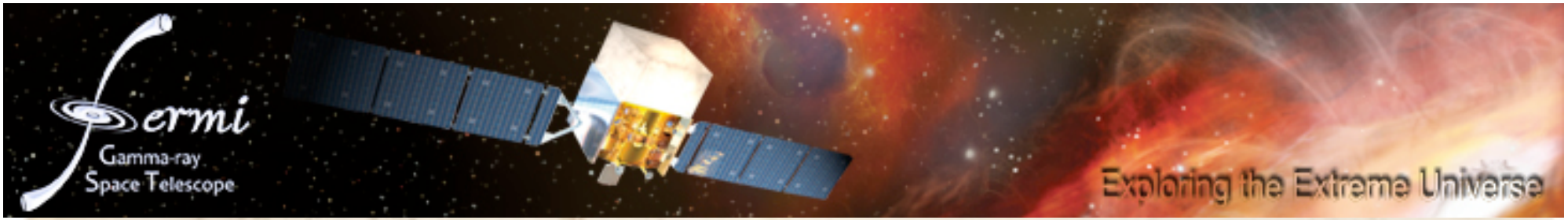


Blazars in the Fermi era

(with some other extragalactic delights…)

Luigi Foschini

INAF – Osservatorio Astronomico di Brera

Sede di Merate

Condensed history of γ-ray astronomy

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe

- **1968:** First detection of photons with energies greater than 100 MeV of Galactic origin with the *OSO3* satellite (Clark et al., 1968).

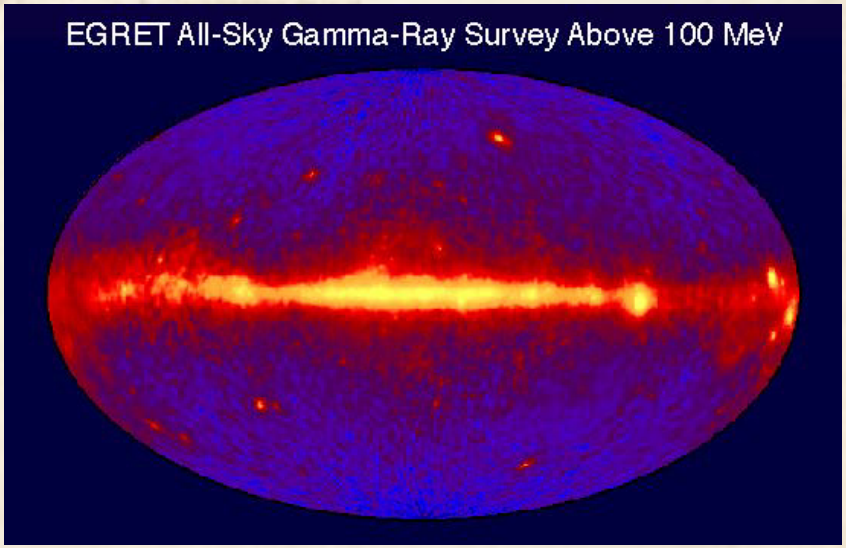
- **1967** (→**1973**, Klebesadel et al.): First detection of Gamma-Ray Bursts by US military satellites *VELA*.

- **1978:** first detection of extragalactic γ (50-500 MeV) from an AGN (3C273) with ESA satellite *COS-B* (Swanenburg et al. 1978).

- **1991-2000:** *Compton Gamma-Ray Observatory*!

- **2007:** Launch of the Italian satellite *AGILE*.

- **2008:** Begin of the *Fermi* era!



The Fermi Gamma-ray Space Telescope

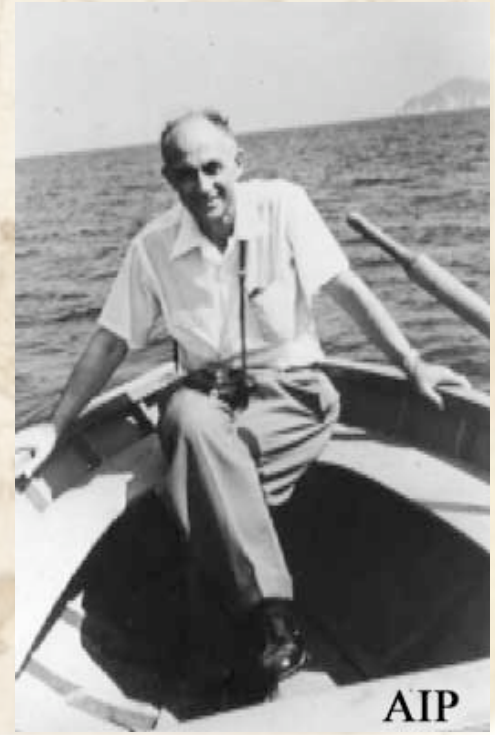
Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe

Launched 11 June 2008

(1) ***Large Area Telescope (LAT)***
20 MeV - 300 GeV and beyond…
FOV = 2.4 sr (@ 1 GeV)
PSLA: a few arcmin
(Atwood et al., 2009, ApJ 697, 1071)

The satellite is named in honour of the Italian scientist Enrico Fermi (1901-1954), Nobel Prize for physics in 1938.



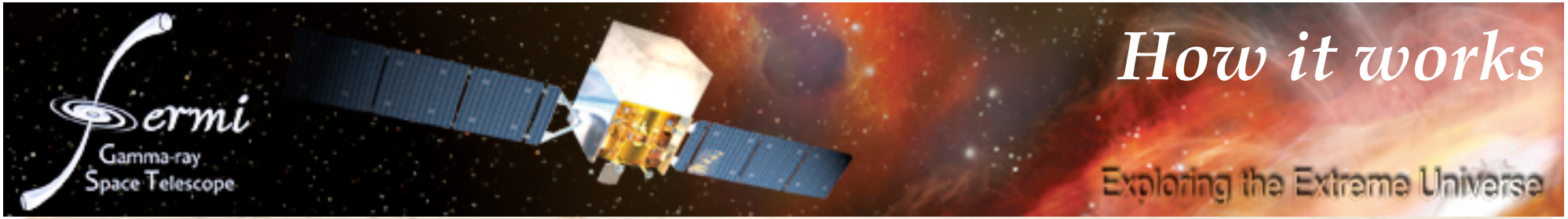
(2) ***Gamma-ray Burst Monitor (GBM)***
8 keV – 40 MeV

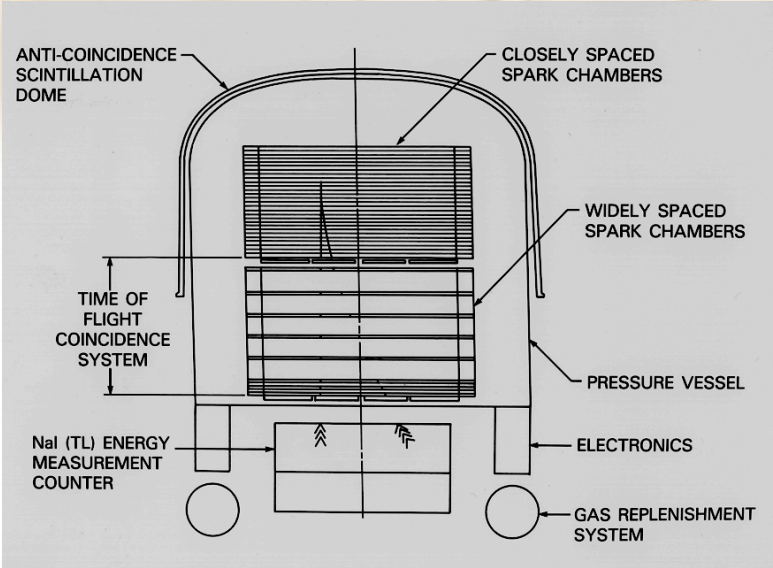
- **France**
  - IN2P3, CEA/Saclay
- **Italy**
  - INFN, ASI, INAF
- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University
- **United States**
  - Stanford University (SLAC and HEPL/Physics)
  - University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - Ohio State University
  - University of Washington

~390 Members
(95 Affiliated Scientists, 68 Postdocs and 105 Graduate Students)

construction managed by
Stanford Linear Accelerator Center (SLAC),
Stanford University, USA

P.I. Peter Michelson (Stanford)



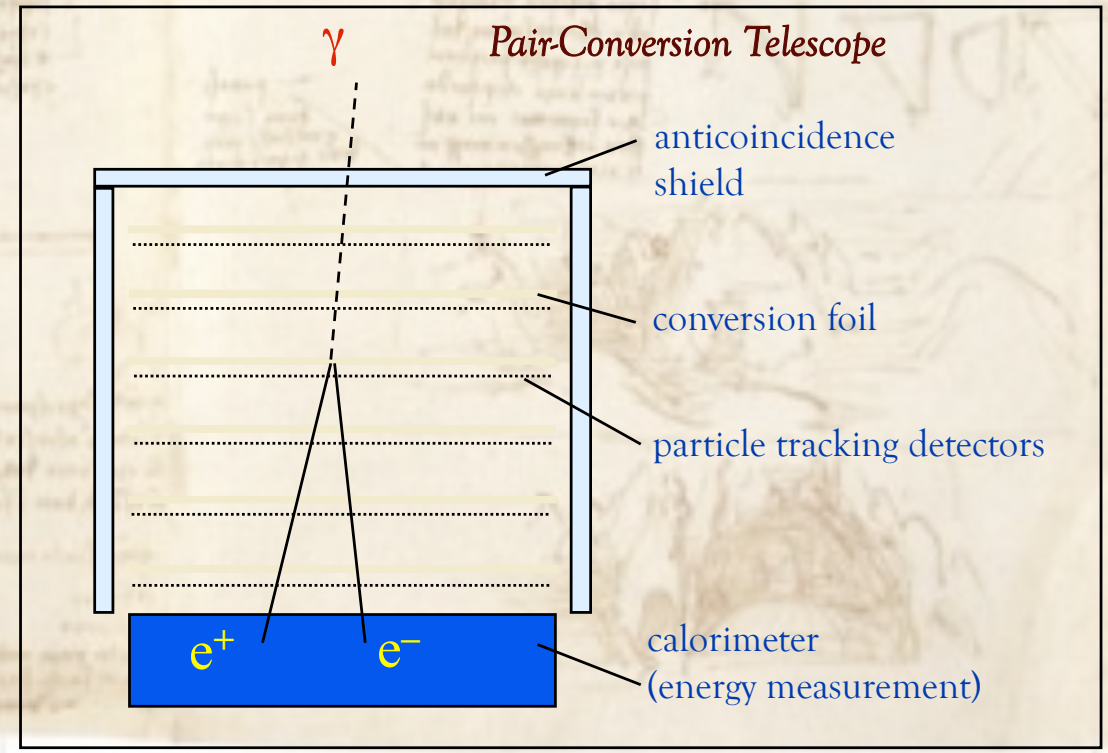


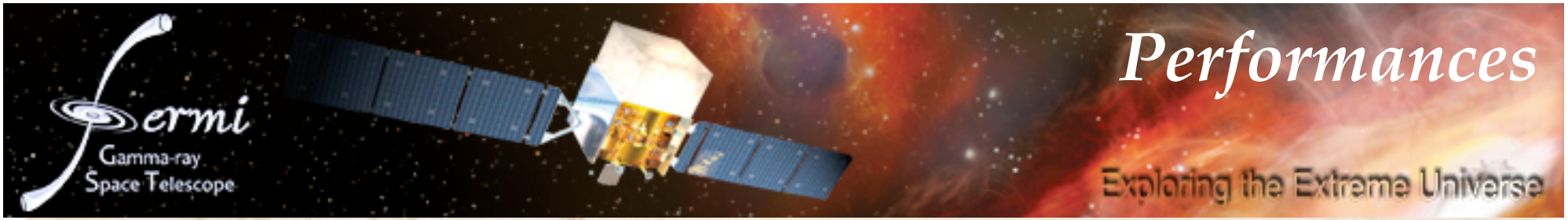
CGRO/EGRET (spark chamber)

Technology changes, not the concepts.

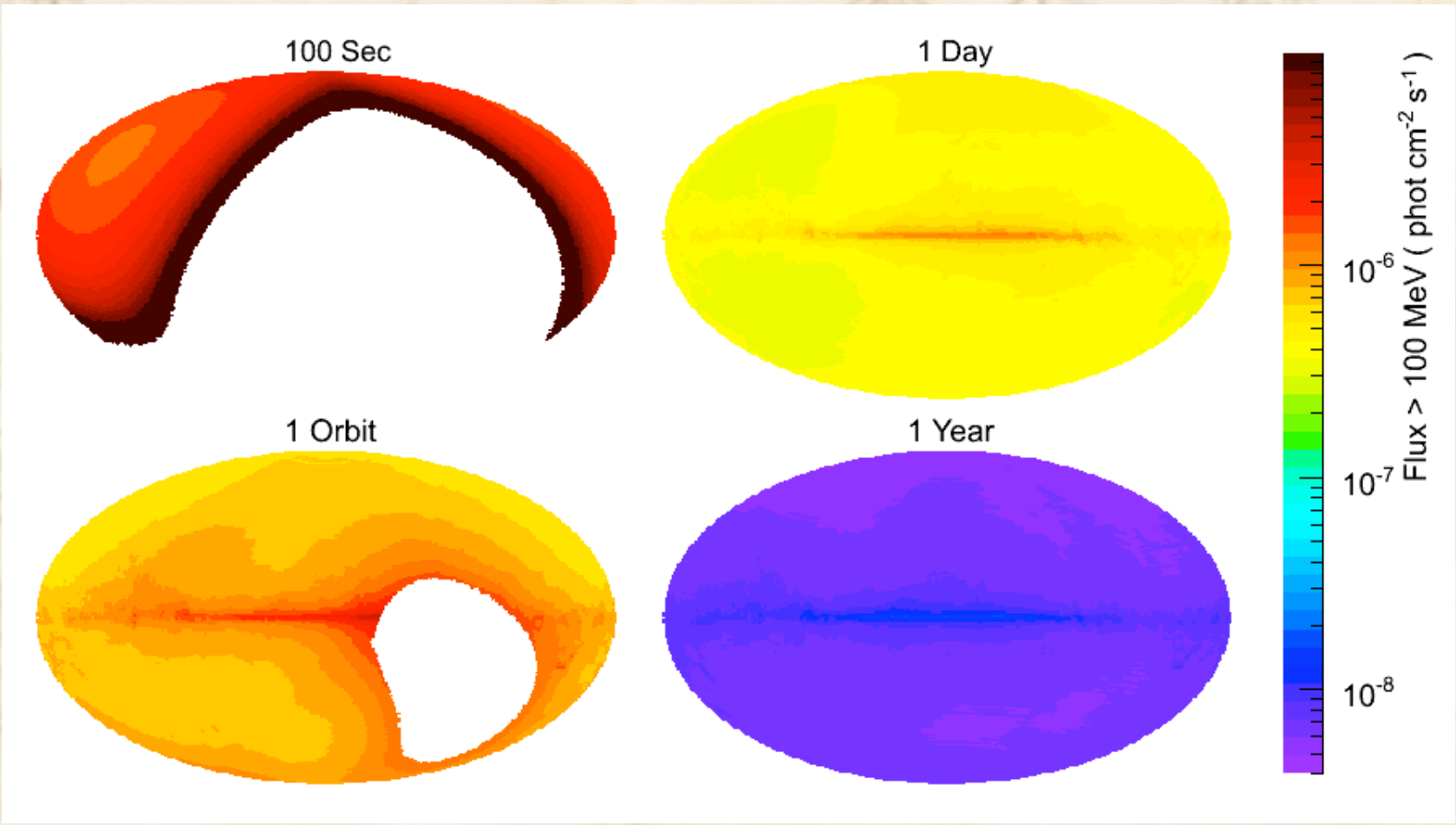
Fermi/LAT (silicon tracker)

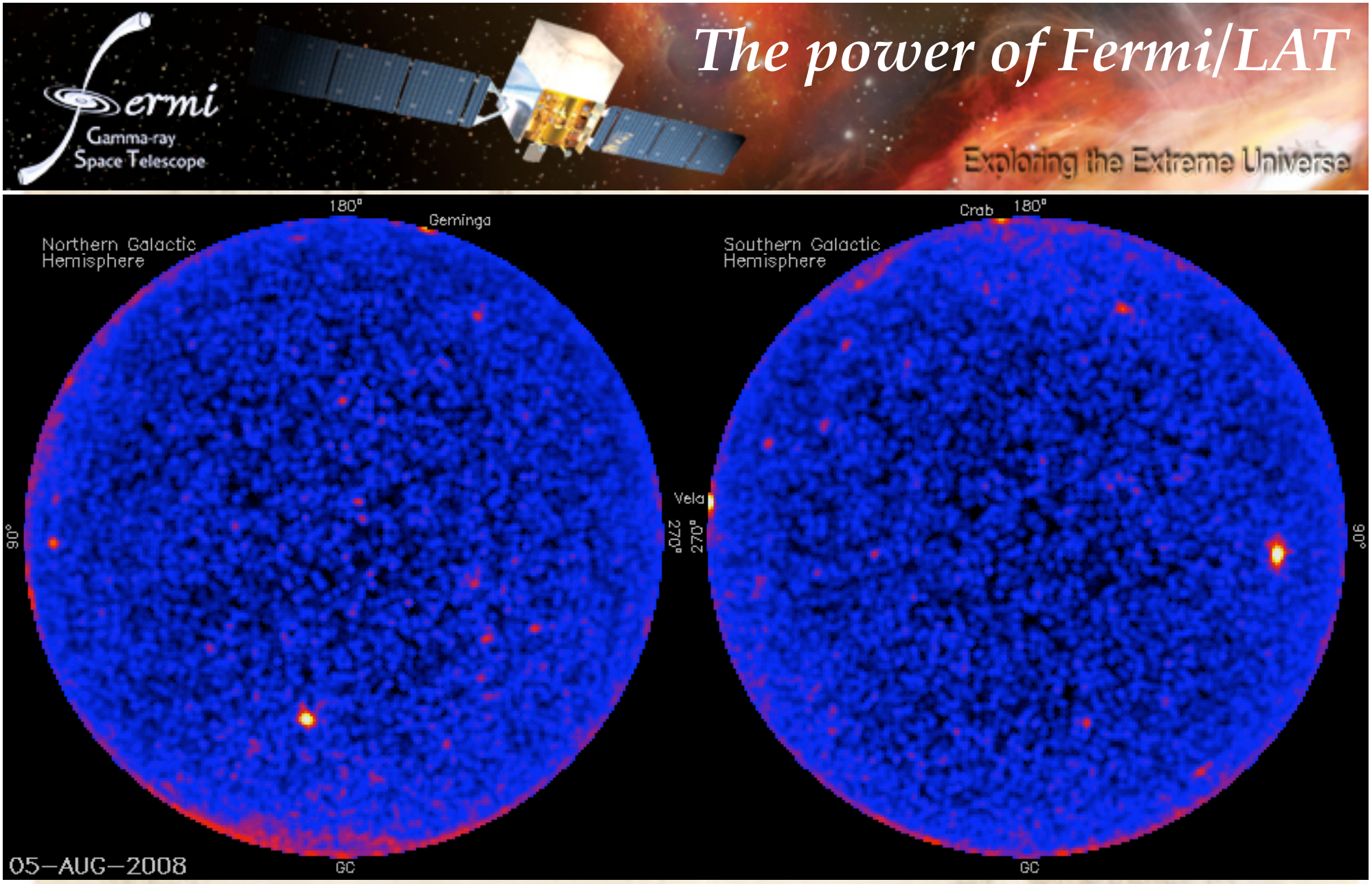
Pair conversion: photons with energies greater then 2x511 keV (511 keV = $m_e c^2$, electron rest mass) transform into electron-positron pairs when they interact with a third particle (principle of conservation of momentum).





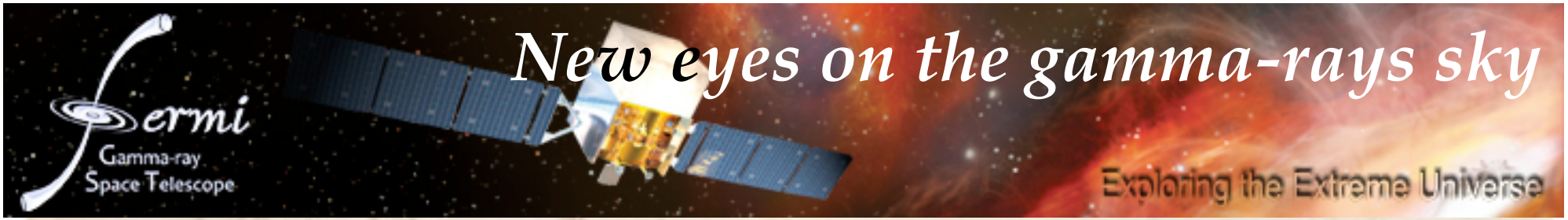
- ✓ Better sensitivity with respect to EGRET and AGILE.
- ✓ EGRET and AGILE sensitivities reached on days timescales.
- ✓ All-sky survey every 2 orbits (3 hours)





First 3 months of operation – August/October 2008

(each frame is 1 day of observation)



3-months high-confidence (>10 σ) sources

205!!

Ref.: arXiv:0902.1340 (Bright Source List) and arXiv:0902.1559 (AGN in the Bright Source List)

- ✓ 562 sources detected at 4σ;
- ✓ 205 sources detected at 10σ, 132 with $|b|>10°$ and 73 with $|b|<10°$;
- ✓ 121 are AGN and 106 have $|b|>10°$ (***Bright AGN List***);
- ✓ Typical PSLA (95% CL) < 10 arcmin;
- ✓ 60 LAT sources have a correspondence in the 3rd EGRET Catalog (271 src);
- ✓ 32 LAT sources have a correspondence in the 1st AGILE Catalog (40 src);
- ✓ 5 blazar detected by EGRET with S/N>10σ, were *not* detected by LAT

  (NRAO 190, NRAO 530, 1611+343, 1406-076, 1622-297 – but now are detected);
- ✓ 11 AGN detected by LAT are also TeV detected (7 HBL, 3 LBL, 1 FSRQ);
- ✓ 3 HBL have been detected by LAT, but not (yet) by Cerenkov telescopes;
- ✓ Sensitivity (3 months): 5×10^{-8} ph cm^{-2} s^{-1} (E>100 MeV, Γ=2.2, 10σ)

  Three times lower than that of the 3rd EGRET Catalog!

Ref.: arXiv:0902.1340 (Bright Source List) and arXiv:0902.1559 (AGN in the Bright Source List)

γ-ray Active Galactic Nuclei

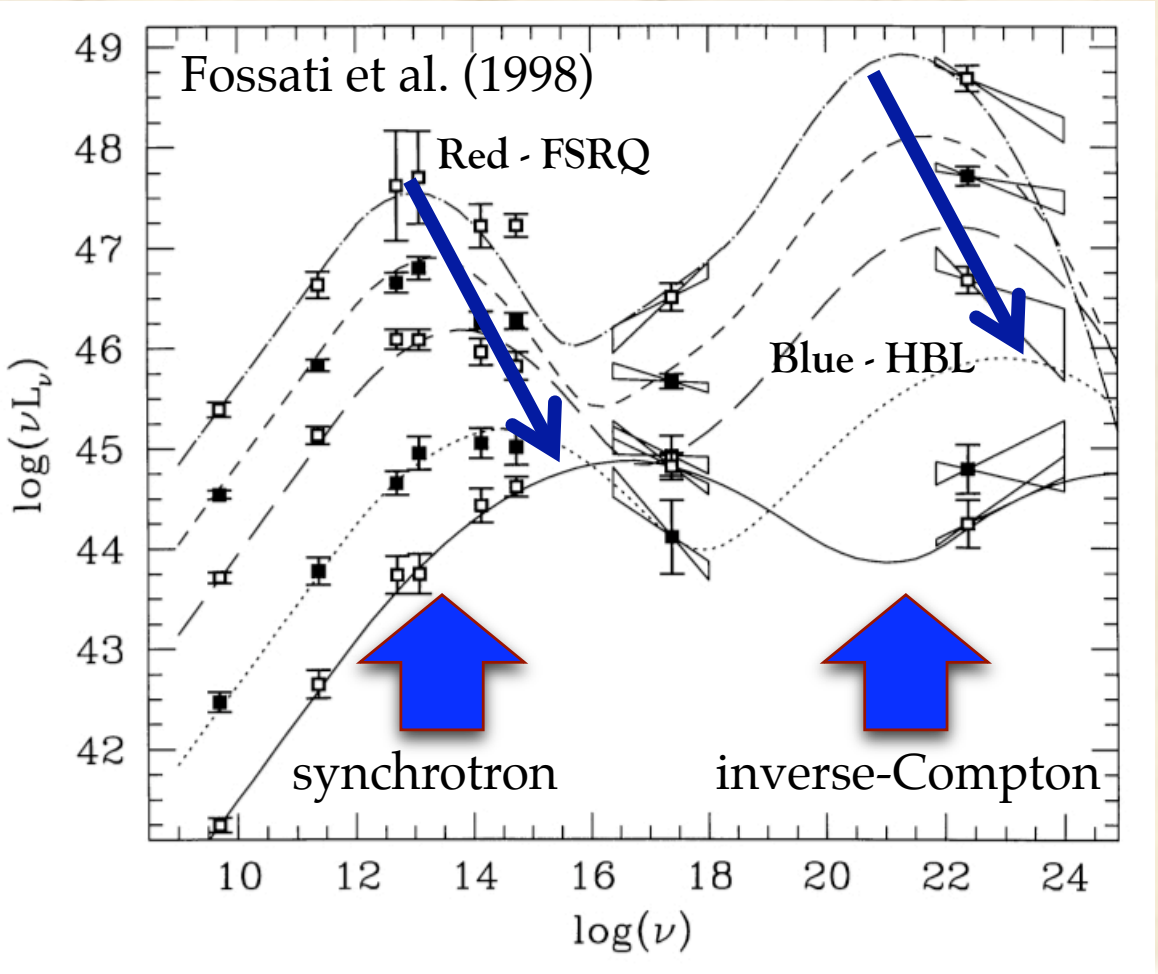
It is known that there are two types of γ-ray emitting AGN: **blazars** and **radiogalaxies.**

SED is typically twin-peaked:
- Low energy: synchrotron
- High-energy: inverse-Compton

The underlying physical mechanism producing such a SED is the same: a relativistic jet, but viewed at different angles (larger for radiogalaxies; very small for blazars).

Changes of the seed photons population (synchro, BLR, disk, torus) result in changes in the SED: **the blazar sequence!**

High-luminosity: low ν peaks
Low-luminosity: high ν peaks

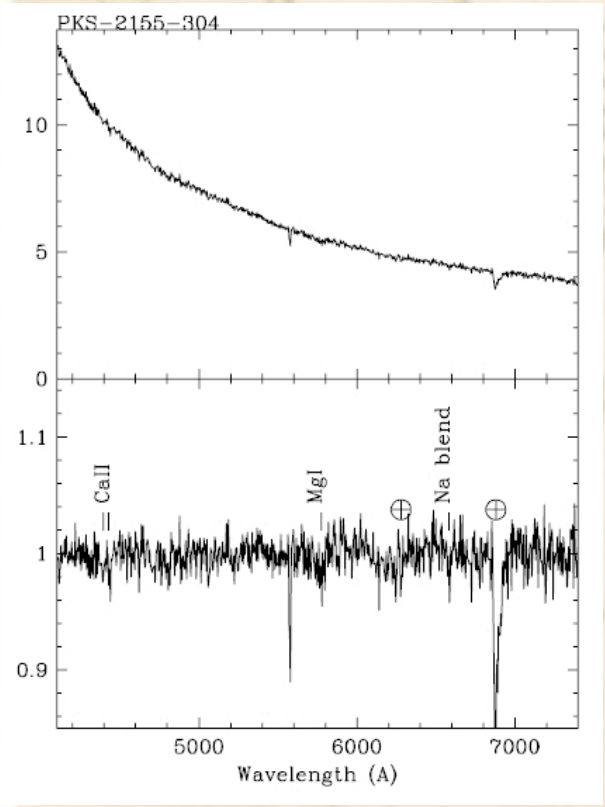


γ-ray Active Galactic Nuclei

Credits: NASA

Optical spectra and seed photons

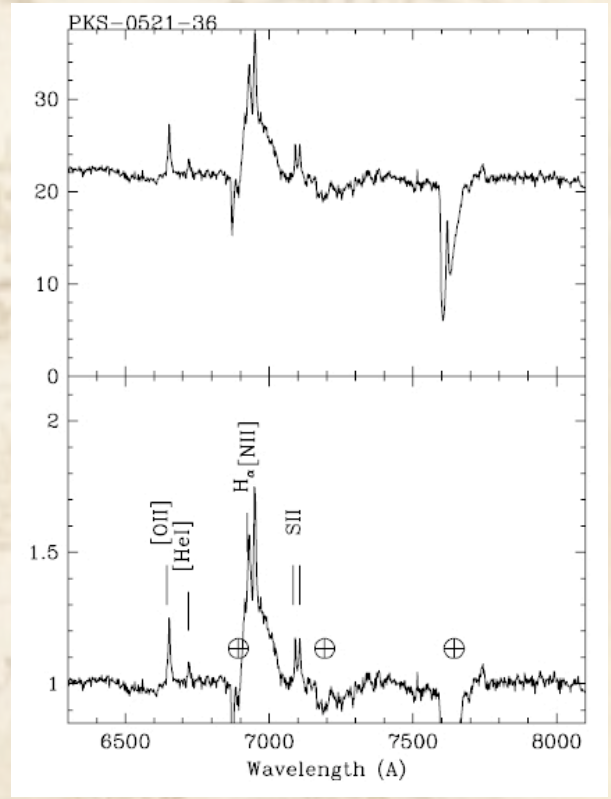
(spectra from Sbarufatti et al. 2006 with ESO 3.6 m and NOT 2.5 m)



Blazar sequence in term of changes of EW (intensity):

- Low-luminosity: No or weak (EW < 5 Å) lines; seed photons from synchrotron radiation.
- High-luminosity: strong (EW > 5 Å) emission lines; seed photons from BLR (or accretion disk or even torus).

All lines are **broad**, i.e. they have always FWHM > 2000 km/s



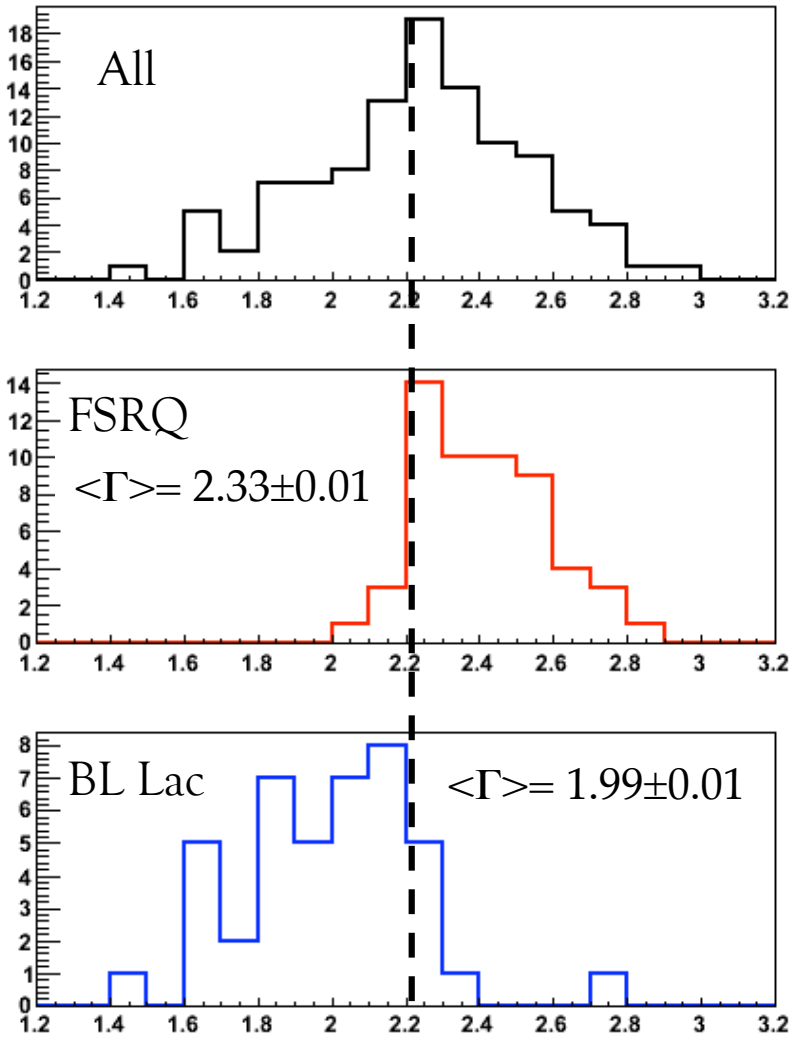
BL Lac Objects:
featureless continuum (lines EW < 5 Å)

Quasars:
strong and broad emission lines

LAT Bright AGN Sample (LBAS)

arXiv:0902.1559

Exploring the Extreme Universe



✓ 106 LAT sources associated with high-confidence (>90%) to AGN;

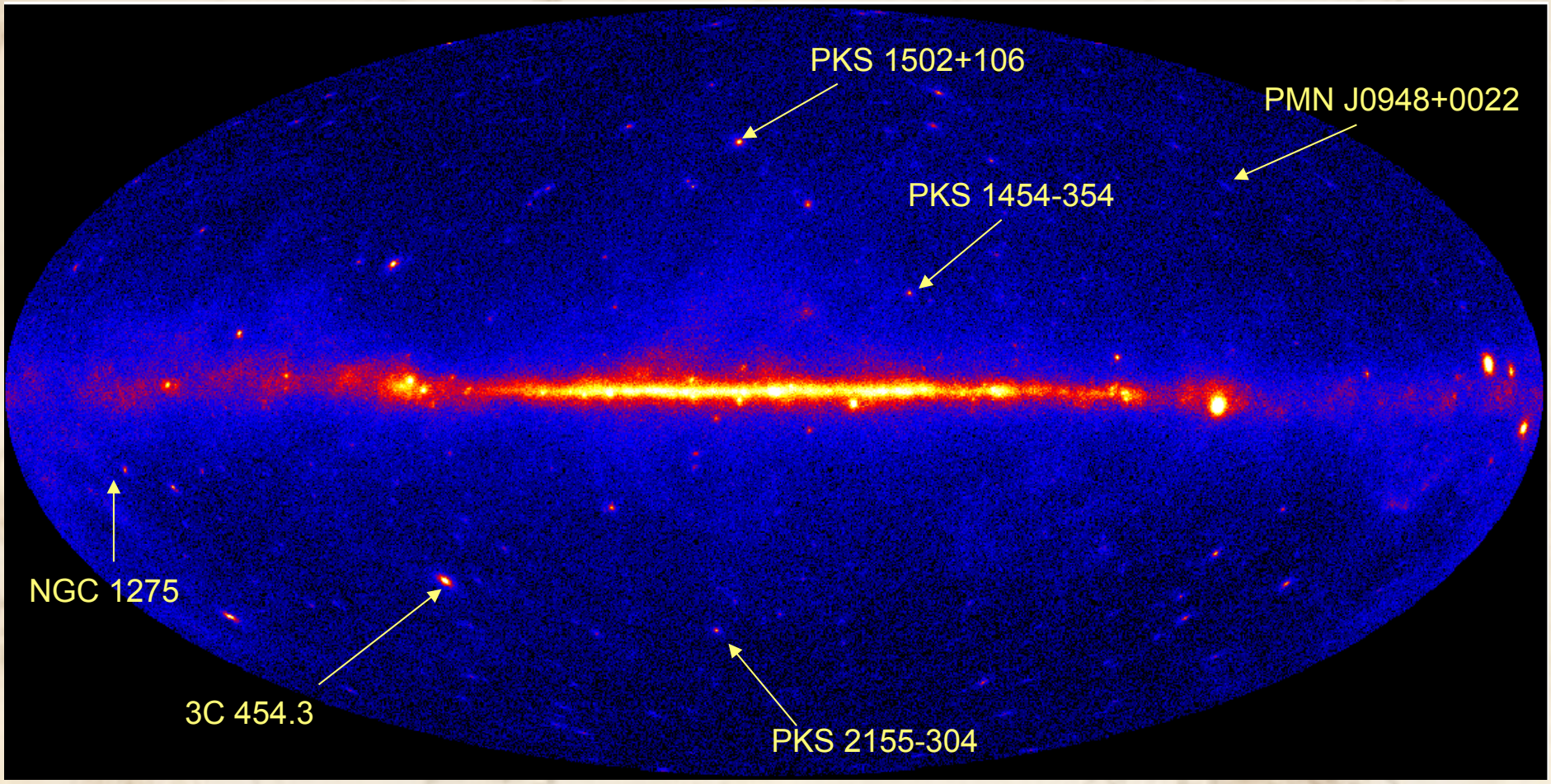
✓ 57 are flat-spectrum radio quasars (**FSRQ**);

✓ 42 are BL Lac Objects (both *Low-frequency peaked BL Lac* – **LBL** – and *High-frequency peaked BL Lac* – **HBL**);

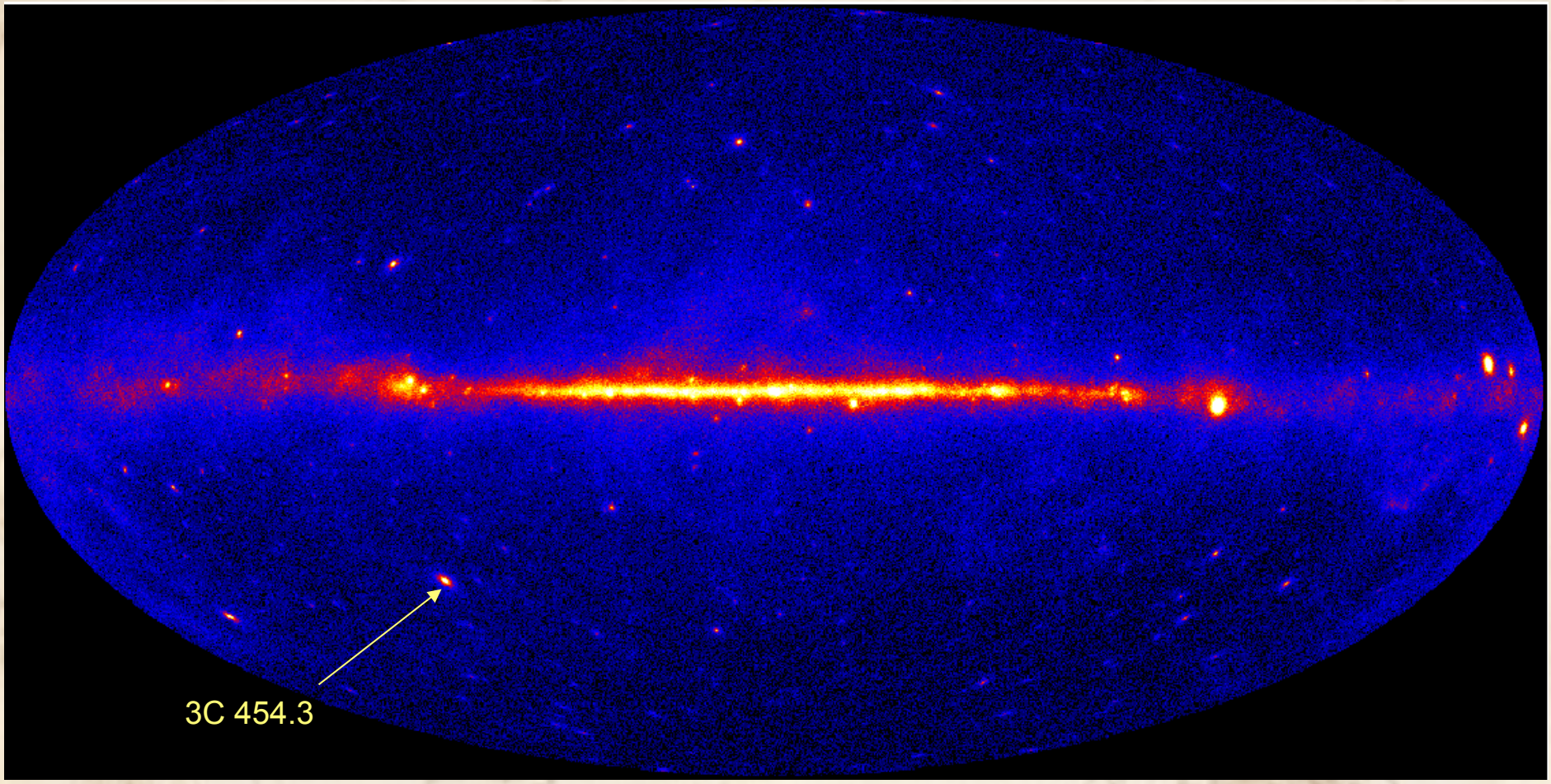
✓ 2 are radiogalaxies (Centaurus A and NGC 1275);

✓ 5 are identified with blazars on the basis of their flat radio spectra, but there are no optical spectra useful for a classification in terms of FSRQ or BL Lac;

Some specific works on AGN



Some specific works on AGN



3C 454.3 (z=0.859): an exception gamma-ray outburst detected by LAT during the verification phase! (Tosti et al., 2008, Atel 1628)

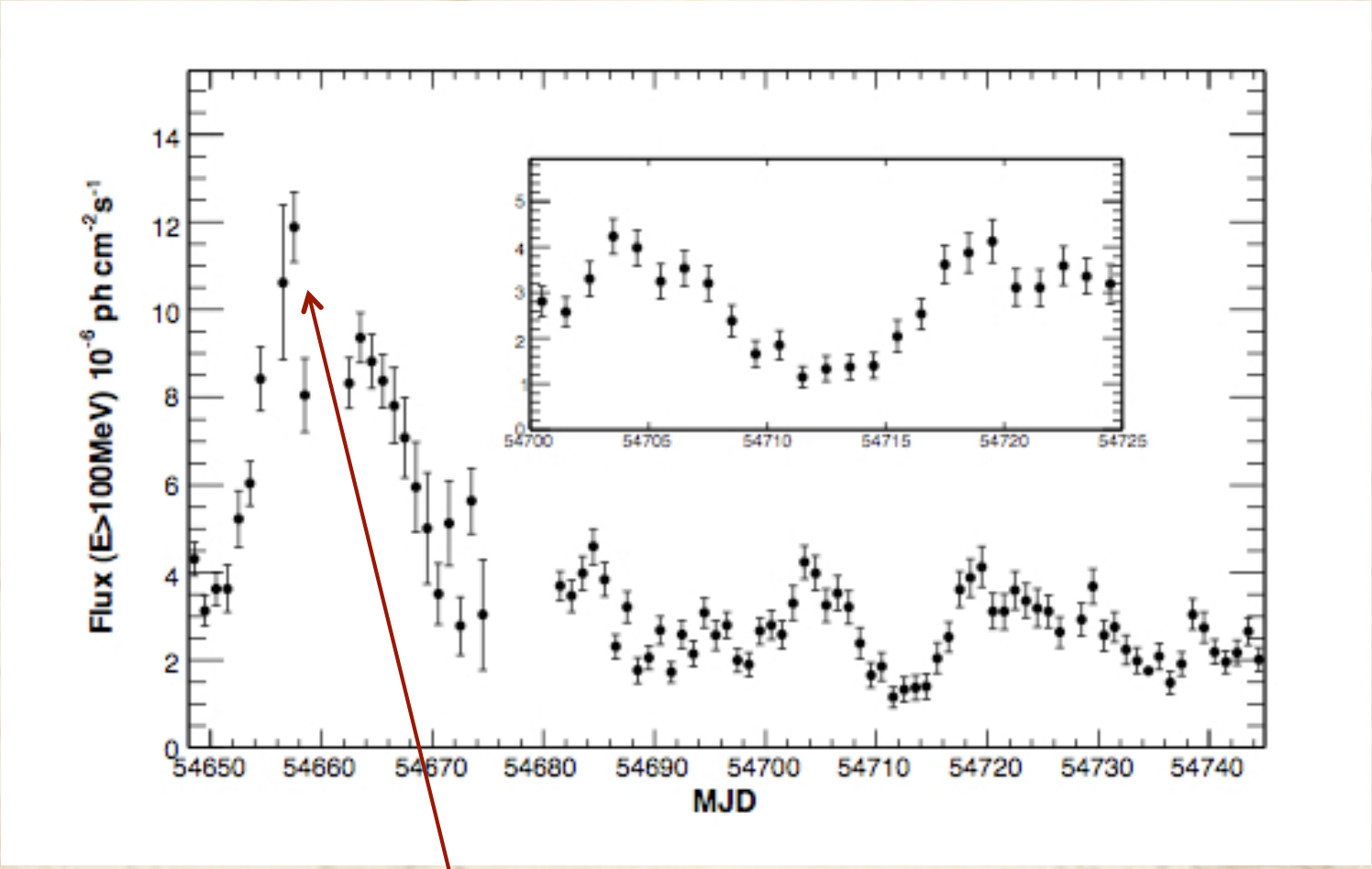
3C 454.3

(Abdo et al., 2009, ApJ, accepted – arxiv:0904.4280)

Contacts: G. Madejski & B. Lott

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe



11 July 2008: peak flux ≈ 1.2 × 10^5 ph cm^{-2} s^{-1} [E > 100 MeV]

The highest ever reached by any blazar at gamma-rays!

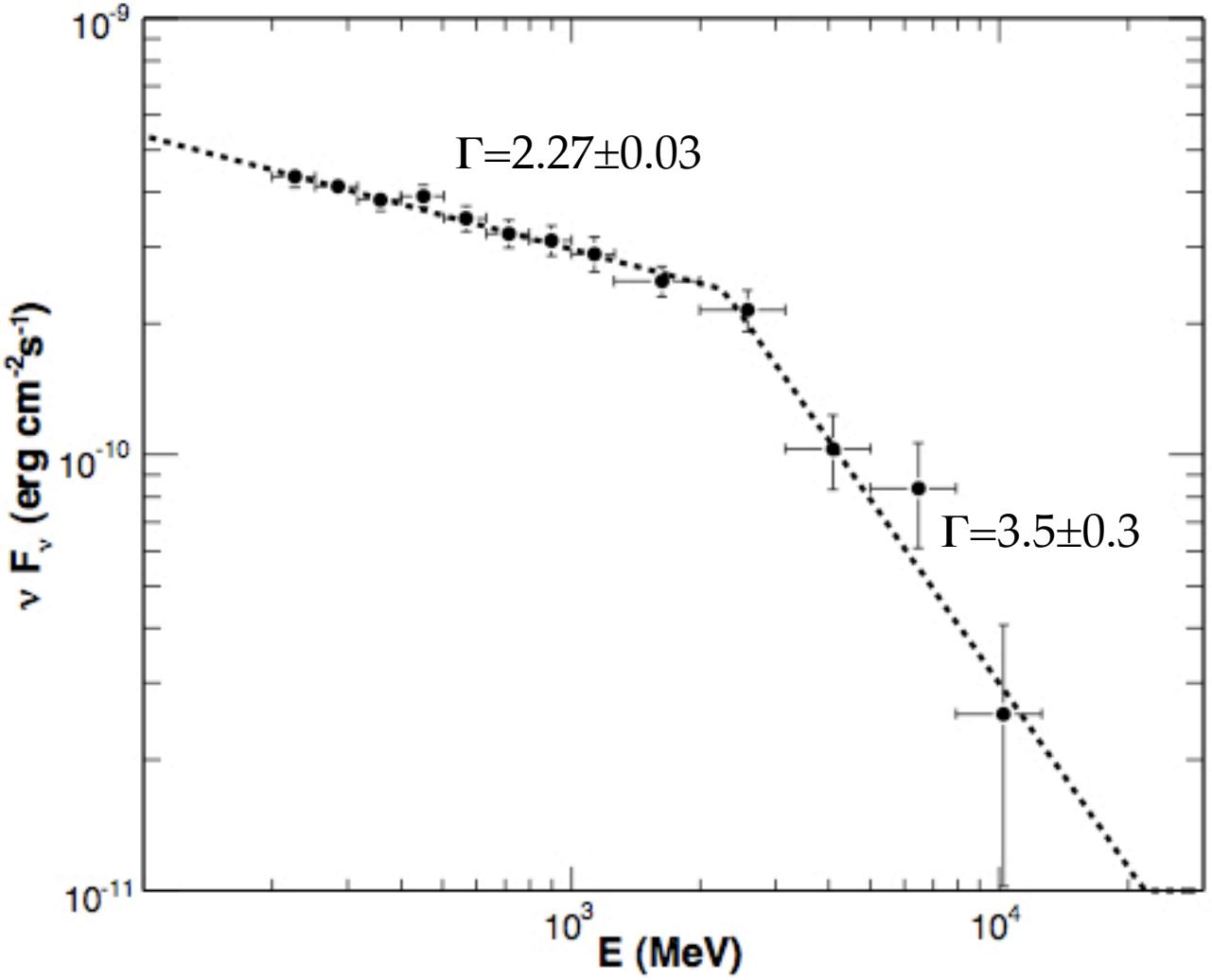
3C 454.3

(Abdo et al., 2009, ApJ, accepted – arxiv:0904.4280)

Contacts: G. Madejski & B. Lott

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe



First evidence of spectral break at gamma-rays:

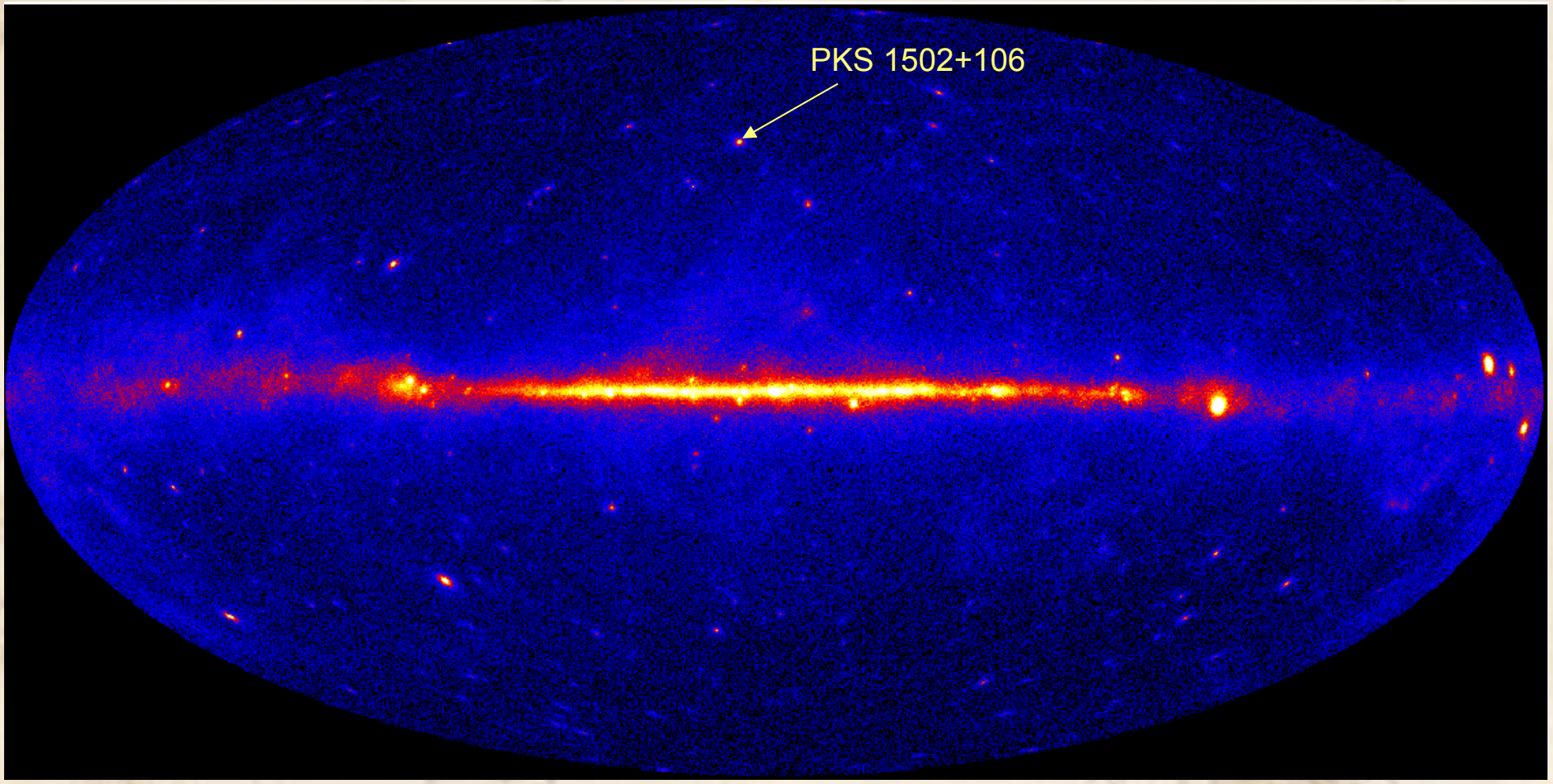
$E_{break} = 2.4 \pm 0.3$ *GeV*

Likely to be due to the intrinsic shape of the electron distribution.

Some specific works on AGN

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe



PKS 1502+106: The first new gamma-ray blazar discovered by LAT!

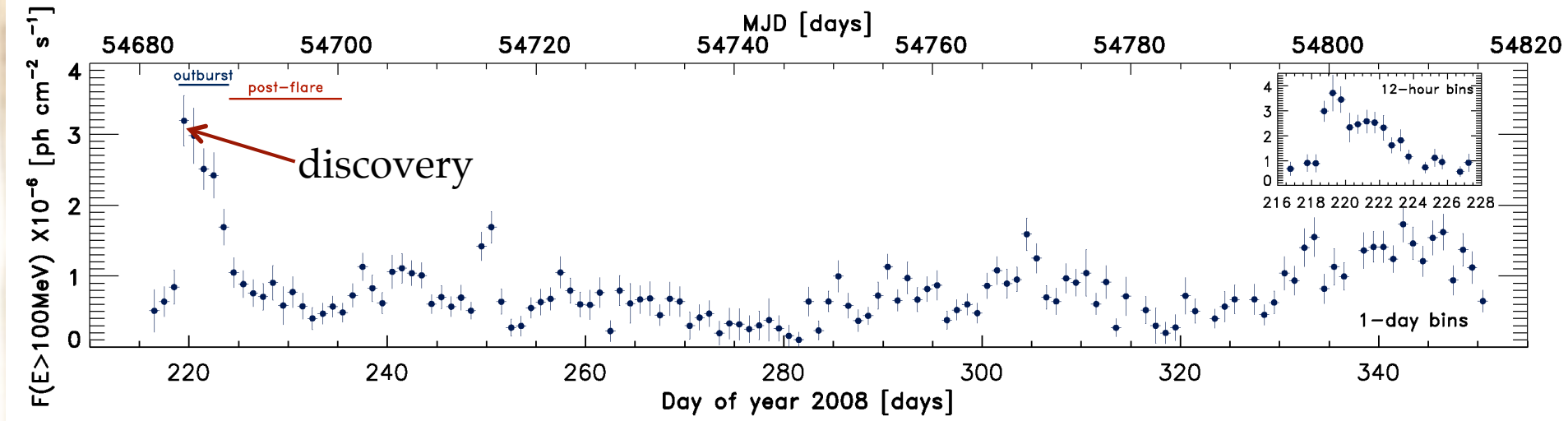
PKS 1502+106

(Abdo et al., ApJ, submitted)

Fermi Gamma-ray Space Telescope

Contact: S. Ciprini

Exploring the Extreme Universe

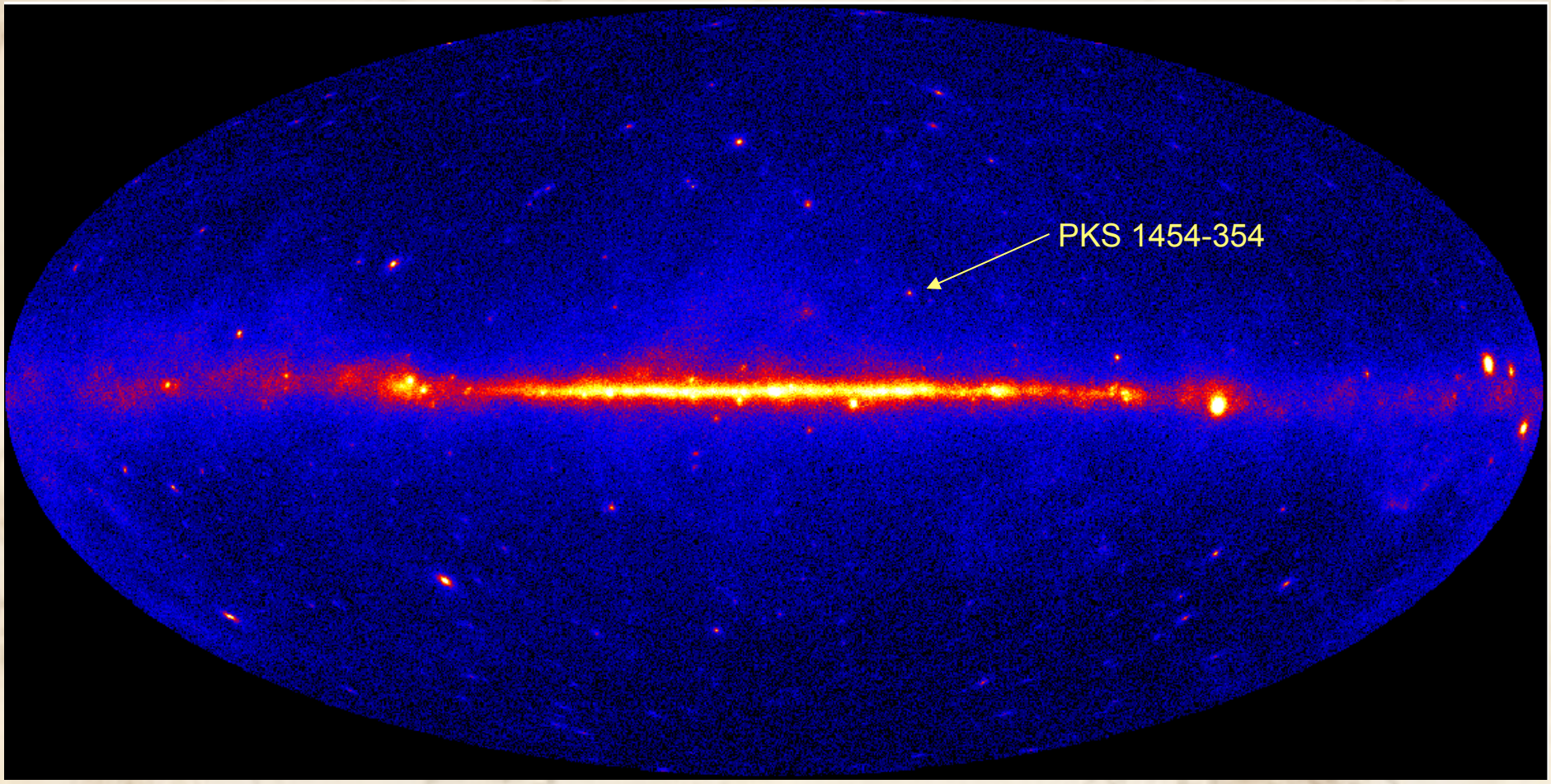


- *PKS 1502+106 is a flat-spectrum radio quasar at z=1.839. It was not detected by EGRET, but during LAT operation it displayed a strong and almost continuous activity.*

- *At the time of the discovery (Ciprini et al., 2008, Atel 1650), it has shown an extremely rapid flare, with a change in flux by an order of magnitude in less than 12 hours.*

- *A MW Campaign started soon after its detection: Swift, INTEGRAL, VLBA(MOJAVE), OVRO, Effelsberg, RATAN and Kanata observatories.*

Some specific works on AGN



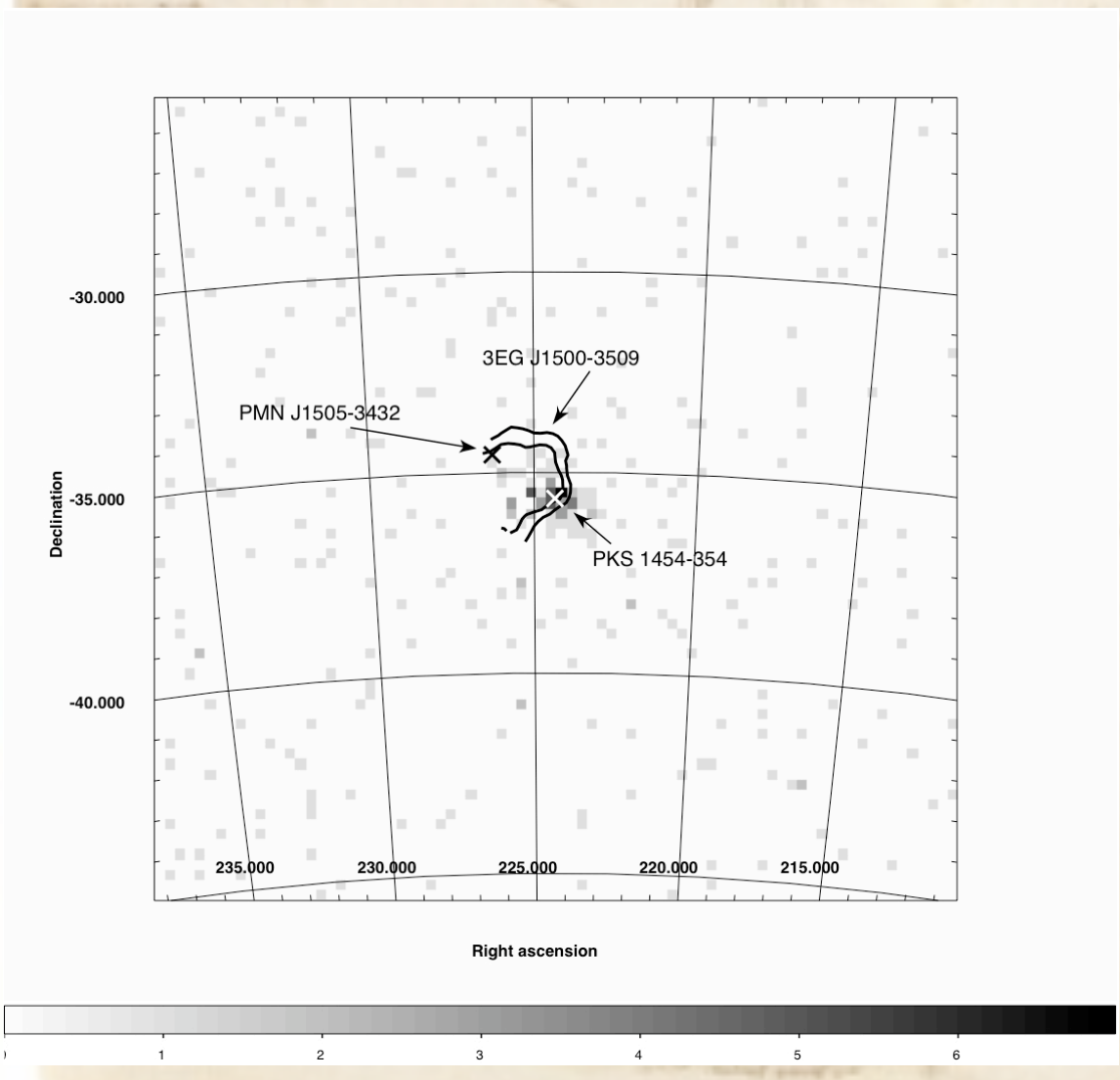
PKS 1454-354: The second new gamma-ray blazar discovered by LAT!
(Marelli et al. 2008, Atel 1701)

PKS 1454-354

(Abdo et al., 2009, ApJ, 697, 934)

Exploring the Extreme Universe

Contact: L. Foschini



PKS 1454-354 (z=1.424) is another FSRQ.

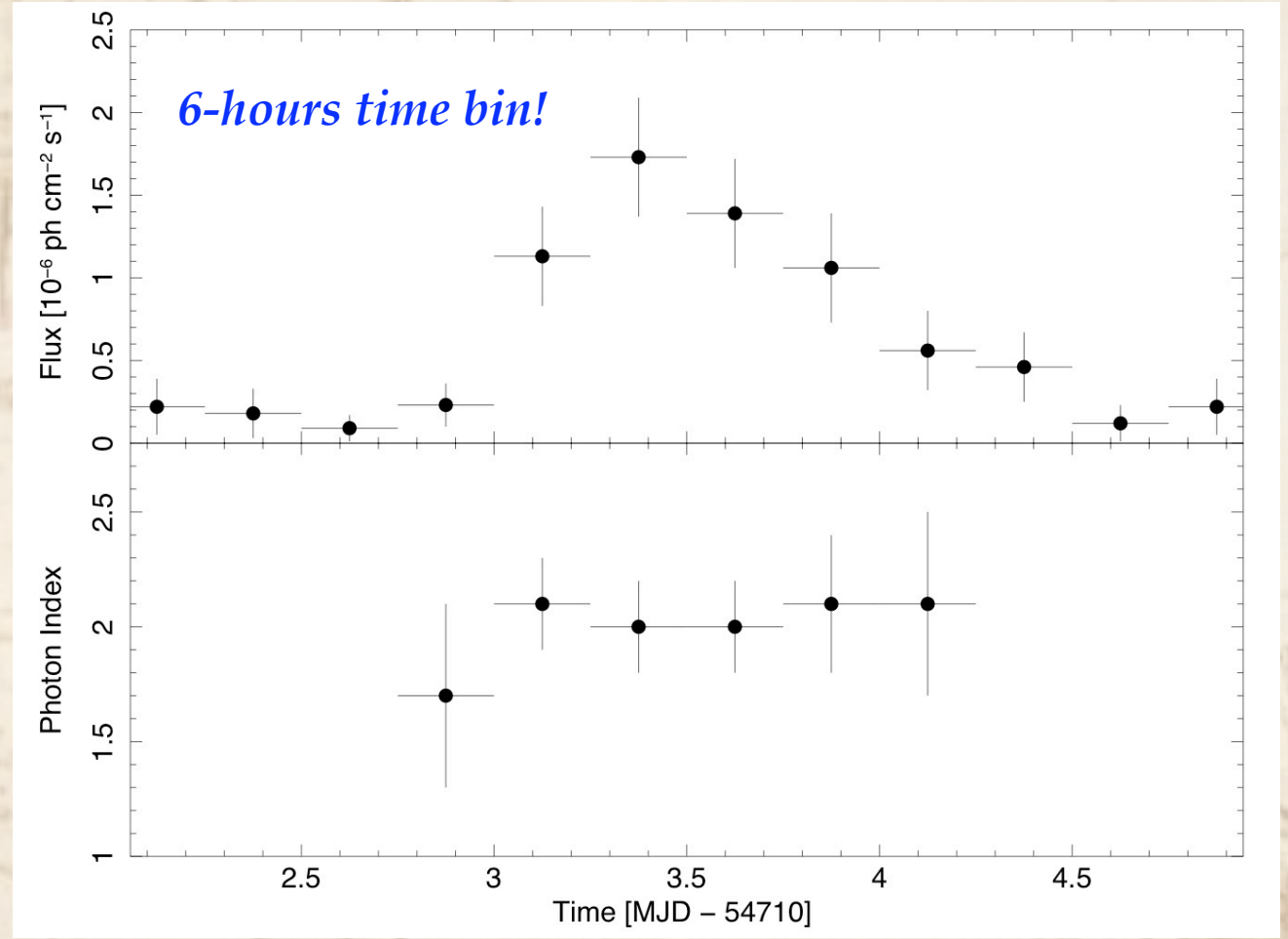
It is likely that EGRET already detected it, but the corresponding source 3EG J1500-3509 was unidenfied and two blazars were indicated as possible counterparts (the other being PMN J1505-3432).

Now LAT – with an improved PSF – has shown that PKS 1454-354 is the likely counterpart of 3EG J1500-3509.

(figure: 1-day count map)

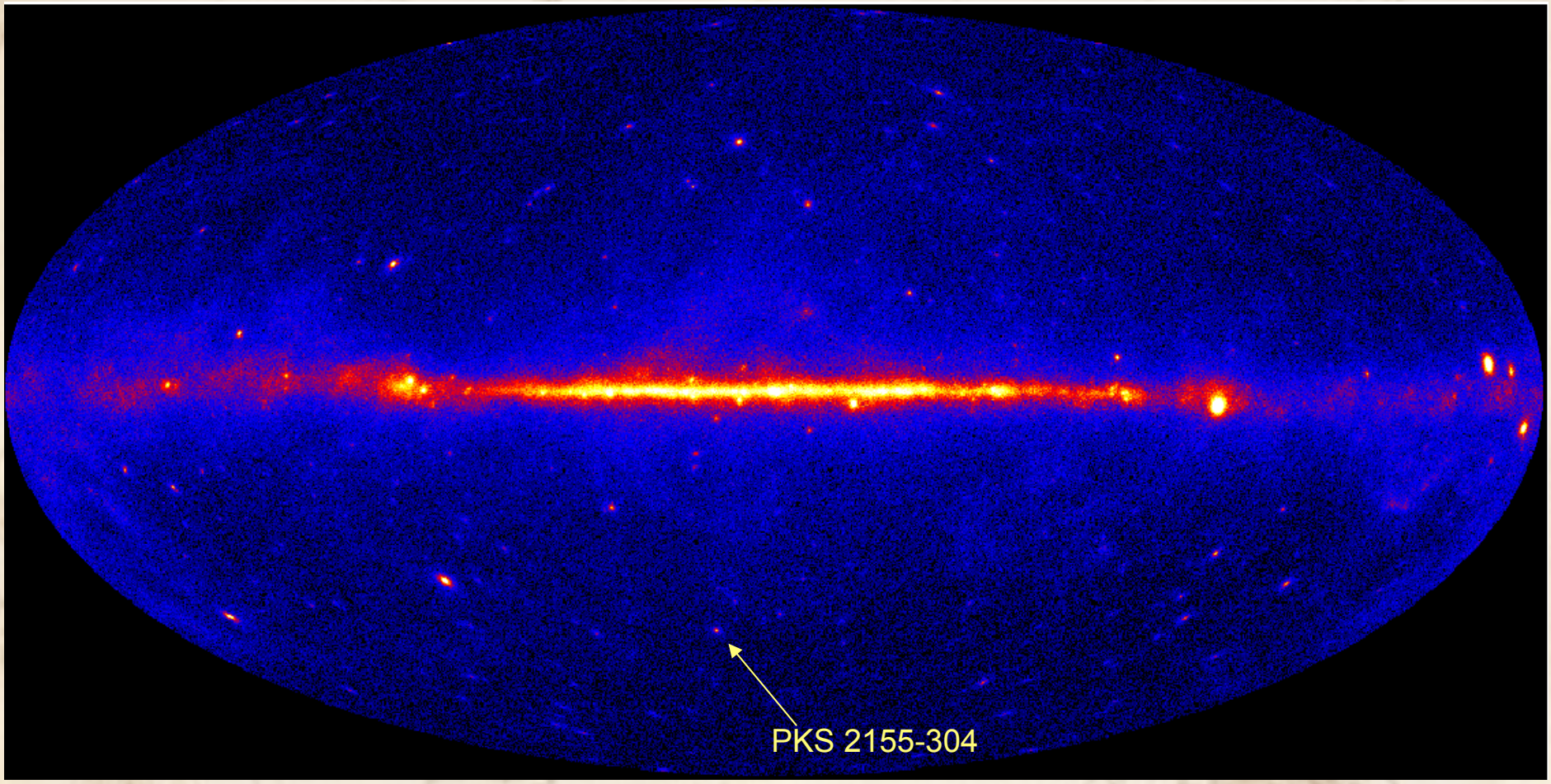
PKS 1454-354

(Abdo et al., 2009, ApJ, 697, 934)



Again, LAT was able to measure extreme flux variability, although no spectral changes were found. Likely to be a change in the injected power of the jet.

Some specific works on AGN



PKS 2155-304 (z=0.116): The first simultaneous GeV-TeV observation of a blazar (Fermi + HESS and Swift, RXTE and ATOM)

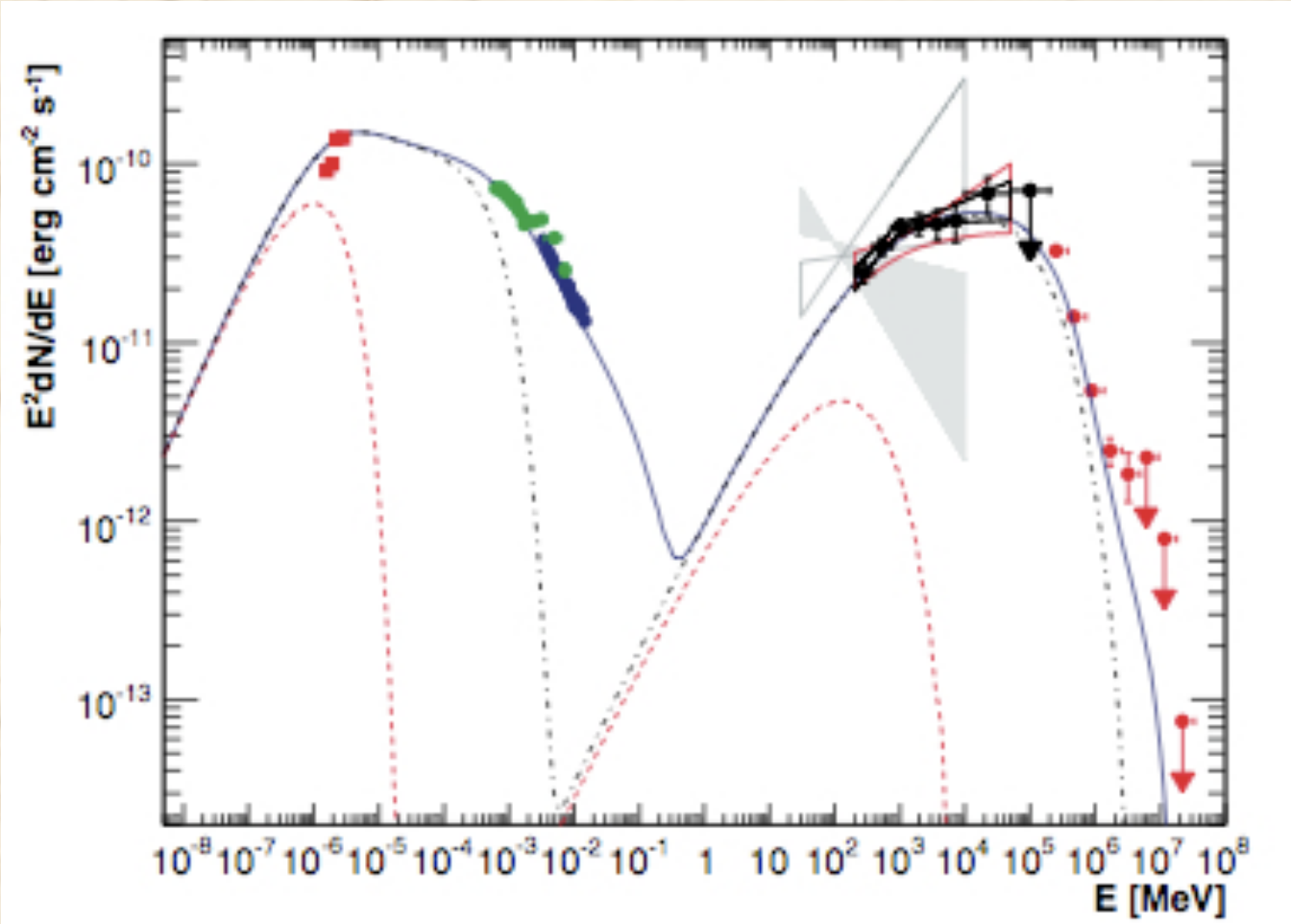
PKS 2155-304

(Aharonian et al., 2009, ApJ, 696, L150)

Contacts: J. Chiang & B. Giebels

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe



The average SED is well fitted with the usual synchrotron self-Compton (SSC) model, but…

PKS 2155-304

(Aharonian et al., 2009, ApJ, 696, L150)

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe

Contacts: J. Chiang & B. Giebels

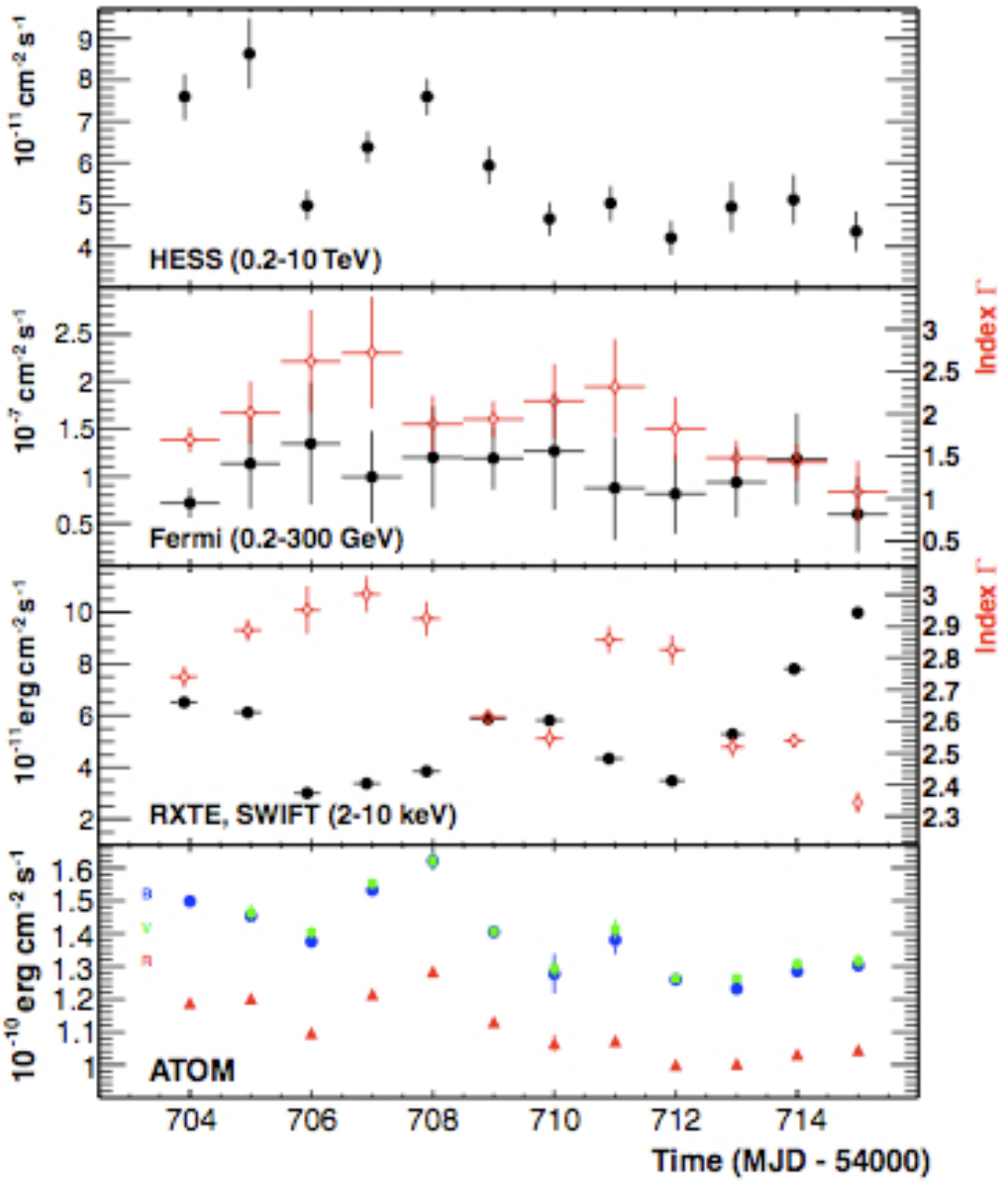
… the analysis of light curves at different energy bands revealed something interesting!

No correlation between X- and gamma-rays!

X-rays shows significant spectral changes, while Fermi and HESS found no spectral variability (only changes in flux).

On the other hand, there is correlation between optical and VHE data.

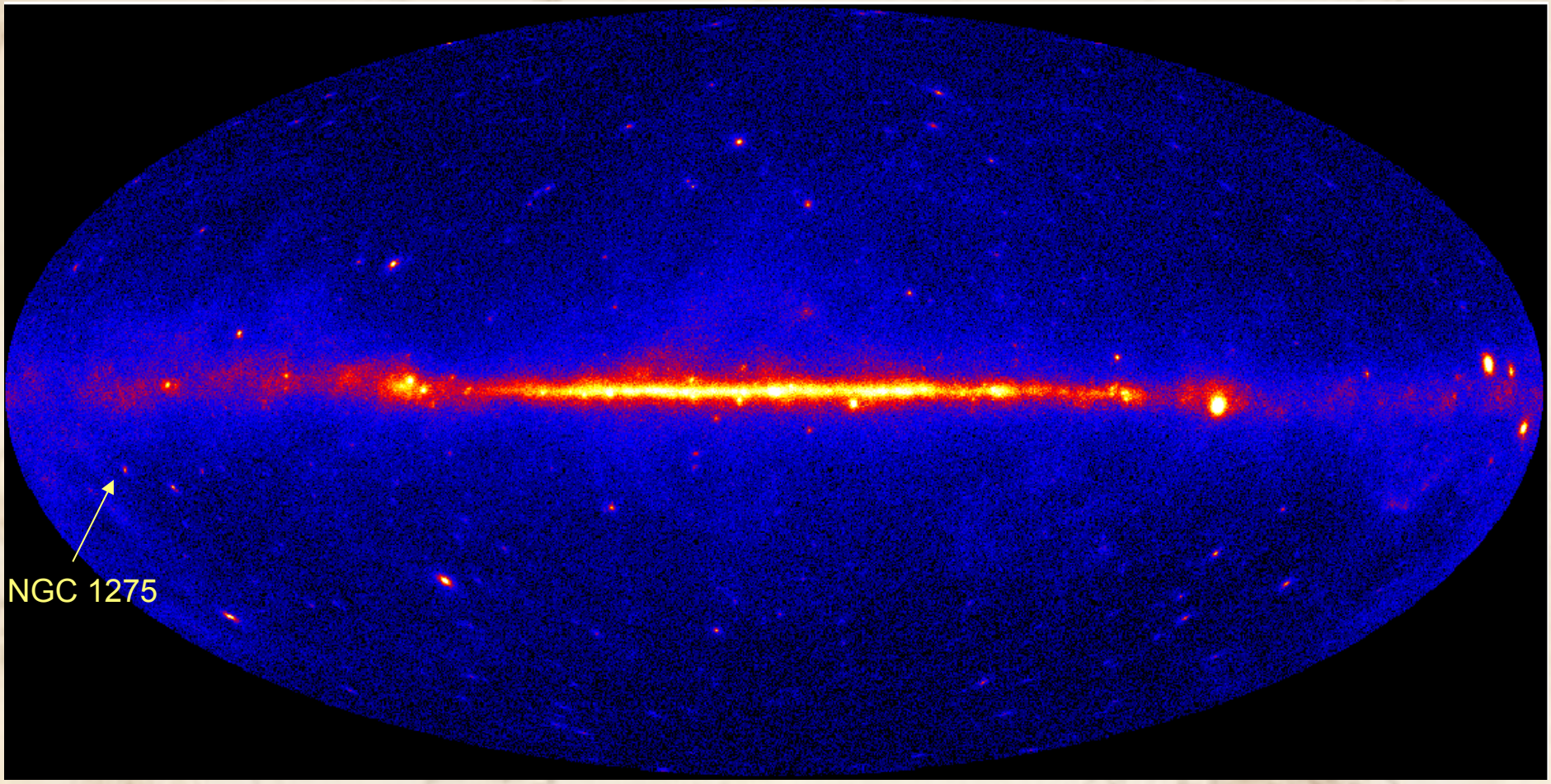
Multi-zone SSC model?



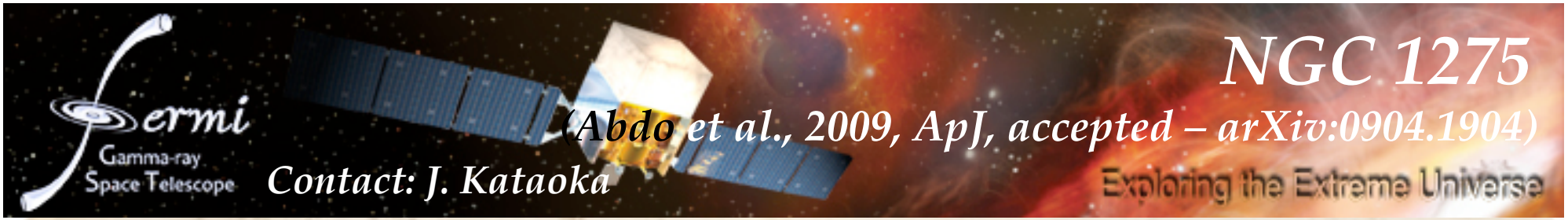
Some specific works on AGN

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe



NGC 1275 (z=0.017559):
a new radio-galaxy detected at gamma-rays by LAT, even though…



THE ASTROPHYSICAL JOURNAL, 274:549–557, 1983 November 15

GAMMA-RAY OBSERVATIONS TOWARD NGC 1275 AND THE ORIGIN OF THE EMISSION IN THE INFRARED, X-RAYS, AND GAMMA-RAYS

A. W. STRONG AND G. F. BIGNAMI
Istituto di Fisica Cosmica, Milano, Italy
Received 1983 February 10; accepted 1983 April 21

ABSTRACT

Gamma-ray data in the region around NGC 1275 and the Perseus cluster are considered in the context of possible emission mechanisms in the halo and nucleus of this galaxy. The *COS B* data show a gamma-ray excess at the position of the galaxy although some additional emission which extends several degrees to the southeast must be explained in some other way. Interpreted as emission from NGC 1275, the data have interesting consequences for the origin of the hard X-rays and the IR-optical emission from the nucleus.

Models for the hard X-rays and gamma-rays involving inverse-Compton scattering of the microwave background by relativistic electrons in the halo cannot easily be reconciled with the measured radio spectrum. Therefore, the data are also studied in the context of various synchrotron self-Compton (SSC) models for the nucleus. If, as seems probable, the nonthermal spectrum includes the observed 10 μm region, the SSC process can easily produce the observed X- and gamma-ray fluxes. Alternatively, if SSC only extends to X-ray energies (with the IR of thermal origin), the same electrons can produce the gamma-rays by inverse-Compton on the IR and optical radiation fields, if these originate in the nucleus.

… in 1983, Strong & Bignami reported about an excess toward NGC 1275 observed with COS-B!

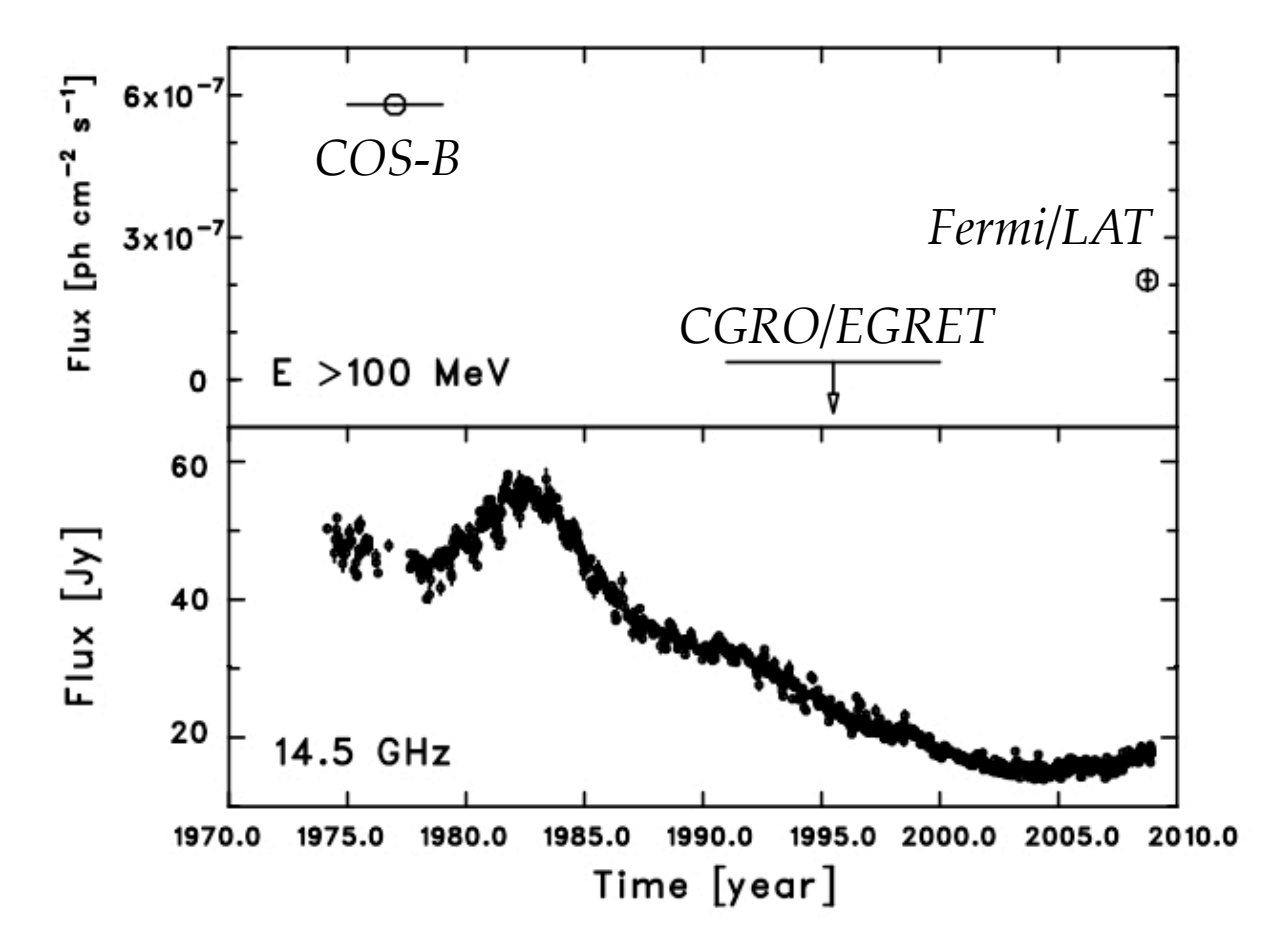
NGC 1275

(Abdo et al., 2009, ApJ, accepted – arXiv:0904.1904)

Fermi Gamma-ray Space Telescope

Contact: J. Kataoka

Exploring the Extreme Universe

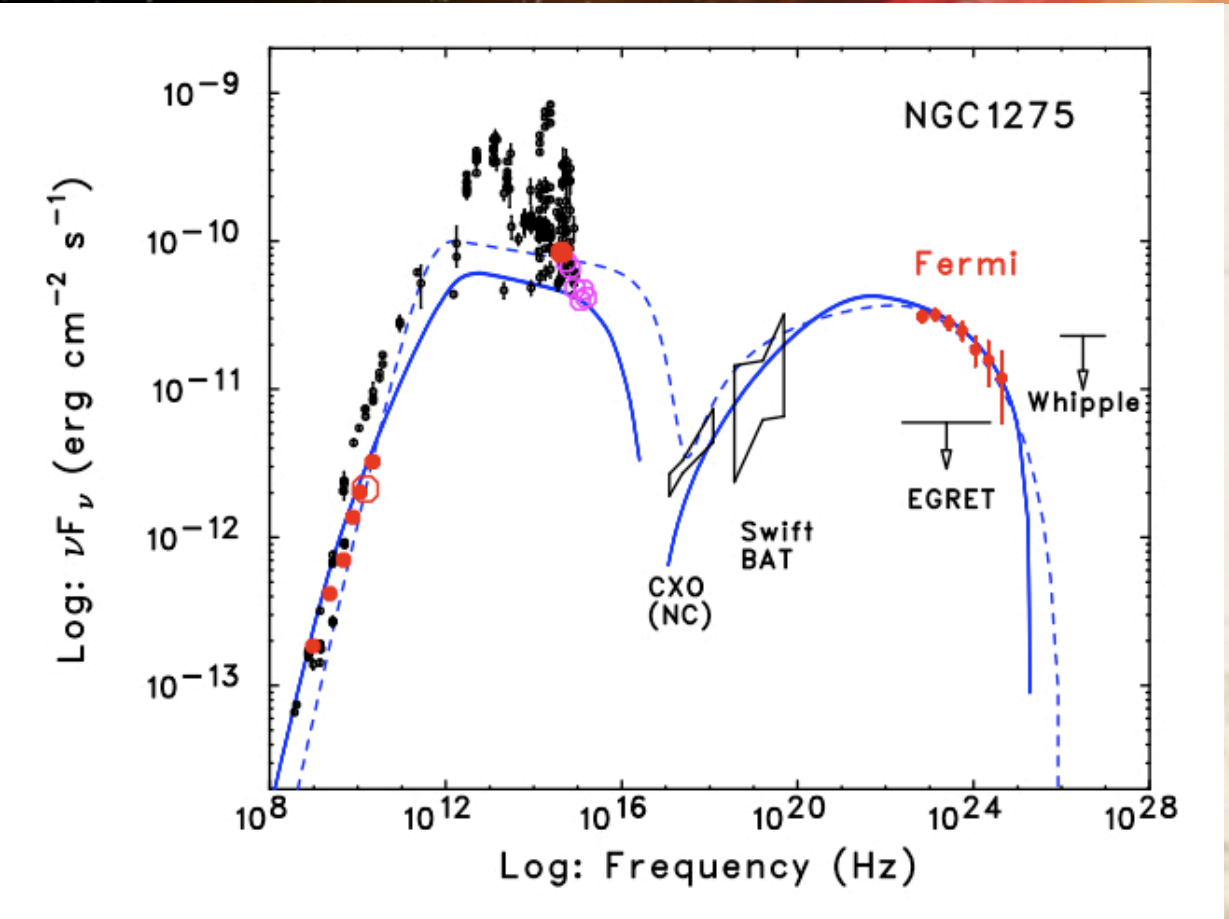


Comparison of radio and gamma-rays lightcurves show that NGC1275 has high radio flux at the time of COS-B observations and now it is again increasing… Variability on years timescale.

NGC 1275

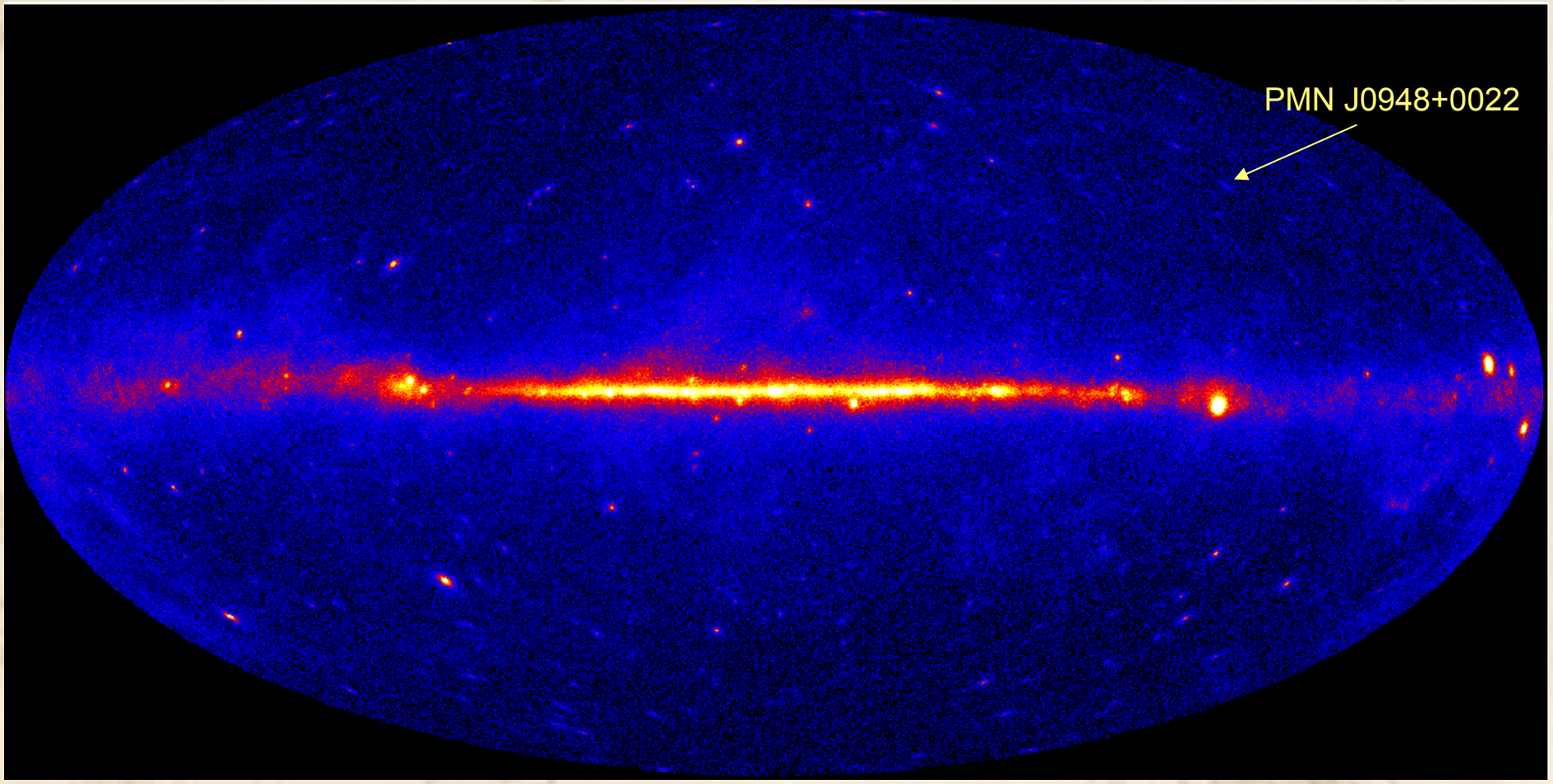
(Abdo et al., 2009, ApJ, accepted – arXiv:0904.1904)

Contact: J. Kataoka



SED modeled with a one-zone SSC (continuous blue line) and a decelerating flow model (spine/sheath) by Geoganopoulos & Kazanas (2003).

Some specific works on AGN

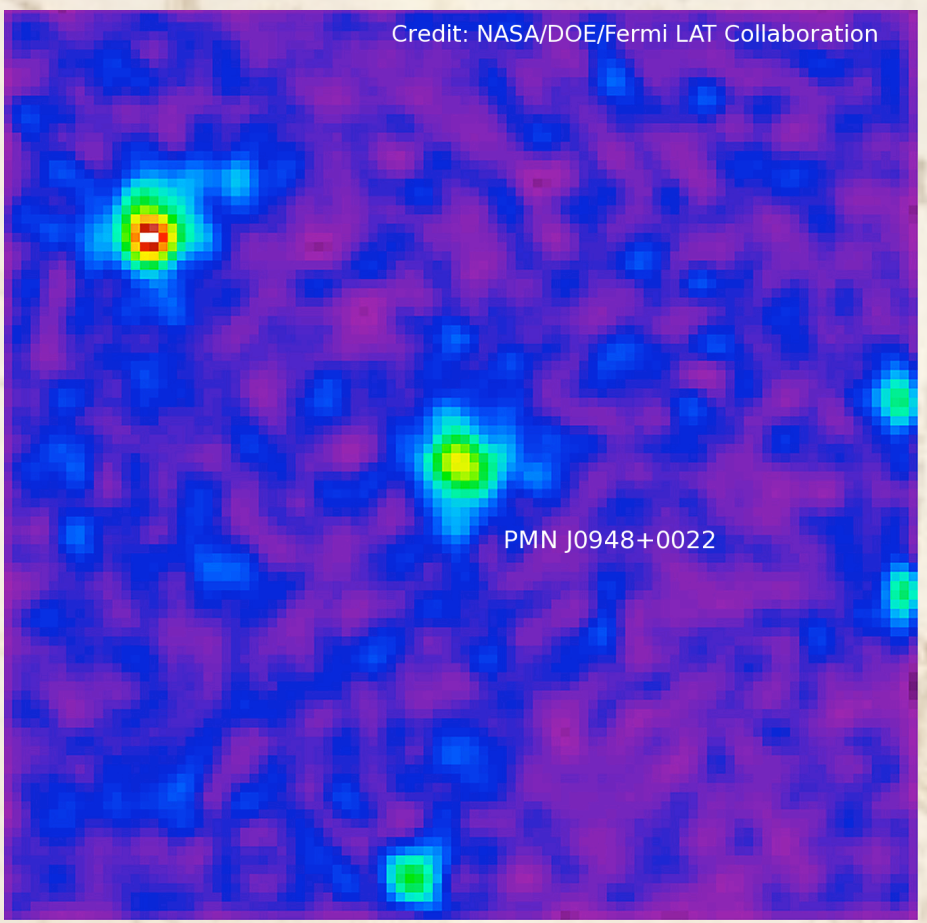


Dulcis in fundo… PMN J0948+0022 (z=0.585):
The first narrow-line Seyfert 1 quasar ever detected at gamma-rays!

PMN J0948+0022

(Abdo et al., 2009, ApJ, accepted; arXiv:0905.4558)

Contact: L. Foschini



Discovery of a LAT source in the Bright AGN List (3 months data), which is associated with the FoM to PMN J0948+0022 at 93% confidence level. By using 5 months of data, the confidence level increased to 99%.

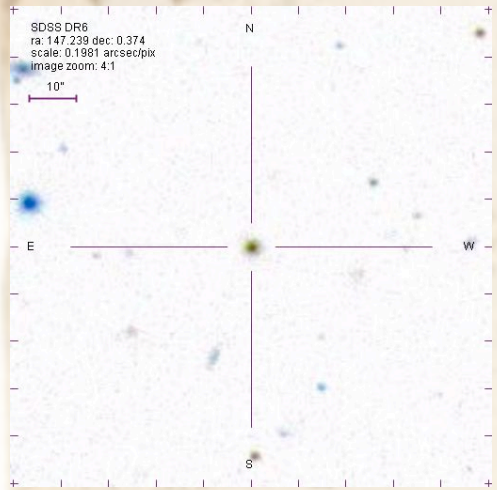
PMN J0948+0022

(Abdo et al., 2009, ApJ, accepted; arXiv:0905.4558)

Contact: L. Foschini

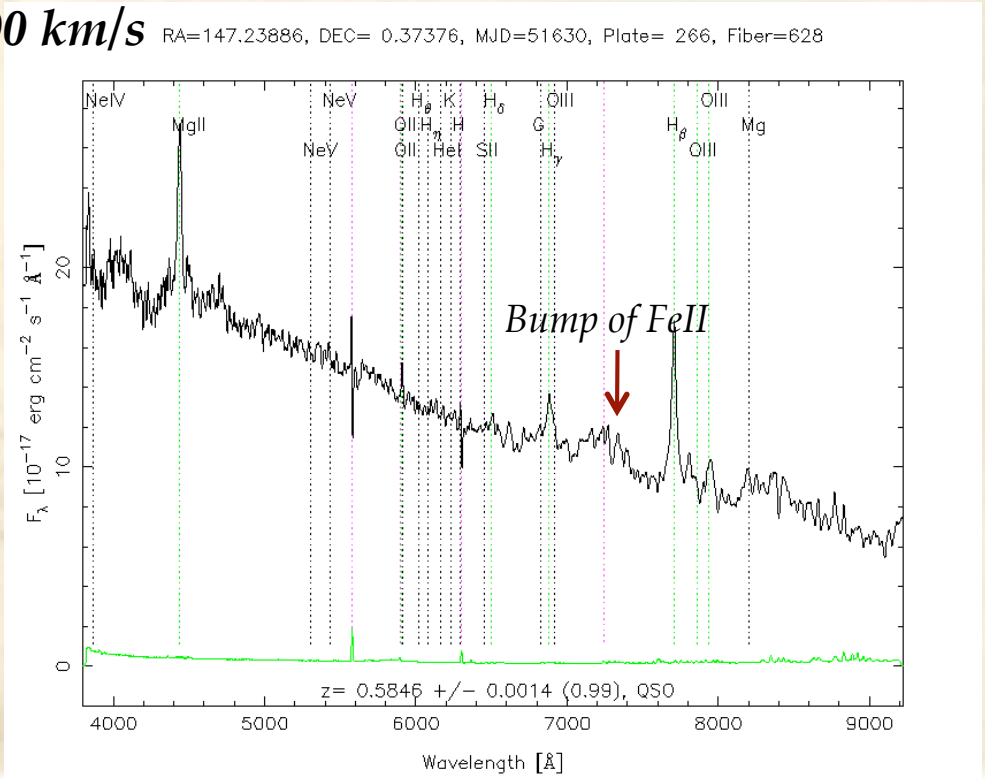
Exploring the Extreme Universe

However, PMN J0948+0022 is very different from the other known FSRQ…



Analyses of the optical spectra from SDSS by Zhou et al. (2003) and Yuan et al. (2008) show that the spectrum is typical of narrow-line Seyfert 1 active nuclei, which are usually radio-quiet and hosted by spiral galaxies!

- ***FWHM(Hβ) ≈ 1500 km/s***
- ***[OIII]/Hβ < 3***
- ***Bump of FeII***



Different epoch radio observations by Doi et al. (2006) suggested the presence of a relativistic jet, now confirmed by detection of gamma-rays by Fermi/LAT.

But the optical spectrum is typical of radio-quiet AGN!

(images courtesy of the Sloan Digital Sky Survey)

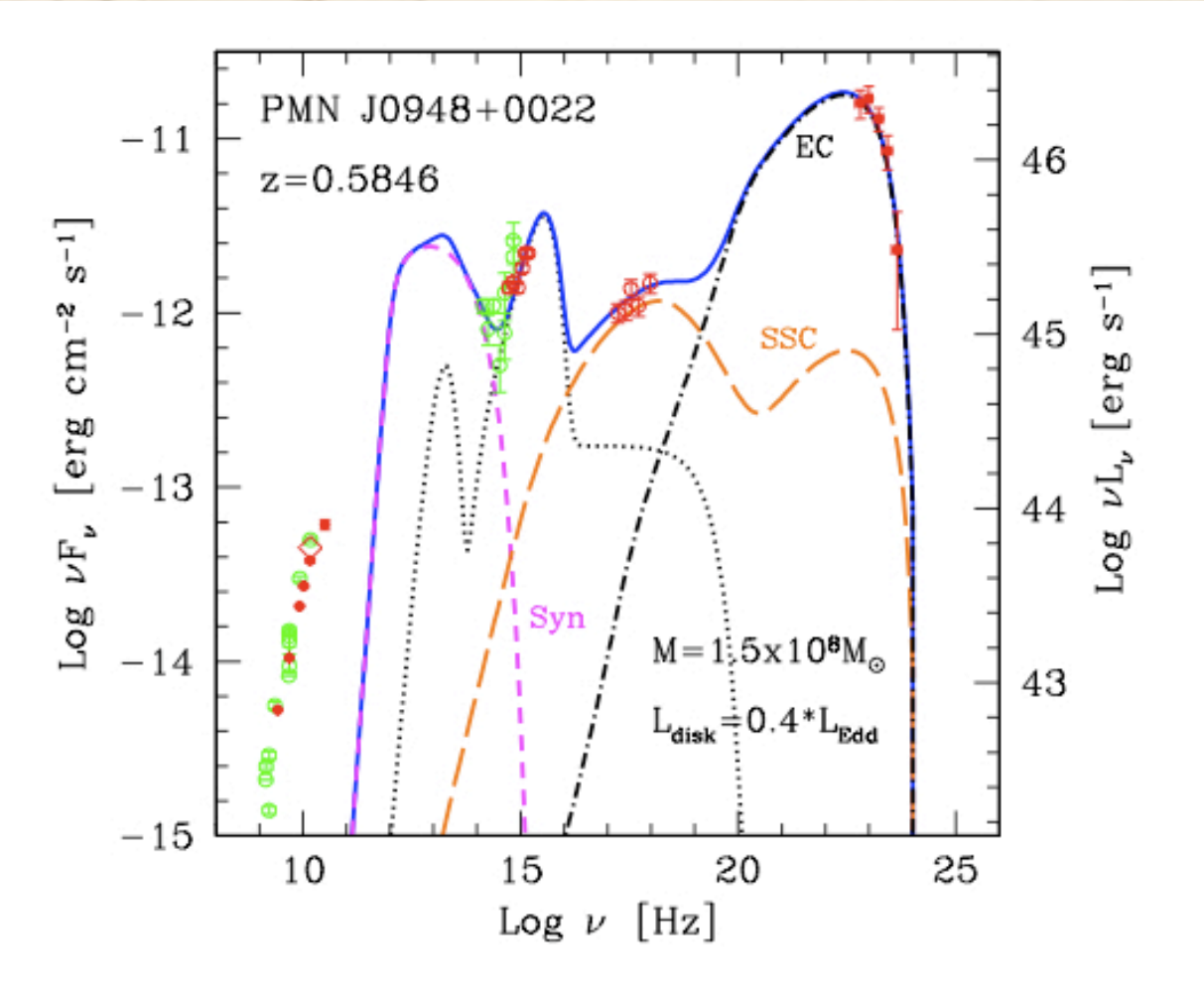
PMN J0948+0022

(Abdo et al., 2009, ApJ, accepted; arXiv:0905.4558)

Fermi Gamma-ray Space Telescope

Exploring the Extreme Universe

Contact: L. Foschini



The SED can be fitted with a model of a typical FSRQ, although with low power, high accretion and relatively "small" mass ($1.5\times10^8\ M_\odot$) ➔

PMN J0948+0022

(Abdo et al., 2009, ApJ, accepted; arXiv:0905.4558)

Fermi Gamma-ray Space Telescope

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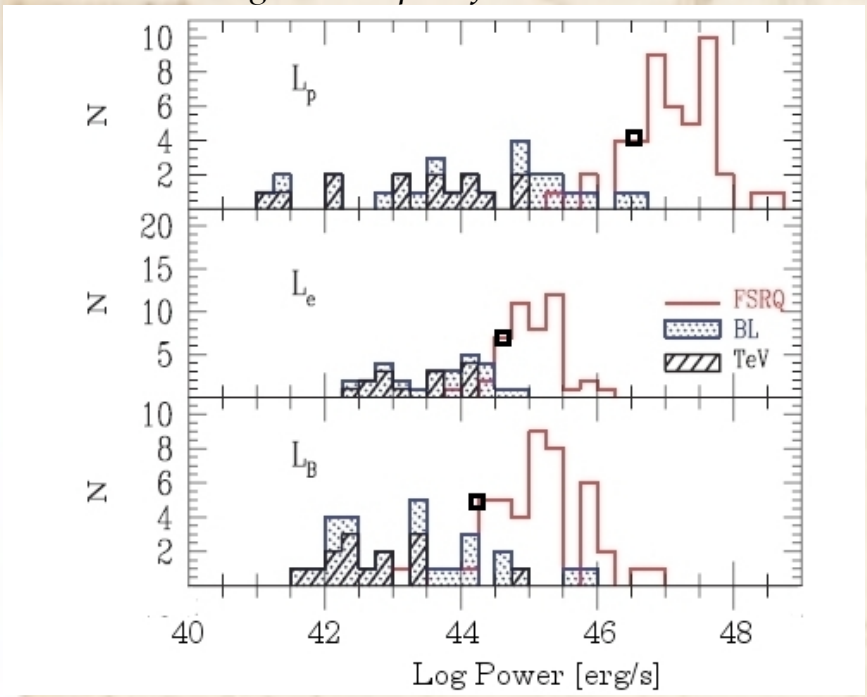
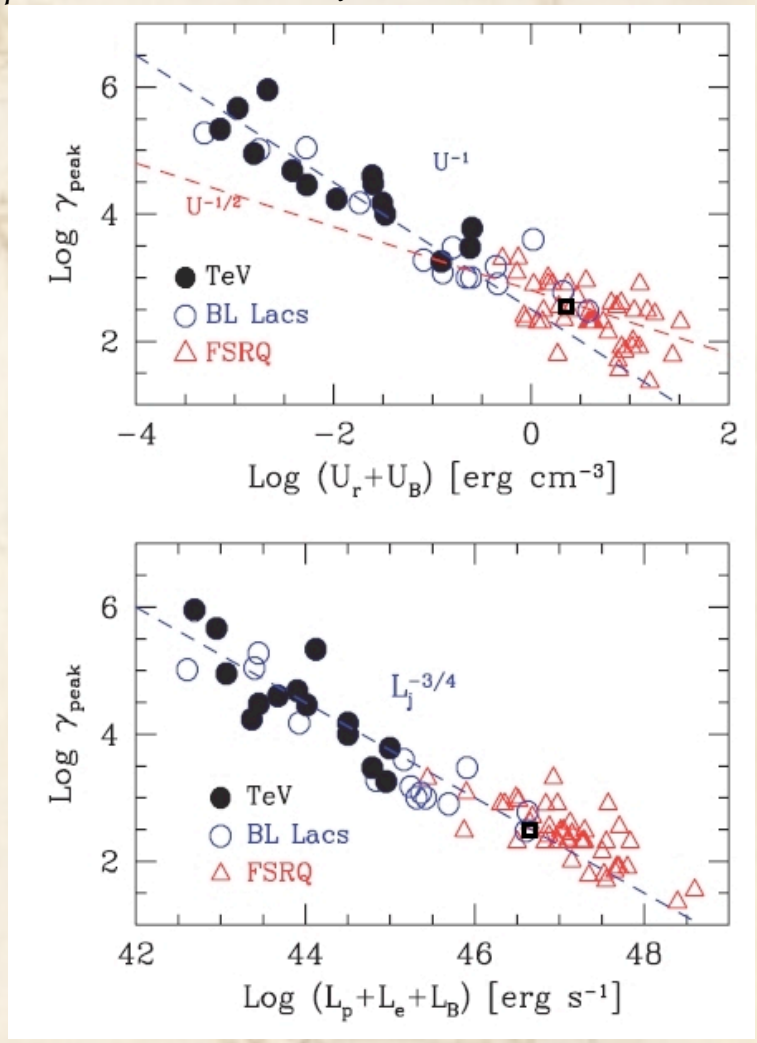
Figures adapted from Celotti & Ghisellini (2008). The black square indicates PMN J0948+0022.

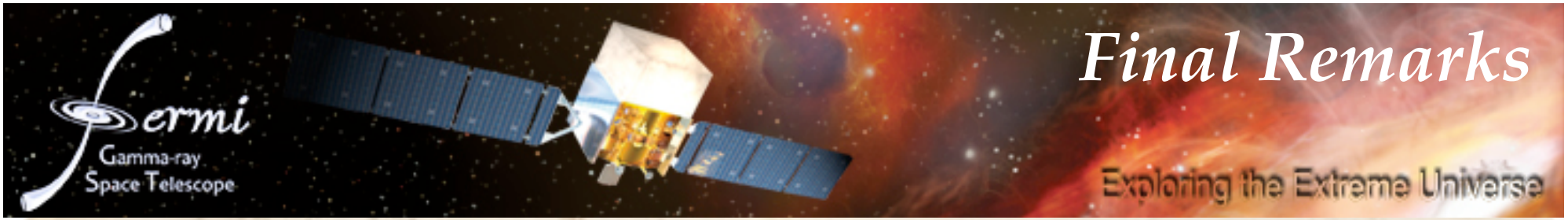




Are we sampling the lower end of the FSRQ distribution?
What is the impact on the blazar evolution?
What is the impact on the unified model of RL-AGN?

A MW Campaign is ongoing to better understand the nature of PMN J0948+0022. See the public web page:

https://confluence.slac.stanford.edu/display/GLAMCOG/MW_Campaign_PMNJ0948p0022



Final Remarks

*In less than 1 year of operation, Fermi/LAT has already an **exceptional** list of discoveries and findings:*

- *First discovery of gamma-rays from a narrow-line Seyfert 1 quasar;*
- *First detection of spectral break at gamma-rays (3C 454.3);*
- *Detection of exceptional variability in some blazars (PKS 1502+106, 3C454.3, PKS 1454-354);*
- *Discovery of several new gamma-ray blazars and new radiogalaxy;*
- ***205** high-confidence (>10 σ) gamma-ray sources detected over only **3 months**.*

Just to compare:

- *EGRET found 31 sources (>10σ) in 9 years;*
- *AGILE found 40 sources (>10 σ) in 1 year.*

- *Many more works are "in preparation" by the LAT team scientists… More, truly more, to come!*

…and I have not mentioned the discoveries in other fields (Galactic, GRB,…)