フェルミ衛星の現状と IceCube ニュートリノイベントの 可視近赤外線フォローアップ

田中康之（広島大学宇宙科学センター）

#一部のフェルミ内部資料を削除しています

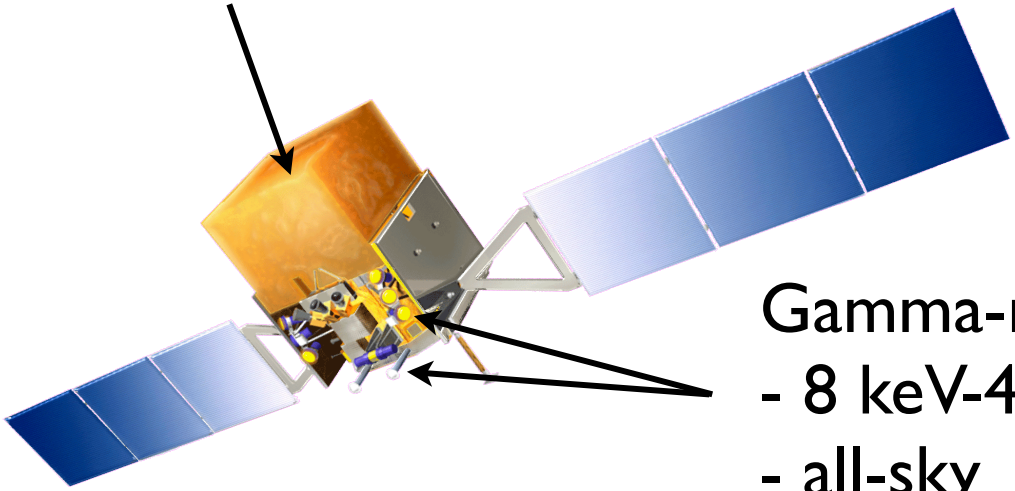
Outline

- Introduction of Fermi/LAT
- Fermi/LAT transient search in various timescales
  - ✓ LAT Transient Factory
  - ✓ LAT automated Science Processing+Flare advocate
  - ✓ Fermi All-sky Variability Analysis (FAVA)
- IceCube optical/NIR follow-up by Japanese telescopes
  - ✓ Kanata/HONIR follow-up for IceCube161210
  - ✓ Future plan

Fermi Gamma-ray Space Telescope

- Launched on 2008 June 11
- Continue to observe without any critical problems
- All sky survey mode

Large Area Telescope (LAT)
- 20 MeV-300 GeV
- Thanks to the wide FoV of 2.4 str, scan all-sky every 3 hours



Gamma-ray Burst Monitor (GBM)
- 8 keV-40 MeV
- all-sky

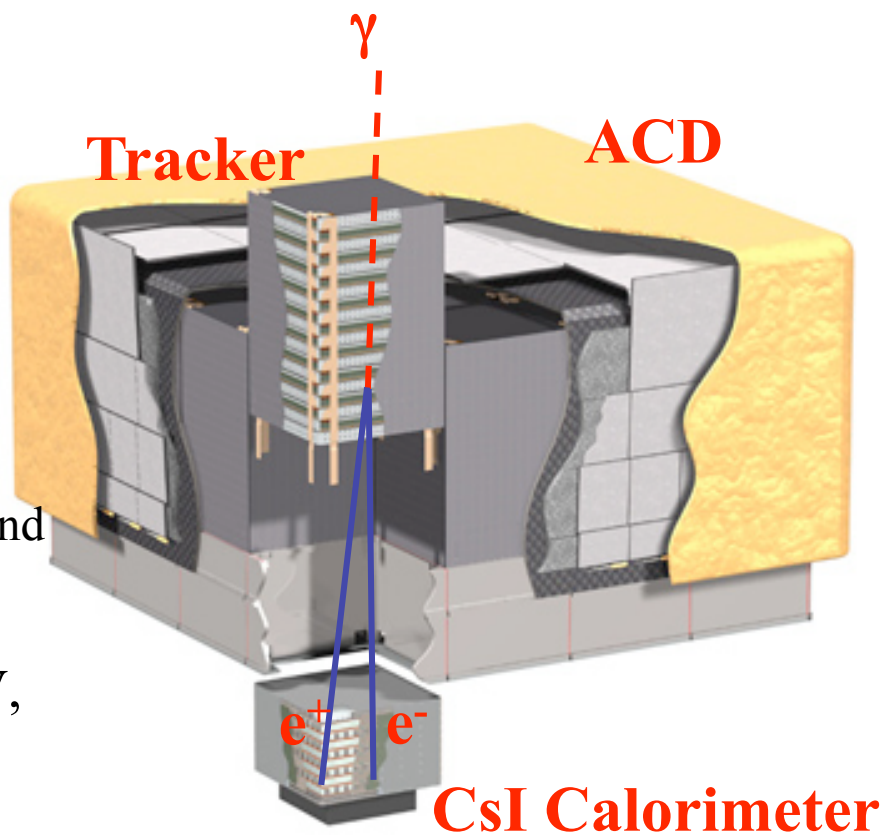
Large Area Telescope

Pair-conversion telescope

Si-strip Tracker with tungsten foil converter:
Measure the photon direction

CsI Calorimeter: Measure the photon energy,
Image the shower

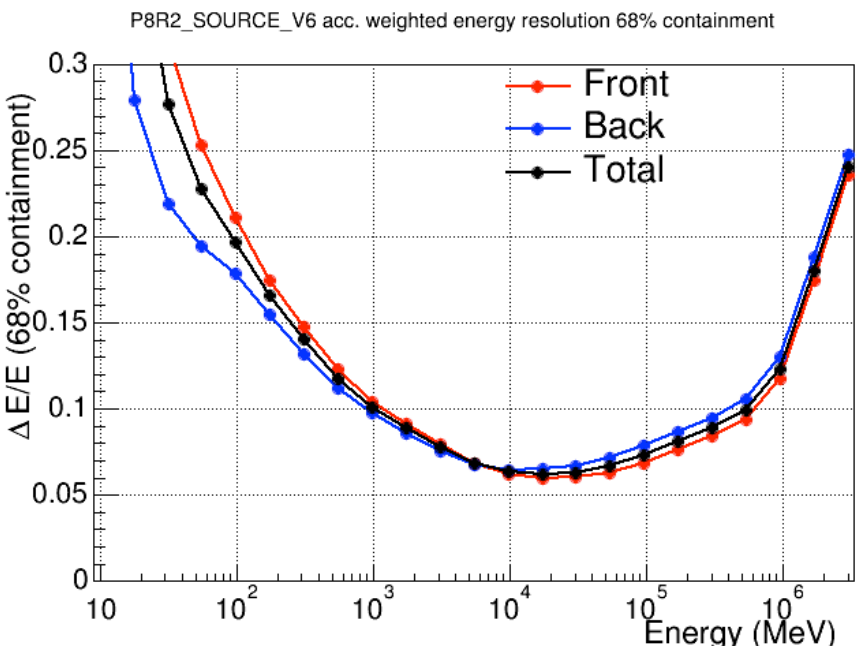
ACD (Plastic scintillator):
Reject charged-particle background

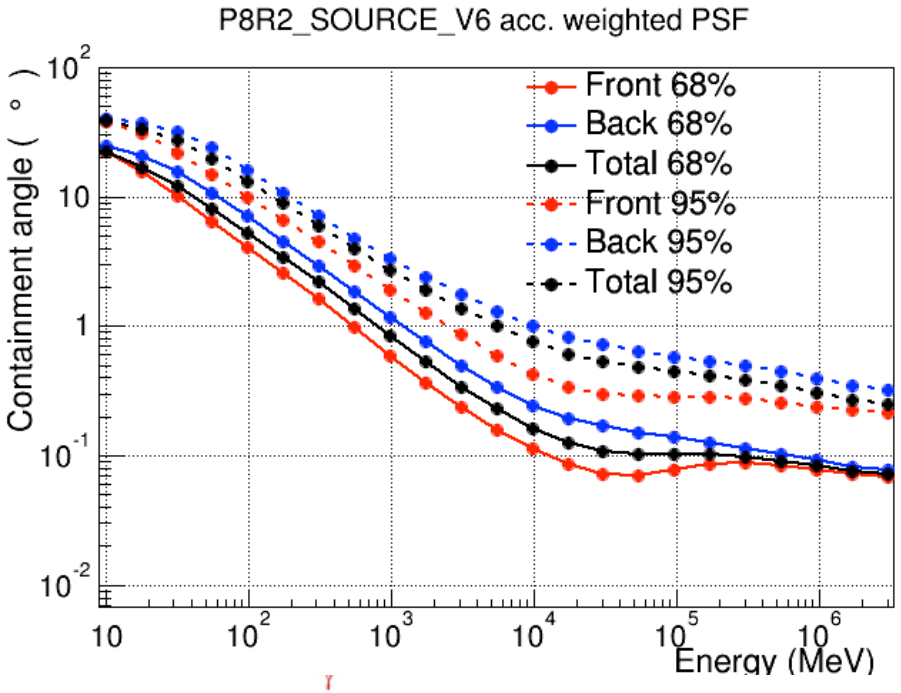


- Large effective area (9000 cm^2 @ 1 GeV, normal incidence)
- Large field-of-view (2.4 str)
- The entire sky is observed every ~3 hours
- Energy range: 20 MeV – 300 GeV
- Angular resolution (68% contaminant radius): 0.6 deg @ 1 GeV

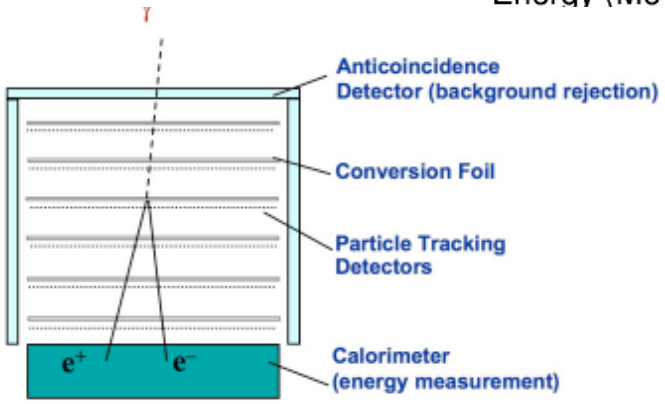
4 x 4 modular array
3000 kg, 650 W

Energy resolution and PSF



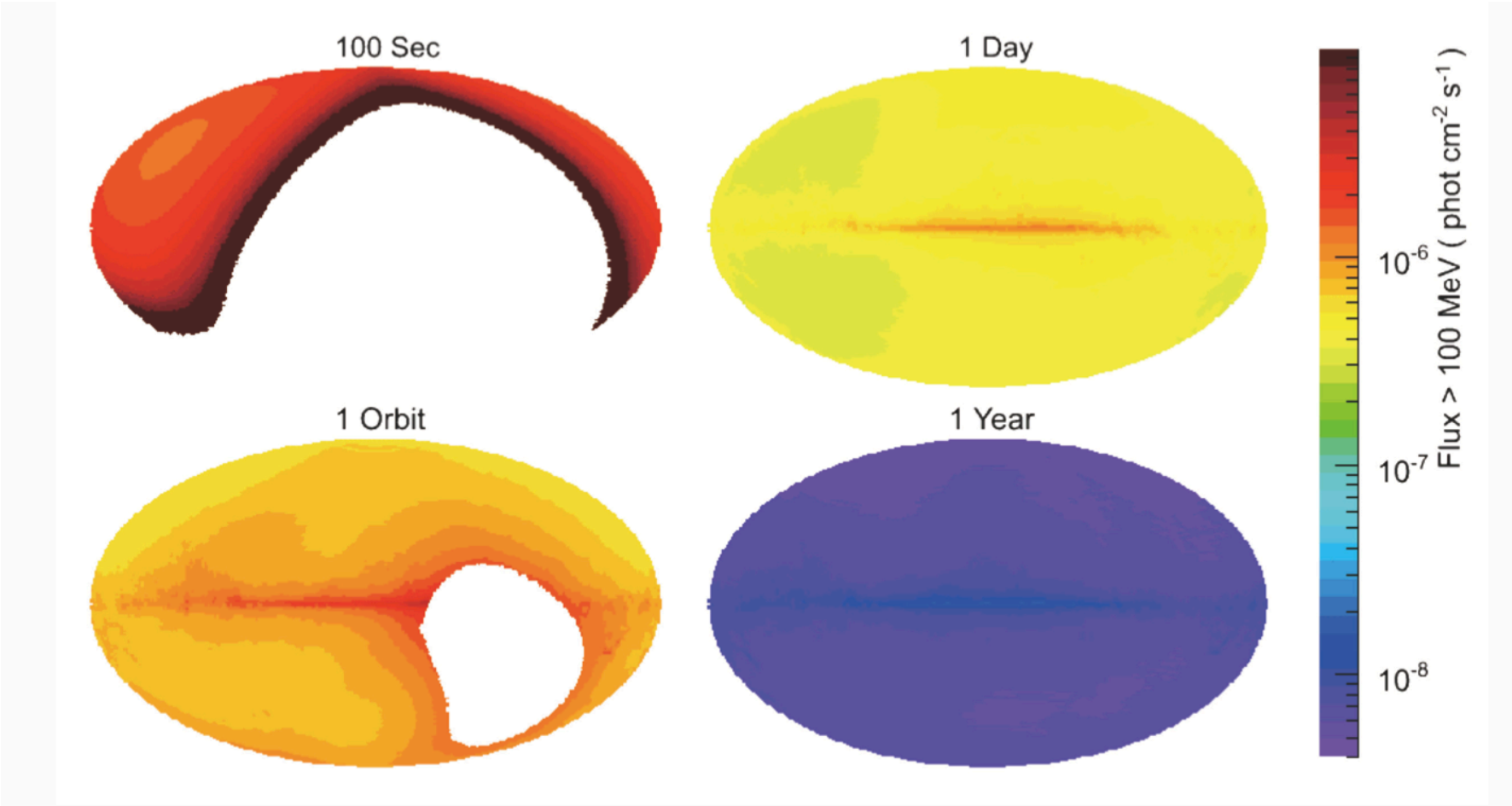


- 12 layer (FRONT)
- 4 layers (BACK)



https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

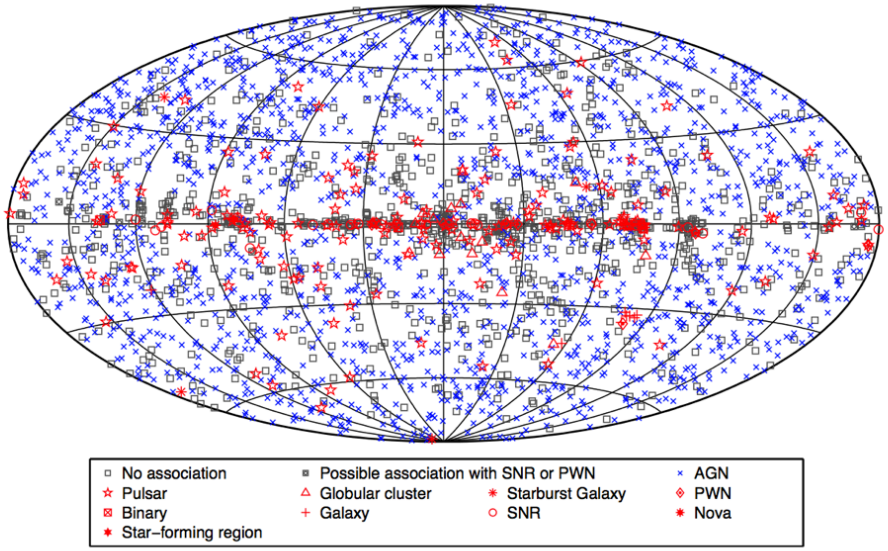
All-sky survey-mode observation

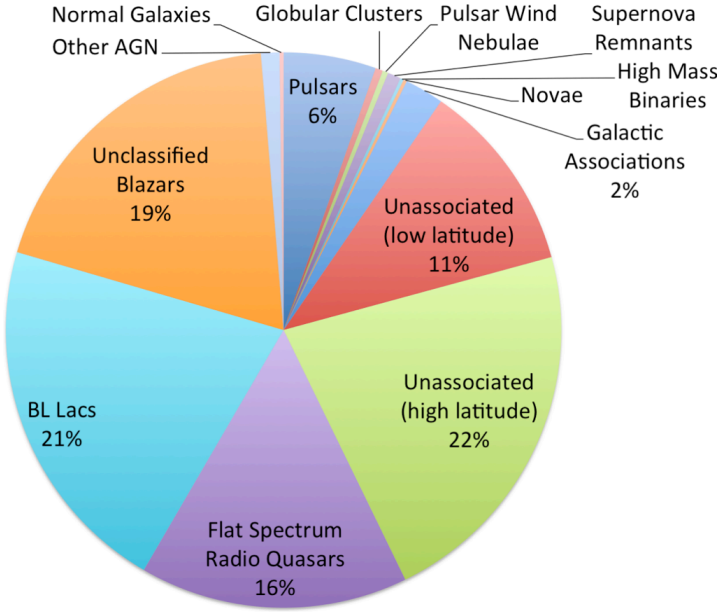


- Thanks to the large FoV of 2.4 str, LAT scans all-sky every 3 hours (i.e., 2 orbits) and perform unbiased survey

3FGL catalog from 4-year data

(http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/)





- Arxiv: 1501.02003
- 3033 sources with TS>25 (~5 sigma) detection
- 992 sources are unID
- GeV spectra and 4-year light curves are available for all the sources

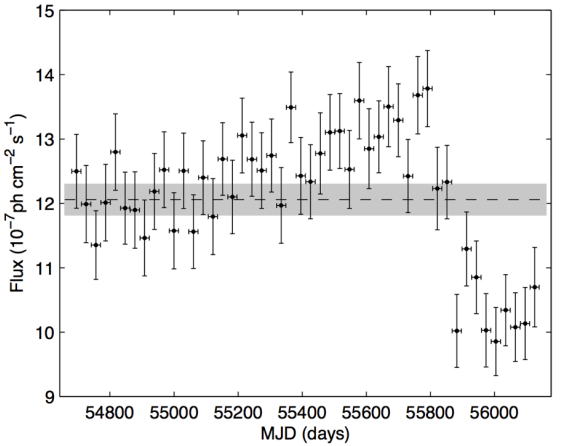
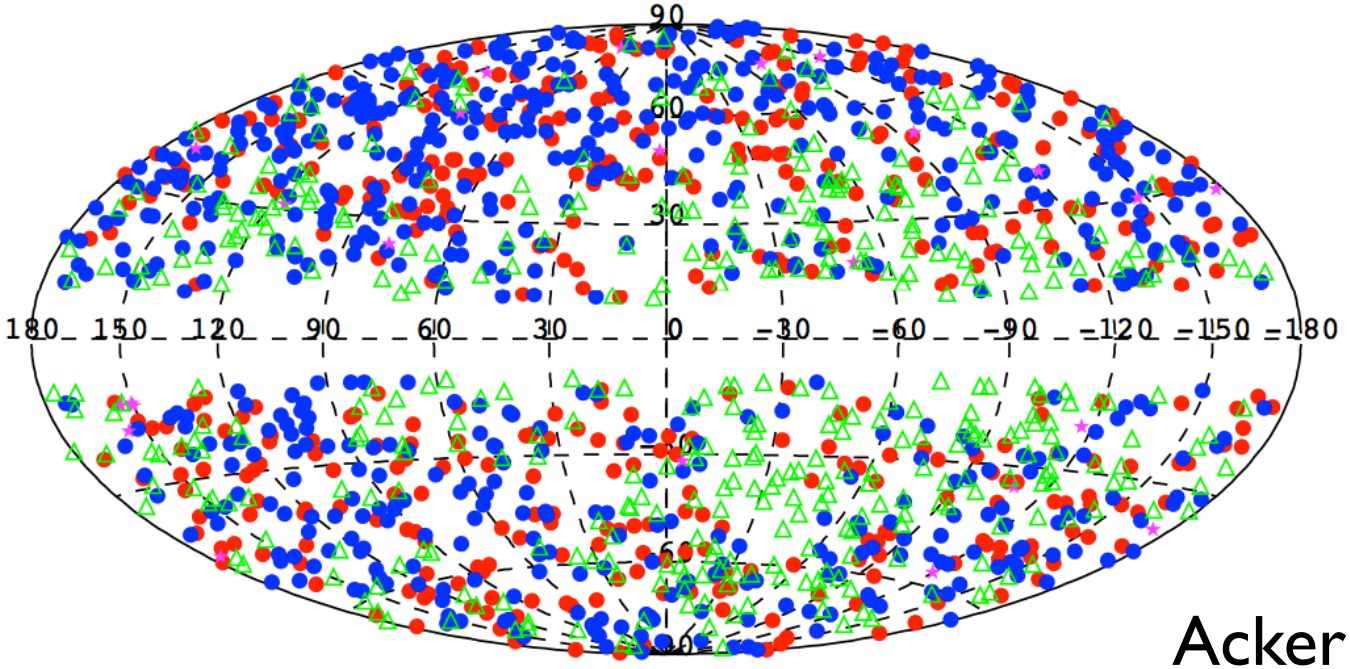


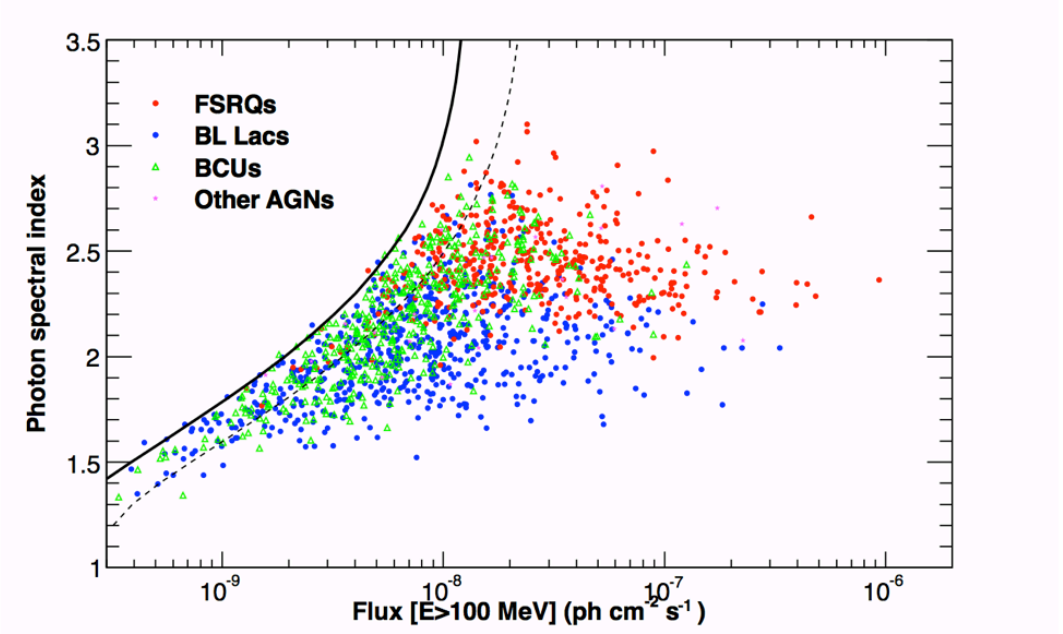
Fig. 12.— Light curve of 3FGL J2021.5+4026 (PSR J2021+4026 in the γ Cygni SNR). The variability of that pulsar is easily detected by the automatic procedure. The vertical scale does not start at 0.

3LAC (LAT AGN Catalog)



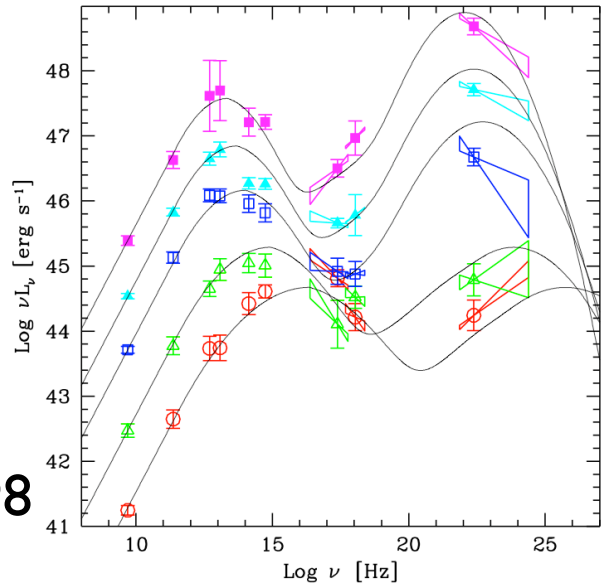
Ackermann+15

- 467 FSRQs
- 632 BL Lacs
- 460 Uncertain type
- 32 non-blazar AGN



Confirmation of Blazar sequence

Fossati+98



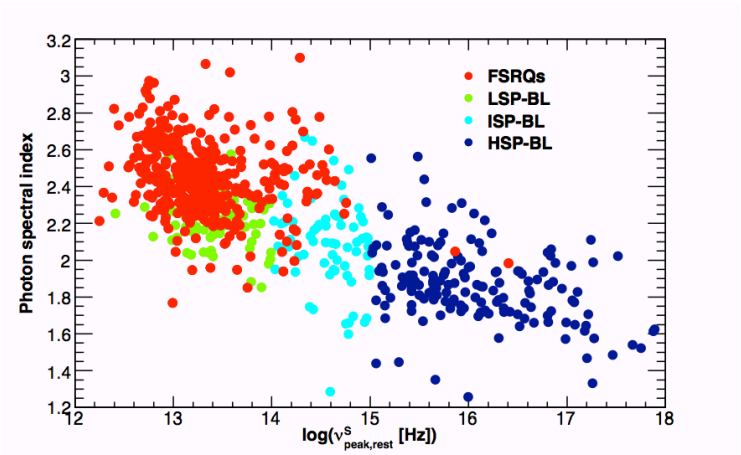


Fig. 10.— Photon index versus frequency of the synchrotron peak $\nu^S_{peak,rest}$. Red: FSRQs, green: LSP-BL Lacs, light blue: ISP-BL Lacs, dark blue: HSP-BL Lacs.

- FSRQ: strong optical emission lines due to bright accretion disk
- BL Lac: weak/no lines (EW<5A)
- Blazar sequence: Bright/faint blazars have lower/higher sync. peak freq.

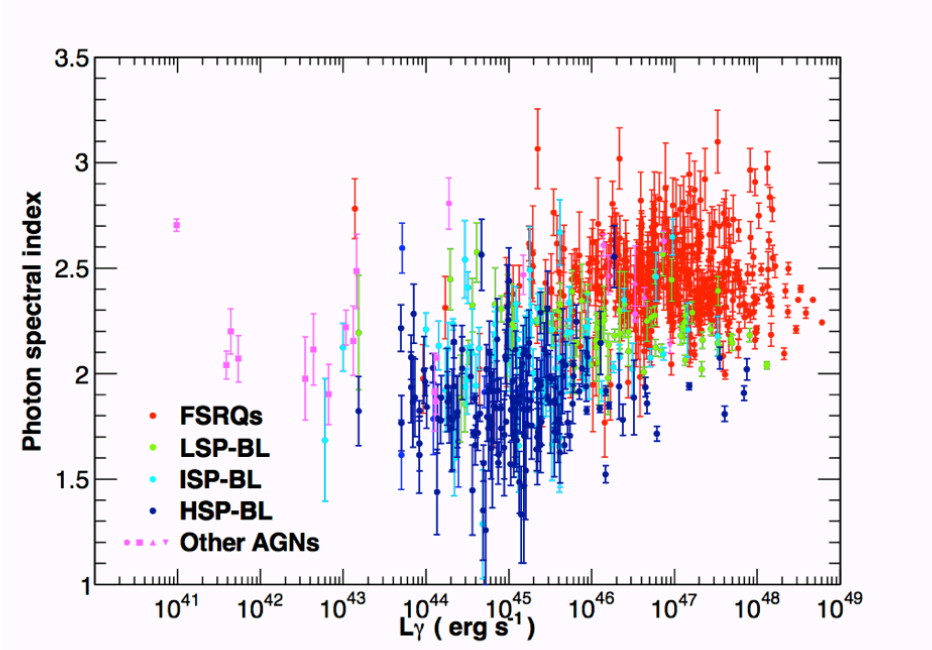


Fig. 14.— Photon index versus gamma-ray luminosity. Red: FSRQs, green: LSP-BL Lacs, light blue: ISP-BL Lacs, dark blue: HSP-BL Lacs, magenta: other AGNs (circles: NLSy1s, squares: radio galaxies, up triangles: SSRQs, down triangles: AGNs of other types).

Fermi Transient Searches

Pipeline
Method
Timescale
Distribution
Status

LAT Transient Factor (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/

GBM Targeted Searches (GW, neutrino)
ground search around external triggers
ms - s
GCNs

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

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

GBM 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

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

Transients Timescale Pipelines

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

Photon Timing

Pulsars

Solar Flares

All Sky Cadence

Novae

γ-ray Binaries

Blazar Flares

Terrestrial γ-ray Flashes

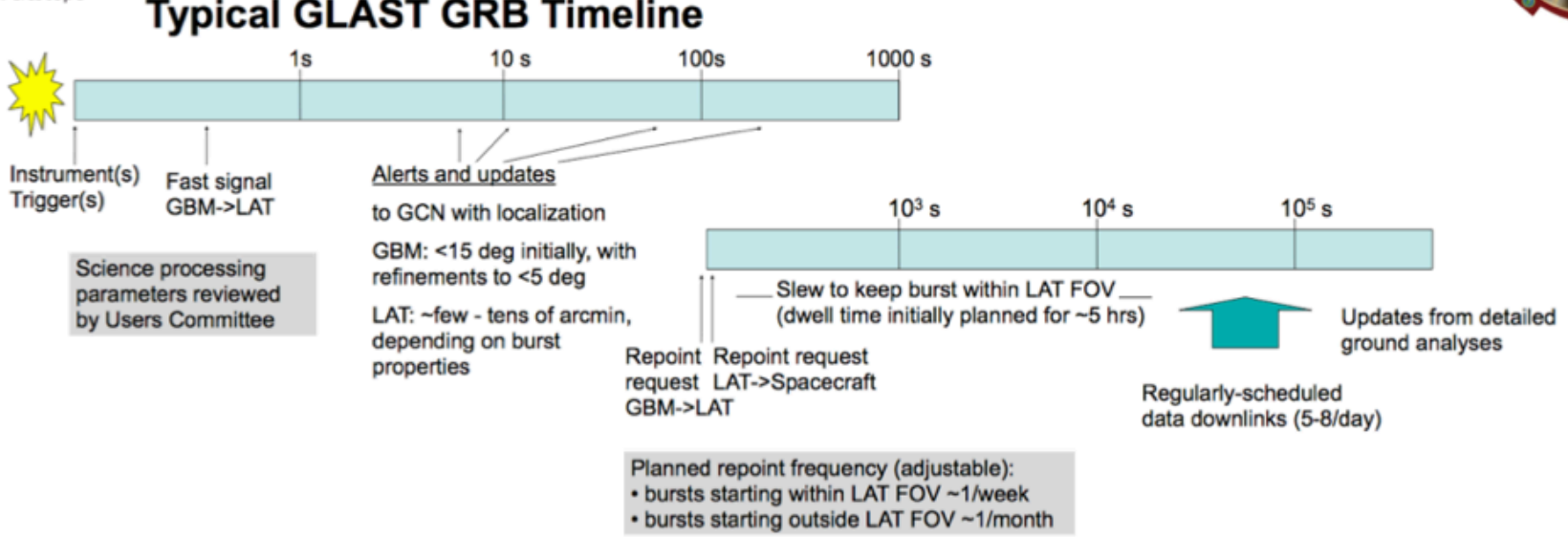
GRBs

Magnetar Flares

Crab Flares

Not to scale

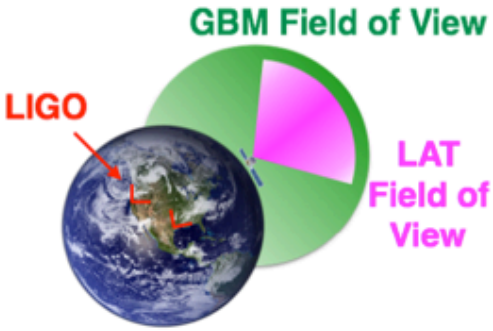
Onboard alert and ground analysis



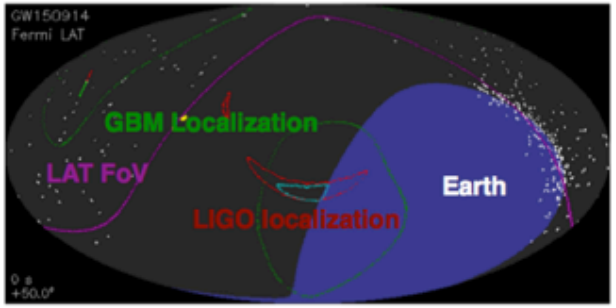
- **GBM/LAT on-board processing (10—15 s):**
  - GCN alert within 10—15 s from the trigger time through TDRSS (alert, location)
  - We have several LAT onboard triggers (GRB 090510, 131108A, 160509A, 160821)
  - Automated repoint for bright GBM burst (1~2/month)
- **LAT ground processing (a few hours after data downlink)**
  - Data downlink (~1hour) and ground processing (~4hours)
  - Pipeline searches for transients (LTF, BA tools, +GW tools in the near future)
  - Quick localization provided via GCN_OFFLINE_NOTICE, and detailed by following circular.

Fermi Observations of GW detections and candidate

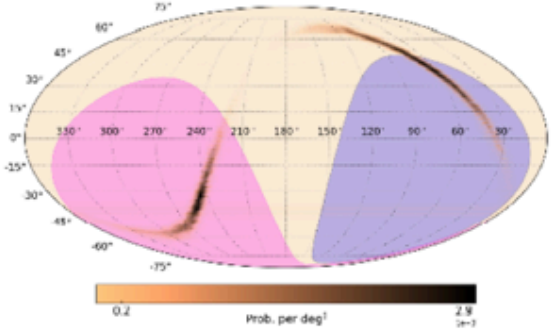
	GW150914	LVT151012	GW151226
GBM coverage of LIGO region at trigger time	75%	68%	83%
GBM observed entire LIGO region within	25 min	8 min	34 min
LAT coverage of LIGO region at trigger time	0%	47%	32%
LAT observed entire LIGO region within	70 min	113 min	140 min



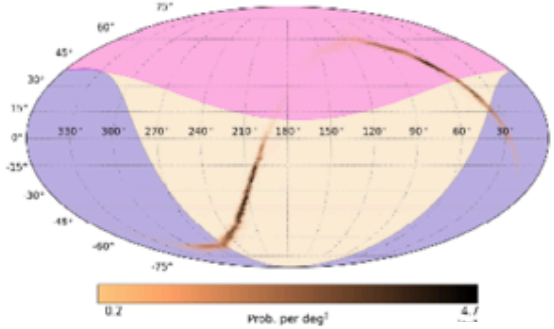
GW150914



LVT151012

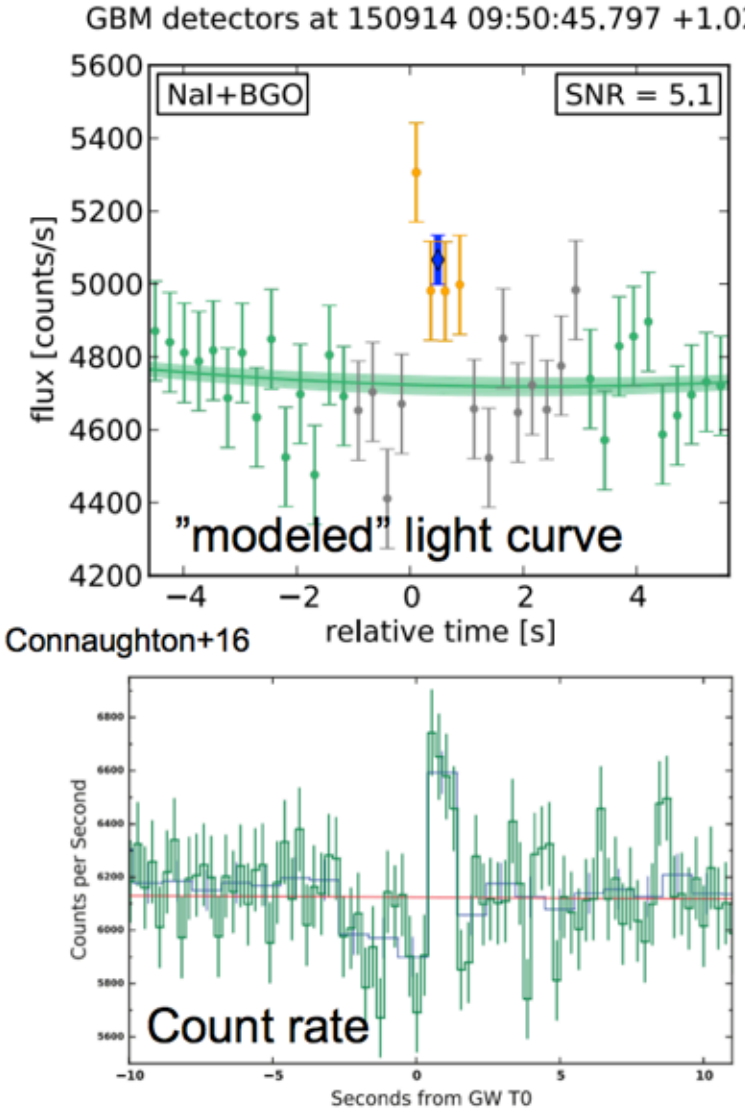


GW151226



LAT FoV
Earth Shadow

Fermi EM Counterpart Search ~GW 150914 - GBM



- One plausible candidate from GBM search
- Temporary coincide to GW150914 (0.4 s after the GW trigger)
- False alarm probability of 0.0022
- Similar spectrum to weak short GRB
- Challenging for BBH merger model if real detection

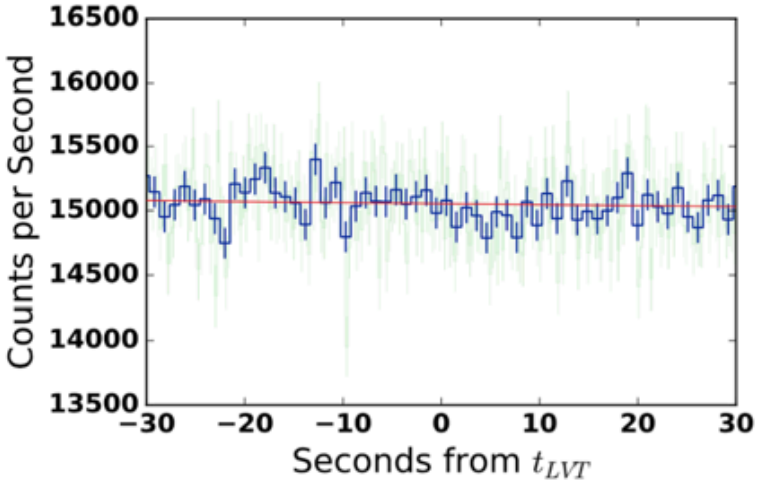
- Non detection by INTEGRAL/SPI-ACS, (larger photon collecting area and allsky coverage)
- Background fluctuation ? (Greiner+16)
- Still in debate on this signal

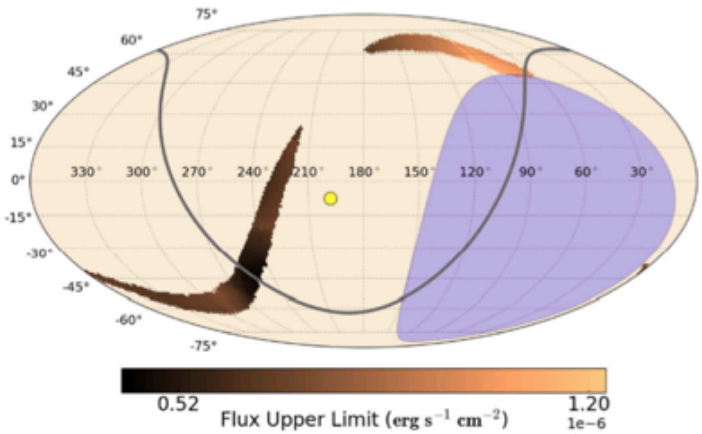
LVT 151012 and GW 151226 - GBM

No evidence for any significant GBM signal from both LVT 151012 and GW 151226

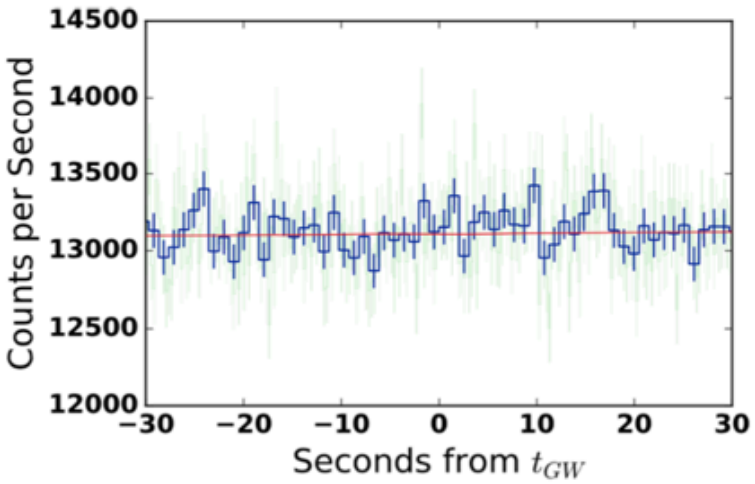
Racusin+17

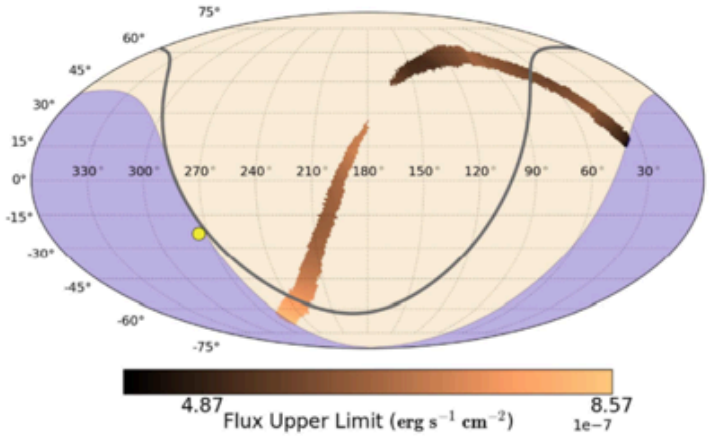
LVT151012





GW151226





LAT Transient Factory

GRB170214

- Once LAT data is processed, automatic analysis at the GBM trigger time is performed
- The result is sent via email
- Once detection with TS>25 is reported, burst advocate run the BA tool and confirm the result
- Immediately GCN draft is prepared and sent

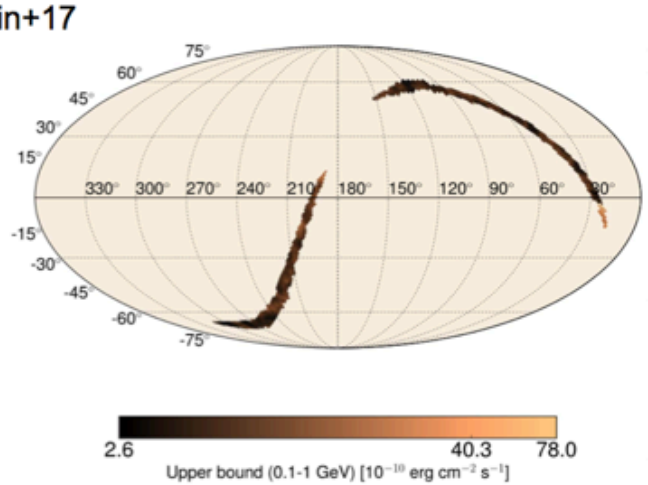
LAT follow-up search for LIGO sources

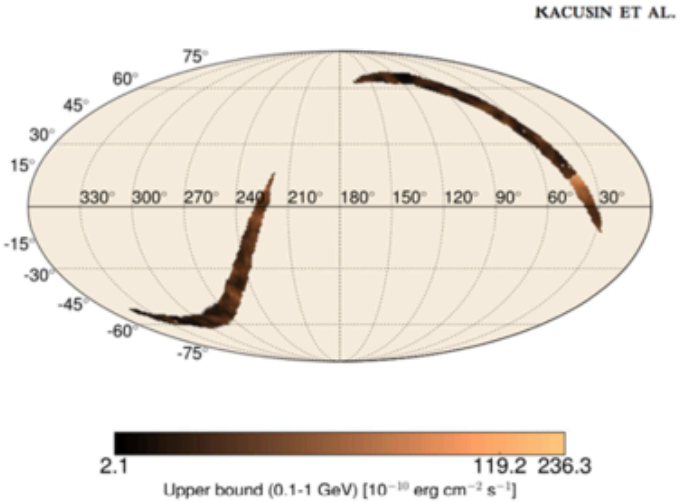
Standard automated analysis method for the GW source search in LAT data is developed

- **Fixed time window search (+-10 s, 0-1.2 ks, 0 – 10 ks …etc. after GW trigger)**
- **Adaptive time window search (optimized time bin for each pixel)**
- **Longer time scale search (6 hour and 1 day) usual pipeline for searching flaring object**
- **Much longer time window (+/- 1week) search for variable sources in 7-day scale**

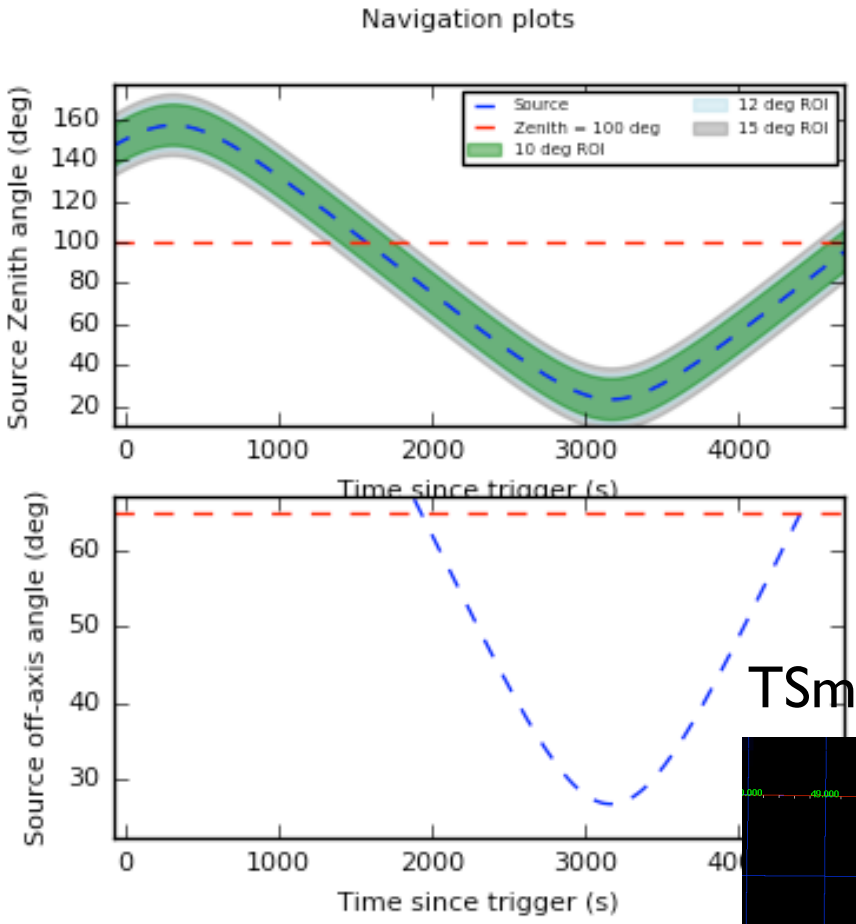
No LAT detection of counterpart for GW detections and candidate so far.

Racusin+17





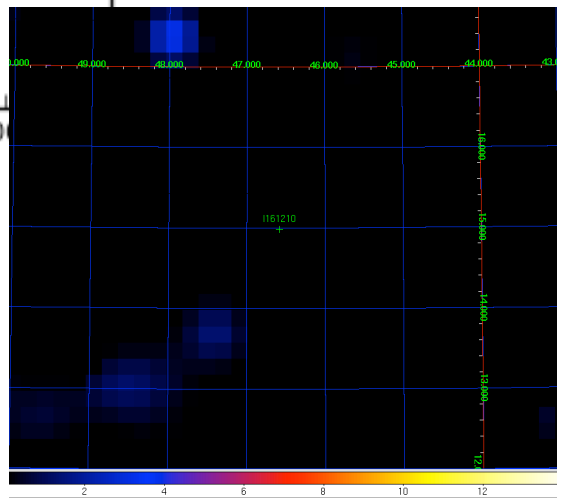
IceCube-161210



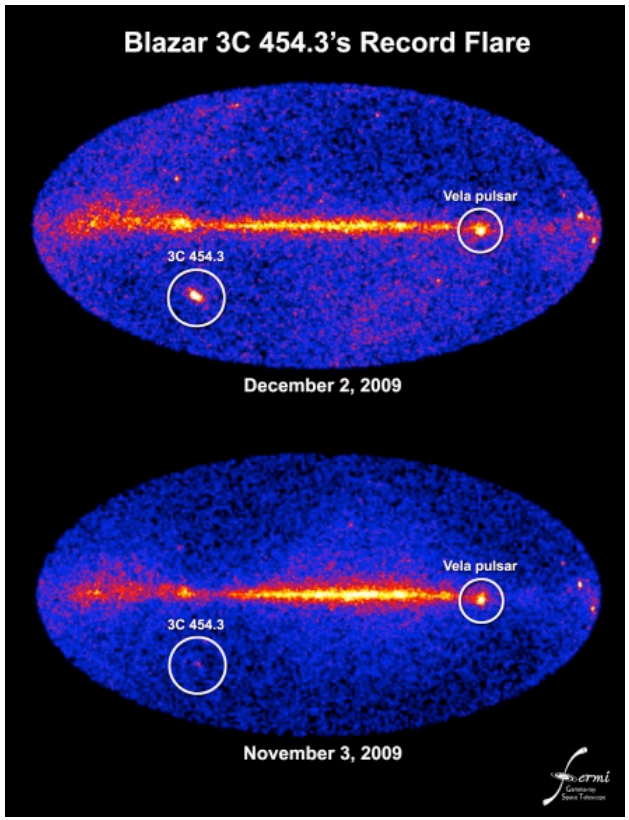
- At the IceCube trigger time, the event position is outside LAT FoV
- No LAT emission by LTF
- TS maps by manual analysis found weak sources at the edge of the IceCube error circle??
- Maybe statistical fluctuation

TSmap for T0-24h~T0

T0~T0+24h



LAT Automated Science Processing (ASP) +Flare advocate



[Previous | Next | ADS]

GLAST LAT detection of a possible new gamma-ray flaring blazar: PKS 1502+106

ATel #1650; *S. Ciprini (Univ./INFN Perugia) on behalf of the GLAST Large Area Telescope Collaboration*
on 8 Aug 2008; 00:02 UT
Credential Certification: Stefano Ciprini (stefano.ciprini@pg.infn.it)

Related
1905 Fermi-LAT detection of renewed activity from the blazar PKS 1502+106
1661 Archival light curve for the flaring GLAST blazar PKS 1502+106
1650 GLAST LAT detection of a possible new gamma-ray flaring blazar: PKS 1502+106

Subjects: Gamma Ray, >GeV, AGN, Quasar

Referred to by ATel #: 1661, 1905

The Large Area Telescope (LAT), one of two instruments on the Gamma-ray Large Area Space Telescope (GLAST) (launched June 11, 2008), which is still in its post-launch commissioning and checkout phase, has been monitoring high flux from a source positionally consistent with the blazar PKS 1502+106 (R.A.:15h04m24.9797s; Dec.:+10d29m39.198s, also known as OR 103 and S3 1502+10) since August 6, 2008.

Preliminary analysis indicates that the source is in a high state with a gamma-ray flux (E>100MeV) well above pre-defined LAT flaring source reporting threshold of 2x10^-6 photons cm^-2 s^-1.

This is a well-known radio source classified as a Flat Spectrum Radio Quasar (FSRQ), observed by several X-ray instruments. This is the first time that it has been reported to have gamma-ray emission.

Please note that PKS 1502+106 has two possible redshifts listed in the literature: z=0.56 and 1.83; the former seems preferred (A.E. Wright et al. 1979 ApJ 229,73; B.J. Wilkes 1986, MNRAS, 218, 331).

Because GLAST has just started its scientific standard operations, regular gamma-ray monitoring of this source will be pursued. In consideration of the ongoing activity of this source we strongly encourage multiwavelength observations of PKS 1502+106.

The GLAST LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

Tweet 0 Recommend 0

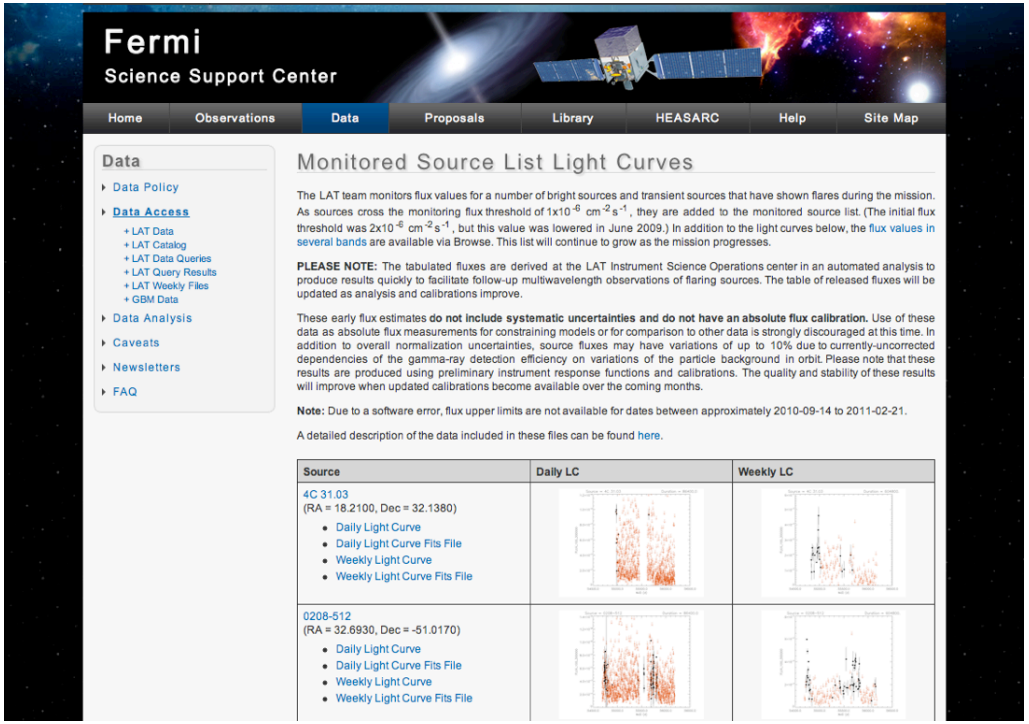
[Telegram Index]

- Flare Advocate run the daily (1-day and 6-hour data) analysis script and check the ASP result
- Once transient objects are found, Astronomers Telegram is issued (typically, flux >1.0×10^{-6} photons/cm^2/s for E>100 MeV)

- LAT daily report is uploaded on the confluence page
- 24-hour, 6-hour x4

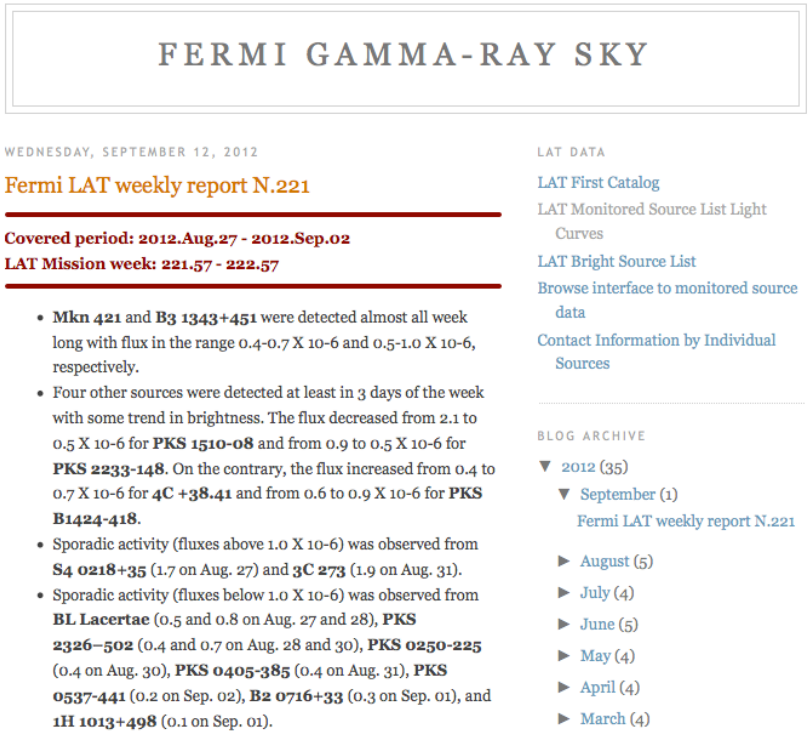
LAT information except Atel

Fermi monitored source list light curve



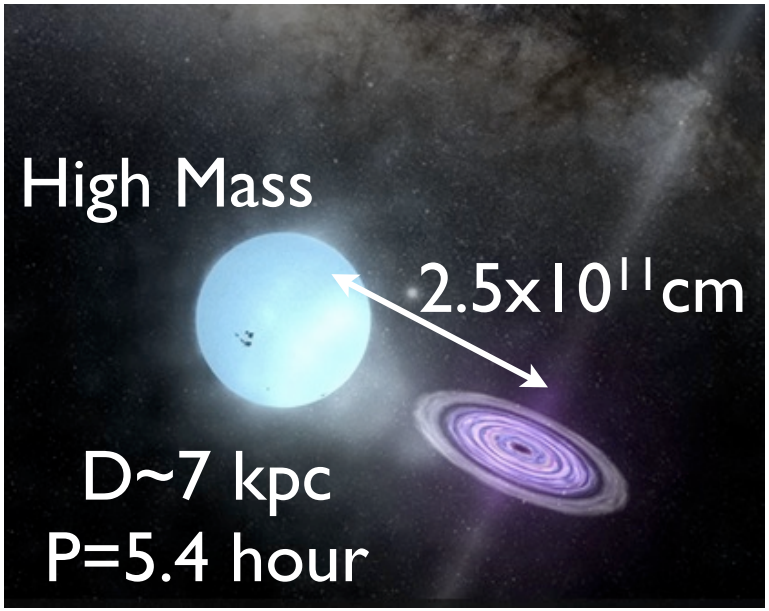
daily, weekly light curves for bright sources

Weekly Fermi sky blog

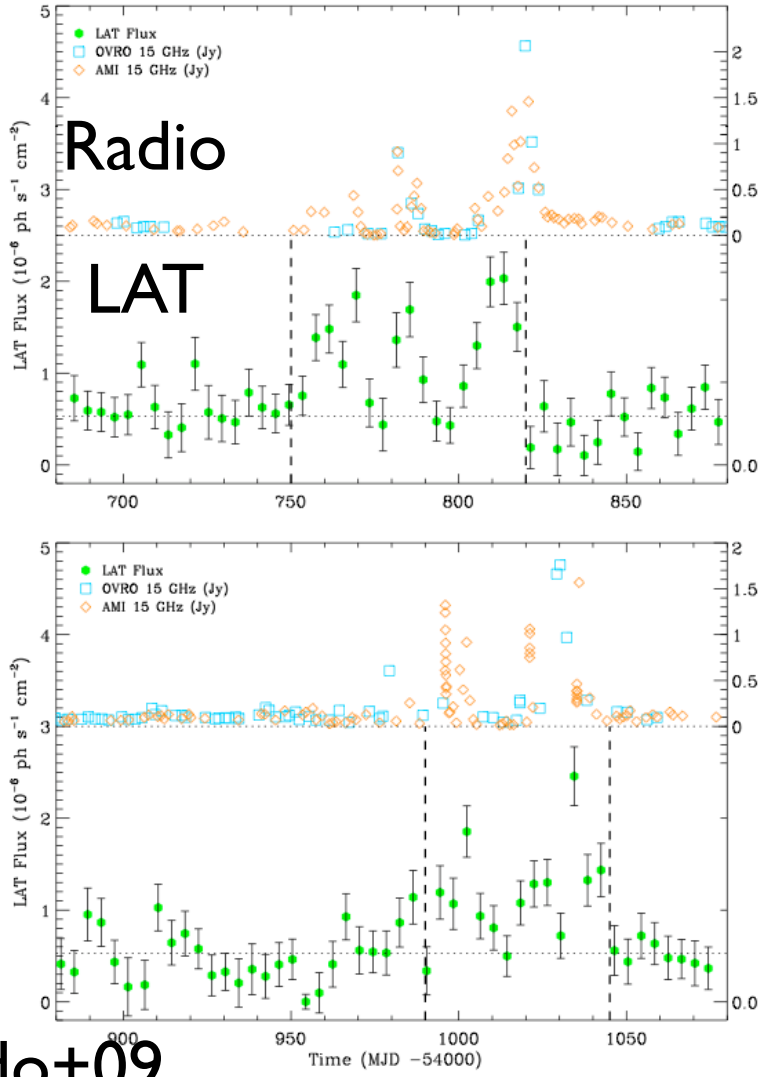


Weekly digest is uploaded every week

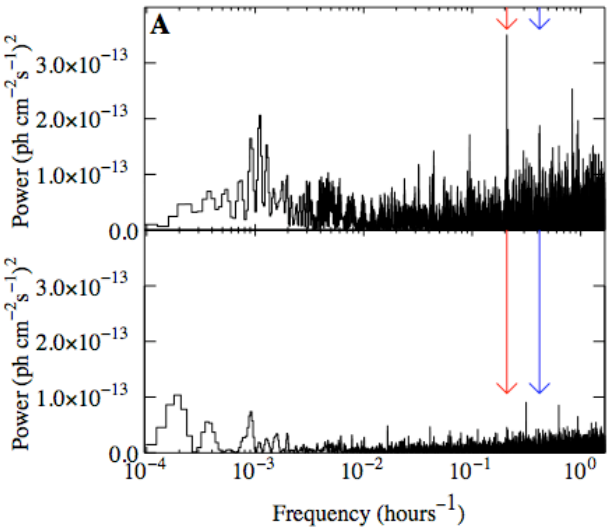
Transient modulated gamma-rays from Cygnus X-3

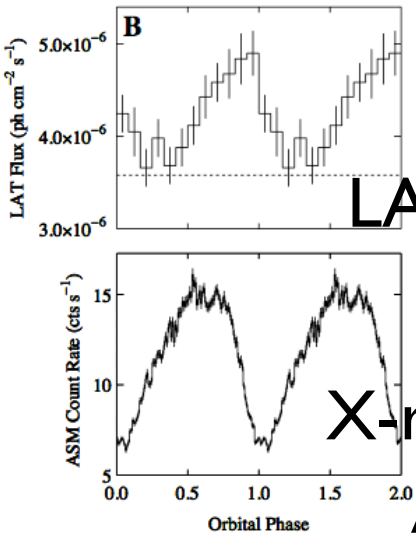


LAT detection during giant radio flare



Clear modulation





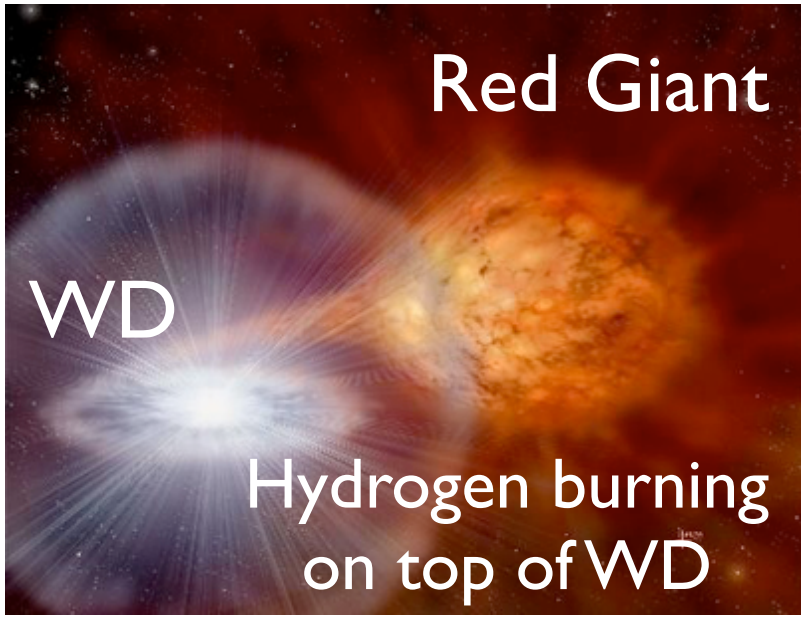
LAT

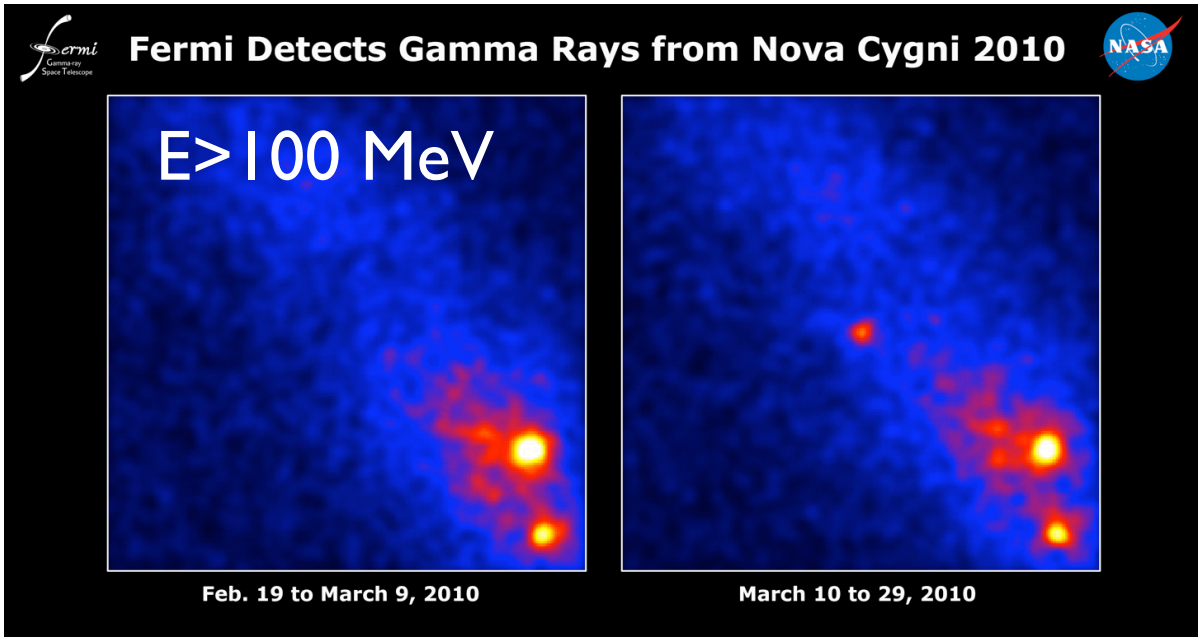
X-ray

Abdo+09

Nova is also GeV emitter

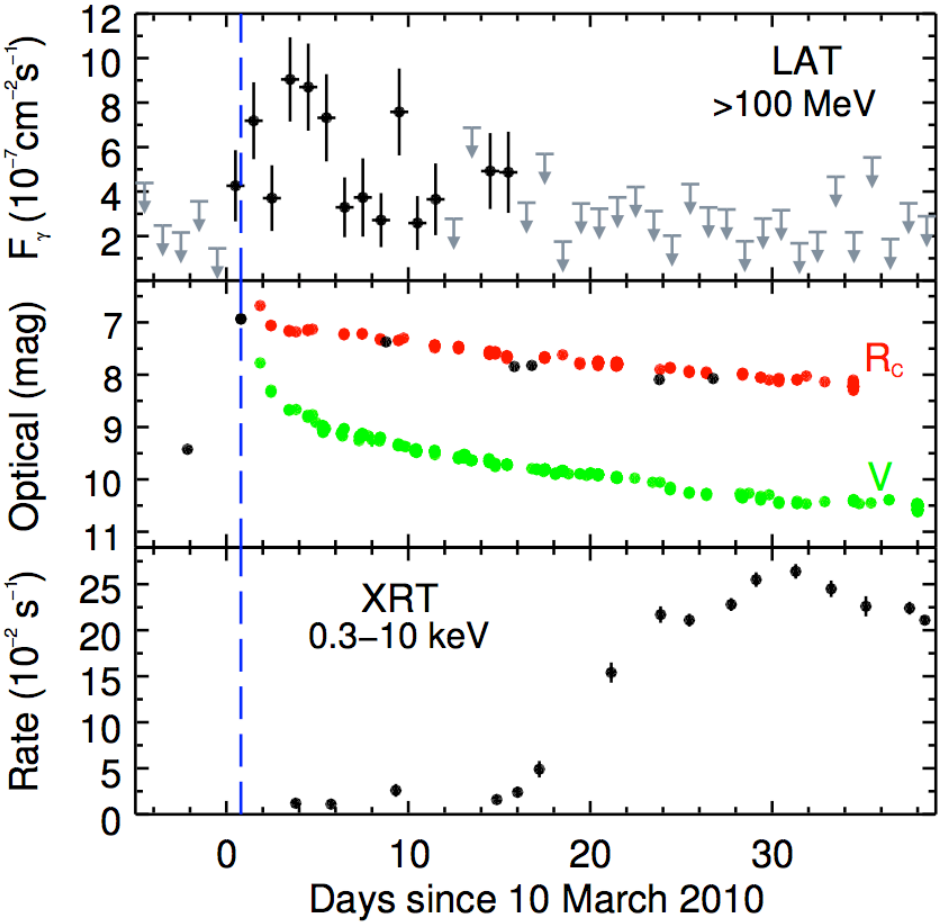
Symbiotic system

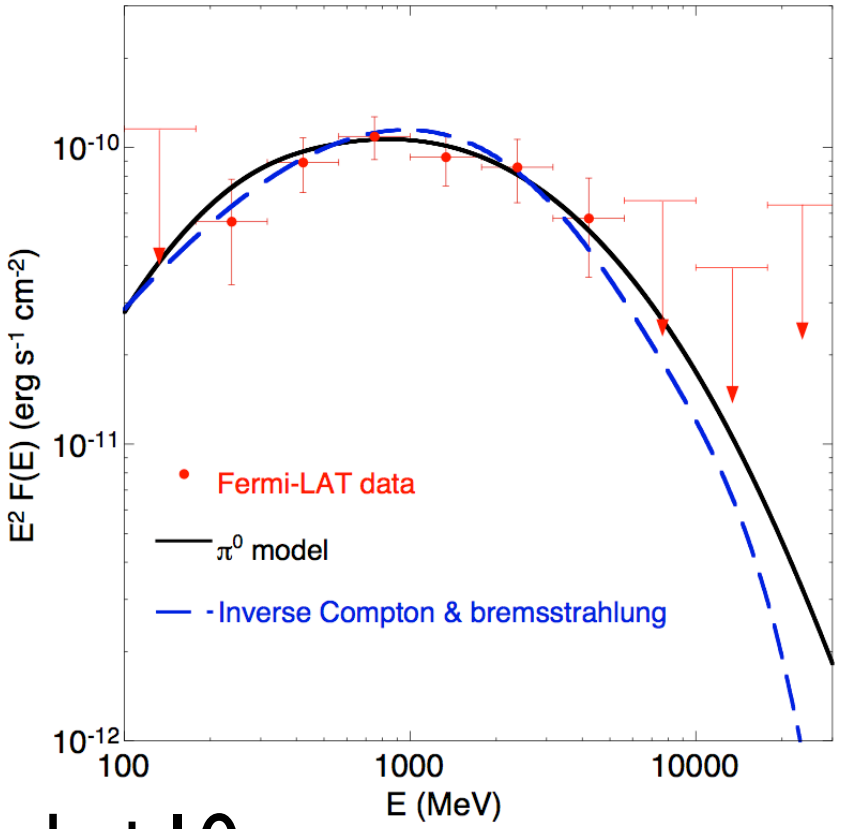




- V407 Cyg is symbiotic nova, not classical nova (D~1 kpc)
- LAT detected high-energy gamma-rays from Nova V407 Cyg in 2010 (Abdo+10)

LAT observation



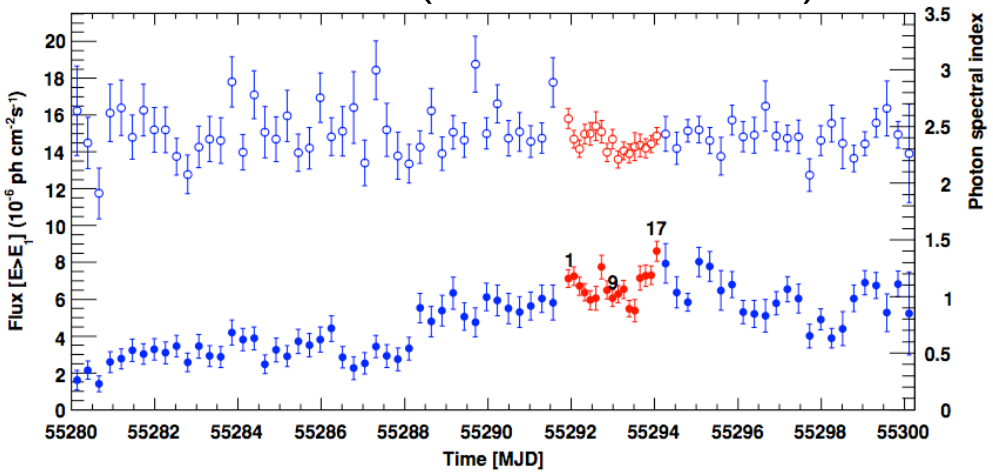


Abdo+10

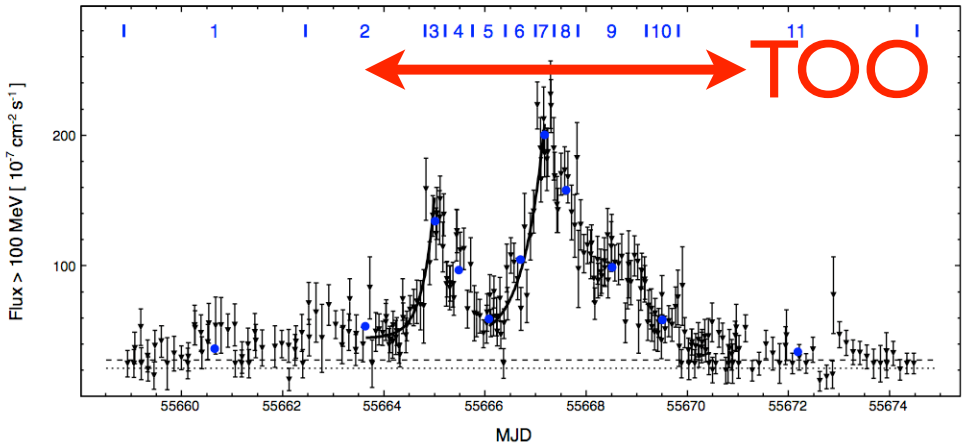
- Gamma-ray emission lated for ~10 days
- Pizero decay is favored, but leptonic origin cannot be ruled out

TOO Pointed observation

3C 454.3 (Ackermann+10)

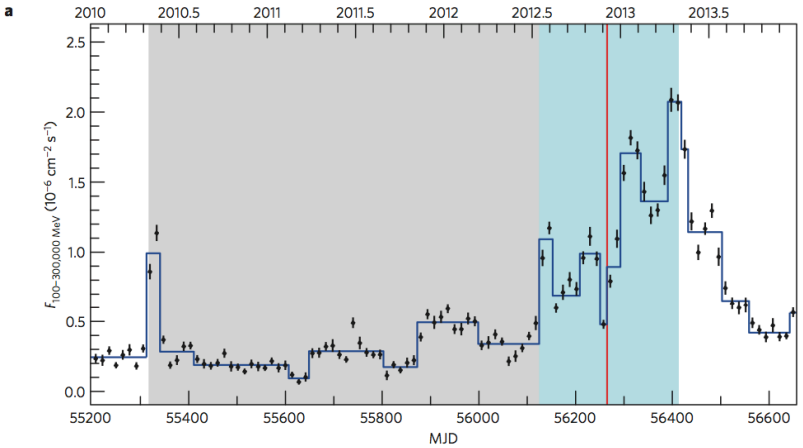


Crab nebula flare (Buehler+12)



- ToO observation sometimes triggered based on interesting phenomena such as brightest flares (3C 454.3, Crab, PSR B1259-63, Cygnus X-3, Sun, 3C 279,,,)
- Exposure increase by a factor of ~5 compared to survey mode
- Modified survey mode is also feasible (one orbit for northern sky and following 2 orbits for southern sky)

PeV neutrino association with high fluence GeV blazars PKS 1424-418



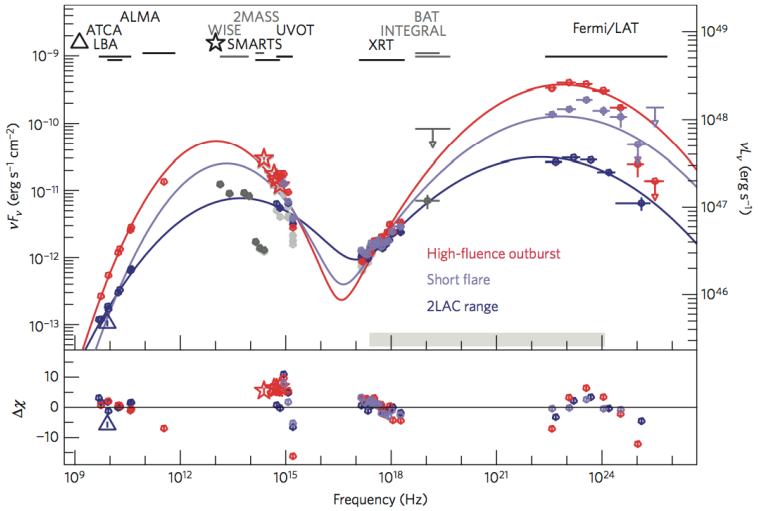


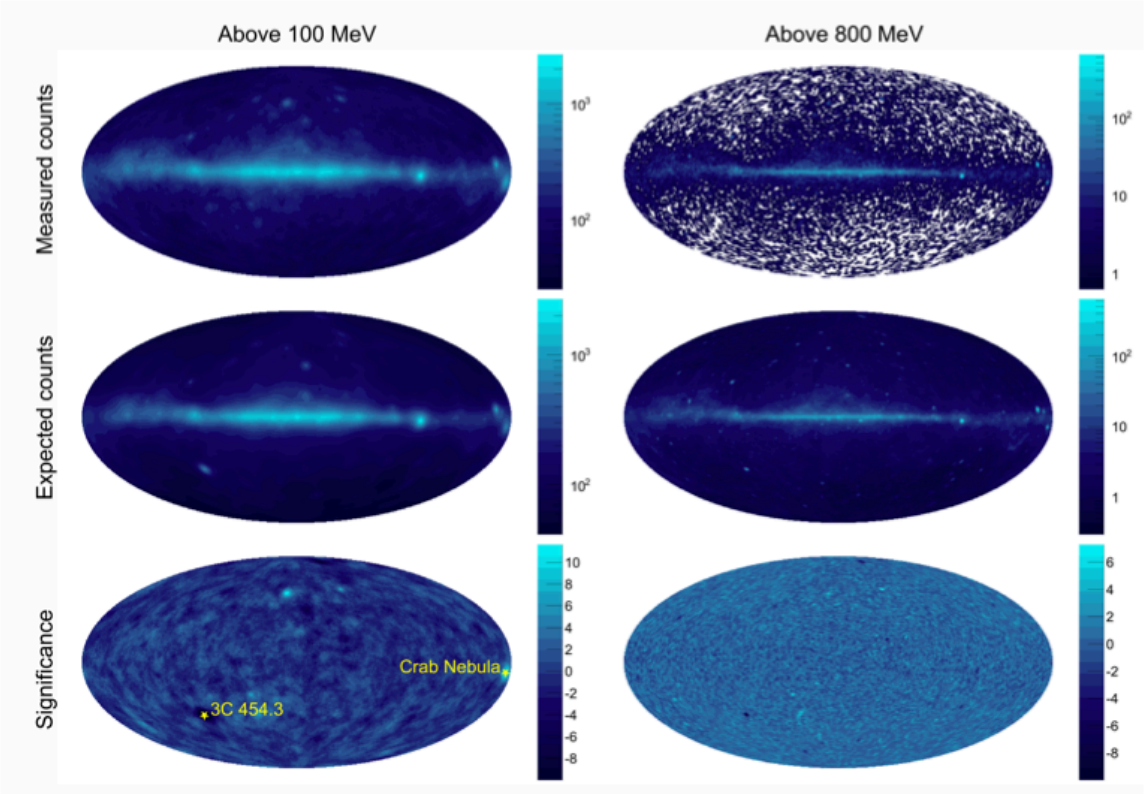
Table 1 | Maximum-possible number of petaelectronvolt-neutrino events in 36 months (988 days live-time) of IceCube data for the 17 2LAC γ-ray blazars in the field of the 2 PeV IceCube event based on 2LAC catalogue γ-ray spectra and contemporaneous X-ray data.

2FGL name	Common name	F_γ (erg cm^{-2} s^{-1})	$N_{\nu,\mathrm{PeV}}^{\max}$
2FGL J1230.2-5258	PMN J1229-5303	$(2.4^{+1.5}_{-1.5}) \times 10^{-11}$	0.14
2FGL J1234.0-5733	PMN J1234-5736	$(1.1^{+0.4}_{-0.4}) \times 10^{-11}$	0.06
2FGL J1303.5-4622	PMN J1303-4621	$(1.9^{+0.6}_{-0.6}) \times 10^{-11}$	0.11
2FGL J1303.8-5537	PMN J1303-5540	$(1.04^{+0.11}_{-0.11}) \times 10^{-10}$	0.38
2FGL J1304.3-4353	1RXS 130421.2-435308	$(2.11^{+0.25}_{-0.25}) \times 10^{-11}$	0.12
2FGL J1307.5-4300	1RXS 130737.8-425940	$(8.4^{+1.7}_{-1.7}) \times 10^{-12}$	0.05
2FGL J1307.6-6704	PKS B 1304-668	$(1.54^{+0.15}_{-0.15}) \times 10^{-10}$	0.89
2FGL J1314.5-5330	PMN J1315-5334	$(8.1^{+0.9}_{-0.9}) \times 10^{-11}$	0.47
2FGL J1326.7-5254	PMN J1326-5256	$(1.04^{+0.21}_{-0.18}) \times 10^{-10}$	0.59
2FGL J1329.2-5608	PMN J1329-5608	$(1.38^{+0.36}_{-0.29}) \times 10^{-10}$	0.93
2FGL J1330.1-7002	PKS B 1326-697	$(1.53^{+0.11}_{-0.11}) \times 10^{-10}$	0.89
2FGL J1352.6-4413	PKS B 1349-439	$(5.4^{+1.0}_{-1.0}) \times 10^{-11}$	0.32
2FGL J1400.6-5601	PMN J1400-5605	$(6.9^{+0.8}_{-0.8}) \times 10^{-11}$	0.40
2FGL J1407.5-4257	CGRaBS J1407-4302	$(1.6^{+0.5}_{-0.5}) \times 10^{-11}$	0.09
2FGL J1428.0-4206*	PKS B1424-418*	$(2.04^{+0.17}_{-0.16}) \times 10^{-10*}$	1.57*
2FGL J1508.5-4957	PMN J1508-4953	$(7.6^{+3.0}_{-2.3}) \times 10^{-11}$	0.55
2FGL J1514.6-4751	PMN J1514-4748	$(5.6^{+0.6}_{-0.6}) \times 10^{-11}$	0.32
Sum (2LAC)			7.9

Kadler+16

Fermi All sky Variability Analysis (FAVA)

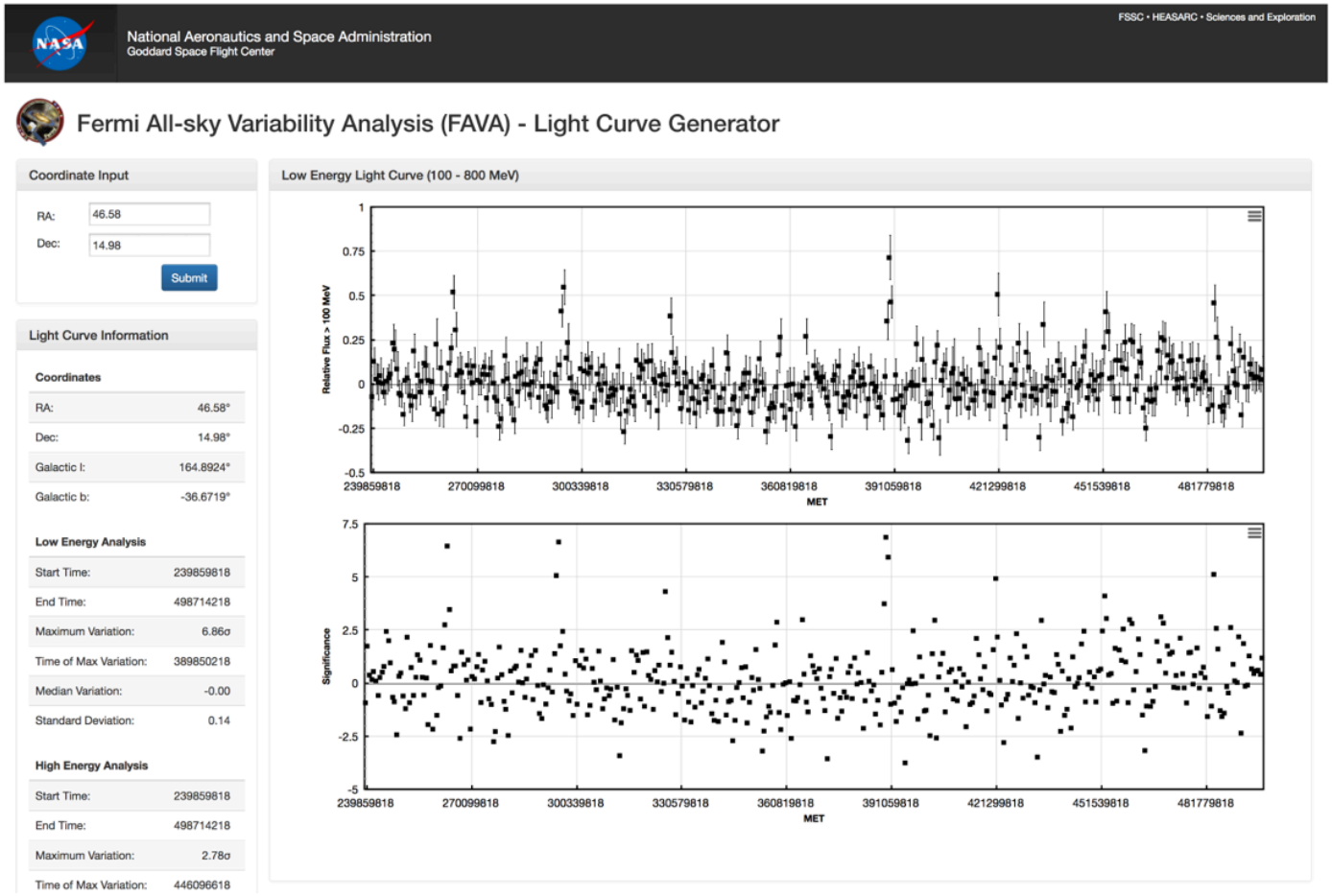
- Comparison of observed emission with average emission
- Weekly time interval
- E>100 MeV, E>800 MeV
- Crab nebula flare is first detected by this analysis
- By using 47 month Fermi/LAT data, 215 sources in the first flare catalog



$$N^{exp}(\phi,\theta) = \sum_{E:j=1..12} \sum_{\alpha:i=1..4} N^{tot}_{i,j}(\phi,\theta) \times \frac{\epsilon^{week}_{i,j}(\phi,\theta)}{\epsilon^{tot}_{i,j}(\phi,\theta)},$$

Exposure ratio

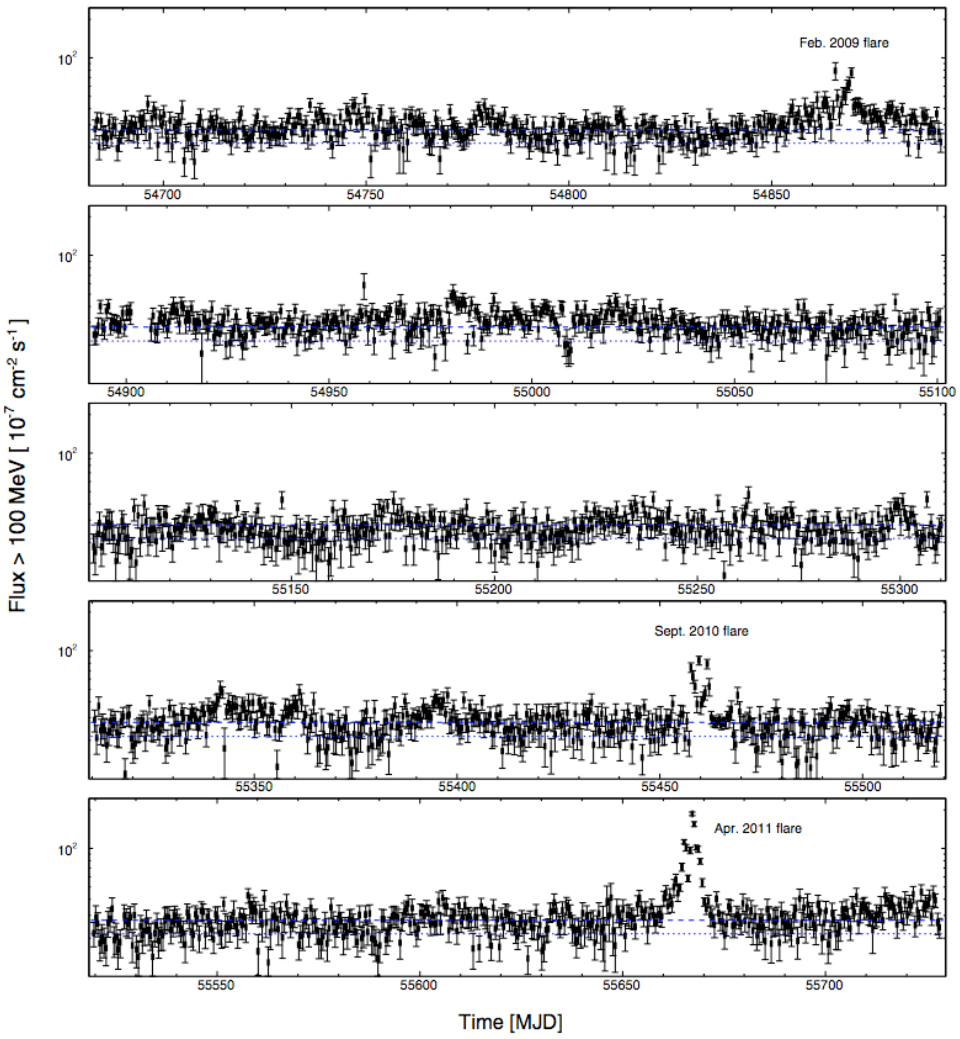
FAVA webpage

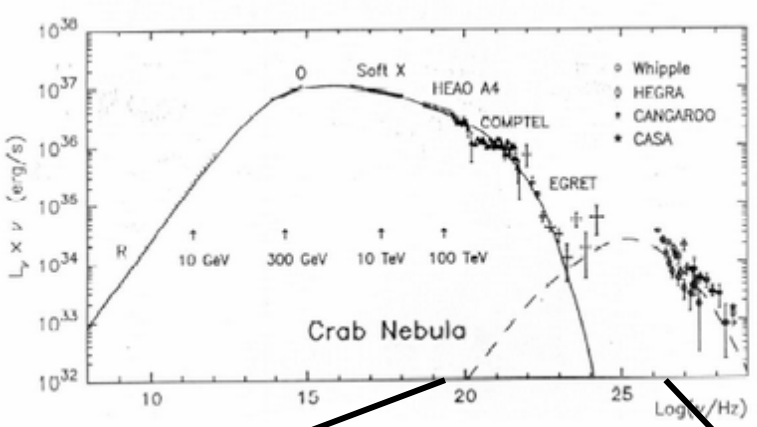


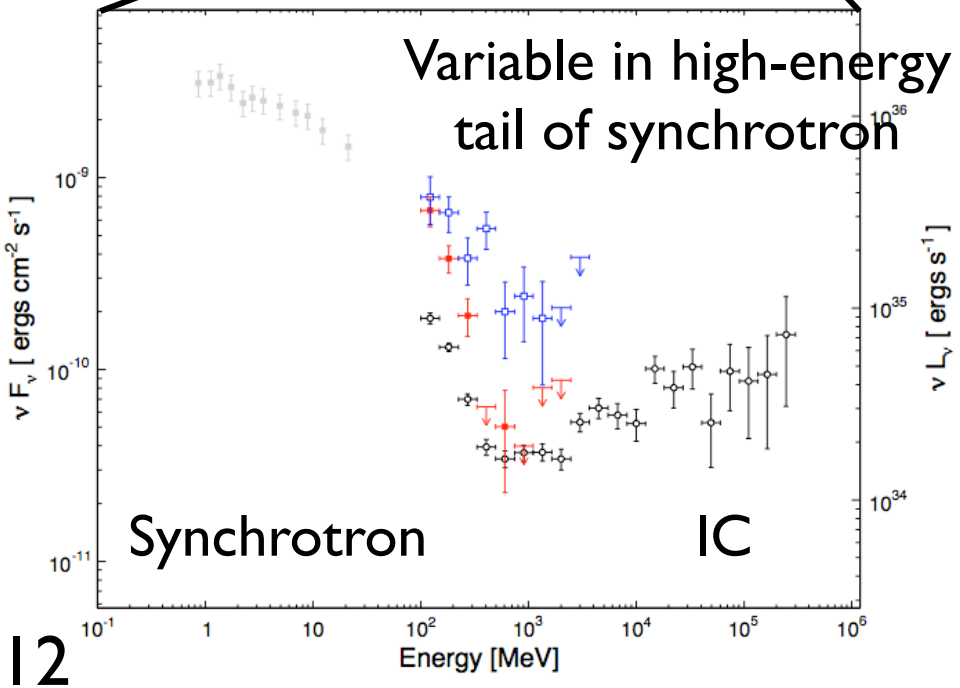
- https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/LightCurve.php
- Automatic production of light curve at any locations (RA, Dec)

Crab nebula flare

LAT light curve (E>100 MeV)

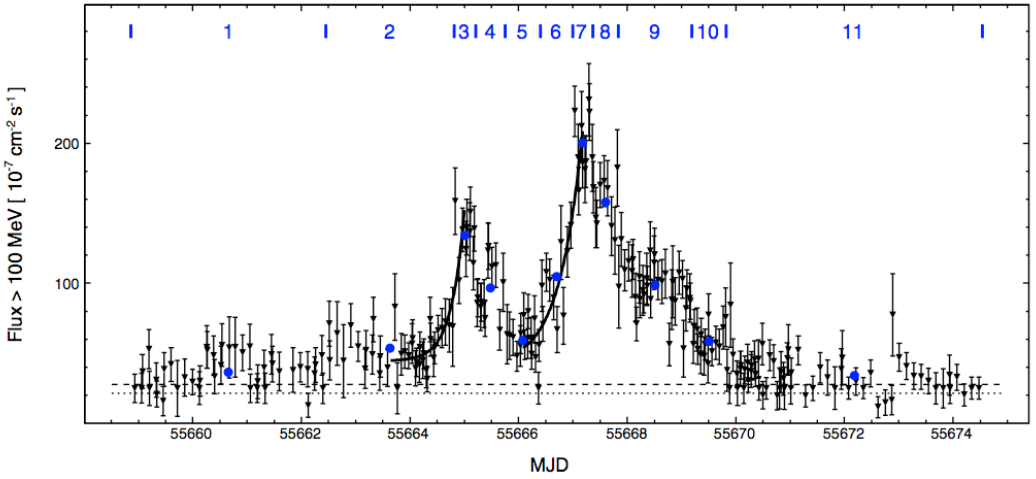


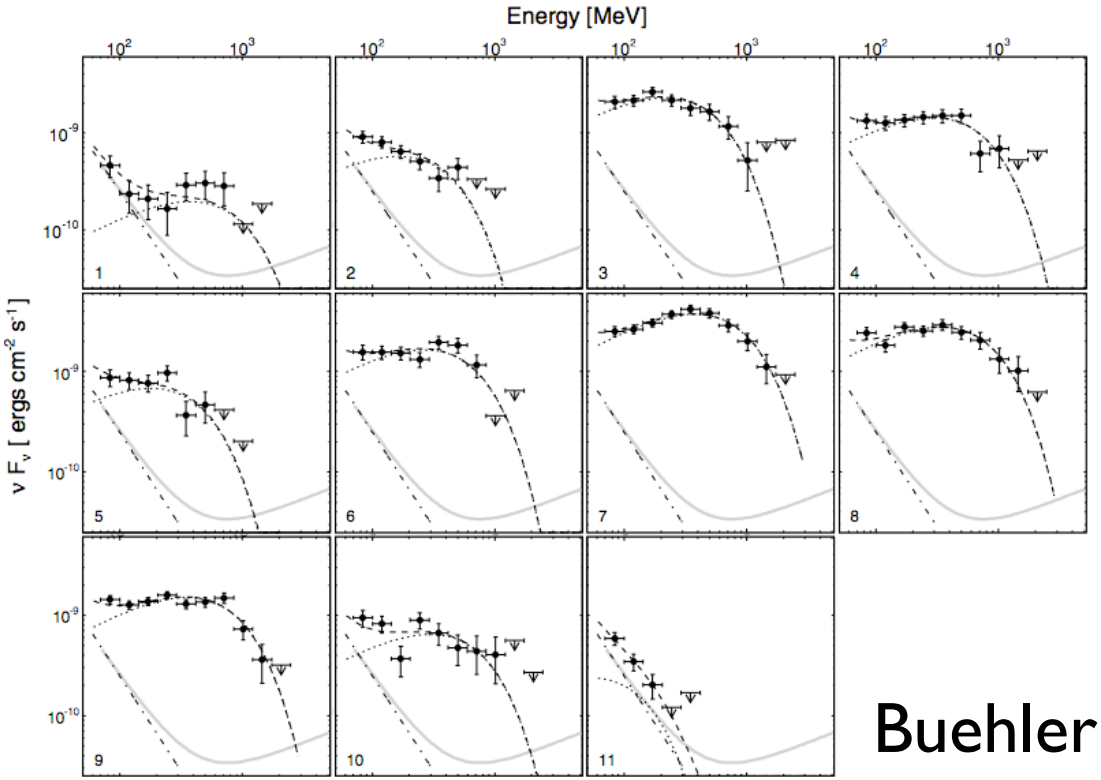




Abdo+11, Buehler+12

Giant flare in 2011 April





Doubling timescale of ~8 hour (Compact emission region of $L<ct_d \sim 2.8 \times 10^{-4}$ pc)

Isotropic peak luminosity is 4×10^{36} erg/s (~1% of total spin-down power)

Cutoff Energy is above 400 MeV (this is above theoretical upper limit of cutoff energy of ~200 MeV)

Buehler+12, 田中孝+12(物理学会誌)

Summary of Fermi LAT transient search

Transients Timescale Pipelines

Pipeline
Method
Timescale
Distribution
Status

LAT Transient Factor (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/

GBM Targeted Searches (GW, neutrino)
ground search around external triggers
ms - s
GCNs

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

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

GBM 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

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

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

Photon Timing

Pulsars

Solar Flares

All Sky Cadence

Novae

γ-ray Binaries

Blazar Flares

Terrestrial γ-ray Flashes

GRBs

Magnetar Flares

Crab Flares

Not to scale

No detection of LAT counterpart for IceCube events (160427)

TITLE: GCN CIRCULAR
NUMBER: 19360
SUBJECT: Fermi/LAT search for counterpart to the IceCube event 67093193 (run 127853)
DATE: 16/04/28 22:38:47 GMT
FROM: Giacomo Vianello at SLAC <giacomov@slac.stanford.edu>

G.Vianello (Stanford), J. D. Magill (UMD/GSFC), N. Omodei (Stanford), D. Kocevski (NASA/Goddard), M. Ajello (Clemson), S. Buson (NASA/GSFC), F. Krauss (ECAP/FAU), J. Chiang (SLAC/Kipac)

report on behalf of the Fermi-LAT team:

We have searched the Fermi Large Area Telescope data for a high-energy gamma-ray counterpart for the IceCube High Energy Starting Event (HESE) 67093193, detected in run 127853 on 2016-04-27 05:52:32.00 UT (AMON GCN notice rev. 2, http://gcn.gsfc.nasa.gov/notices_amon/67093193_127853.amon. See http://gcn.gsfc.nasa.gov/doc/Public_Doc_AMON_IceCube_GCN_Alerts_v2.pdf for a description of HESE events and related GCN notices).

The localization region was outside the LAT field of view at the time of the detection by IceCube (T0). It entered the LAT FoV at ~T0 + 6140 s and exited again at ~T0 + 8420 s. We ran the standard GRB search (Vianello et al. 2015) plus an ad-hoc search for a counterpart in this time interval and in 10 h intervals before and after the event. We found no significant transient candidate associated with the neutrino event.

Source name	Distance	Association	Blazar Type
3FGL J1603.7+1106	108'	MG1 J160340+1106	BL Lac
3FGL J1608.6+1029	117'	4C +10.45	FSRQ
3FGL J1555.7+1111	147'	PG 1553+113	BL Lac
3FGL J1552.1+0852	153'	TXS 1549+089	BL Lac
3FGL J1546.0+0818	249'	1RXS J154604.6+081912	BL Lac

Outline

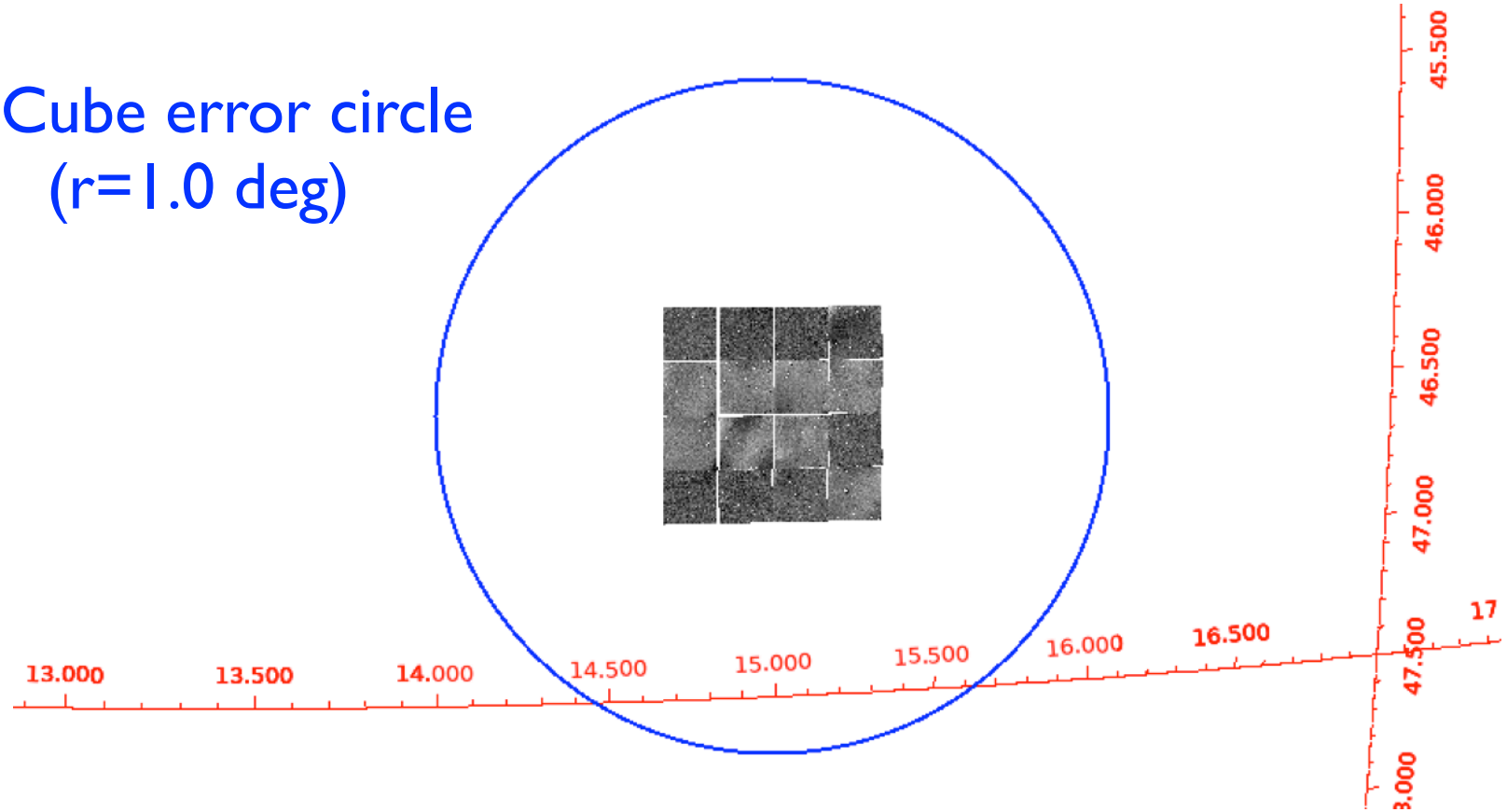
- Introduction of Fermi/LAT
- Fermi/LAT transient search in various timescales
  - ✓ LAT Transient Factory
  - ✓ LAT automated Science Processing+Flare advocate
  - ✓ Fermi All-sky Variability Analysis (FAVA)
- IceCube optical/NIR follow-up by Japanese telescopes
  - ✓ Kanata/HONIR follow-up for IceCube161210
  - ✓ Future plan

Kanata/HONIR ToO observation for IceCube-161210

- IceCube-161210
- 2016 December 10, UT 20:06:40.31
- RA=46.58, Dec=14.98, error circle radius=1 degree (50% C.L., systematic error included)
- 1.5m Kanata telescope located at Higashi-Hiroshima
- J and R-band simultaneous imaging
- 60 s (J) and 75 s (R) exposure in 1 frame
- 5-dithtering
- HONIR FoV: 10'x10'
- Central region of the large error circle was observed by 4x4 tiling observation (2hours for 16 pointings)

J-band tiling observation

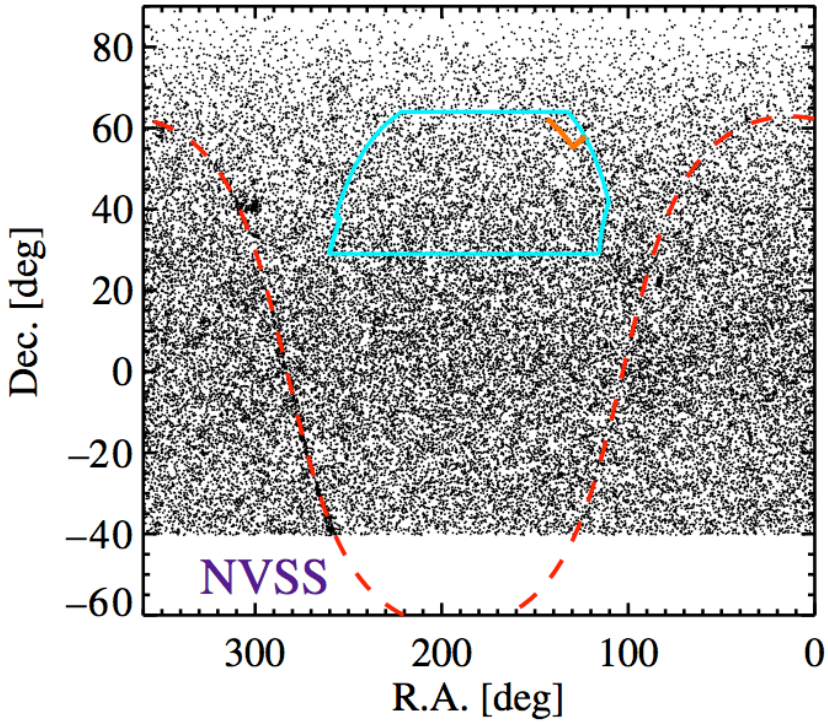
IceCube error circle
(r=1.0 deg)



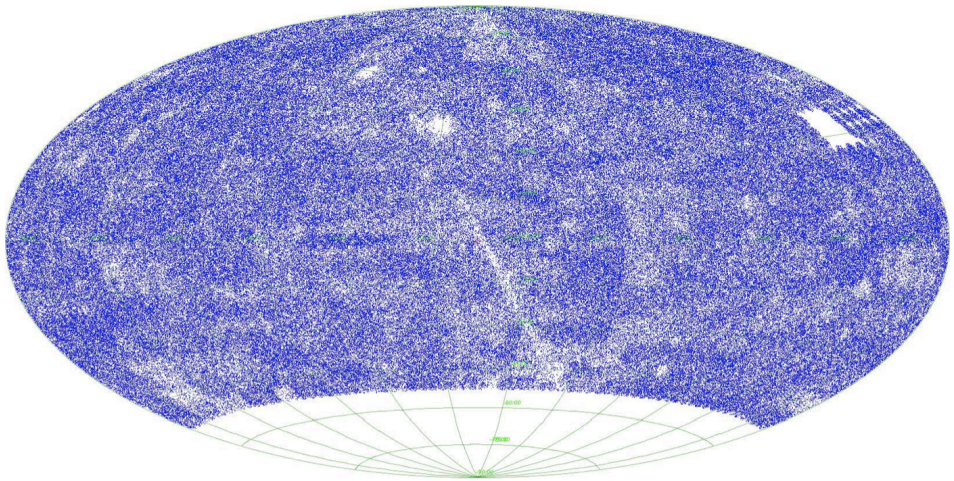
- As a reference frame, we used 2MASS images (2 Micron All Sky survey) and produced subtracted image
- Check the transients by eye
- No bright transient in the image, 5 sigma limiting magnitude J=18.8 (Mori et al., GCN20263)
- R-band analysis is still ongoing. (Subtraction of Pan-STARRS images is not going well)

Blazar candidate selected by radio catalogs

- Blazars usually show flat radio spectrum with spectral index $\alpha<-0.5$ ($F_\nu \propto \nu^\alpha$)
- Flat spectrum radio sources are selected from latest radio catalog
  - ✓ NVSS (NRAO VLA Sky Survey) 1.4 GHz catalog (>2.5 mJy, 2 million sources, Condon+98)
  - ✓ TGSS (TIER GMRT Sky Survey) 150 MHz catalog (>3.5 mJy, 0.6 million sources, Intema+16)

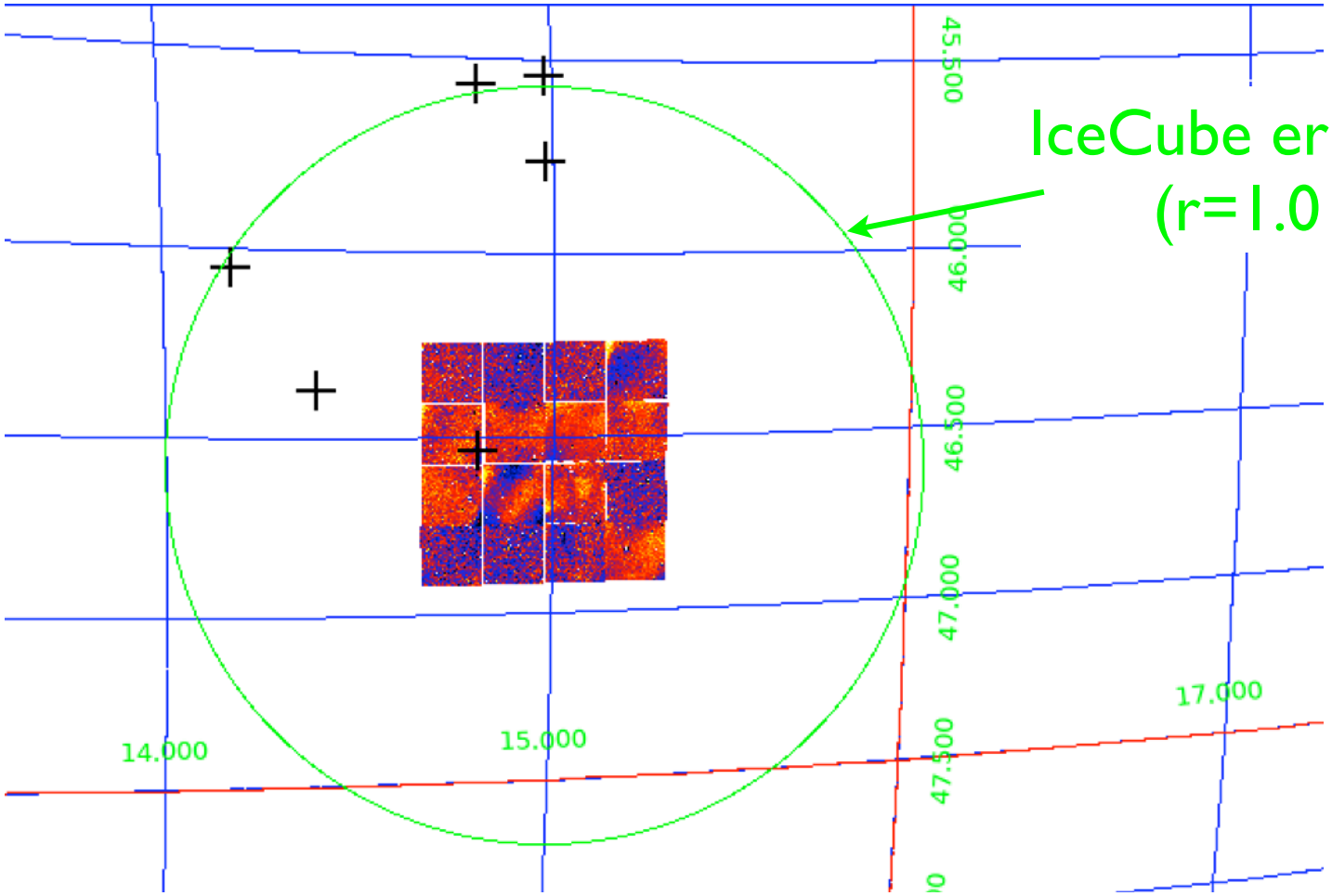


Kimball+08



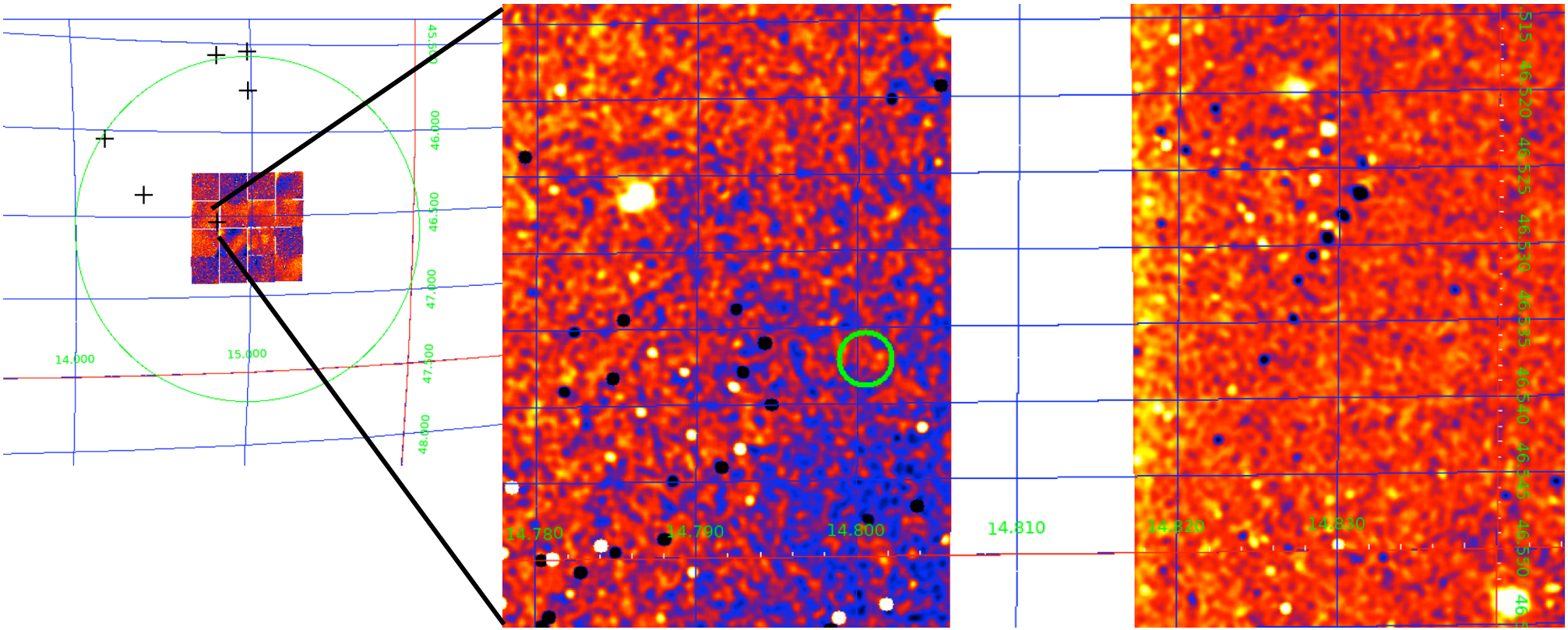
Intema+16

Flat-spectrum radio sources within IceCube error circle



- 6 flat-spectrum radio sources are found within the IceCube error circle
- No CRATES source within the error circle (CRATES catalog is all-sky blazar catalog)
- Only one sources within HONIR tiling observation region

Search for NIR counterpart for flat-spectrum radio source



- No bright transiet is found at the location of one flat-spectrum radio source (J>18.8)
- Pointing observation toward CRATES sources and/or flat spectrum radio sources would be efficient strategy for standard FoV instruments such as Kanata/HONIR

Summary

- We performed Kanata/HONIR R and J-band simultaneous imaging observation for IceCube161210
- No bright transient: J>18.8 (R-band data analysis is ongoing)
- Wide-field camera such as Kiso/KWFC, Kiso/Tomo-e Gozen, Mitsume is needed
- Selection of flat-spectrum radio sources by using NVSS (1.4 GHz) and TGSS (0.151 GHz) catalogs
- Pointing observation toward flat spectrum radio sources would be efficient strategy for standard FoV instruments such as Kanata/HONIR
- Subaru/HSC deep observation is essential to catch IceCube counterpart (based on the flaring blazar hypothesis)