The Gamma-ray Sky with Fermi

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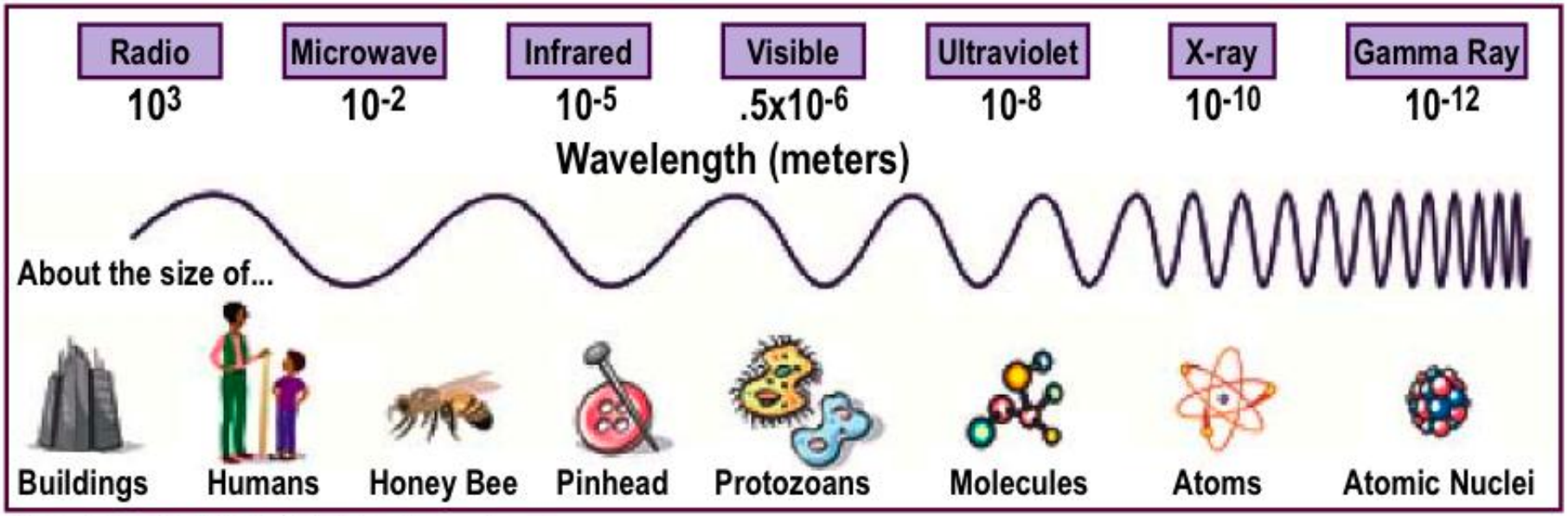
Outline

- **Why do we study gamma rays from space?**
- **How do space gamma-ray telescopes work?**
- **What are gamma-ray telescopes seeing?**

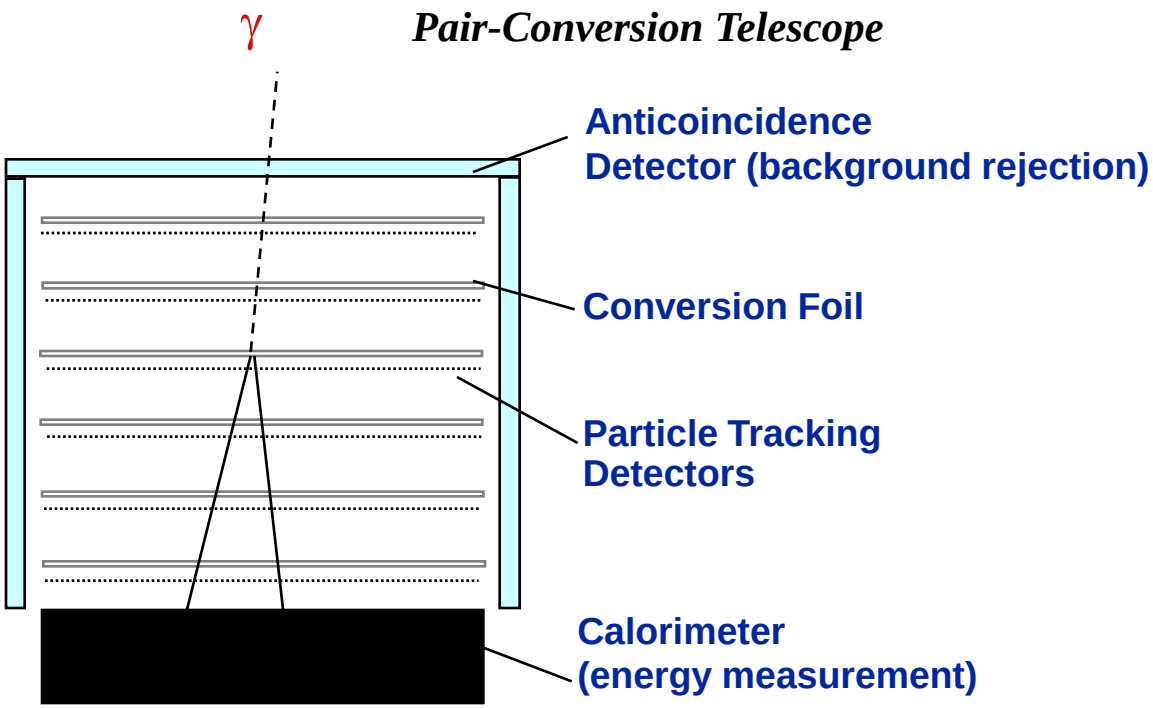
Gamma Rays – the Most Energetic Form of Electromagnetic Radiation



Credit: NASA / Ruth Jennings

- **Gamma rays are almost exclusively nonthermal, produced by interactions or decays of high-energy particles - energetic processes.**
- **Because they are photons, they point back to their origin in space.**

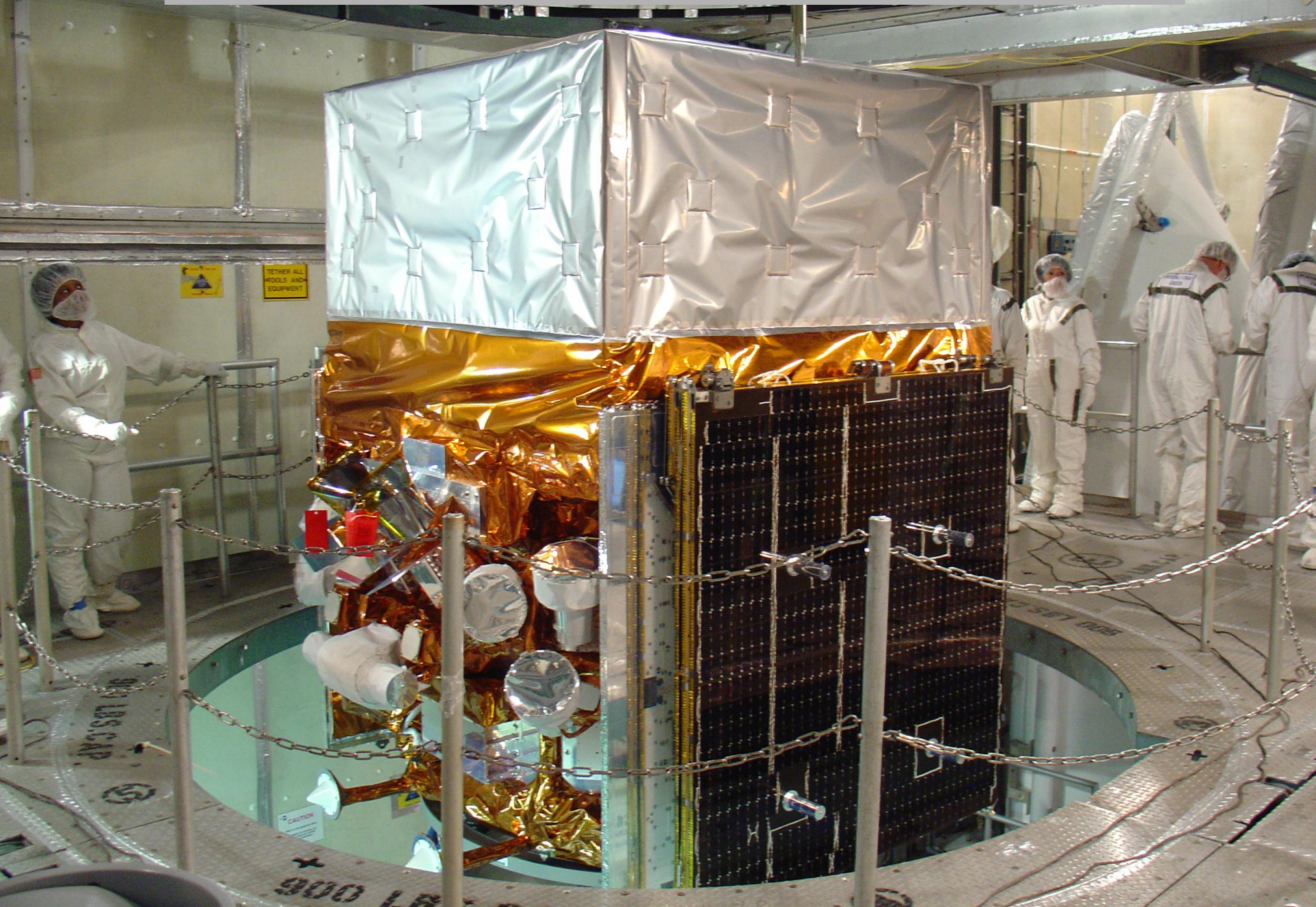
How to Detect High-Energy Gamma Rays?



- **Gamma rays, at least at energies above 10's of MeV, interact by electron-positron pair production ($E = mc^2$); a gamma-ray telescope is really a particle detector.**

- **This same interaction process makes the Earth's atmosphere opaque to these gamma rays, so direct gamma-ray astrophysics is a space endeavor.**

Fermi Gamma-ray Space Telescope



The Fermi Observatory

Large AreaTelescope (LAT)
20 MeV - >300 GeV

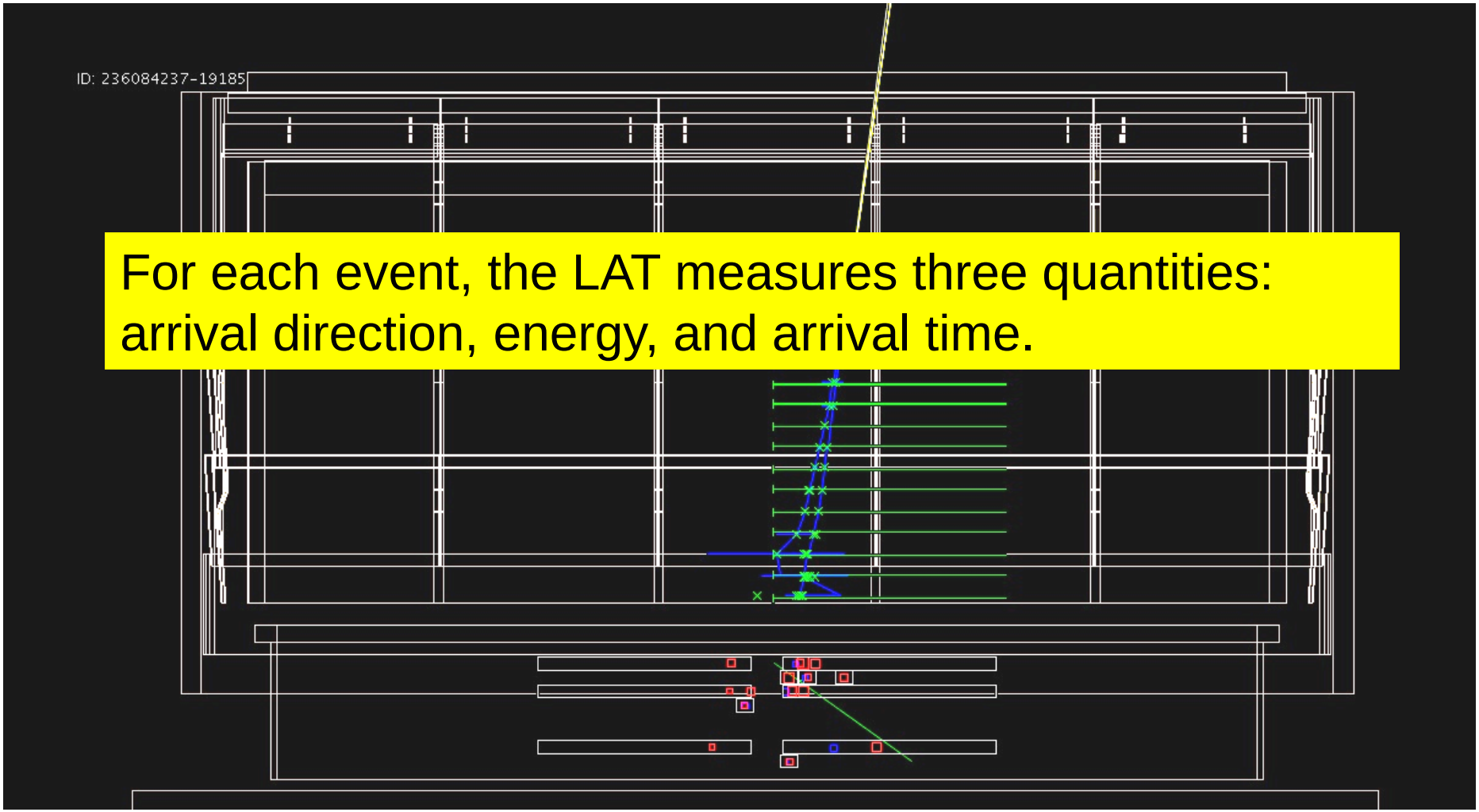
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

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

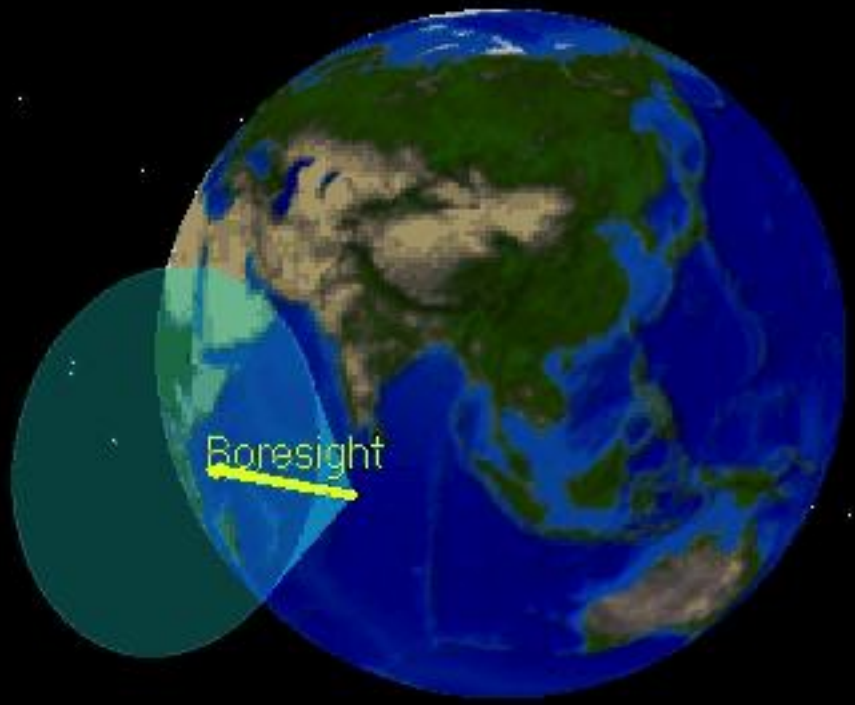
LAT Gamma-ray Candidate Event



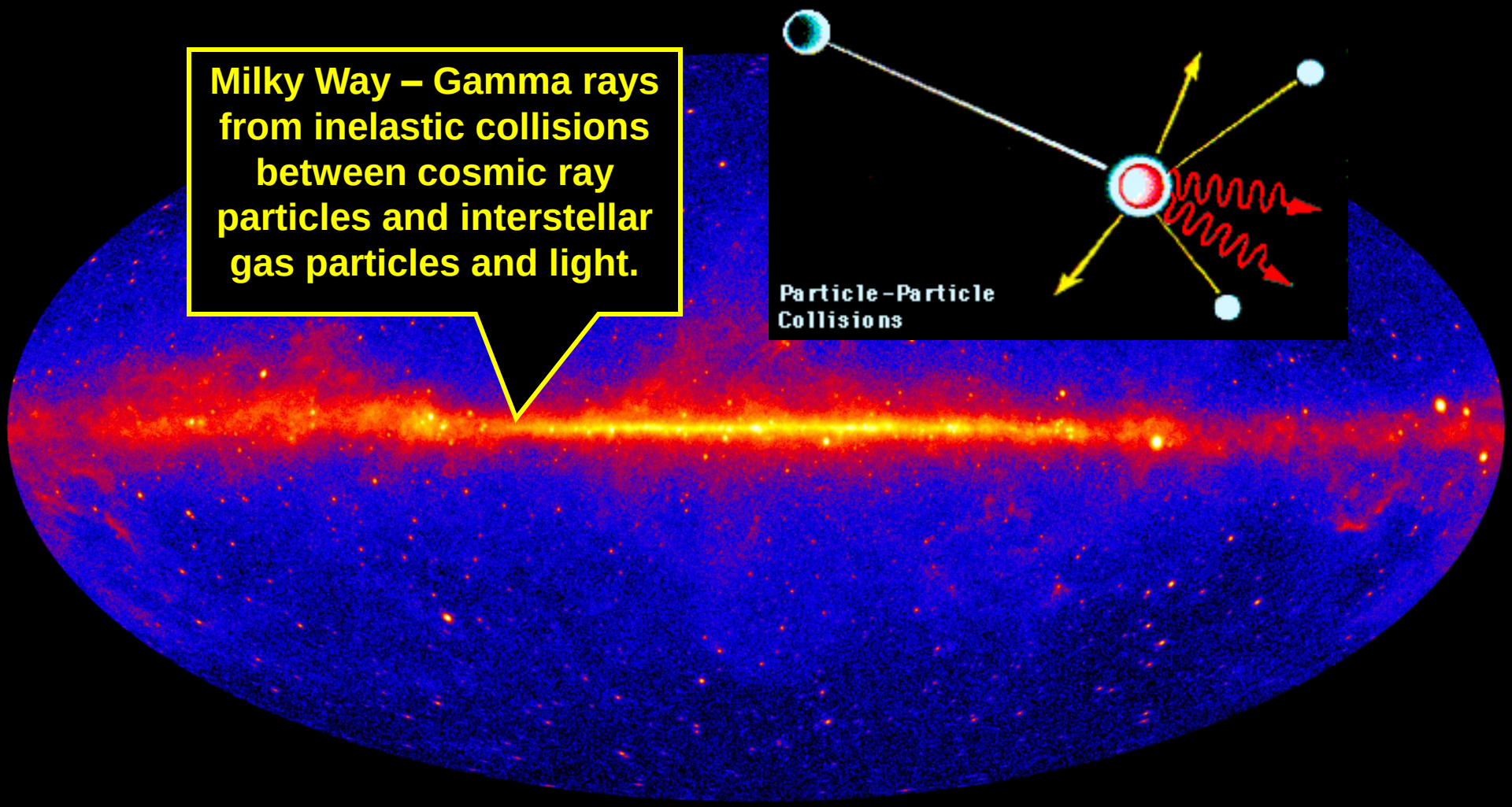
For each event, the LAT measures three quantities: arrival direction, energy, and arrival time.

The green crosses show the detected positions of the charged particles, the blue lines show the reconstructed track trajectories, and the yellow line shows the candidate gamma-ray estimated direction. The red crosses show the detected energy depositions in the calorimeter.

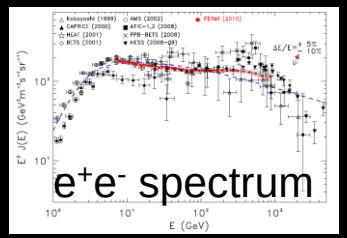
Fermi Survey Mode - Default

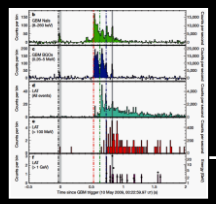


Four years of Fermi LAT scanning data

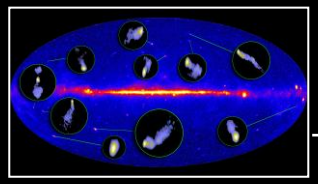


Fermi Reveals the Very High Energy Universe

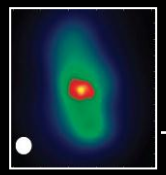




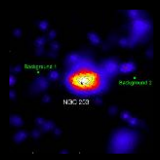
GRBs



Blazars

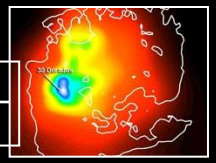


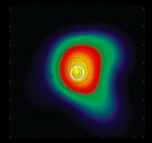
Radio Galaxies



Starburst Galaxies

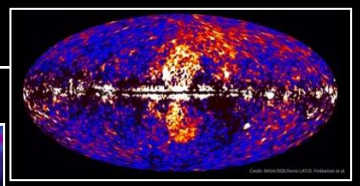
LMC SMC

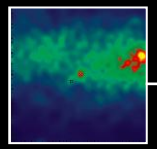




Globular Clusters

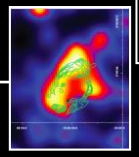
Fermi Bubbles



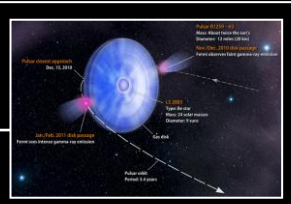


Nova

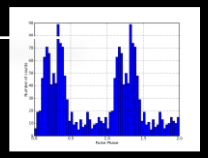
SNRs & PWN



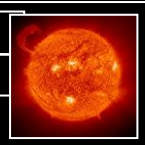
γ-ray Binaries



Pulsars: isolated binaries, & MSPs



Sun: flares & CR interactions



Terrestrial γ-ray Flashes

Extragalactic

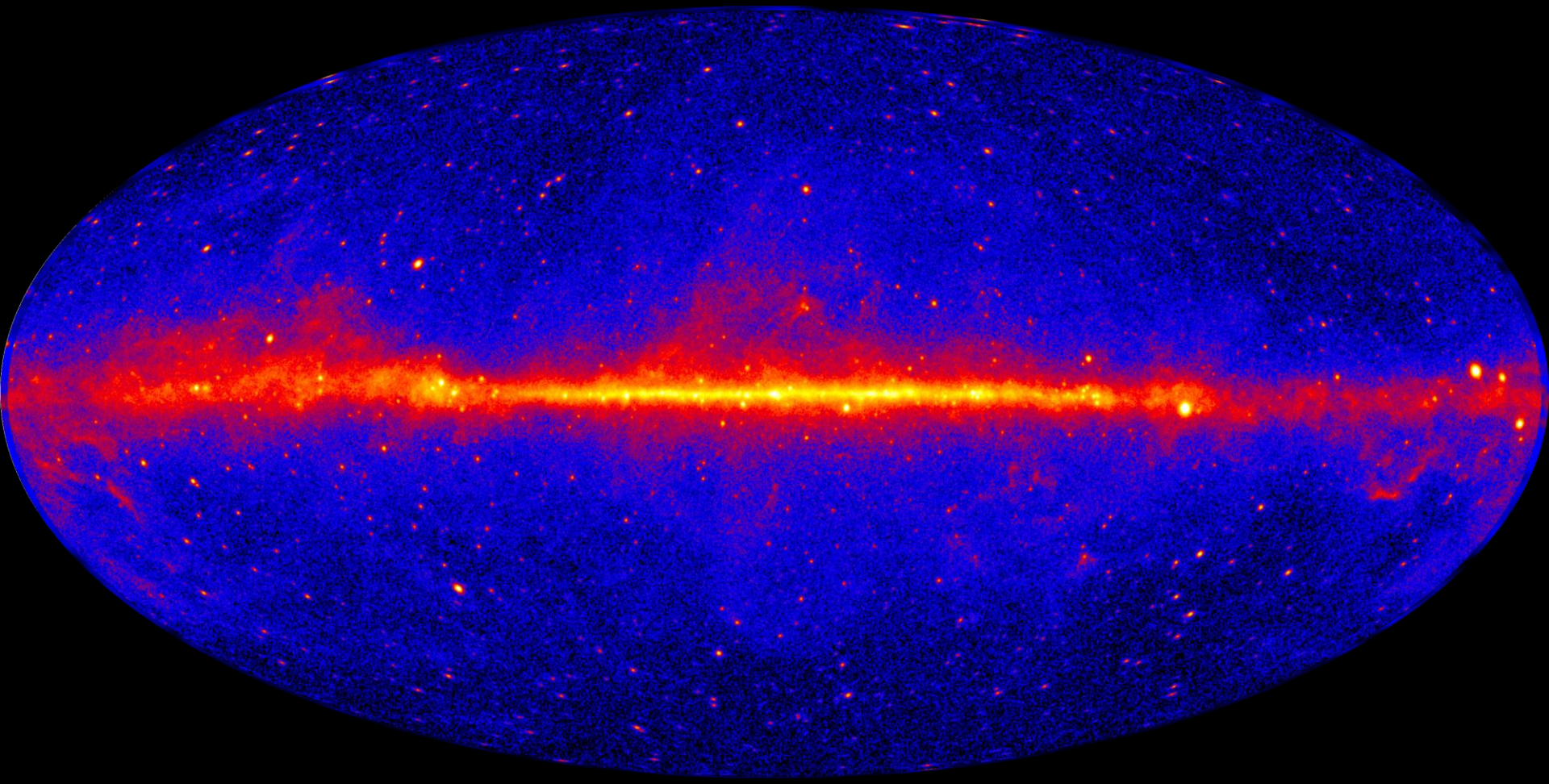
Galactic

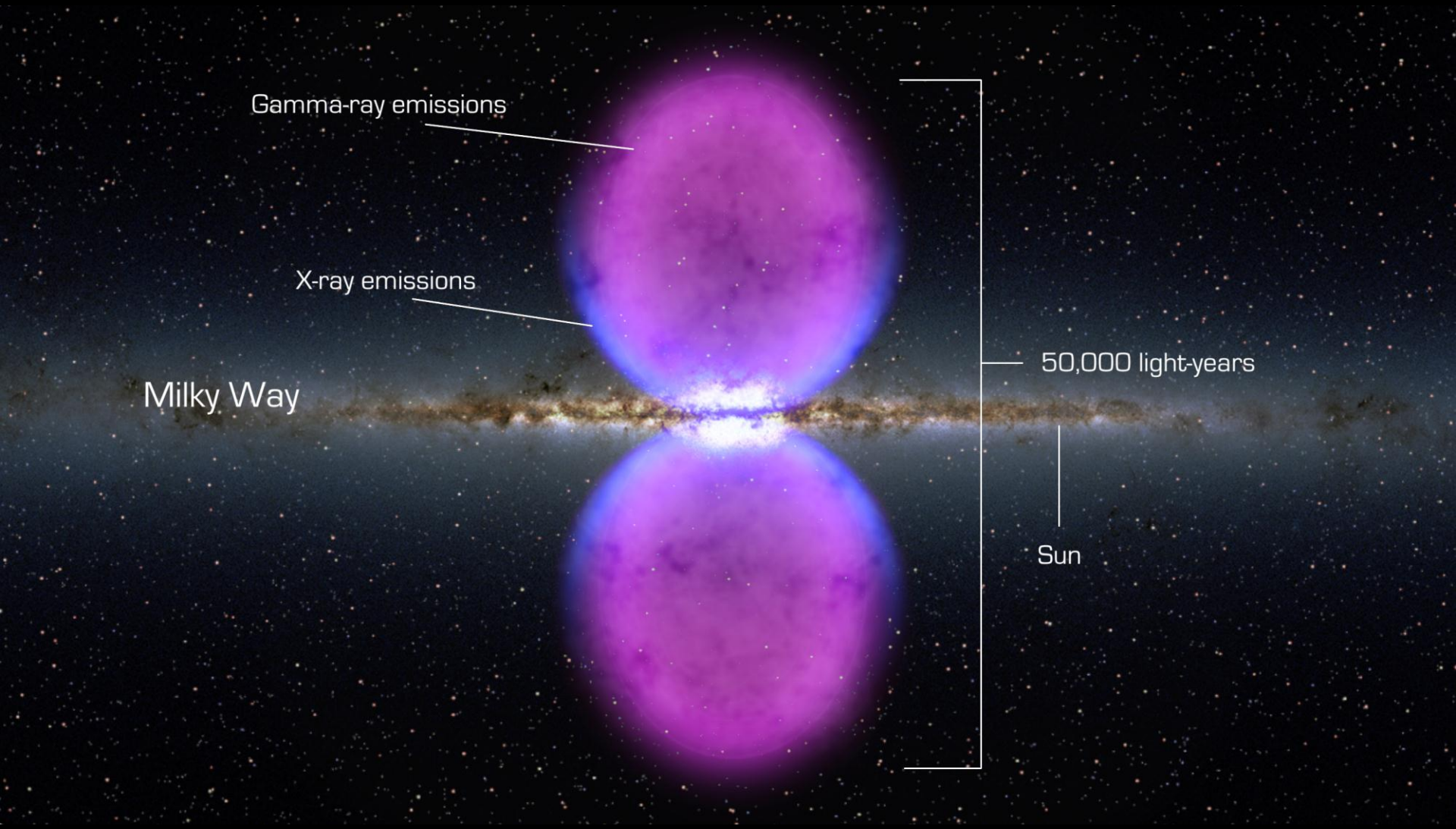
Local

Unidentified Sources (577/1873)

The Gamma-ray Sky above 10 Billion Electron Volts (10 GeV)

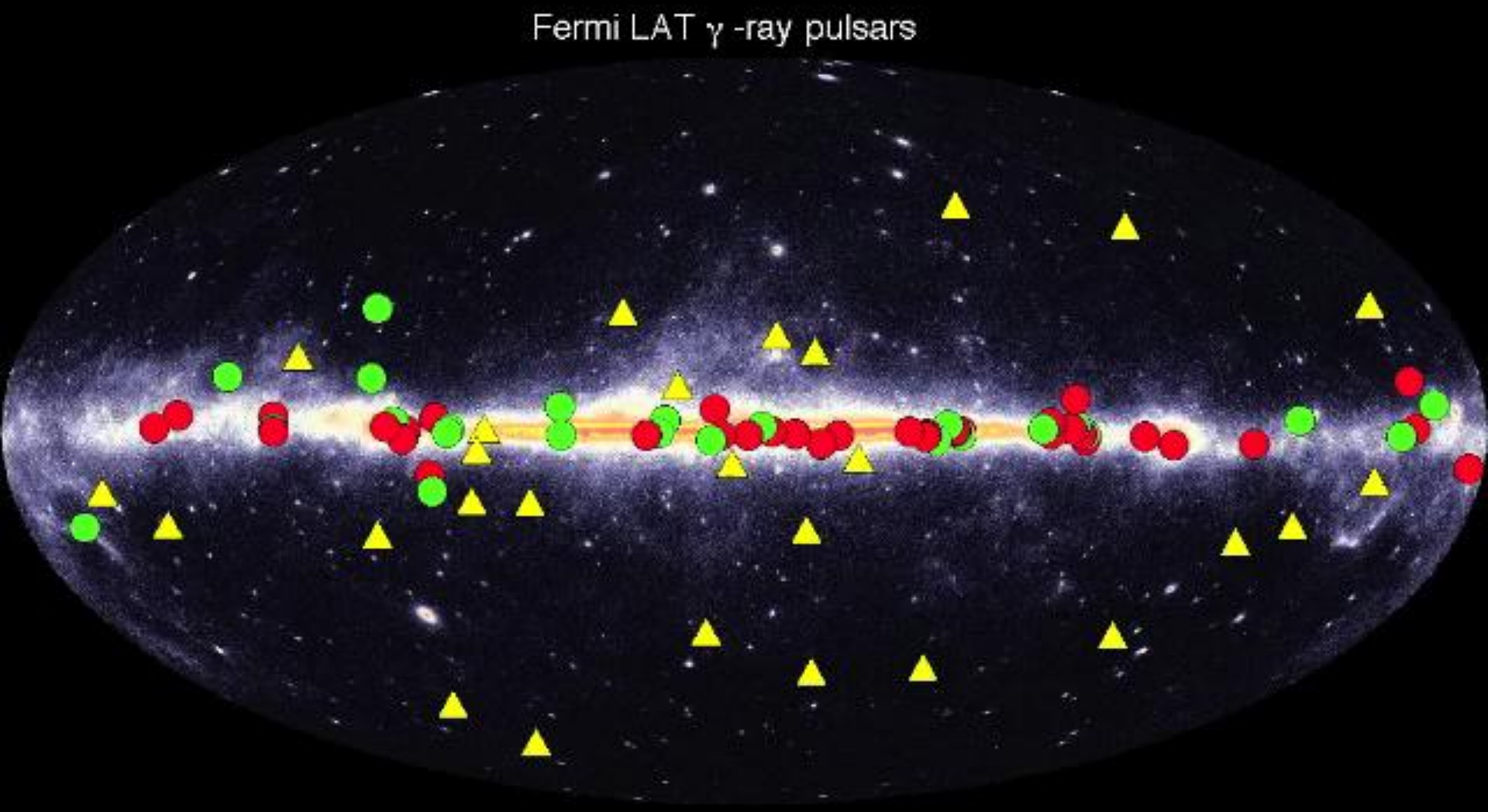
The Gamma-ray Sky above 1 Billion Electron Volts (1 GeV)





These “Fermi Bubbles” may indicate past energetic activity in the center of our Galaxy.

Pulsars – Rapidly Rotating Neutron Stars



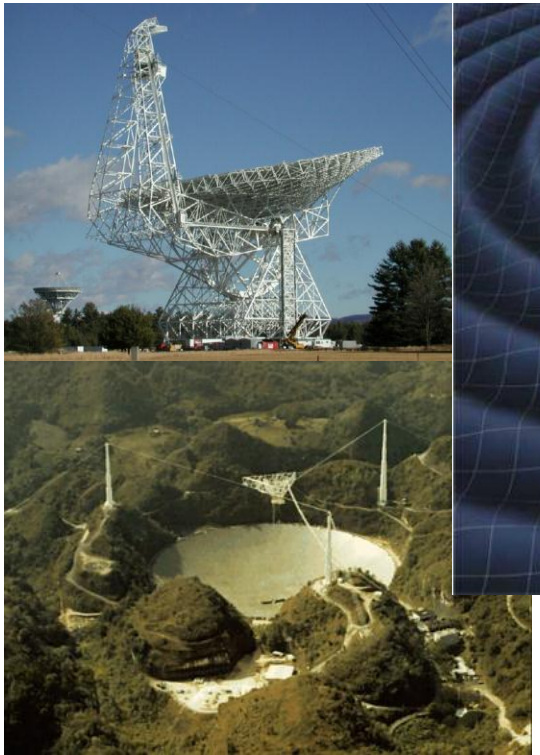
What Are We Learning about Pulsars?

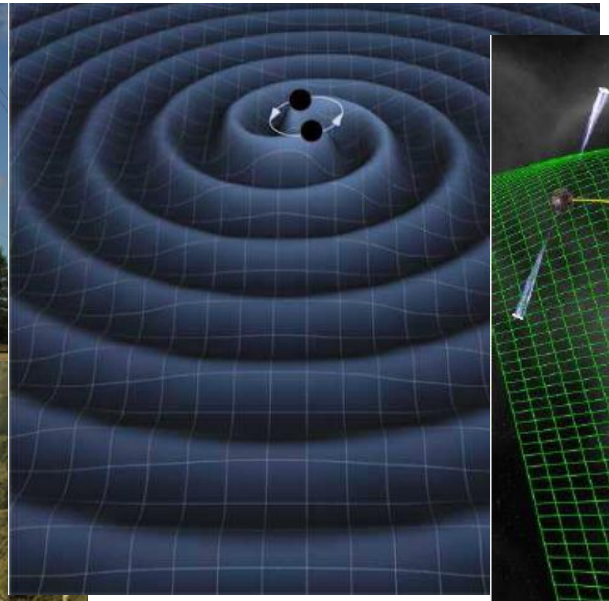
- About 1/3 of the Fermi pulsars are seen only in gamma rays. The gamma rays are being produced in a wide beam far from the neutron star surface, unlike radio pulsar emission.
- Pulsars are highly efficient particle accelerators. 10% or more of their available energy appears as gamma rays.
- Close cooperation between radio and gamma-ray astronomers has produced new pulsar discoveries at both ends of the electromagnetic spectrum, including finding over 40 new millisecond pulsars, which are extremely accurate “clocks.”

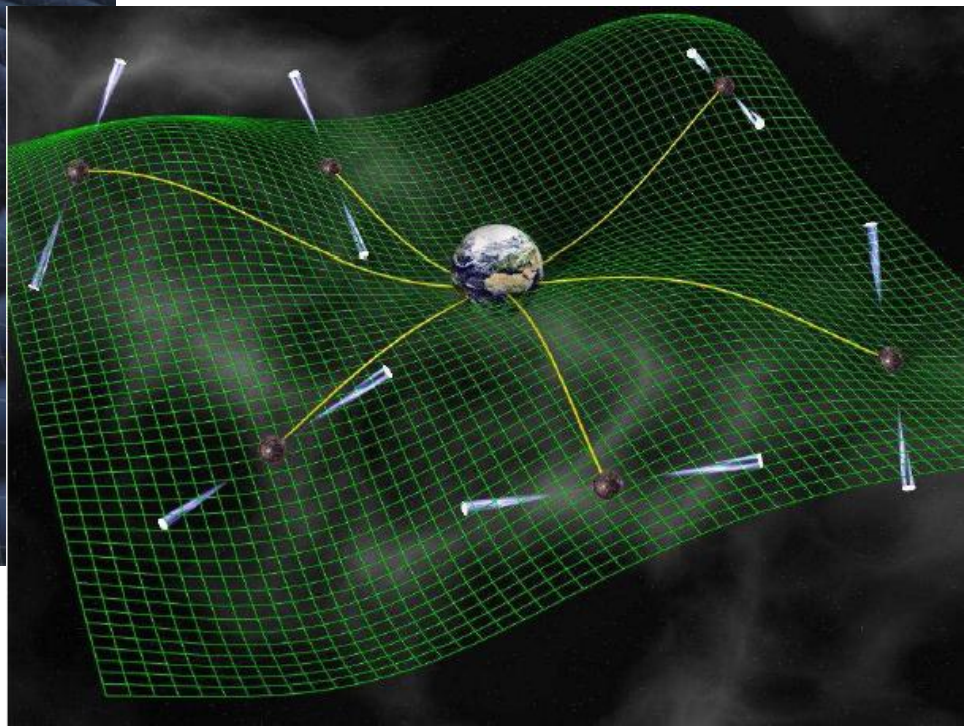
Effelsberg 100-m radio telescope

Pulsar Timing Arrays as Gravitational Wave Detectors

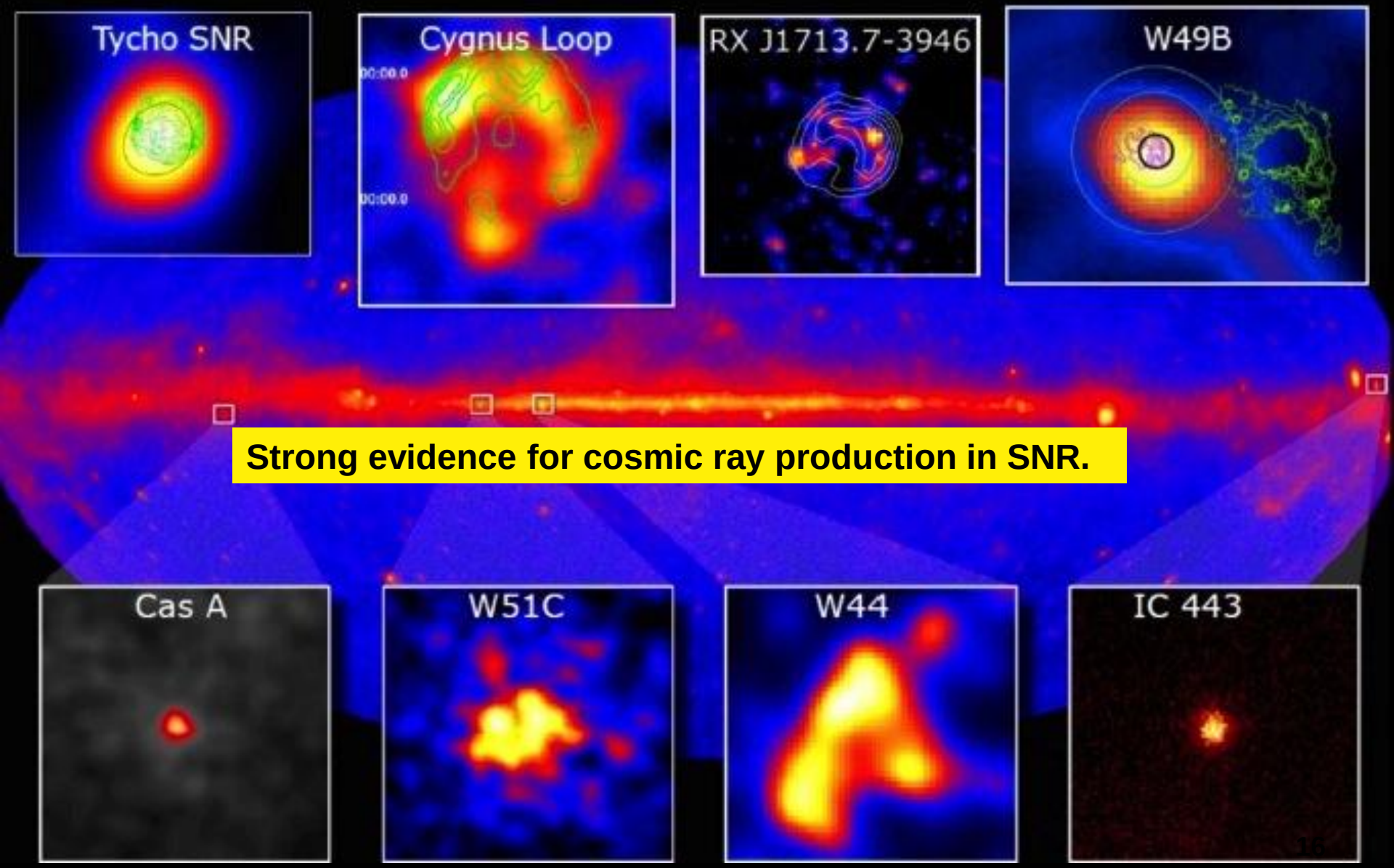
- Radio telescopes can time millisecond pulsars to 100 nanoseconds
- Arrays of MSPs can be sensitive to nHz gravitational waves – need 20-40 MSPs for detection in 5 years
- Search for stochastic gravitational wave background from black hole/galaxy mergers





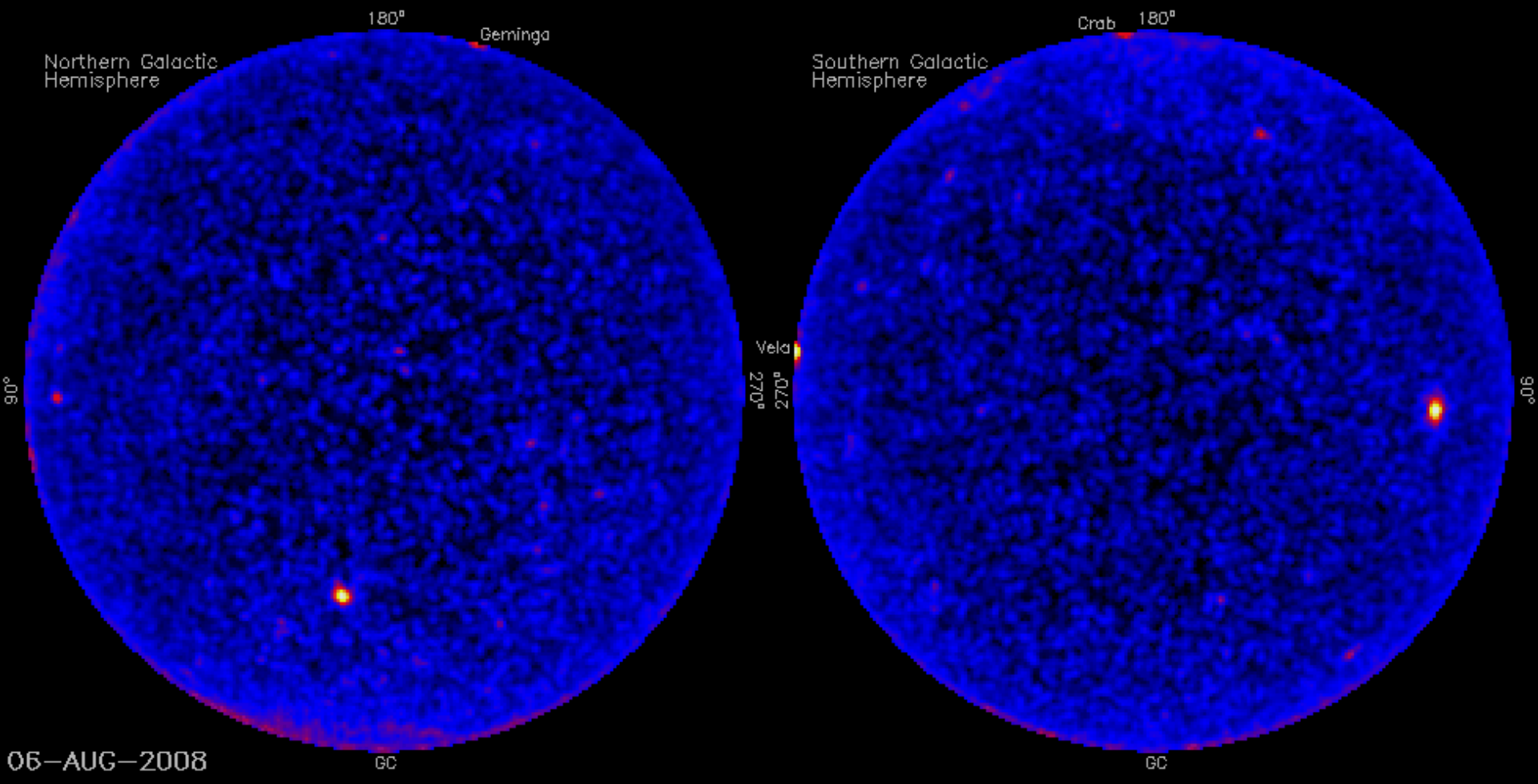


Supernova Remnants - Spatially Resolved



Strong evidence for cosmic ray production in SNR.

The Variable Gamma-ray Sky

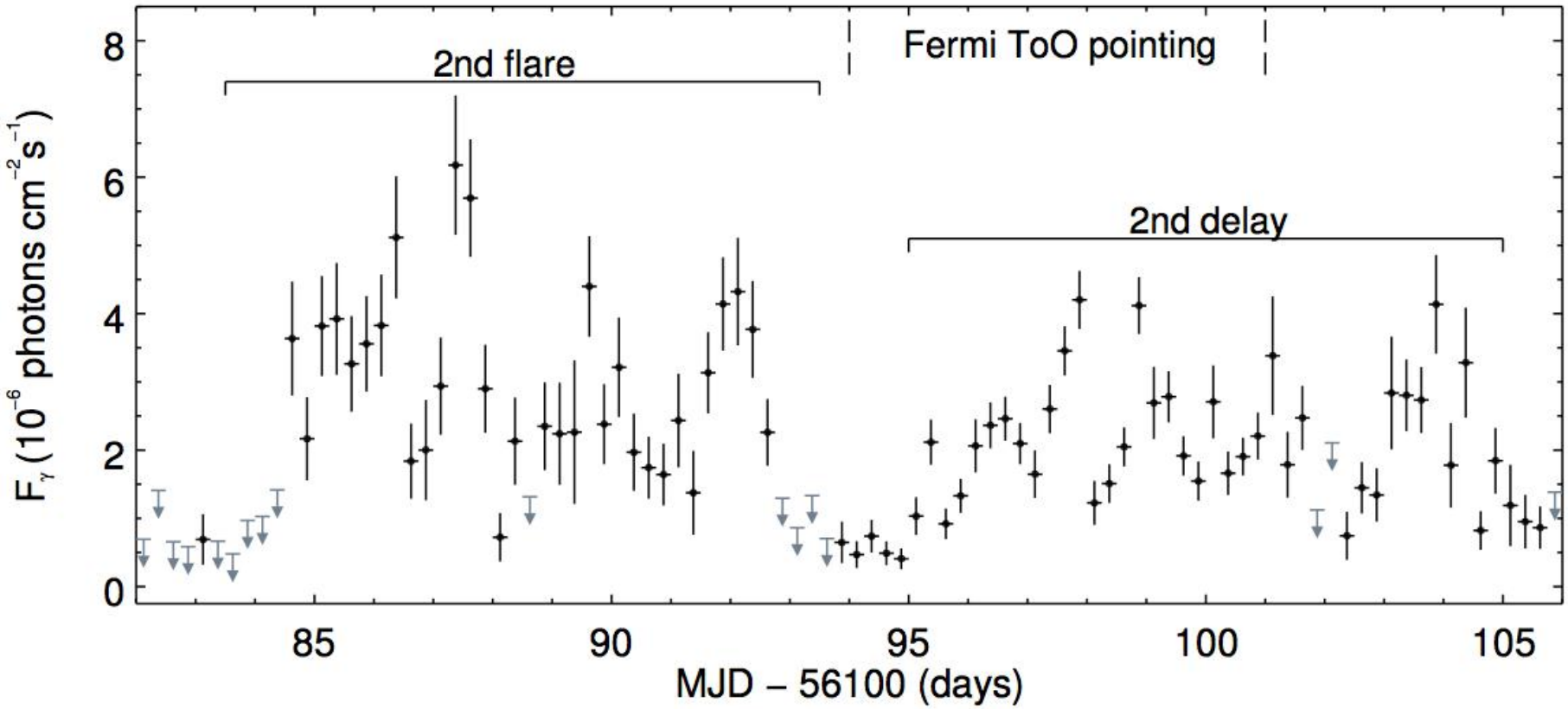


Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)

- 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 AGN with the jet pointed toward us.

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.

An Application of Blazar Variability

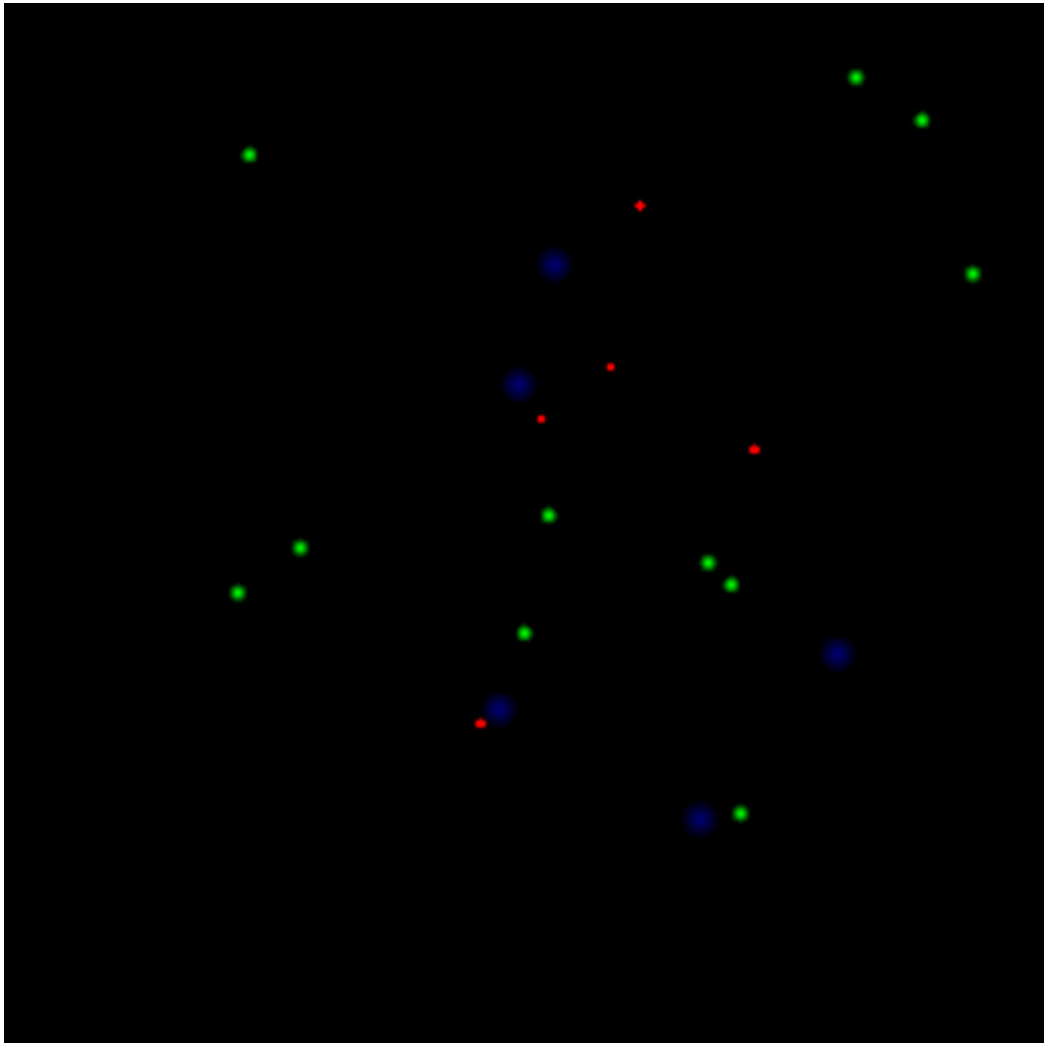


The flaring pattern is repeated with a delay of ~10 days.

Gravitational lensing – two images of the same source.

From Teddy Cheung

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.

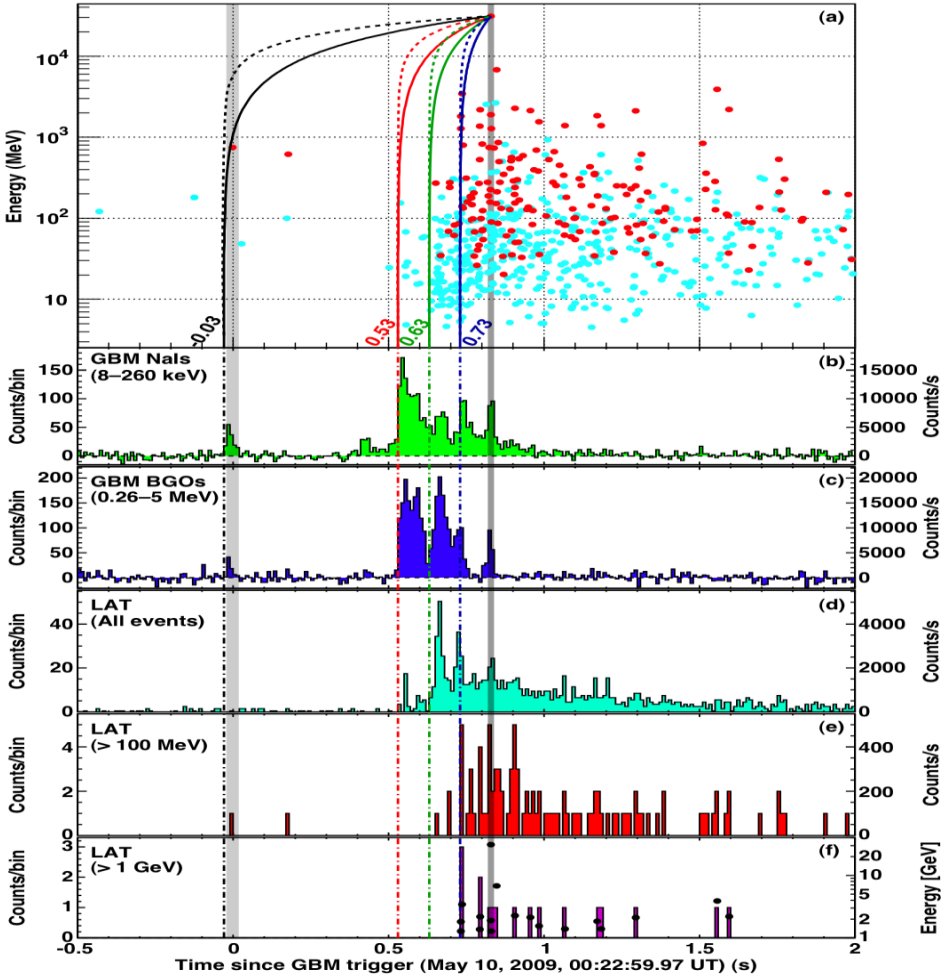
Testing Einstein's Theory of Special Relativity

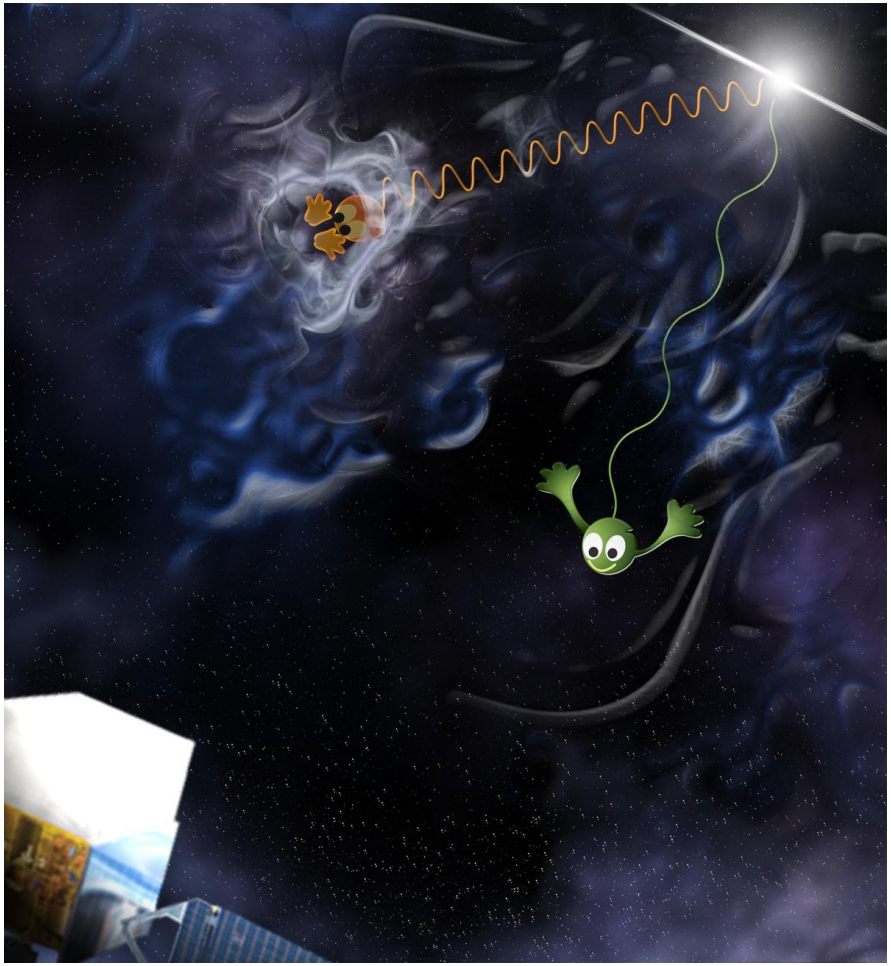
- The Principle of Invariant Light Speed – *Light in vacuum propagates with the speed c (a fixed constant) in terms of any system of inertial coordinates, regardless of the state of motion of the light source.*

- 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

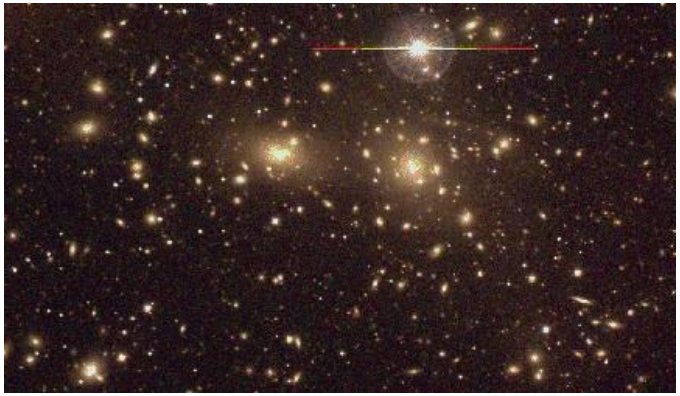
GRB 090510 - testing models of Quantum Gravity





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

What is Not Seen Can Also Be Important

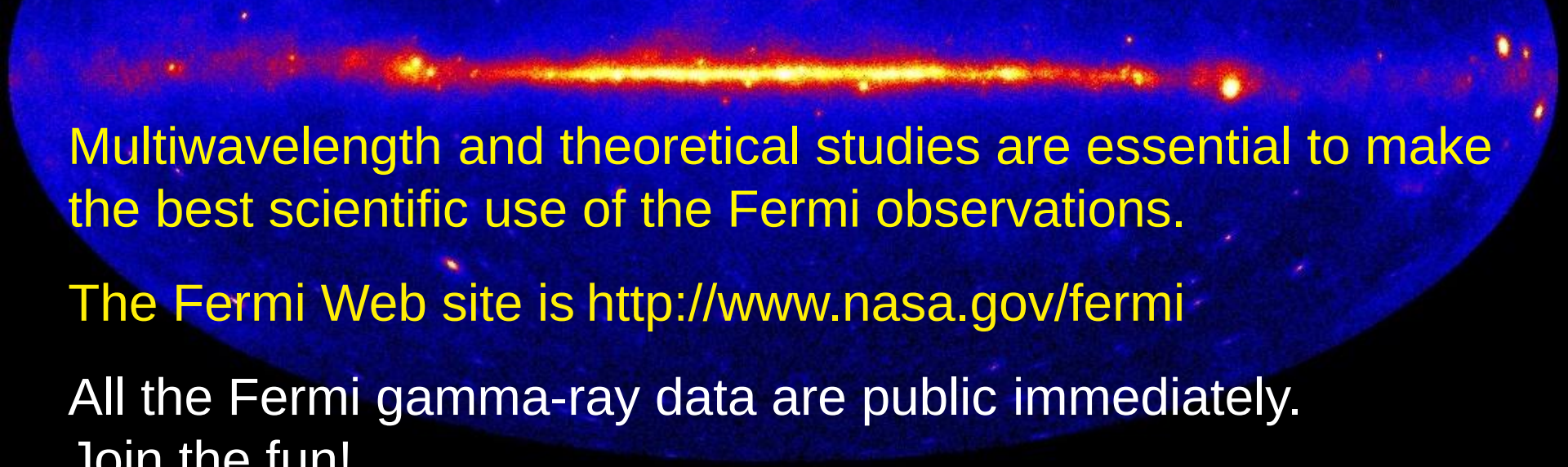


Some clusters of galaxies were predicted to be gamma-ray sources. None are seen in the Second LAT Catalog, indicating that the predictions were too optimistic.

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.

Summary – Exploring the Extreme Universe

The flexibility and versatility of the Fermi (and AGILE, Fermi's smaller cousin) 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 Web site is http://www.nasa.gov/fermi

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