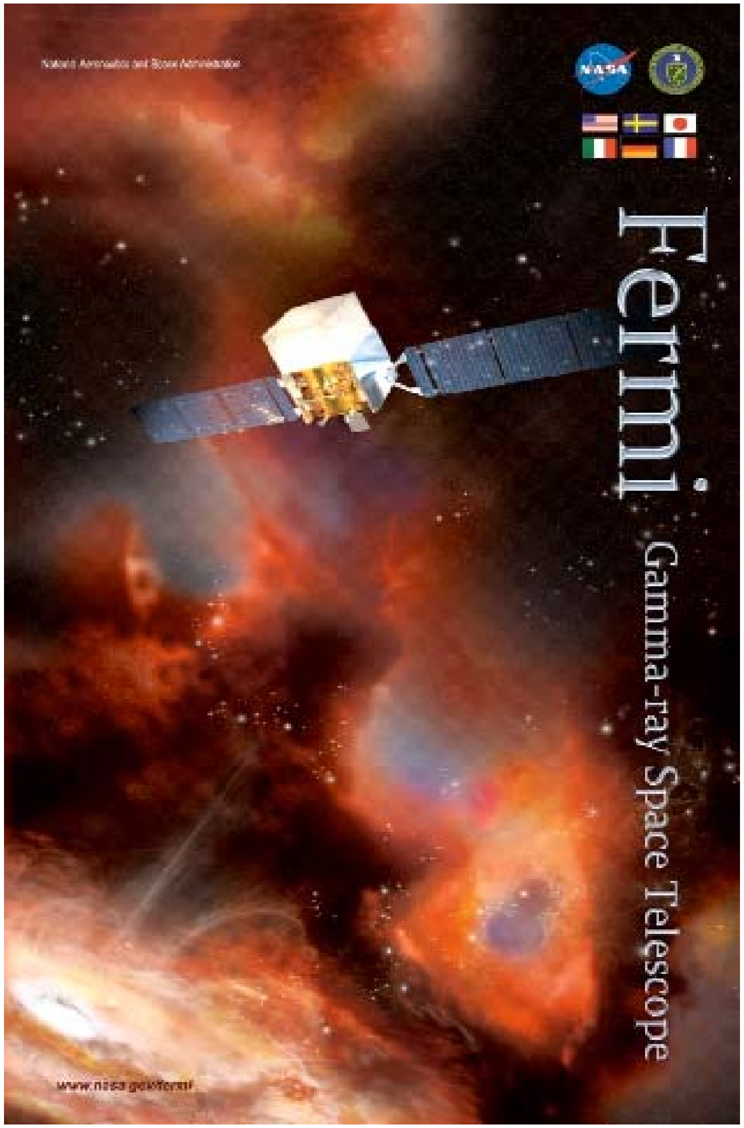
Fermi
Gamma-ray
Space Telescope



First results on Fermi LAT observations of AGNs

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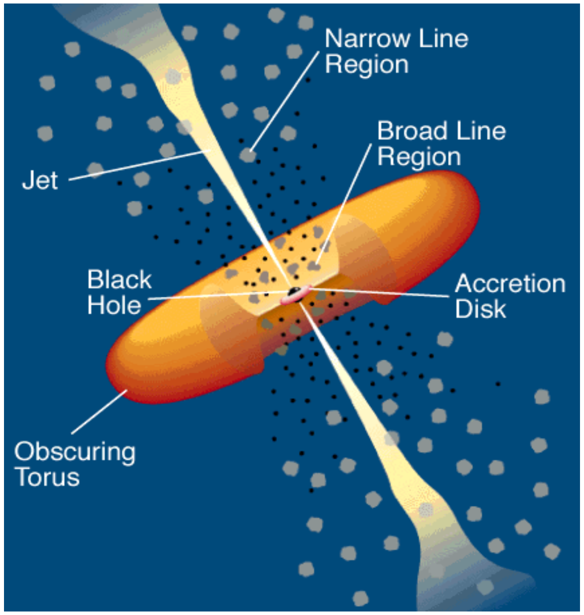
On behalf of the Fermi LAT collaboration

AGN & blazar characteristics



Almost all galaxies contain a massive black hole

★ 99% of them are (almost) silent (e.g. our Galaxy)

★ 1% is active (mostly radio-quiet AGNs): accretion onto a central, supermassive black hole Accretion disks produce optical/UV/X-ray emission via various thermal processes

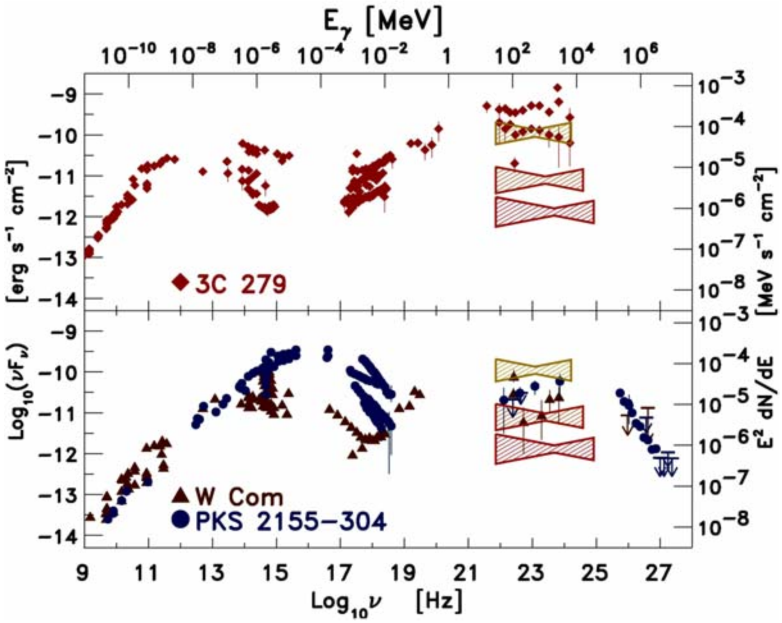
★ 0.1% is radio loud: jets mostly visible in the radio

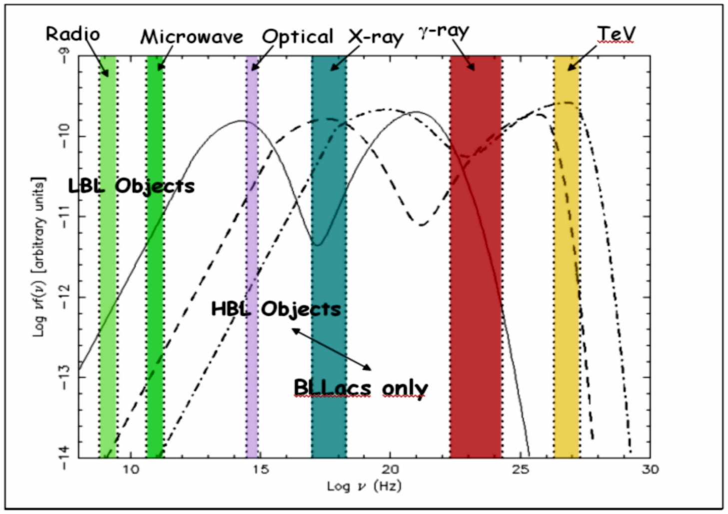
★ Jets: highly collimated relativistic outflows with Lorentz factor about 10

- ✓ Compact radio core, flat or inverted spectrum, relatively high radio and optical polarization
- ✓ Extreme variability at all frequencies (gamma-rays too), large brightness temps, superluminal motion
- ✓ Unified Model: observer line-of-sight determines source properties, e.g., radio galaxy vs blazar
- ✓ Other factors: accretion rate, BH mass and spin, host galaxy
- ✓ **FSRQs:** bright broad emission lines, sometimes a "blue bump" (accretion disc), multi-temperature disk emission, broad lines in OUV, non-thermal components peak in IR & hard X-ray/MeV regime, high luminosity (L $\sim 10^{48}$ erg s^{-1}) and $z \geq 1$
- ✓ **BL Lacs**: weak (EW<5 Å) emission lines, little or no evidence of disk or emission lines in Opt-UV, non-thermal peaks in UV/soft X-rays & GeV, lower luminosity (L$\sim 10^{45}$ erg s^{-1}) and z < 0.5

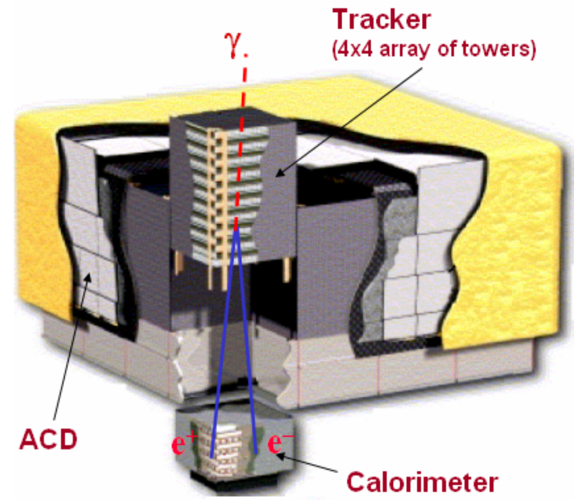
Key question for blazars

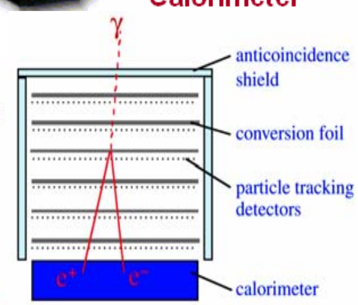
- Emission mechanisms (especially for high energy component)
  - Leptonic (IC of synchrotron or external photons) vs hadronic ($\pi_0 \rightarrow \gamma\gamma$, proton synchrotron)
- Emission location
  - Single zone for all wavebands (completely constraining for simplest leptonic models)
  - Opacity effects and energy-dependent photospheres
- Particle acceleration mechanisms
  - Shocks, Blandford-Znajek
- Jet composition
  - Poynting flux, leptonic, ions
- Jet confinement
  - External pressure, magnetic stresses
- Accretion disk—black hole—jet connection
- Blazars as probes of the extragalactic background light (EBL)
- Effect of blazar emission on host galaxies and galaxy clusters

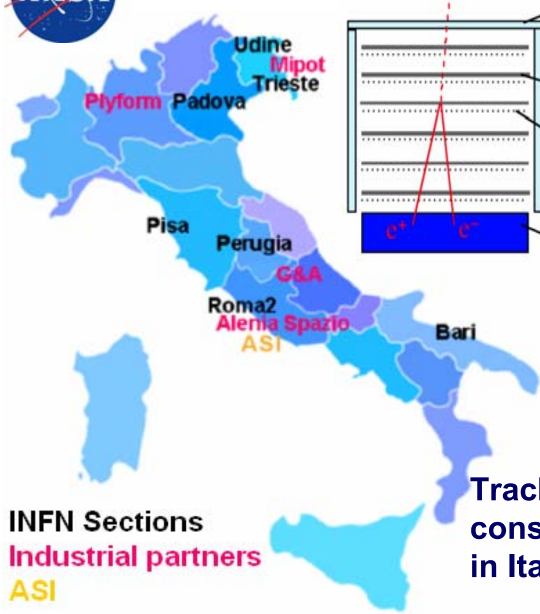




Fermi Gamma-ray Space Telescope (formerly GLAST)







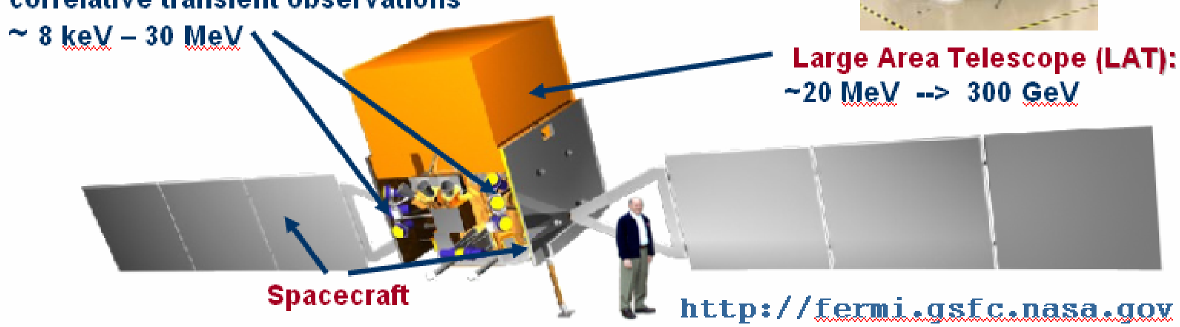
Tracker construction in Italy

The Large Area Telescope (LAT)

fgst.slac.stanford.edu

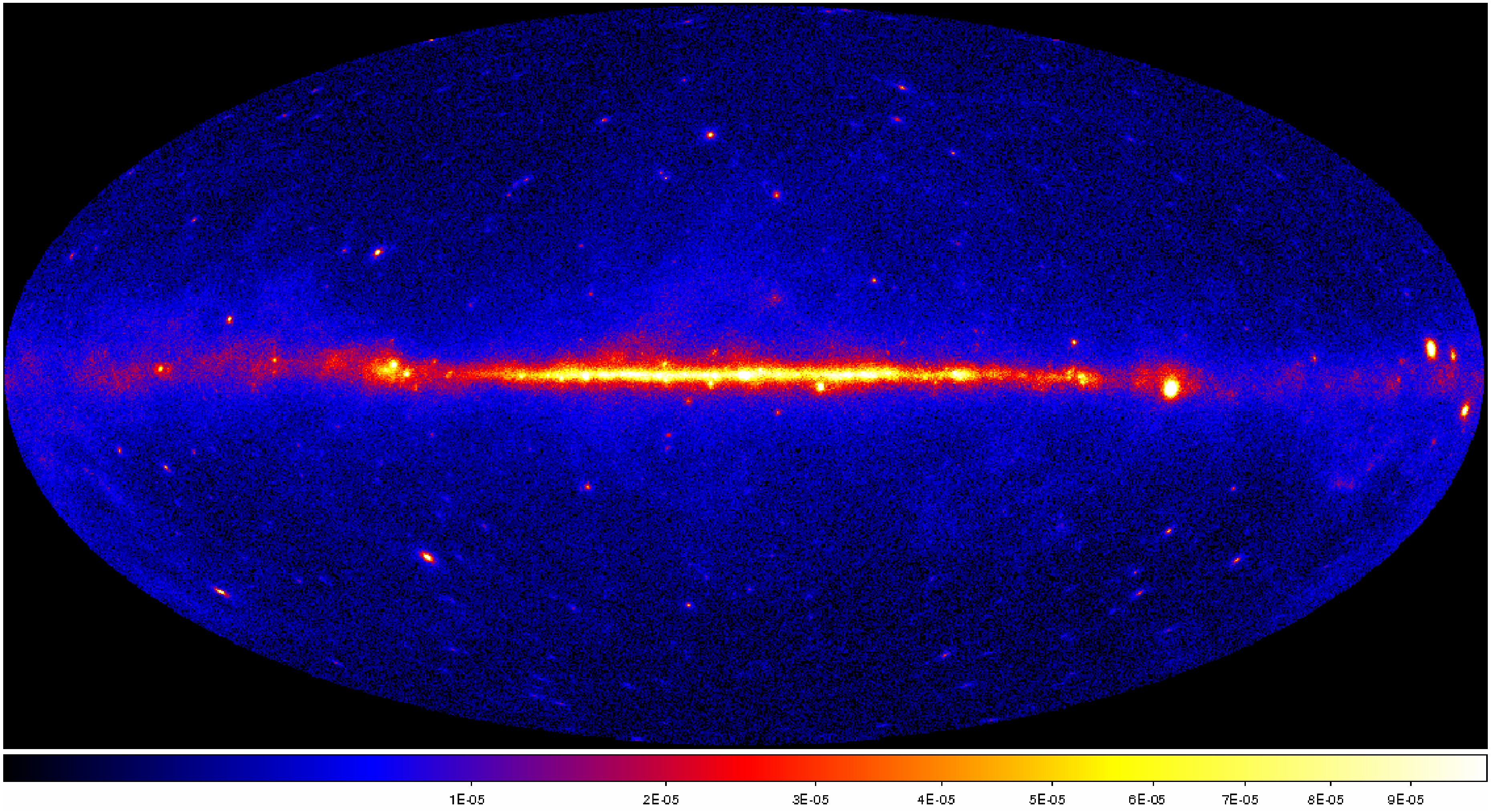
PI: P. Michelson (Stanford Univ.)

- Launched 11 June 2008
- 2.4 sr FOV
- First year survey mod operation: ±35° rocking about orbital plane each orbit ⇒ full sky coverage every 3 hours
- Energy range: 20 MeV to >300 GeV, ΔE/E ≈ 10–15 %



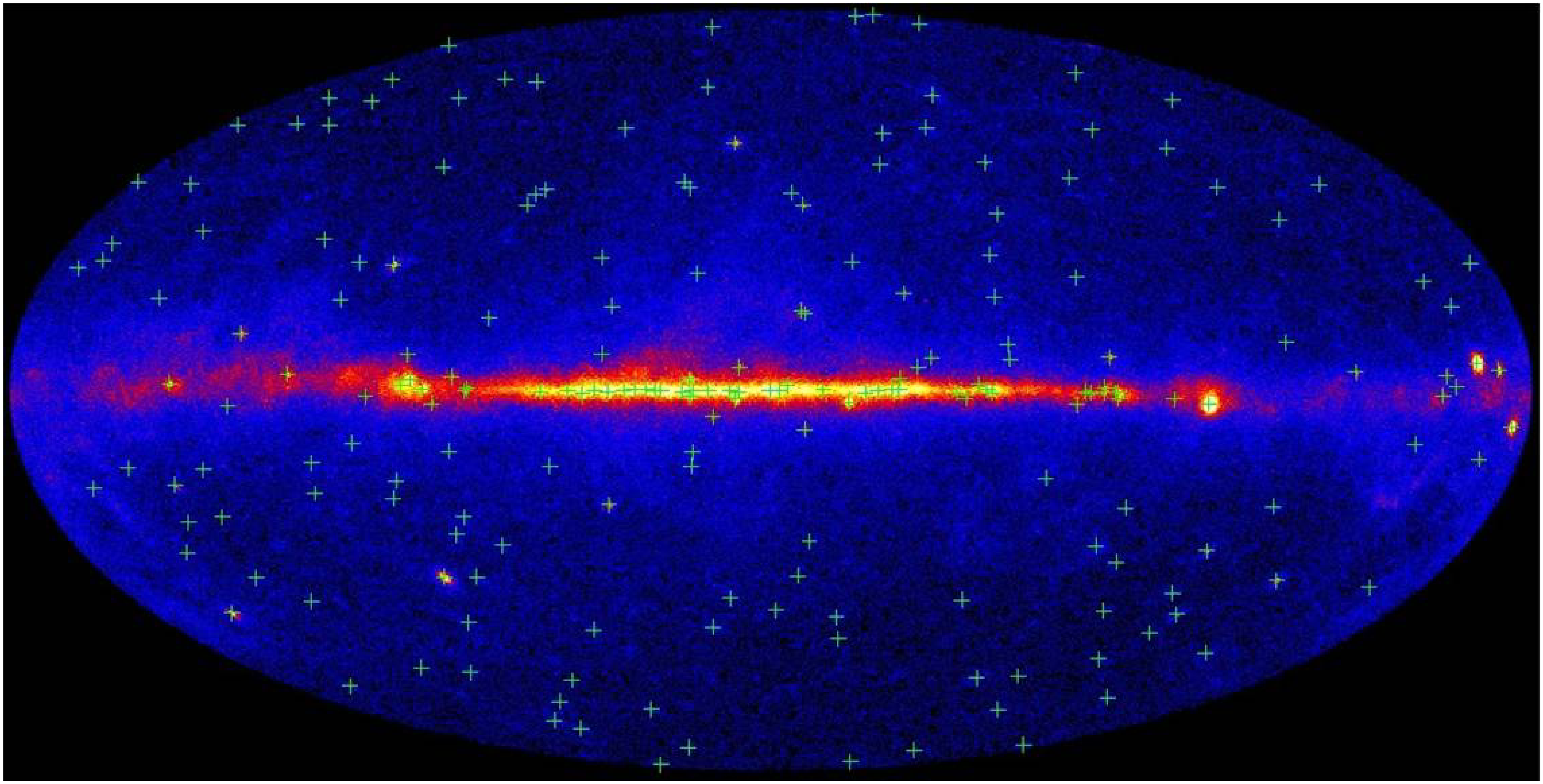
http://fermi.gsfc.nasa.gov

3 month photon counts map

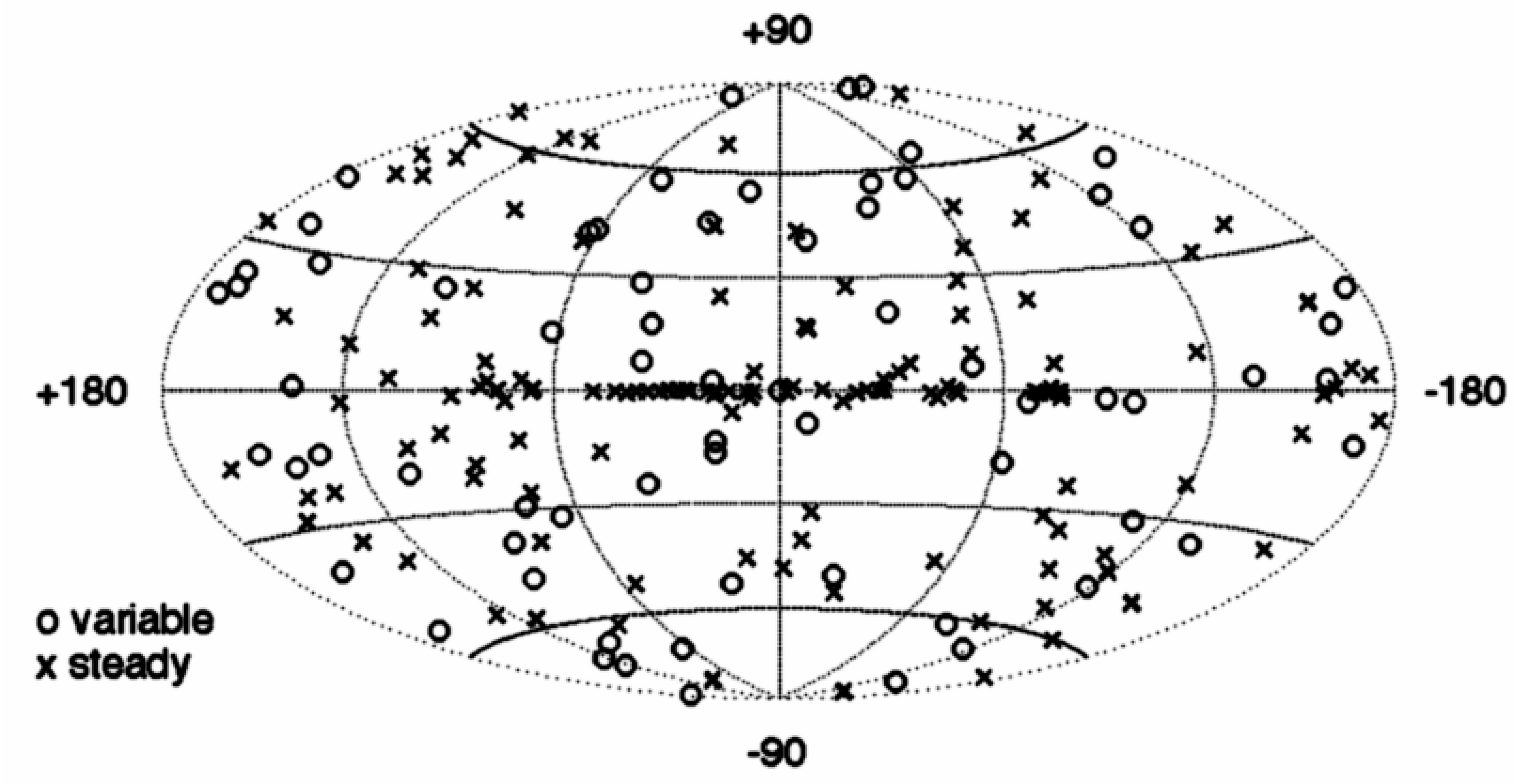


3 month high confidence source list

- **205 sources with significance > 10σ (EGRET found fewer than 30). Typical 95% CL error radius is <10 arcmin.**



Variable sources in the LAT Bright Source List



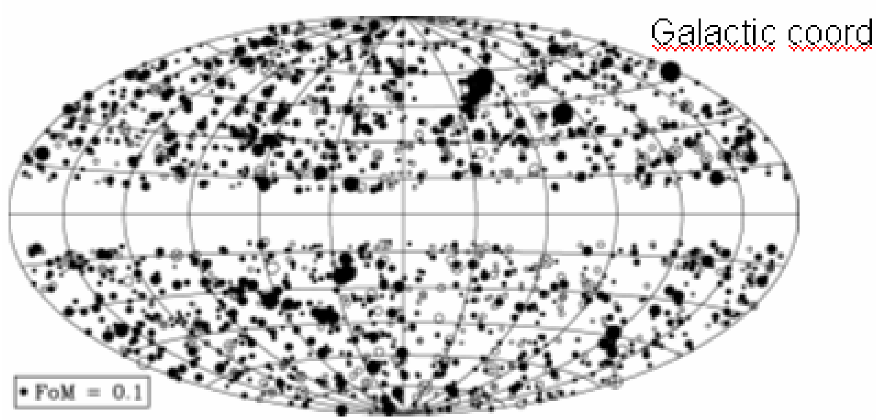
- **Based on 1 week time scales**
- **68/205 show variability with probability > 99%**
- **Isotropic distribution ⇒ blazars**

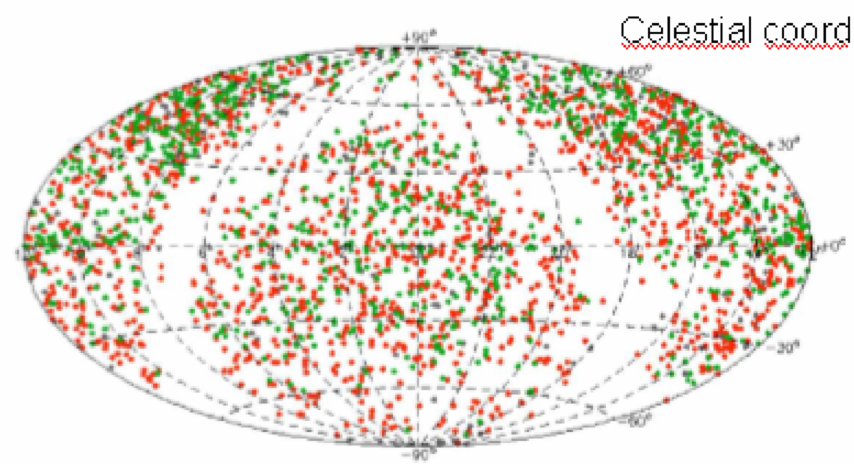
AGN/blazar associations

Fermi-GST LAT bright source list catalog, 0FGL:
132 sources with TS>100, |b|>10° 7 pulsars, **125 AGN candidates**

CGRaBS (Healey et al. 08)
1627 radio sources from CRATES
association based on Figure-of-Merit (spatial, radio and X spectrum) established from EGRET

BZCat (Massaro et al. 08)
Compilation of 2500 known blazars
association based on spatial coincidence (Mattox et al., 01)

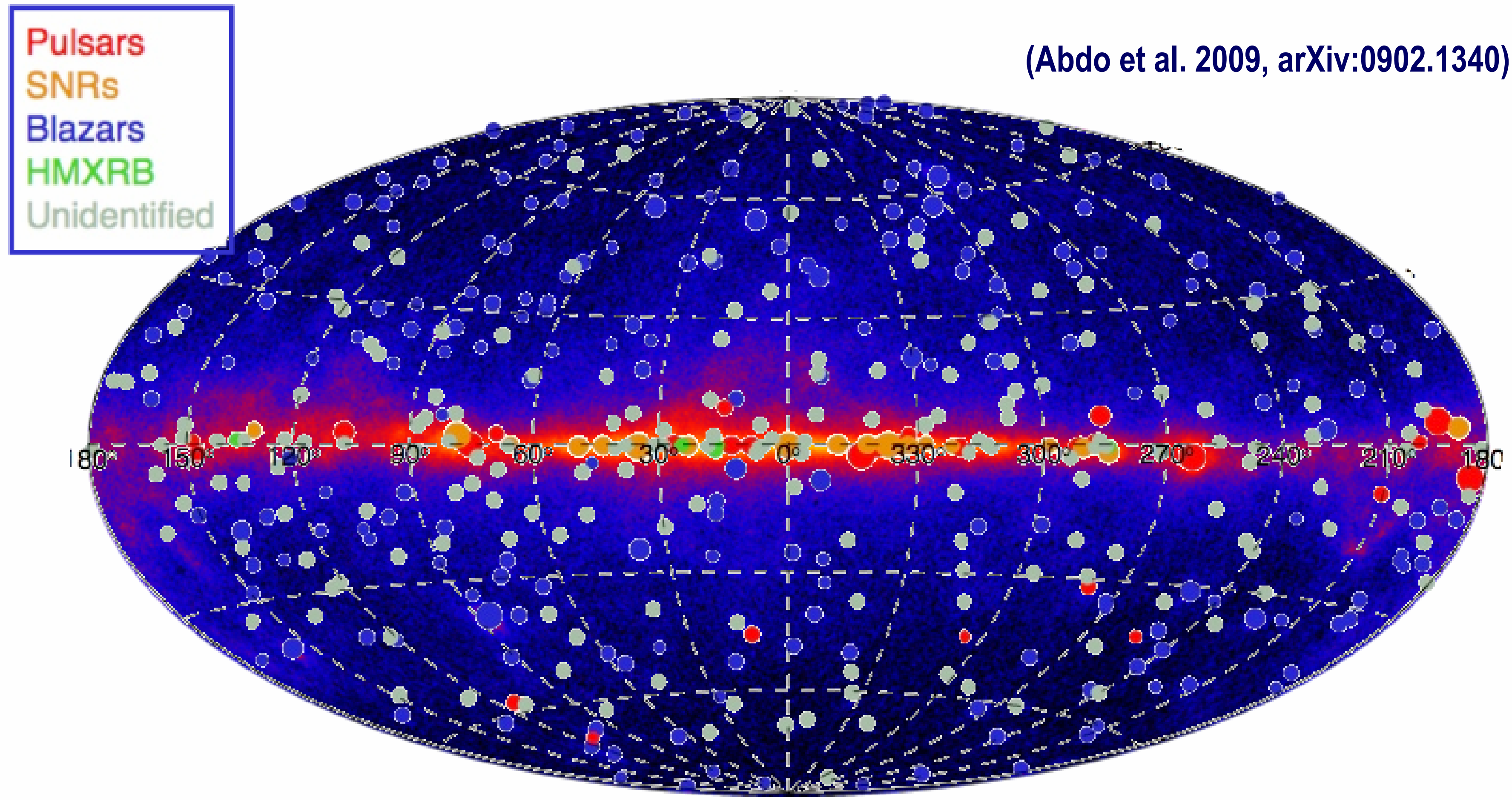




101 high-conf. (P>90%) associations
14 low-conf. (40%<P<90%) associations

102 high-conf. (P>90%) associations
4 low-conf. (40%<P<90%) associations

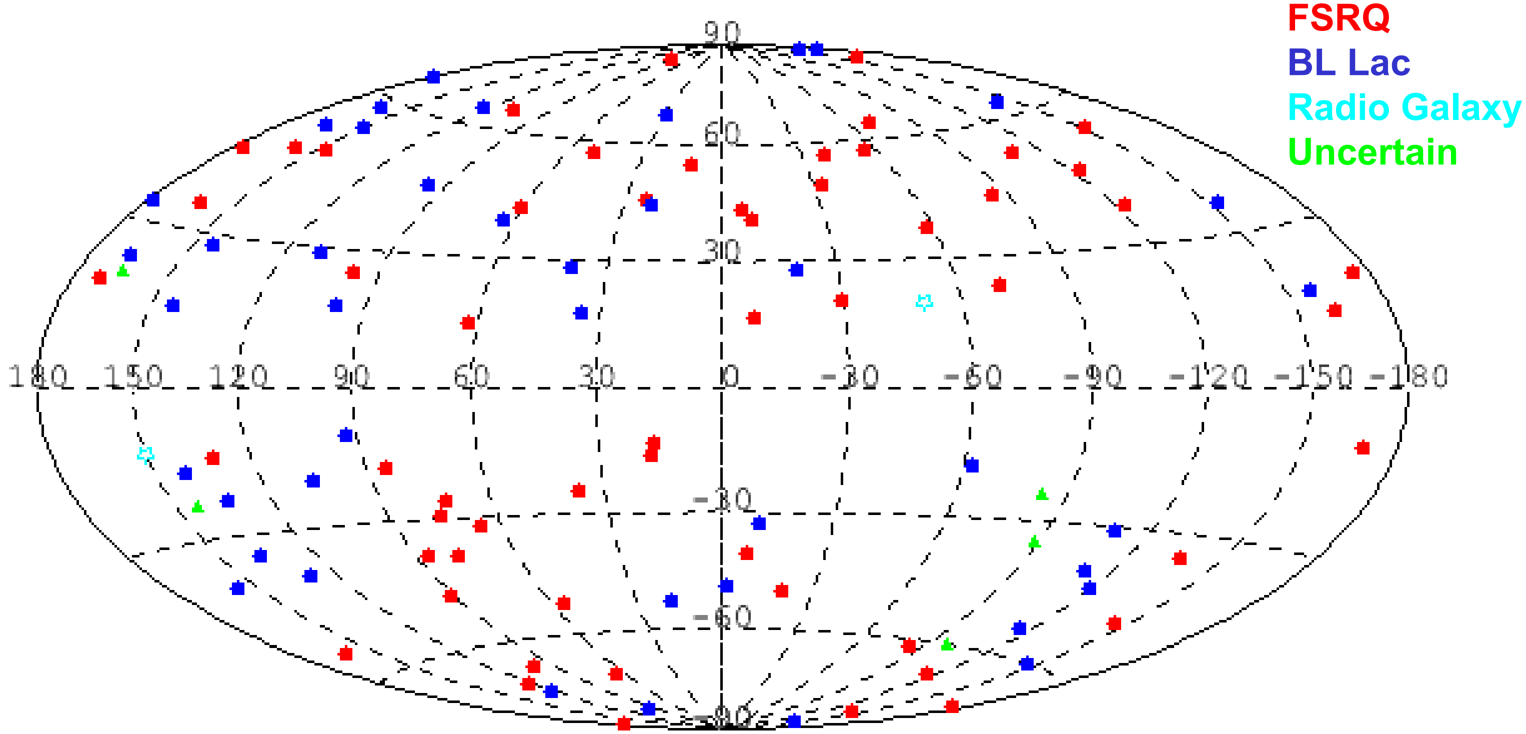
3-month Survey: 205 LAT Bright Sources (LBS)



- 205 sources with significance > 10σ (EGRET found fewer than 30).
- Typical 95% CL error radius is <10 arcmin. ~1/3 show variability.

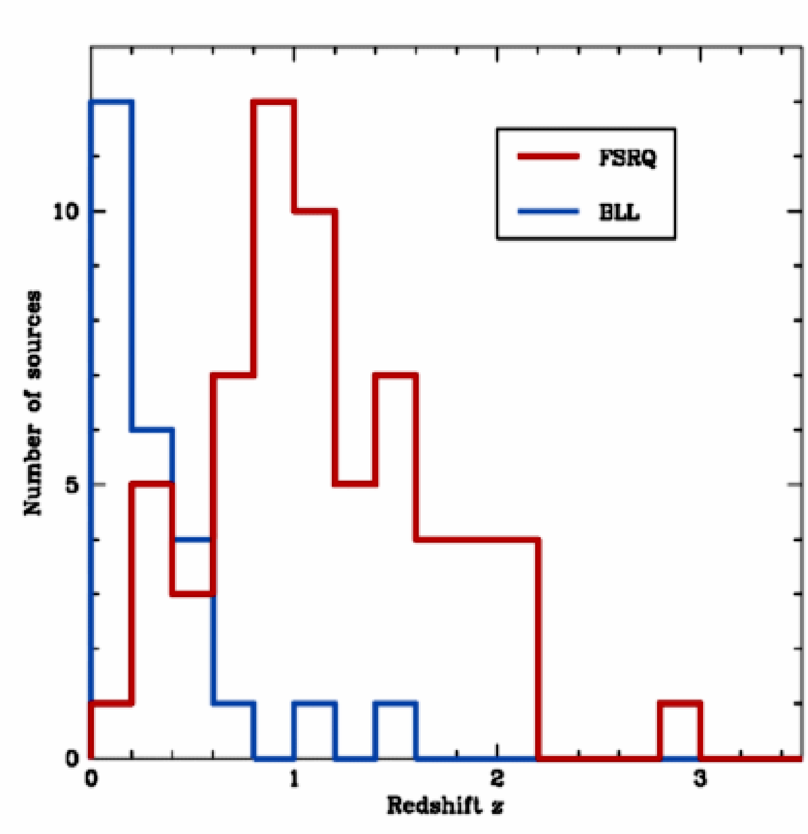
Blazar population properties

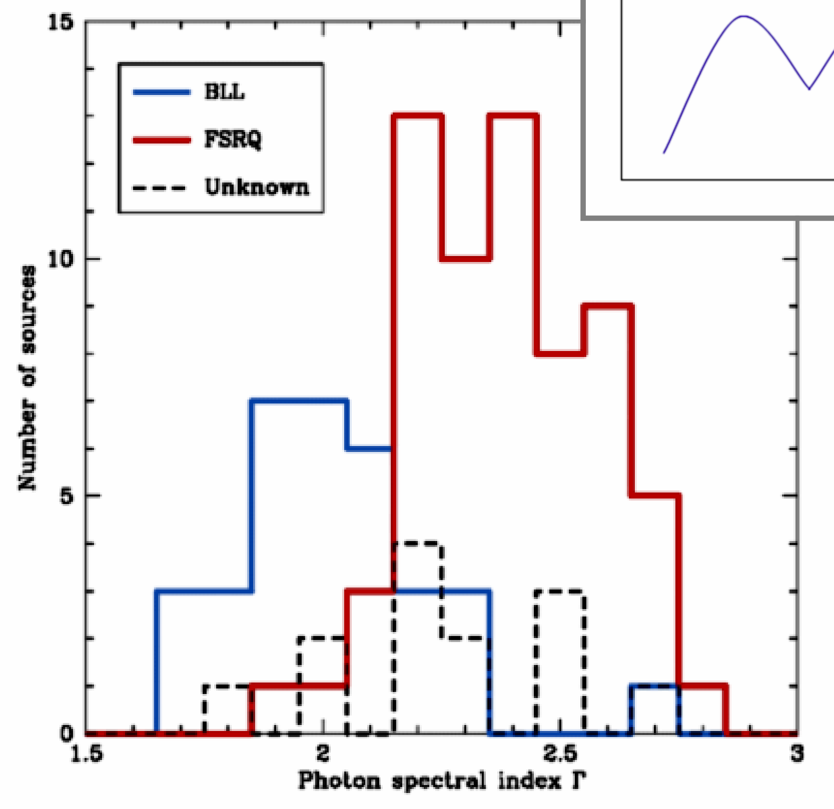
- Aug/Sep/Oct high confidence list: 205 sources with >10σ detection
- 132 with |b| > 10° (7 pulsars, 14 unid)
  - 111/125 are bright, flat spectrum radio sources
  - 98/111 have optical classifications, 89/111 have redshifts
  - CRATES (all-sky radio catalog), CGRaBS (all-sky optical spectra)

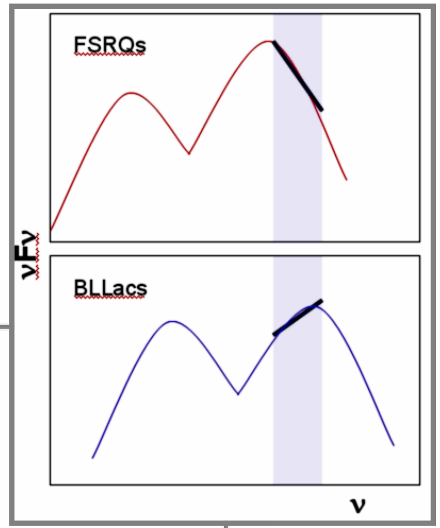


Blazar population properties

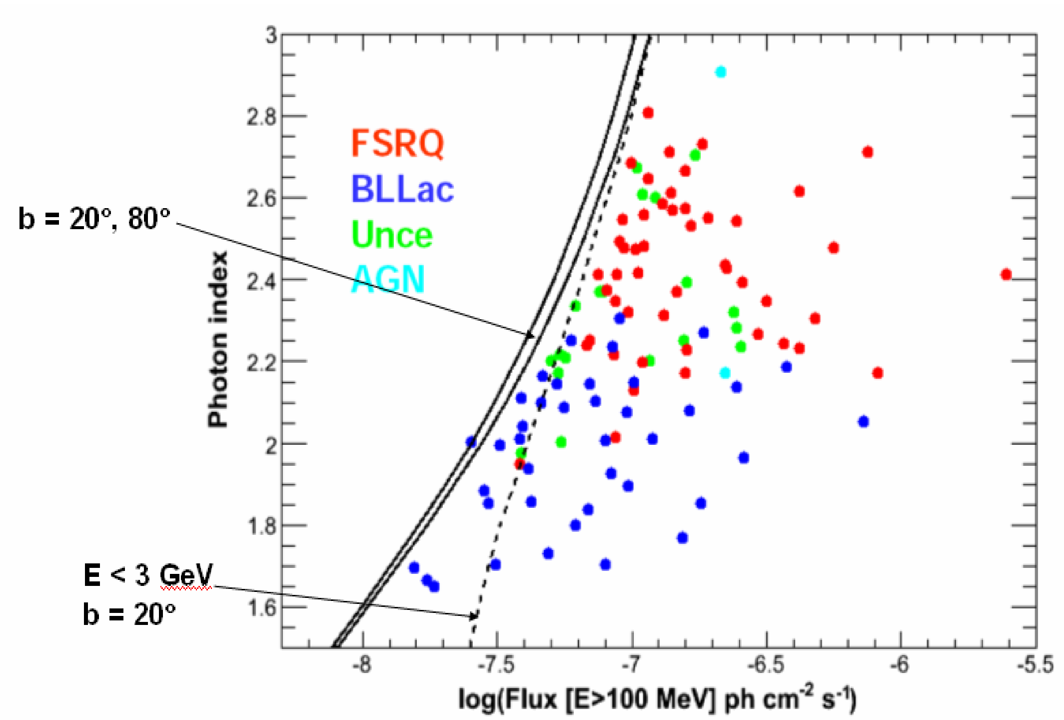
- **34% BL Lac fraction (vs 19% for EGRET)**



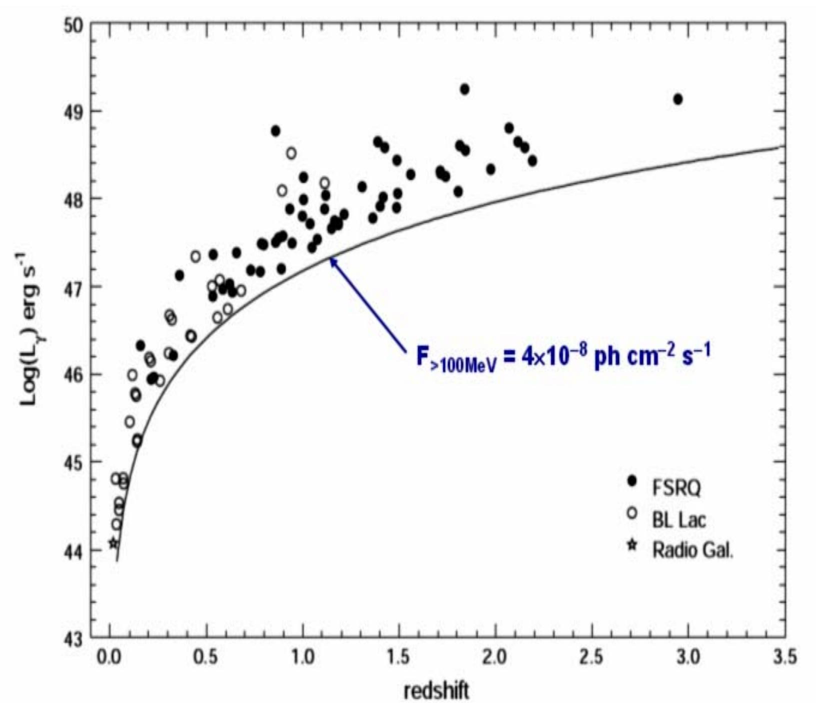




Blazar population properties



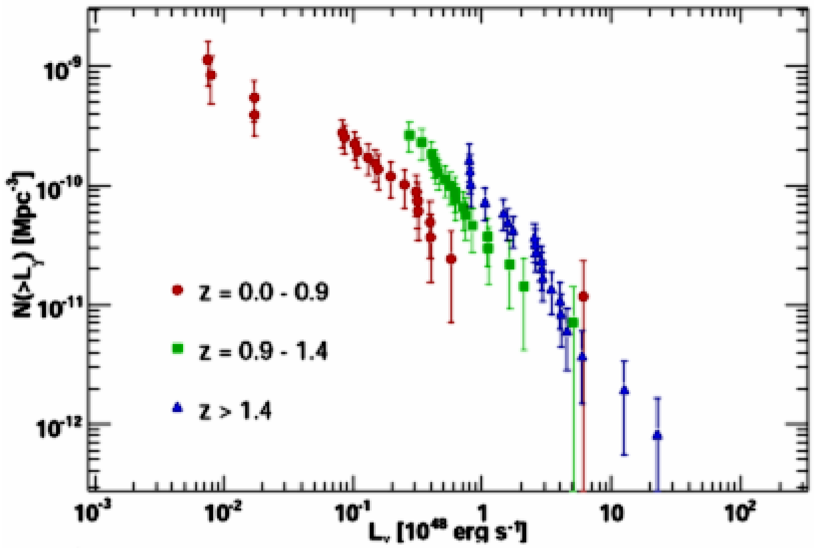
Photon index vs flux

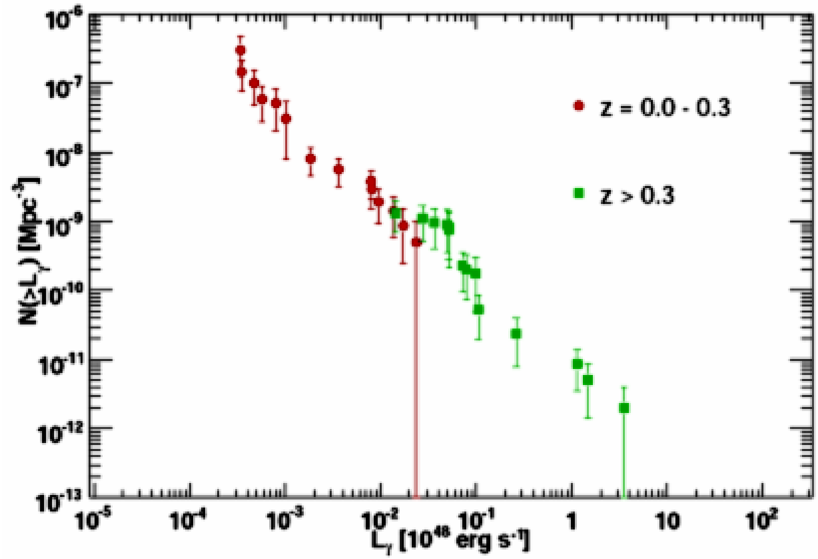


Luminosity vs redshift

Luminosity functions

- **FSRQs**
  - Strong evolution
  - The 3 month LAT AGN sample measures the bright end of the luminosity distribution.
- **BL Lac objects**
  - No evidence of evolution
- **Combined emission from individual blazars in 3 month sample corresponds to 7% of EGRET extragalactic diffuse**





Fermi Gamma-ray Space Telescope

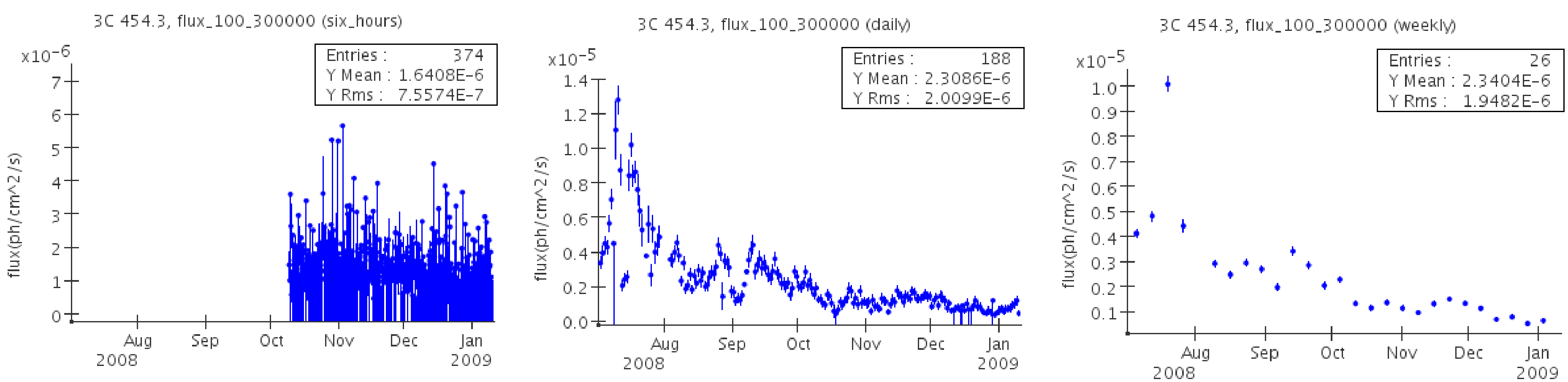
Publicly LAT monitored source list

Source Name	3EG Flux $(10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1})$	Source Name	3EG Flux $(10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1})$
0208−512	85.5 ± 4.5	H 1426+428† ?	...
0235+164	65.1 ± 8.8	1510−089	18.0 ± 3.8
PKS 0528+134	93.5 ± 3.6	PKS 1622−297	47.4 ± 3.7
PKS 0716+714	17.8 ± 2.0	1633+383	58.4 ± 5.2
0827+243	24.9 ± 3.9	Mrk 501†	...
OJ 287	10.6 ± 3.0	1730−130	36.1 ± 3.4
Mrk 421†	13.9 ± 1.8	1ES 1959+650† ?	...
W Comae ?	11.5 ± 1.8	PKS 2155−304†	13.2 ± 3.2
3C 273	15.4 ± 1.8	BL Lacertae†	39.9 ± 11.6
3C 279	74.2 ± 2.8	3C 454.3	53.7 ± 4.0
1406−076	27.4 ± 2.8	1ES 2344+514† ?	...
LSI+61 303†	69.3 ± 6.1		

(?) Awaiting definitive detection by LAT.

LAT source monitoring activities

- Automated Science Processing (ASP)
  - Transient detection: Uses source detection (pgwave) to find all point sources in data from each epoch (6hr, day, week)
  - Follow-up monitoring: Runs full likelihood analysis on list from source detection step + "Data Release Plan" (DRP) sources
  - 2×10^{-6} ph cm^{-2} s^{-1} threshold (daily) for public release of non-DRP
- Flare Advocates:
  - LAT scientists from Galactic and Extragalactic groups examine output from ASP pipeline and perform follow-up analyses, produce ATels, and propose ToOs

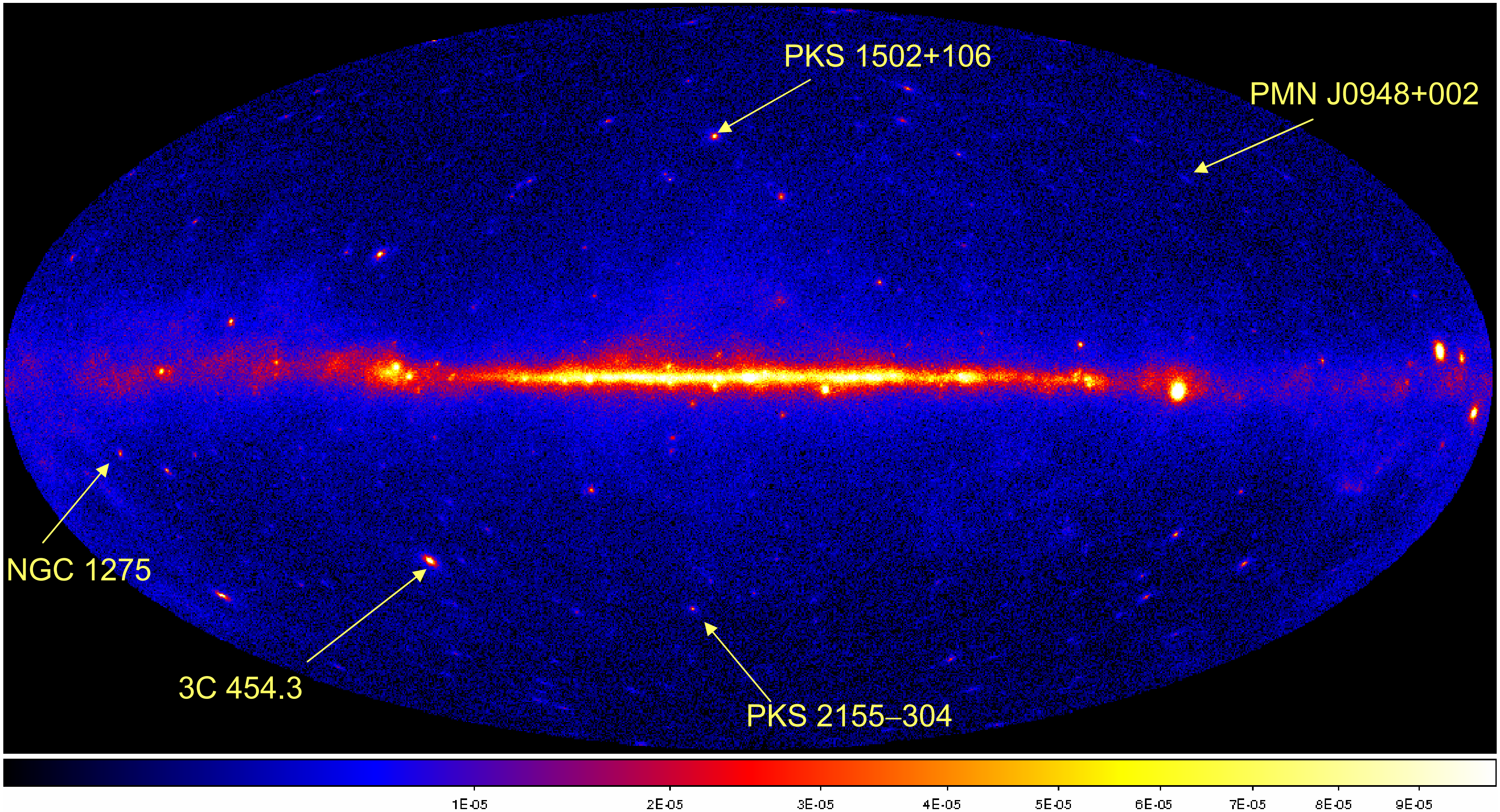


LAT Astronomer's Telegrams

date	number	title
2009-04-26	2033	Fermi LAT detection of gamma-ray re-brightening of blazar PKS1510-089
2009-04-21	2026	Fermi LAT detection of a GeV flare from blazar B2 1520+31
2009-04-17	2021	Fermi LAT detection of increasing gamma-ray activity of blazar PKS 1222+216
2009-03-27	1991	Swift-XRT follow-up of FSRQ GB6 J1700+6830
2009-03-27	1989	Fermi LAT detection of a GeV flare from PMN J2250-2806
2009-03-23	1986	Fermi LAT detection of a possible new gamma-ray blazar: GB6 J1700+6830
2009-02-25	1943	Swift XRT/UVOT follow-up of blazar PKS 1118-056 after a gamma-ray flare
2009-02-19	1933	Fermi LAT detection of Increased Flux from new gamma-ray blazar PKS 0250-225
2009-02-18	1932	Fermi LAT detection of a GeV flare from new gamma-ray blazar PKS 1118-056
2009-01-29	1919	Fermi-LAT detection of increased gamma-ray activity from the blazar PKS 0727-115
2009-01-22	1905	Fermi-LAT detection of renewed activity from the blazar PKS 1502+106
2009-01-19	1902	Fermi LAT detection of a high gamma-ray state from high-redshift blazar 0917+449
2009-01-12	1898	Fermi LAT detection of increasing gamma-ray activity of blazar PKS 0454-234
2009-01-09	1897	Fermi-LAT detection of another rapid GeV flare from the blazar PKS 1510-089
2009-01-08	1894	Fermi-LAT detection of a GeV flare from a source positionally consistent with PKS 1244-255

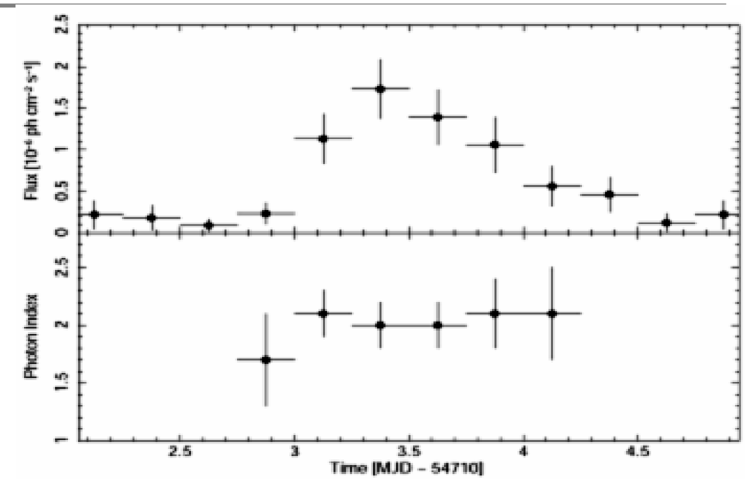
date	number	title
2009-01-04	1888	Fermi-LAT and Swift detection of a large GeV and optical flare from J123939+044409
2008-12-17	1877	Fermi LAT detection of a gamma-ray source positionally consistent with QSO B0133+47
2008-12-06	1864	Fermi LAT detections of increasing gamma ray activity of blazar 3C 279
2008-11-21	1850	Fermi LAT Observations of the Cygnus Region
2008-10-17	1788	Fermi LAT Detection of a New Gamma-ray Transient in the Galactic Plane: J0910-5041
2008-10-15	1784	Fermi/LAT detection of strong activity on short timescales of the blazar AO 0235+164
2008-10-08	1771	Fermi LAT Detection of Brightening of the Galactic Plane Source 3EG J0903-3531
2008-10-03	1759	Fermi LAT detections of gamma ray activity in three blazars: 3C 66A, PKS 0208-512, PKS 0537-441
2008-09-26	1744	Fermi LAT strong detection of blazar AO 0235+164 during outburst at Optical-to-Radio Wavelengths
2008-09-26	1743	Fermi LAT observations of the PKS 1510-089 outburst
2008-09-08	1707	Fermi LAT detection of 3C 273 in flaring state
2008-09-05	1701	Fermi LAT detection of a possible new gamma-ray flaring blazar: PKS 1454-354
2008-08-08	1650	GLAST LAT detection of a possible new gamma-ray flaring blazar: PKS 1502+106
2008-07-24	1628	GLAST-LAT detection of extraordinary gamma-ray activity in 3C 454.3

Fermi results for individual AGNs

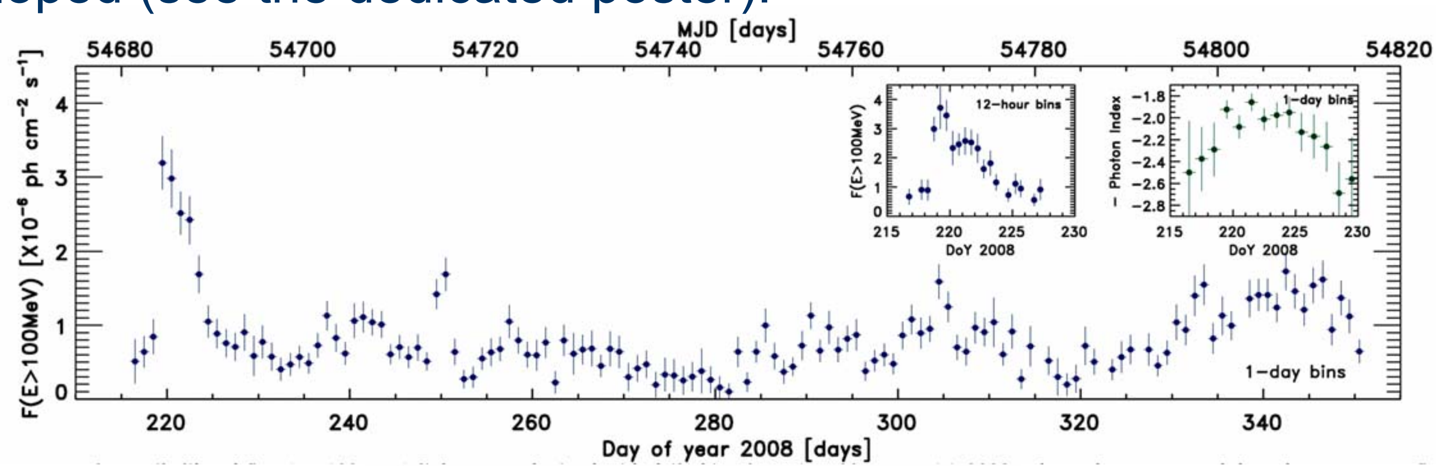


Fast flaring blazars:
PKS 1454-354 and PKS 1502+106

- **PKS 1454-354**: factor ~5 increase of >100 MeV flux in 12 hours; achromatic flux variations
- ⇒ weak radiative cooling regime, GeV variability driven by seed photon changes (cf. PKS 2155–304)

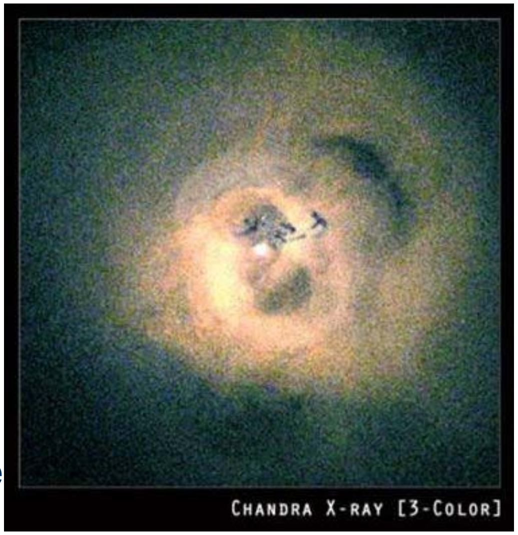


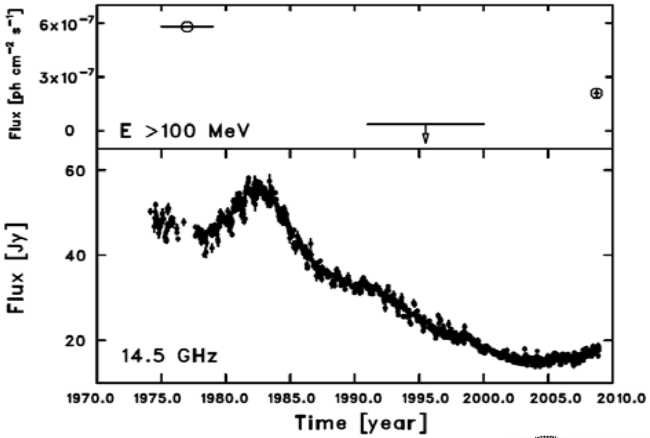
- **PKS 1502+106**: z=1.839, factor 3 increase in <12 hrs, highest ΔL/Δt in GeV band. Relevant varibaility and multifrequency campaign developed (see the dedicated poster).

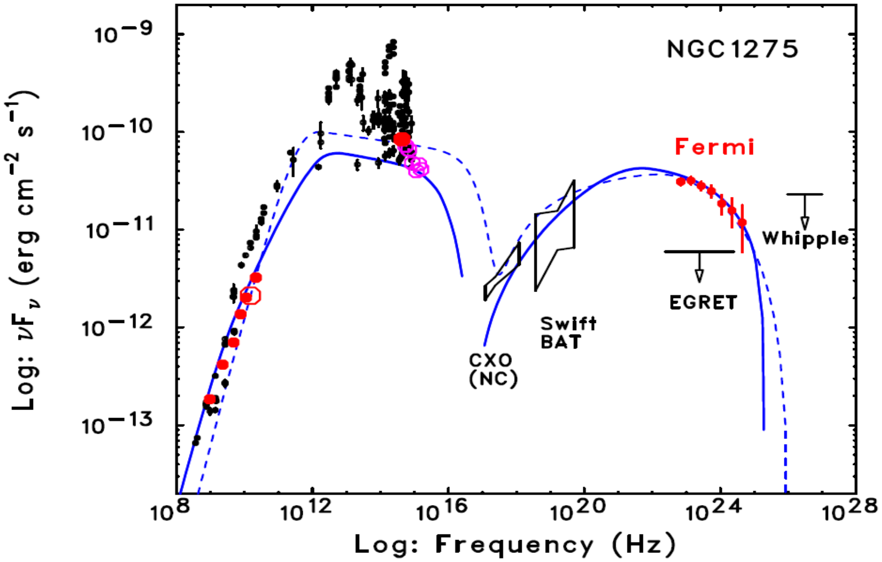


Fermi-LAT detection of NGC 1275 (Per A, 3C 84)

- NGC 1275: Classic example of a "cooling core" cluster. Voids or "bubble" seen in the X-ray must be inflated by some central source of power, i.e., an AGN.
- Variable emission on month to year time scales ⇒ AGN. Cannot be dark matter or diffuse cluster emission.
- Inferred blazar luminosity, $L_\gamma \sim 10^{44}$-10^{45} erg s^{-1}, is consistent with power needed to inflate the voids.
- SED fitted with single zone SSC model (solid curve) and spine-sheath model (dashed)



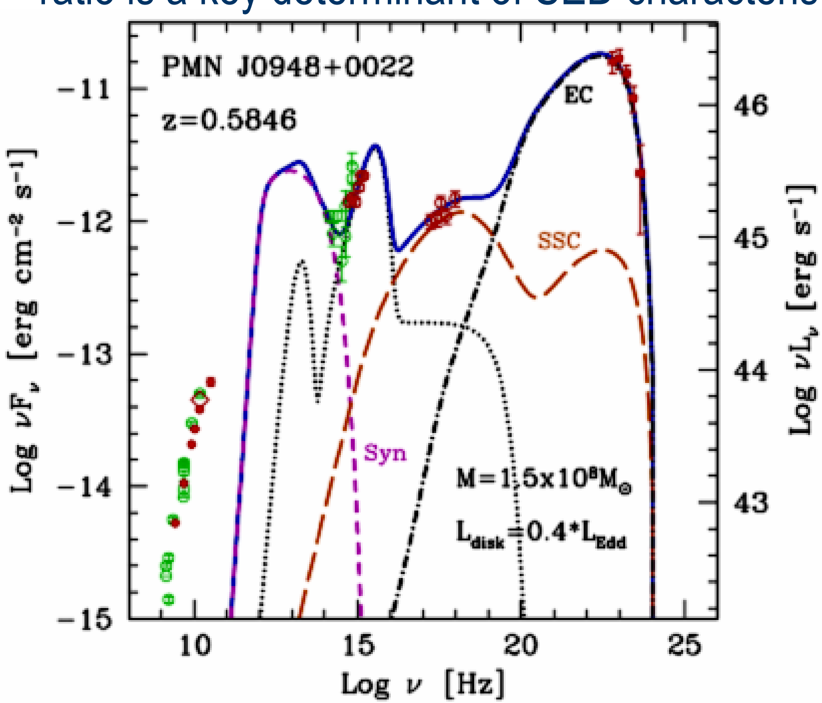




LAT detection of PMN J0948+0022 (a narrow Line Seyfert 1) and very large outburst from 3C 454.3

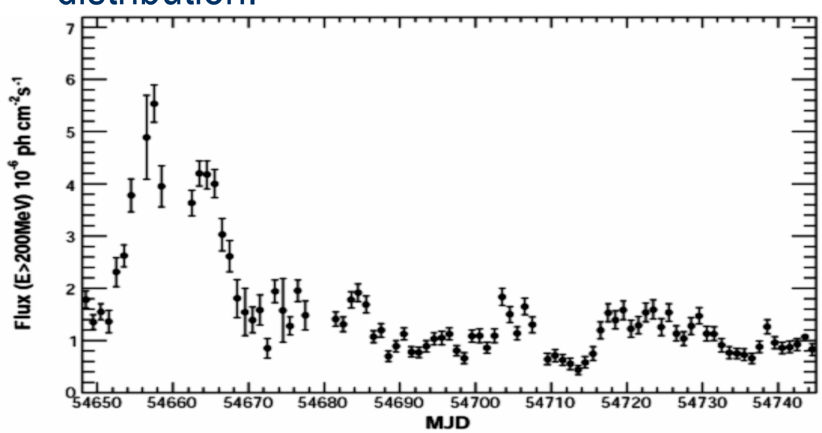
PMN J0948+0022

- Seyfert galaxies are not normally associated with blazar emission
- PMN J0948+0022 SED is similar to an FSRQ's, but at much lower luminosity.
- Seyfert galaxies have lower mass BHs ($\sim 10^7 M_{sun}$) & NS1s have high accretion rates $\Rightarrow$ Eddington ratio is a key determinant of SED characteristics.



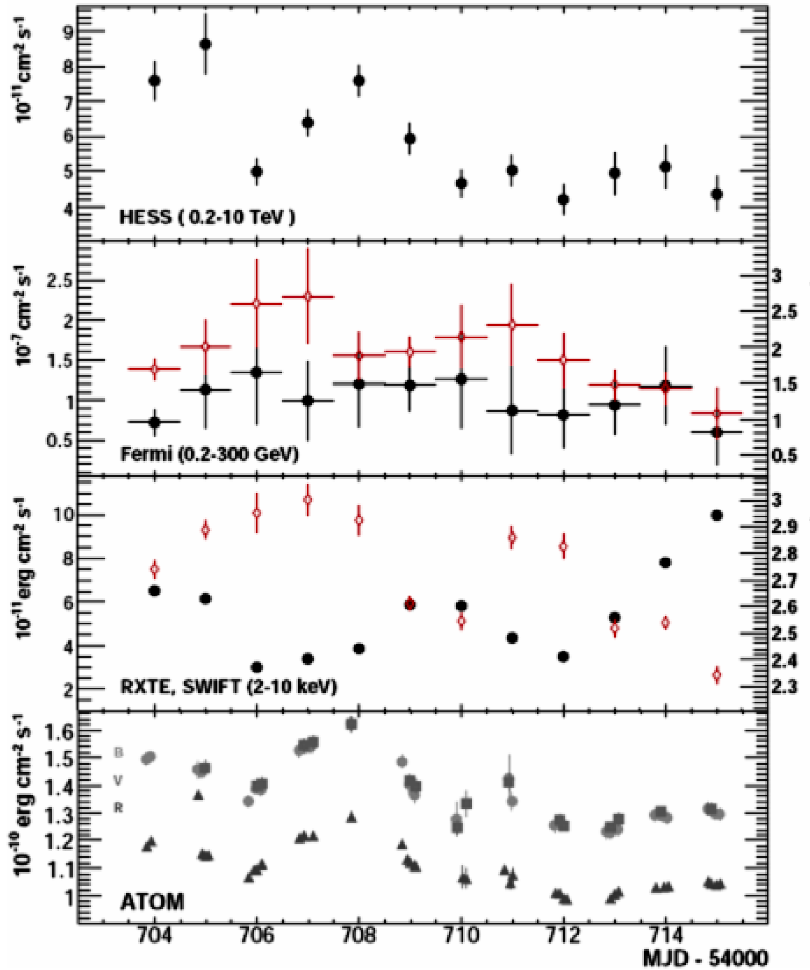
3C 454.3

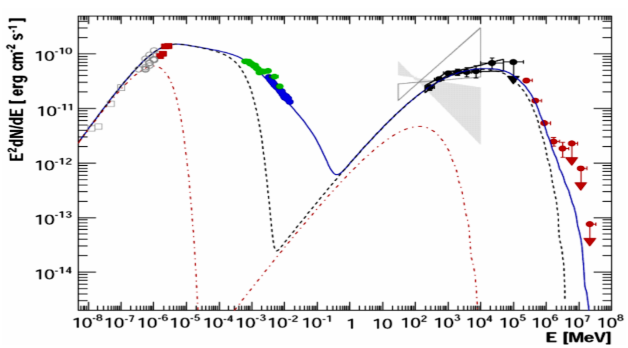
- OVV quasar, very active since 2000; z = 0.859; VLBI, superluminal motion, $\delta \sim 25$
- Brightest blazar during first few months of operations and variability time scales of < 3 days $\Rightarrow \delta > 6$
- First definitive evidence of a spectral break in the GeV range: E_{br} = 2 GeV, Γ_1=2.3, Γ_2=3.5
- $\Delta\Gamma$=1.2 > 0.5 $\Rightarrow$ not from radiative cooling.
- This feature could either arise from "intrinsic" absorption, e.g., via $\gamma\gamma$ opacity from accretion disk photons or it may represent a characteristic energy in the underlying particle distribution.



PKS 2155-304: the Fermi-HESS MW campaign (Fermi, HESS, ATOM, RXTE (+ Swift)

- X-ray and VHE fluxes are not correlated, in contrast to July 2006 flare
- Lack of spectral variability in HESS band ($\Delta\Gamma_{VHE}$ < 0.2) $\rightarrow$ weak radiative cooling regime
- Signifcant spectral variability in X-rays ($\Delta\Gamma_X \sim$ 0.5) $\rightarrow$ strong cooling regime
  - $\Rightarrow$ Electrons producing the X-rays have higher energies than those producing the TeV.
- Optical and VHE fluxes are correlated
  - Optical is driving the TeV variability
- Lack of opt-GeV correlation
- X-ray flux and HE photon index are correlated
- Multizone SSC models are required.





Conclusions

- The LAT is performing spectacularly well, both operationally and scientifically.
- Current set of results are just the tip of the iceberg.
- AGN/blazars field is among the main and fruitful science topic for the mission.
- Several Fermi multiwavelength campaigns on blazars have been completed and others are on-going
- The optimal high energy synergy between Fermi and Swift and between Fermi and TeV telescopes already demonstrated.