# *Fermi:* Ten Years of Monitoring the Gamma-ray Sky

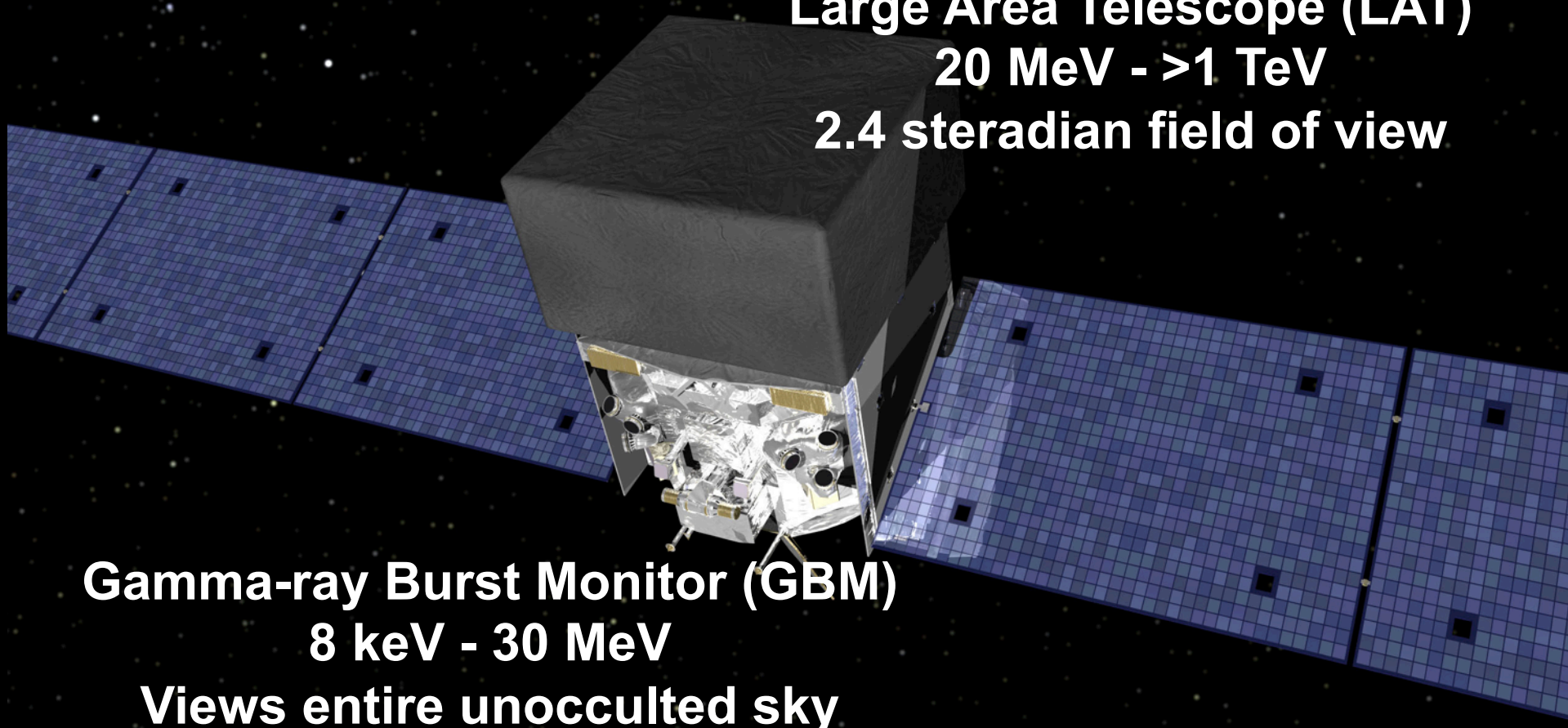

**Dave Thompson**
**NASA Goddard Space Flight Center**
***Fermi* Deputy Project Scientist**

**HAP Workshop: Monitoring the Non-thermal Universe**
**Cochem, Germany**
**September, 2018**

# Outline

- How does *Fermi Gamma-ray Space Telescope* monitor the sky, and how do we share the monitoring results with the scientific community?
- What sorts of scientific results have emerged from *Fermi's* all-sky monitoring?
- What is the future for *Fermi?*

# The *Fermi* Observatory - Characteristics

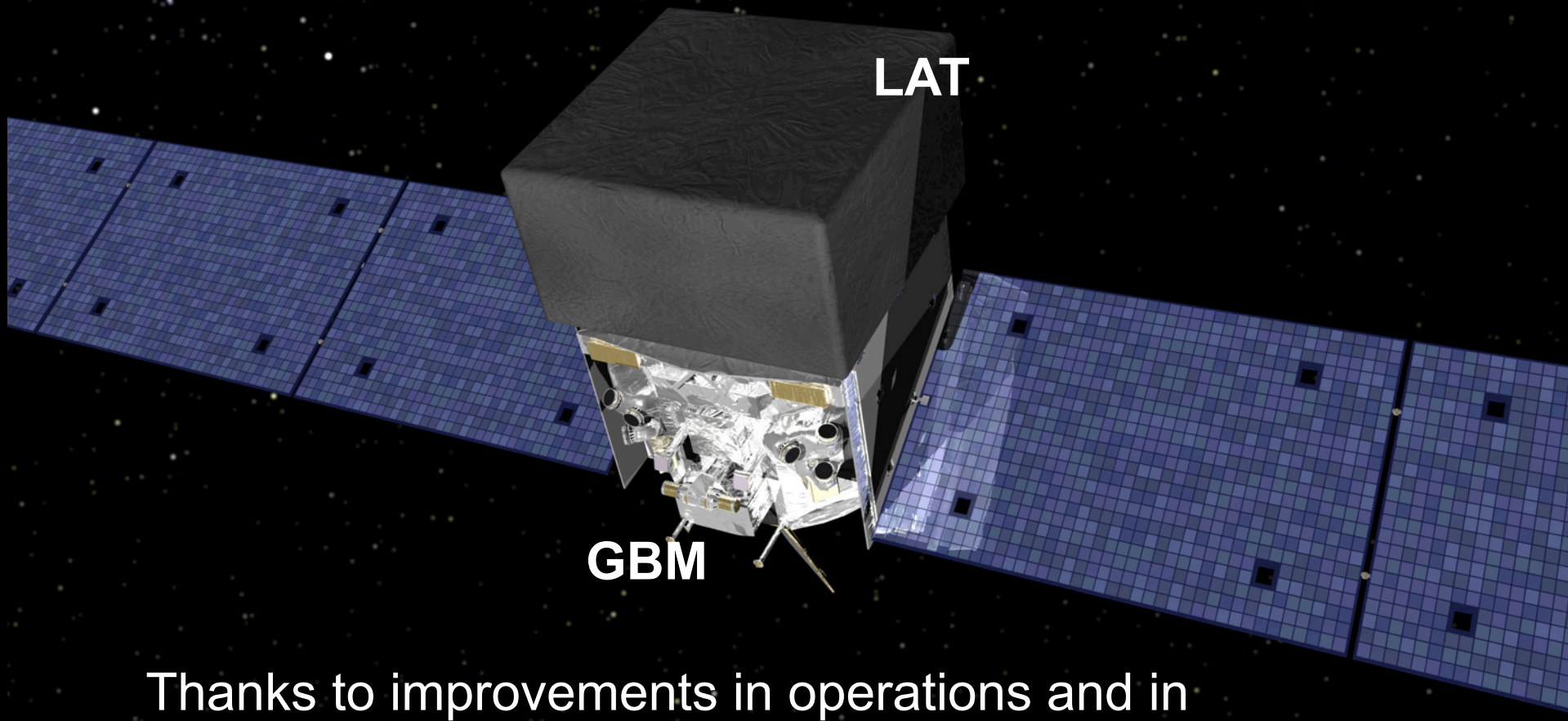


**Large Area Telescope (LAT)**
**20 MeV - >1 TeV**
**2.4 steradian field of view**

**Gamma-ray Burst Monitor (GBM)**
**8 keV - 30 MeV**
**Views entire unocculted sky**

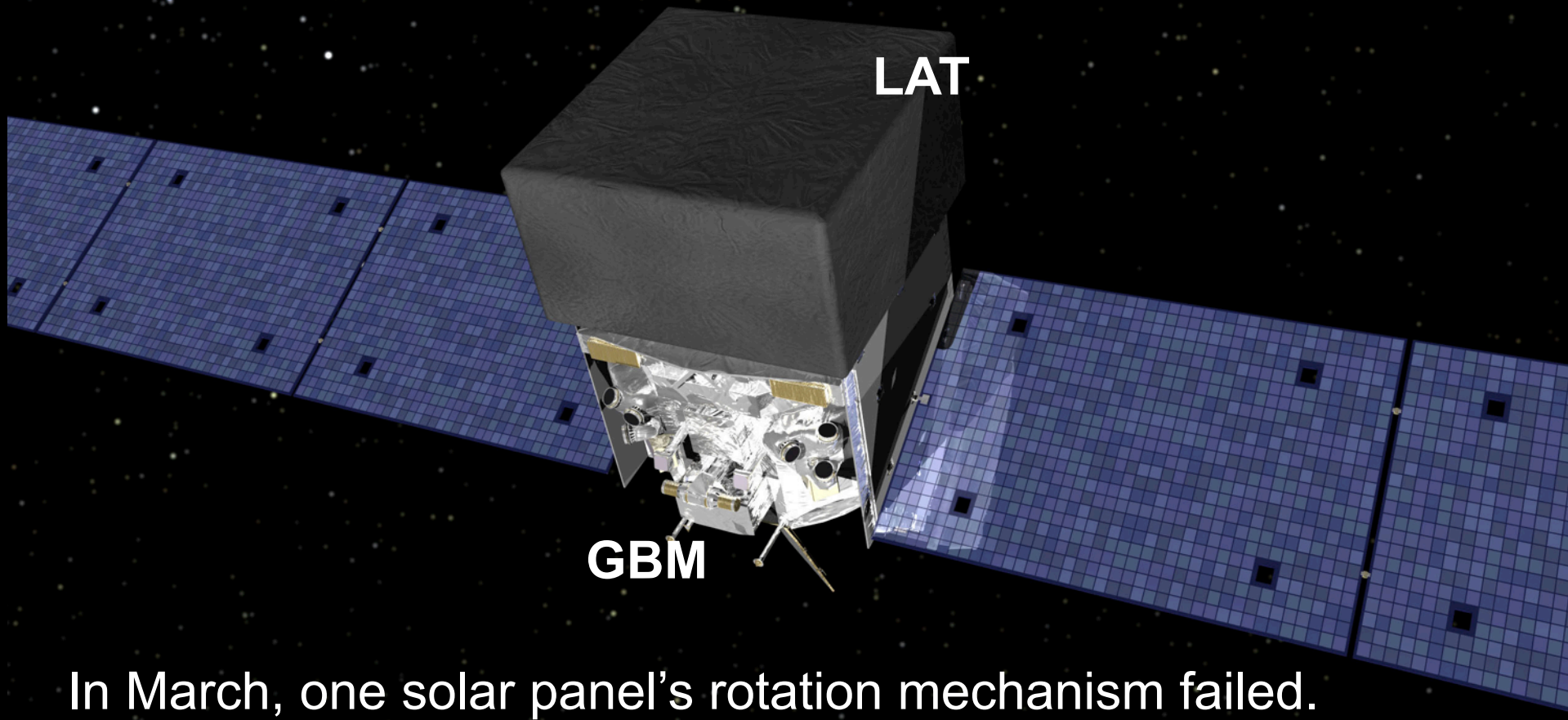
**Scanning enables both instruments to view the entire sky.**

# The *Fermi* Observatory - Characteristics




Thanks to improvements in operations and in data analysis, both instruments have better scientific performance now than at launch.

# The *Fermi* Observatory - Characteristics




In March, one solar panel's rotation mechanism failed. The *Fermi* observing strategy for LAT changed to cover the whole sky in weeks rather than hours.

# From Observations to Useful Data

Gamma-ray bursts are the only sources bright enough to be detected on board. Other *Fermi* data follow a long path:

*Fermi* satellite
Tracking and Data Relay Satellite (TDRS)
Ground station
Mission Operations Center
Instrument Operations Centers
Fermi Science Support Center (FSSC)

The process takes about 6 hours, with some variation.

**At the FSSC, all *Fermi* gamma-ray data immediately become public to everyone.**

Most scientists prefer not to analyze *Fermi* data directly. The instrument teams have made a variety of high-level data products available.

# Automated Alerts

Two types of automated *Fermi* alerts are distributed by the Gamma-ray Coordinates Network (GCN):

Gamma-ray Burst (GRB) Notices. These are generated on board the satellite by either the GBM or the LAT and can be distributed within seconds of the trigger.

Flaring LAT Source Notices. These are based on an automated analysis of LAT data and have a latency of about one day (but we are working to shorten that).

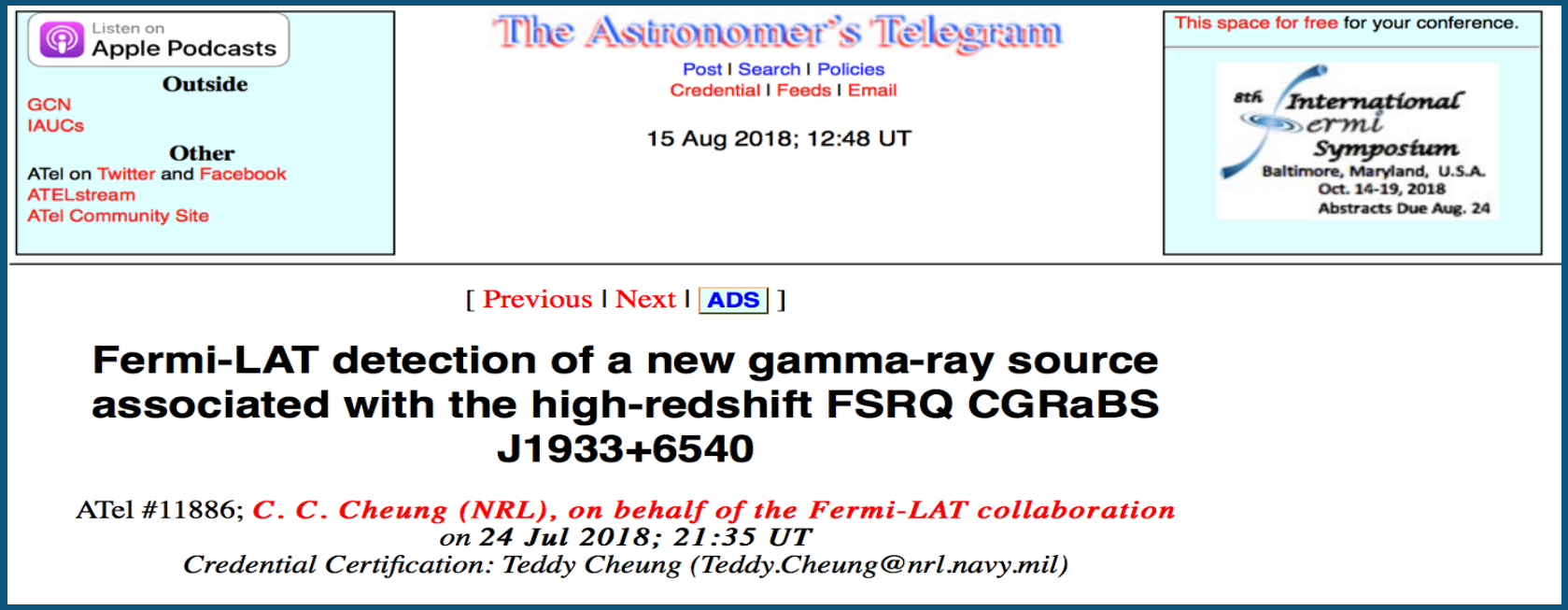
```
TITLE:            GCN/FERMI NOTICE
NOTICE_DATE:      Wed 18 Jul 18 15:29:17 UT
NOTICE_TYPE:      Fermi-LAT Monitor
SOURCE_OBJ:       PKS2247-131_86400.png
REF_NUM:          1531927757
RA:               342.498d {+22h 49m 59s} (J2000),
                  342.742d {+22h 50m 58s} (current),
                  341.838d {+22h 47m 21s} (1950)
DEC:              -12.855d {-12d 51' 17"} (J2000),
                  -12.756d {-12d 45' 22"} (current),
                  -13.120d {-13d 07' 11"} (1950)
CURR_FLUX:        1.70e-06 +- 1.70e-07 [ph/cm2/sec]
BASE_FLUX:        5.20e-07 +- 1.50e-07 [ph/cm2/sec]
```

# Follow-up Alerts

GBM and LAT volunteer scientists monitor the *Fermi* data and issue several types of alerts of interesting gamma-ray activity.

Gamma-ray Burst (GRB) Circulars, sent through GCN. These include additional ground analysis of GRBs.

Astronomer's Telegrams. These cover a variety of topics, most often flares of Active Galactic Nuclei.



# Semi-Public and Private Alerts

## Semi-public – gamma-ray/multiwavelength mailing list
## https://lists.nasa.gov/mailman/listinfo/gammamw

Multiwavelength Colleagues,

As the Fermi Gamma-ray Space Telescope starts its second decade of science operations, I would like to call your attention to an ongoing program, the Very Important Project (VIP) for AGN studies by the Fermi LAT team. Please see https://confluence.slac.stanford.edu/display/GLAMCOG/VIP+List+of+AGNs+for+Continued+Study

While the LAT team will continue to monitor the entire gamma-ray sky, including sources of all types, we noted these AGNs as ones that appear worth extra effort. They all have multiwavelength monitoring programs. We have identified LAT scientists who will be paying particular attention to these objects.

## Direct e-mails under Memoranda of Understanding

From Dave Thompson

Subject **Fermi LAT flaring sources** 3/10/17, 1:52 PM

To Michelle Hui <cmhui@mtu.edu>, Rene Ong, Massimo Persic, wagner, Pete **20 more**

TeV Colleagues,

From Roopesh Ojha, the current Fermi LAT Flare Advocate:

S4 0110+49 from which two photons above 10 GeV were detected yesterday has a daily averaged flux of 0.4 units which is 23 times its 3FGL value. Its photon index is 1.90+-0.19. It has z=0.389.

There are three high energy photons detected from S5 1044+71 which is at z=1.15. As you know, this source has been pretty active over the last few months (e.g. http://www.astronomerstelegram.org/?read=9928).

# *Fermi* Public Data Products

Beyond these active efforts to share *Fermi* monitoring results, there are many public data products, most of which are available through the Fermi Science Support Center (FSSC): https://fermi.gsfc.nasa.gov/ssc/. A mirror site at the Italian Space Agency's Space Science Data Center also has many of these: http://www.ssdc.asi.it.

Among these:

General catalogs – LAT sources, GBM GRBs

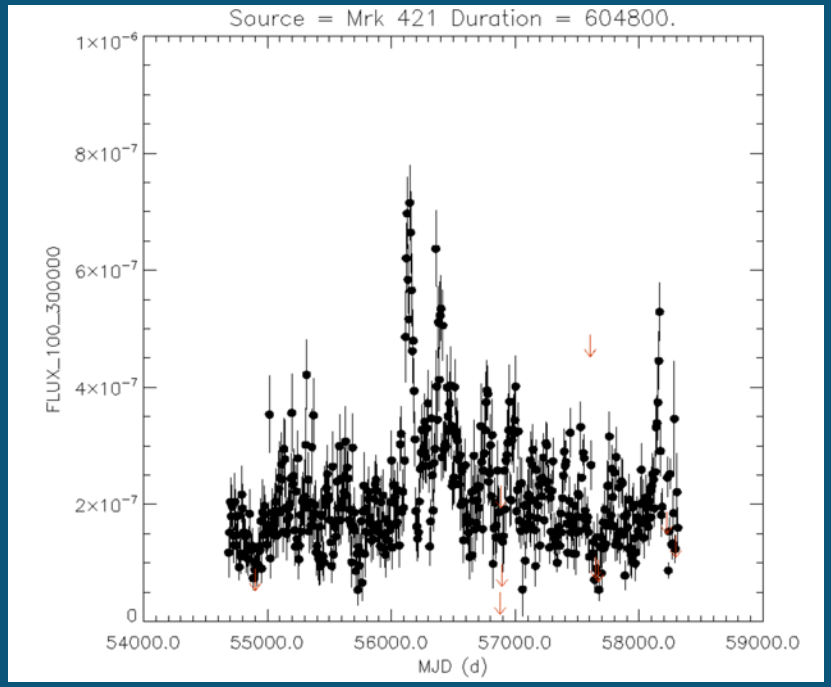
Specialized catalogs

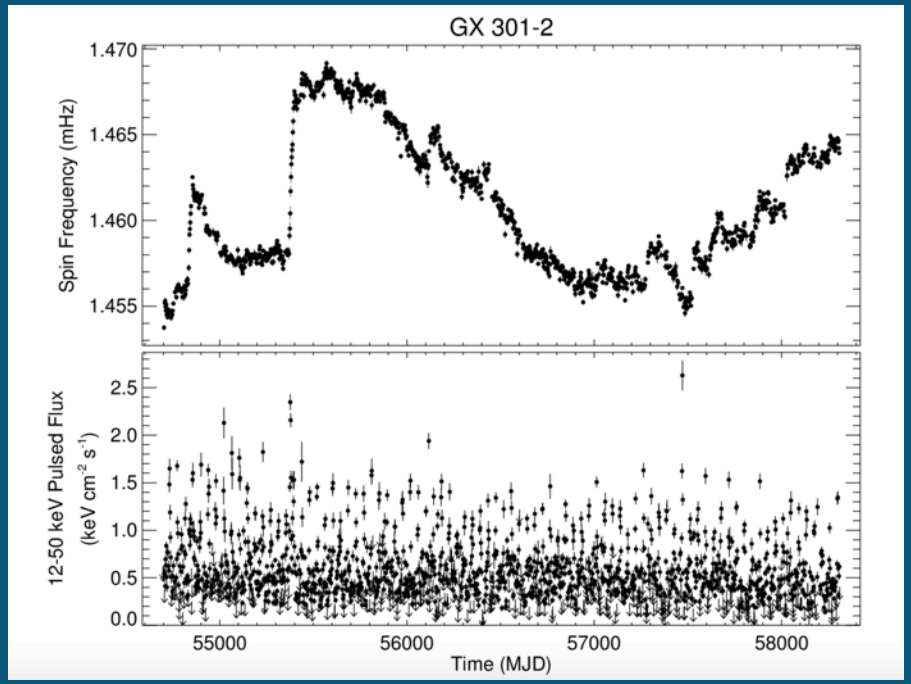
LAT – high-energy sources, supernova remnants, pulsars, flaring sources, GRBs

GBM – X-ray bursts, terrestrial gamma-ray flashes, magnetars

# *Fermi* Public Data Products

**The FSSC site also includes online resources. Two examples:**



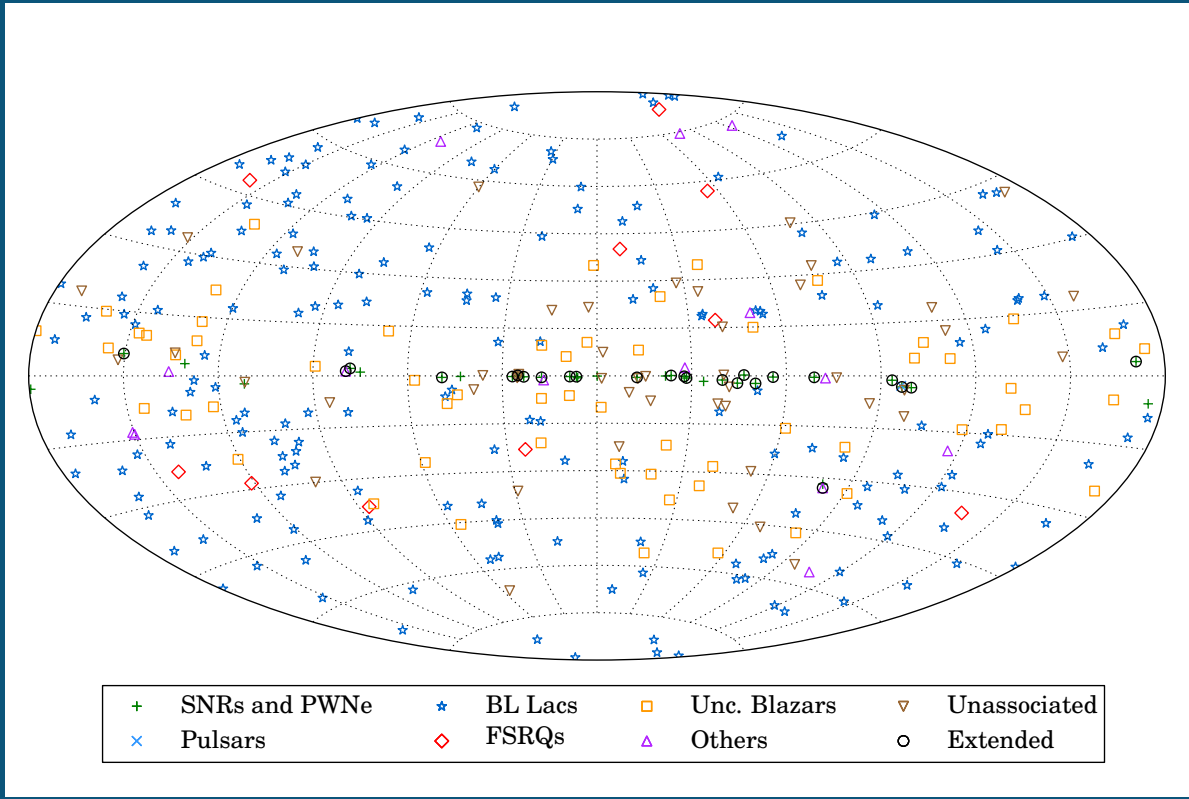

Updated regularly, the Monitored Source List shows daily and weekly LAT light curves for 158 sources that have been bright at least once.

The GBM monitors over 30 accretion-powered pulsars, providing histories of flux and spin periods.

**What sorts of scientific results have emerged from *Fermi's* long-term, all-sky monitoring?**

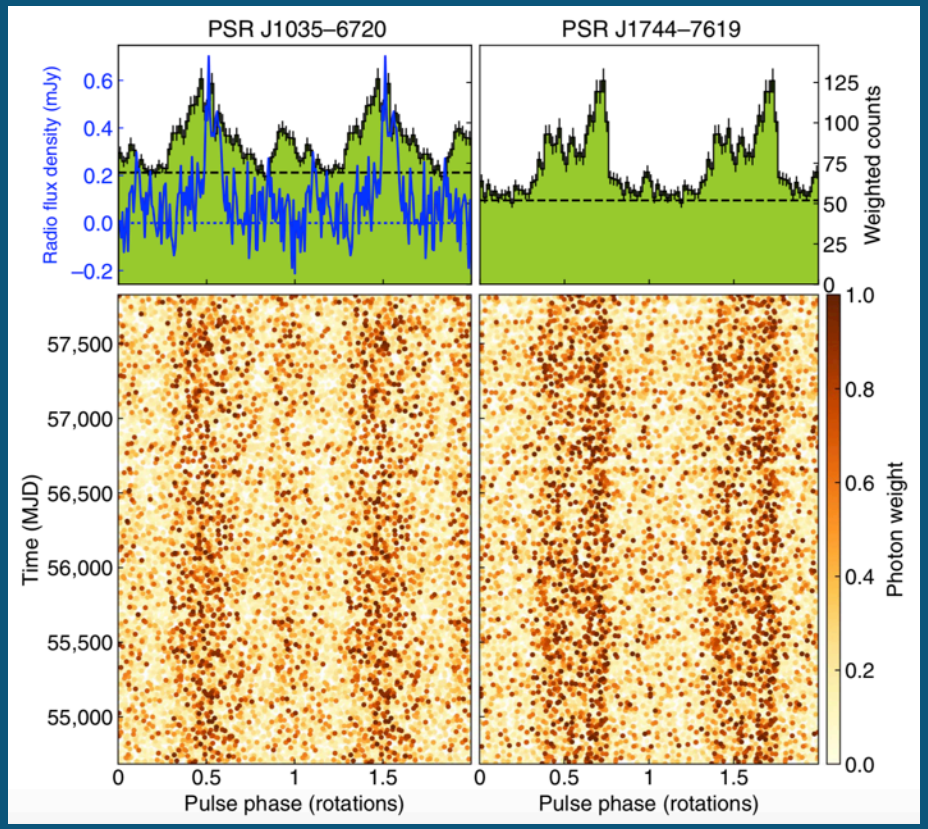
**Long-term monitoring to accumulate statistics is important for *Fermi* LAT, which has a fairly small collecting area.**

# The 2FHL Catalog




**With 80 months of LAT data, it was possible to construct the 2FHL catalog of sources in the energy range 50 GeV--2 TeV. These 360 sources include some that were seen with as few as 3 photons. Only about 25 percent of these sources had been detected by IACTs, making this catalog a valuable roadmap for future TeV observatories like the Cherenkov Telescope Array (CTA).**

# Millisecond Pulsars

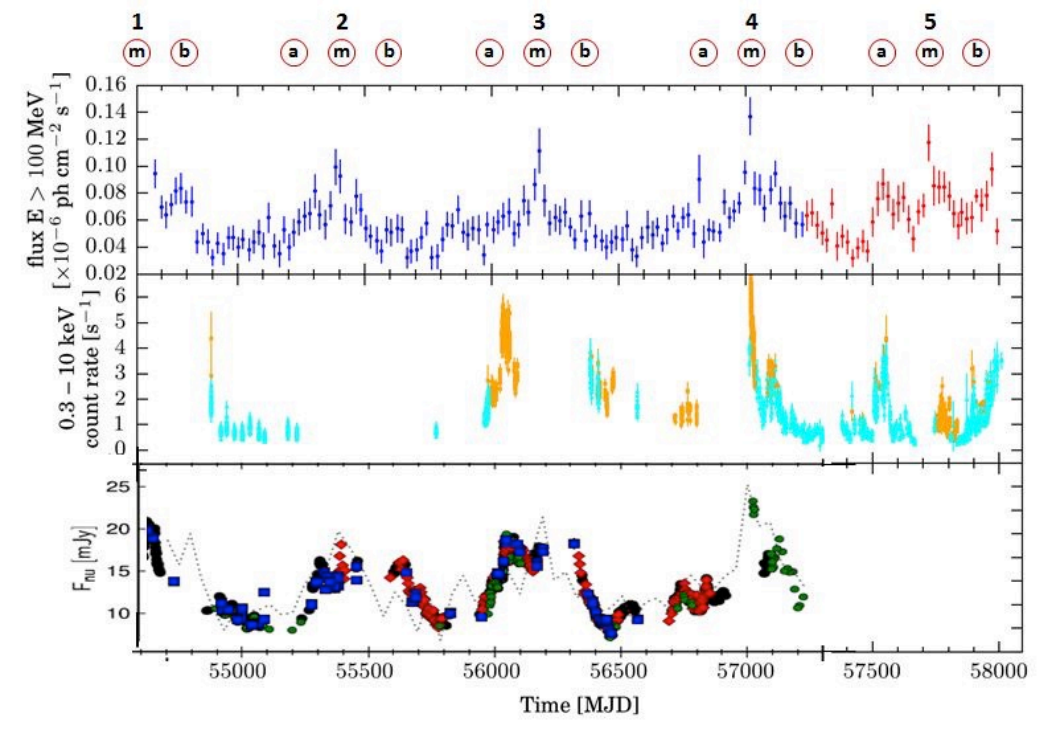



Clark et al. 2018

**Using 5.5 years of LAT data, combined with advanced pulse-searching methods, the Einstein@Home distributed computing project was able to reveal two millisecond pulsars in blind searches, and one of these was the first radio-quiet millisecond pulsar. Although the Einstein@Home project was able to accumulate the equivalent of 10,000 years of CPU time, this computing power still required enough detected gamma rays to make this discovery.**

# Monitoring to search for long-term trends

# Possible AGN Periodicity



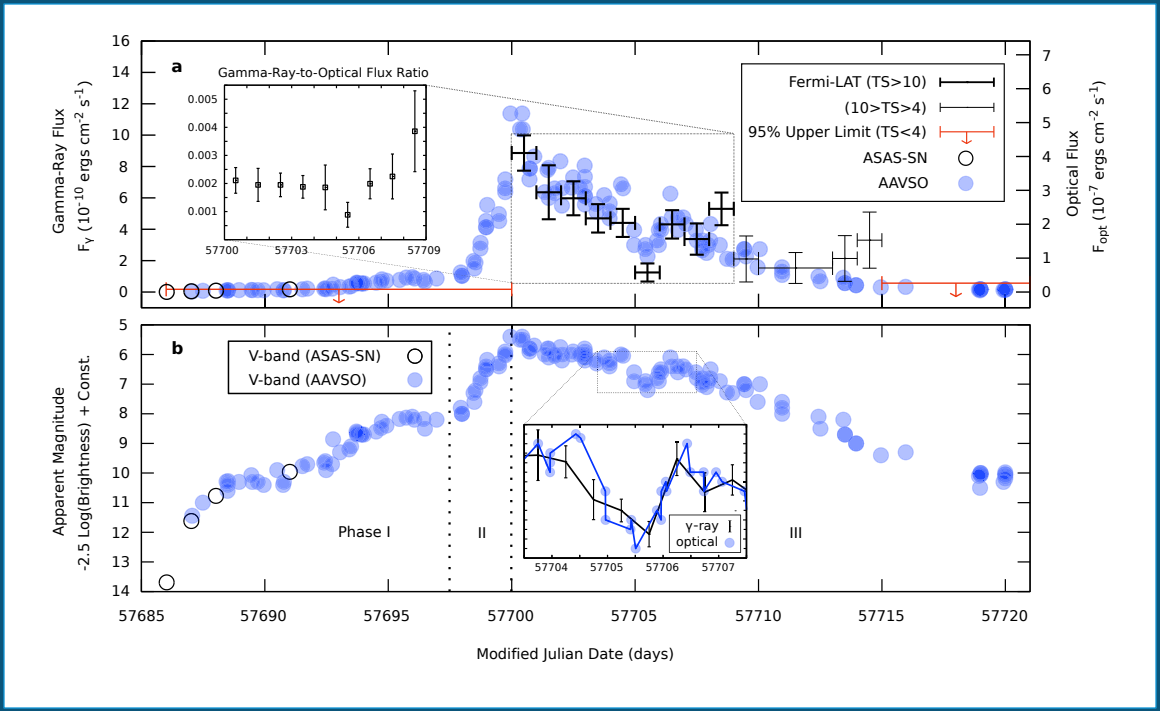

Tavani et al. 2018

**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.**

# Monitoring to detect rare transients

**For variable or transient phenomena, which are often unpredictable, extreme cases can provide the greatest insight.**

# 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.**

# Monitoring for synergy with new facilities

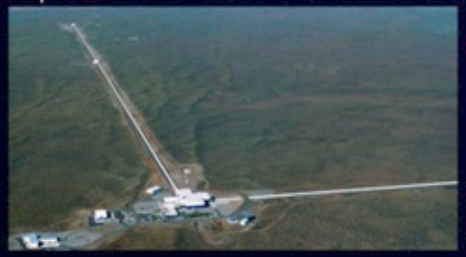
# Gravitational Wave Event

## Fermi

Reported 16 seconds after detection

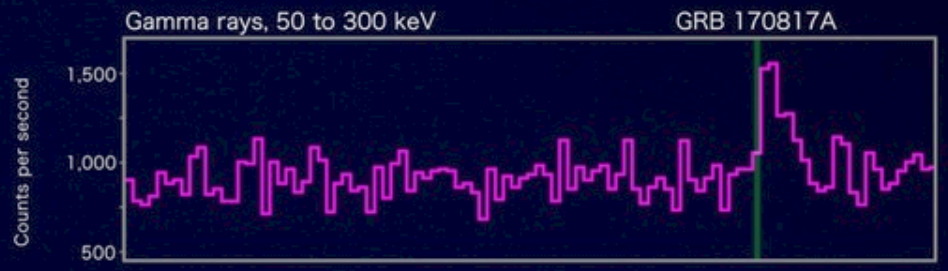
## LIGO-Virgo

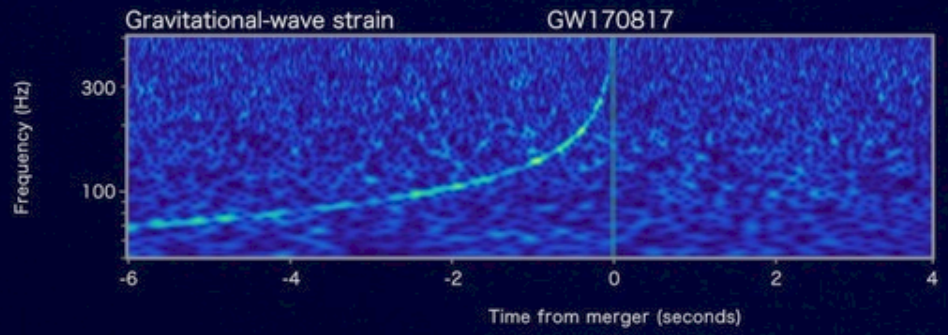
Reported 27 minutes after detection

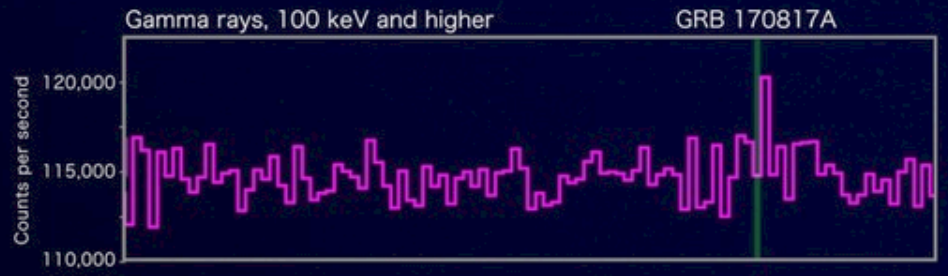


## INTEGRAL

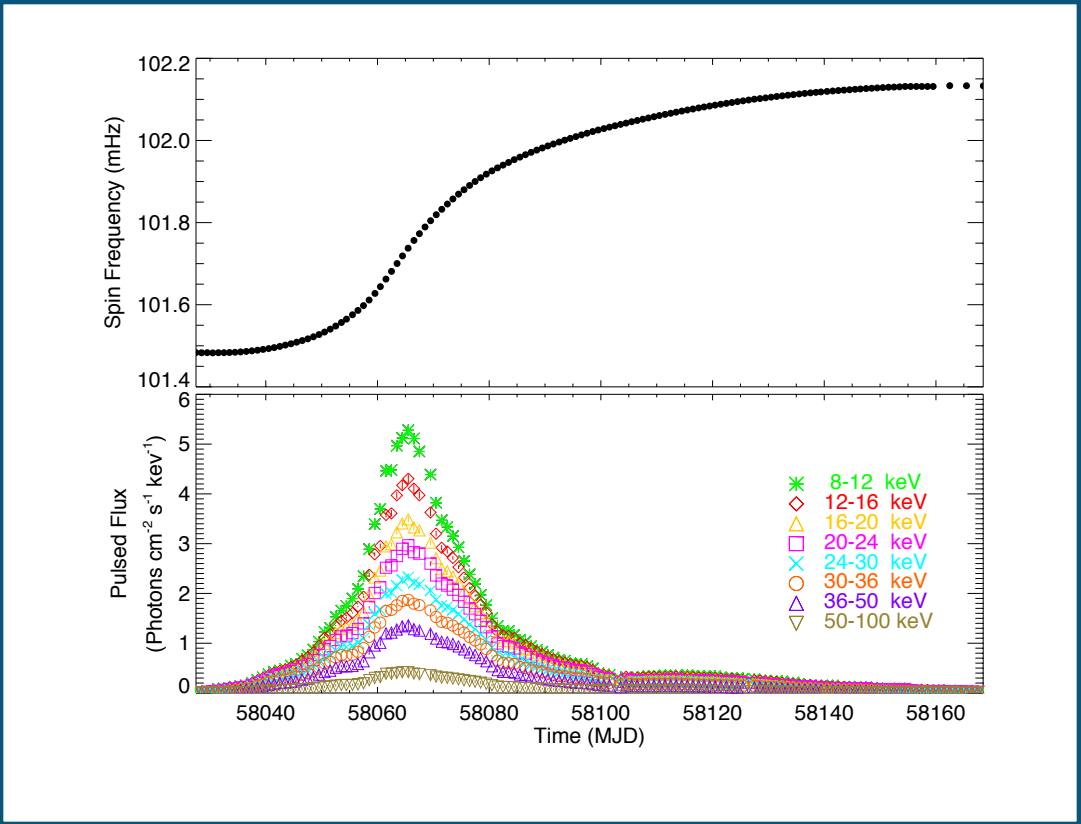
Reported 66 minutes after detection



# First Known Galactic Ultraluminous X-ray Pulsar



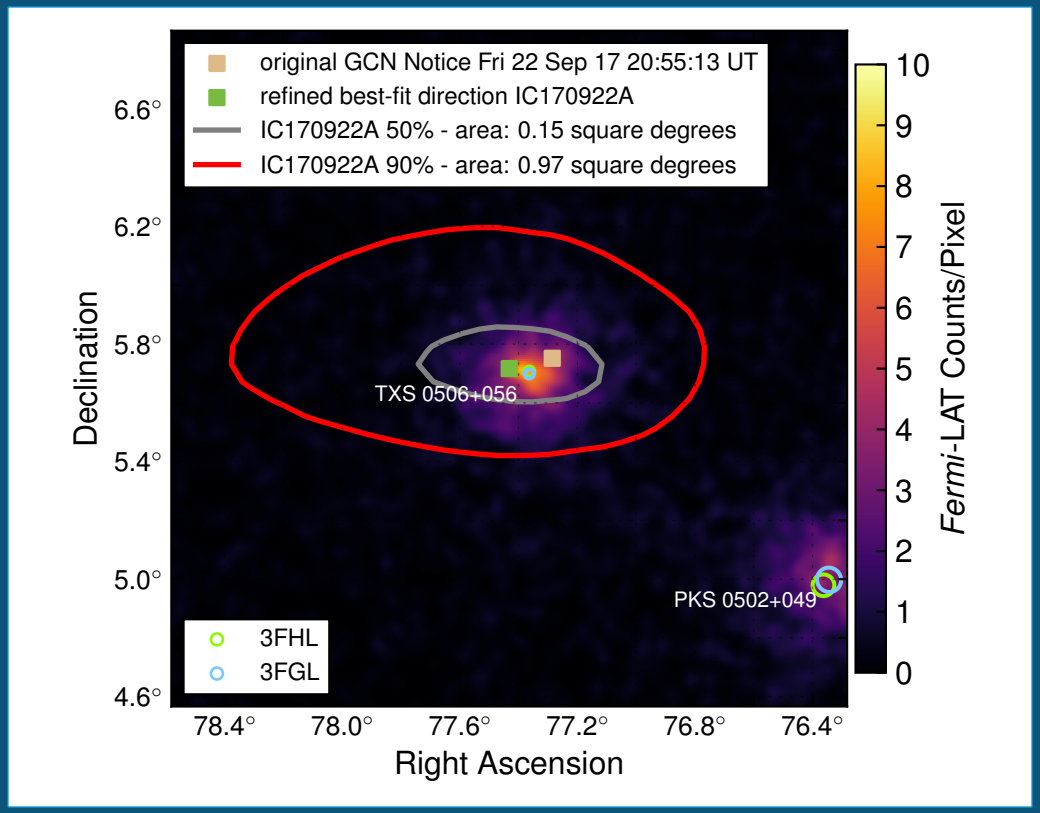

Wilson-Hodge, et al., 2018

In 2017 September, a massive outburst from a newly discovered Be/X-ray binary system was detected by the *Swift* Burst Alert Telescope. The nature of Swift J0243.6+6124 was only revealed by combining data from *Swift*, *Fermi*-GBM, *NuSTAR*, *NICER*, and *Gaia*, with the GBM providing the detailed evolution of the flux and pulse spin frequency.

# Monitoring to establish context

**In some cases, an astrophysical observation is only meaningful in the context of historical or comparative observations.**

# 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.

# What is the future for *Fermi?*

# Status and Prospects

- The *Fermi* GBM and LAT are working well, continuing to produce high-quality results.
- The *Fermi* spacecraft, despite the nuisance of the stuck solar panel, continues to support the instrument operations effectively.
- The *Fermi* satellite is in an orbit that will be stable for decades.
- *Fermi* has no expendable supplies to be used up.
- The instrument and operations teams are staffed with experienced and enthusiastic personnel.
- New multiwavelength and multimessenger facilities will provide additional opportunities for *Fermi* science.

**However, *Fermi* must periodically convince NASA to continue funding. The next review comes this winter.**

# Summary

**After ten years in orbit, the *Fermi Gamma-ray Space Telescope* continues to monitor the high-energy sky, providing a broad range of results related to simultaneous and near-simultaneous multiwavelength and multimessenger observations. As we enter Fermi's second decade, we look forward to more exciting discoveries.**

**If you have questions or comments about *Fermi's* monitoring programs or data sharing, please contact me: David.J.Thompson@nasa.gov**