Exploring the Extreme Universe with the *Fermi Gamma-ray Space Telescope*

David Thompson
Astrophysicist Emeritus
Fermi Gamma-ray Space Telescope Project
NASA Goddard Space Flight Center

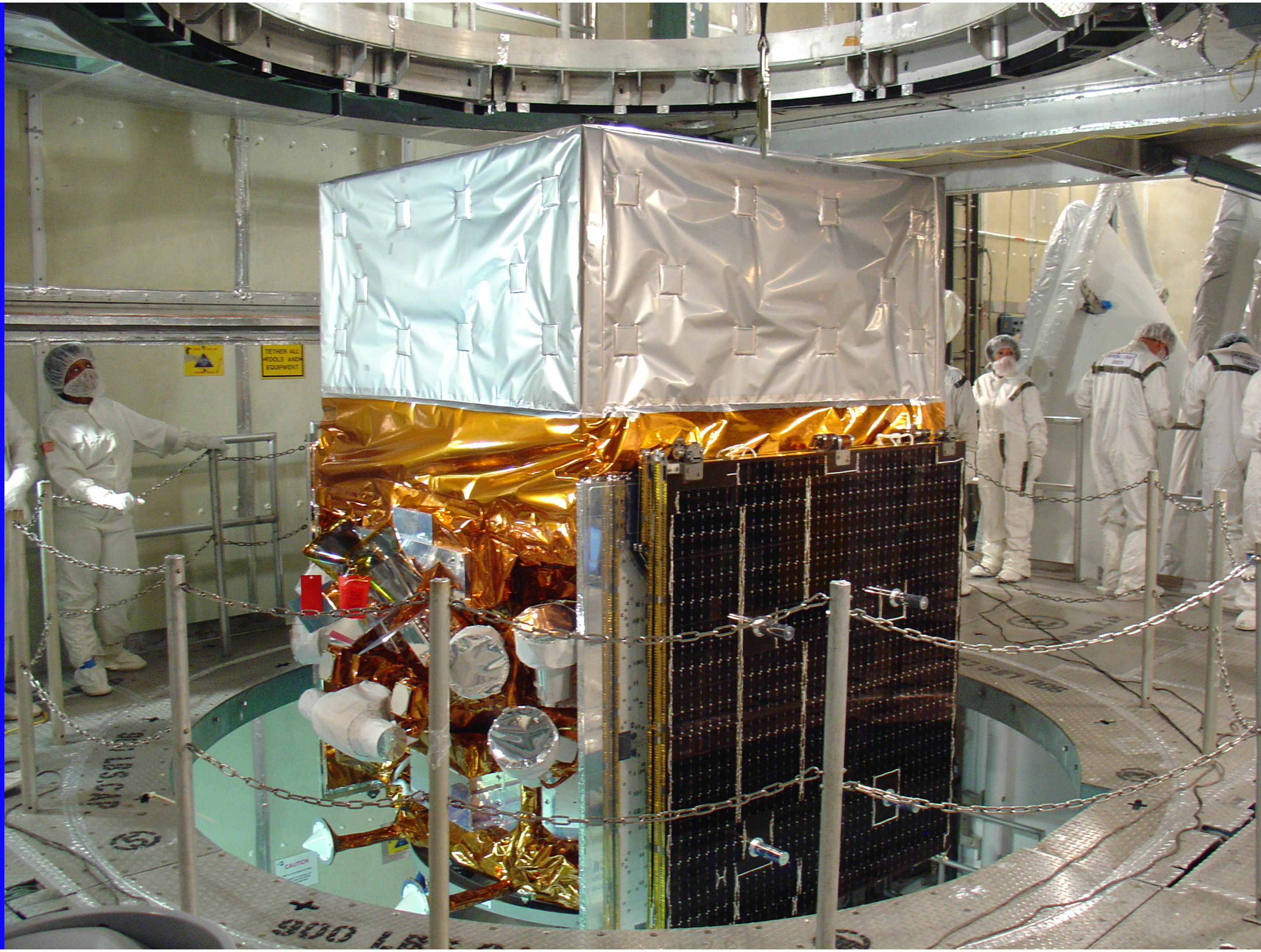
High-Energy Astrophysics in Southern Africa 2022
September 30, 2022

Basic idea: survey missions like the *Fermi Gamma-ray Space Telescope* are vitally important to enable multiwavelength and multimessenger astrophysics.

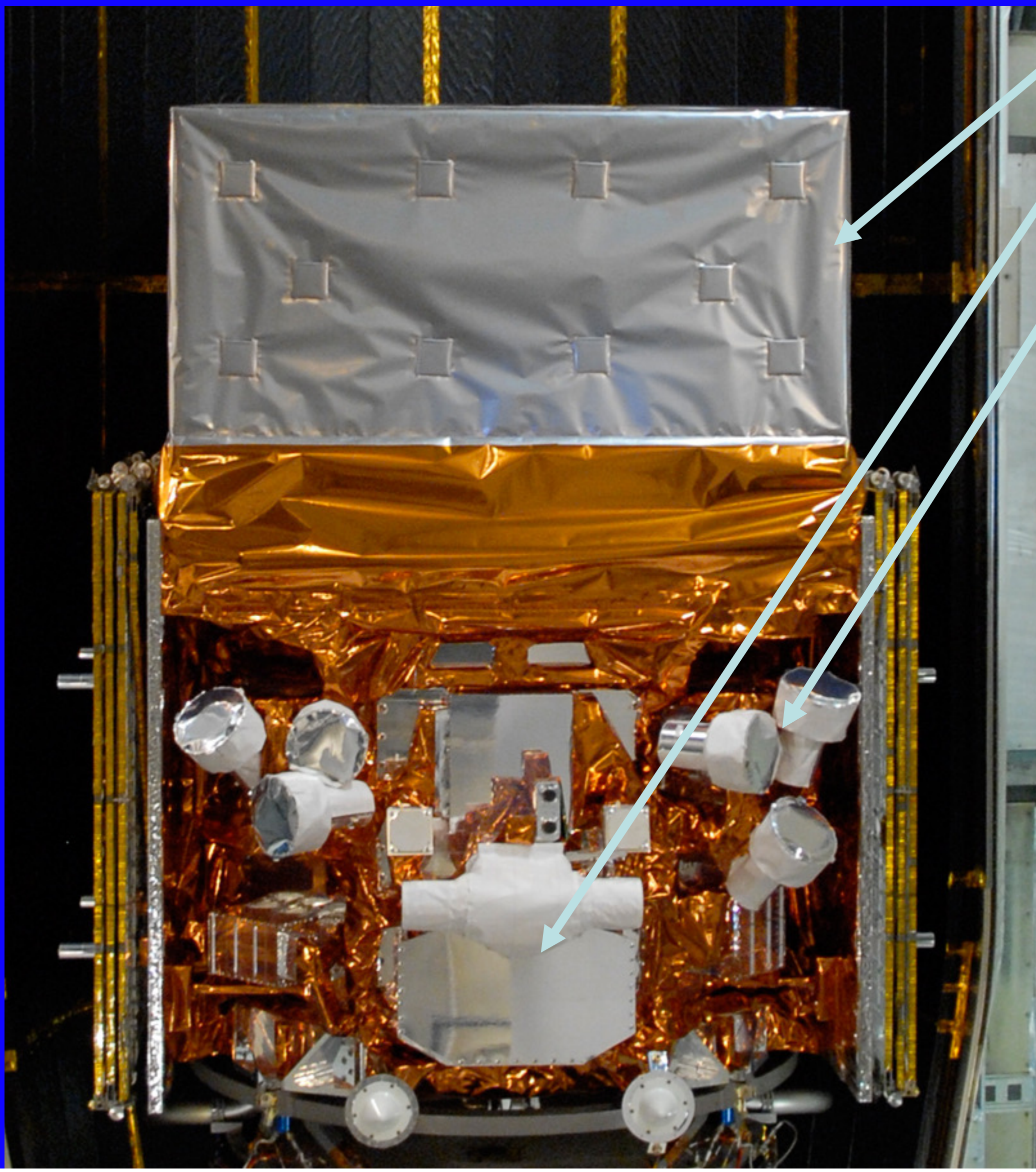
Three aspects of surveys:

1. **Discovering and studying transients.**
2. **Establishing long-term, wide-field archival information.**
3. **Using non-detections to constrain astrophysical phenomena.**

The Fermi Gamma-ray Space Telescope


TETHER ALL TOOLS AND EQUIPMENT
CAUTION

The *Fermi* Observatory



Large Area Telescope (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 steradians; 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**

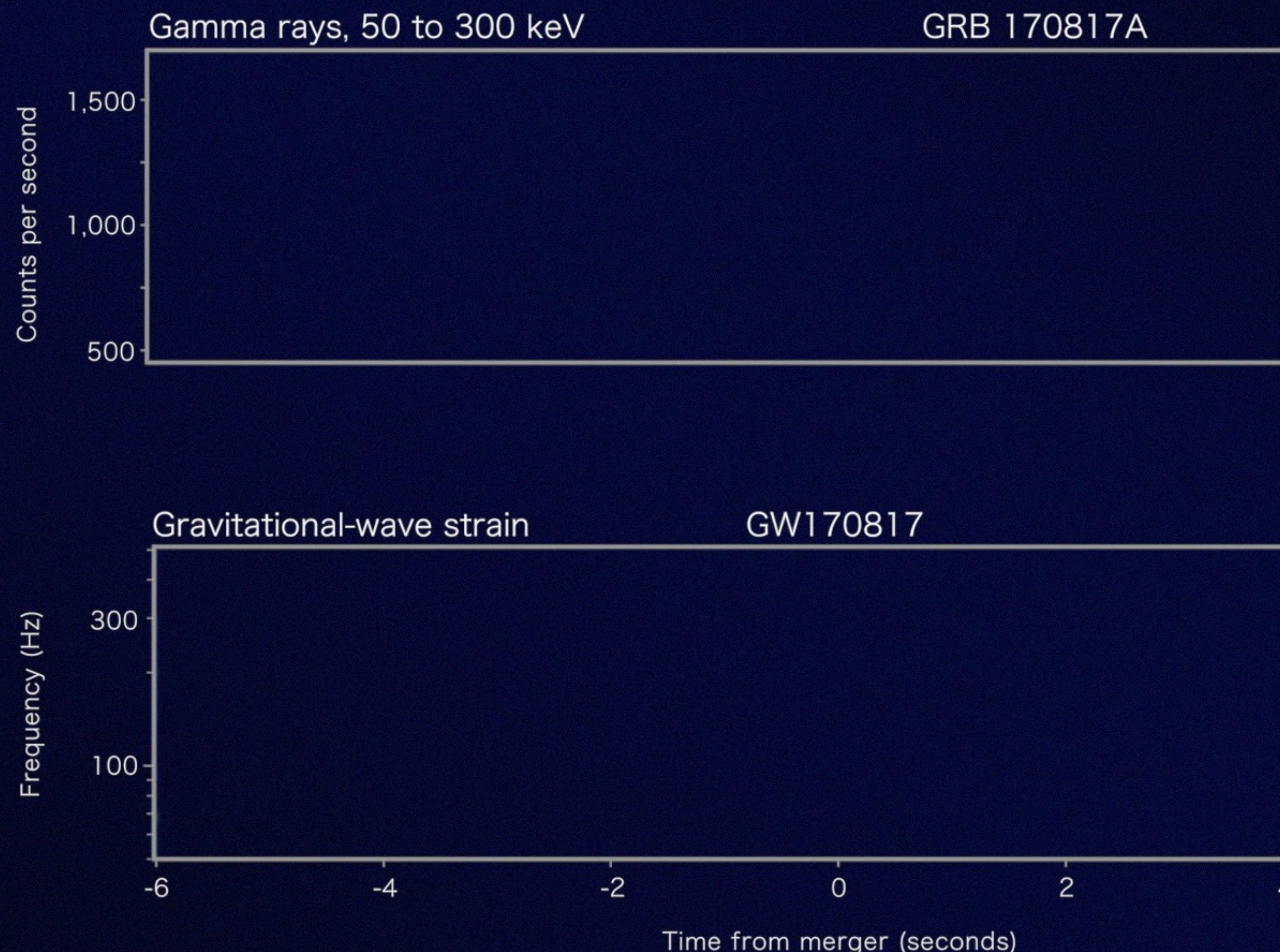
How does *Fermi* operate?

- Because gamma rays are detected one at a time like particles, the *Fermi* telescopes do not have angular resolution as good as radio, optical or X-ray telescopes. Few pretty pictures of individual objects.
- Instead, *Fermi* trades resolution for field of view.
- The *Fermi* satellite is usually operated in a scanning mode, always looking away from the Earth.
- **The combination of huge field of view and scanning means that the LAT and GBM view the <u>entire sky</u> every three hours!**
- **We now have over 14 years of gamma-ray survey data.**

Gamma-ray Transients

Gravitational waves and gamma rays from merging neutron stars

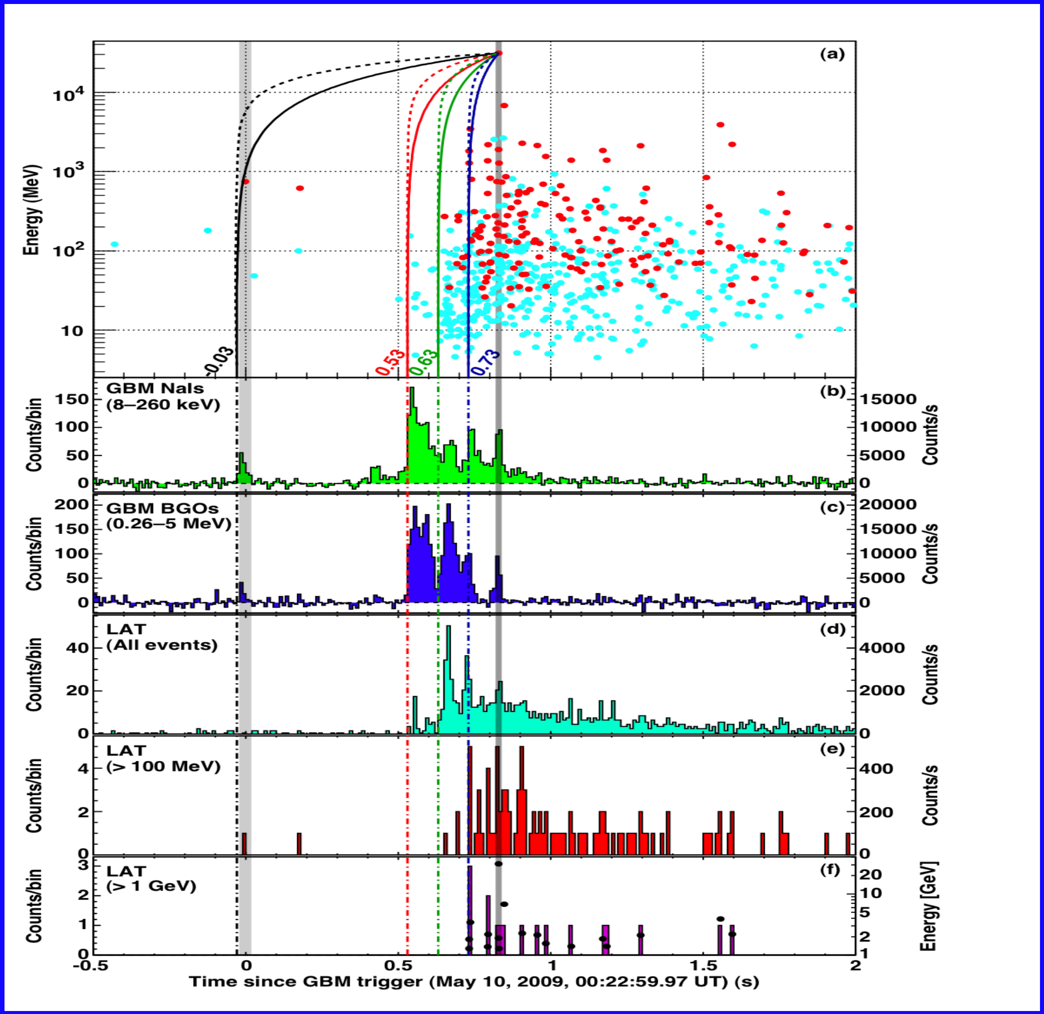
Fermi



LIGO

After 130 million years, the gravitational waves and gamma rays arrived within 2 seconds, implying that the speed of gravity is almost identical to the speed of light.

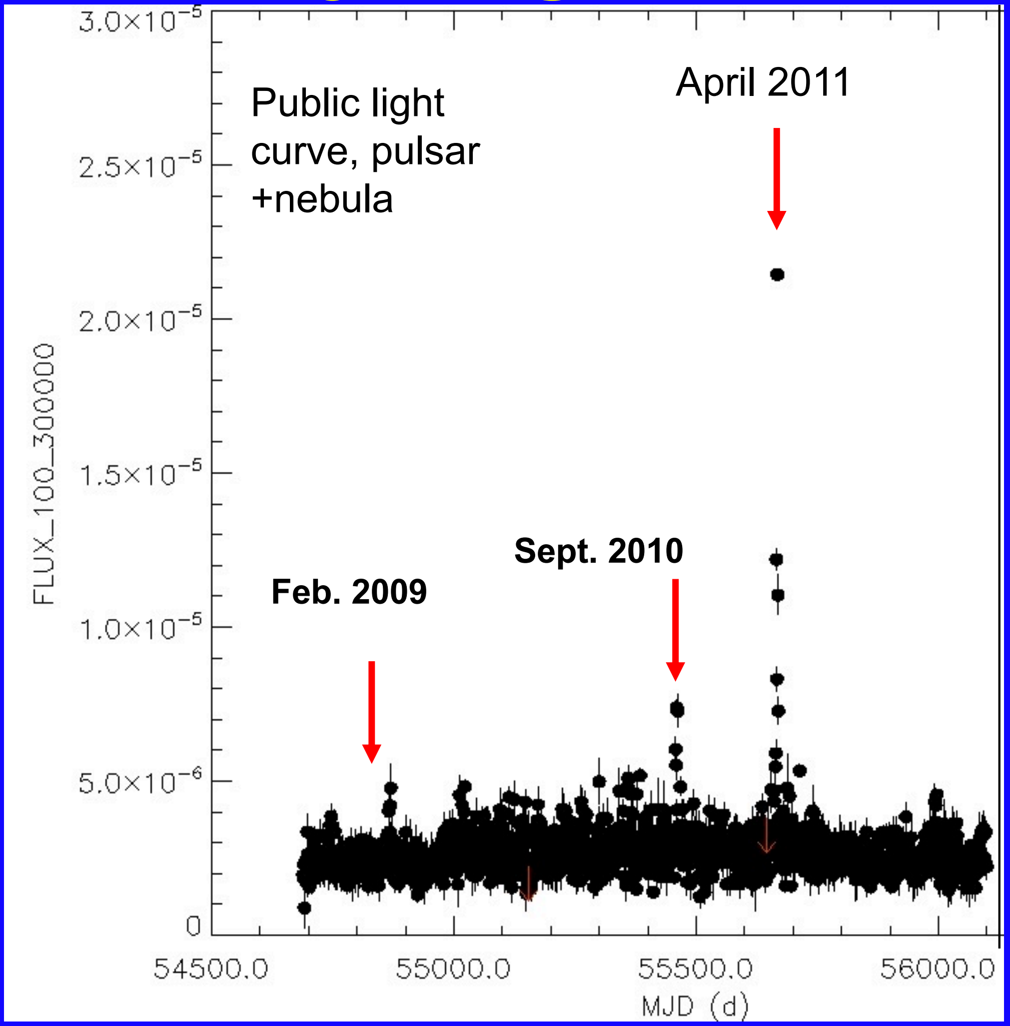
GRB 090510 - testing models of Quantum Gravity



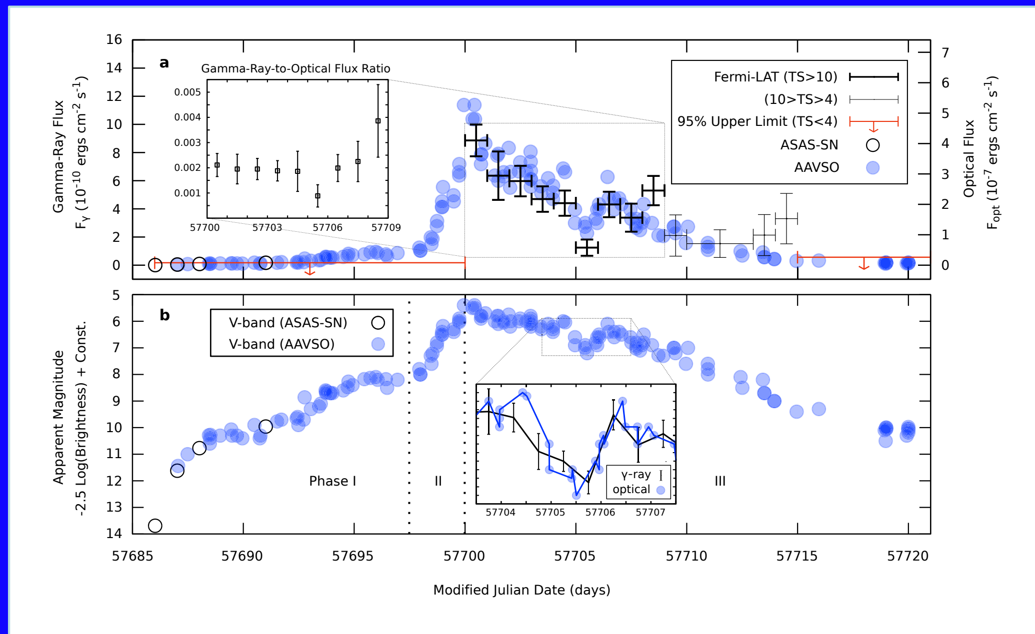
Highest energy gamma-ray arrived within 0.9 s of the lower energy photons after traveling 7 billion years. Eliminates theories of quantum gravity that predict space-time is "foamy" enough to interfere strongly with light.

Crab Nebula Gamma-Ray Brightness

- **Shockingly bright flares in Sept 2010 and April 2011.**
- **Rapid identification of flares by LAT team enabled *Chandra* and *Hubble* Target of Opportunity observations in Sept, and sequence of *Chandra* observations in April (target visibility issues for *Hubble*)**
- **Rapid (hour-scale) variability of PeV electrons poses severe challenges for acceleration mechanisms**



A Shock-Powered Nova

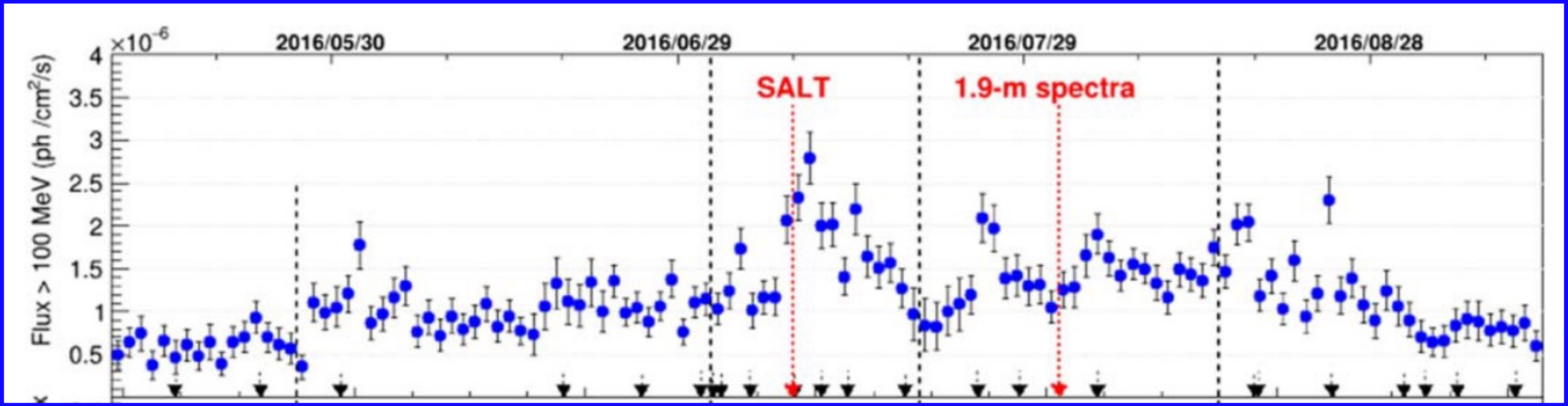


Li et al. 2017

Gamma-ray and optical light curves of nova ASASSN-16ma, showing the correlation that implies a common production mechanism. Since the gamma rays must be produced by shock-accelerated particles, the optical must also originate from the shocks.

Talk by Dr. Metzger later today.

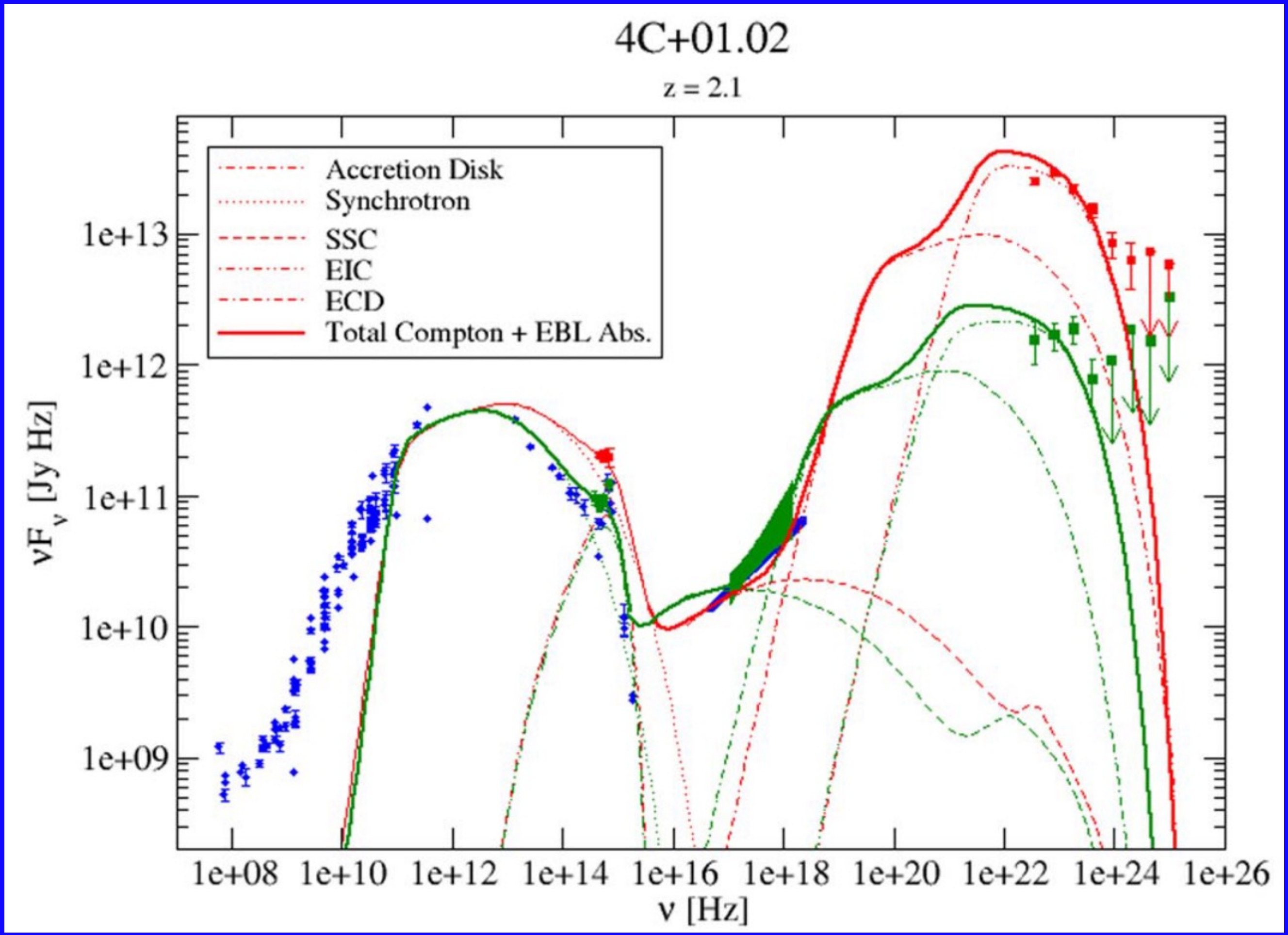
Blazar Flares



Schutte et al. 2022

Blazars are characterized by variability, and only with surveys is it possible to identify and characterize the flaring vs quiescent states.

Blazar Flares



Schutte et al. 2022

Simultaneous observations, enabled by surveys, are essential to model the broadband spectra. Modeling allows extraction of physical parameters.

Blazars and Neutrinos

[Previous | Next | ADS]

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942, 11419, 11430, 11489, 12260

Tweet

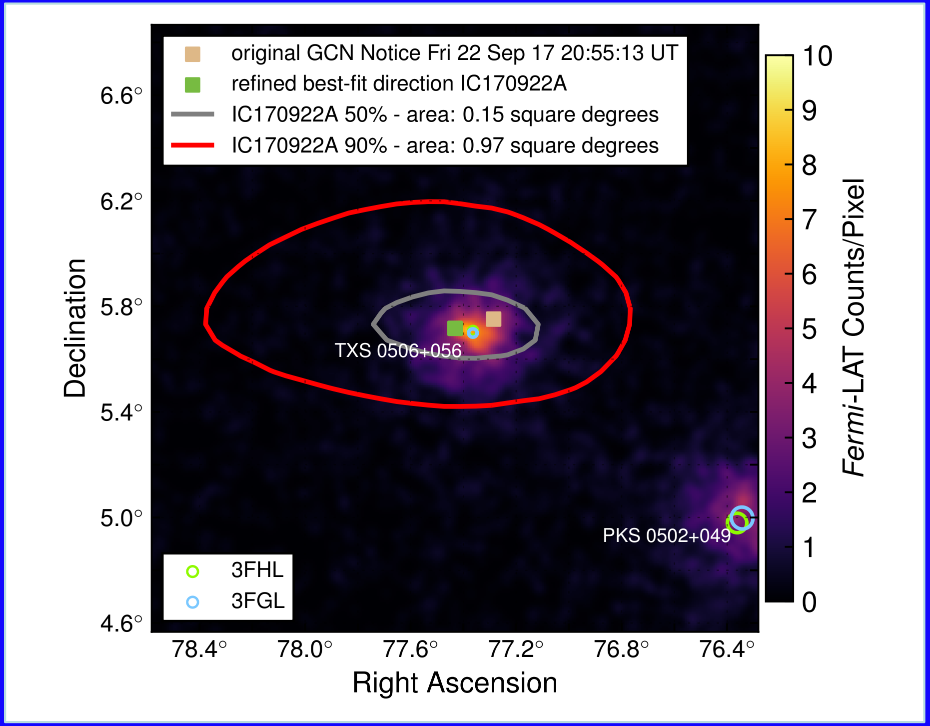
We searched for Fermi-LAT sources inside the extremely high-energy (EHE) IceCube-170922A neutrino event error region (https://gcn.gsfc.nasa.gov/gcn3/21916.gcn3, see also ATels 10773, 10787) with all-sky survey data from the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope. We found that one Fermi-LAT source, TXS 0506+056 (3FGL J0509.4+0541 and also included in the 3FHL catalog, Ajello et al., arXiv:1702.00664, as 3FHL J0509.4+0542), is located inside the IceCube error region. The FAVA (Fermi All-sky Variability Analysis) light curve at energies above 800 MeV shows a flaring state recently (https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/SourceReport.php?week=477&flare=27). Indeed, the LAT 0.1--300 GeV flux during 2018 September 15 to 27 was (3.6+/-0.5)E-7 photons cm-2 s-1 (errors are statistical only), increased by a factor of ~6 compared to the 3FGL flux, with nearly the same power-law index of 2.0+/-0.1. We strongly encourage multiwavelength observations of this source. We also encourage optical spectroscopy for this source, because the redshift is still unknown. According to NED, the R-band magnitude is reported as 15.1 (Healey et al. 2008, ApJS 175, 97). Radio observations show that this blazar has had increasing flux during the past year: http://www.astro.caltech.edu/ovroblazars/data.php?page=data_query, http://www.physics.purdue.edu/astro/MOJAVE/sourcepages/0506+056.shtml.

Related

- 12274 Search for neutrinos from TXS 0506+056 with the ANTARES neutrino telescope
- 12267 IceCube search for neutrinos from TXS 0506+056 between November 28, 2018 and December 4, 2018
- 12260 MAGIC detects enhanced flux of VHE gamma rays from TXS 0506+056
- 11850 MASTER: IceCube 171106A follow up observations
- 11489 Optical and near-infrared polarimetric observations of the IceCube-170922A counterpart candidate TXS 0506+056
- 11430 Optical polarimetry of TXS 0506+056 (possible counterpart of IceCube-170922A)
- 11419 Fermi-LAT detection of enhanced gamma-ray activity and hard spectrum of TXS 0506+056, located inside the IceCube-170922A error region
- 10942 IceCube-171106A: Swift observations
- 10890 Subaru/FOCAS Optical Spectroscopy for a possible IceCube-170922A counterpart TXS 0506+056
- 10861 VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event
- 10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
- 10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
- 10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)

An IceCube neutrino notice, followed by this Astronomer's Telegram about a gamma-ray blazar flare, triggered a major multiwavelength and multimessenger campaign.

Possible Blazar Origin for an IceCube Neutrino



Ice Cube Collaboration, et al., 2018

Because Ice Cube and *Fermi* are both monitoring facilities, it was possible to construct an empirical calculation of the probability that this was a chance coincidence, based on the history of Ice Cube alerts and a comparison with over 2000 *Fermi*-LAT blazar light curves.

Archival Information

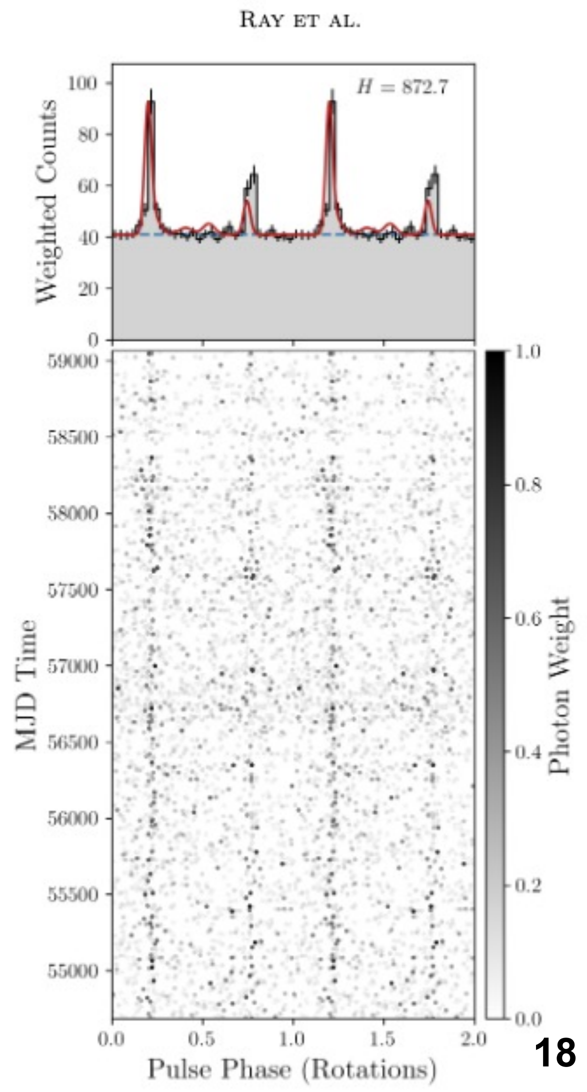
Gamma-ray Source Catalogs

Because the high-energy gamma-ray observations are not background-limited, as the data archive grows, more sources can be detected:

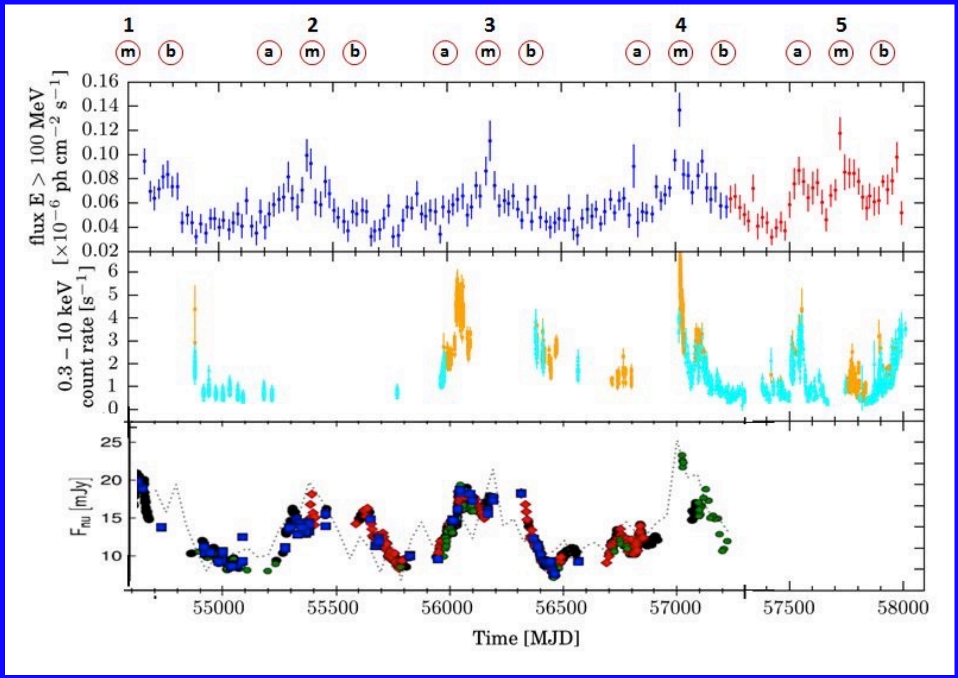
1FGL Catalog – 1451 sources
2FGL Catalog – 1873 sources
3FGL Catalog – 3033 sources
4FGL Catalog – 5064 sources
4FGL-DR2 – 5788 sources
4FGL-DR3 – 6658 sources

Pulsar Timing with Gamma Rays

PSR J1555-2908 was discovered in 2017 as a radio pulsar in a search of unidentified *Fermi*-LAT source regions. Starting with the radio timing information, it was possible to derive gamma-ray pulsations back to the start of the *Fermi* mission in 2008.

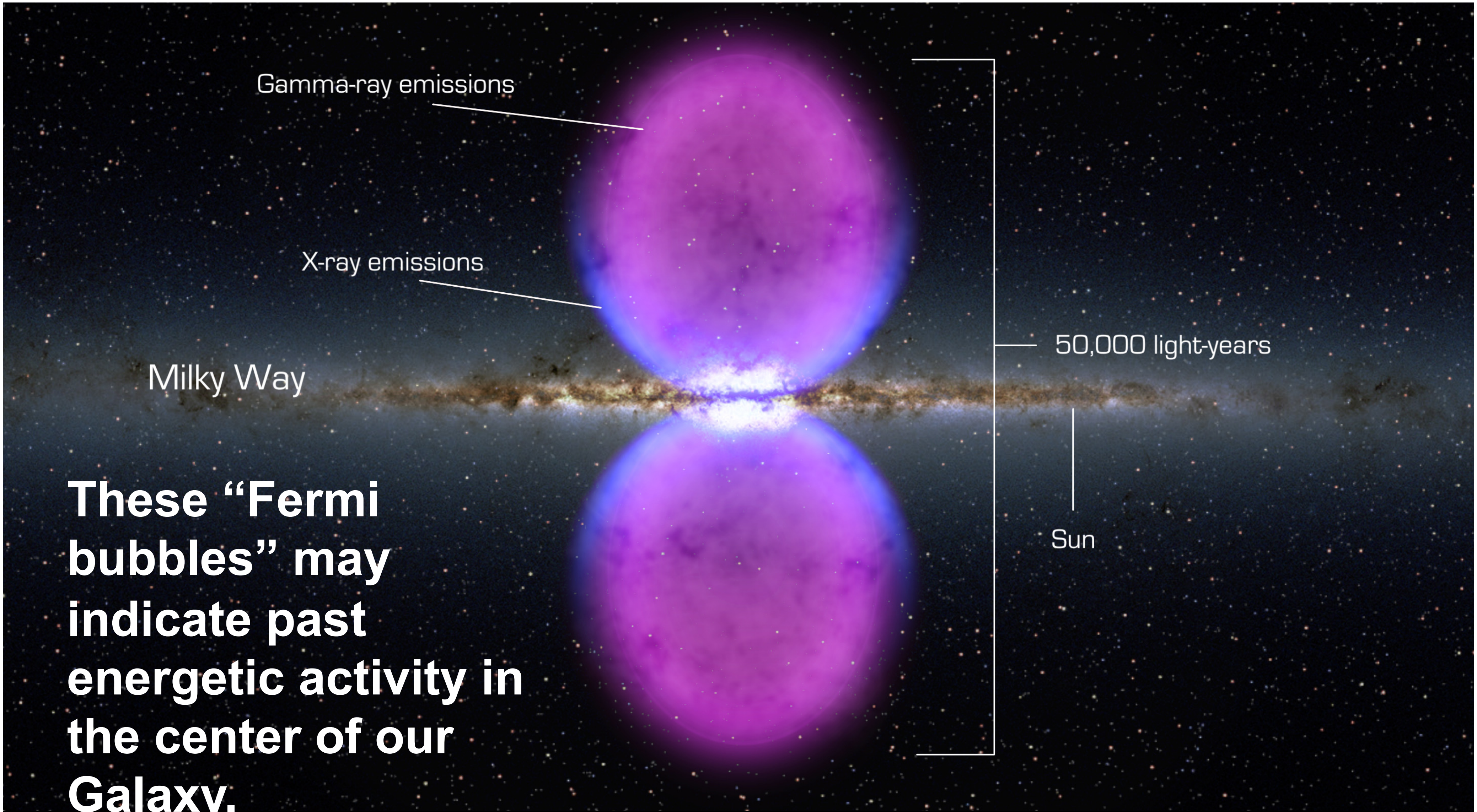


Possible AGN Periodicity



Tavani et al. 2018

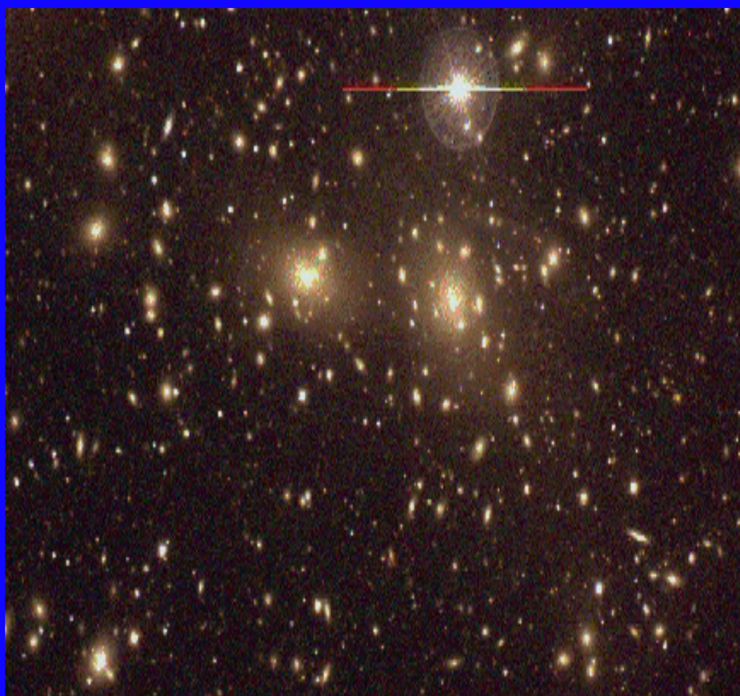
Light curves of PG 1553+113 in various bands. Top panel: gamma rays from *Fermi* LAT, with the 2016 - 2017 data traced in red. Middle panel: keV X-rays from *Swift*. Bottom panel: optical R band. This periodicity, now reaching 5 cycles, suggests that this system may contain two supermassive black holes.



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

Non-detections

What is Not Seen Can Also Be Important



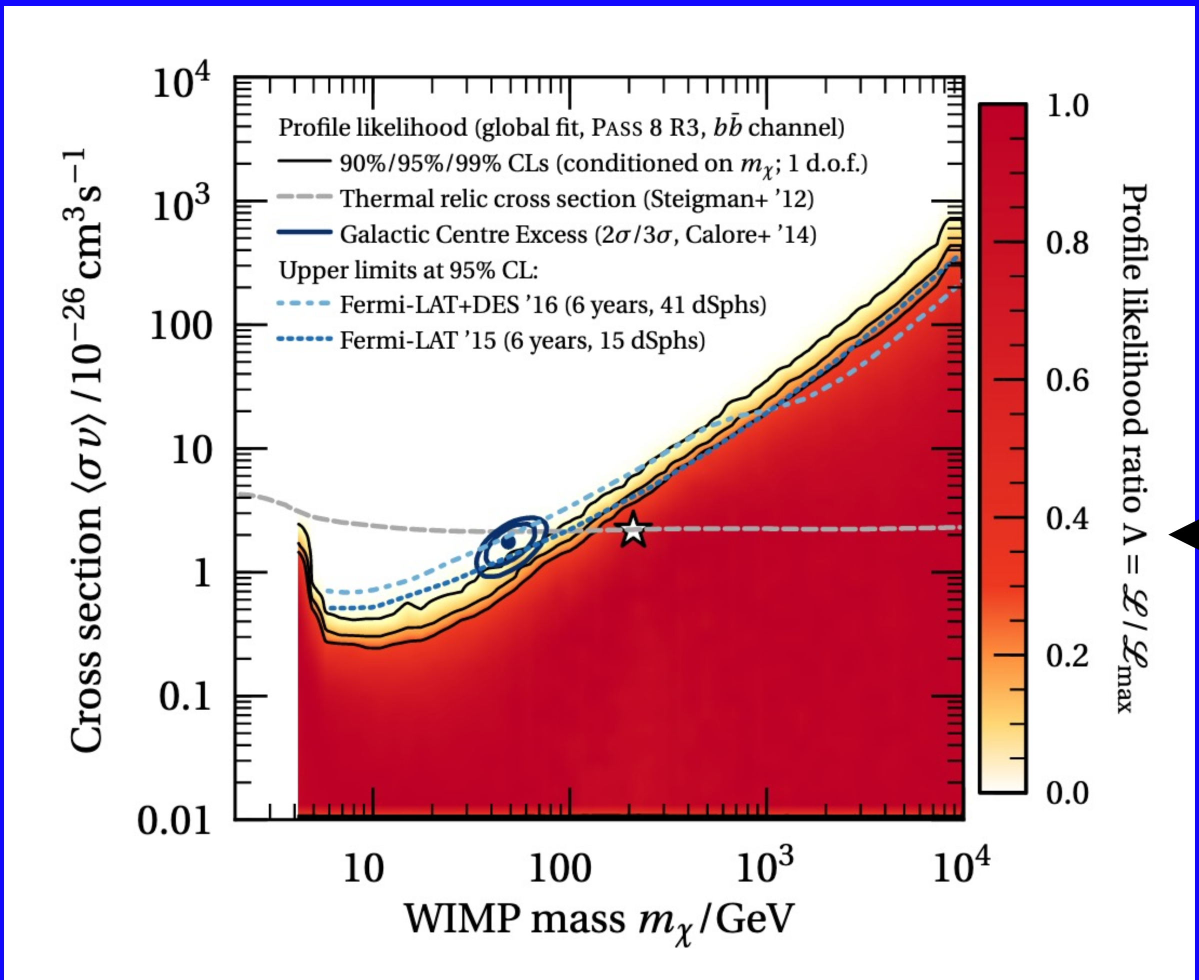
With an all-sky survey mission like *Fermi*, when we study a class of sources, we can rule out the possibility that we just picked the wrong candidate.

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

What is Not Seen Can Also Be Important

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

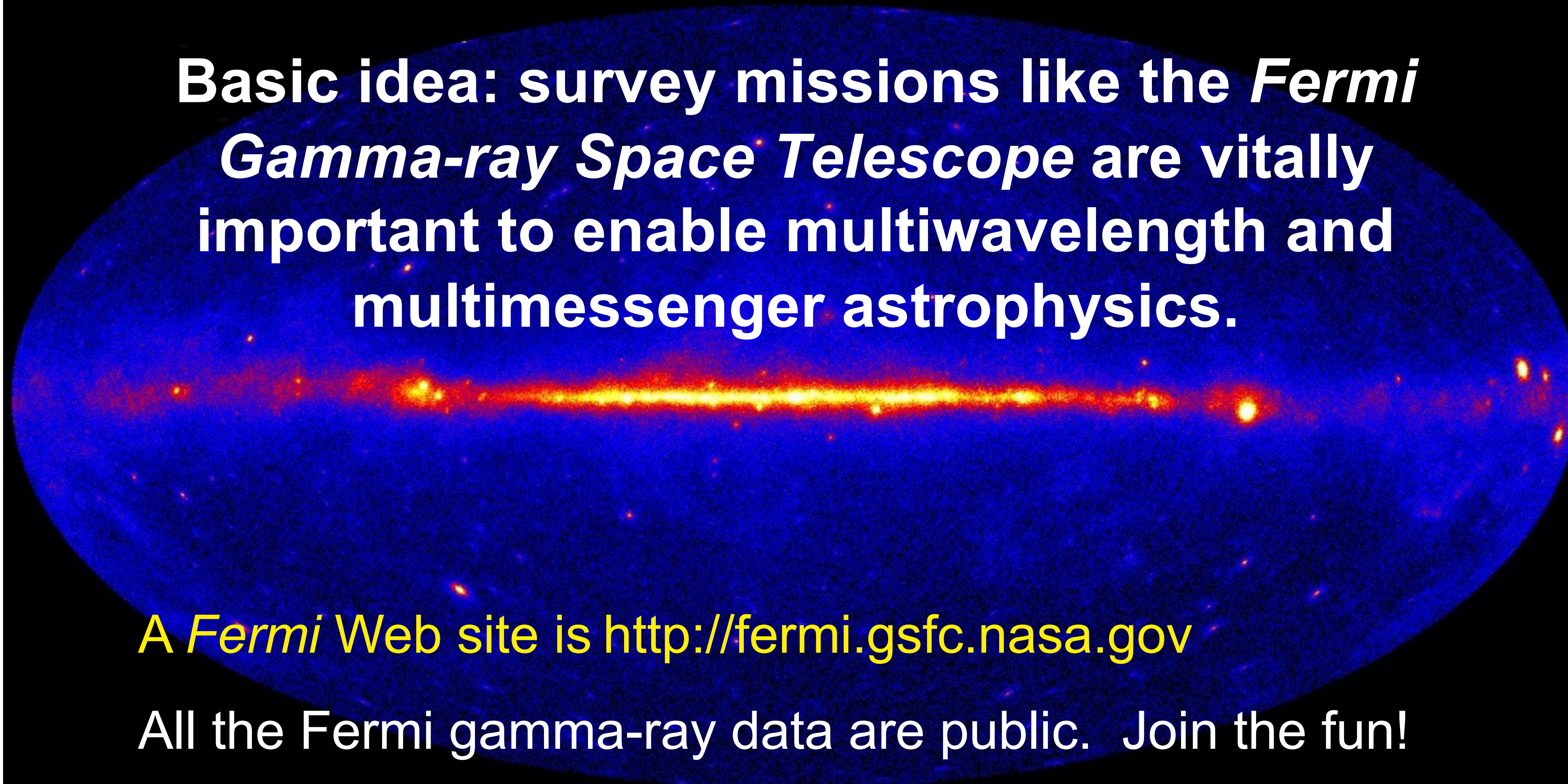


Hoof, Geringer-Smith, Trotta, 2020

Thermal limit

We can conclude that lower-mass WIMPS cannot account for all the dark matter in the Universe.

Summary – Surveying the Extreme Universe



Basic idea: survey missions like the *Fermi Gamma-ray Space Telescope* are vitally important to enable multiwavelength and multimessenger astrophysics.

A *Fermi* Web site is http://fermi.gsfc.nasa.gov

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