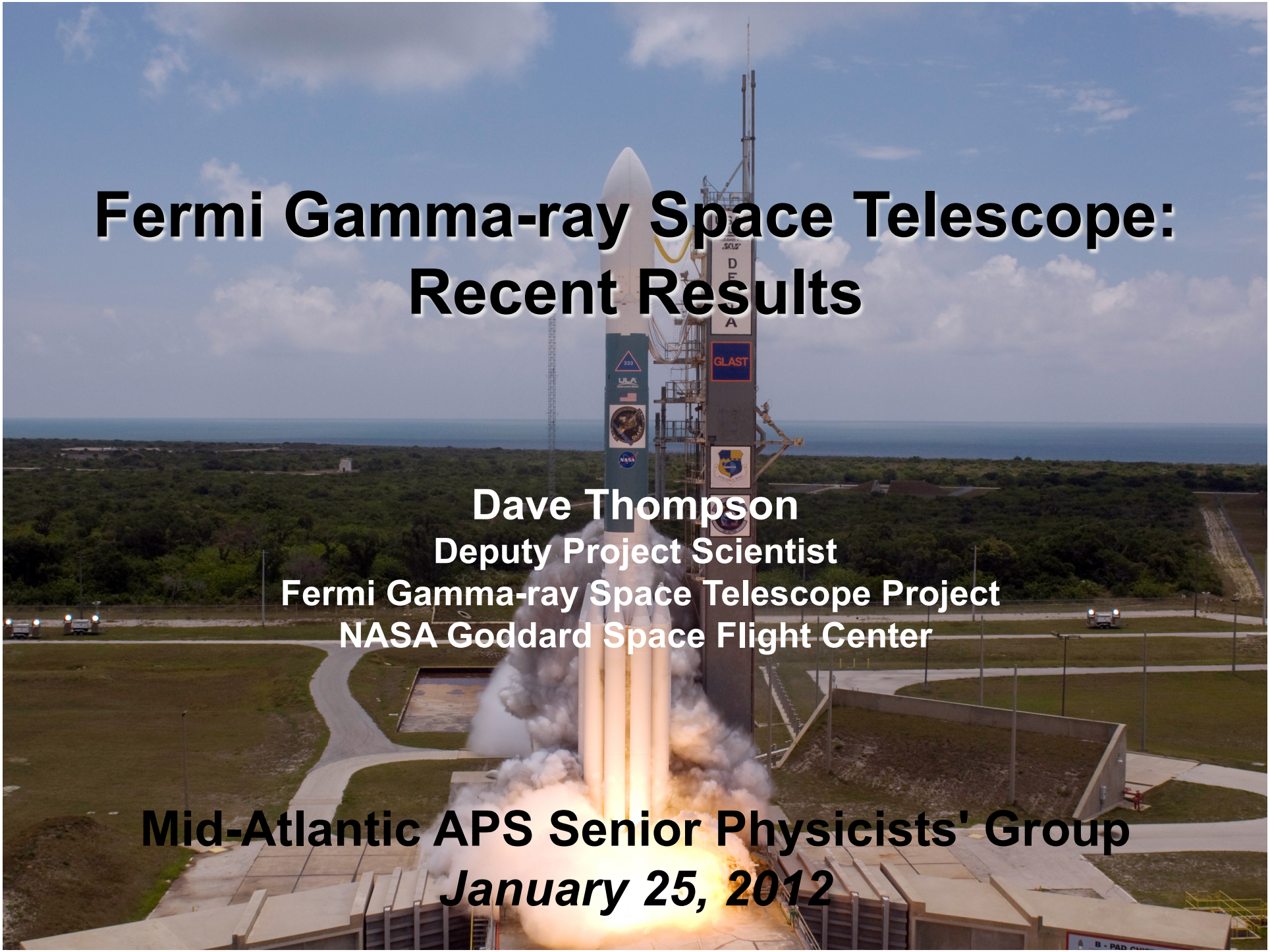


Fermi Gamma-ray Space Telescope: Recent Results

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

Mid-Atlantic APS Senior Physicists' Group

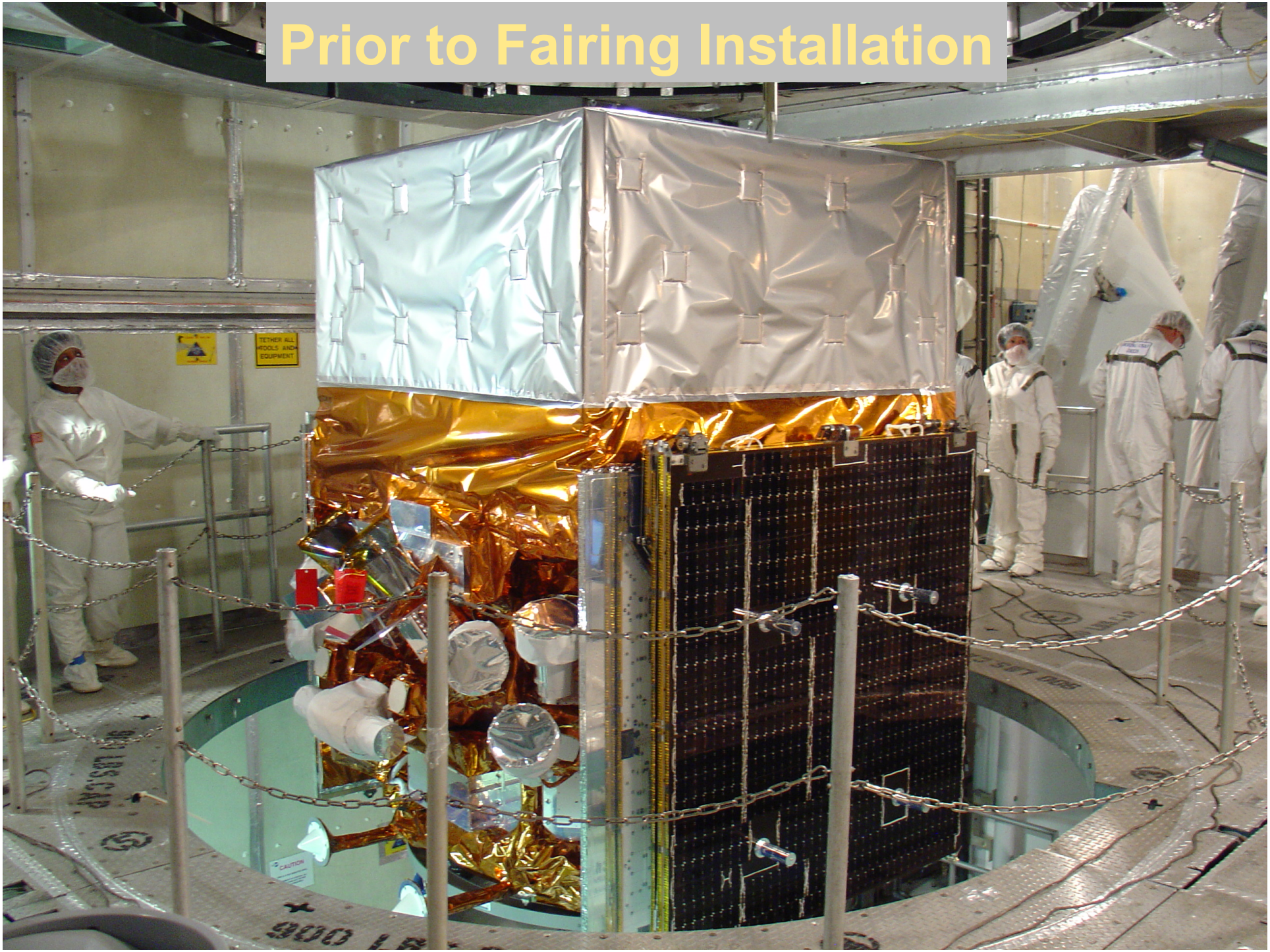
January 25, 2012

Outline

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

The Fermi Gamma-ray Space Telescope

Prior to Fairing Installation



The Observatory

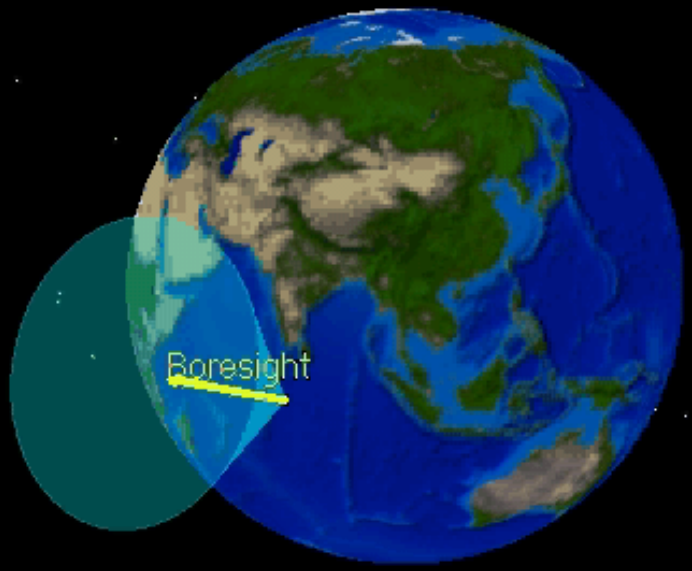
Large AreaTelescope (LAT)
20 MeV - >300 GeV

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

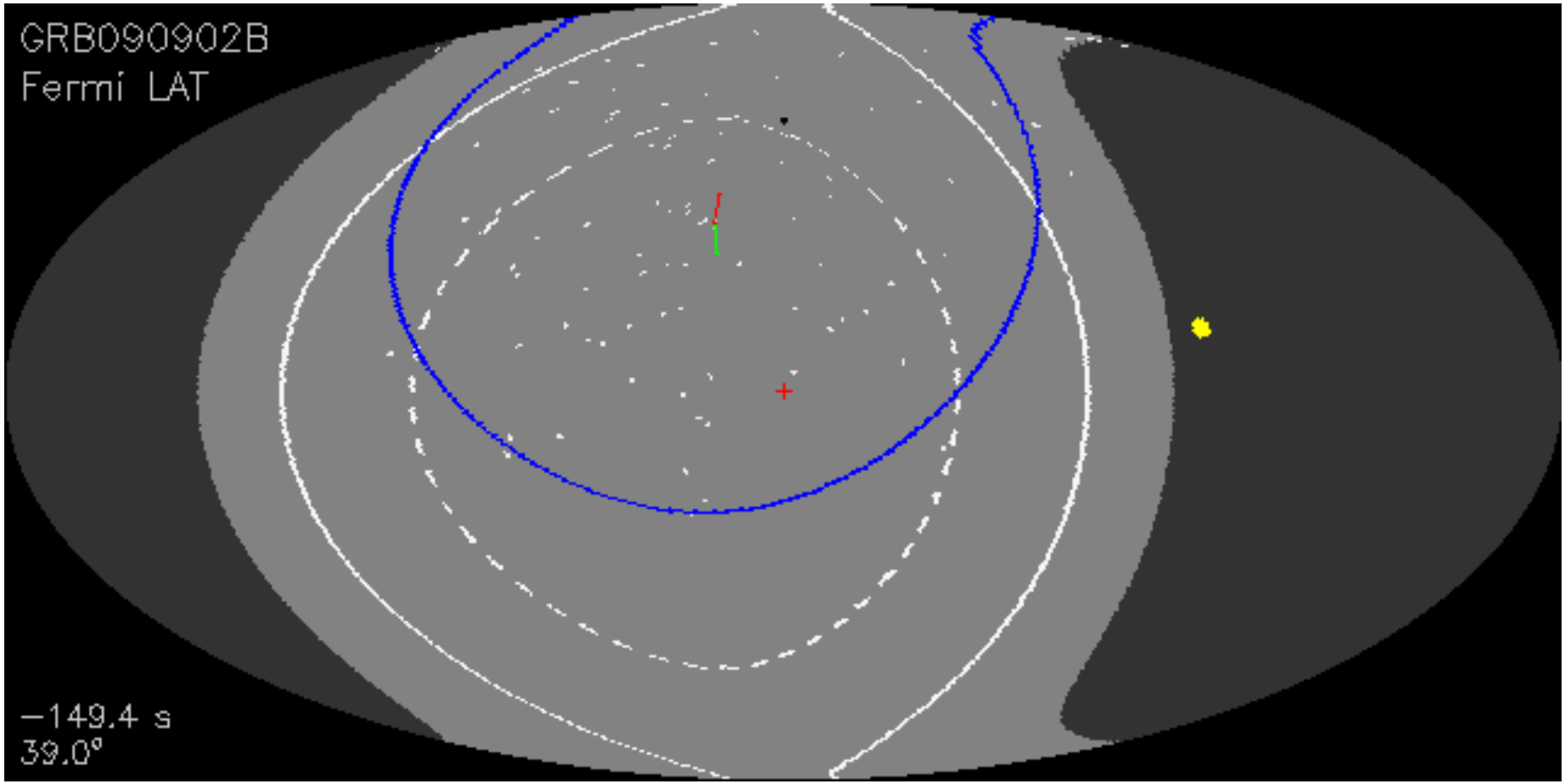
Survey Mode - Default



- Rock north for one orbit and south for the next.
- Keep LAT Field of View away from the bright Earth limb
- Covers the full sky every 3 hours.

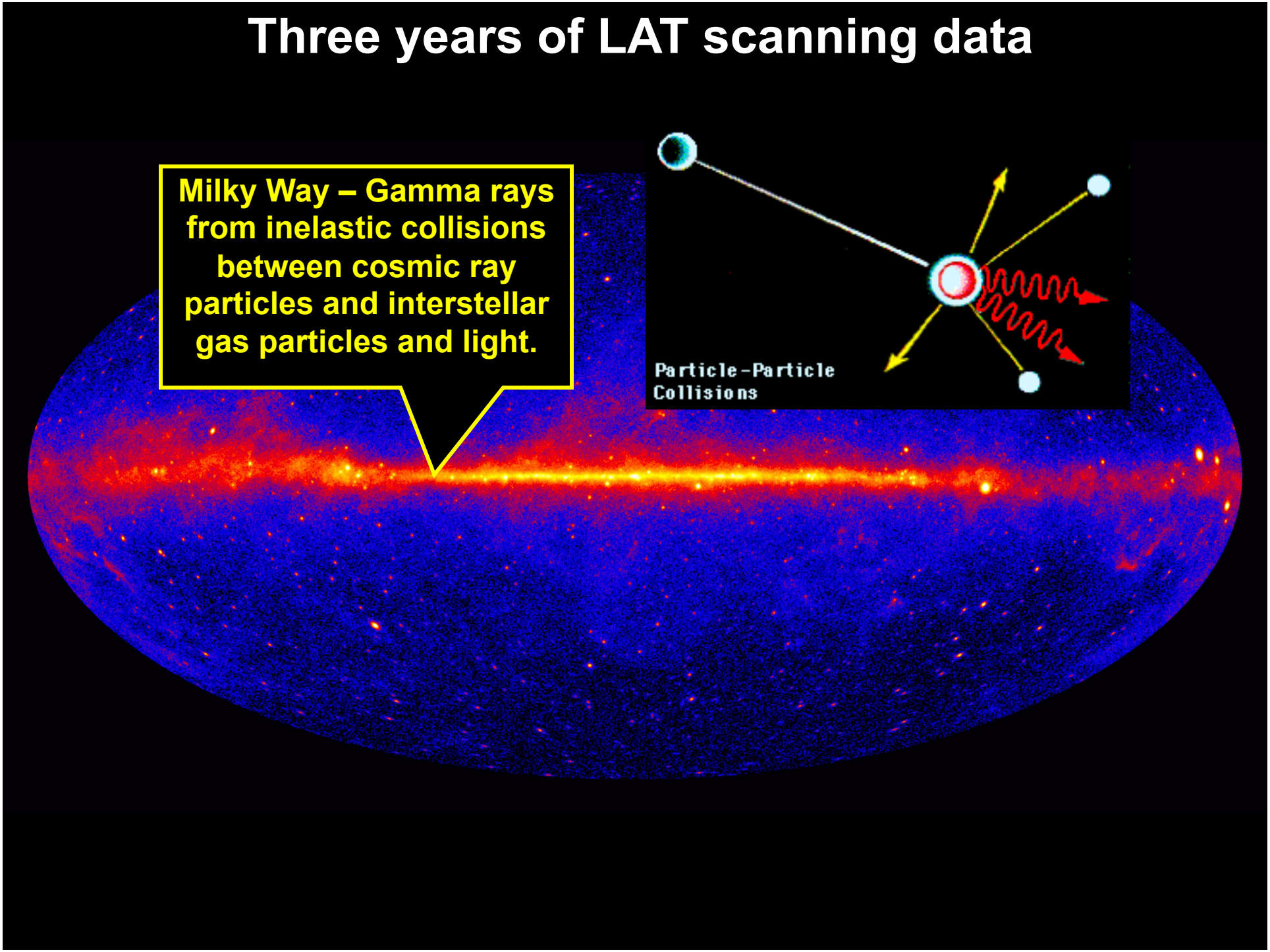
GRB090902B - Autonomous repoint

- LAT pointing in celestial coordinates from -120 s to 2000 s
  - Red cross = GRB 090902B
  - Dark region = occulted by Earth; Yellow disk = Sun
  - Blue line = LAT FoV
  - White lines = 20° (Earth avoidance angle) / 50° above horizon
  - White points = LAT events



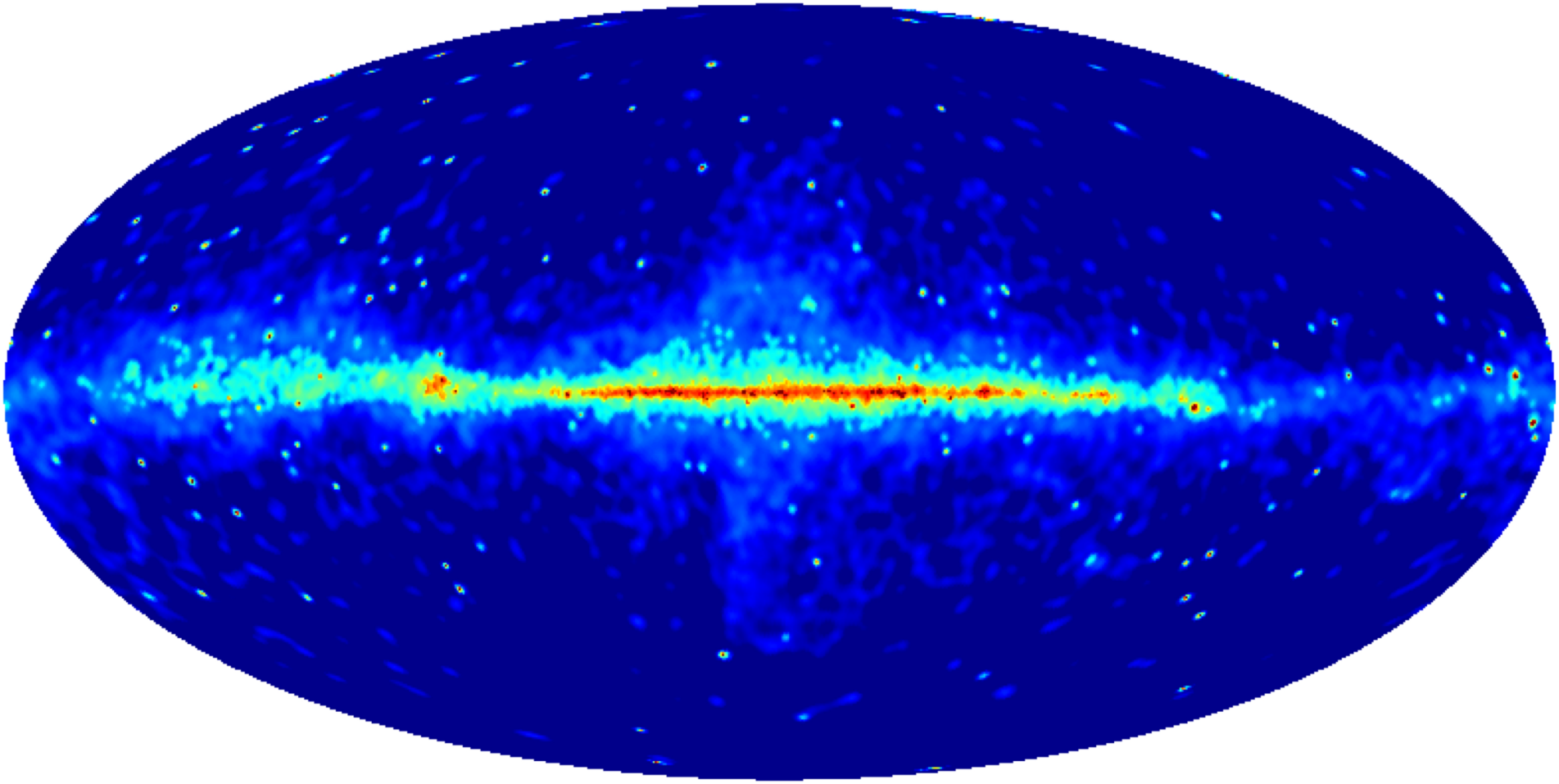
Overview of the Gamma-ray Sky

Three years of LAT scanning data

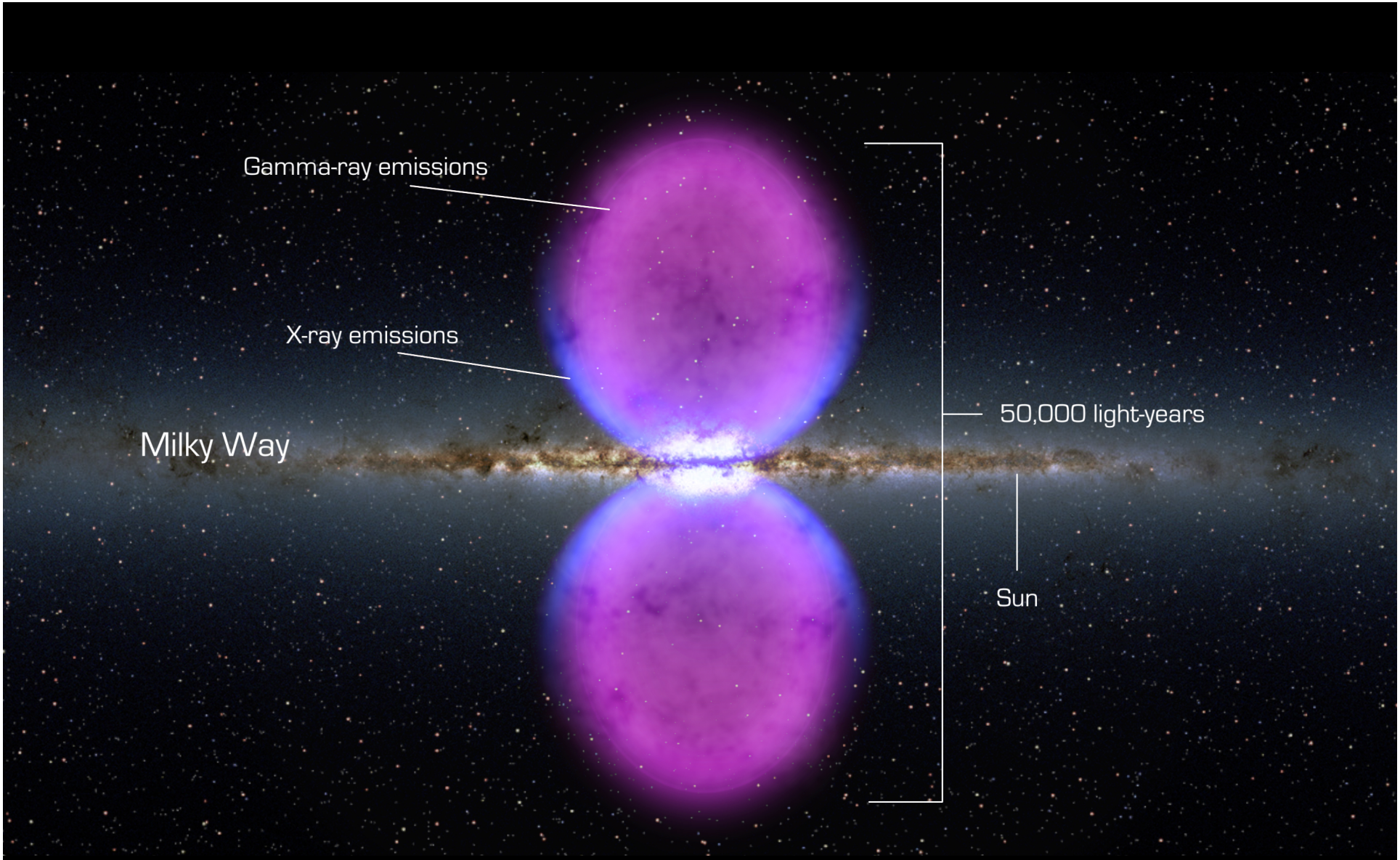


The Gamma-ray Sky above 10 GeV

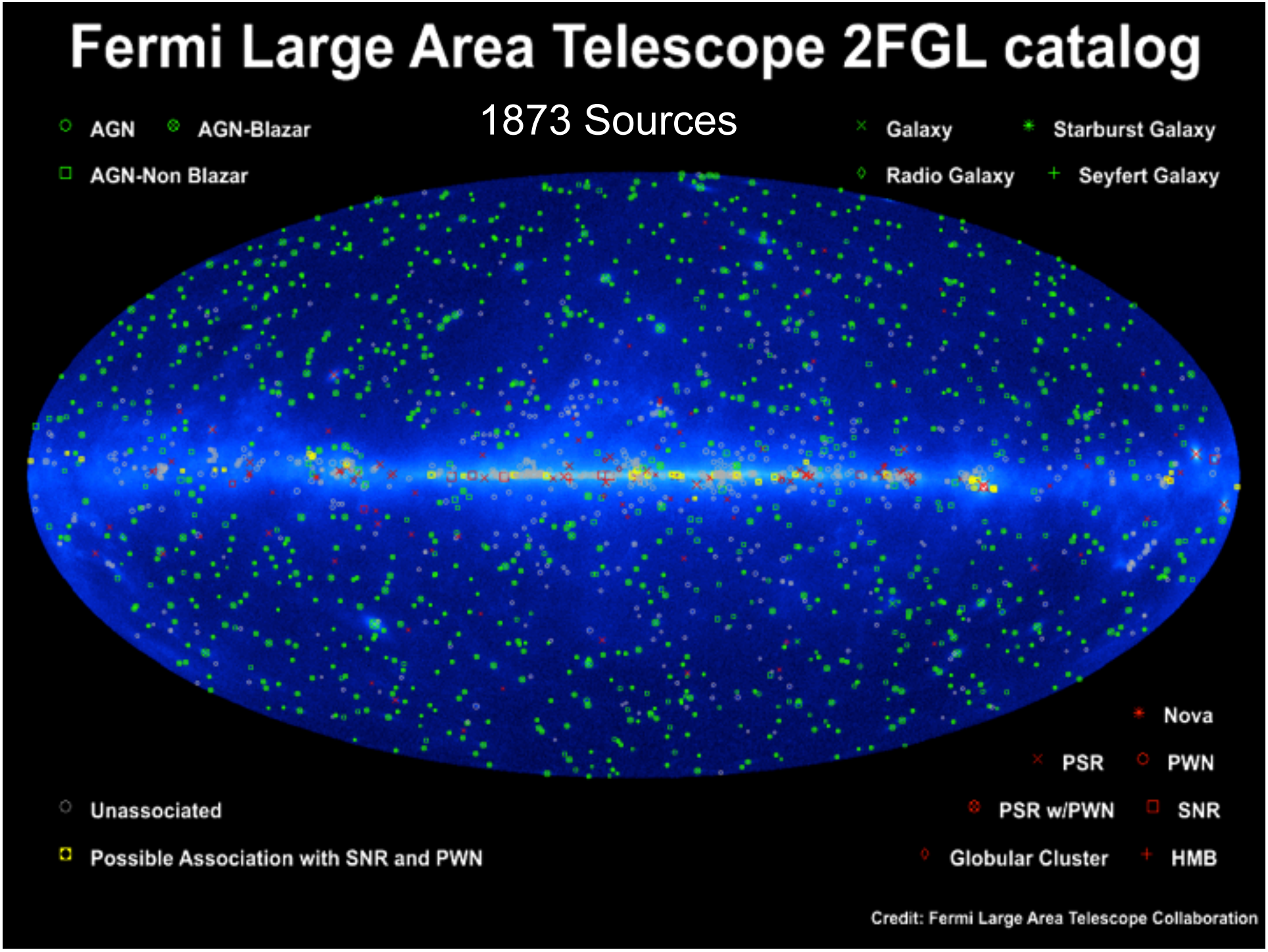
Adaptively smoothed image courtesy of the LAT collaboration



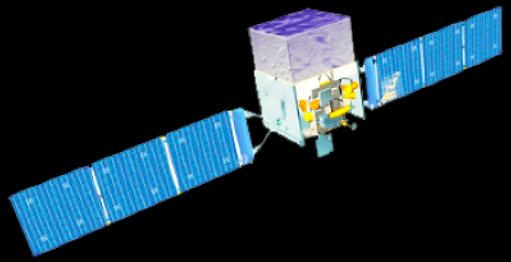
In addition to nearly 500 sources at these energies, the sky shows large-scale features like the previously reported "Fermi bubbles" (Su, Slatyer, Finkbeiner, 2010)



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

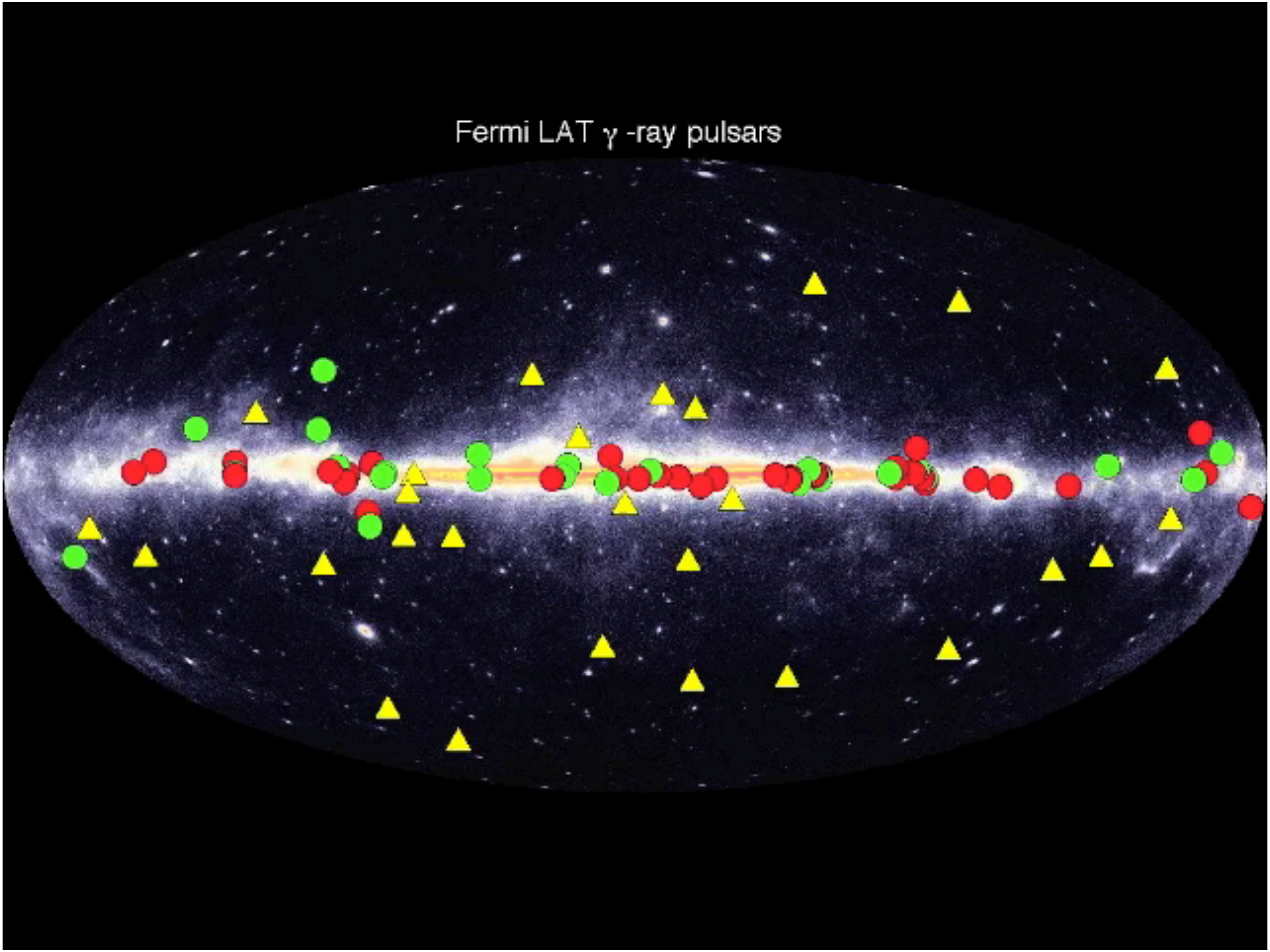

Fermi Large Area Telescope 2FGL catalog
1873 Sources
AGN
AGN-Blazar
AGN-Non Blazar
Galaxy
Starburst Galaxy
Radio Galaxy
Seyfert Galaxy
Nova
PSR
PWN
PSR w/PWN
SNR
Globular Cluster
HMB
Unassociated
Possible Association with SNR and PWN
Credit: Fermi Large Area Telescope Collaboration

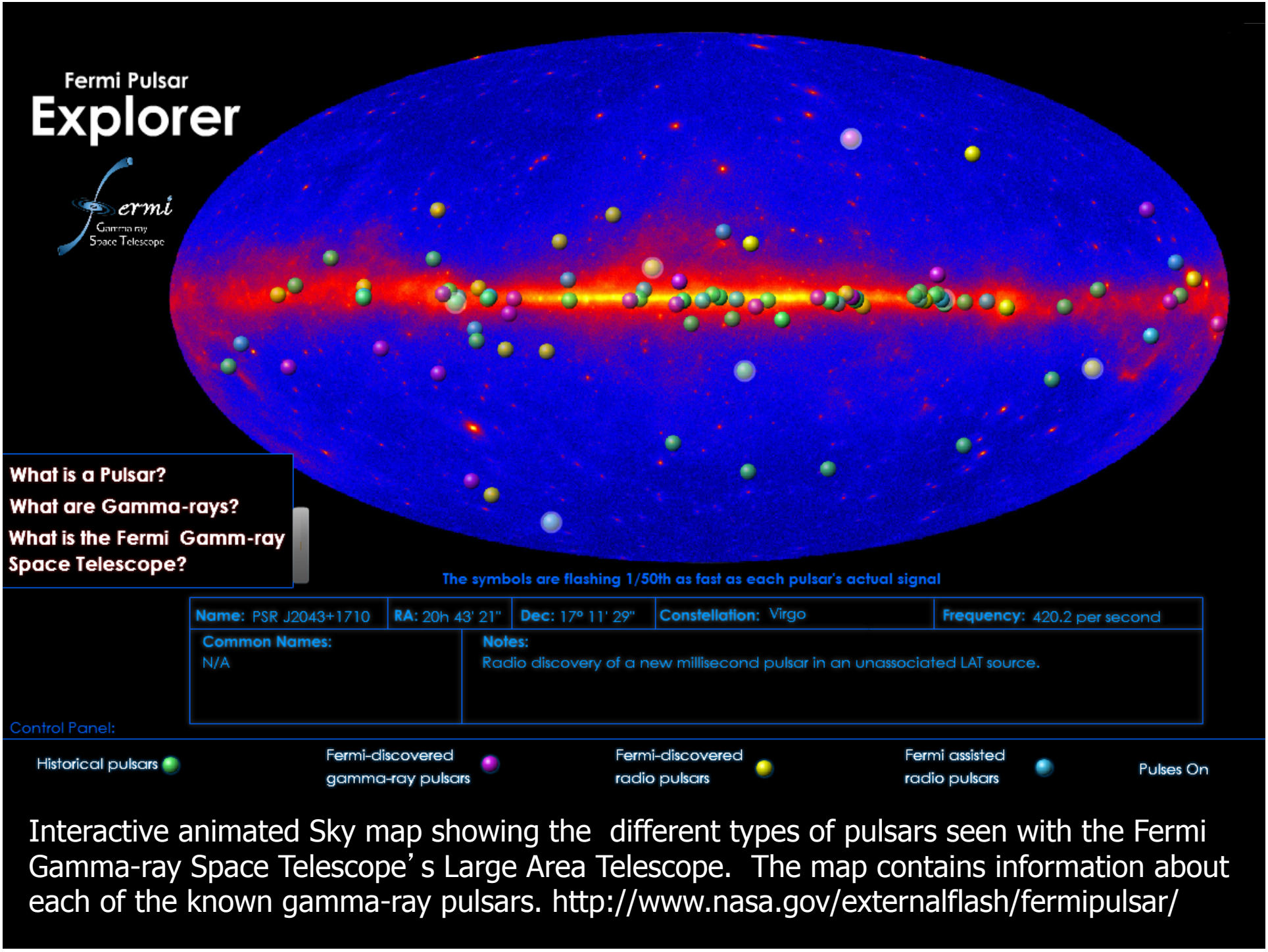
What has Fermi found: The LAT two-year catalog



Credit: NASA/Goddard Space Flight Center

Some Galactic results from Fermi


Fermi LAT γ -ray pulsars



Interactive animated Sky map showing the different types of pulsars seen with the Fermi Gamma-ray Space Telescope's Large Area Telescope. The map contains information about each of the known gamma-ray pulsars. http://www.nasa.gov/externalflash/fermipulsar/

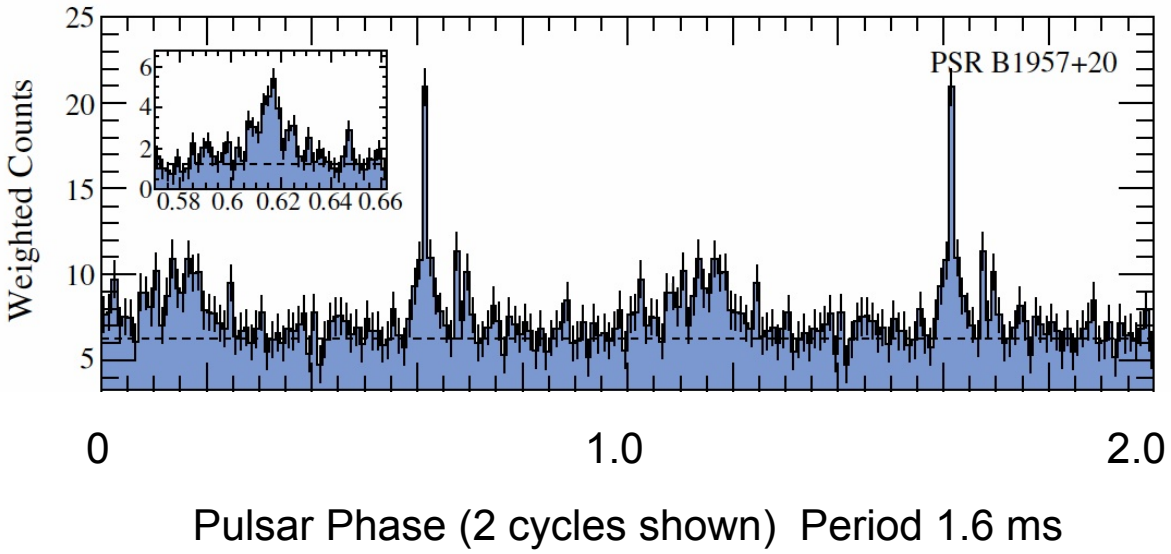
How can you join the search for more gamma-ray pulsars?

Some of the same search techniques that have discovered gamma-ray pulsars in the Fermi LAT data are now available on home computers, using computer processing cycles when other activities are not in progress. http://einstein.phys.uwm.edu/

If you join the Einstein@Home project, your home computer may be processing Fermi LAT data, as well as LIGO and radio astronomy data. Perhaps you can be the first to discover a gamma-ray-only millisecond pulsar!

More information: http://einstein.phys.uwm.edu/apps.php

Variability on Very Short Time Scales

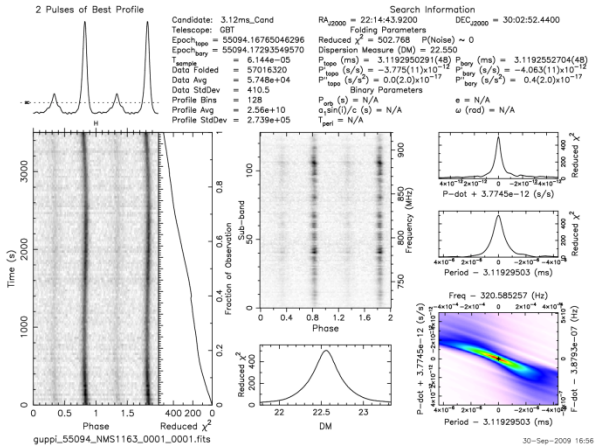


FWHM of the sharp peak of this ms pulsar is 23 ± 11 microseconds.
Guillemot et al. 2012

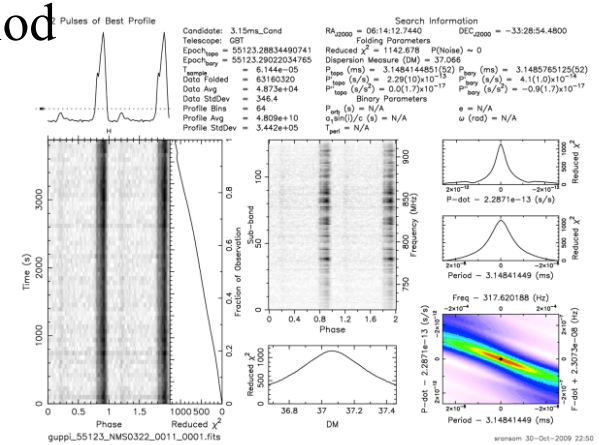
Search for Radio Pulsars in LAT UnID Source Error Boxes

- **More than 30 new millisecond pulsars found!**

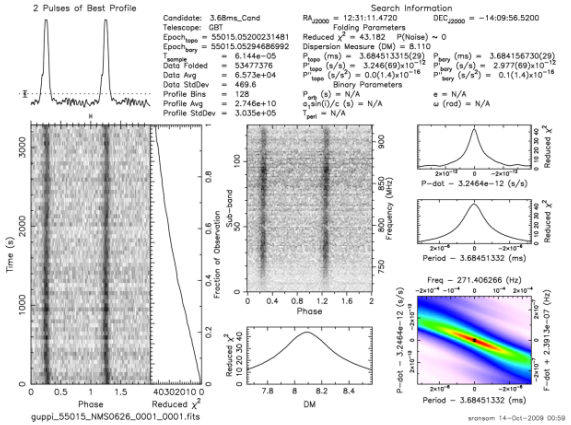
0FGL J2214.8+3002 is PSR J2214+30
'Black Widow' pulsar
3.12 ms spin period
10 hour orbit



0FGL J0614.3-3330 is PSR J0614-33
3.15 ms spin period
Unknown orbit



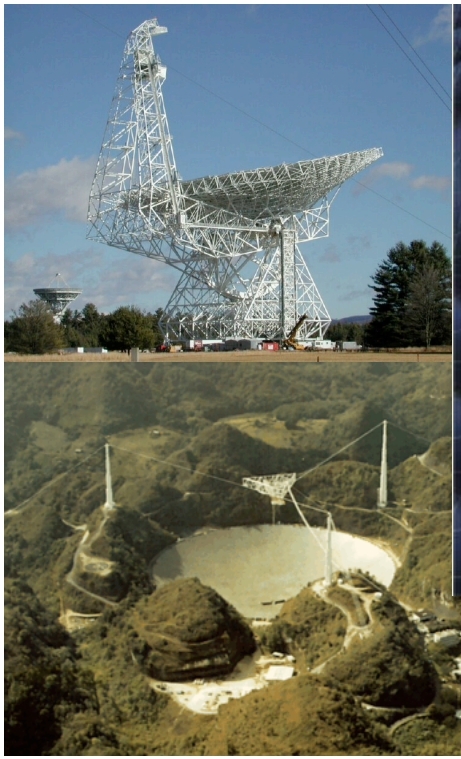
0FGL J1231.5-1410 is PSR J1231
3.68 ms spin
1.86 day orbit

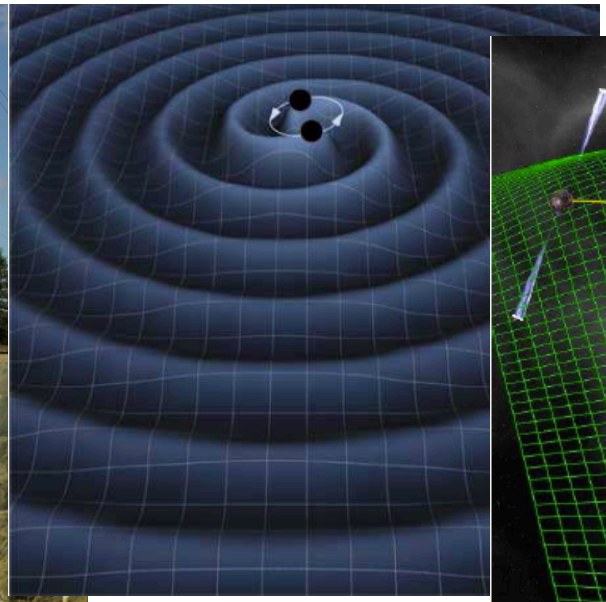


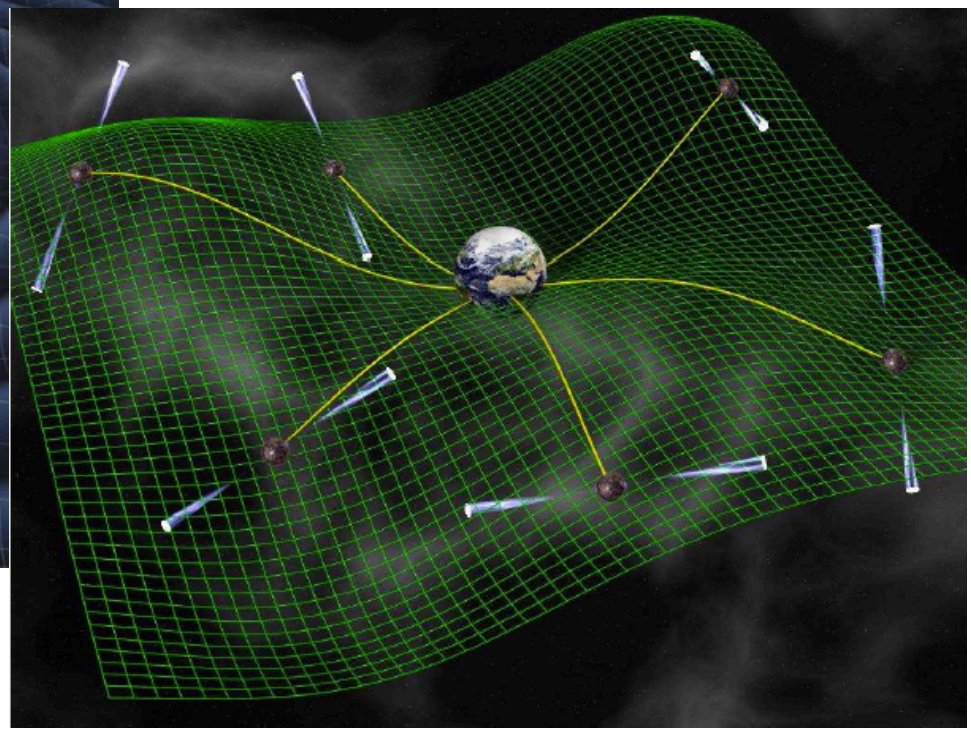
Bright and stable millisecond pulsars are in high demand to complete timing arrays searching for gravitational radiation

Pulsar Timing Arrays as Gravitational Wave Detectors

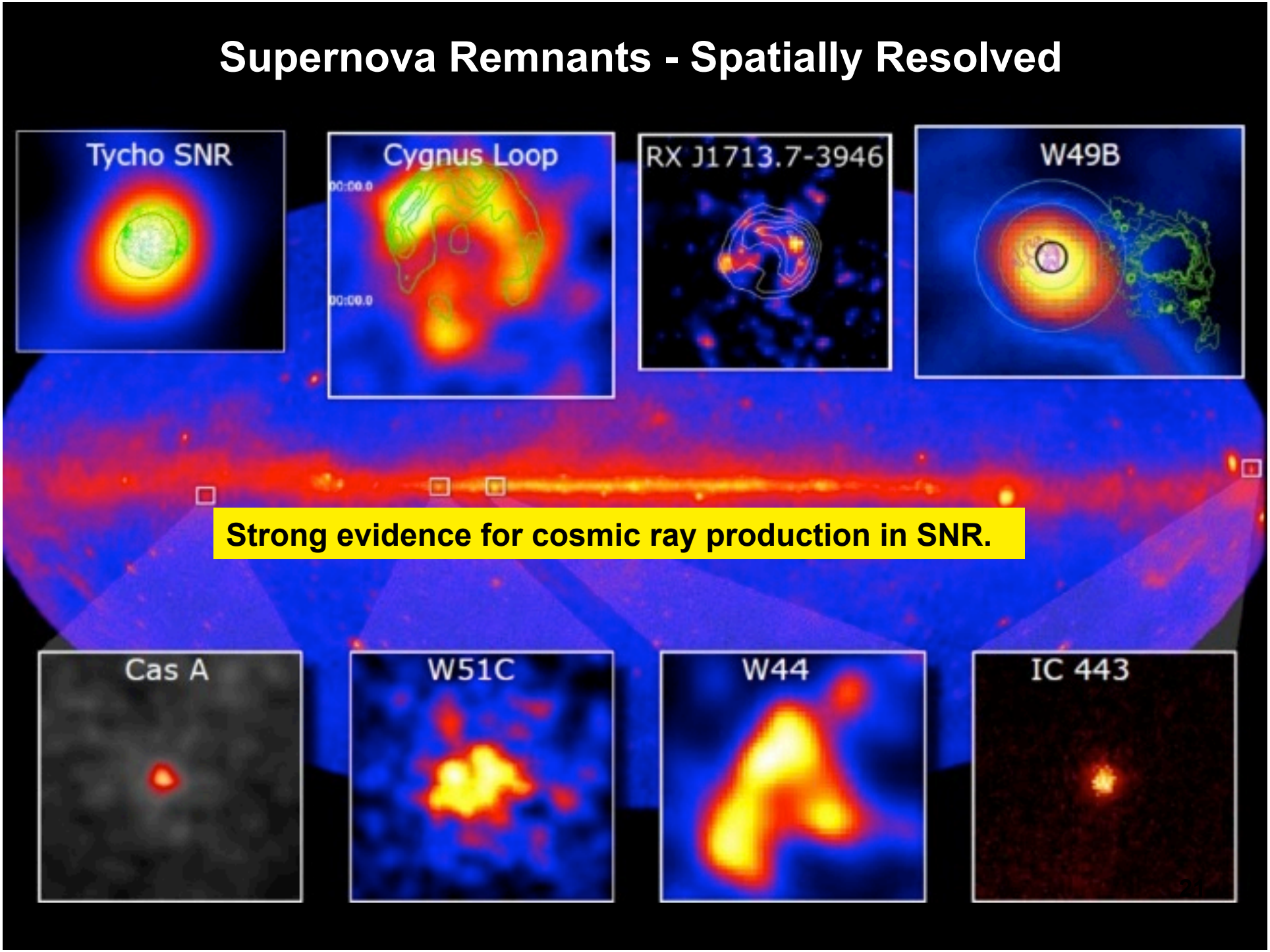
- Time millisecond pulsars to 100 nanoseconds
- Arrays of MSPs can be sensitive to nHz gravitational waves – need 20-40 MSPs for detection in 5 years
- Search for stochastic gravitational wave background from black hole/ galaxy mergers







Supernova Remnants - Spatially Resolved

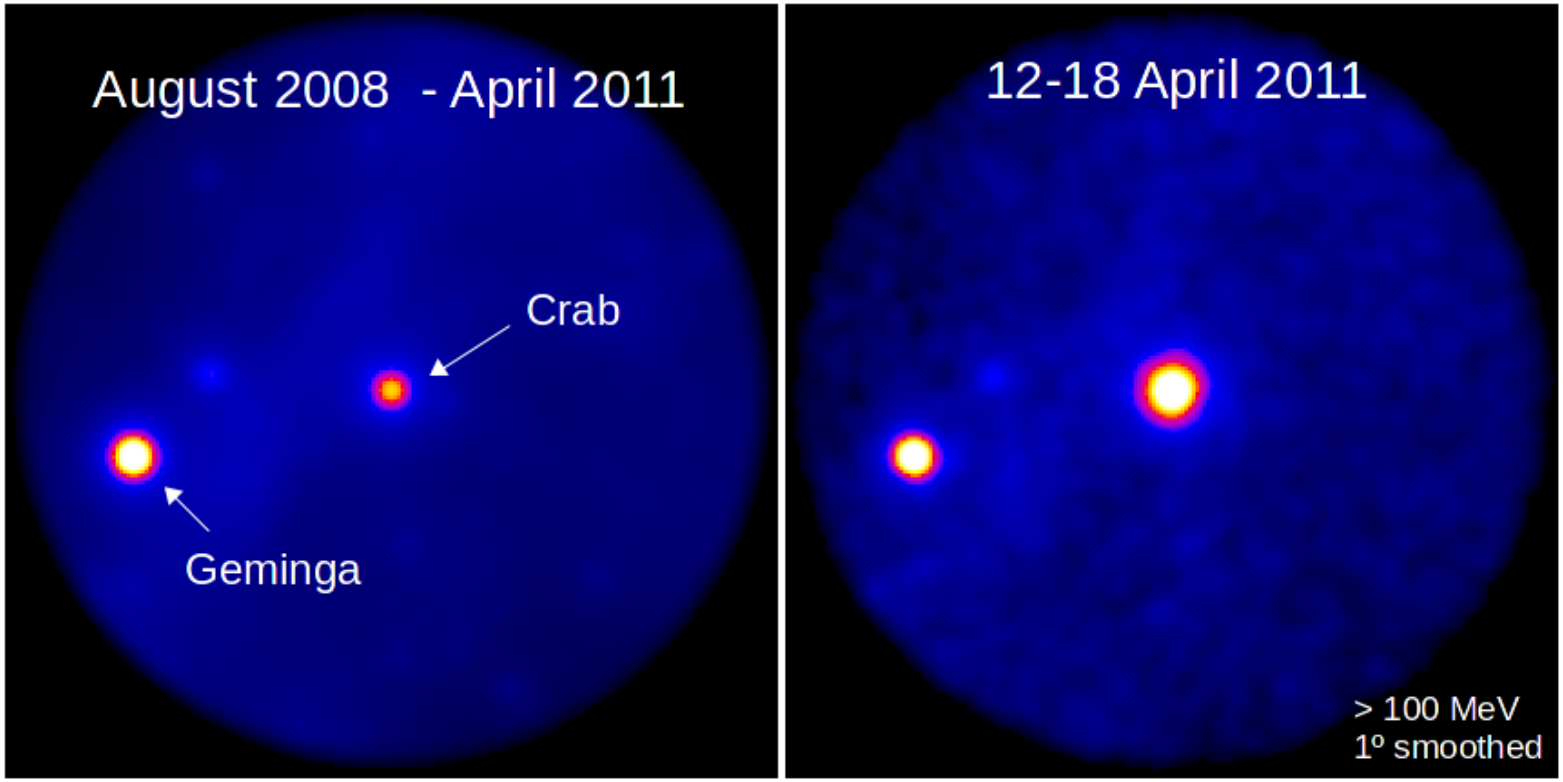


Strong evidence for cosmic ray production in SNR.

The Crab Nebula - A Rosetta Stone of Astrophysics

Supernova seen in 1054 → Supernova remnant and pulsar

Exposure corrected counts map >100 MeV



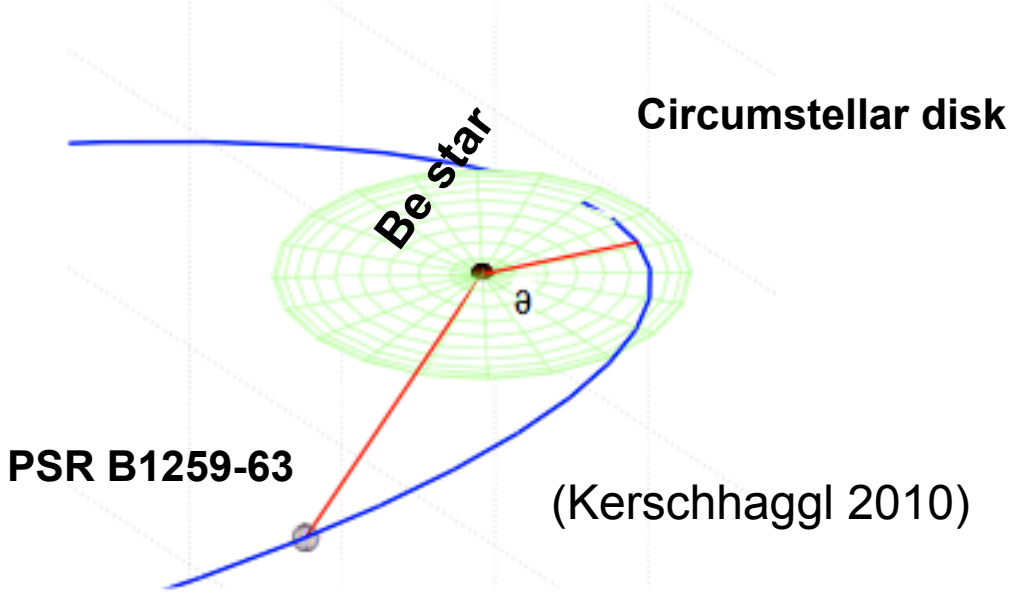
Geminga constant, Flare stands out

Crab Nebula Flaring

- **The measurement of >1 GeV synchrotron gamma-rays implies electrons > 1 PeV are present**
  - **The loss time scales are extremely short (cooling length ~ Larmor radius) as are acceleration time scales**
  - **A potential interpretation is enormous accelerating potential from the interaction of the pulsar wind with the nebula**
  - **Likely to require relativistic beaming to explain the short time scale for variability.**

PSR B1259-63 System

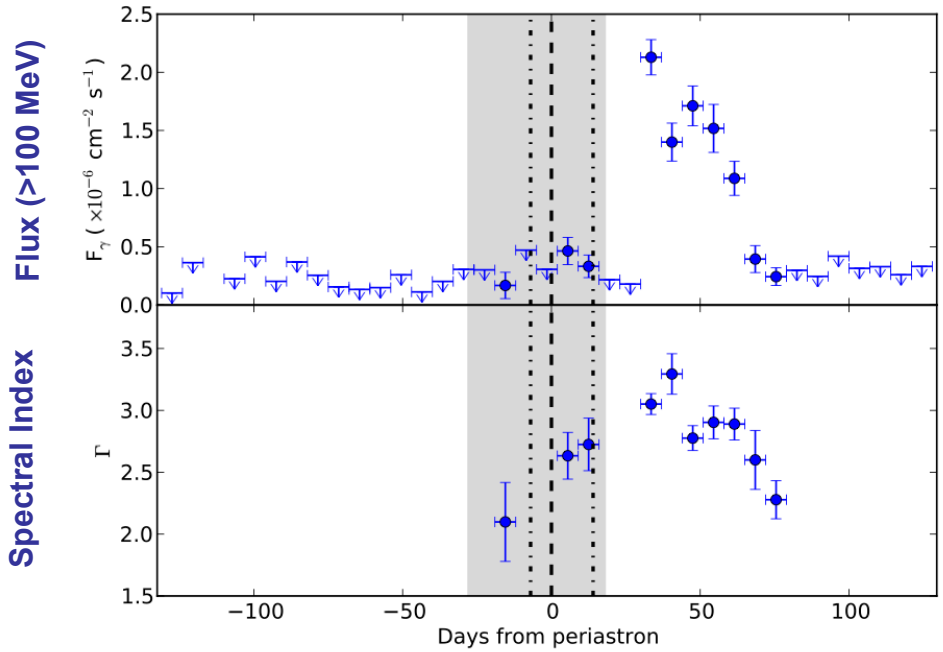
- **Pulsar/Be star binary – a well-studied system with a 3.4-year period**



- **December 2010 was the first periastron passage during the Fermi mission**

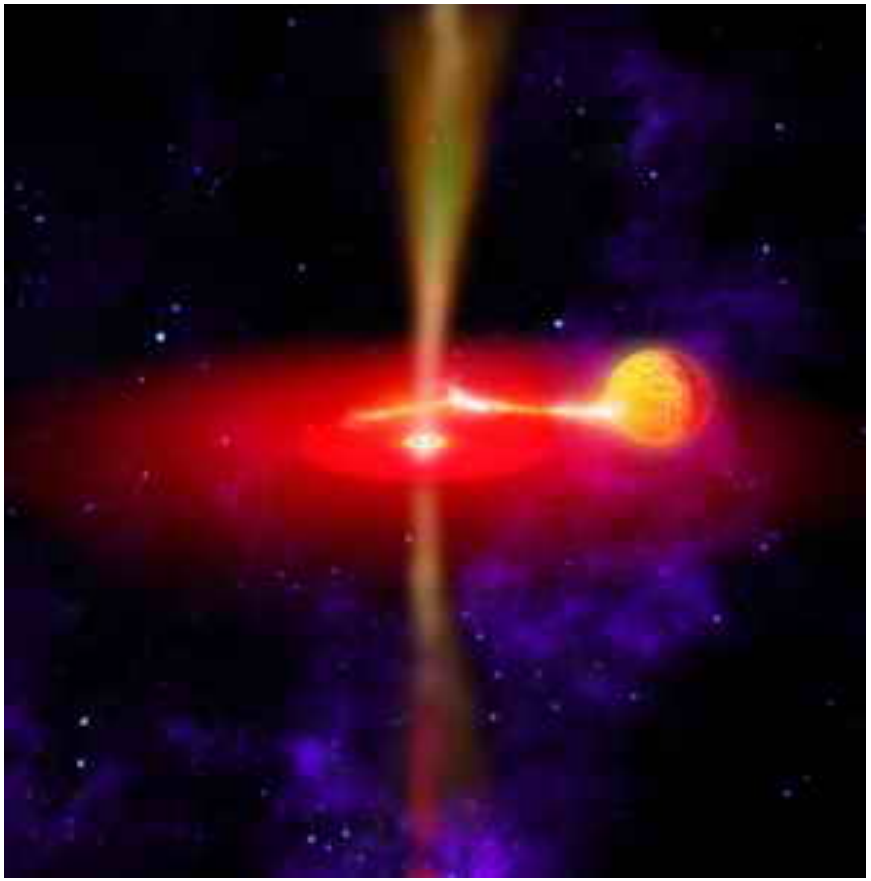
PSR B1259-63 System

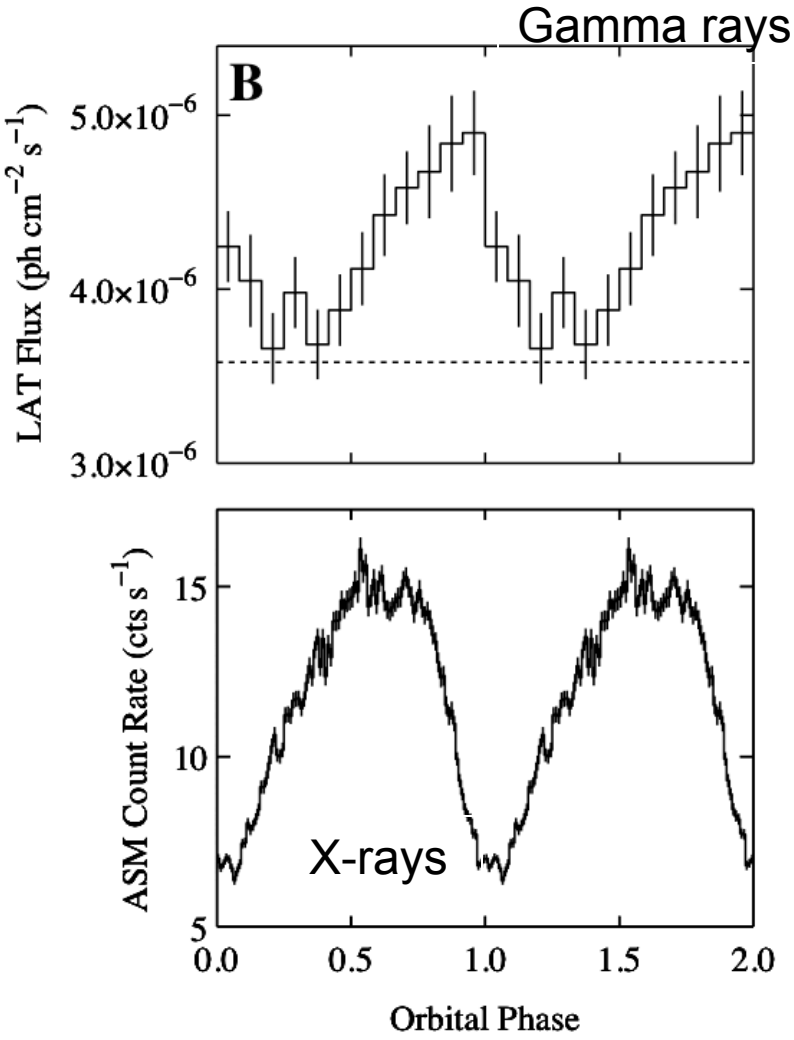
- **The gamma-ray flux was detected faintly around the time of the first passage through the circumstellar disk.**



- **Unexpectedly the system flared dramatically in gamma rays during the second disk passage, with luminosity nearly that of the spin-down power of the pulsar – relativistic beaming may somehow be required**

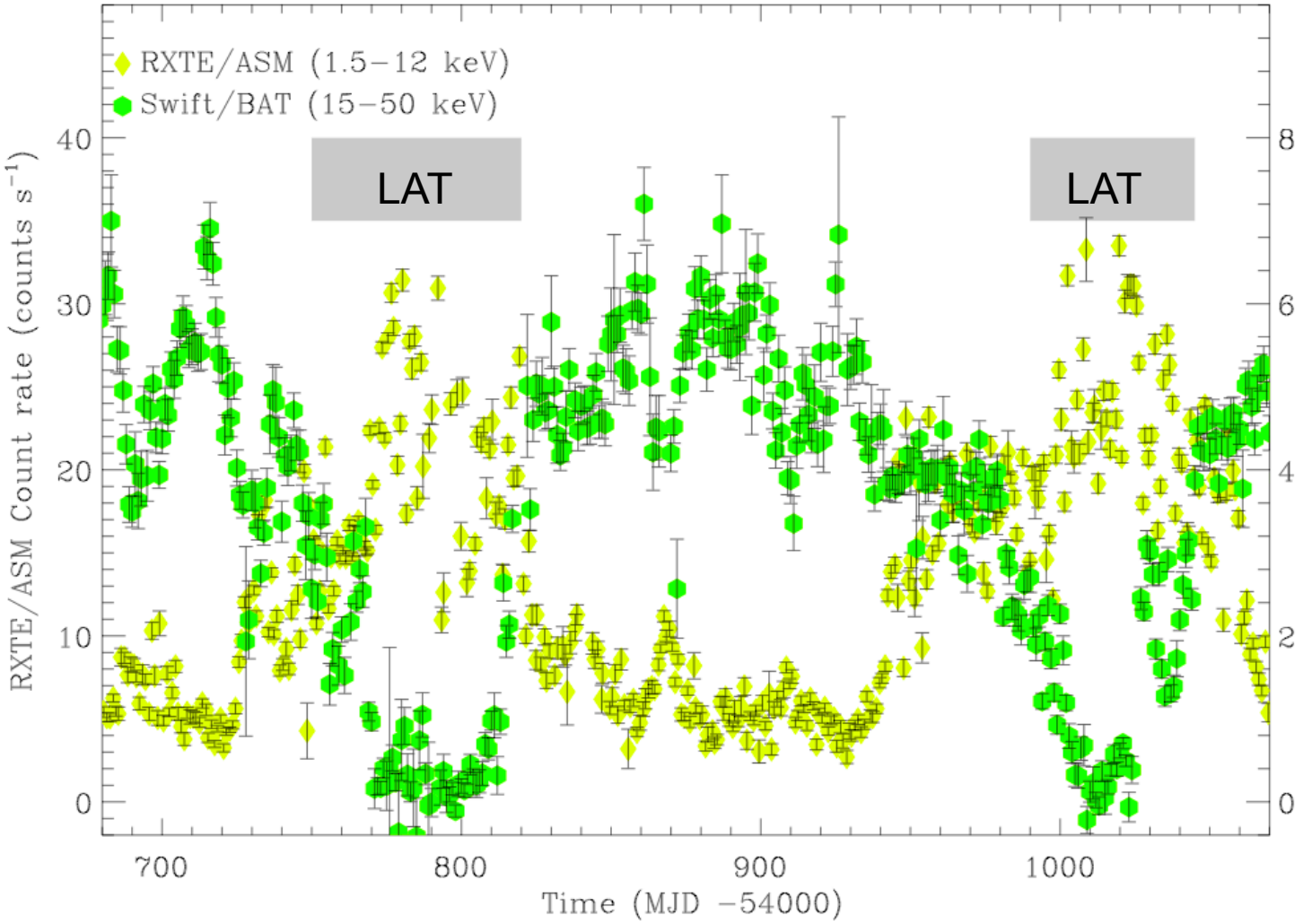
Cygnus X-3 - Binary System - 4.8 Hour Period





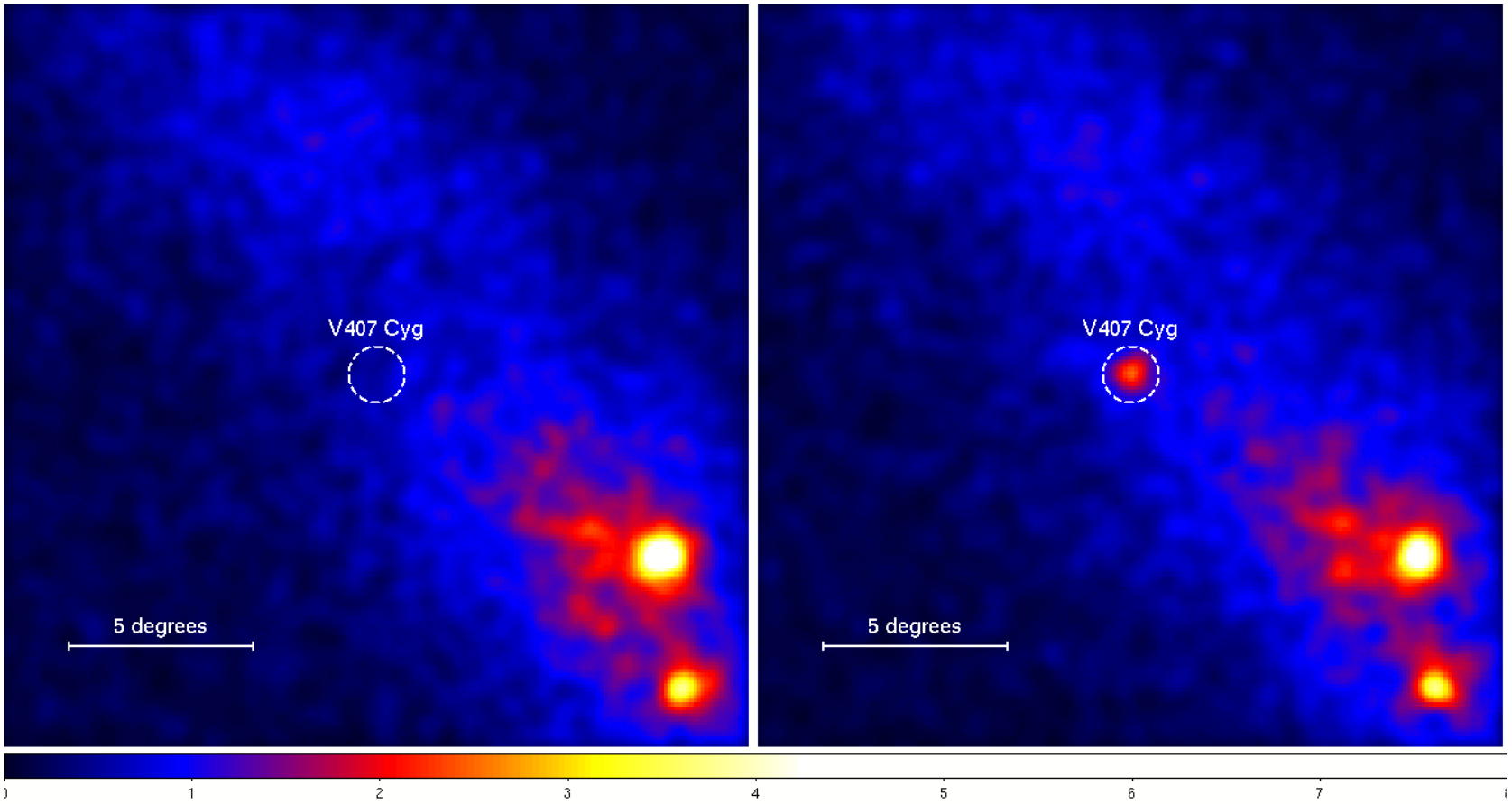
Neutron star or black hole binary system, accelerating particles to high energies. The system remains largely a mystery.

Cygnus X-3 - Binary System - 4.8 Hour Period



Fermi LAT only sees gamma-ray emission when Cyg X-3 has strong low-energy X-ray flux and weaker high-energy X-ray flux.

March 2010 - a Galactic plane transient



When we looked at the Swift webpage to request X-ray observations, we noticed that Swift was already looking at this location!

A Surprise - A Gamma-ray Nova

Electronic Telegram No. 2199

Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
CBAT Director: Daniel W. E. Green; Room 209; Dept. of Earth and Planetary Sciences; Harvard University; 20 Oxford St.; Cambridge, MA 02138; U.S.A.
e-mail: cbat@iau.org; cbatiau@eps.harvard.edu
URL http://www.cfa.harvard.edu/iau/cbat.html

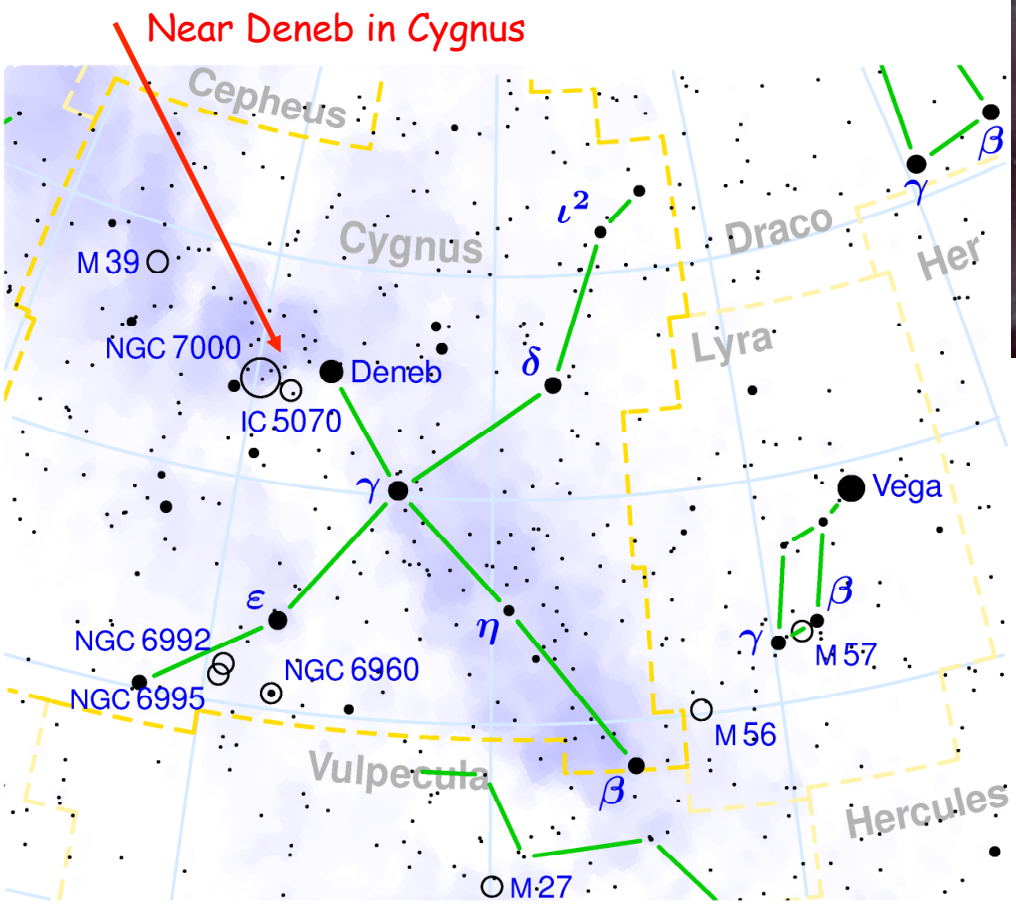
V407 CYGNI

Hiroyuki Maehara, Kwasan Observatory, Kyoto University, reports the discovery by Koichi Nishiyama (Fukuoka, Japan) and Fujio Kabashima (Saga, Japan) of an apparent unusually bright outburst (mag 7.4) of the symbiotic star V407 Cyg on an unfiltered CCD image [illegible] a 105-mm camera lens (+ SBIG STL6303E came[illegible] confirmed the outburst on two unfiltered[illegible]3 (at mag 6.8) and 10.814 (mag 6.9) using a 0.[illegible]

The amateur astronomers who discovered the optical flare.

V407 Cygni: a binary system

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

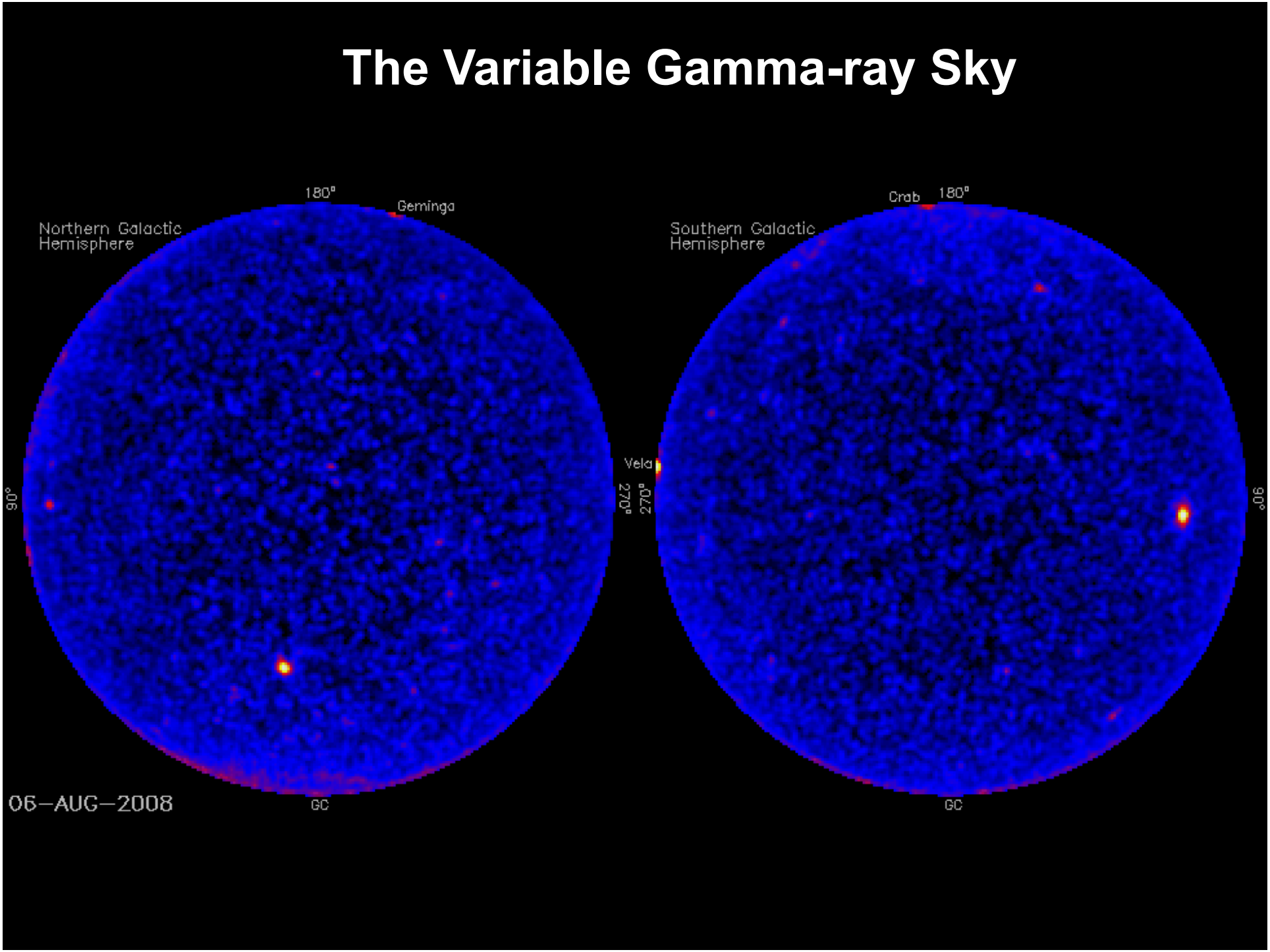


The shock wave from the nova thermonuclear explosion accelerates particles that interact with the surrounding material to produce the gamma rays.

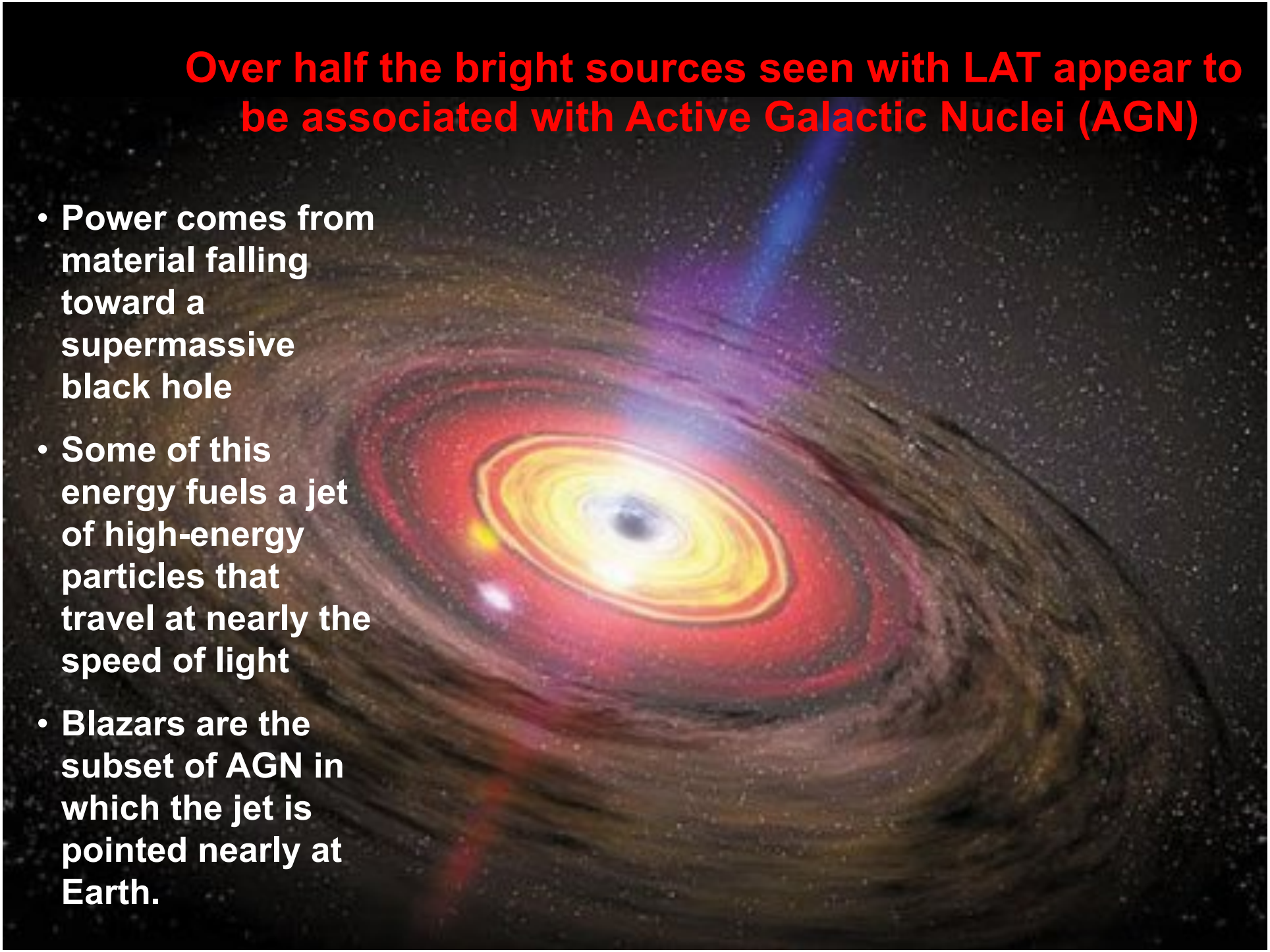
V407 Cyg ~ 6000 light years away

Some Fermi results on extragalactic sources

The Variable Gamma-ray Sky

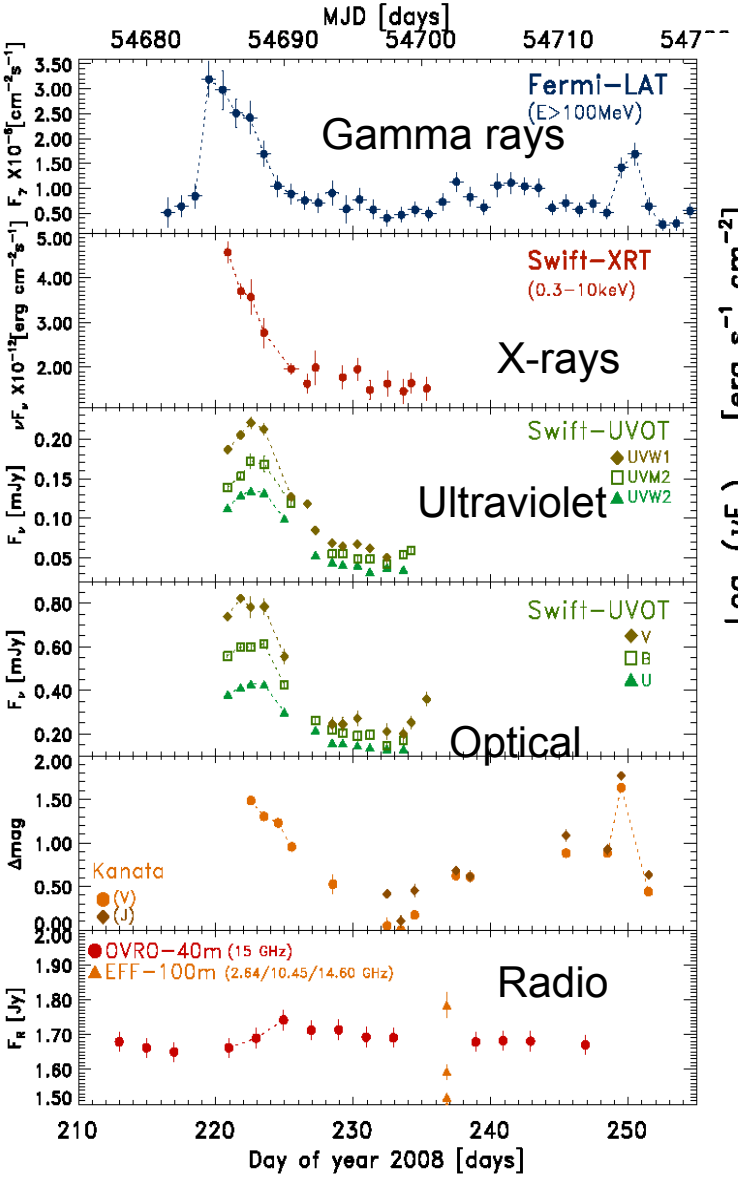


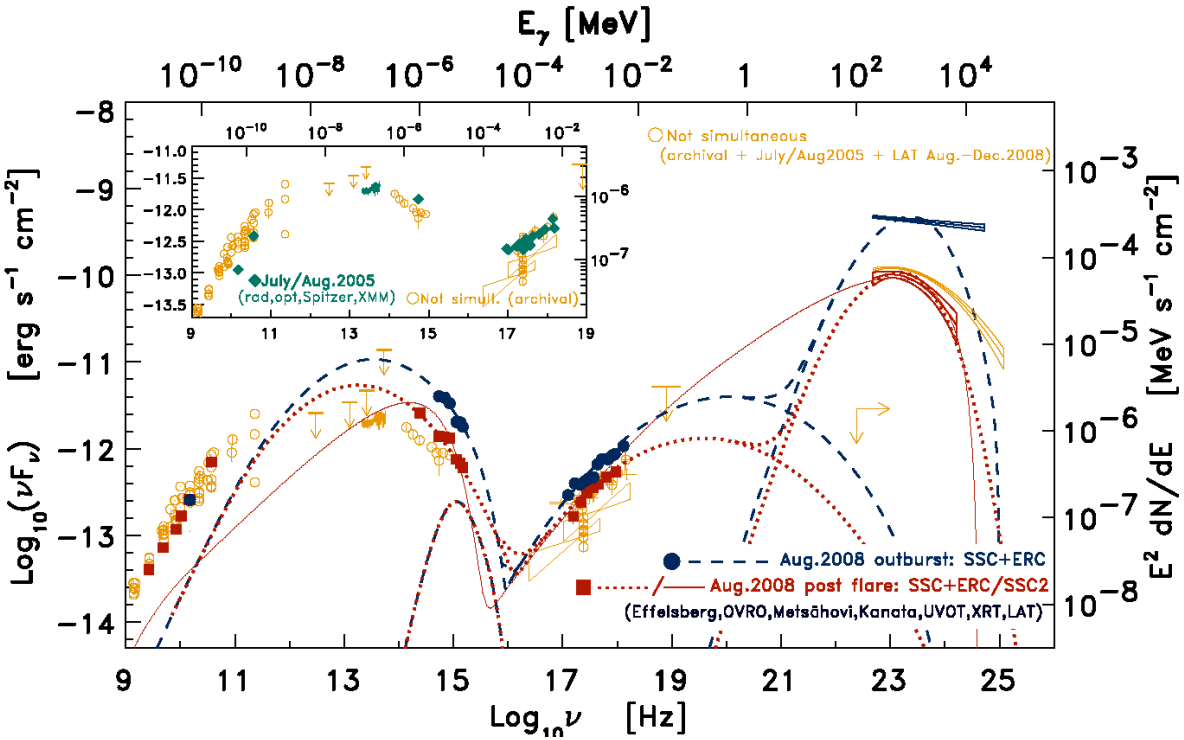
Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)



- 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
- Blazars are the subset of AGN in which the jet is pointed nearly at Earth.

PKS 1502+106

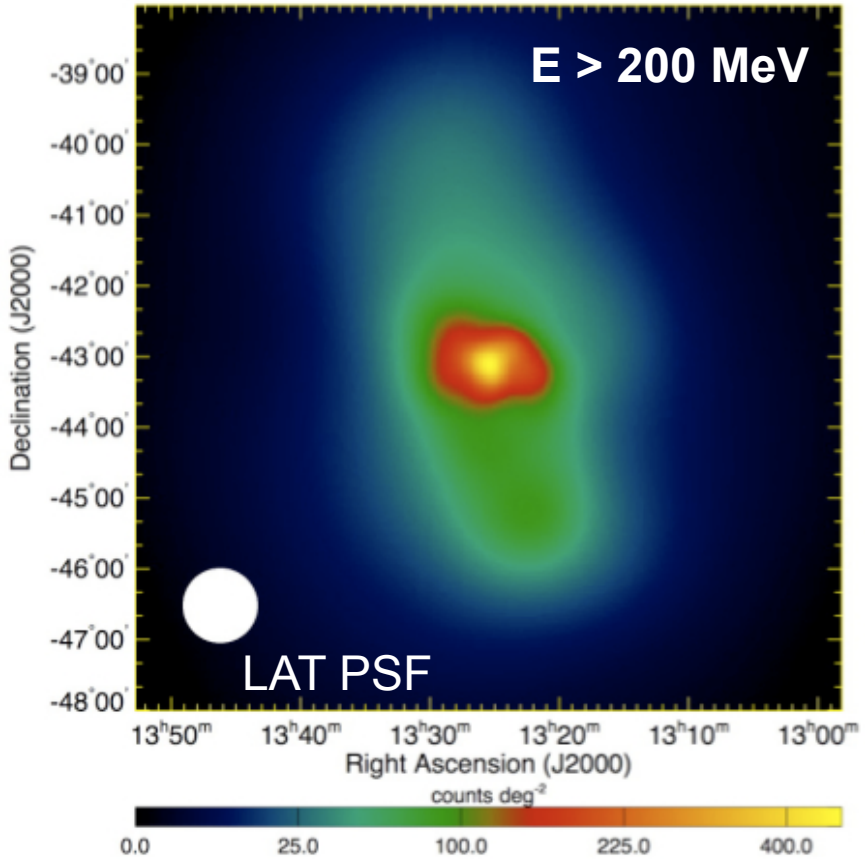




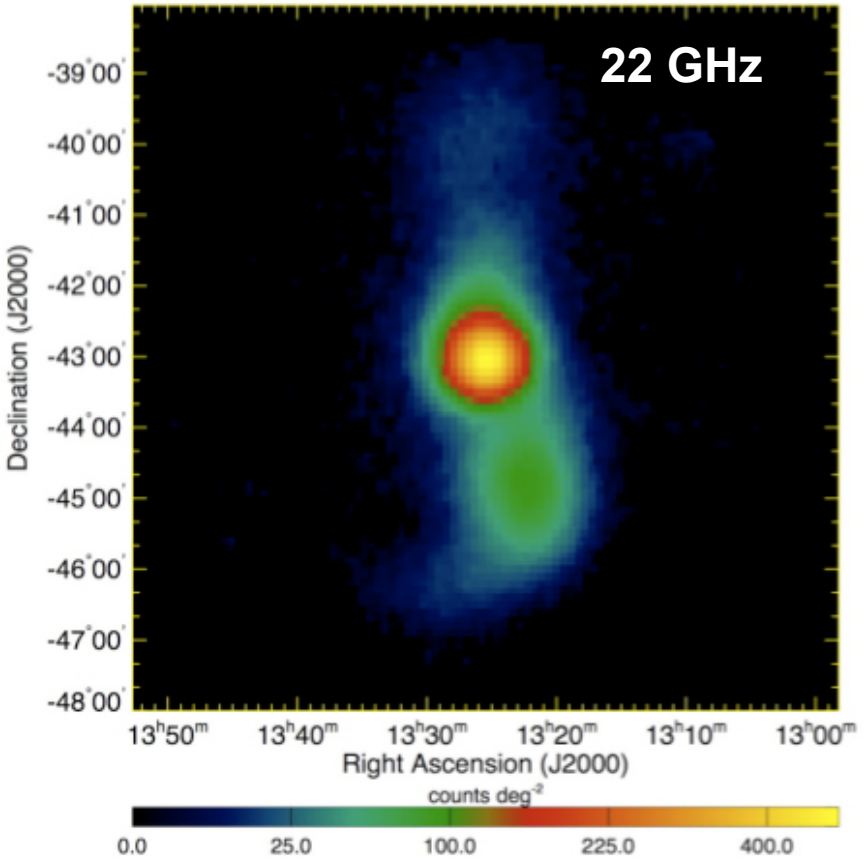
The radio-to-gamma-ray averaged Spectral Energy Distributions collected during the *Fermi-Swift* Aug.2008 multi-frequency campaign for both the outburst state (MJD: 54685-54689, blue data points) and the subsequent post-flare state (MJD 54690-54701, red data points). The archival data are reported as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

Centaurus A - Radio Galaxy

Over ½ of the total >100 MeV observed LAT flux in the lobes



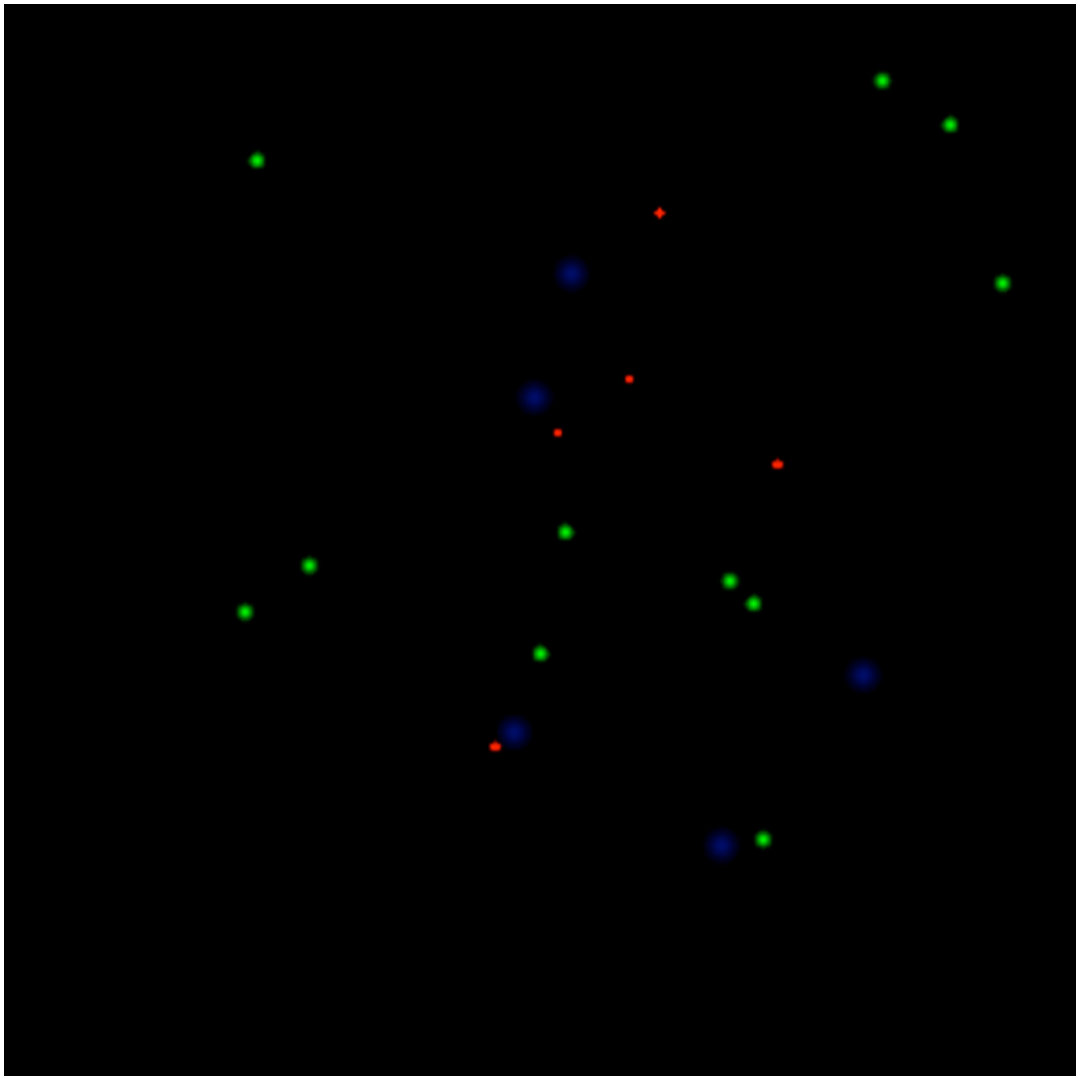
LAT counts map with background (isotropic and diffuse) and field point sources subtracted



WMAP image provided by Nils Odegard (GSFC)

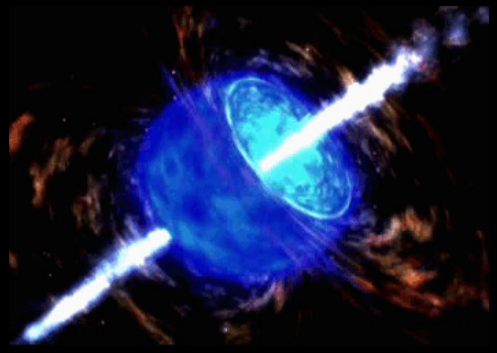
Requires 0.1-1 TeV electrons in giant 'relic' lobes: accelerated in-situ or efficient transport from center

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.

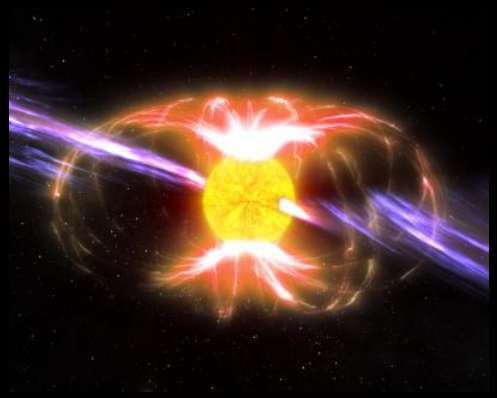
Gamma-ray bursts come in at least three flavors



Collapsars: A rapidly spinning stellar core collapses and produces a supernova, along with relativistic jets that can produce long GRBs

Compact Mergers: Two neutron stars, or a neutron star and a black hole, collide and merge, producing a jet that gives rise to a short GRB

In both these cases, the burst probably produces a black hole.

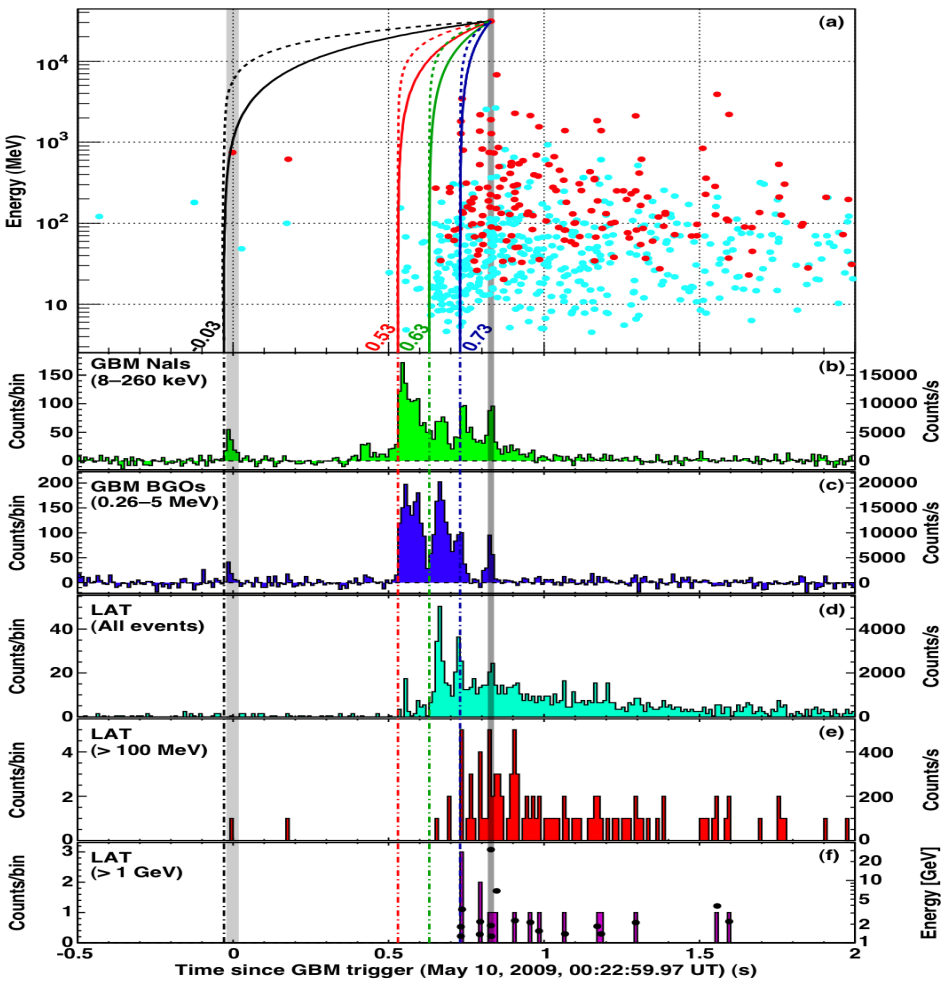


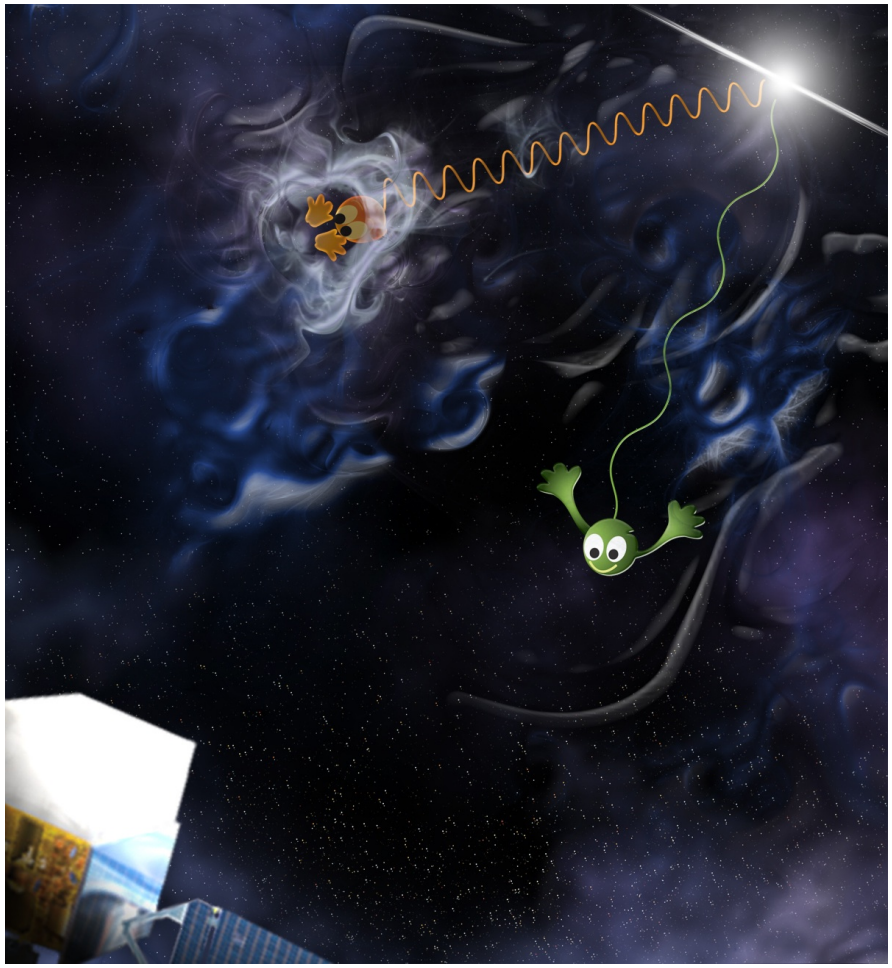
Magnetars: Neutron stars in our Galaxy or nearby galaxies with extremely strong magnetic fields can give off powerful bursts that resemble short GRBs

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.

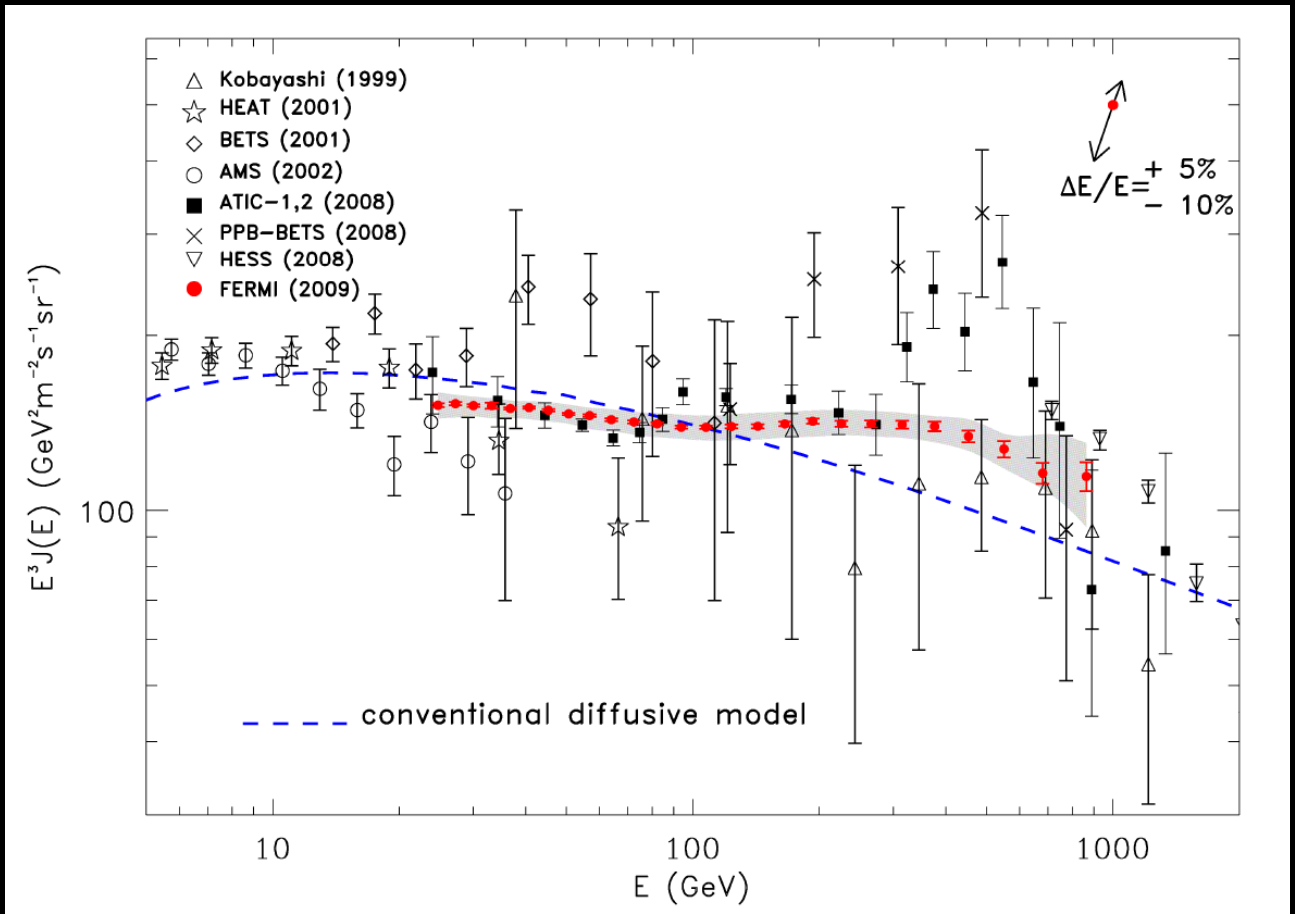
Non-gamma-ray results, the unseen, and the future

Fermi LAT: $e^+ + e^-$ spectrum

- **no prominent spectral features between 20 GeV and 1 TeV; significantly harder spectrum than inferred from previous measurements**

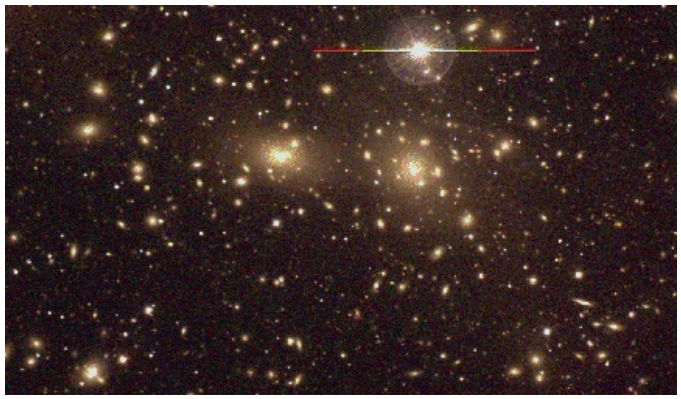
Abdo et al. 2009, Phys. Rev. Lett. 102, 181101

- **events for e^+ e^- analysis required to fail ACD vetoes for selecting γ events; resulting γ contamination < 1%**
- **further cuts distinguish EM and hadron events; rejection 1:10^3 up to 200 GeV; ~1:10^4 at 1 TeV**
- **energy reconstruction aided by shower imaging capability of calorimeter**
- **more than 4x10^6 e^- e^+ events in selected sample**



The excess above the conventional model suggests a local source, but what?

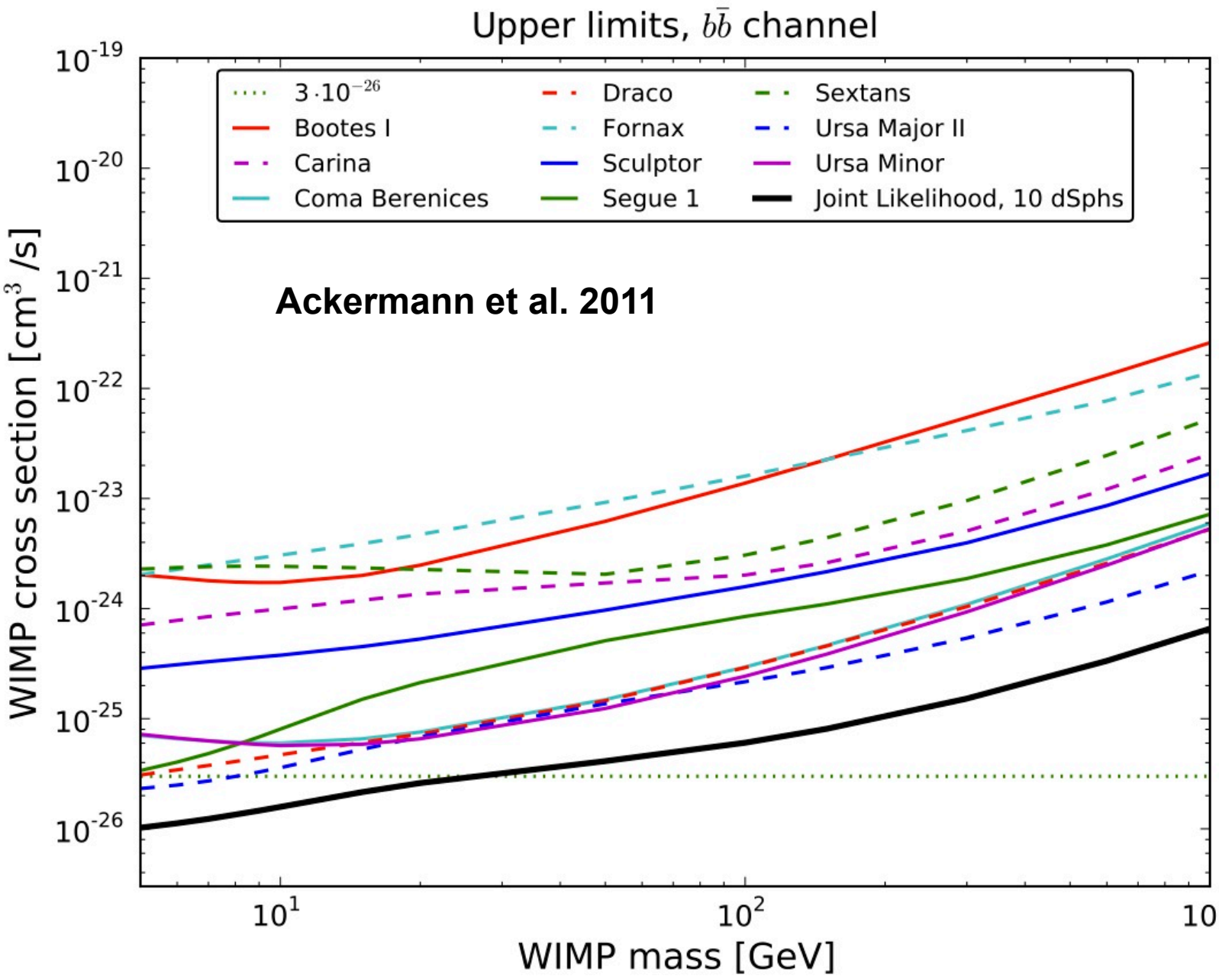
What is Not Seen Can Also Be Important



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.

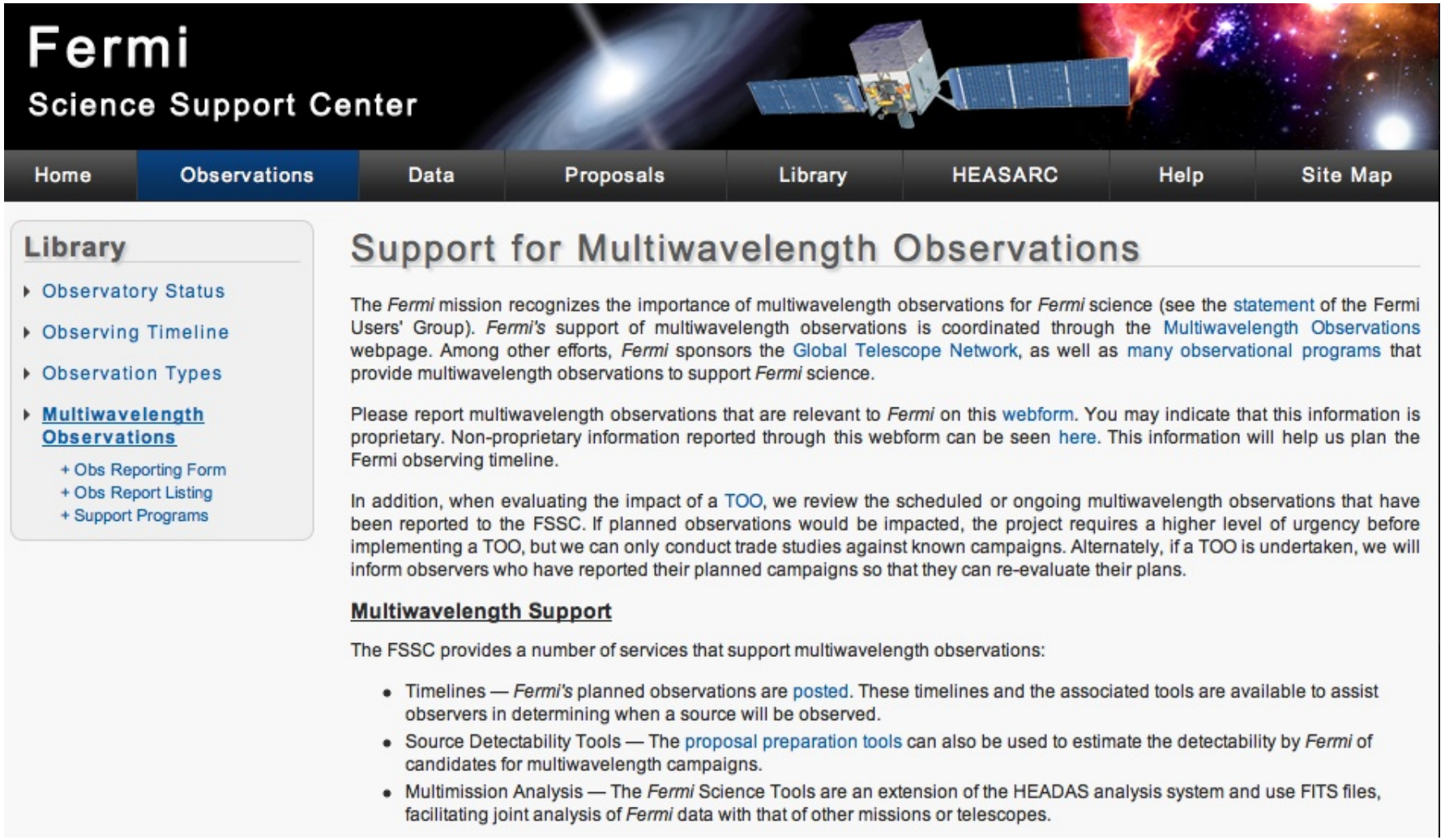
Dwarf spheroidal galaxies are thought to be largely composed of dark matter. If dark matter consists of some types of Weakly Interacting Massive Particles (WIMPs), such galaxies would be gamma-ray sources visible to Fermi LAT. Their absence puts constraints on dark matter models.

Fermi LAT Constraints on Dark Matter



Thermal limit

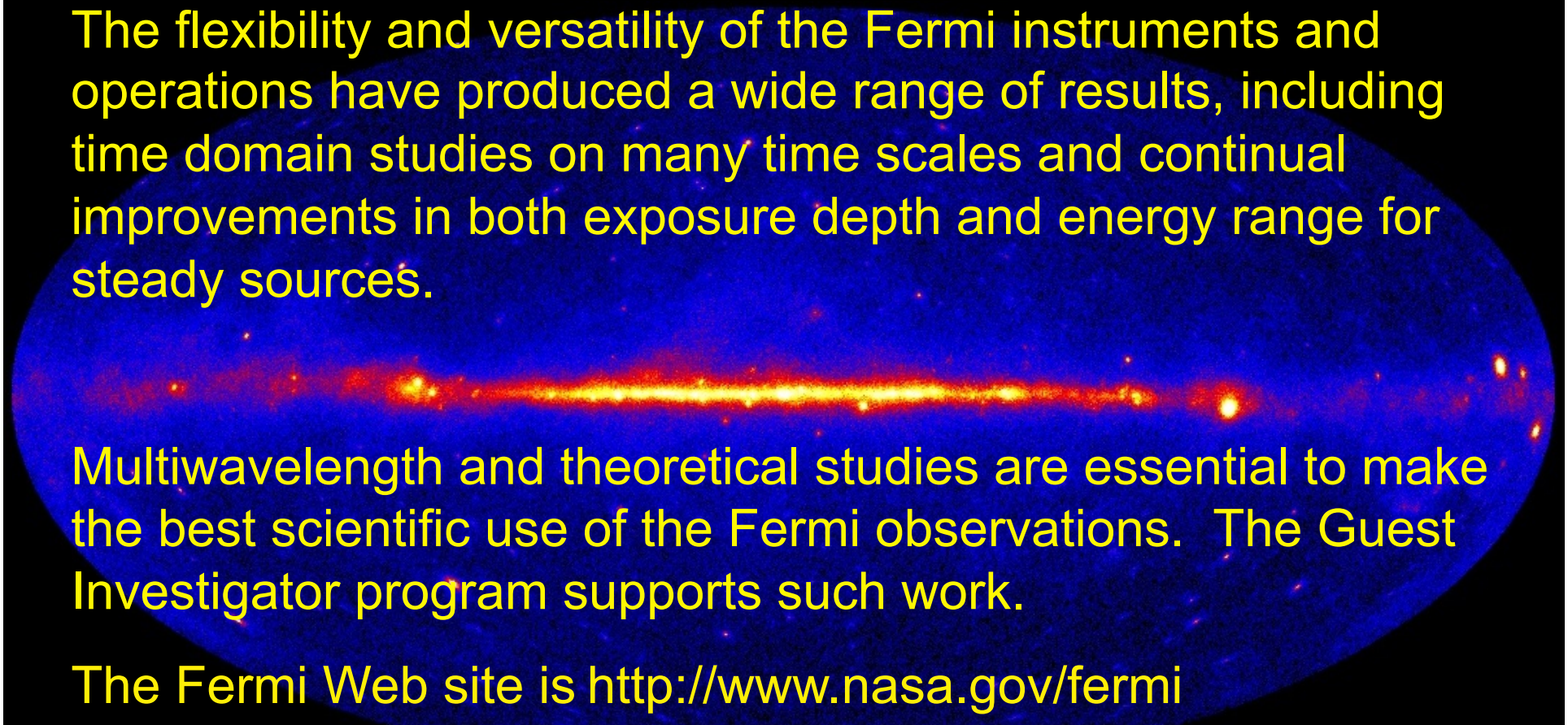
From Observations to Understanding



http://fermi.gsfc.nasa.gov/ssc/observations/multi/

Summary - Expecting the Unexpected

The flexibility and versatility of the Fermi instruments and operations have produced 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 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!