GeV Gamma-Ray Variability

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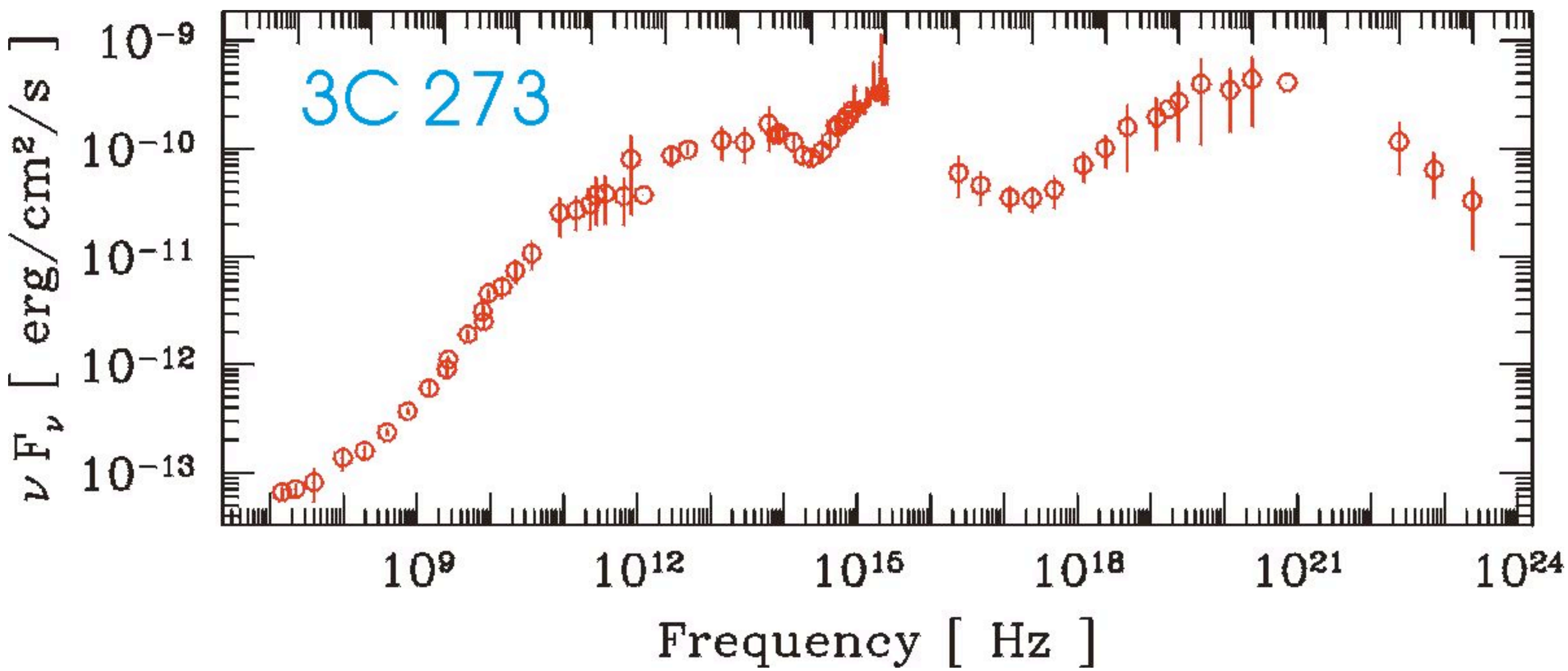
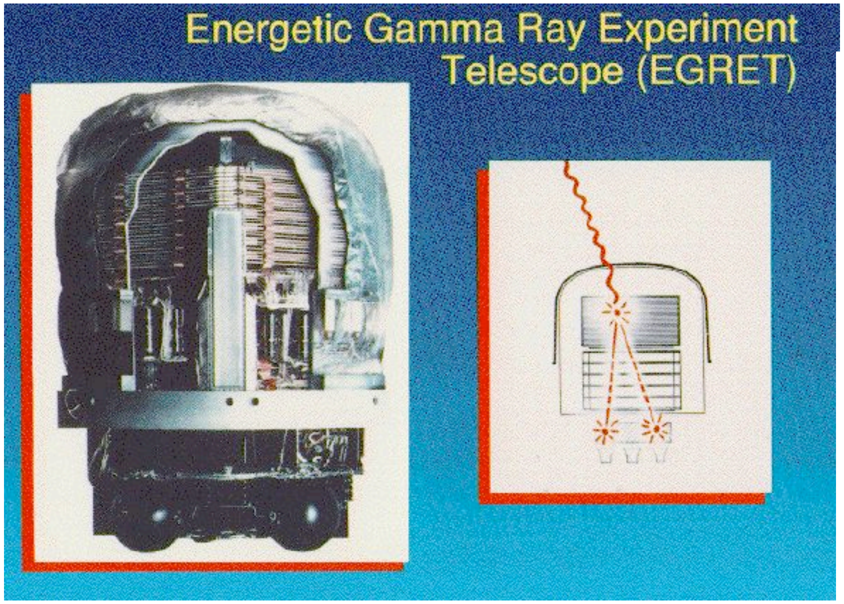
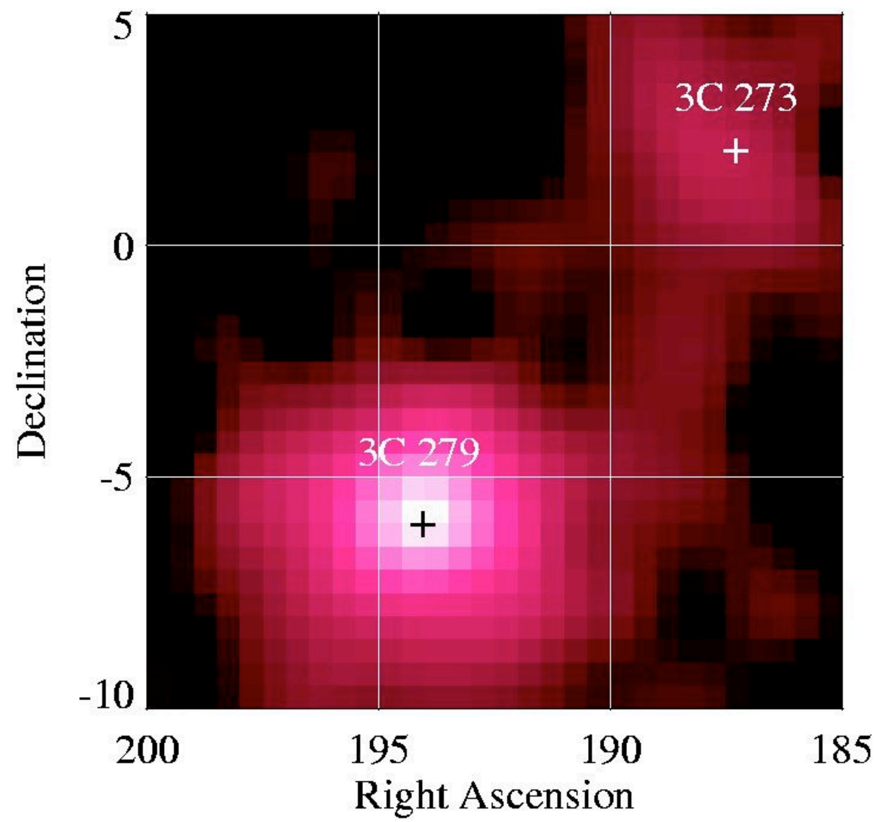
Gamma-Ray Observations of AGN

- **Importance in the 1990's**
- **What do they tell us: in blazars, short-term gamma variab provides a model-independent confirmation of beaming (to avoid pair-production; Maraschi et al. 1992)**

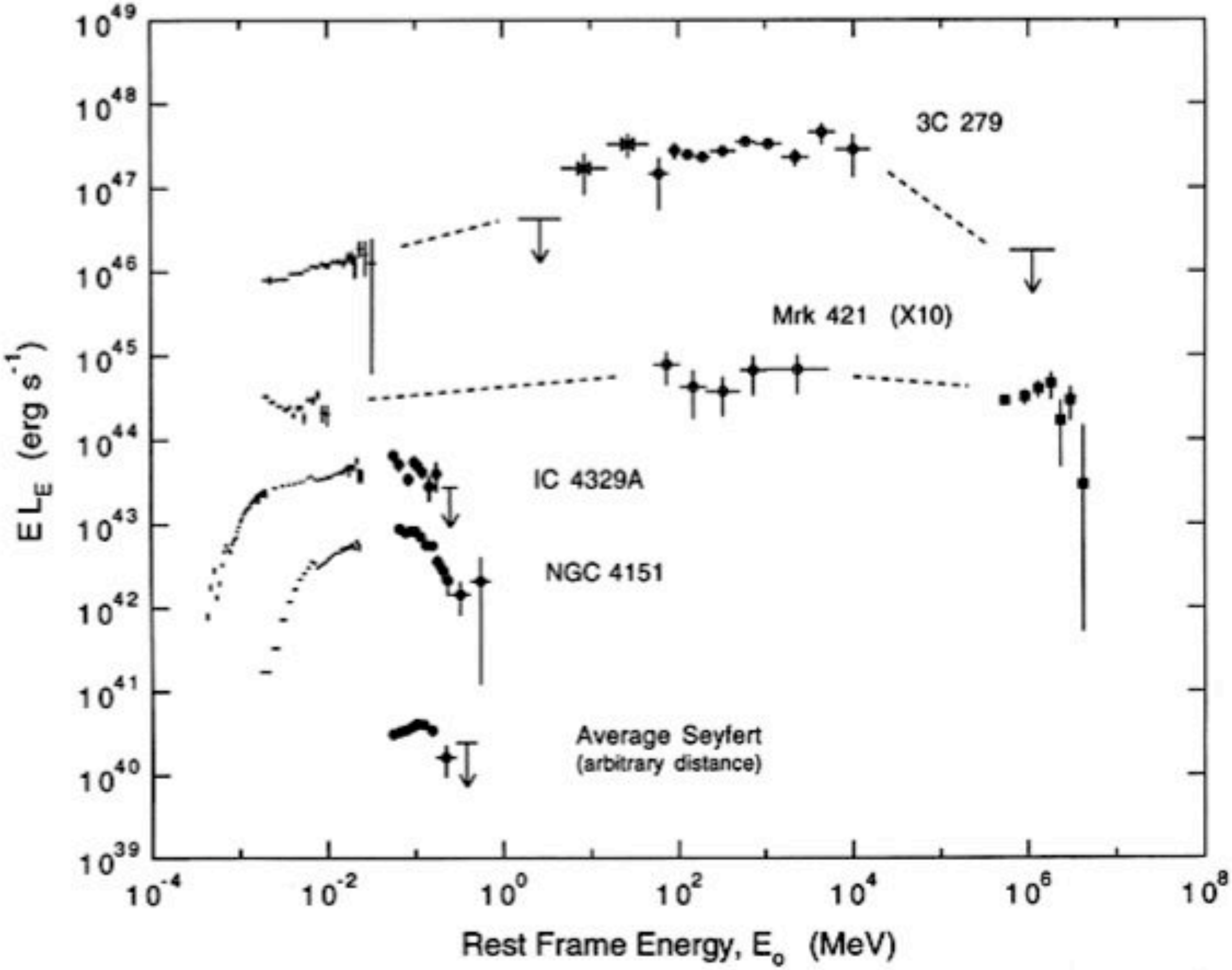


GeV Observations - EGRET



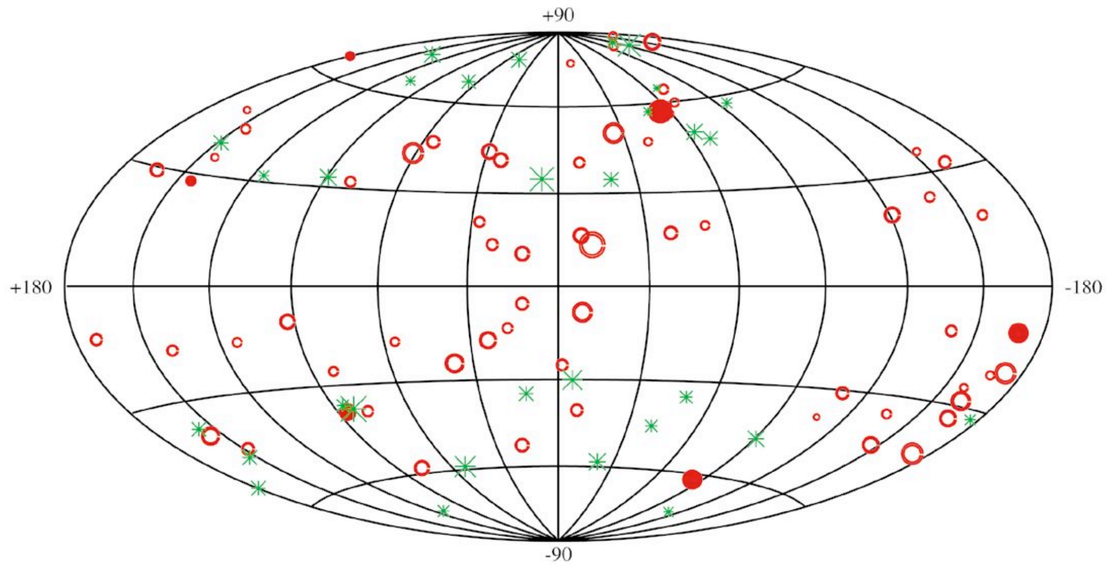


- **Pair conversion telescope**
  - **20 MeV - 30 GeV**
- **First survey of the GeV sky**
- **AGN immediately came to the fore as exciting sources!**



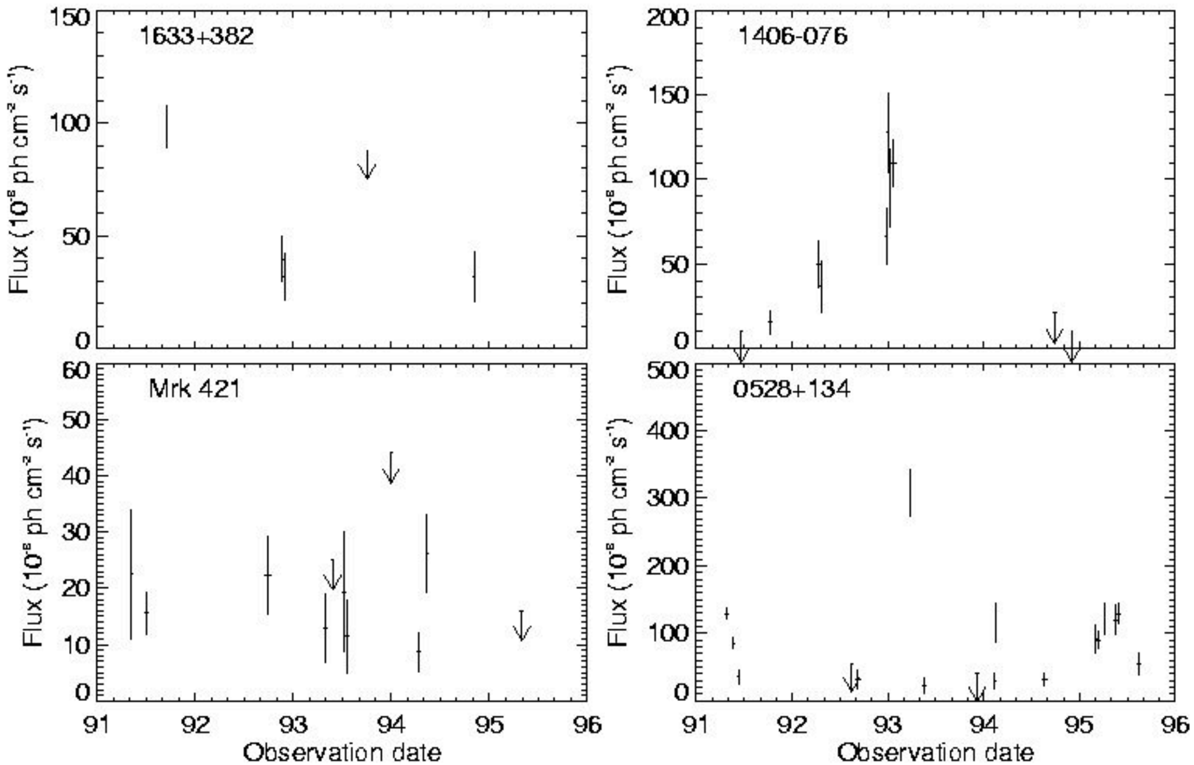
Dermer & Gehrels 1994

EGRET AGN



- EGRET 3rd catalog had 66 blazar identifications
  - 46 FSRQs
  - 17 BL Lacs (mostly LBLs)
- Many of the high latitude unidentified sources are likely to be blazars.
- Average spectral index (assuming a simple power-law) was -2.2, with no evidence of a cutoff below 10 GeV.
- Most EGRET blazars were only seen during flares

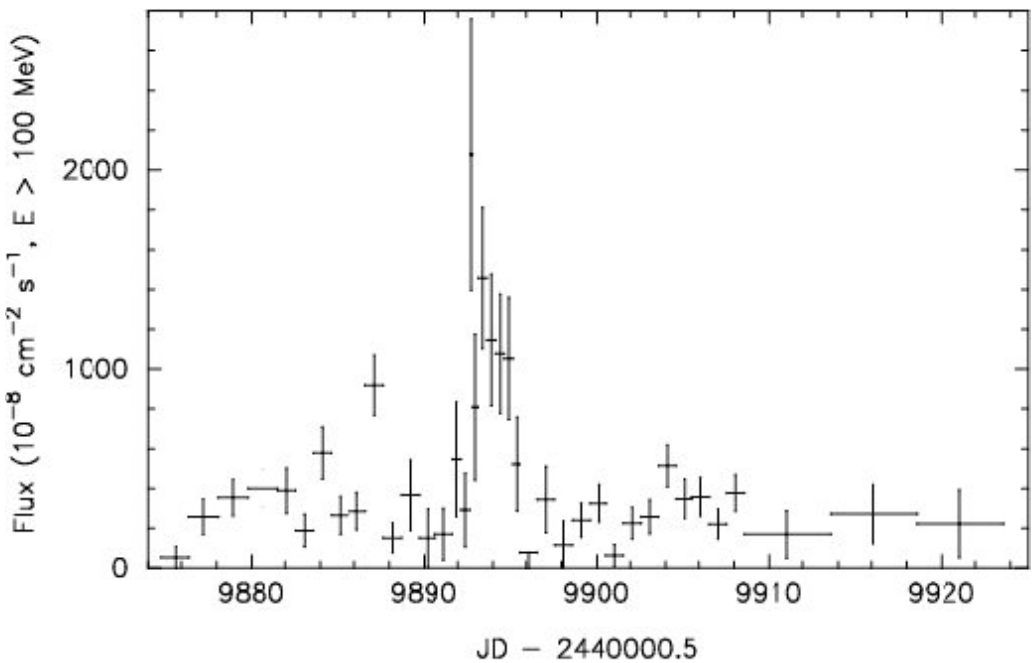
GeV Variability



Flux history of a sample of blazars over the 5 years of EGRET observations (Mukherjee 1999)

- **Gamma-ray variability is a characteristic feature in GeV blazars**
  - **All bright, well observed blazars exhibited variability in EGRET observations.**

Short Duration Variability



PKS 1622-297 in June/July 1995
Mattox et al (1997)

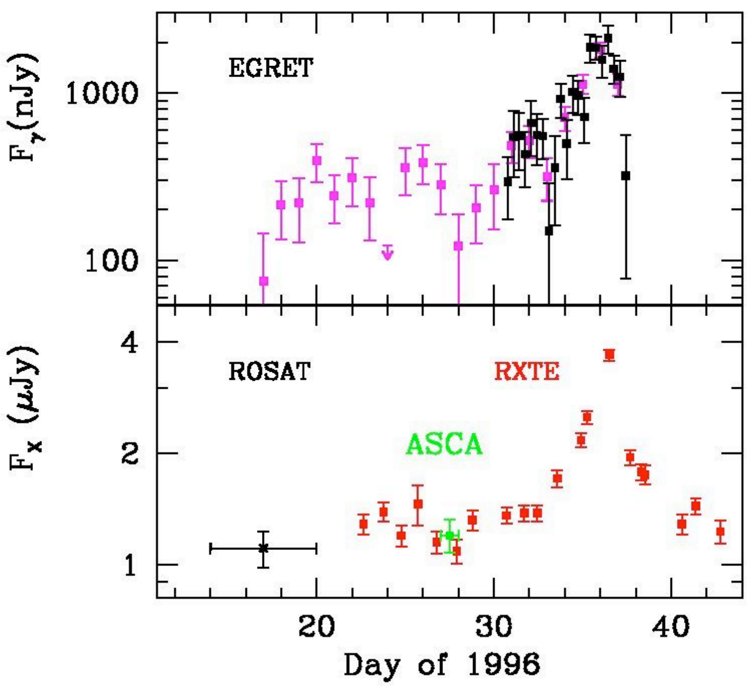
- **Several short duration flares were found on timescales of days, or even hours.**

Multiwavelength observations

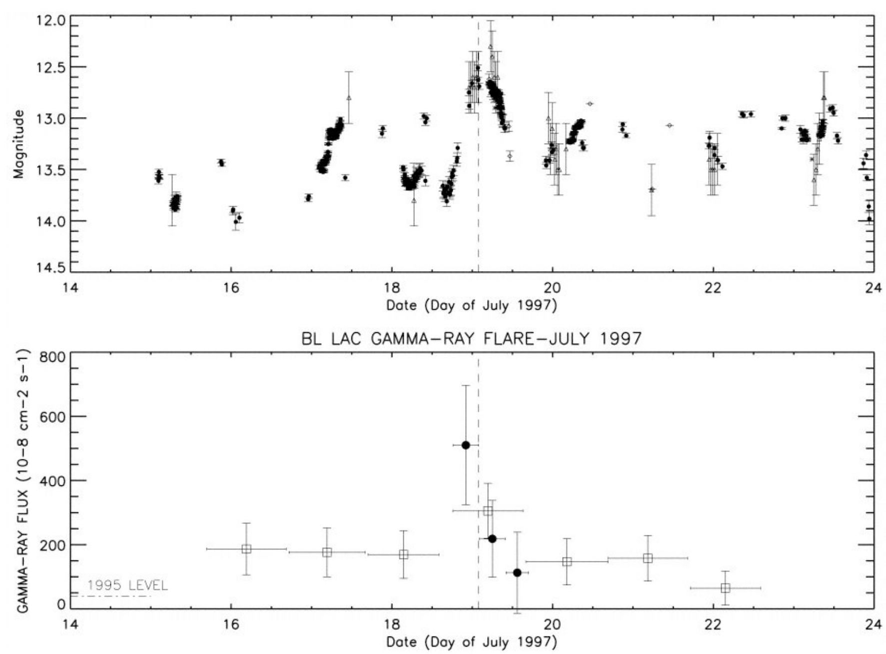
- **Variability:**
  - Strength and phasing of flaring at different wavelengths is a powerful tool for constraining emission models.
  - Observations of simultaneous variability between gamma-ray and lower energy data allows unambiguous identification of the gamma-ray source.
- **Population studies**
  - Relating the properties measured at gamma-ray energies to those at other wavebands can help us understand the properties of blazars as a general class.

Multiwavelength observations

- **Gamma-ray and X-ray well correlated > 1 day**
- **Optical and gamma-ray : but need more flares!**



Wehrle et al. 1996

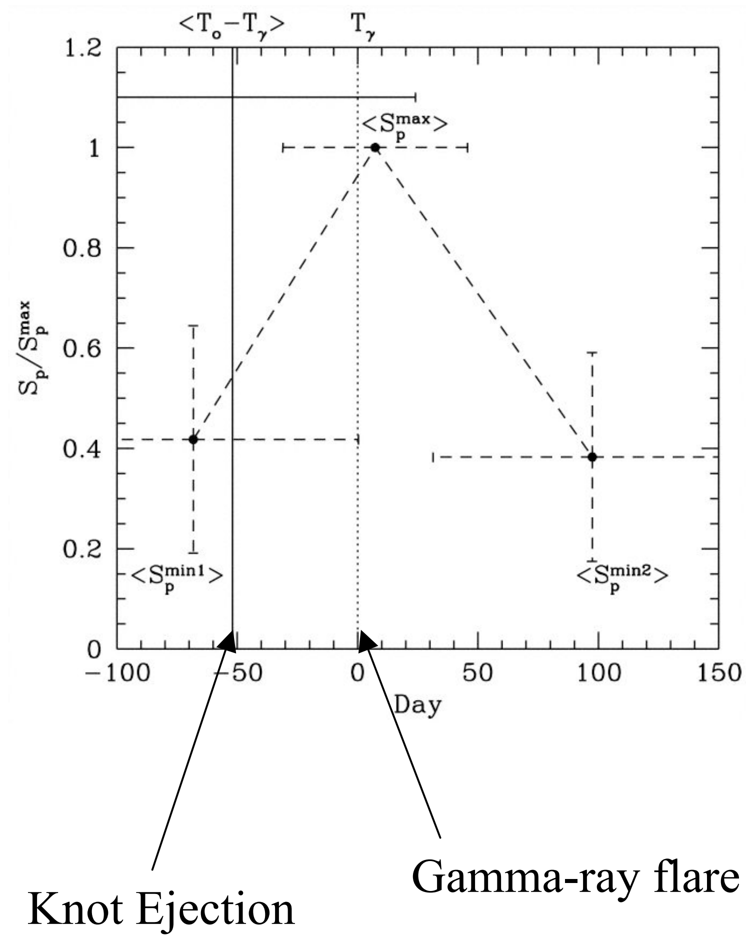


Bloom et al. 1999

Multiwavelength observations - radio/gamma

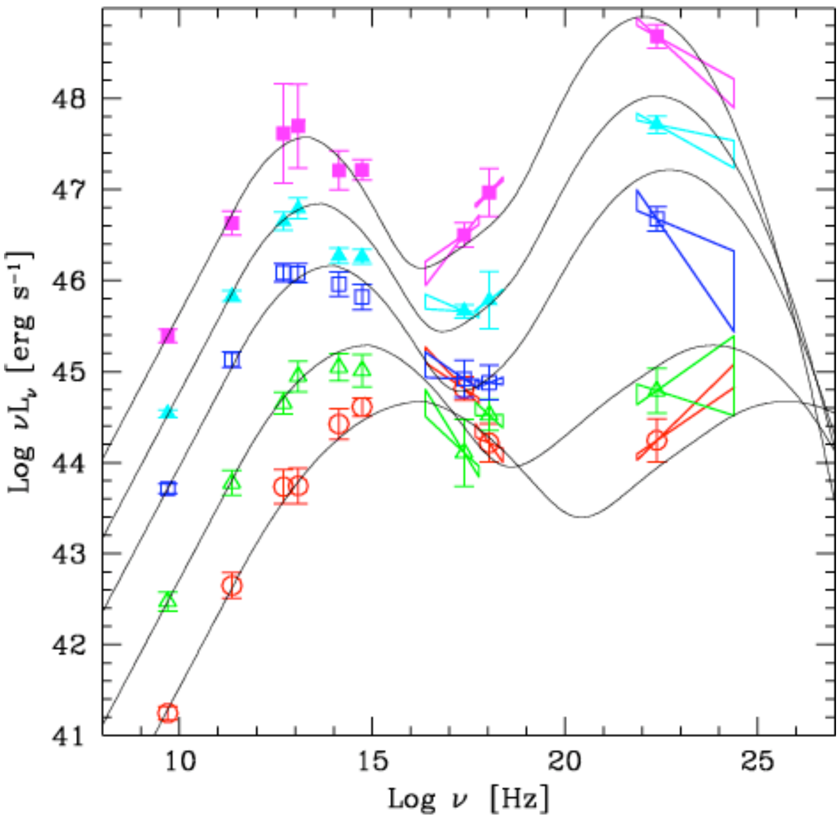
- **mm wave outburst and superluminal knot ejection occur before peak in gamma-ray flux (Valtaoja and Terasranta 1995, Jorstad et al 2001)**
  - **Might imply that gamma-rays are produced in the knots well beyond broad line emission region**

Jorstad et al. 2001

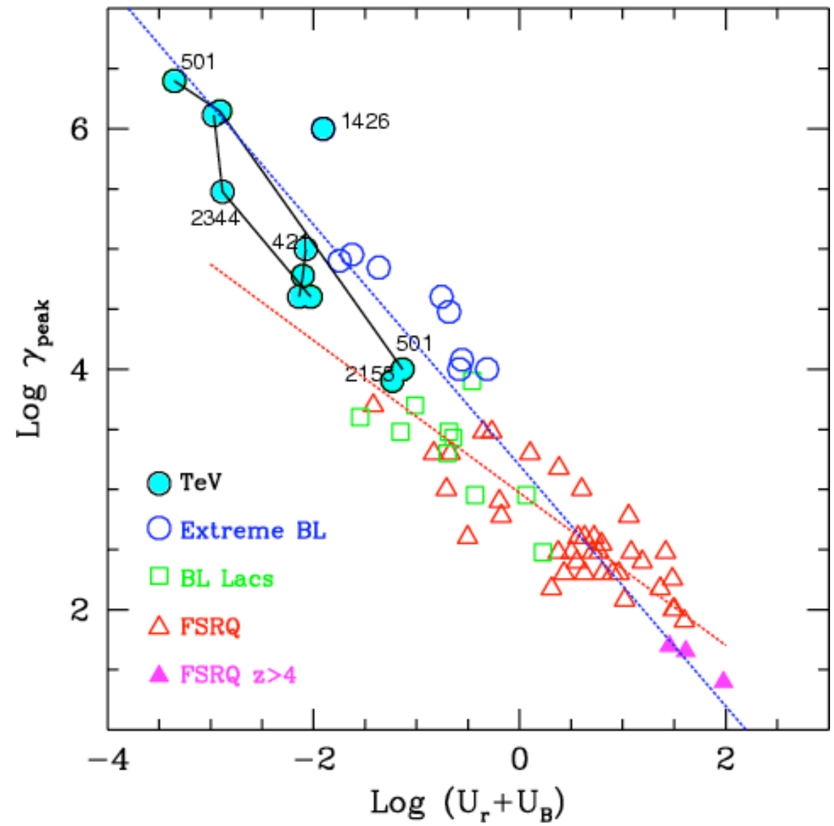


Population studies with EGRET

- **Blazar sequence**



Donato et al. 2003



Ghisellini et al. 2003

Population studies - radio/gamma

- **EGRET blazars have**
  - **faster jets**
  - **Brighter jet components**
  - **higher average polarization**
  - **More variable**
  - **More compact**
  - **Harder radio spectra**
  - **(e.g. Kellerman et al, 2004)**
- **Blazars simply classified into gamma-ray bright or not (for correlation studies between gamma-ray and radio properties).**

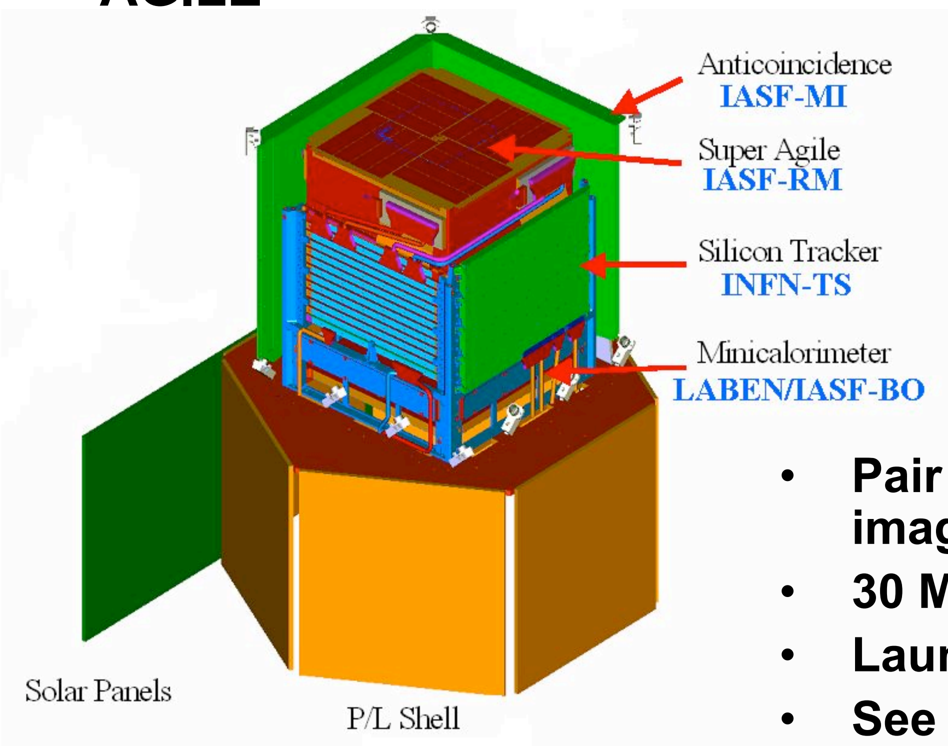
Some thoughts

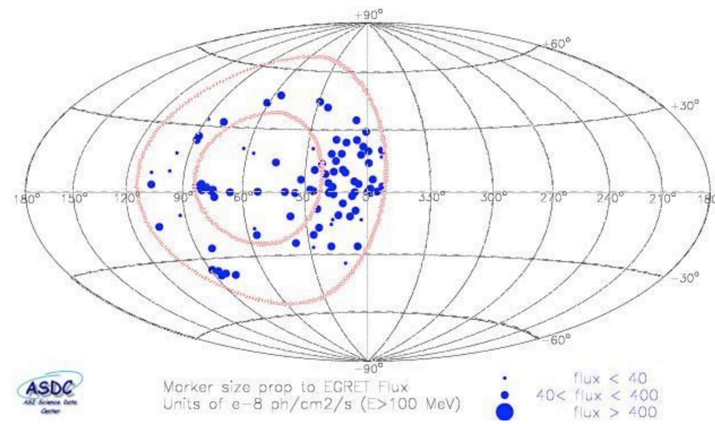
- MW studies of EGRET blazars: Often very detailed MW data/analysis, fairly simple gamma-ray information
  - Was it an EGRET source or not?
  - When did gamma-ray flares occur?
- Possibly some selection effects/biases in both of these.
  - Gamma-ray source id has a built in assumption that flat spectrum radio sources are likely counterparts.
  - In some cases ToO gamma-ray observations were triggered when a source was active.
- Some suggestions that gamma-ray spectrum is harder during flares, but there was limited sensitivity for time resolved spectroscopy, so conclusive analysis is difficult.
- Lots of possibilities for including more detailed gamma-ray properties

A Great Leap Forward - Solid State Detectors

- **The arrival of silicon detector technology has enabled huge advances in pair conversion telescopes, bringing instruments with greatly enhanced trigger efficiency, angular resolution and field of view.**

- **AGILE**

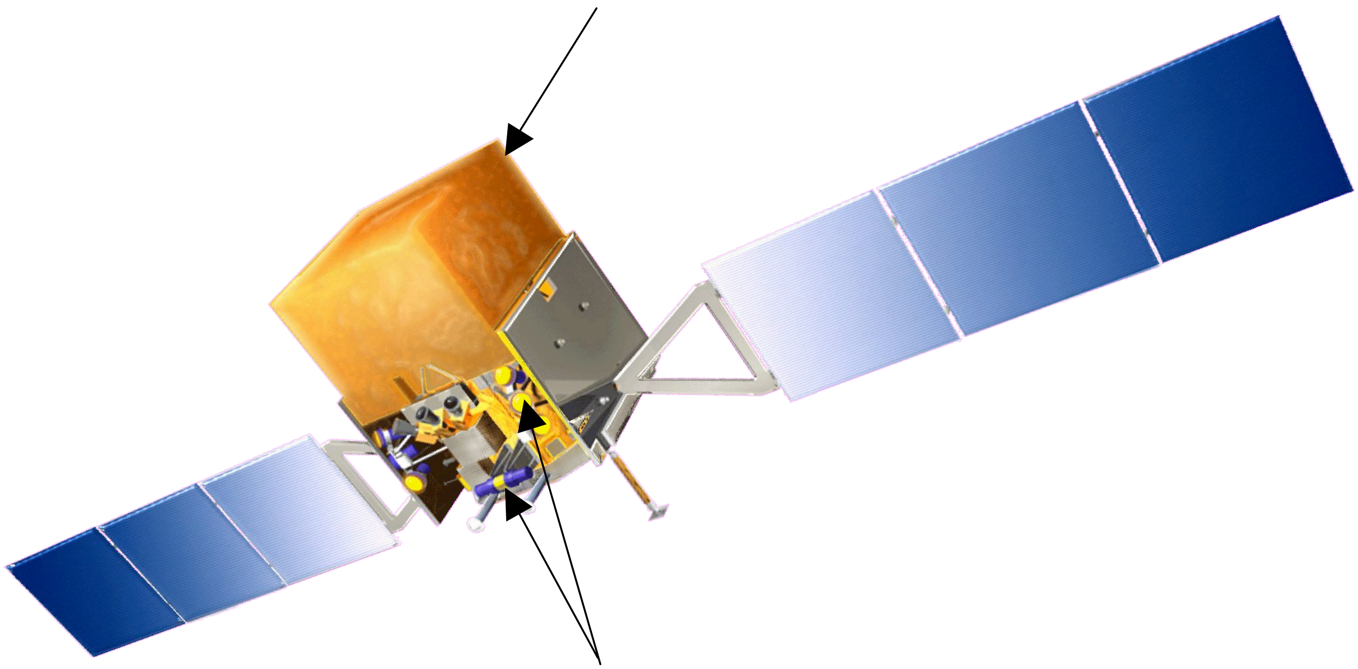




- **Pair conversion telescope + hard X-ray imager.**
- **30 MeV to 50 GeV + 10-40 keV**
- **Launched in April 2007!**
- **See talk by Marco Tavani for more details**

The (near) future with GLAST

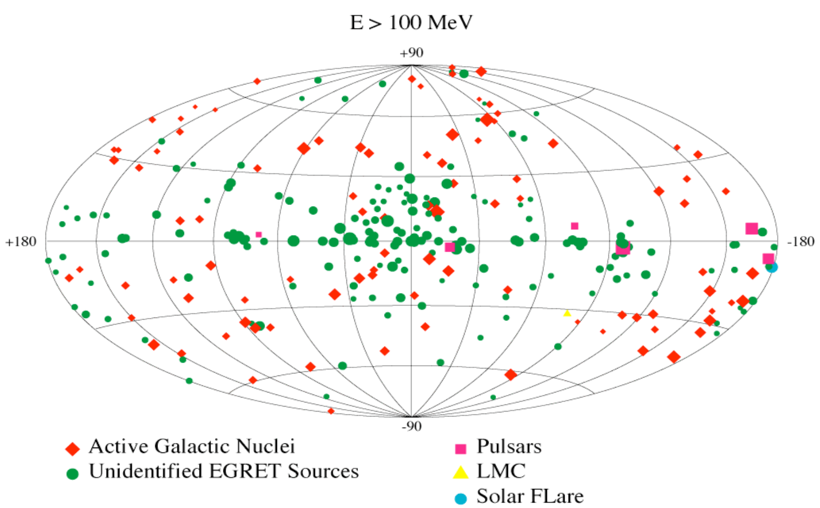
Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - 300 GeV

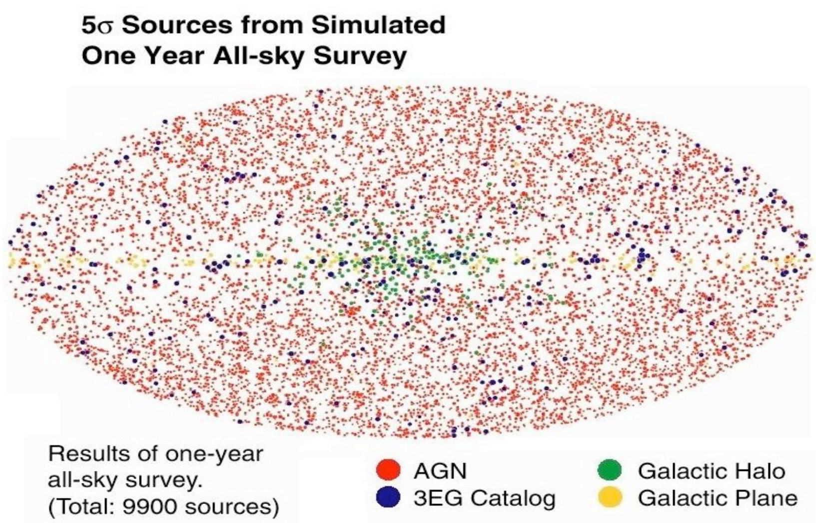


GLAST Burst Monitor (GBM)
Observes entire unocculted sky
Detects transients from 8 keV - 30 MeV

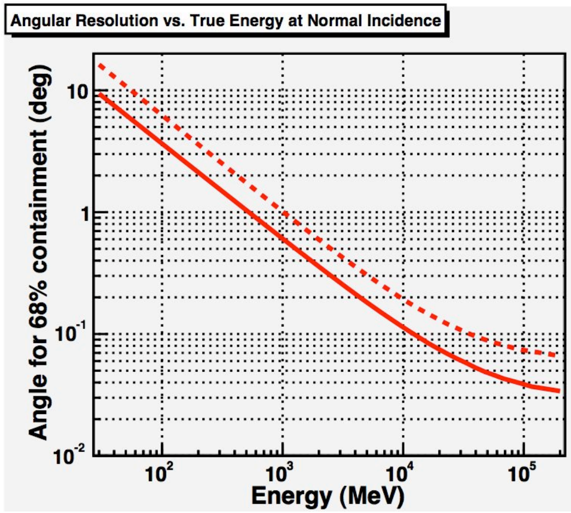
Why should you care about GLAST?

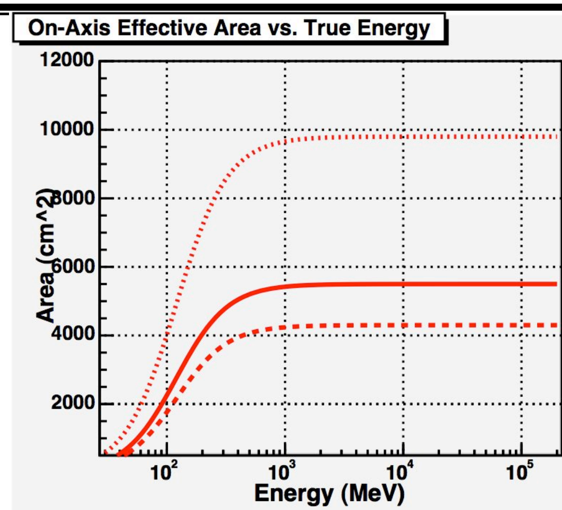
- High energy gamma-rays explore nature's accelerators - "Where the energetic things are"
- Huge improvement over previous missions in this waveband
  - Huge field of view, optimized for sky survey
    - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours.
  - Huge energy range, including largely unexplored 10 GeV - 100 GeV band
  - Will transform the HE gamma-ray catalog:
    - By > order of magnitude in number of point sources
    - Sub-arcmin localizations (source-dependent)
    - Map spatially extended sources

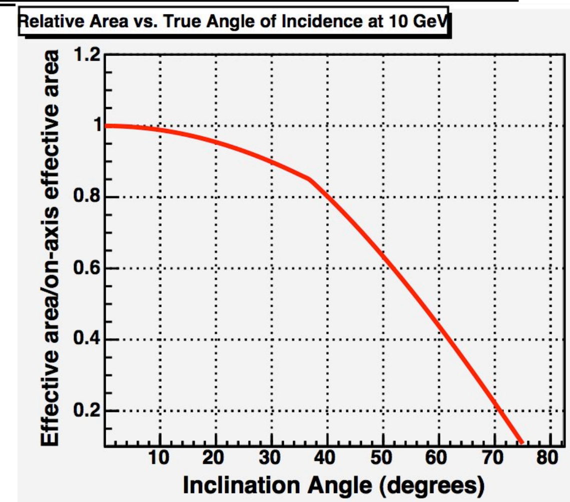




LAT Performance



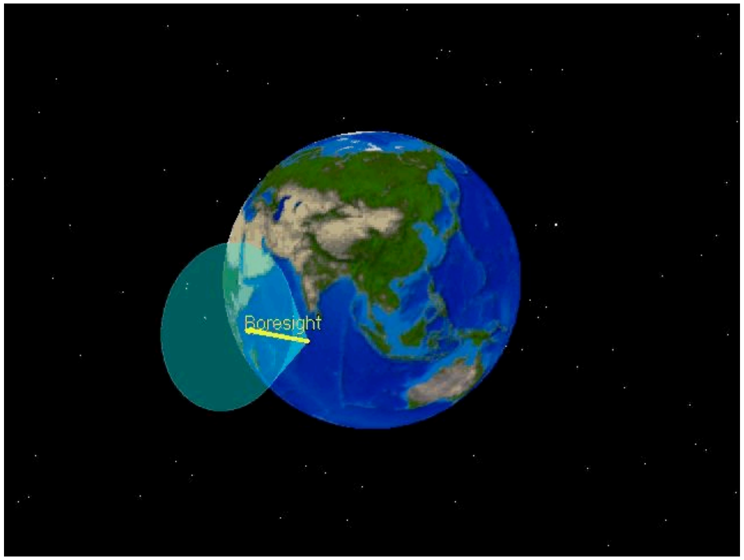


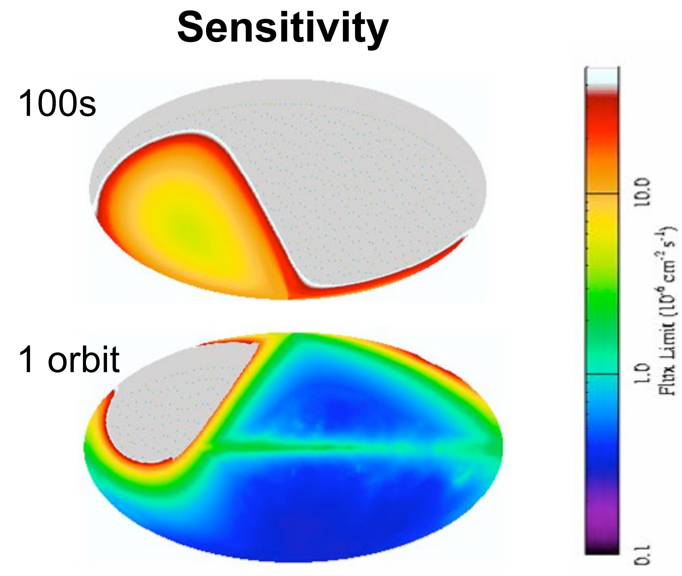


	GLAST/LAT	EGRET
Energy Range	20 MeV - >300 GeV	30 MeV – 30 GeV
Energy Resolution	0.1	0.1
Effective Area	10000 cm^2	1500 cm^2
Field of View	2.2 sr.	0.5 sr.
Angular Resolution	3.5 @ 100 MeV 0.1@10 GeV	5.8@100 MeV 0.5@10 GeV
Sensitivity (>100 MeV)	$3x10^{-9}$ cm^{-2} s^{-1}	~10^{-7} cm^{-2} s^{-1}
Deadtime	27 μs	100ms

http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Operating mode

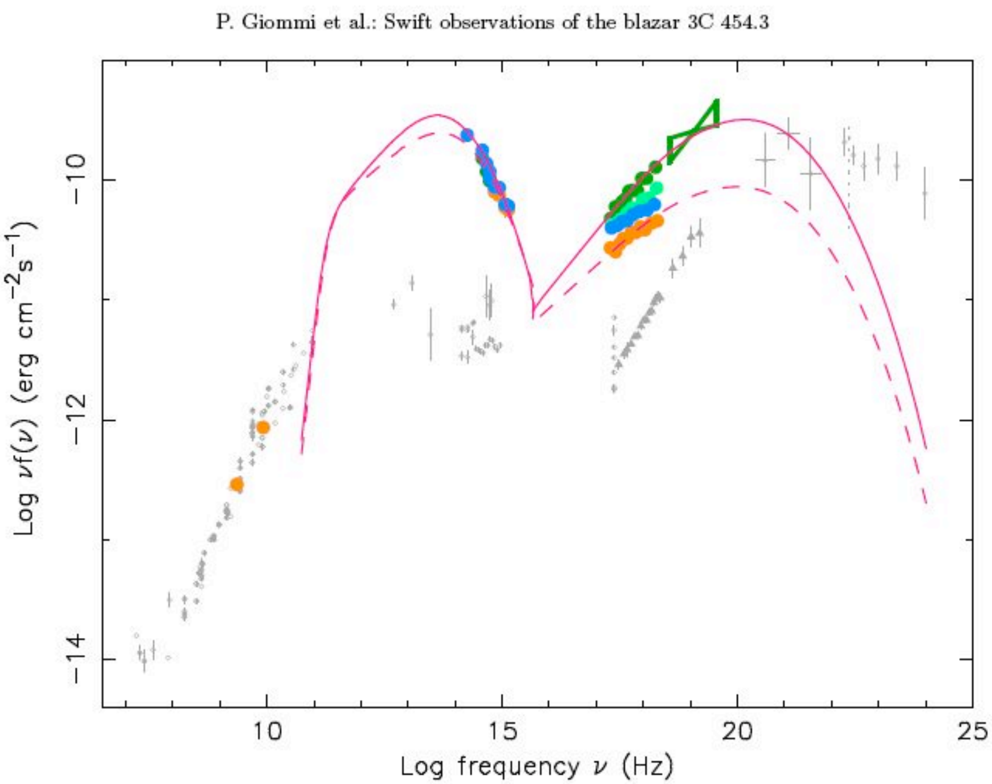




- **LAT has a huge field of view >20% of the sky (>2.5 sr)**
  - **Excellent for "catching" short bright transients**
- **In survey mode, the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time.**
- **The LAT will produce long, evenly sampled lightcurves for every source in the sky (excellent for blazar monitoring).**
- **Multiwavelength observations with the LAT will be limited only by the ability to coordinate to other observations in other wavebands.**

Swift: A perfect match

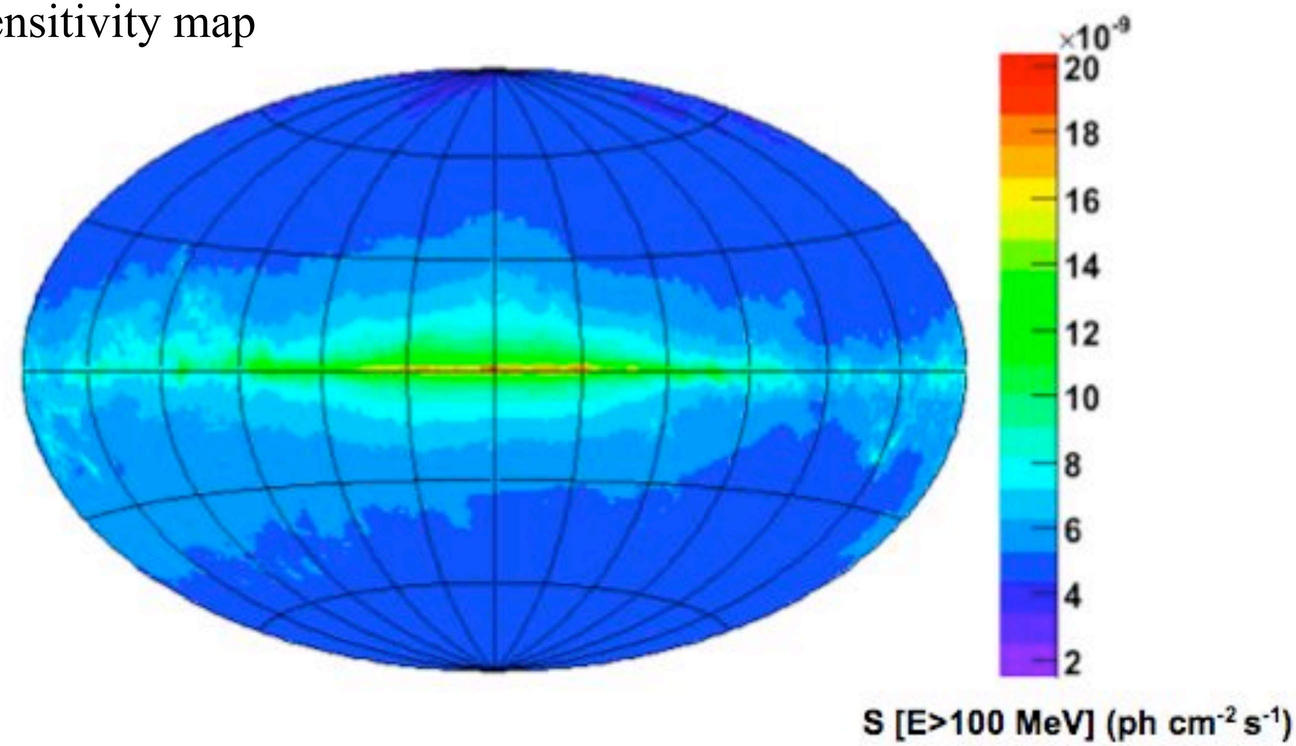
- ✓ Broad-band emission requires optical-to-X-ray coverage
- ✓ Rapid variability requires rapid maneuvers
- ✓ Unexpected flaring requires flexible scheduling and large fov (BAT)



Survey mode

- **Survey mode observations will produce uniform exposure on the sky -> minimize biases in population studies. Make it easier to compile unbiased gamma-ray selected samples.**

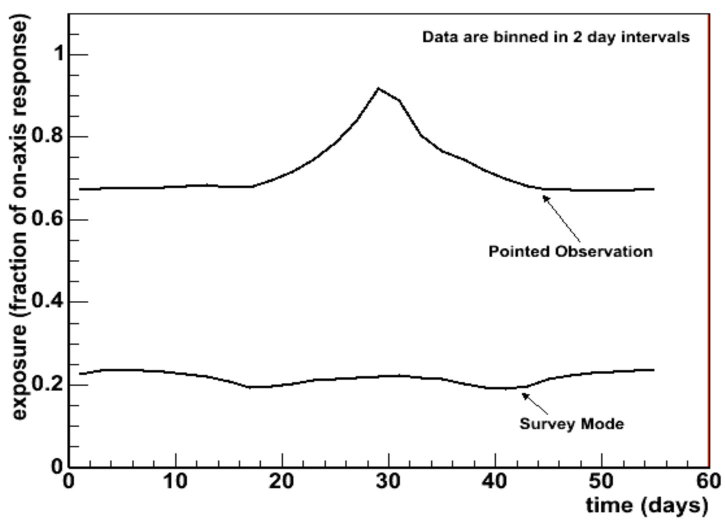
1-year 5 sigma sensitivity map



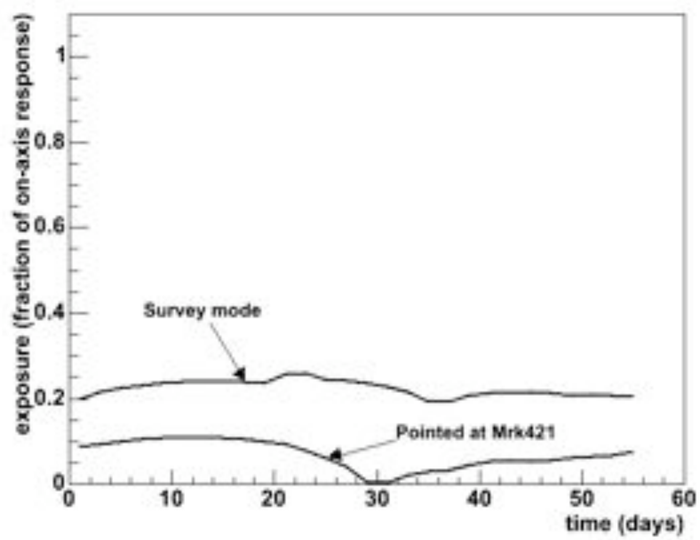
Survey mode observations

- **Survey mode is designed to provide uniform coverage over as short a timescale as possible**
  - **Thus also provides continuous uniform temporal coverage down to short timescales.**

Mrk 421

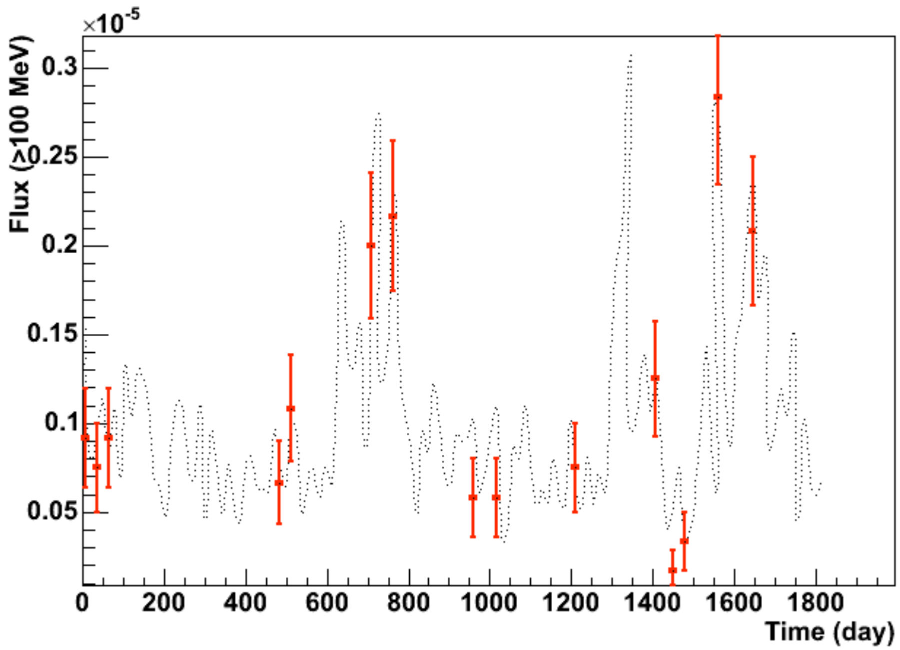


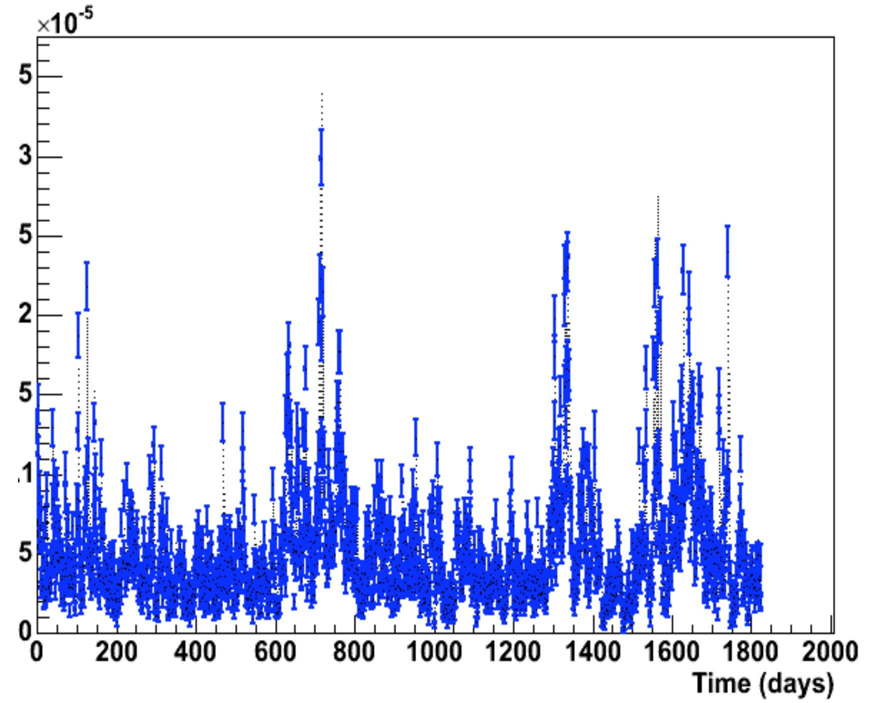
PKS 1622-295



Long term monitoring

Simulated 5 year AGN lightcurve with simulated EGRET (red) and LAT (blue) observations.





LAT will provide detailed unbiased sampling of the lightcurves of a large number of gamma-ray bright objects on a wide range of timescales.

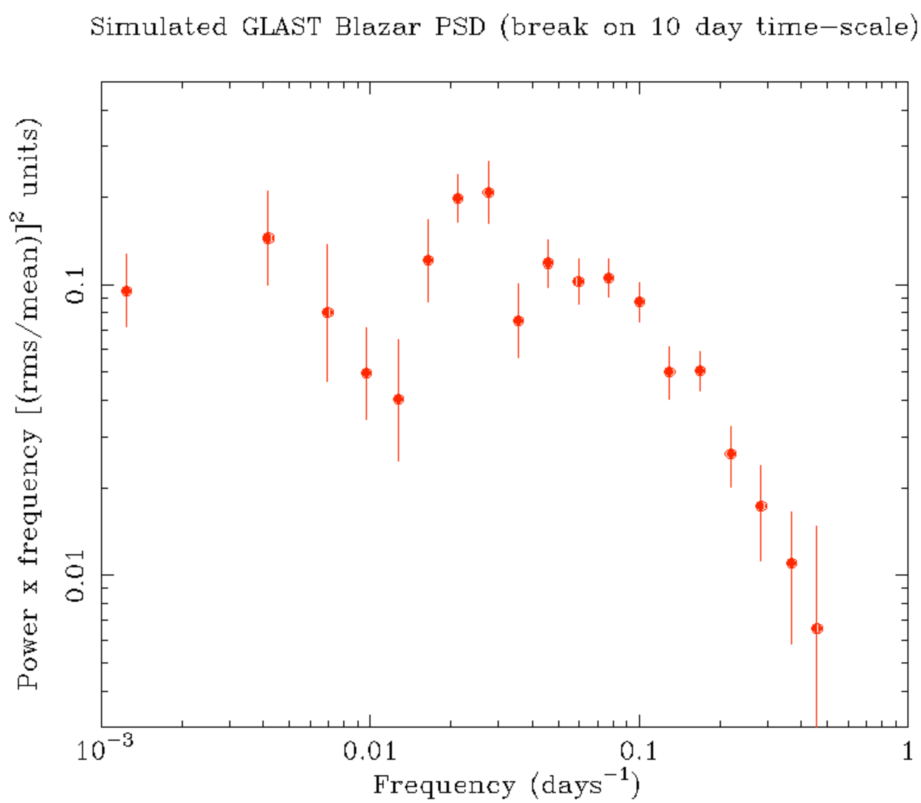
=> contribute to the understanding of the underlying causes of the variability

Long term lightcurves

- **The long duration, evenly sampled lightcurves will allow the calculation of higher order variability products.**

PSD from the lightcurve shown on the previous slide (calculated by P. Uttley), illustrating our ability to determine a break timescale

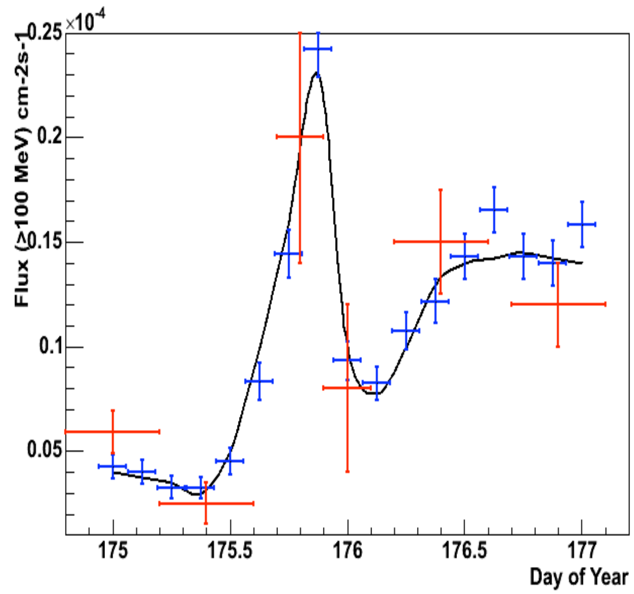
Enable search for QPO or possibly periodic signals



Short timescale variability

- **Survey mode observations will allow us to “catch” the brightest things in the sky.**
- **Increased effective area will allow us to resolve variability to shorter timescales (which would have been photon limited with previous instruments)**

EGRET observations (red points) of a flare from PKS 1622-297 in 1995 (Mattox et al), the black line is a lightcurve consistent with the EGRET observations and the blue points are simulated LAT observations. **In survey mode, the LAT would detect a flare like this from any point in the sky at any time!**

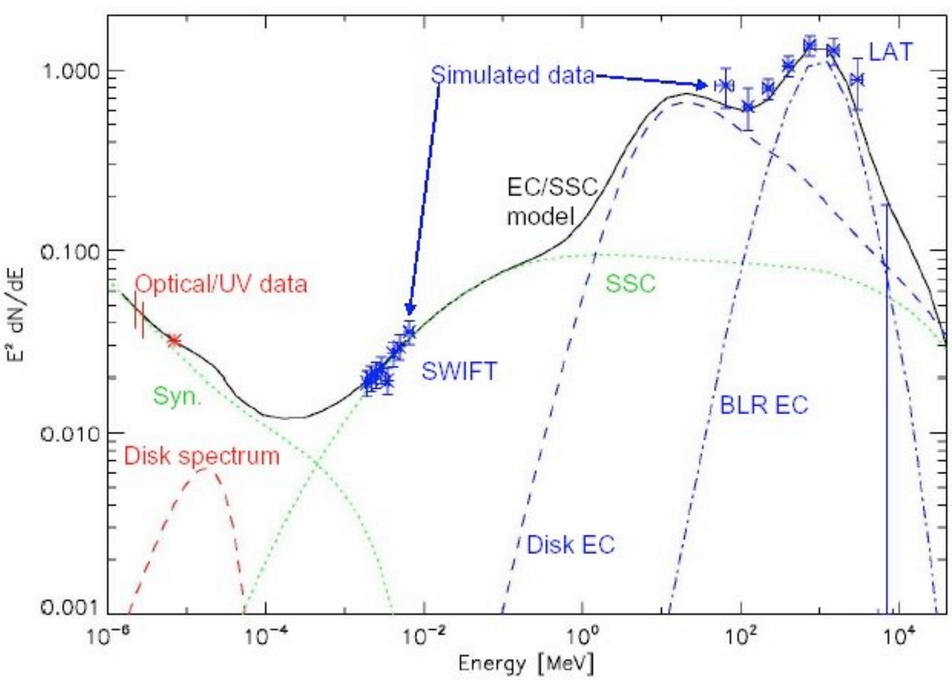


- **TOO observations at other wavebands triggered by GLAST**
- **Identify bright blazars for detailed studies at other wavebands - i.e. soft X-ray observations of blazars to probe WHIM.**

Time Resolved Spectroscopy

3C279 simulations: optical/X-ray data constrain the underlying electron distribution, LAT data probe the optical/UV radiation fields in the emission region.

Gamma-ray spectra are for a 1 week integration



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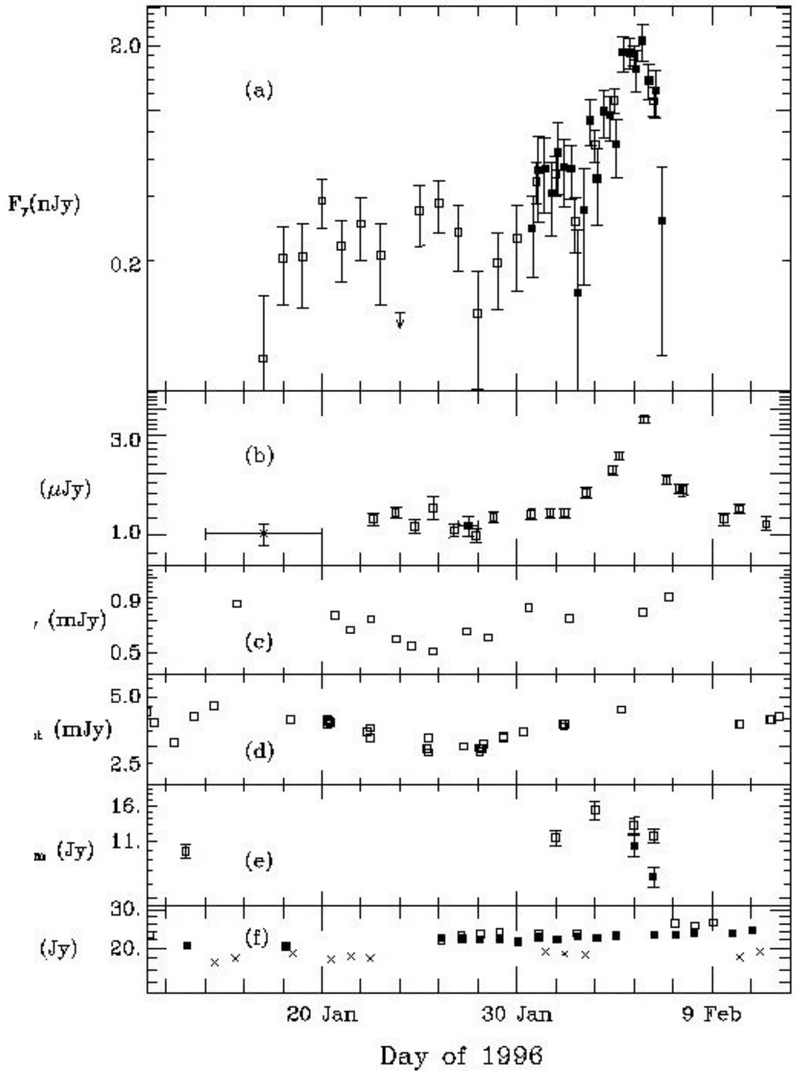
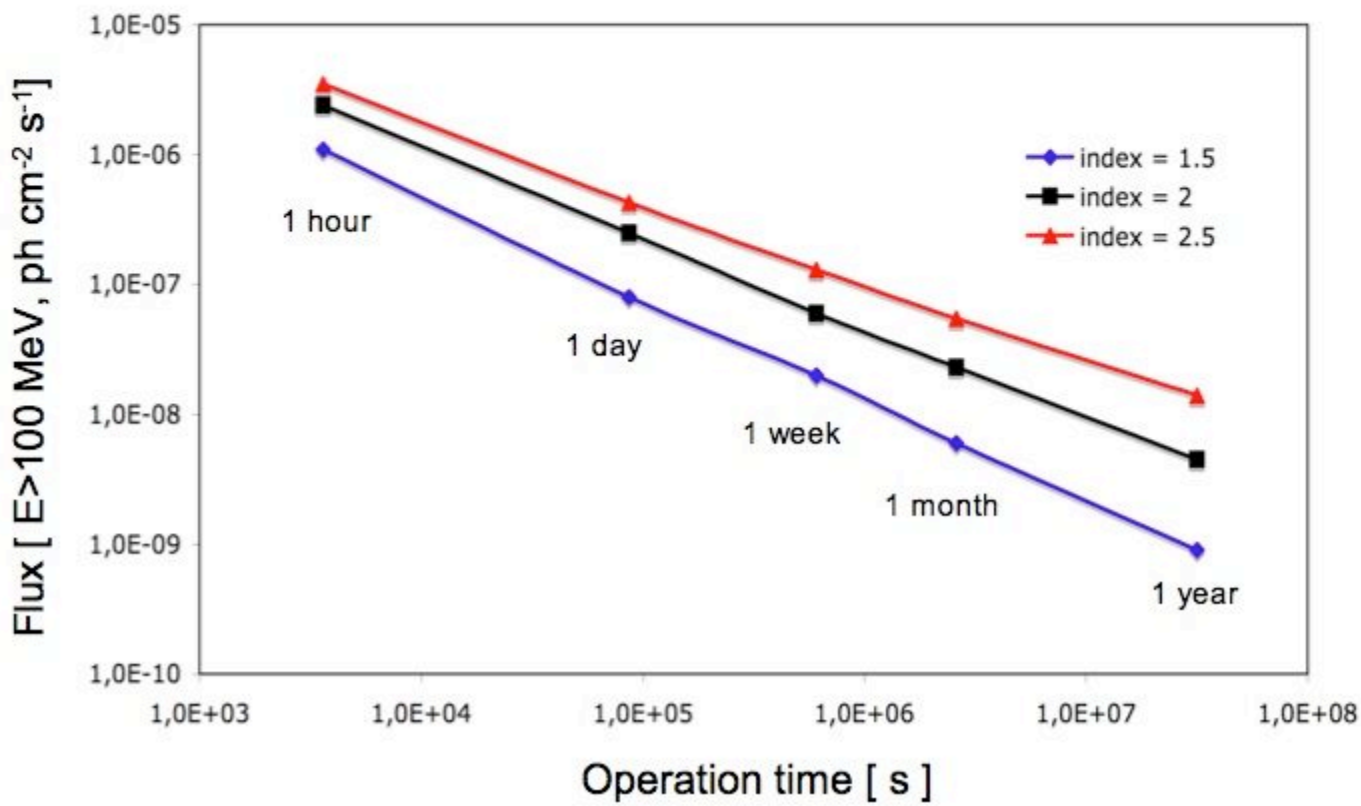
Wehrle 1997



A word of caution

- **Even with GLAST, only the very brightest sources can be seen on timescales of hours**



V. Lonjou

Putting this in context

Except for gamma-ray bursts, none of the sources are bright enough to produce statistically-significant detections of very short time variations.

Time estimates

Source	l (deg)	b (deg)	z	Flux*/index	Time**
BL Lac	92.6	-10.44	0.069	11.1 /2.60 39.9/2.60	20 d 2 d
3C273	289.9	64.4	0.158	15.4/2.58	5.5 d
3C279	305.10	57.06	0.536	74.2/1.96 1000/2	4 h 9 min
PKS0528+134	191.4	-11.01	2.06	93.5/2.46 300/2.21 30/2.5	11 h 1.4 h 3 d
PKS2155-304	17.73	-52.25	0.116	13.2/ 2.35	5 d
1ES1959+650	98.0	17.7	0.047	13.3/2.45	9.5 d

* [E>100 MeV] 10^{-8} ph $cm^{-2}s^{-1}$

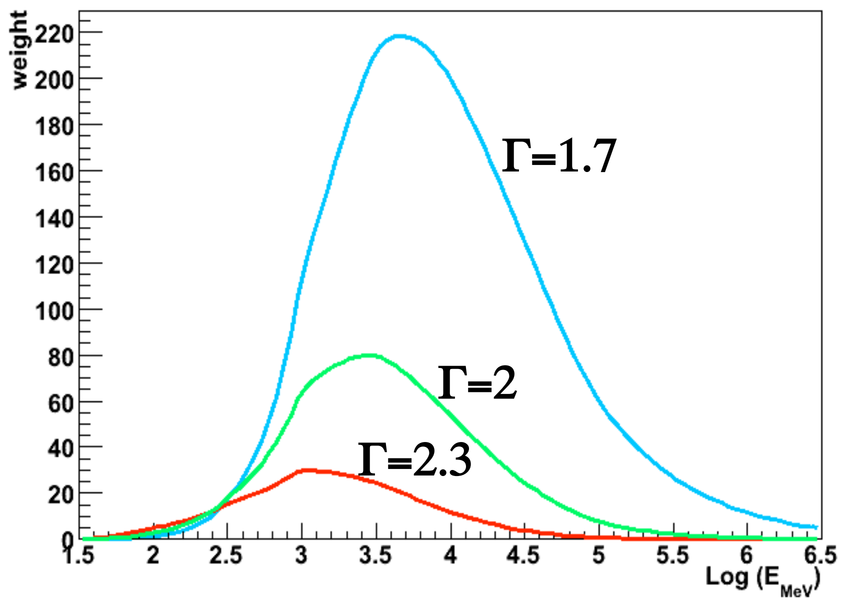
** to achieve 5 σ

Estimates of times for source detections with LAT.

GLAST Energy Range

- The LAT energy range extends to much higher energies compared with previous space borne observatories.
  - Broad energy range implies that we will have good sensitivity to identify non-power law spectral shapes.
- Peak sensitivity is significantly higher (1-10 GeV) than for EGRET.

$$TS = 2T_0 \int A_{eff}(E) S_B(E) dE \int \left[1 + g(r,E)\right] \ln\left[1 + g(r,E)\right] - g(r,E) d\Omega$$



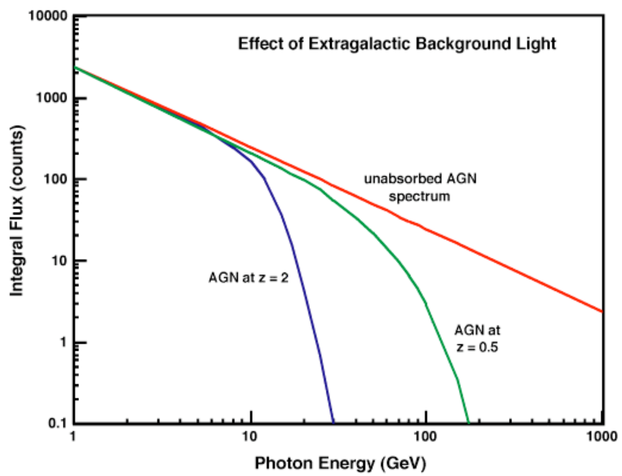
$S_s(E) \propto E^{-\Gamma}$

B. Lott

Maximum sensitivity between 1 and 10 GeV (depending on spectrum)

Energy range

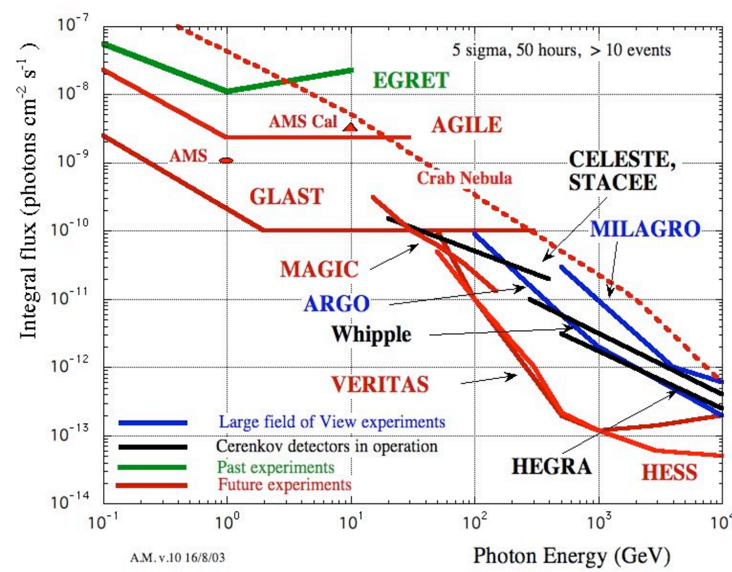
The LAT has greatly improved sensitivity w.r.t. EGRET at high energies.
Lots to be learned from measuring high energy cutoffs (acceleration mechanisms, radiation and magnetic fields at the source)



Extragalactic background light (EBL):
Photons with E>~10 GeV are attenuated by the diffuse UV-optical-IR EBL. Measurement of attenuation of high energy spectra as a function of redshift will provide information on the EBL.

TeV Connection: Ground-based and space based gamma-ray instruments will overlap in energy coverage for the first time.

The entire range from 30 MeV – 30 TeV will be covered with unprecedented sensitivity. Including the as yet unexplored region from ~10 GeV – 100 GeV.



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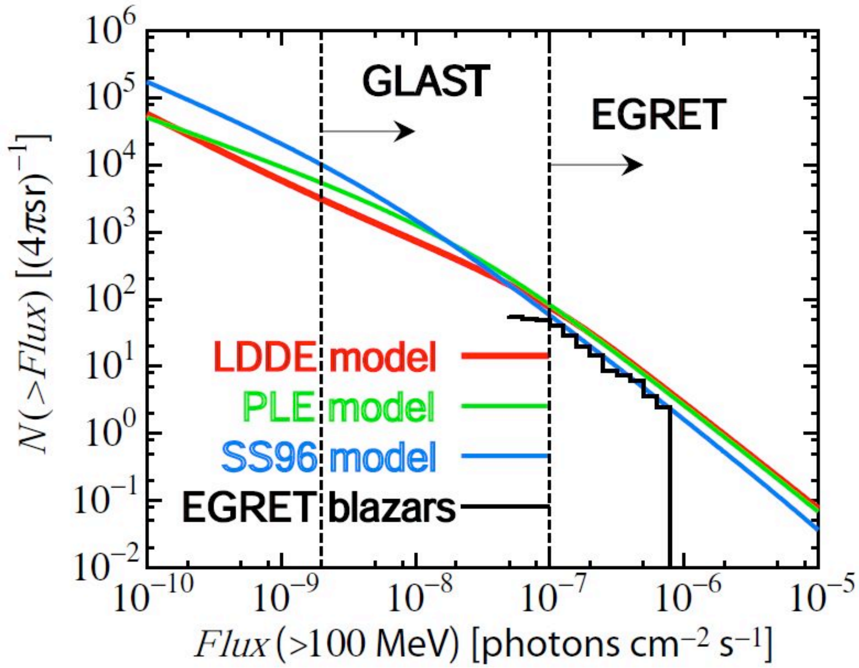
Population Studies with GLAST

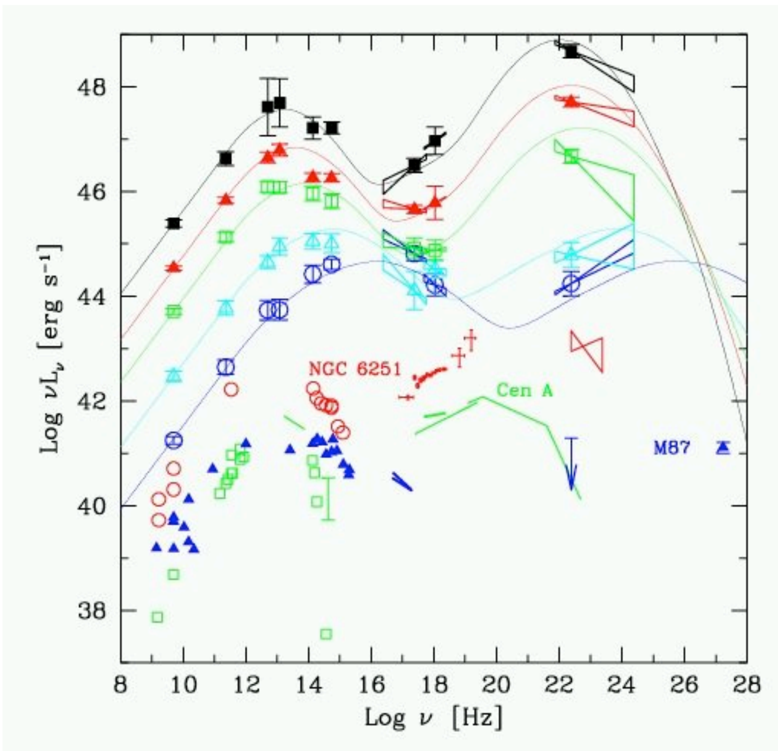
- GLAST will detection 1500-10,000 blazars (estimates depend on assumptions of redshift distributions and luminosity functions.
- The broad energy range of GLAST implies that the sample will contain "GeV-like" and "TeV-like" objects.
- Greater sensitivity and temporal coverage:
    - Detailed spectral informatio
    - Variability properties
  – Many more observational handles to use in population studies.

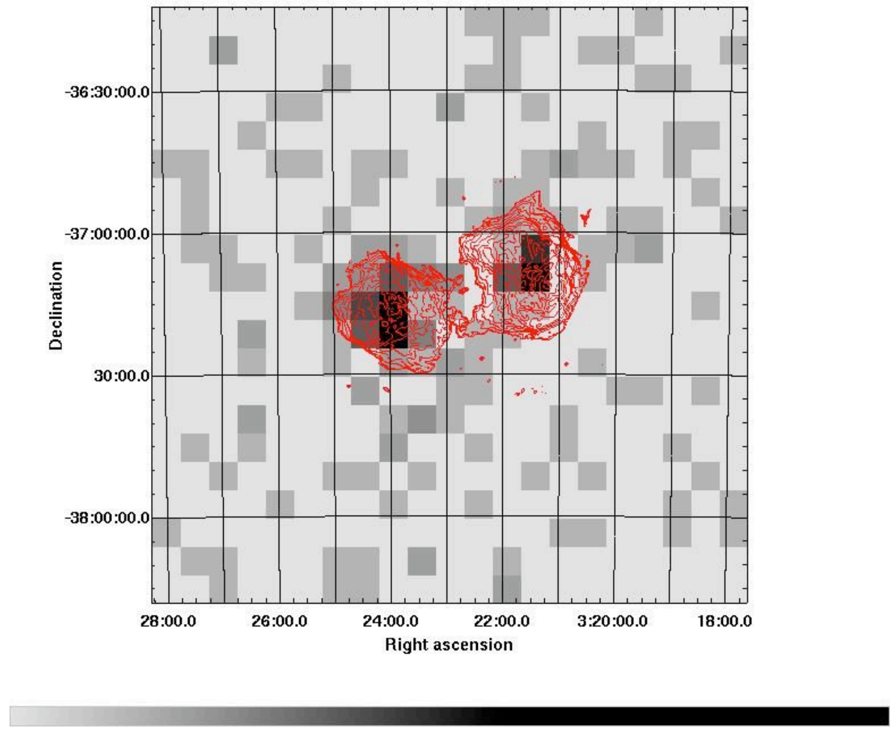
Narumoto and Totani 2005



New Sources

- **Radio galaxies**





LAT First Year Source Monitoring List

Flux/spectra as a function of time (daily and weekly integrations) for all sources in the list.

PLUS, same for any source flaring above 2e-6 ph/cm^2/s until the flux drops below 2e-7 ph/cm^2/s (~several per month)

A "quicklook" analysis to get the results out as quickly as possible. Tables will be updated as analysis and calibrations improve.

Source Type	Source Name	EGRET Name	Average or Min. Flux (10^{-8} γ $cm^{-2}s^{-1}$)	Galactic Lattitude	Redshift	TeV Source
Blazar	0208-512	3EGJ0210-5055	85.5 ± 4.5	-61.9	1.003	
	0235+164	3EGJ0237+1635	65.1 ± 8.8	-39.1	0.94	
	PKS 0528+134	3EGJ0530+1323	93.5 ± 3.6	-11.1	2.060	
	PKS 0716+714	3EGJ0721+7120	17.8 ± 2.0	28	0.3	
	0827+243	3EGJ0829+2413	24.9 ± 3.9	31.7	0.939	
	OJ 287	3EGJ0853+1941	10.6 ± 3.0	35.8	0.306	
	Mrk 421	3EGJ1104+3809	13.9 ± 1.8	65.0	0.031	Yes
	W Com 1219+285	3EGJ1222+2841	11.5 ± 1.8	83.5	0.102	
	3C 273	3EGJ1229+0210	15.4 ± 1.8	64.5	0.158	
	3C 279	3EGJ1255-0549	74.2 ± 2.8	57.0	0.538	
	1406-076	3EGJ1409-0745	27.4 ± 2.8	50.3	1.494	
	H 1426+428	NA		64.9	0.129	Yes
	1510-089	3EGJ1512-0849	18.0 ± 3.8	40.1	0.36	
	PKS 1622-297	3EGJ1625-2955	47.4 ± 3.7	13.4	0.815	
	1633+383	3EGJ1635+3813	58.4 ± 5.2	42.3	1.814	
	Mrk 501	NA		38.9	0.033	Yes
	1730-130 NRAO 530	3EGJ1733-1313	36.1 ± 3.4	10.6	0.902	
	1ES 1959+650	NA		17.7	0.048	Yes
	PKS 2155-304	3EG2158-3023	13.2 ± 3.2	-52.2	0.116	Yes
	BL_Lacertae (2200+420)	3EGJ2202+4217	39.9 ± 11.6	-10.4	0.069	Yes
	3C 454.3	3EGJ2254+1601	53.7 ± 4.0	-38.3	0.859	
	1ES 2344+514	NA		-9.9	0.044	Yes
HMXB	LSI+61 303 2CG135+01	3EGJ0241+6103	69.3 ± 6.1	1.0		Yes

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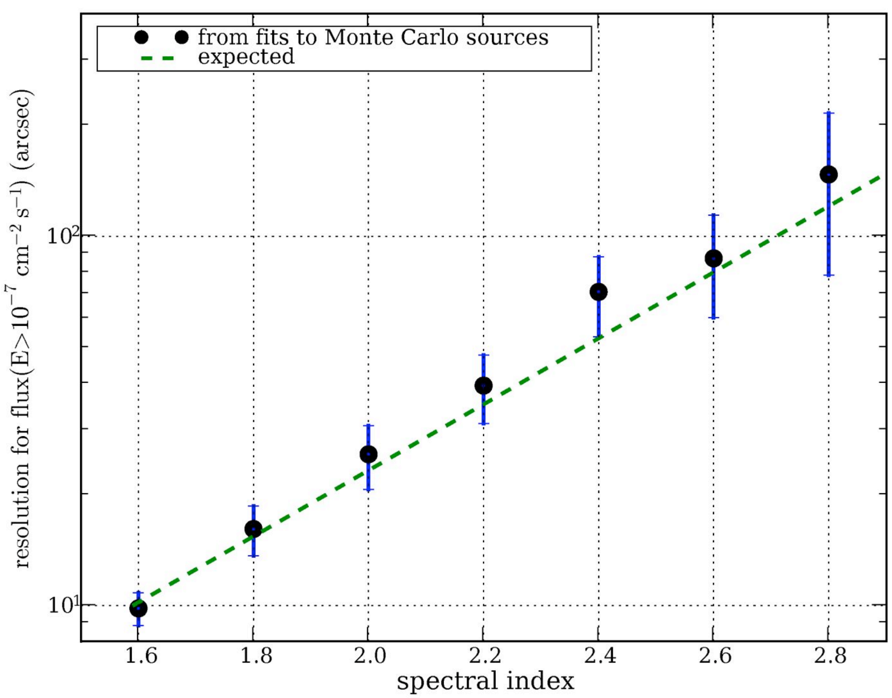
Flaring Source Localization

- **It is likely that at least some of the released flaring sources will not have a confirmed counterpart (I.e. we won't be sure what it is)**



Localization as a function of spectral index for a source flux of 1e-7 ph/cm2/s for a one year observation.

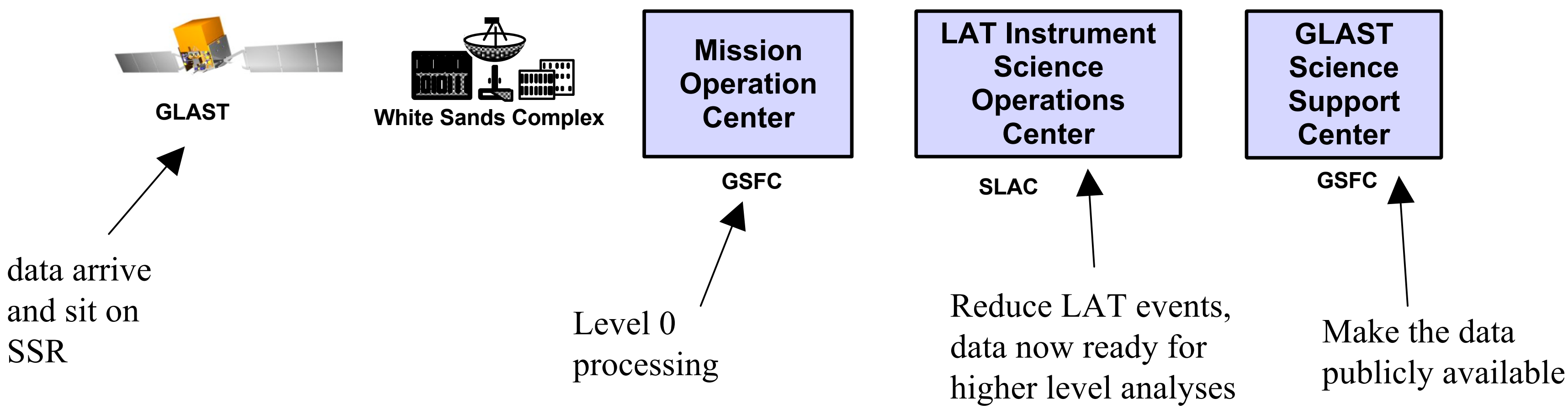
Scales as ~1/sqrt(flux), ~1/sqrt(time)

- **Flaring sources: 1e-6 integrated for one week would result in 0.5'-5' locations (depending on spectral index)**

Where is my data?

Data are reduced and made publicly available relatively quickly.

LAT DATA PATH



- At the ISOC, LAT data are processed (calibrated etc) and initial "quicklook" analysis (monitoring of known sources and search for transient events) is performed.
- After the first year, all LAT data will be made publicly available from the GSSC.
- The latency requirement for both of these is several days but the system, as currently designed, may reduce this to 12 hours or less in the nominal case.

Data Release plan and operations

- First Year observations - Sky Survey
  - After initial on-orbit checkout (60 days), the first year of observations will be a sky survey.
  - Repoints for bright bursts and burst alerts will be enabled
  - Extraordinary ToOs will be supported.
  - First year data will be used for detailed instrument characterization and key projects (catalog, background models etc).
- First Year Data release
  - All GBM data
  - Information on all LAT detected GRB (flux, spectra, location)
  - High level LAT data (time resolved flux/spectra) on ~20 selected sources and on all sources which flare above $2x10^{-6}$, continued until the source flux drops below $2x10^{-7}$ (rate ~ 1-4 such objects per month).
  - The LAT team will produce a preliminary source list after ~6 months on a best effort basis
- Subsequent years: Observing plan driven by guest observer proposal selections by peer review. Default is sky survey mode.
  - All data publicly released within 72 hours through the Science Support Center (GSSC).
- See http://glast.gsfc.nasa.gov/ssc/data/policy/ for more details

GLAST status

- Observatory is currently in Florida undergoing final testing.
- Rocket is partially assembled
  - First stage and all solid boosters completed
  - Second stage will be added in the next day or so.
- Launch TBD (likely late May or early June, 2008)

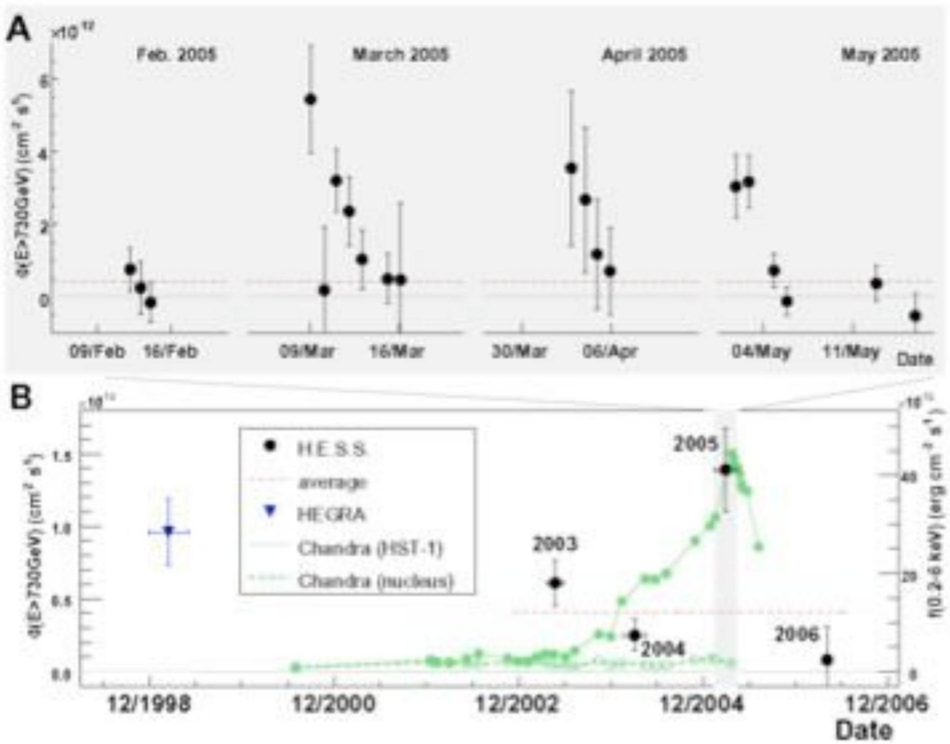
Conclusions

- GLAST: new fundamental constraints on AGN high-energy emission/identification
- New sources

- Success of GLAST blazar science will depend on level of coordinated multiw observations

backup

Identifying the Gamma-Ray Emission region



M87: Suggestion of correlated variability between Chandra (x-ray) and HESS (gamma-ray) observations of HST1

- **Illustrates the value of joint observations!**
- **A much more conclusive analysis could be done if the gamma-ray and X-ray lightcurves were differently sampled.**