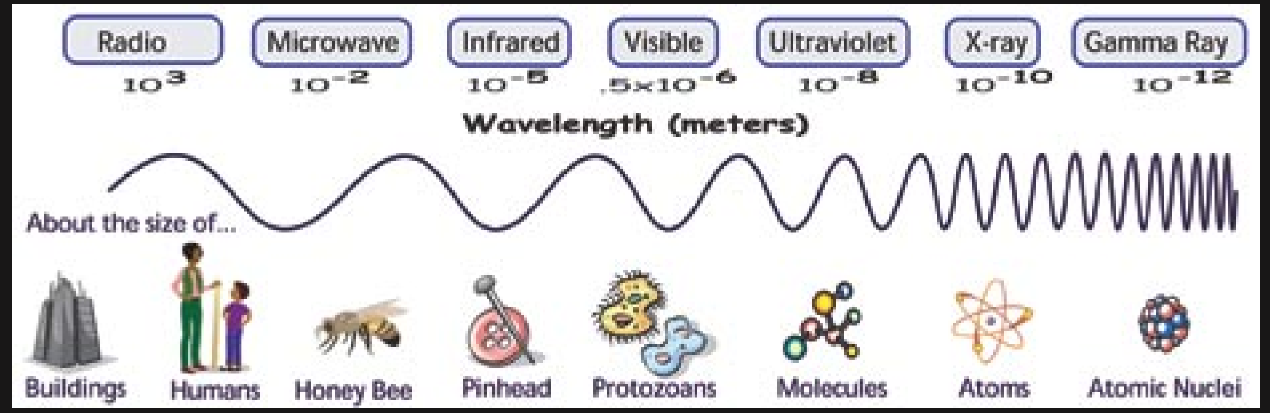
What Are Gamma Rays?

What we call light is really just a tiny fraction of the broad range of the electromagnetic radiation spectrum. The entire span stretches from very low-energy radio waves through microwaves, infrared radiation, visible light, ultraviolet light, X-rays, and finally to very high-energy gamma rays. The processes producing photons (single particles of electromagnetic radiation) of each type of radiation differ, as do their energy, but all of the different forms of radiation emitted are still just part of the electromagnetic spectrum's family. The only real difference between a gamma-ray photon and a visible light photon is the energy. Gamma rays can have over a billion times the energy of the type of light visible to our eyes.



In fact, gamma rays are so energetic that they are harmful to life on Earth. Luckily, the Earth's atmosphere absorbs gamma rays, preventing them from affecting life on the ground. However, if you want to observe the Universe in gamma-ray light, this poses a problem. The very atmosphere that protects us from gamma rays prevents us from observing them from the ground. Astronomical observations of gamma-ray sources in the GLAST energy range are therefore done with high-altitude balloons or satellites launched into space, above the protective blanket of the Earth's atmosphere.

The high energy of gamma rays poses another problem: they can pass right through any lens or mirror, making it very difficult to focus them in a telescope. Astronomical observations, therefore, must rely on a different technology to view the gamma-ray Universe. Scientists must make use of methods developed in the world of particle physics, where techniques for measuring high-energy particles have long been understood. GLAST's specialized astronomical instruments will therefore employ detectors used and perfected by physicists interested in the interactions of subatomic particles.

GLAST Science

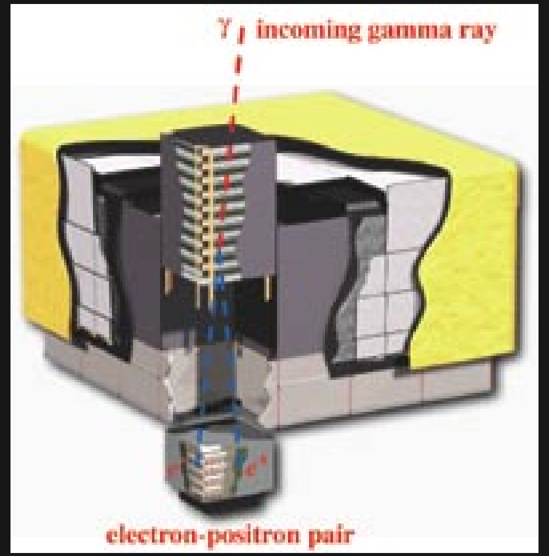
A considerable improvement over its successful predecessor – the Compton Gamma Ray Observatory – GLAST will have the ability to detect gamma rays in a range of energies from thousands to hundreds of billions of times more energetic than the light visible to the human eye. Radiation of such a magnitude can only be generated under the most extreme conditions; therefore GLAST will focus on studying the most energetic objects and phenomena in the Universe.

Because of their tremendous energy, gamma rays travel through the Universe largely unobstructed. This means GLAST will be able to observe gamma-ray sources near the edge of the visible Universe. Gamma rays detected by GLAST will originate near the otherwise obscured central regions of exotic objects like supermassive black holes, pulsars, and gamma-ray bursts. GLAST will study mechanisms of particle acceleration in extreme astrophysical environments. Among topics of cosmological interest will be the information obtained about the periods of star and galaxy formation in the early Universe and on dark matter.

Studying these high-energy objects and events with the advanced technologies of GLAST could give us an entirely new understanding of our Universe, revealing unanticipated phenomena. Historically, such new knowledge has eventually given rise to altogether new technologies.

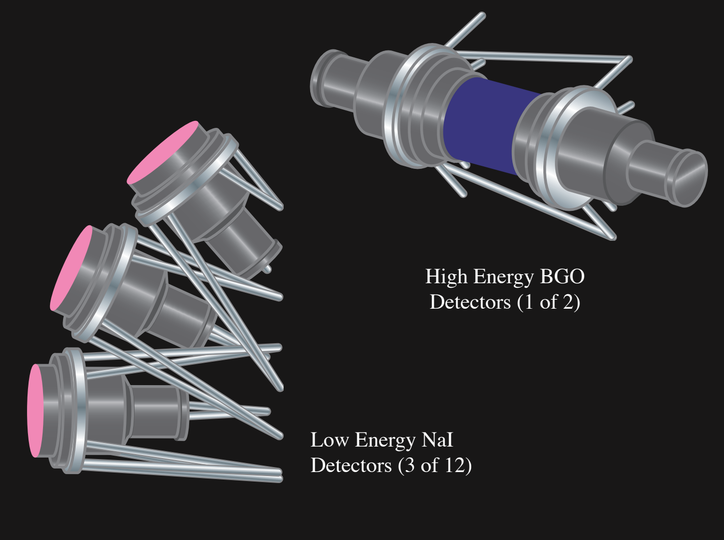
The Instruments

GLAST will employ two instruments to observe the gamma-ray Universe. The primary instrument is the Large Area Telescope, or LAT. It has a wide field-of-view, allowing it to see large areas of the sky at the same time. It will detect gamma rays with 10 million to 150 billion times the energy of the light detected by the human eye (in technical terms, it detects gamma-ray energies of 20 million electron volts to greater than 300 billion electron volts, where the energy of visible light is roughly 2 electron volts).



The LAT will detect gamma rays by using a technique known as pair-conversion. When a gamma ray slams into a layer of tungsten in the detector, it creates a pair of subatomic particles (an electron and its anti-matter counterpart, a positron). These particles in turn hit another, deeper layer of tungsten, each creating further particles and so on. The direction of the incoming gamma ray is determined by tracking the direction of these cascading particles back to their source using high-precision silicon detectors. Furthermore, a separate detector counts up the total energy of all the particles created. Since the total energy of the particles created depends on the energy of the original gamma ray, counting up the total energy determines the energy of that gamma ray. In this way, GLAST will be able to make gamma-ray images of astronomical objects, while also determining the energy for each detected gamma ray.

The secondary instrument onboard is the GLAST Burst Monitor, or GBM. The GBM is designed to observe gamma ray bursts, which are sudden, brief flashes of gamma rays that occur about once a day at random positions in the sky. These bursts are still a mystery to astronomers; no one knows what causes them, or what physical forces are at work. All that is known is that they are among the most powerful explosions in the Universe. The GBM has such a large field-of-view that it will be able to see bursts from over 2/3 of the sky at one time, providing locations for follow-up observations of these enigmatic explosions. The GBM is composed of two sets of detectors – 12 sodium iodide (NaI) scintillators and two cylindrical bismuth germanate (BGO) detectors. When gamma rays interact with these crystalline detectors, they produce flashes of visible light, which the detector can use to locate the gamma-ray burst on the sky. The GBM works at a lower energy range than the LAT, so together they provide the widest range of energy detection in the gamma-ray regime for any satellite ever built.



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Cosmology and Particle Astrophysics – NASA/STScI
Pulsars – NASA/CXC/SAO

GLAST

Gamma-ray Large Area Space Telescope

The Universe is home to exotic and beautiful phenomena, some of which produce fantastic amounts of energy. Supermassive black holes, merging neutron stars, streams of hot gas moving close to the speed of light ... these are but a few of the marvels that generate gamma rays, the most energetic form of electromagnetic radiation.

The Gamma-ray Large Area Space Telescope (GLAST) will explore this high-energy cosmos. With GLAST, astronomers will have a sensitive tool to study how black holes – well known for their ability to swallow up matter – can actually accelerate jets of matter outward at fantastic speeds; physicists will be able to search for new fundamental interactions between subatomic particles, and cosmologists will gain valuable information about the birth and early evolution of the Universe. In a real sense, GLAST will explore the links between the realm of the very small with the Universe of the very large.

For this unique endeavor – one that combines many scientific disciplines – NASA is teaming up with the U.S. Department of Energy and institutions in France, Germany, Italy, Japan, and Sweden. The launch is scheduled for 2006.

http://glast.gsfc.nasa.gov/

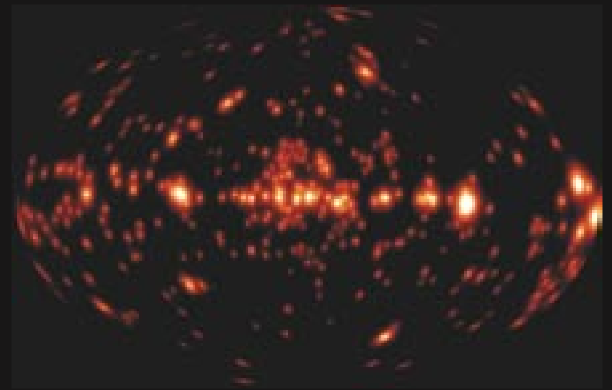
The Gamma-ray Sky

Gamma Ray Bursts

Intense flashes of gamma rays lasting from fractions of a second to hours, some with fading afterglows visible for months. Apparently associated with star forming regions in galaxies, these are among the most powerful explosions in the universe. Left: Artist's conception of a gamma-ray burst

Example: GRB 990123
Distance – 10 billion light-years
Size – emitting region is light-seconds across
Power – at maximum up to 1,000,000,000,000,000,000 (quintillion) times the Sun's power

Unidentified EGRET Sources

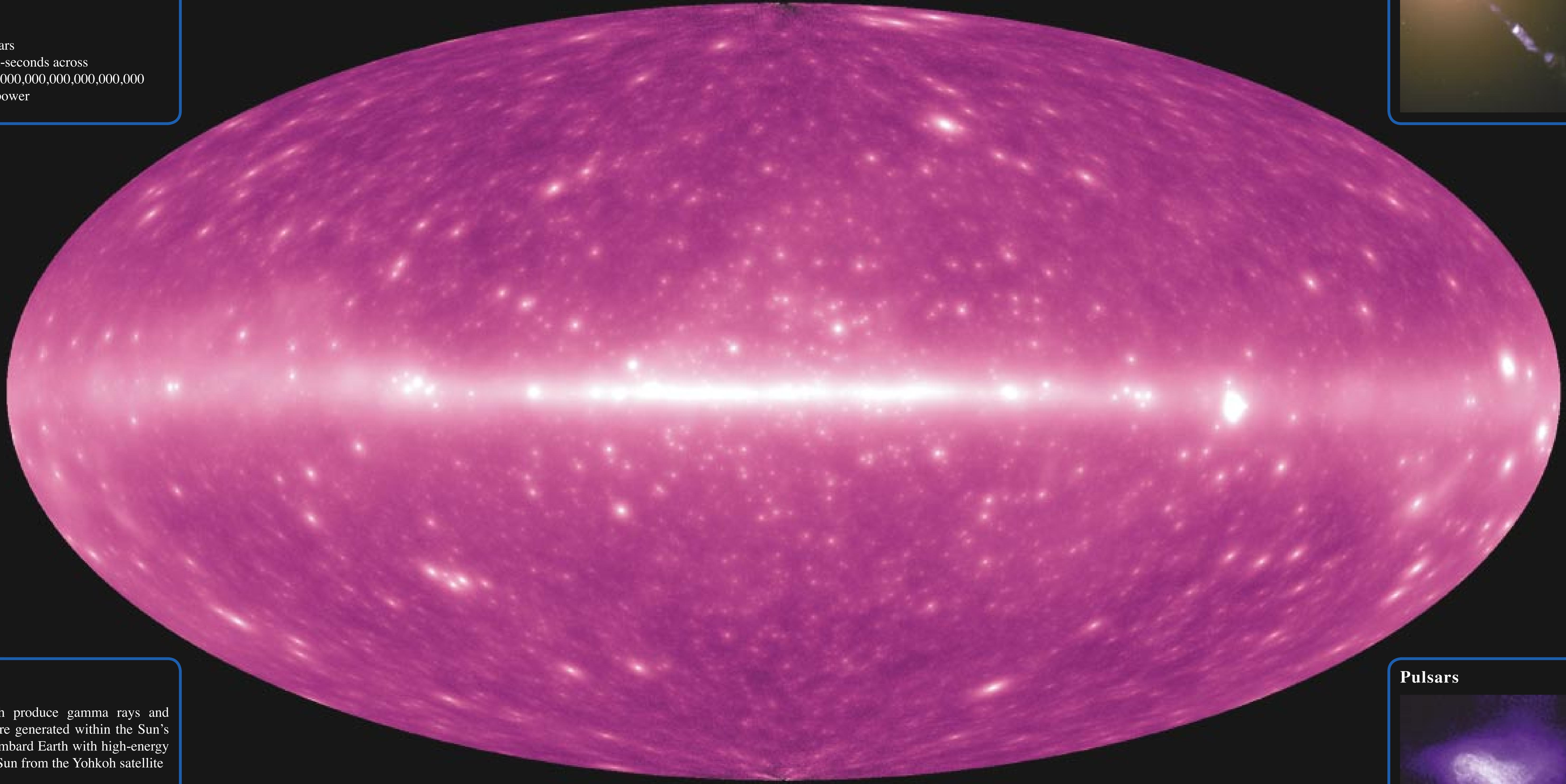


Of the 271 gamma-ray sources detected by the EGRET instrument onboard the Compton Gamma-Ray Observatory, 172 are unidentified sources. Possible candidates for these sources include active galactic nuclei, pulsars, supernova remnants, dense molecular clouds, and stellar-mass black holes within our Galaxy. It is even quite possible that entirely new phenomena could account for some portion of these unidentified sources. GLAST will localize the positions of the unidentified sources accurately enough to make searches for counterparts at other wavelengths much more feasible. Above: Compton Observatory all sky gamma-ray image of the unidentified sources

Solar Flares

Intense energetic solar explosions which produce gamma rays and accelerate atomic particles. Solar flares are generated within the Sun's highly magnetic active regions and can bombard Earth with high-energy radiation. Left: X-ray image of the flaring Sun from the Yohkoh satellite

Example: Solar Flare 11 June 1991
Distance – 8 light-minutes
Size – solar active regions are several times the size of planet Earth
Power – a typical flare has one-tenth the power output of the entire quiet Sun



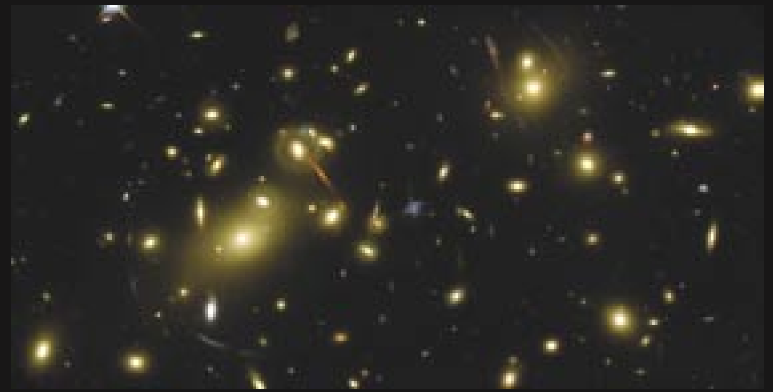
Simulation of the gamma-ray sky (E > 100 MeV) as observed by the GLAST Large Area Telescope (LAT).

Active Galactic Nuclei (AGN)

Distant galaxies, some of which are intense and highly variable flaring sources of high-energy gamma rays. AGN are powered by supermassive black holes with up to billions of times the Sun's mass. The gamma rays seen from some AGN arise from relativistic jets of material that are aimed in our direction. Left: Hubble Space Telescope optical image of M87's jet.

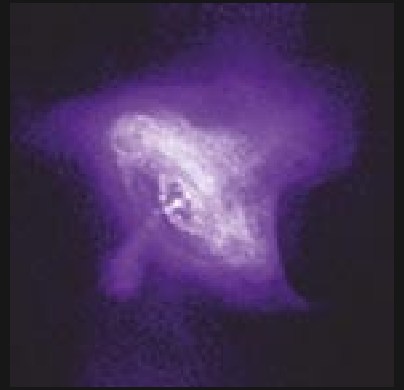
Example: 3C279
Distance – 7 billion light-years
Size – central region 3 light-days across
Power – at flare maximum near 1,000,000,000,000,000 (trillion) times the power output of the Sun

Cosmology and Particle Astrophysics



There is strong evidence that matter that radiates across the entire electromagnetic spectrum is only 10% of the total mass of the universe. In other words, 90% of the mass of the universe does not emit light at any wavelength. Currently the only way to detect this so-called dark matter is by its gravitational effects on luminous matter. One theoretical candidate for what dark matter might be is a type of hypothetical particle called a weakly interacting massive particle, or WIMP. The theory that predicts the existence of WIMPS also predicts that they may annihilate one another, producing gamma rays. If the theory is correct, then GLAST may be capable of observing radiation from these particles in the galactic halo, helping to unravel the mystery of dark matter. Above: Hubble Space Telescope optical image of a gravitationally lensed cluster of galaxies

Pulsars



Rotating neutron stars with strong magnetic fields. Neutron stars are collapsed stellar cores with the density of an atomic nucleus (about 1 billion tons per cubic centimeter!) and are slightly more massive than the Sun. Left: Chandra Observatory X-ray image of the Crab Nebula pulsar

Example: The Crab Nebula Pulsar
Distance – 7,000 light-years
Size – 10 kilometer diameter neutron star rotating 30 times per second
Power – 75,000 times the power output of the Sun