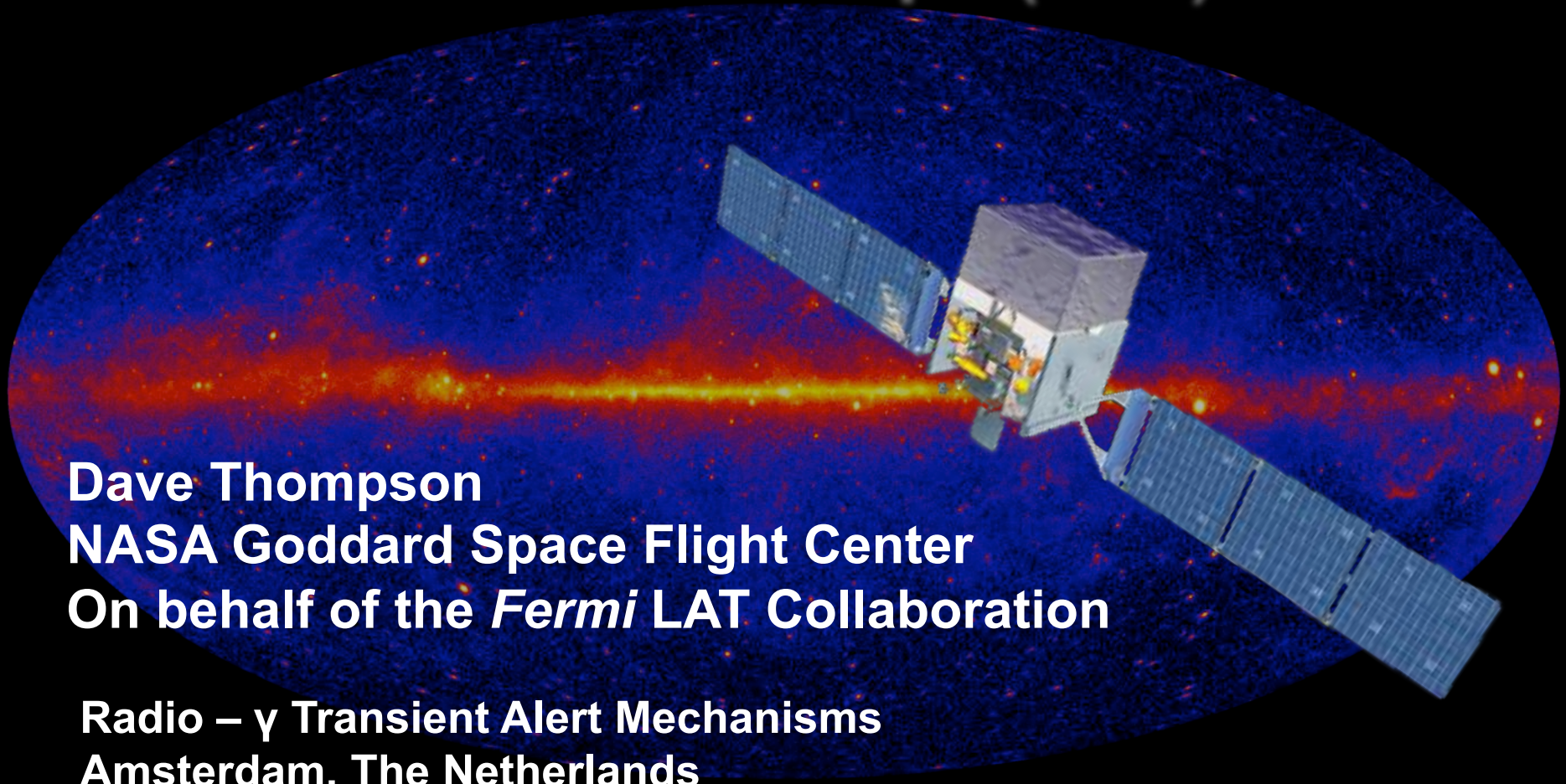
Transient Events with the *Fermi Gamma-ray Space Telescope* Large Area Telescope (LAT)



Dave Thompson
NASA Goddard Space Flight Center
On behalf of the *Fermi* LAT Collaboration

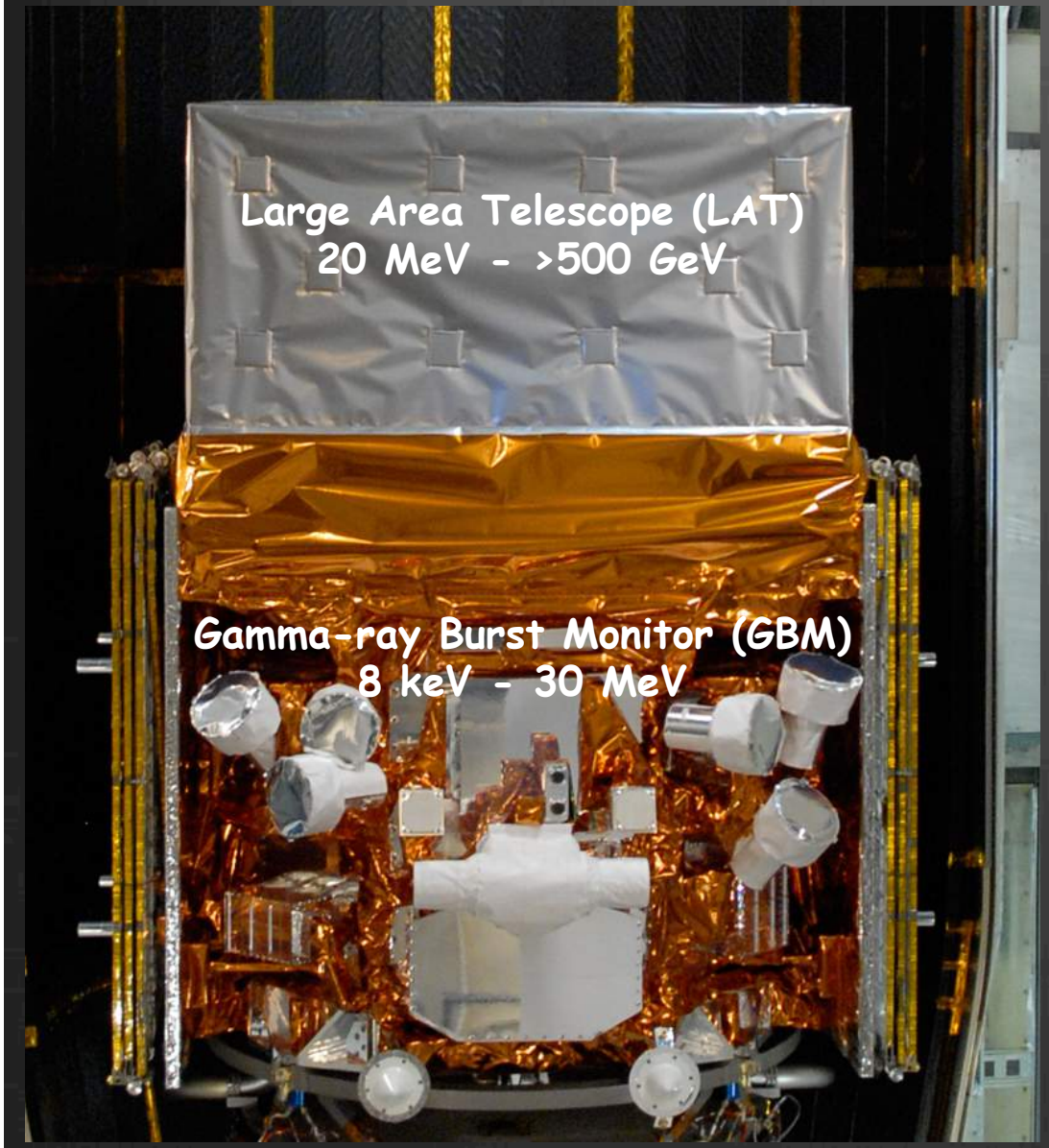
Radio – γ Transient Alert Mechanisms
Amsterdam, The Netherlands
26-28 September, 2017

Outline – Two Obvious Topics

- **Finding transients in the gamma-ray sky**
  - Methods for finding transients on different time scales
- **Sharing alerts about those transients**
  - Public announcements and targeted communications

Finding Transients

The *Fermi* Observatory - Characteristics



Huge fields of view

- **LAT: 2.4 steradians**
- **GBM: whole unocculted sky at any time (9 steradians)**

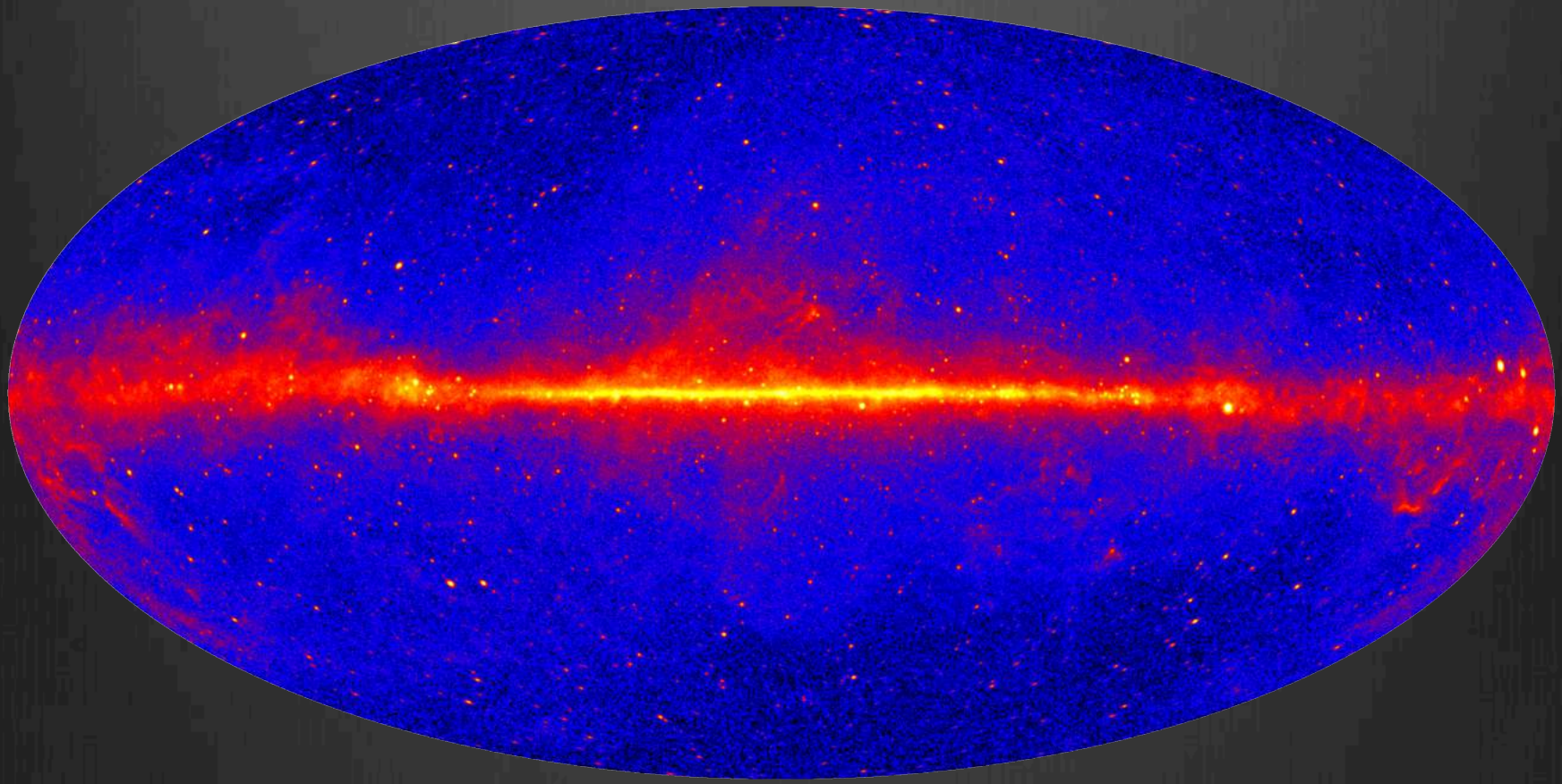
- **Very broad energy range**
  - **Combined coverage about 8 orders of magnitude**

- **Good timing**
  - **Individual photons measured to 1-2 microsecond absolute**

- **All gamma-ray data are immediately public**

Fermi Survey Mode - Default

Result - The Big Picture

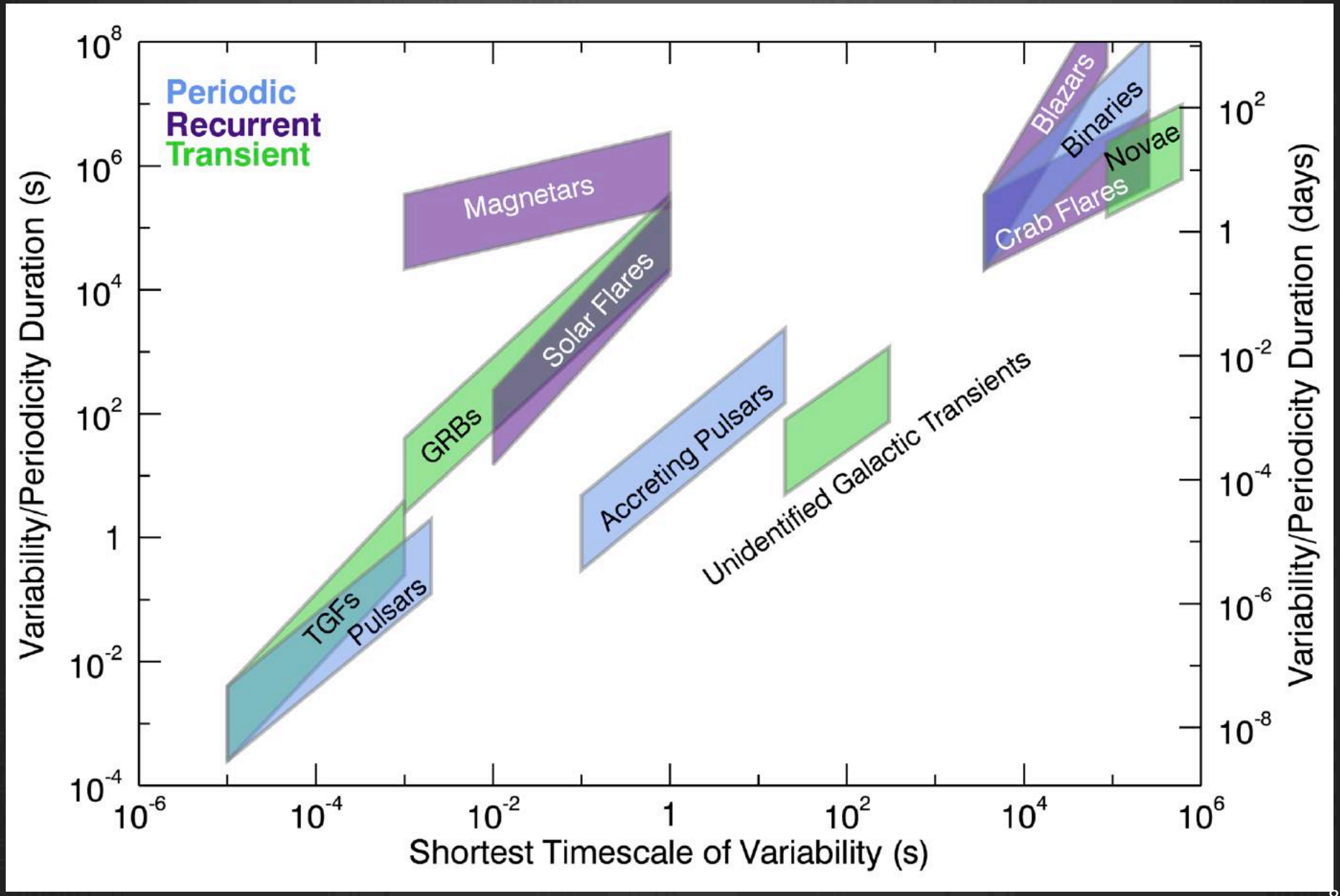


Energy Range: E>1 GeV Duration: 9 years

Fermi LAT generates a lower-resolution version of this map every three hours.

With over nine years of experience with *Fermi*, we know the average appearance of the gamma-ray sky. Transients are seen as deviations from that average.

Fermi and Time-Domain Astrophysics



Fermi as a Transient Event Detector

BENEFITS

- A satellite is the only way to observe the full sky with a single instrument.
- No problem with seasons or day/night (the Sun is just another source for *Fermi*).
- No problem with weather (almost).

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LIMITATIONS

- The *Fermi* instruments are not very big. The LAT in particular is limited by photon statistics.
- Data collection, transmission, and processing take some time.
- Angular resolution is limited.

Fermi Transient Searches

Fermi Gamma-ray Space Telescope

Transients Timescale Pipelines

Pipeline
Method
Timescale
Distribution
Status

LAT Transient Factory (LTF)
Likelihood Around GBM/BAT triggers
seconds to orbits
LAT Team - Results in GCNs
Triggered Operating + *Blind Search Coming Soon*

***Fermi* All-sky Variability Analysis (FAVA)**
Counts Map Aperture Photometry
3 day (coming soon), 1 week
ATels
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/

LAT Burst Advocate Tool
Likelihood Around GBM/BAT triggers
100 s, 1000 s
LAT Team - Results in GCNs
Operating

LAT Catalogs
Likelihood, associations
3 month (0FGL), 1 year (1FGL), 2 years (2FGL), 4 years (3FGL)
http://fermi.gsfc.nasa.gov/ssc/data/access/
4FGL in progress

GBM Untriggered Search
ground search
ms - s
GCN Notices
http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

GBM/LAT Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices
Operating

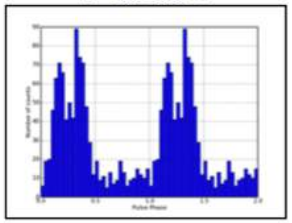
LAT Automated Science Processing (ASP) + Flare Advocates
Likelihood
6 & 24 hour
ATels, GCN notices (on AGN)
Operating

μs ***ms*** ***s*** ***minutes*** ***hours*** ***days*** ***months*** ***years***

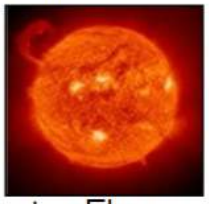
Photon Timing

All Sky Cadence

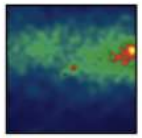
Pulsars



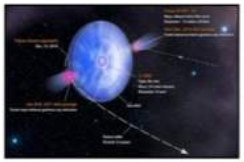
Solar Flares



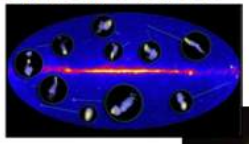
Novae



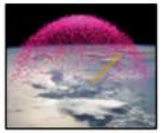
γ-ray Binaries



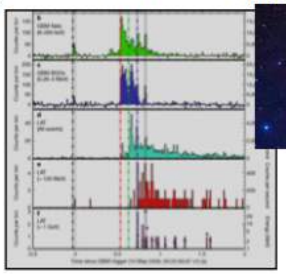
Blazar Flares



Terrestrial γ-ray Flashes

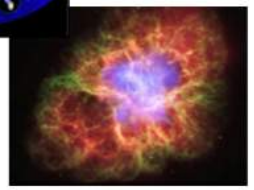


GRBs



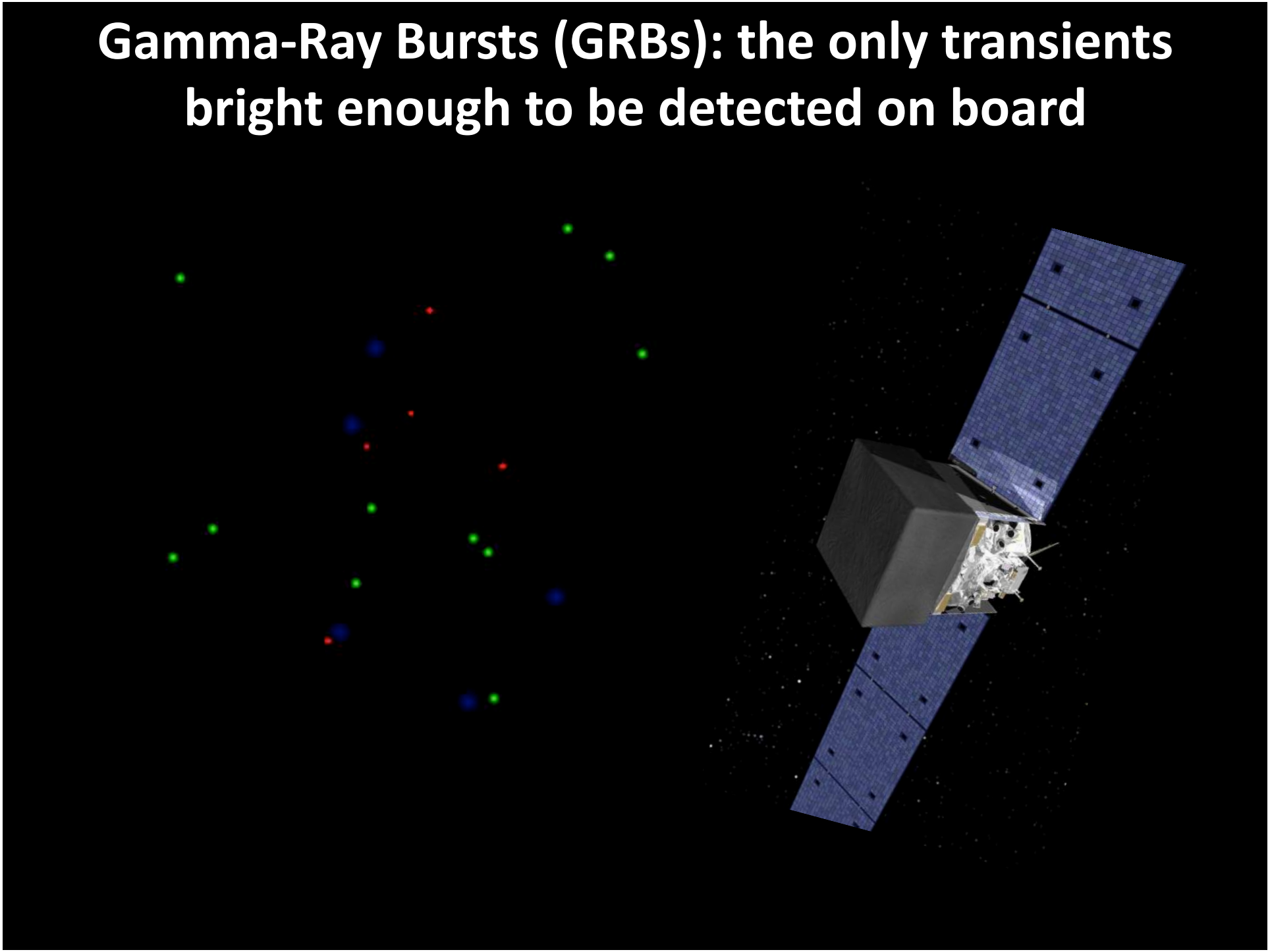
Magnetar Flares

Crab Flares

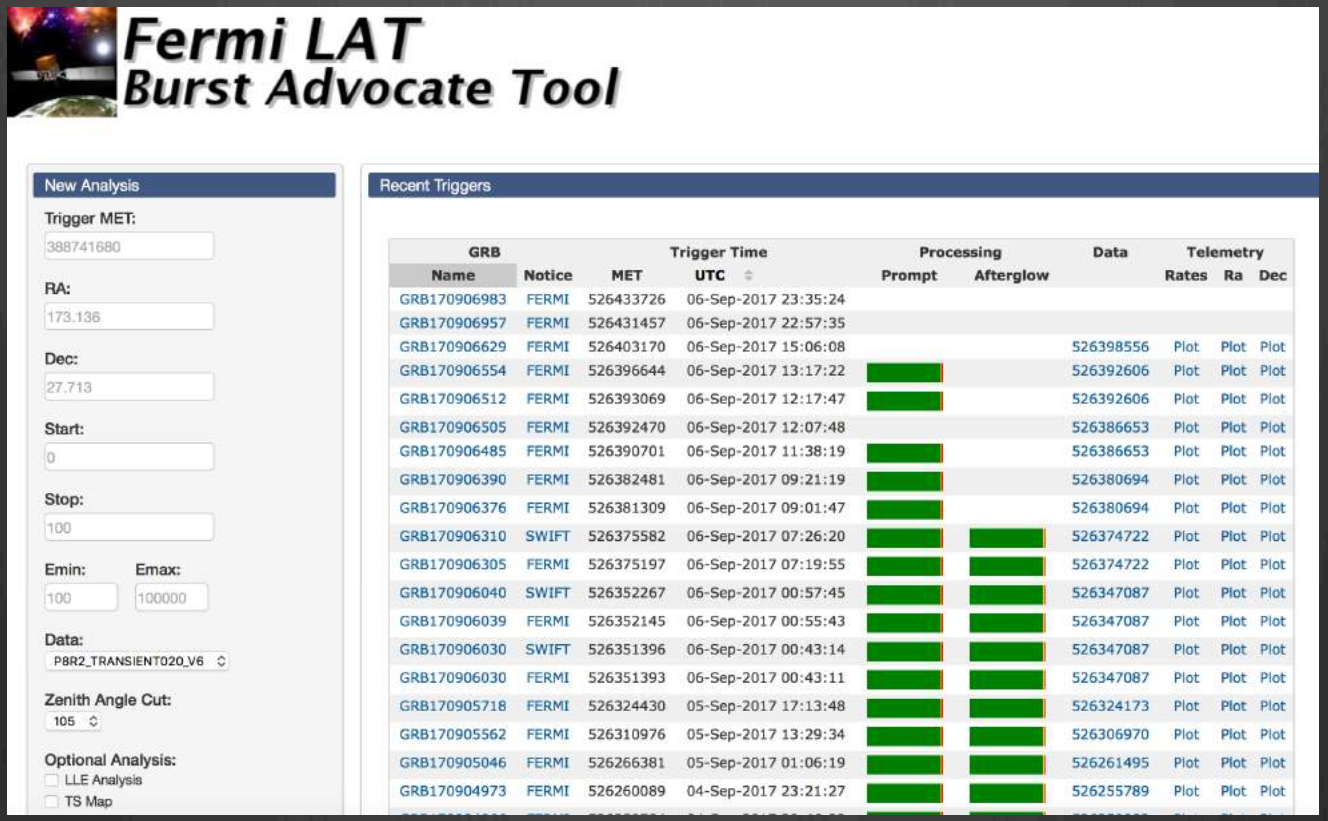


Not to scale

Gamma-Ray Bursts (GRBs): the only transients bright enough to be detected on board



LAT Burst Advocate Tool to Search for Bursts



The BA Tool automatically runs a series of jobs to analyze LAT data when a burst trigger is received from GBM or *Swift*, looking for evidence of the burst on various time scales.

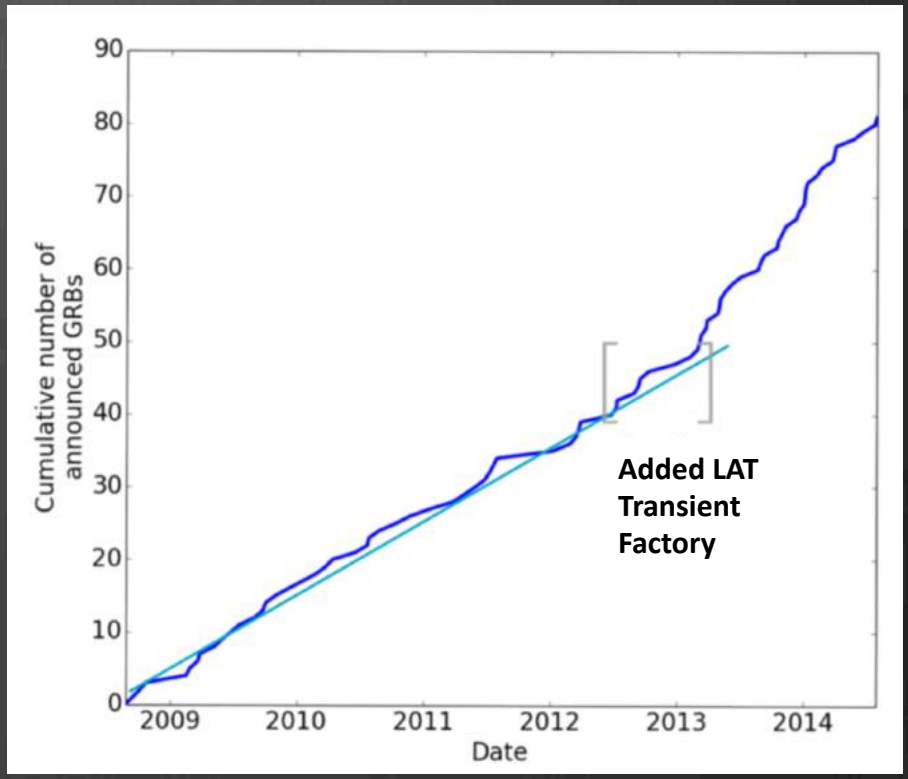
The output is sent to the Burst Advocate for evaluation and further action.

LAT Transient Factory – New Burst Detection System

Since 2013 October, the LAT team has been running a new burst detection system called the LAT Transient Factory.

It analyzes larger sections of the sky and different time scales (10 of these) than the original BA Tool.

The new system plus the use of the new Pass 8 LAT data set has increased the rate of LAT burst detections from about 10/year to about 15/ year.

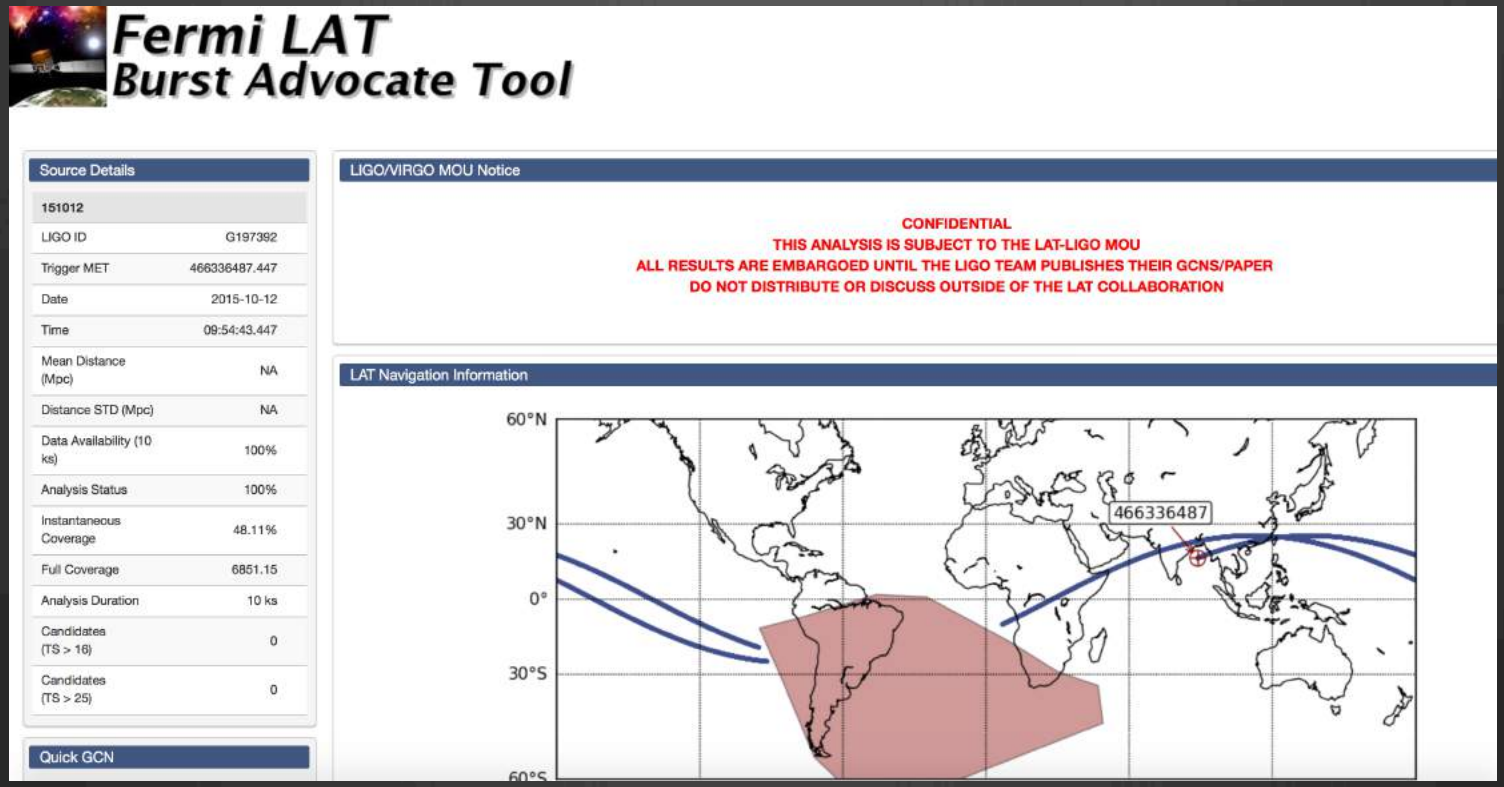


Other Automated Searches

There are at least two pipelines that do blind searches of the LAT data for short bursts, independent of any external trigger.

Yet another pipeline – a Solar Flare search pipeline.

Special Version of the Burst Advocate Tool for GW Events



A special version of the Burst Advocate Tool has been developed for analysis of LAT data around the times of possible gravitational wave events. It includes information about the location of *Fermi* and the length of time it took the LAT to completely observe the LIGO/VIRGO target region.

The Gravitational Wave Follow-Up Pipeline (GWFUP)

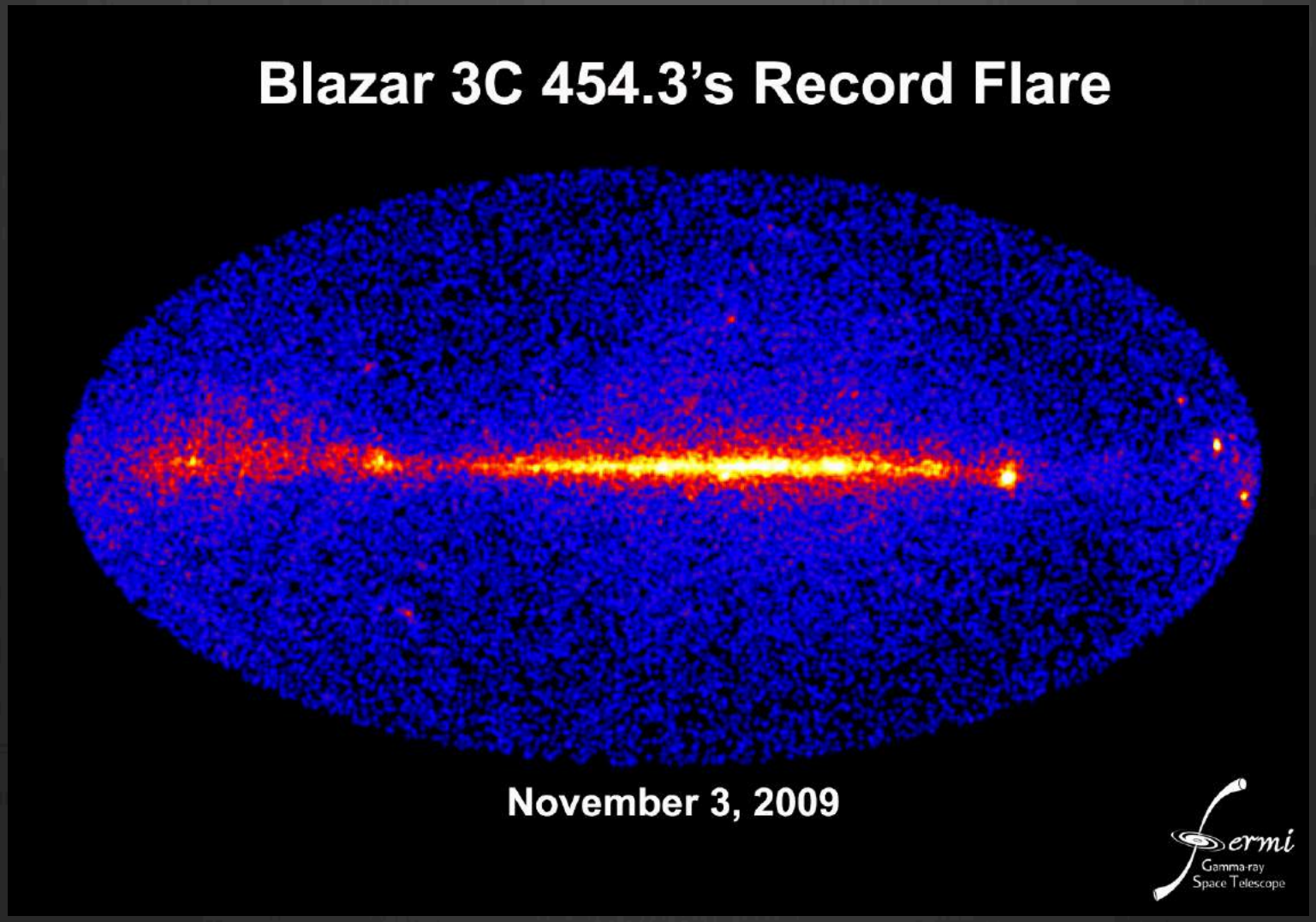
- **Fixed Time Interval Analysis (FTI):**
  - Similar to the BA Tool, computes source likelihood for each pixel of the LIGO probability map (with P>0.9), providing flux and Test Statistic (significance)
    - In addition, can automatically calculate the value of the bayesian upper limit for the entire map
- **Adaptive Time Interval (ATI):**
  - The source likelihood is calculated only for the interval of time when the pixel is in the LAT field of view, for each pixel.
- **LAT Low Energy events (LLE – relaxed acceptance, higher background source selection):**
  - Around the time of the trigger we extract LLE data for each pixel of the map producing a Light Curve and estimating the significance. This also produce a map of the significance.

Searching for High-energy Gamma-ray Counterparts to Gravitational-wave Sources with Fermi-LAT: A Needle in a Haystack, G. Vianello, N. Omodei, J. Chiang, and S. Digel, ApJ Letters, Volume 841, Number 1

Longer Transients

For *Fermi* LAT, the primary issue is collecting enough photons to recognize a transient

Automated Science Processing (ASP)



Maps are constructed on 6-hour, 1-day, and 1-week time scales, then analyzed for source fluxes and energy spectra. One-day examples here.

Automated Science Processing (ASP)

Analysis produces reports automatically, including:

Source location
Significance
Flux and uncertainty
Spectral index and uncertainty
Likely source association, source type and distance from measured position

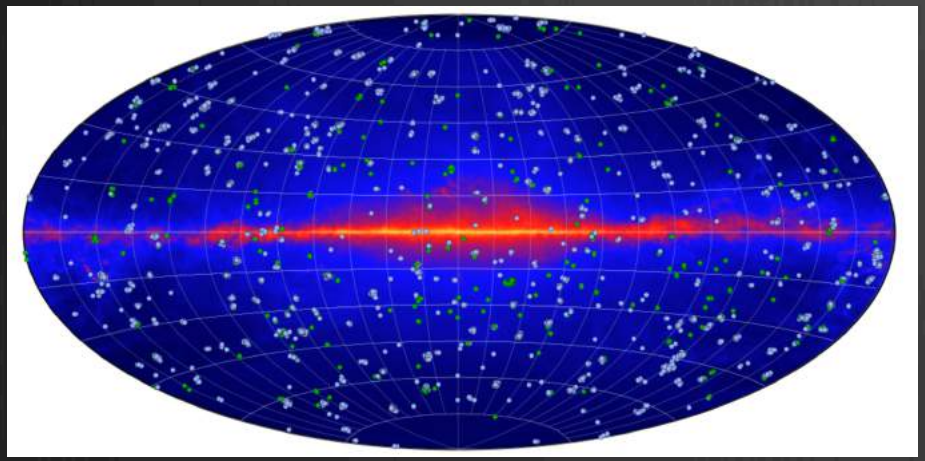
- Ratio of current flux to the catalog flux for this source.
- Individual gamma rays with energy greater than 10 GeV from known sources.

These reports are reviewed by a LAT Flare Advocate for further action.

Fermi All-sky Variability Analysis (FAVA)

Found at the *Fermi* Science Support Center
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/

Basic idea: use the long-term *Fermi* LAT observations as a baseline for the "average" gamma-ray sky, then look for differences from that average. This is a photometric method.



The FAVA map, updated weekly (although other durations are possible), shows flares.

FAVA is also able to generate a relative gamma-ray light curve for any point on the sky.

Other Pipelines

Pacciani et al. 2014 ApJ 790, 45: use clusters of photons with E>10 GeV as a first-level trigger.

FLaapLUC: H.E.S.S. team aperture photometry system. https://arxiv.org/pdf/1709.04065.pdf

Transient Alert Mechanisms

GRBs – The Most Rapid Alerts

Gamma-Ray Bursts (GRBs), inherently fast and bright, provide the fastest release of information from the *Fermi* instruments. On-board analysis, followed by transmission through the TDRS System and the Gamma-ray Coordinates Network (GCN)/Transient Astronomy Network (TAN), allows burst alerts to be sent within seconds of the actual burst.

These notices are also sent by GCN/TAN as VOEvents.

No other gamma-ray sources are bright enough to allow on-board recognition.

Automated LAT Transient Alerts

```
////////////////////////////////////////////////////////////////////////
TITLE:            GCN/FERMI NOTICE
NOTICE_DATE:      Wed 15 Mar 17 15:21:35 UT
NOTICE_TYPE:      Fermi-LAT Monitor
SOURCE_OBJ:       3C279_86400.png
REF_NUM:          1489591295
RA:               194.047d {+12h 56m 11s} (J2000),
                  194.270d {+12h 57m 05s} (current),
                  193.400d {+12h 53m 36s} (1950)
DEC:               -5.789d {-05d 47' 19"} (J2000),
                   -5.882d {-05d 52' 53"} (current),
                   -5.518d {-05d 31' 05"} (1950)
CURR_FLUX:        2.90e-06 +- 1.30e-07 [ph/cm2/sec]
BASE_FLUX:        1.10e-06 +- 1.39e-07 [ph/cm2/sec]
SIGNIFICANCE:     9.19 [sigma]
TIME_SCALE:       0  {0=1day, 1=1week}
ENERGY_BAND:      0.1 - 300.0 [GeV]
OUTBURST_DATE:    17826 TJD;    73 DOY;   17/03/14 (yy/mm/dd)
OUTBURST_TIME:    43200.00 SOD {12:00:00.00} UT
SOLN_STATUS:      0x0
LC_URL:           http://fermi.gsfc.nasa.gov/FTP/glast/data/lat/catalogs/asp/current/lightcurves/3C279_86400.png
SUN_POSTN:        355.63d {+23h 42m 30s}   -1.89d {-01d 53' 35"}
SUN_DIST:         159.82 [deg]   Sun_angle= 10.8 [hr] (West of Sun)
MOON_POSTN:       209.53d {+13h 58m 08s}   -7.33d {-07d 20' 01"}
MOON_DIST:         15.23 [deg]
MOON_ILLUM:       91 [%]
GAL_COORDS:       305.11, 57.06 [deg] galactic lon,lat of the burst (or transient)
ECL_COORDS:       195.17,  0.20 [deg] ecliptic lon,lat of the burst (or transient)
COMMENTS:         Fermi-LAT Monitor flare alert.
COMMENTS:         This Notice was ground-generated -- not flight-generated.
COMMENTS:
```

GCN/TAN Notice

http://gcn.gsfc.nasa.gov/fermi_lat_mon_trans.html

An automated daily check of source fluxes from the Automated Science Processing (ASP) looks for flaring activity compared to the average flux of the previous two weeks.

Manual LAT Transient Alerts - ATels

Outside
GCN
IAUCs

Other
ATel on Twitter and Facebook
ATELstream
ATel Community Site
MacOS: Dashboard Widget

The Astronomer's Telegram

Post | Search | Policies
Credential | Feeds | Email

8 Sep 2017; 15:16 UT

[Previous]

Fermi-LAT Detection of Gamma-ray Emission from PMN J1747-5236

ATel #10721; ***Roopesh Ojha (NASA/GSFC/UMBC), Bryce Carpenter (CUA/NASA/GSFC) and Janeth Valverde (LLR/Ecole Polytechnique) on behalf of the Fermi Large Area Telescope Collaboration***
*on **8 Sep 2017; 14:39 UT***
Credential Certification: Roopesh Ojha (Roopesh.Ojha@gmail.com)

Subjects: Gamma Ray, >GeV, AGN, Blazar, Quasar

Tweet Recommend 3

The Large Area Telescope (LAT) on board the Fermi Gamma-ray Space Telescope has observed a gamma-ray flare from a source positionally consistent with the radio source PMN J1747-5236 with coordinates RA: 17h47m05.68s, Dec: -52d36m32.5s, J2000, (Healey et al. 2007, ApJS, 171, 61). This source is not in any published LAT catalog and was not detected by AGILE or EGRET. Its redshift is unknown.

Manual LAT Transient Alerts - gammamw

Multiwavelength Colleagues,

Information that might be of interest. You may receive a second copy.
My apologies if you do.

Dave Thompson

Gammamw mailing list

https://lists.nasa.gov/mailman/listinfo/gammamw

-------- Forwarded Message --------
Subject: FGAMMA legacy program and polarisation conference
Date: Tue, 14 Mar 2017 09:03:36 +0100
From: Emmanouil Angelakis <eangelakis@mpifr-bonn.mpg.de>
To: David J. Thompson <David.J.Thompson@nasa.gov>
CC: Emmanouil Angelakis <eangelakis@mpifr-bonn.mpg.de>

I am writing to kindly inform you of the "F-GAMMA legacy dataset? which
is available at or new page

http://www3.mpifr-bonn.mpg.de/div/vlbi/fgamma/fgamma.html

This mailing list is maintained at Goddard for exchange of any information about gamma-ray multiwavelength work. It is limited to registered users, and the messages are archived. We often use it to report continuing flares rather than a new ATel.

Manual LAT Transient Alerts – e-mail

From Dave Thompson

Subject **Fermi LAT flaring sources**

MOU direct message

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:

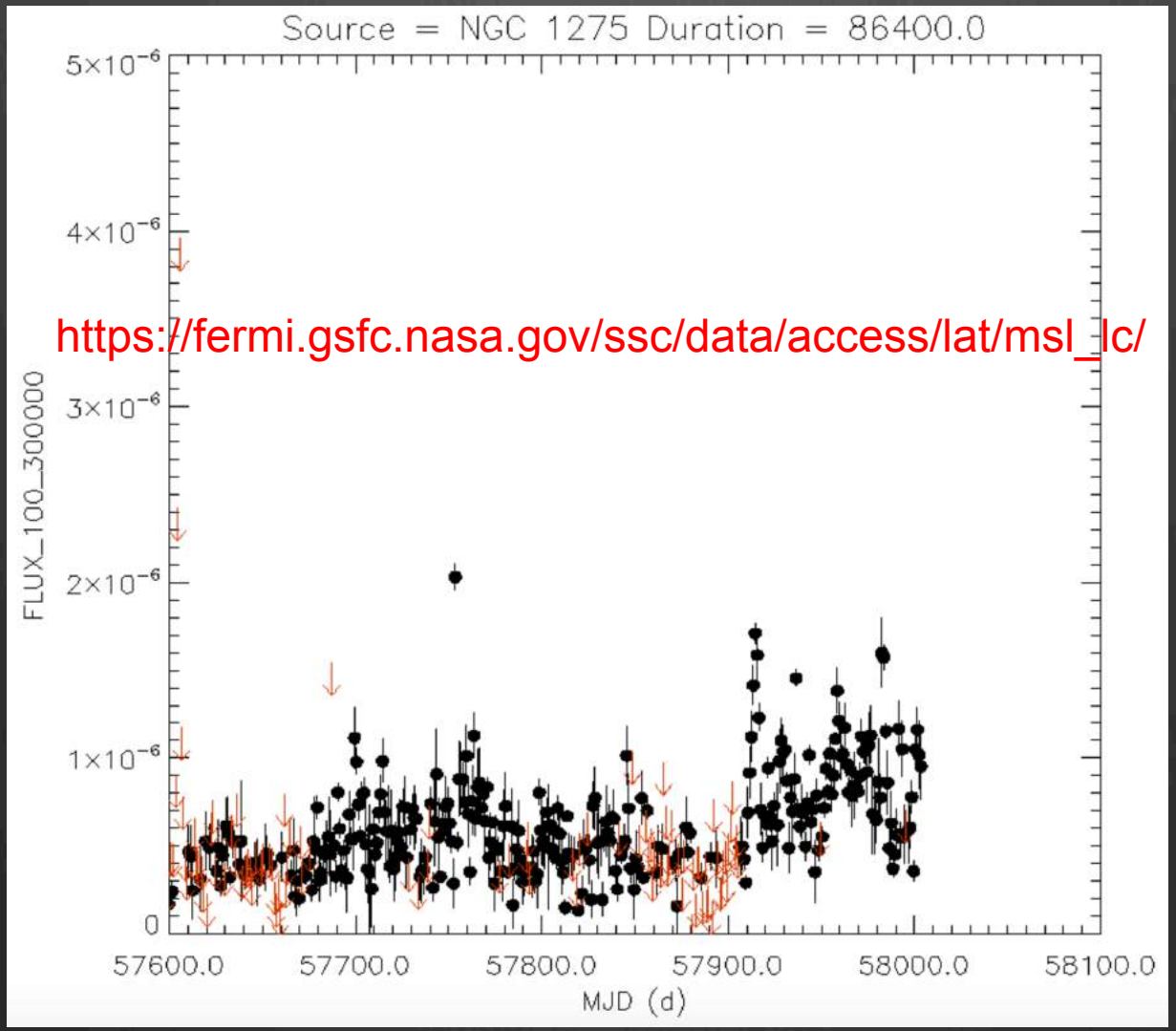
S4 0110+49 from which two photons above 10 GeV were detected yesterday has a daily averaged flux of 0.4 units which is 23 times its 3FGL value. Its photon index is 1.90+-0.19. It has z=0.389.

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).

Direct contacts under Memoranda of Understanding

- **E-mail or other sharing of information that may be useful for collaborative work**
- **Recent addition – information about individual gamma rays with energies greater than 10 GeV**

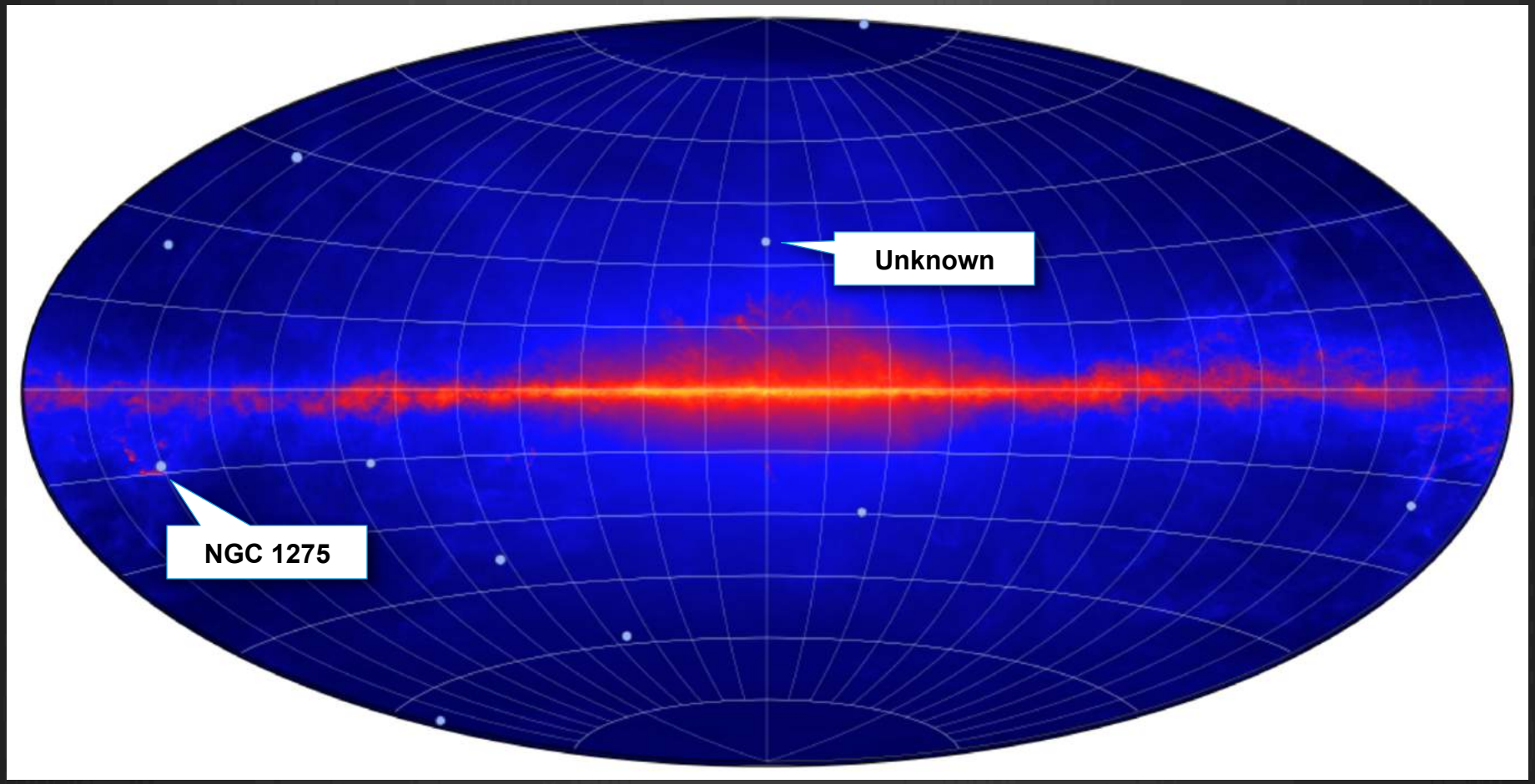
Alerts from Public *Fermi* LAT Information



https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

One-year daily light curve of NGC 1275, derived from ASP.
148 sources are updated daily in the Monitored Source List.

Alerts from Public *Fermi* LAT Information



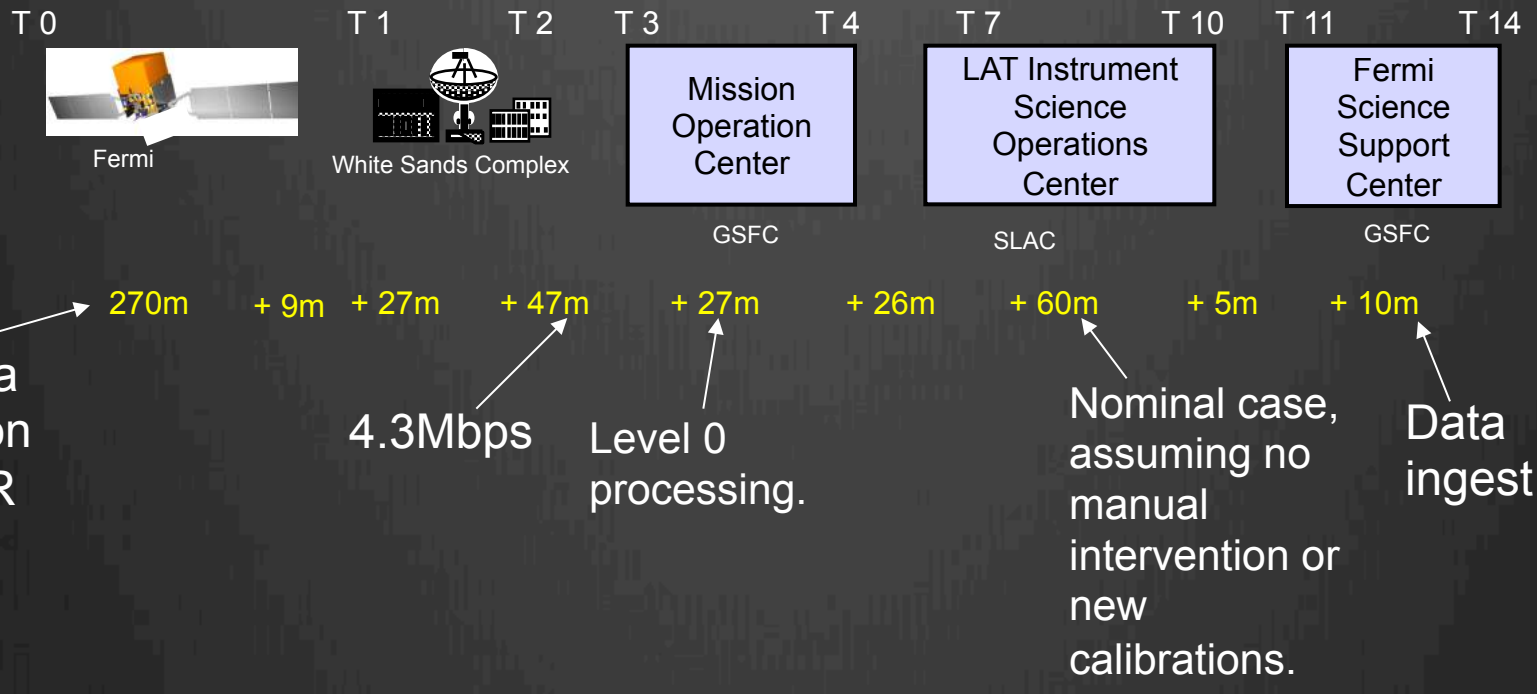
One-week map of flares seen by FAVA. Flares are not necessarily associated with known sources.
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/index.php

Continuing Improvements and the Future

Ideas in progress are focused on getting transients and other information out faster.

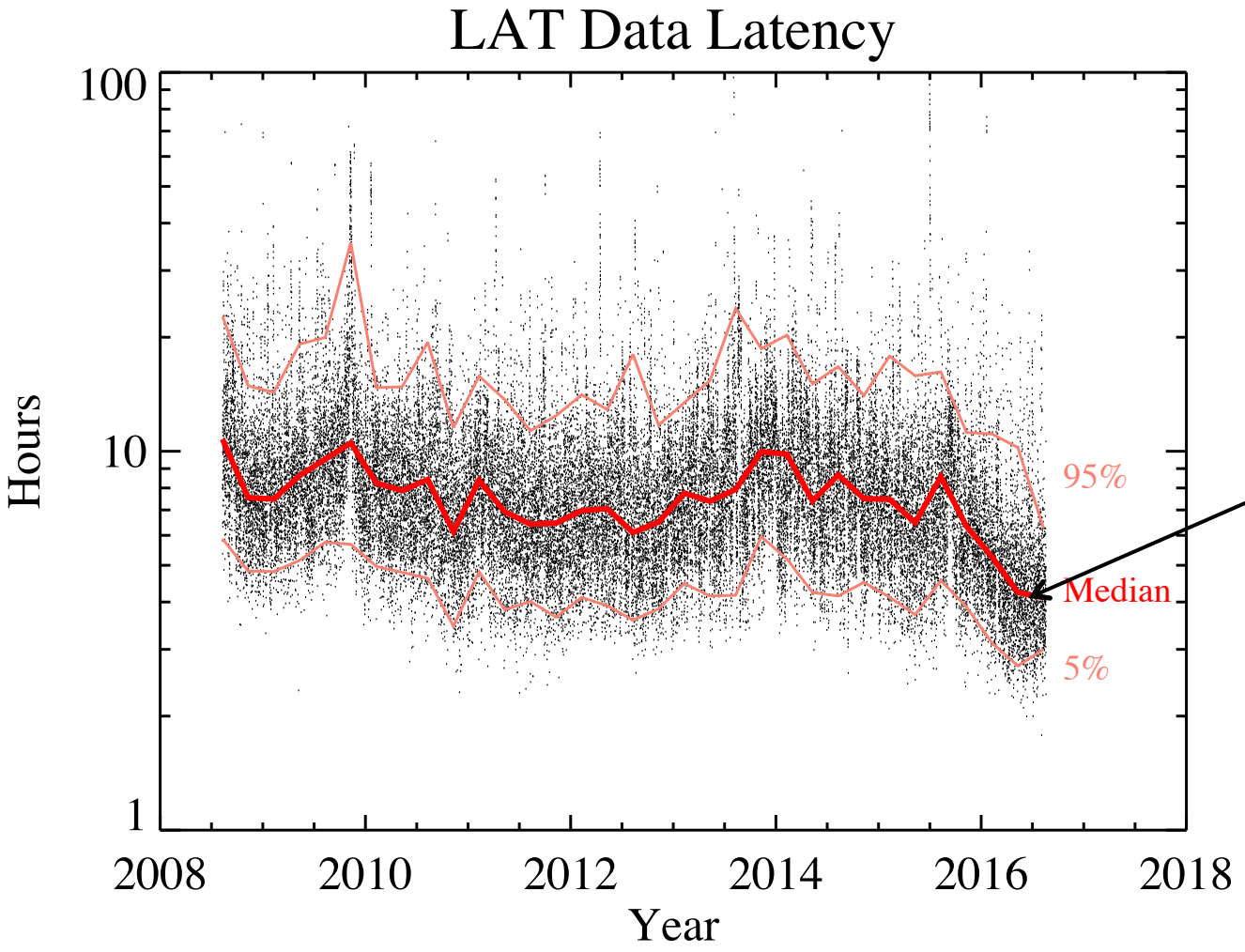
Fermi LAT Data Latency

LAT DATA PATH



- **Changed downlink scheduling to reduce time that data sit on SSR.**
- **Parallelizing data transfer from White Sands provides additional saving.**

Data Latency Improvements



Significantly improved performance after Flight Operations team optimization

Still improving scripts that process the data when available at the Science Support Center – faster cadence for analysis, more automation are examples.

Thanks to some of the people making these improvements: Nicola Omodei, Giacomo Vianello, Dan Kocevski, Sara Buson, Denis Bastieri

Feedback? What would you like to see from the *Fermi* LAT team?

How Long Will *Fermi* Continue?

1. The spacecraft, instruments, and orbit are all doing fine. Thanks to operations and analysis improvements, both instruments are performing better now than at launch. We have no on-board expendables being used up, and the orbit is stable for another decade or longer. Unless there is some major failure (always a possibility), *Fermi* can continue operating for many years.

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2. Money is a different story. NASA requires that each operating mission has a "Senior Review" every three years to evaluate whether the mission is still scientifically productive. If not, the mission could be ended. We strongly encourage you to speak out at meetings if you think that *Fermi* is a valuable asset to your science.

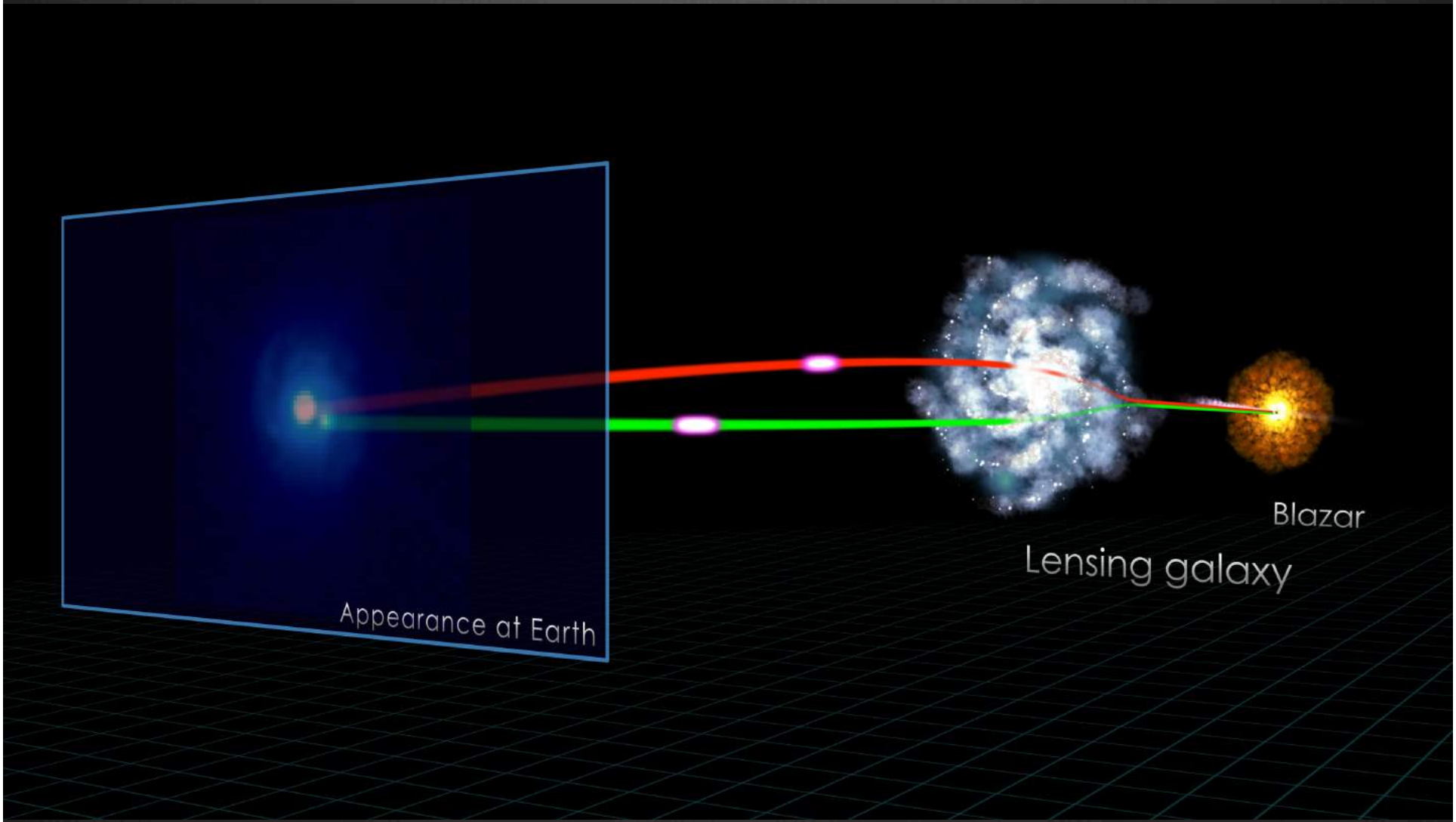
Summary

After more than nine years in orbit, the *Fermi Gamma-ray Space Telescope* continues to monitor the high-energy sky, providing a broad range of results, including a wide variety of transient alerts.

If you have questions or comments about *Fermi's* transient alert programs or any other topic, please contact me: David.J.Thompson@nasa.gov

Backup

Gravitional Lensing in Gamma Rays



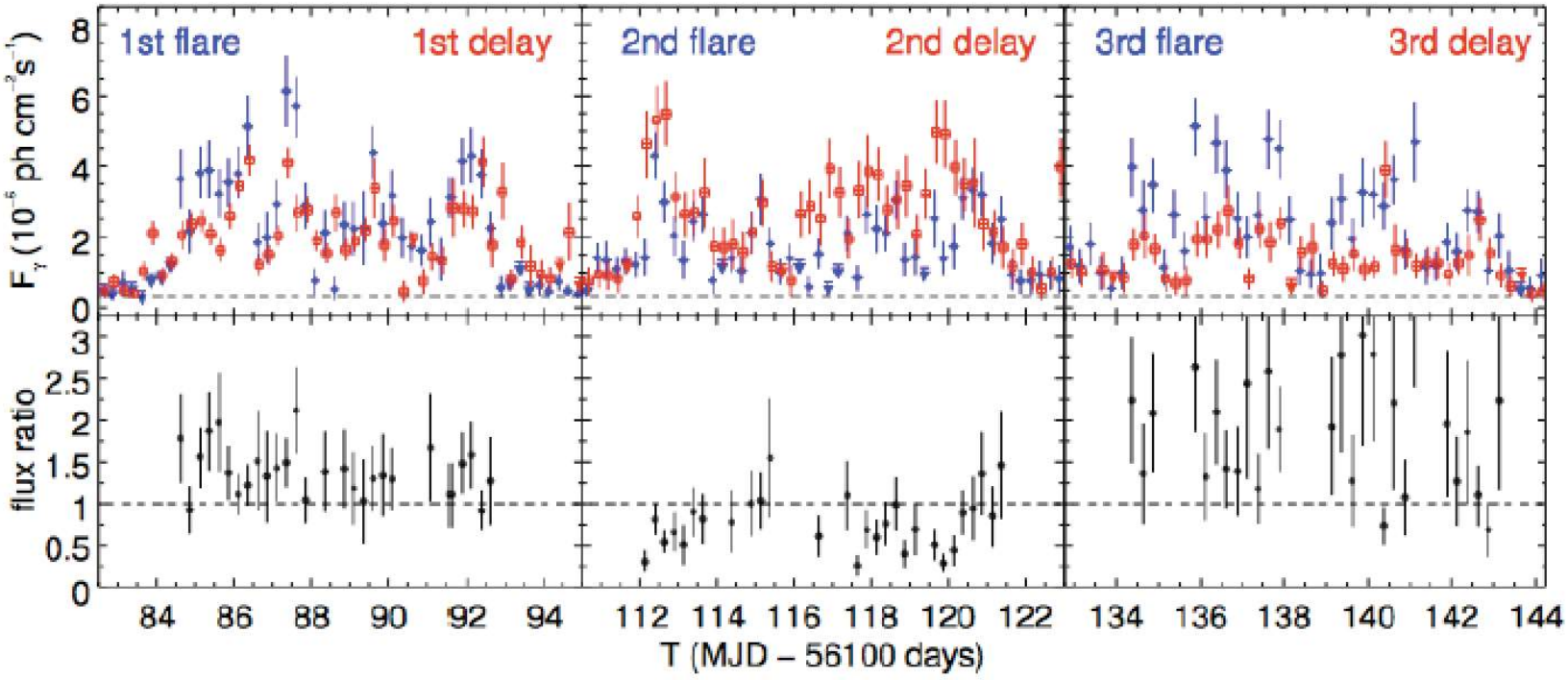
Gravitational Lensing in Gamma Rays
Blazar B0218+35

B0218+35

Delay estimated = 11.46 +/- 0.16 days
Flux ratio = 1.16 +/- 0.07
Magnification ratio = 1.32 +/- 0.09

Cheung+ 2014,
ApJL, 782, L14

Flare emission divided by the observed flux ratio of 1.16 and shifted by +11.46 days to match the delayed emission

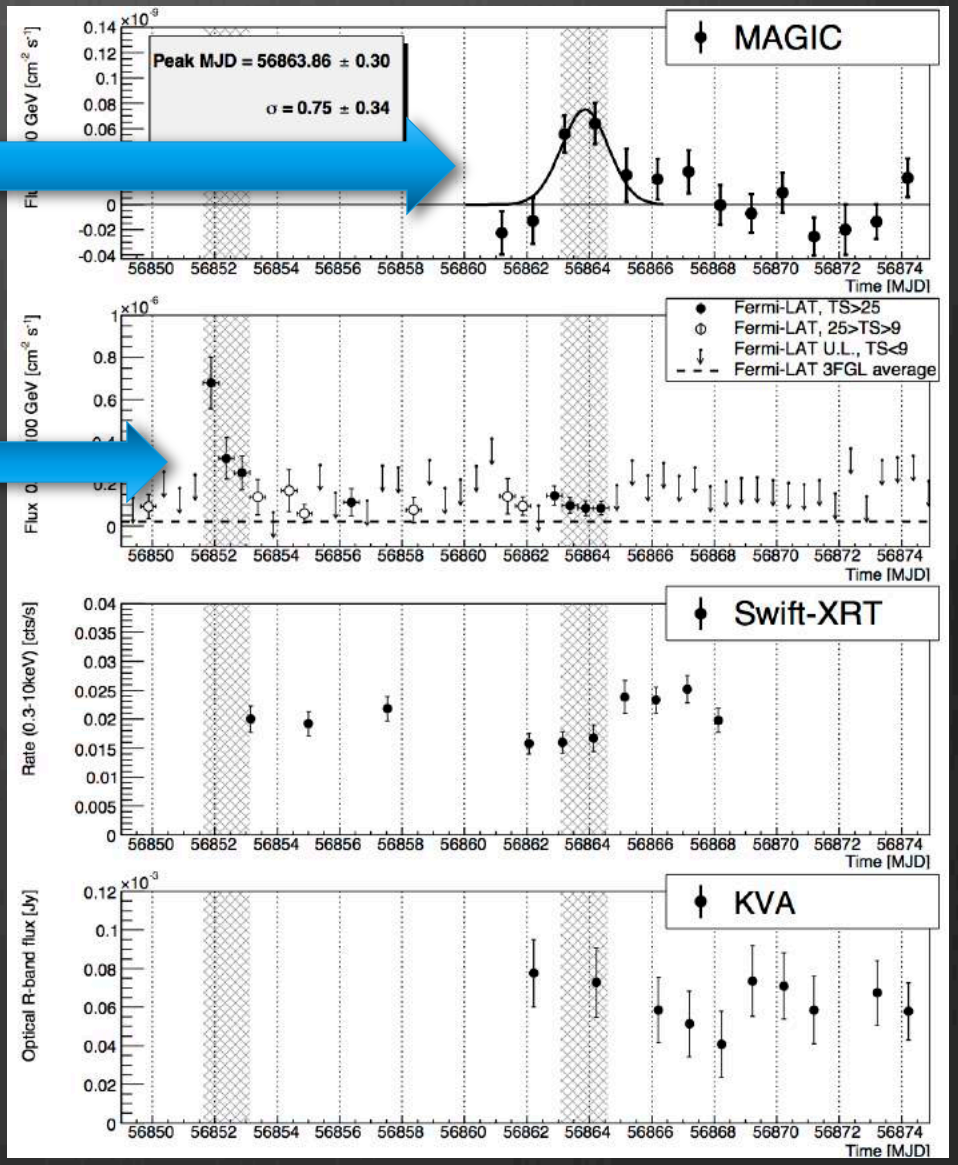


Graviational Lensing in Gamma Rays Blazar B0218+35

The MAGIC ground-based TeV telescopes detected the delayed flare 11 days later.

In July, 2014, Fermi LAT saw another flare. It was announced in an ATel.

Ahnen, M. L. et al. 2016, A&A



Multiwavelength

- Gamma-ray sources are almost entirely nonthermal, typically produced in interactions of high-energy particles.
- Astrophysical particle acceleration produces a broad range of particle energies, whose interactions are therefore going to produce a broad range of photon energies.
- Energetic particles can interact in more than one way, such as Inverse Compton and synchrotron, producing photons in very different energy ranges.

Multimessenger (non-photon)

- Gamma rays trace the properties of their parent particles – origin, acceleration, propagation of cosmic rays. For hypothesized dark matter particles, gamma rays test their very existence.
- Hadronic particle interactions produce gamma rays and neutrinos, providing a very direct connection between these two fields.
- Phenomena like merging neutron star binary systems, which can produce detectable gravitational radiation, are the same sorts of things that produce gamma rays.