The Gamma-ray Universe through Fermi

David J. Thompson
NASA Goddard Space Flight Center
Greenbelt, Maryland

Gamma rays, the most powerful form of light, reveal extreme conditions in the Universe. The Fermi Gamma-ray Space Telescope and its smaller cousin AGILE have been exploring the gamma-ray sky for several years, enabling a search for powerful transients like gamma-ray bursts, novae, solar flares, and flaring active galactic nuclei, as well as long-term studies including pulsars, binary systems, supernova remnants, and searches for predicted sources of gamma rays such as dark matter annihilation. Some results include a stringent limit on Lorentz invariance derived from a gamma-ray burst, unexpected gamma-ray variability from the Crab Nebula, a huge gamma-ray structure associated with the center of our galaxy, surprising behavior from some gamma-ray binary systems, and a possible constraint on some WIMP models for dark matter.

The Gamma-ray Universe through Fermi

Dave Thompson
Deputy Project Scientist
Fermi Gamma-ray Space Telescope Project
NASA Goddard Space Flight Center

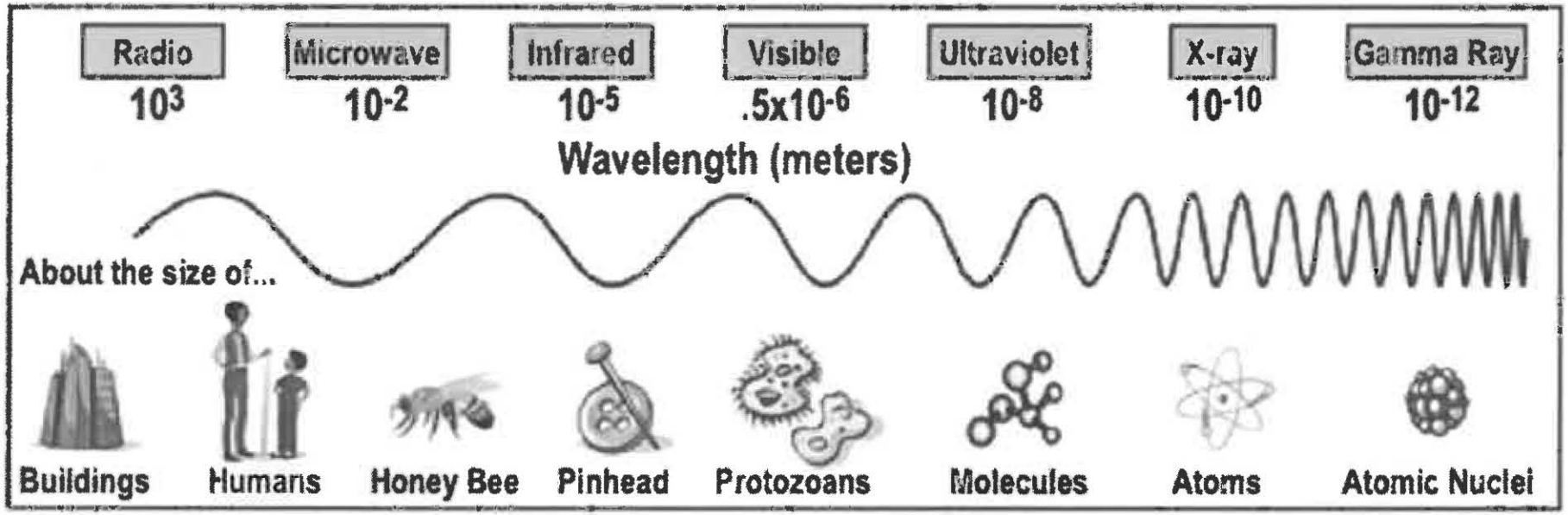
COSPAR Interdisciplinary Lecture
Mysore, India
July, 2012

Outline

- Introduction - the Fermi Gamma-ray Space Telescope
- Overview of the gamma-ray sky
- Some Galactic gamma-ray sources
- Some extragalactic gamma-ray sources
- The unseen and the future

What is a Gamma Ray?

One of The Many Forms of Light



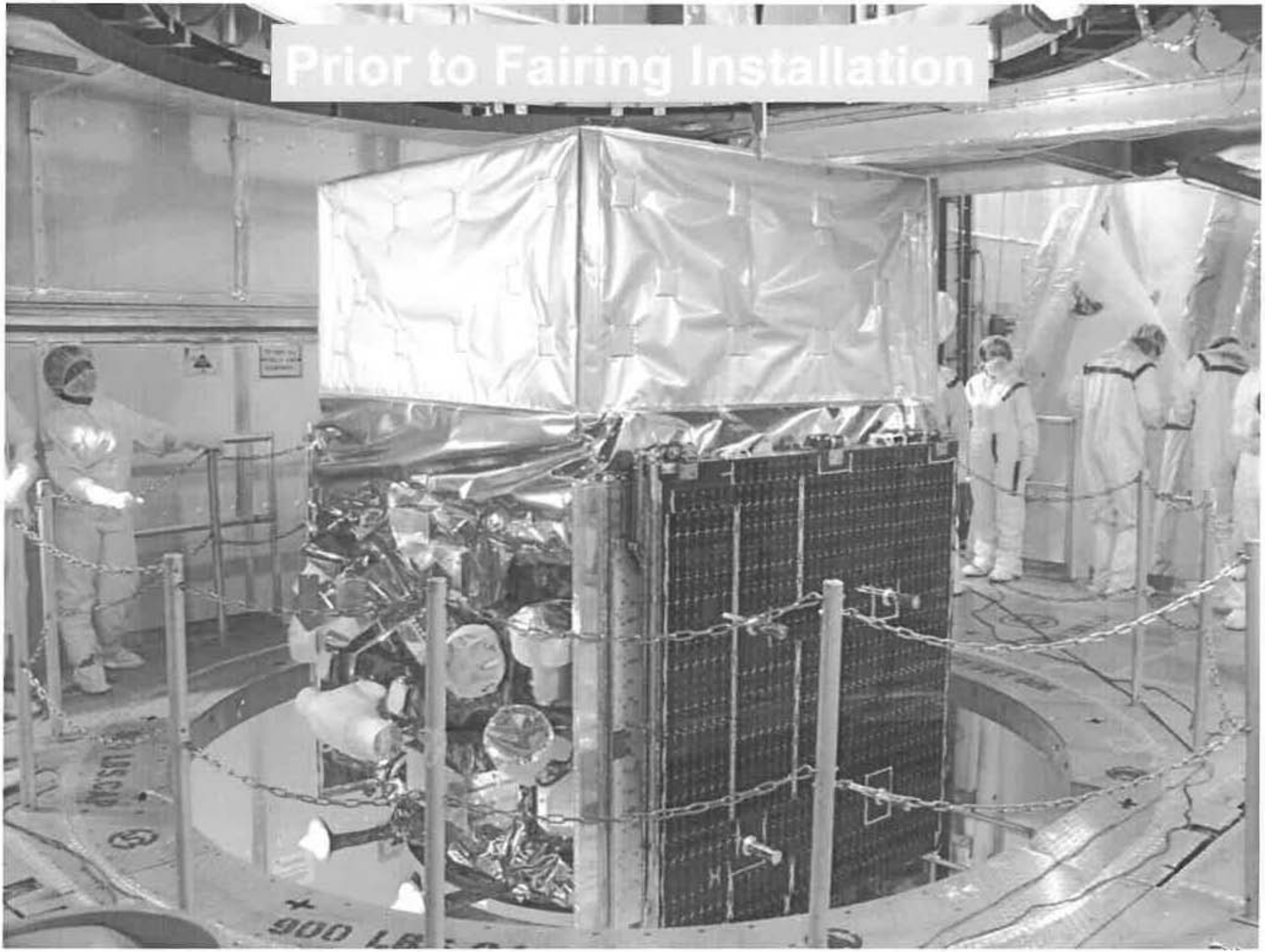
Credit: NASA / Ruth Jennings

Each type of light carries different information.

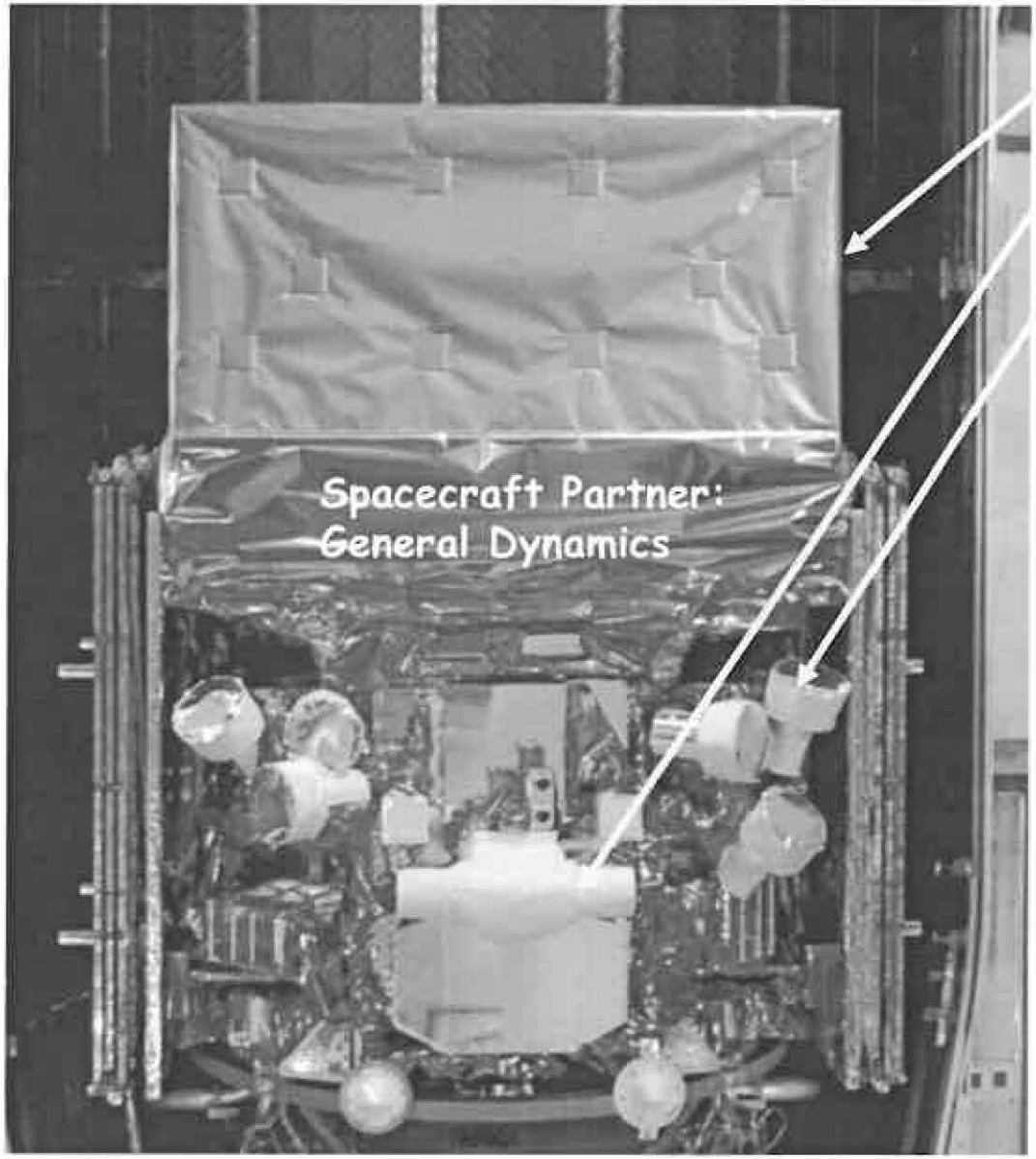
Gamma rays, the highest-energy type of light, tell us about the most energetic processes in the Universe.


But what if you had gamma-ray vision?

The Fermi Gamma-ray Space Telescope


Prior to Fairing Installation

The Fermi Observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

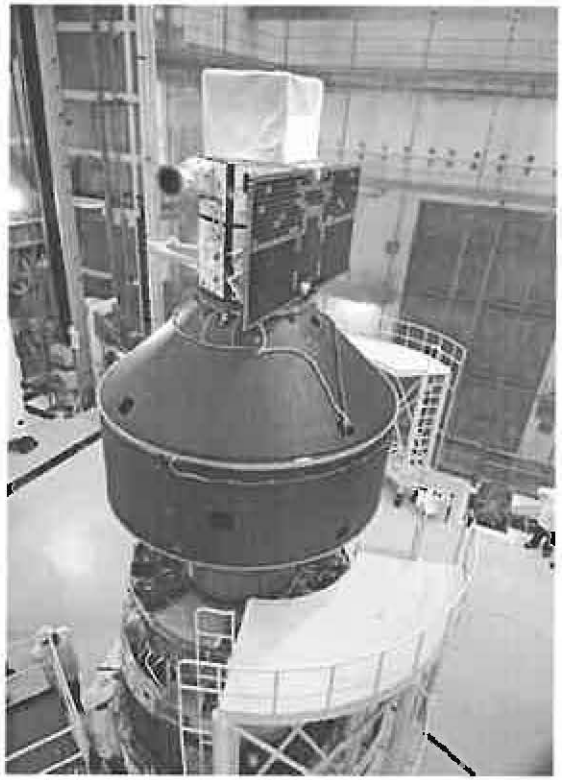
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

- Huge field of view
  - LAT: 2.4 sr; 20% of the sky at any instant;
  - GBM: whole unocculted sky at any time.
- Broad energy range.
  - Total of >7 energy decades!
- Every photon can be time-tagged.
  - 1 microsecond accuracy

Launched June 11, 2008

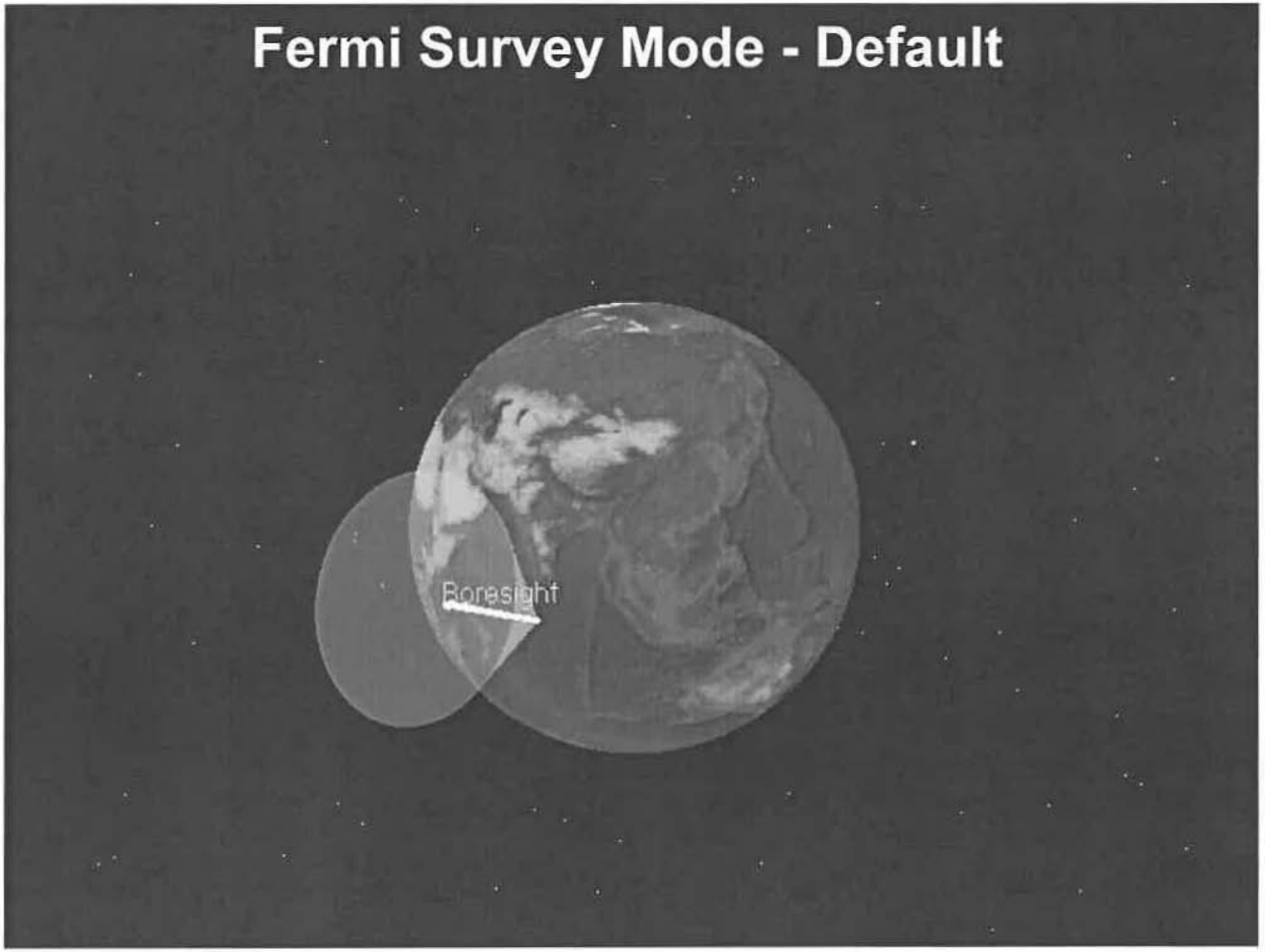
AGILE – Fermi's Smaller Cousin



KEY FEATURES

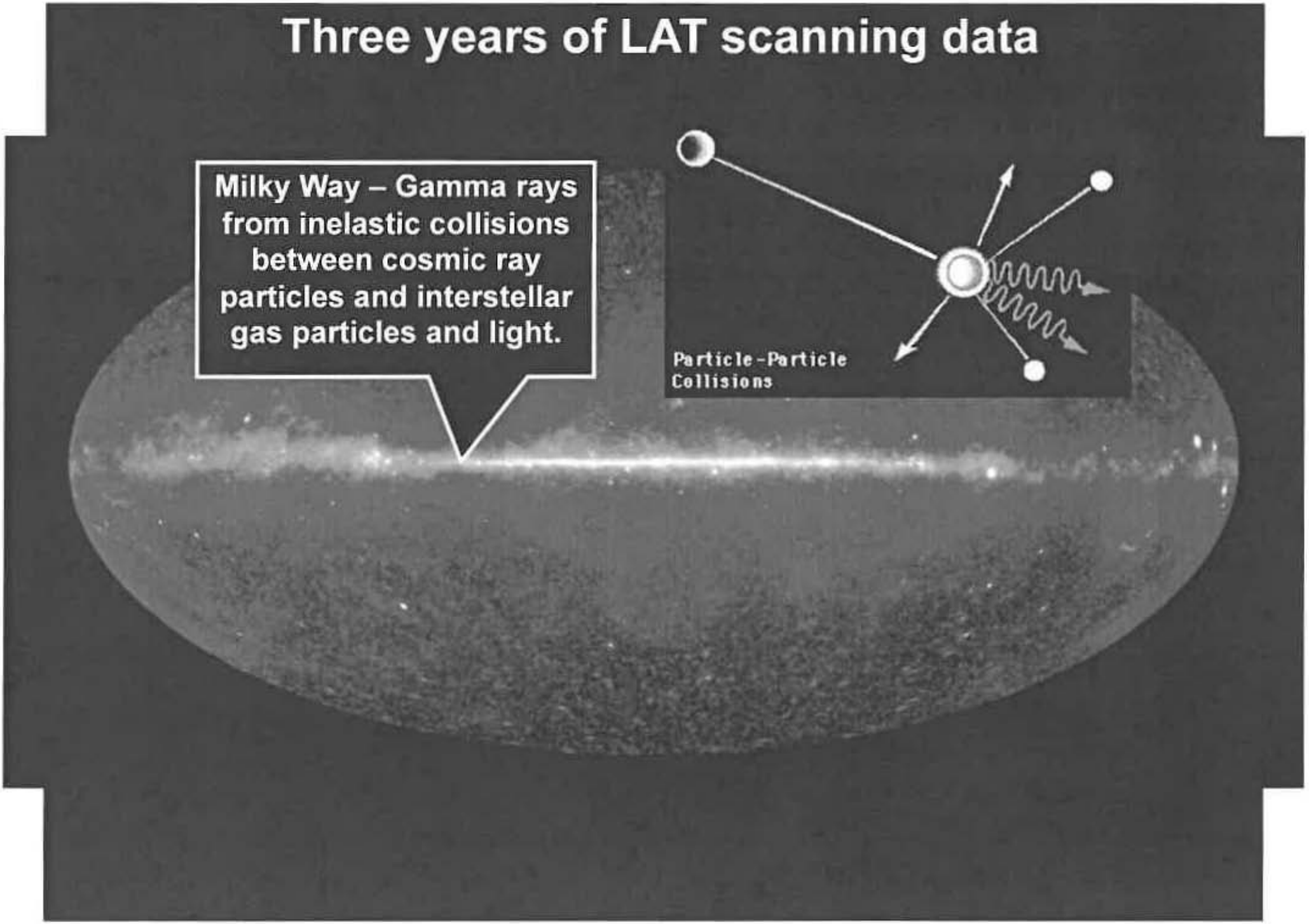
- **Italian gamma-ray telescope**
- Similar to the Fermi Large Area Telescope, but about 1/16 the size
- **Launched April 23, 2007, from ISRO facility in Sriharikota, India**
- Indian PSLV rocket
- **AGILE has contributed to many of the same science topics as Fermi**

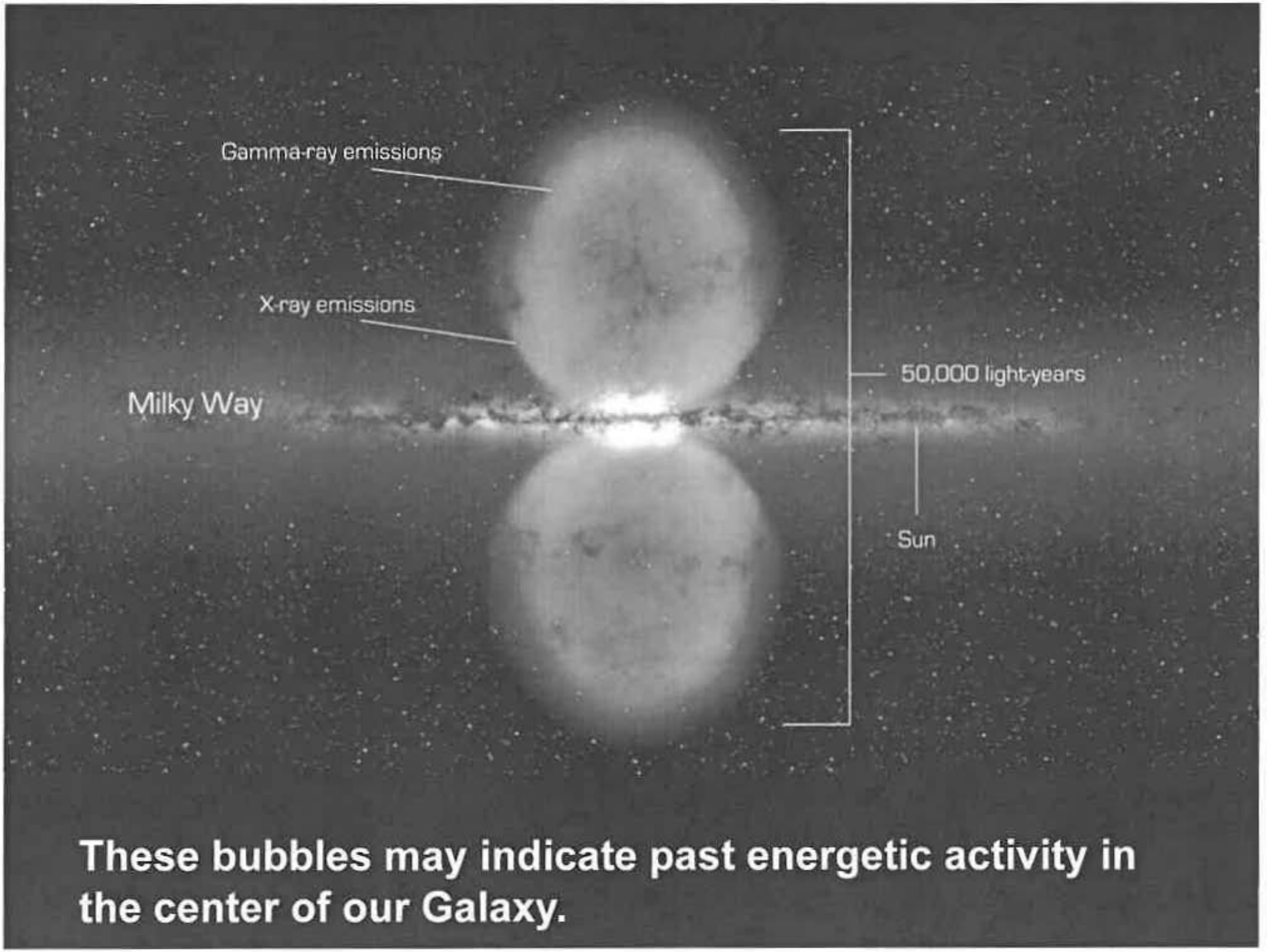
Fermi Survey Mode - Default



Overview of the Gamma-ray Sky

Three years of LAT scanning data

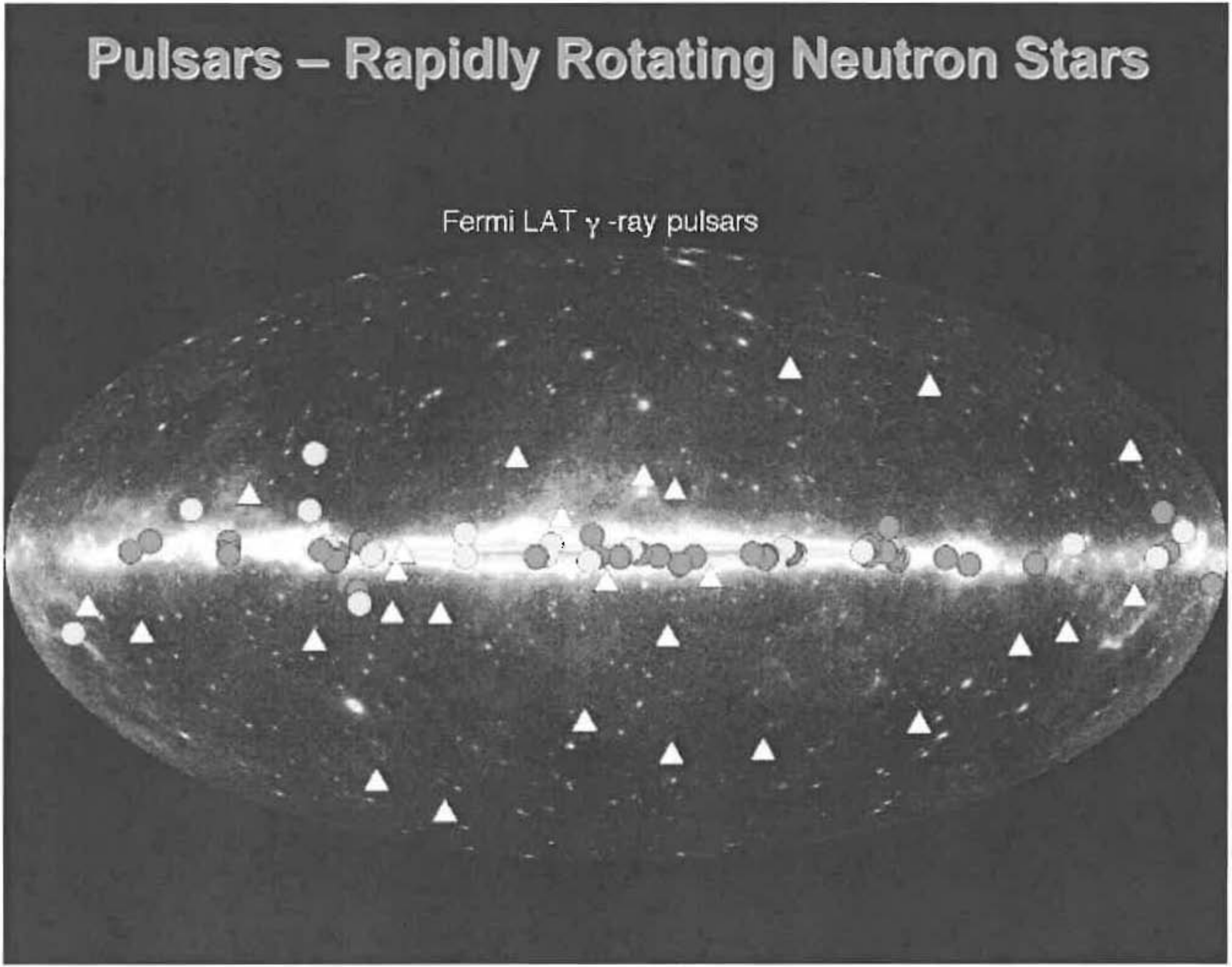




These bubbles may indicate past energetic activity in the center of our Galaxy.

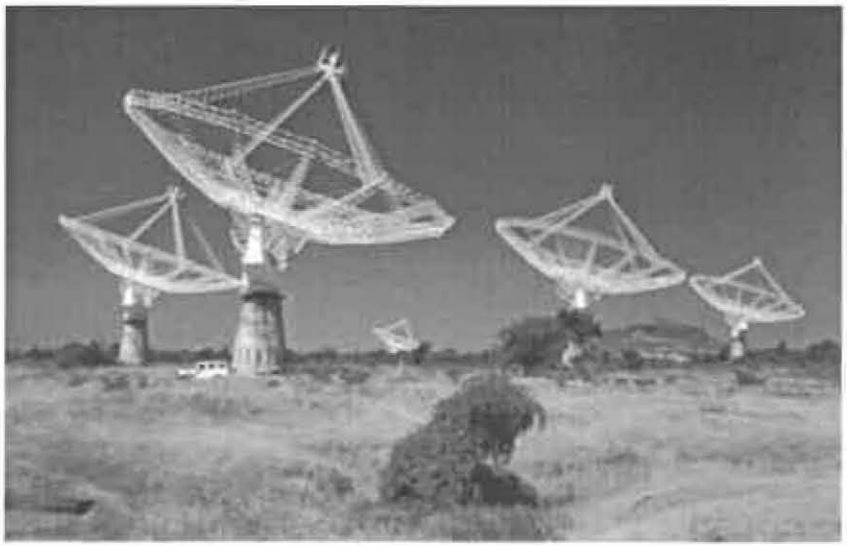
Some Galactic results from Fermi

Pulsars – Rapidly Rotating Neutron Stars



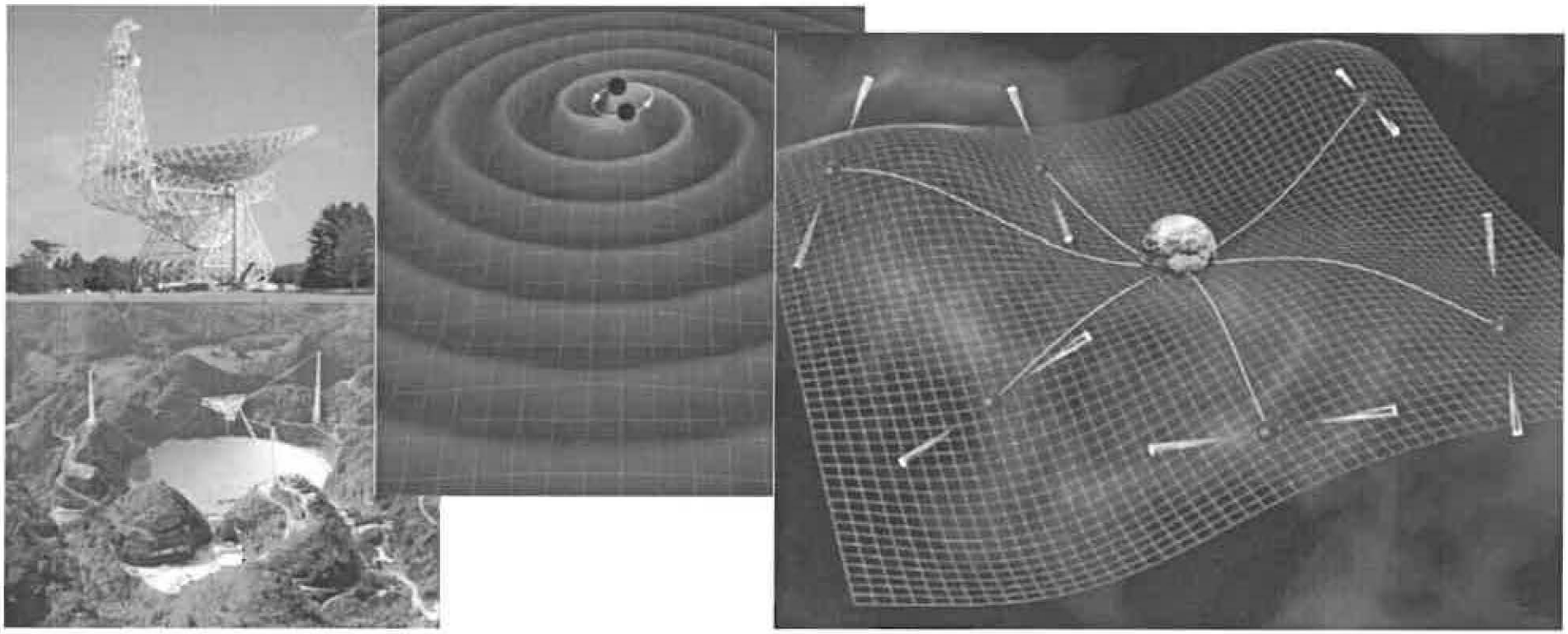
What Are We Learning about Pulsars?

- About 1/3 of the Fermi pulsars are seen only in gamma rays. The gamma rays are being produced in a wide beam far from the neutron star surface, unlike radio pulsar emission.
- Old, "recycled" pulsars with millisecond periods can produce gamma rays in much the same way as younger pulsars. Some of the early work predicting such pulsars was done by Prof. Srinivasan over 20 years ago.
- Close cooperation between radio and gamma-ray astronomers has produced new pulsar discoveries at both ends of the electromagnetic spectrum, including some made at the Giant Metrewave Radio Telescope.

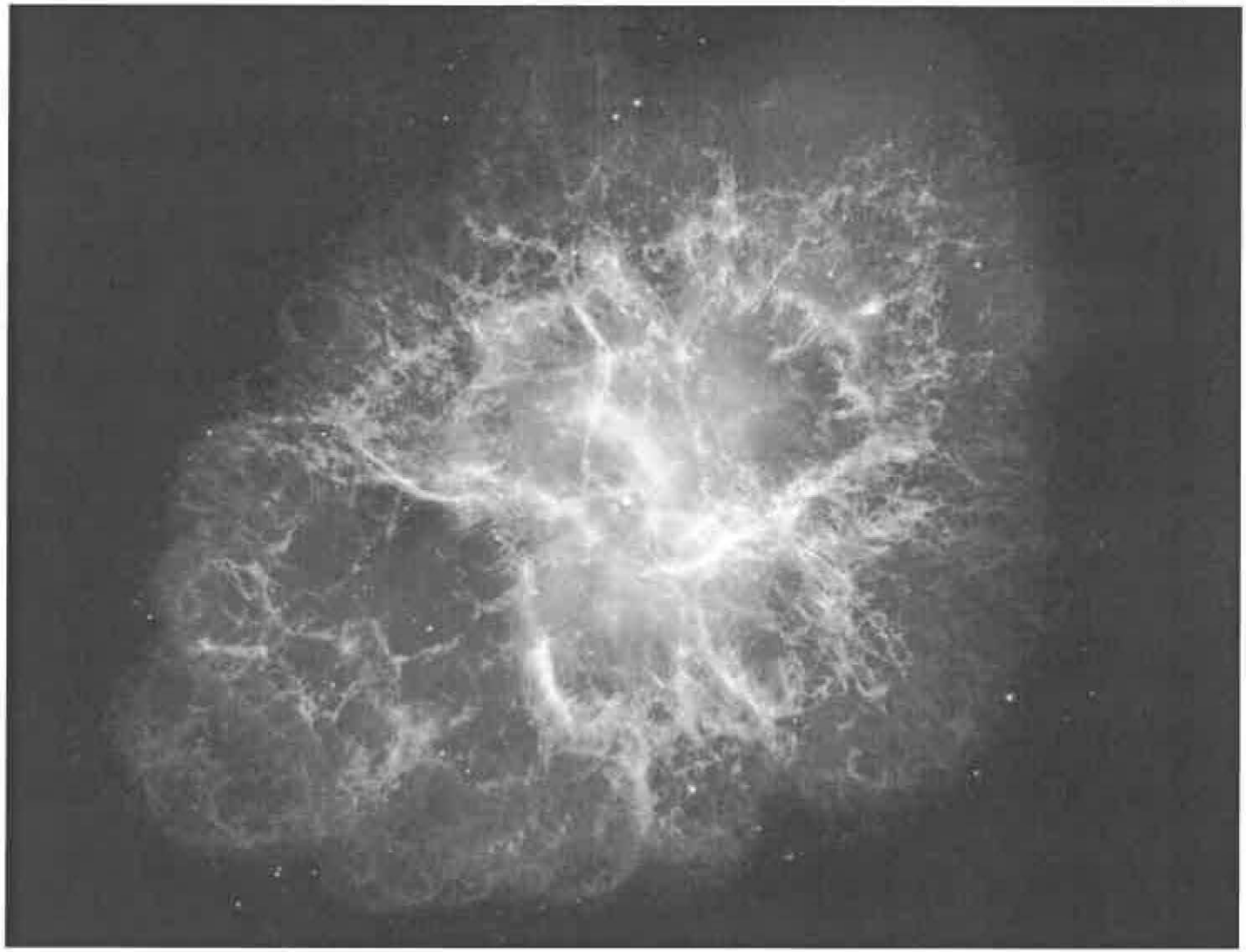


Pulsar Timing Arrays as Gravitational Wave Detectors

- Time millisecond pulsars to 100 nanoseconds
- Arrays of MSPs can be sensitive to nHz gravitational waves – need 20-40 MSPs for detection in 5 years
- Search for stochastic gravitational wave background from black hole/ galaxy mergers

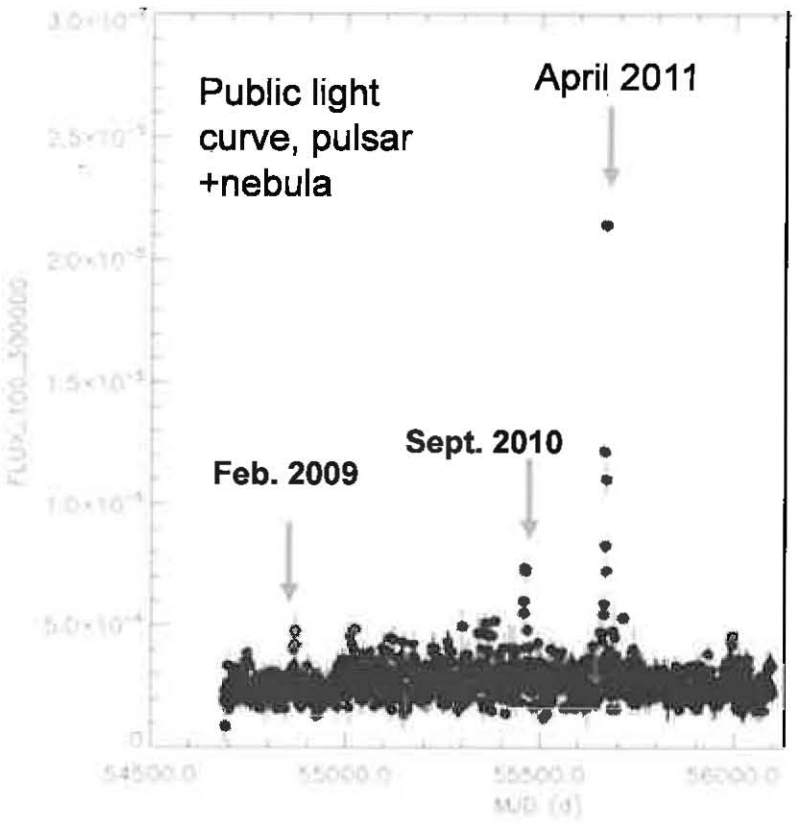


The Crab Nebula - A Rosetta Stone of Astrophysics



Supernova seen in 1054 → Supernova remnant and pulsar

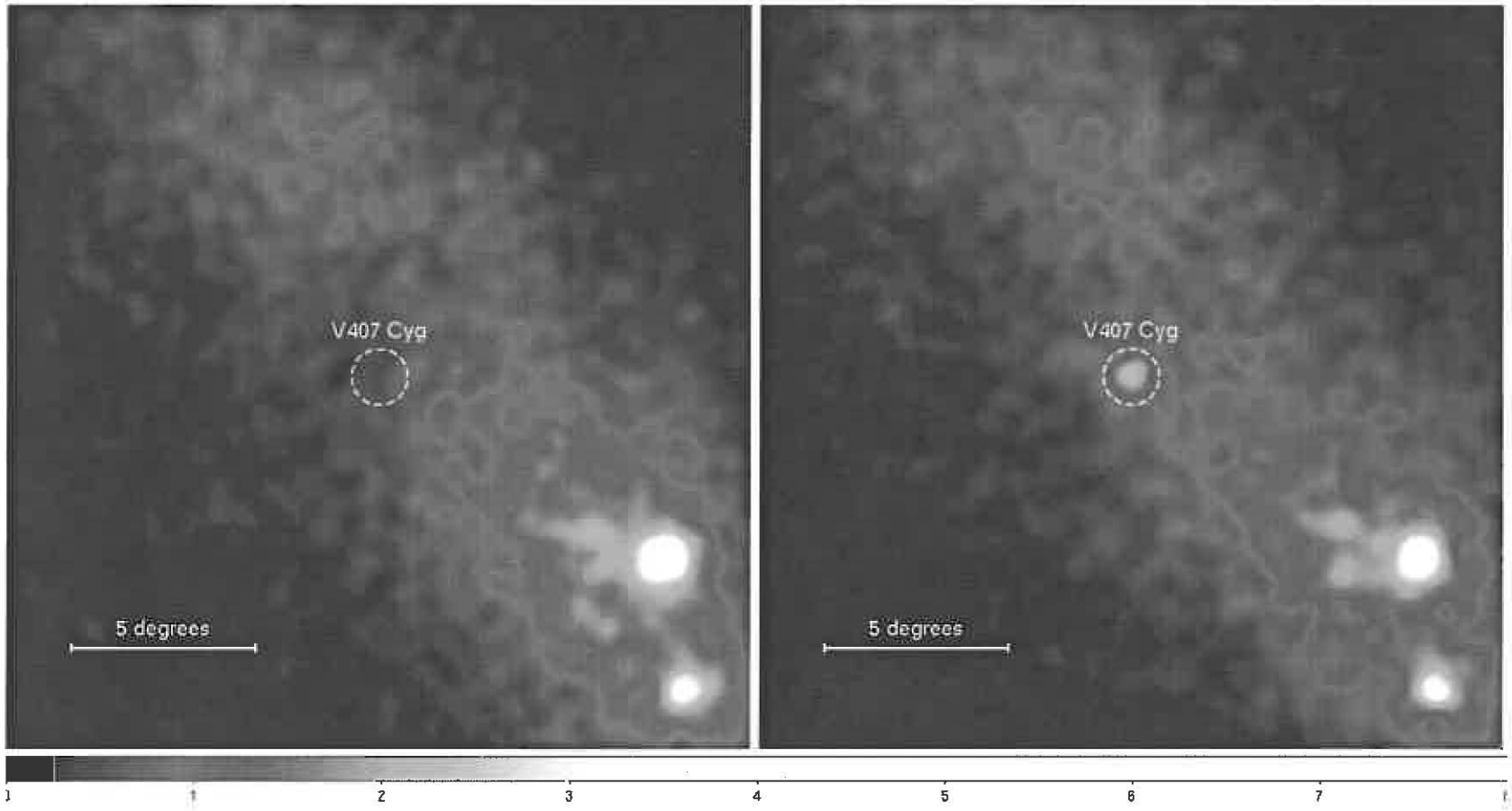
Crab Nebula Flaring



First Crab gamma-ray flare was seen by AGILE before the Fermi launch.

- Fast, high-energy flares from the Crab nebula appear to be a uniquely gamma-ray phenomenon.
- Rapid variability and high energy suggest relativistic beaming of electron synchrotron radiation.
- Time scale and small region imply electrons accelerated to PeV energies by electrostatic acceleration or magnetic reconnection.

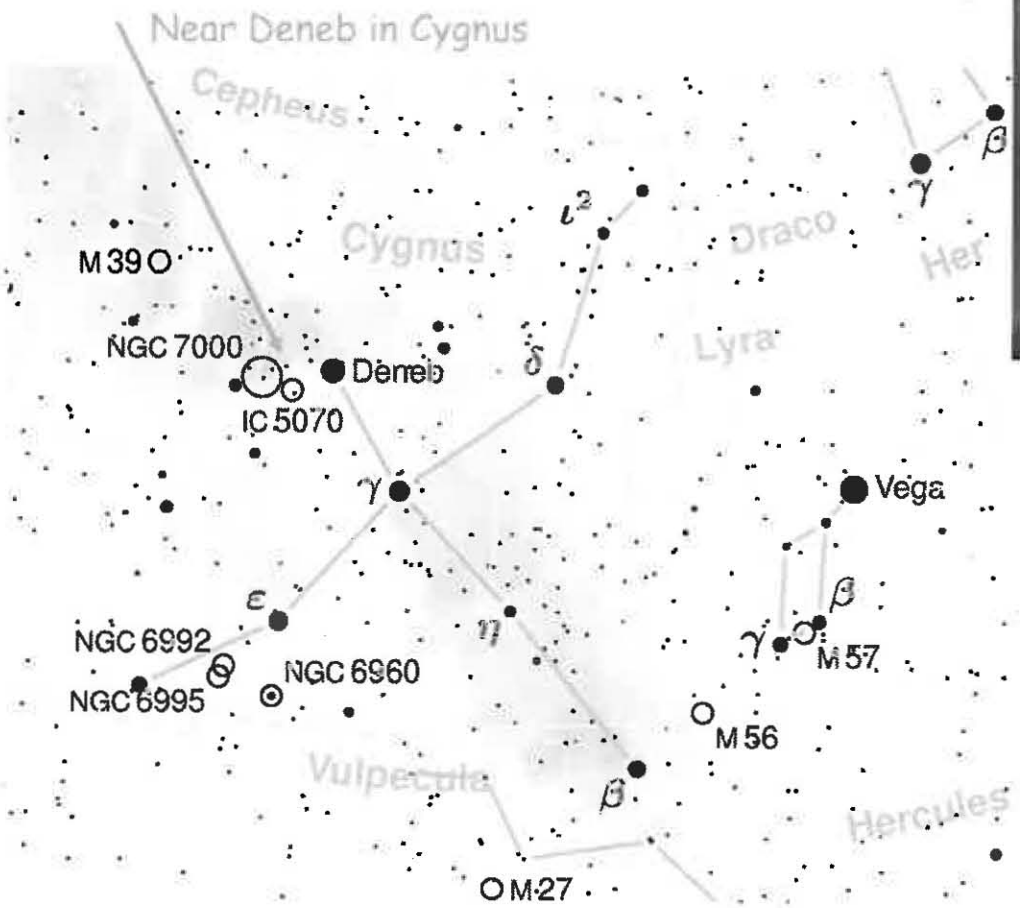
March 2010 - a Galactic plane transient



The flare turned out to come from a nova, something not widely expected to be energetic enough to produce gamma rays.

V407 Cygni: a binary system

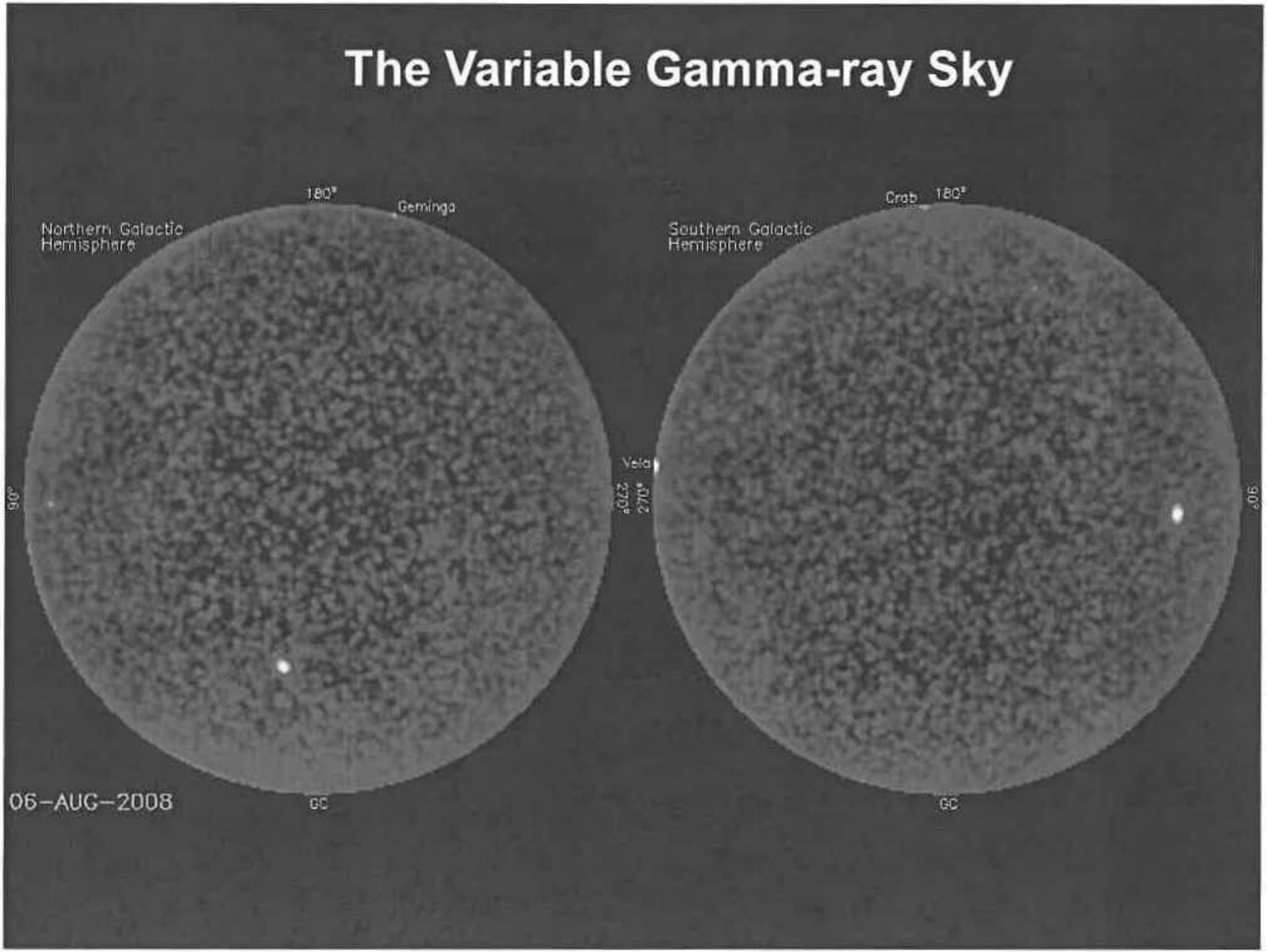
Symbiotic binary:
small white dwarf star and large red giant star orbiting each other closely



The shock wave from the nova thermonuclear explosion accelerates particles that interact with the surrounding material to produce the gamma rays.

V407 Cyg ~ 6000 light years away

Some Fermi results on extragalactic sources

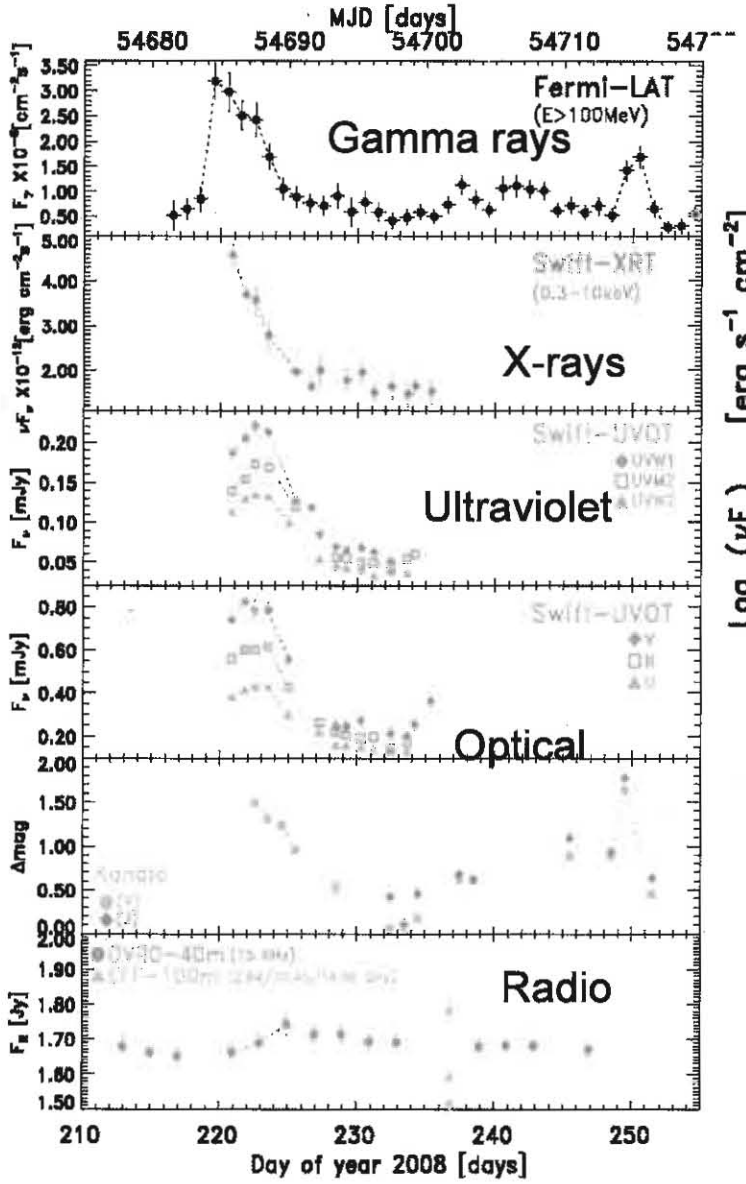

The Variable Gamma-ray Sky
Northern Galactic Hemisphere
180°
Geminga
90°
GC
06-AUG-2008
Vela
0°
270°
Southern Galactic Hemisphere
Crab
180°
90°
GC

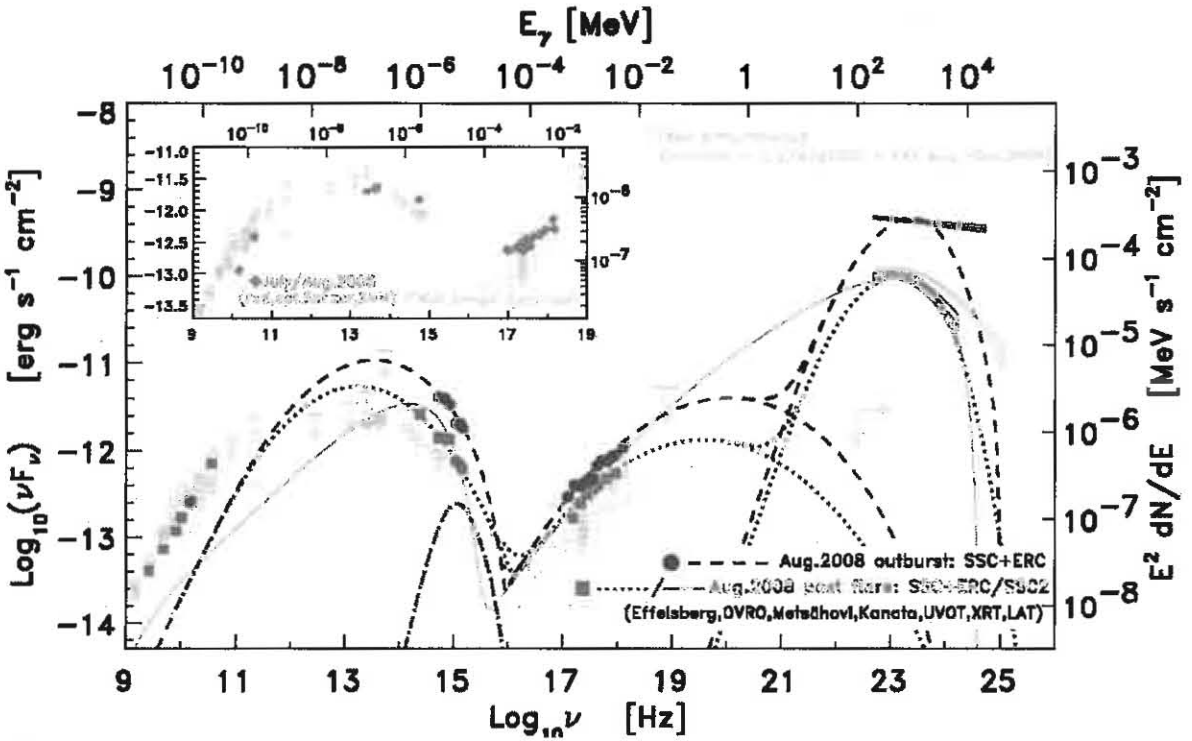
Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)

- Power comes from material falling toward a supermassive black hole
- Some of this energy fuels a jet of high-energy particles that travel at nearly the speed of light

How black holes, which pull things in, can produce jets, which shoot material away, is still not fully understood. It is probably related to rotation and magnetic fields.

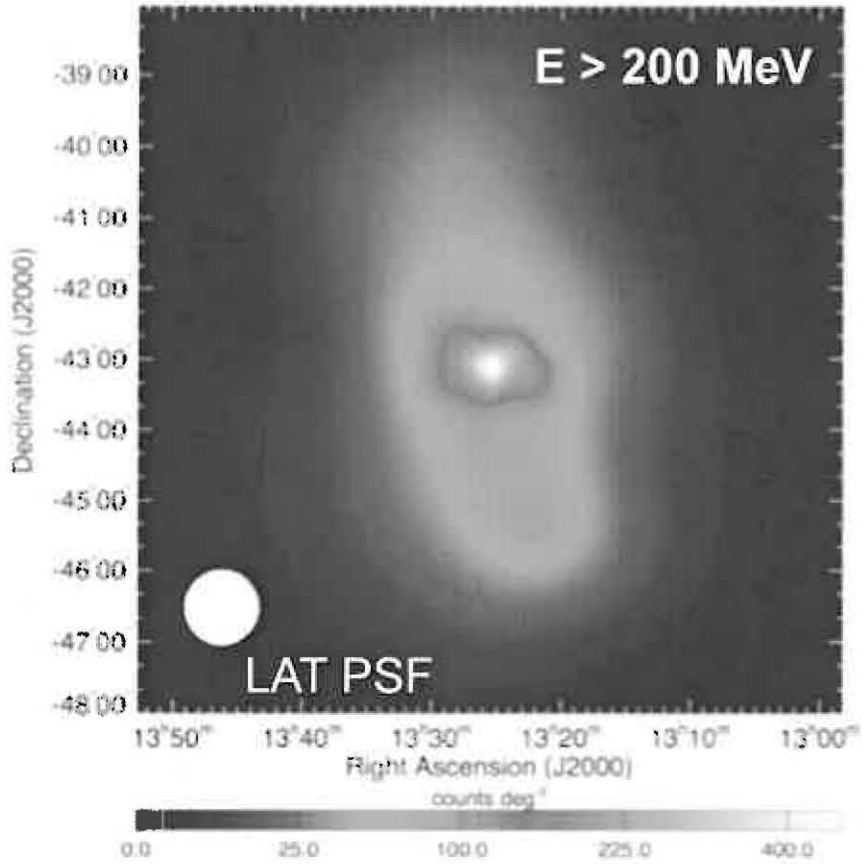
PKS 1502+106



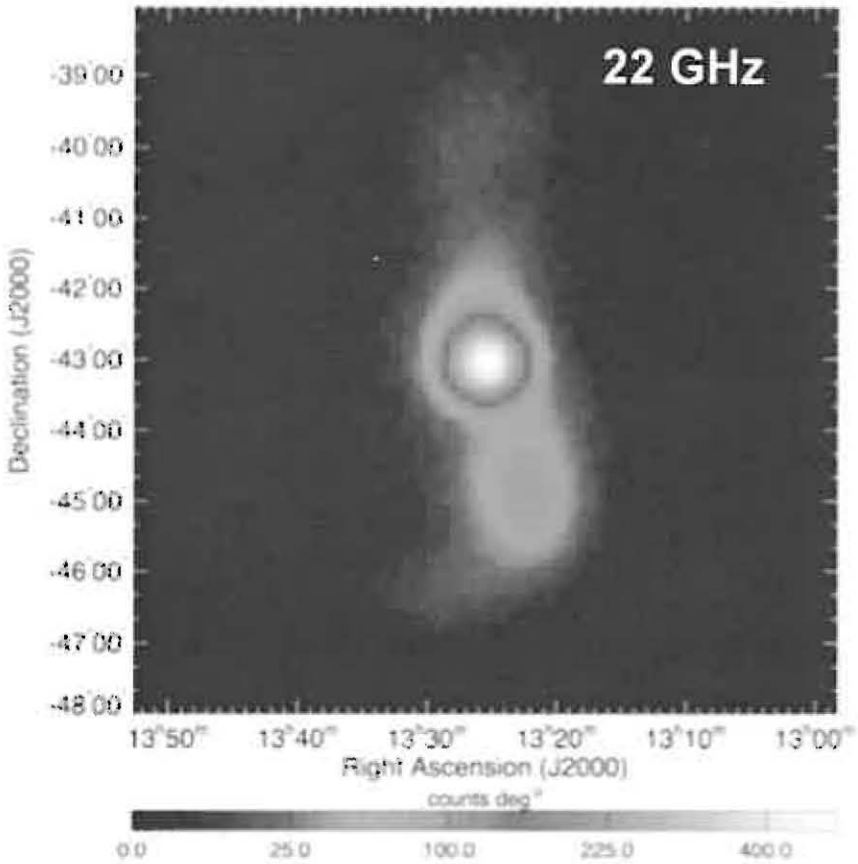


The radio-to-gamma-ray averaged Spectral Energy Distributions collected during the *Fermi-Swift* Aug.2008 multi-frequency campaign for both the outburst state (MJD: 54685-54689, blue data points) and the subsequent post-flare state (MJD 54690-54701, red data points). The archival data are reported as orange data points.

Centaurus A - Radio Galaxy



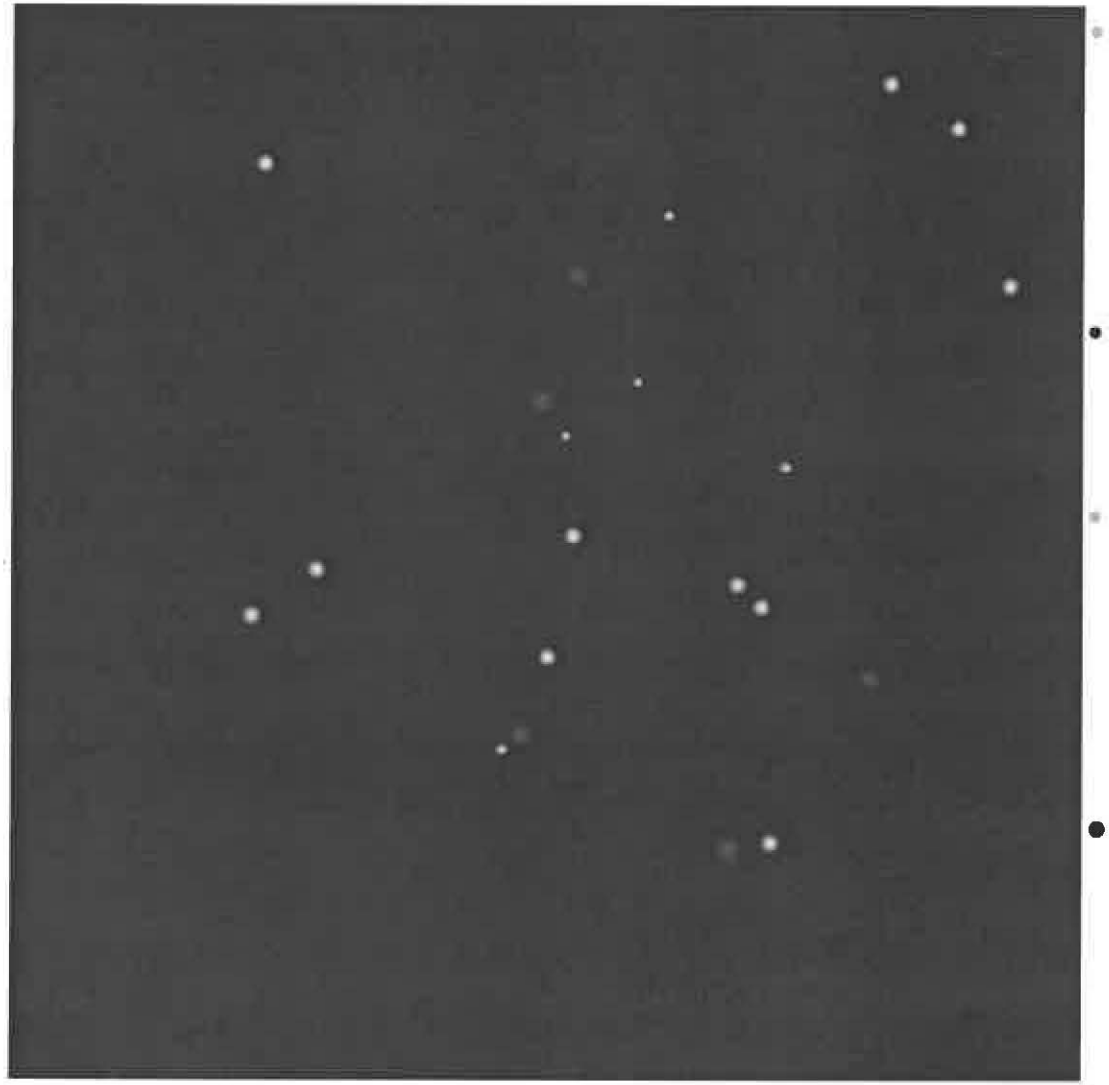
LAT counts map with background (isotropic and diffuse) and field point sources subtracted



WMAP image provided by Nils Odegard (GSFC)

Requires 0.1-1 TeV electrons in giant 'relic' lobes: accelerated in-situ or efficient transport from center

Gamma-Ray Bursts (GRBs): the most powerful explosions since the Big Bang

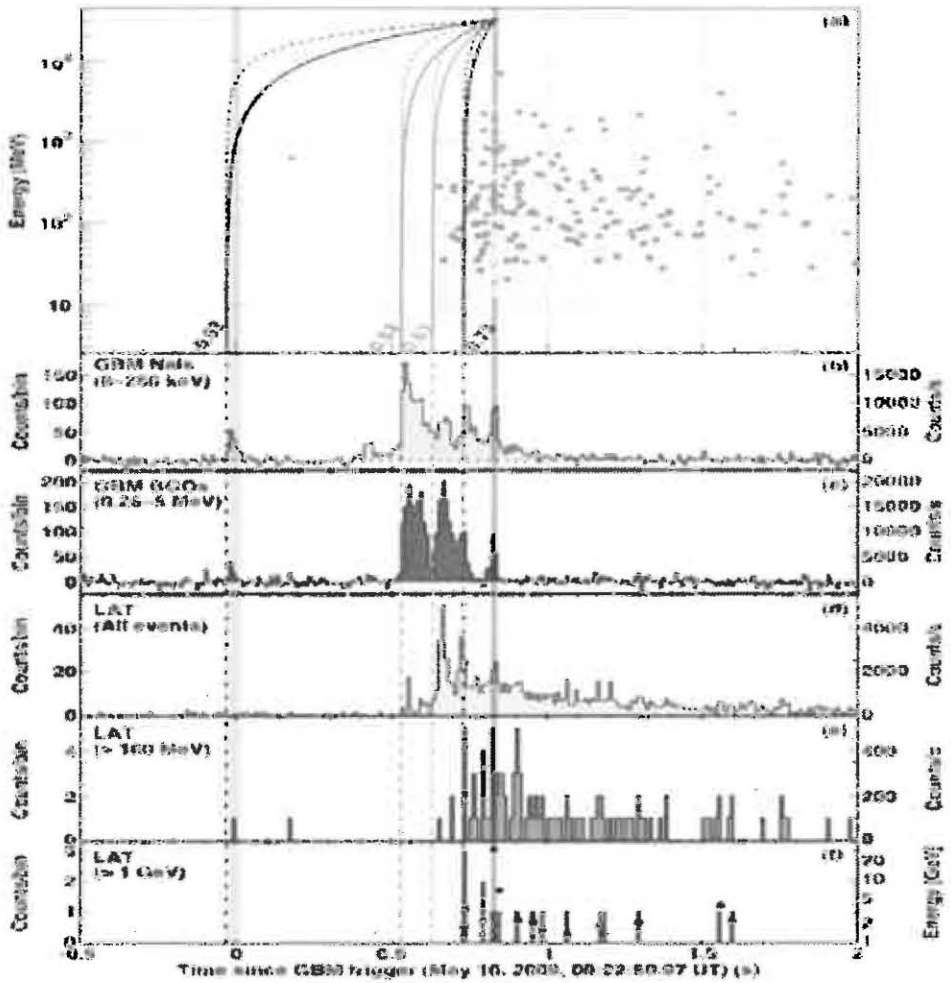


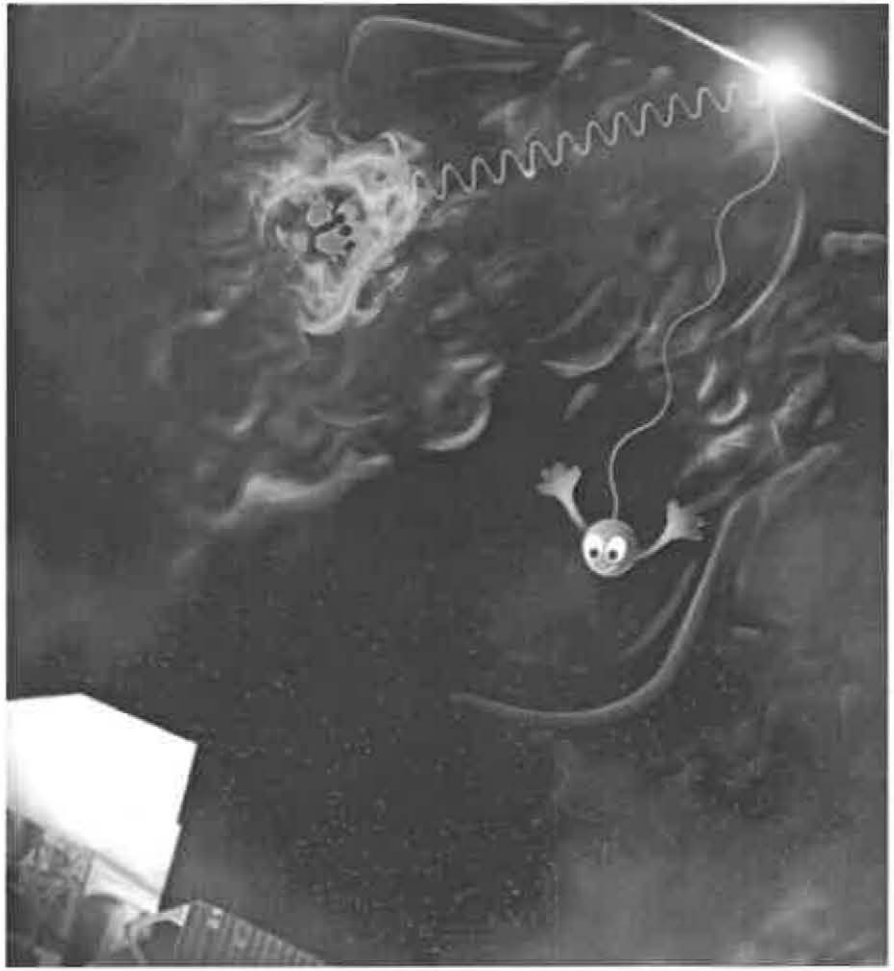
- Originally discovered by military satellites, GRBs are flashes of gamma rays lasting a fraction of a second to a few minutes.
- Optical afterglows reveal that many of these are at cosmological distances
- The GBM and LAT extend the energy range for studies of gamma-ray bursts to higher energies, complementing Swift and other telescopes.
- Fermi is helping learn how these tremendous explosions work.

Testing Einstein's Theory of Special Relativity

- The Principle of Invariant Light Speed – *Light in vacuum propagates with the speed c (a fixed constant) in terms of any system of inertial coordinates, regardless of the state of motion of the light source.*
- Some models of Quantum Gravity challenge Einstein's idea, predicting that not all photons travel at the same speed; "foamy" space-time might slow down higher-energy photons.
- Consider a race between two photons traveling a very large distance at slightly different speeds. The slower photon will arrive later.
  - To do this we need
    - Distant object
    - Very bright
    - Well defined start time

GRB 090510 - testing models of Quantum Gravity





Highest energy gamma-ray arrived within 0.9s of the lower energy photons after traveling 7 billion years.
Eliminates theories of quantum gravity that predict space-time is "foamy" enough to interfere strongly with light.

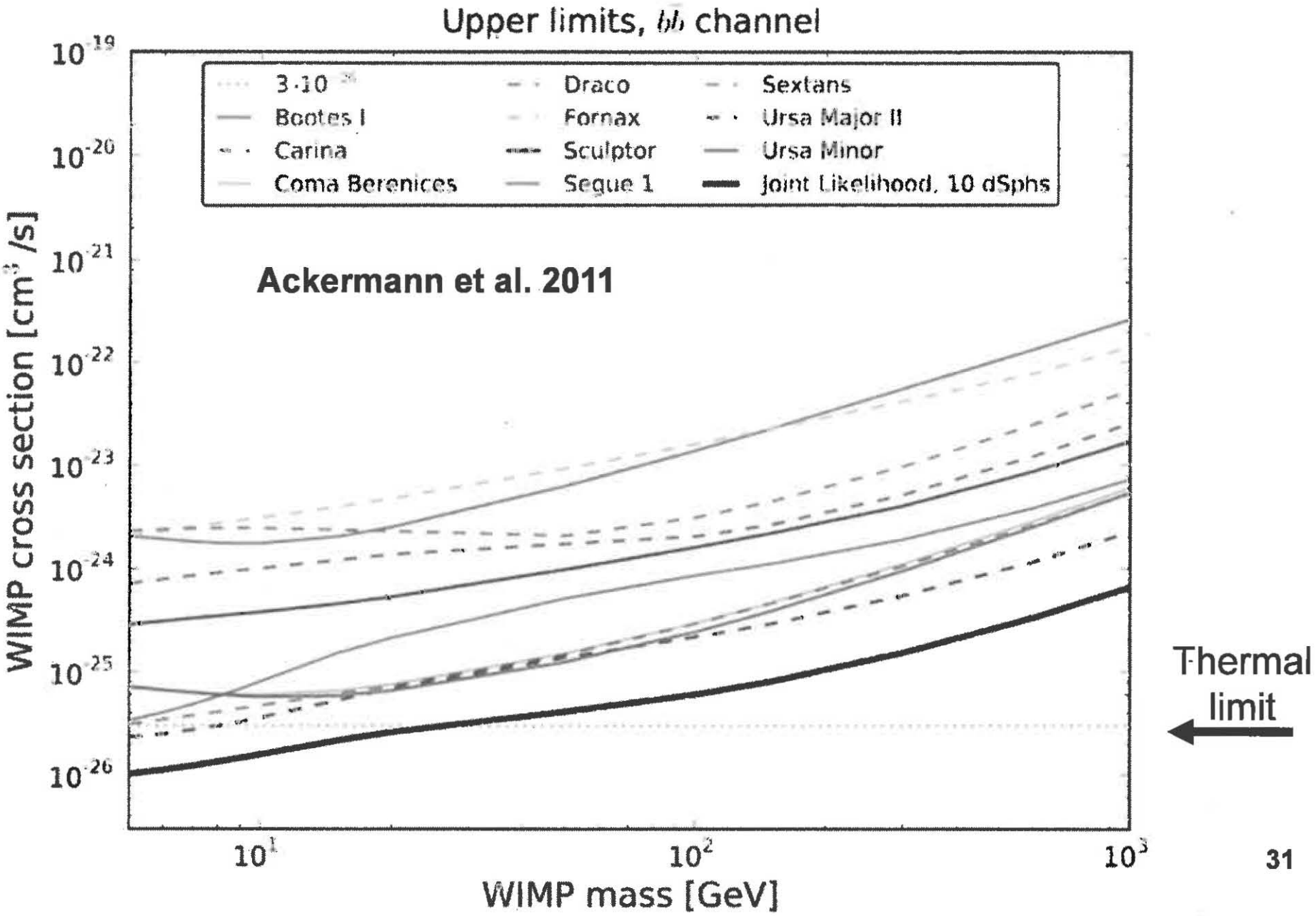
The unseen and the future

What is Not Seen Can Also Be Important

Some clusters of galaxies were predicted to be gamma-ray sources. None are seen in the Second LAT Catalog, indicating that the predictions were too optimistic.

Dwarf spheroidal galaxies are thought to be largely composed of dark matter. If dark matter consists of some types of Weakly Interacting Massive Particles (WIMPs), such galaxies would be gamma-ray sources visible to Fermi LAT. Their absence puts constraints on dark matter models.

Fermi LAT Constraints on Dark Matter



Summary - Expecting the Unexpected

The flexibility and versatility of the Fermi instruments and operations are producing a wide range of results, including time domain studies on many time scales and continual improvements in both exposure depth and energy range for steady sources.

Multiwavelength and theoretical studies are essential to make the best scientific use of the Fermi observations. The Fermi Guest Investigator program supports such work.

The Fermi Web site is http://www.nasa.gov/fermi

All the Fermi gamma-ray data are public immediately.
Join the fun!